GENETIC EVALUATION OF GROWTH AND WOOL YIELD TRAITS USING ANIMAL MODEL IN AVIKALIN CROSSBRED SHEEP

Thesis

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Maroof Ahmad

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Dedicated to

my beloved parents

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October, 2002

(Maroof Ahmad)
Author

Dr. C.V. Singh
Assoc. Professor
(Animal Breeding)

Department of Animal Science
College of Agriculture
G.B. Pant Univ. of Agric. & Tech.,
Pantnagar - 263 145
Distt.– U.S. Nagar
Uttaranchal, INDIA

CERTIFICATE

This is to certify that the thesis entitled **"GENETIC EVALUATION OF GROWTH AND WOOL YIELD TRAITS USING ANIMAL MODEL IN AVIKALIN CROSSBRED SHEEP"** submitted in partial fulfilment of the requirements for the degree of **DOCTOR OF PHILOSOPHY** with major in **Animal Breeding** and minor in **Molecular Biology & Biotechnology** of the College of Post-Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. Maroof Ahmad, Id. No. 24694**, under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been acknowledged.

(C.V. Singh)
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr. Maroof Ahmad, Id. No. 24694**, a candidate for the degree of **Doctor of Philosophy** with major in **Animal Breeding** and minor in **Molecular Biology & Biotechnology** and agree that the thesis entitled **"GENETIC EVALUATION OF GROWTH AND WOOL YIELD TRAITS USING ANIMAL MODEL IN AVIKALIN CROSSBRED SHEEP"** may be submitted in partial fulfilment of the requirements for the degree.

(C.V. Singh)
Chairman

(Harpal Singh)
Member

(D. Kumar)
Member

(Anil Kumar Gupta)
Member

4/10/02

Head
Department of Animal Science
(Ex-Officio member)

LIST OF ABBREVIATIONS

AM	Animal Model
ANOVA	Analysis of variance
BLM	Border Leicester Merino
BLUE	Best linear unbiased estimation
BLUP	Best linear unbiased prediction
BWT	Birth weight
CRP	Coopworth, Romney, Perendale
CT	Conical transformation
DF	Derivative free
DFREML	Derivative free restriction maximum likelihood
GFY1	Greasy fleece yield at six month of age
h^2	Heritability
IAM	Individual animal model
LSA	Least –square analysis
LSMLMW	Least-squares means and maximum likelihood method of W. R. Harvey
MINQUE	Minimum Norm Quadratic Unbiased Estimation
ML	Maximum likelihood
MME	Mixed model equation
PHS	Parental half sibs
RAM	Reduced animal model
r_e	Environmental correlation
REML	Restricted maximum likelihood
r_g	Genetic correlation
r_p	Phenotypic correlation
SA Merino	South African Merino
SB	Scottish Blackface
WT12	Weight at 12 month of age
WT6	Weight at 6 month of age
WWT	Weaning weight

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Introduction

Chapter 1 INTRODUCTION

Sheep (*Ovis aries* 2n=54) play an important role in national economy, especially in arid, semi-arid and drought prone areas of the country. Sheep are the most important livestock species of economic value to the small and marginal farmers and landless labourers. They constitute very valuable and renewable resources and fulfill an important socio-economic role in traditional farming system. Moreover, industry set up for converting sheep produces into products are also providing employment to million of people directly or indirectly. The notable countries in the world for sheep production are Australia, New Zealand, South Africa, Argentina, U.S.A. etc. The productivity of sheep of these countries is superior to those of India. The major factors responsible for low productivity of Indian sheep are poor genetic potential and poor quality feeding resources.

India has a population of 58.2 million sheep, ranking 4th in the world and constitute about 5.31% of the world sheep population. About 230.4 m kg. of mutton, 47.6 m kg. of wool and 52.38 m kg. of skin are produced annually in the country (FAO, 2001). Indian wool are internationally well known excellent carpet wool due to their coarseness and medullary fibre content. It is estimated that wool produced in the country and the carpet made out of it are exported amounting Rs. 3000.00 crores per annum. India is a rich repository of sheep genetic resources with 42 recognized breeds, apart from several non-descript

breeds in different agro-climatic regions of the country. Rajasthan is one of the leading state in sheep population for last four decades, having about 25% of the total sheep of the country and produces 40% of the total wool production (Arora *et al.*, 2001). The state has predominantly eight recognized breeds of sheep namely Malpura, Marwari, Jaisalmeri, Chokla, Nali, Pugal, Sonadi and Magra.

Avikalin strain of sheep was evolved at CSWRI, Avikanagar in 1977 by the cross breeding of Rambouillet × Malpura (indigenous sheep breed) stabilizing at 50% inheritance, through inter-se-mating and selection for greasy fleece weight. This breed is quite suitable as a dual-purpose sheep for carpet wool and mutton production. Avikalin sheep produced about 80% more wool compared to native Malpura breed and this can be used as an improver breed for crossbreeding with coarse wool breed (CSWRI, 1998).

In animal breeding, knowledge of genetic properties of the economic traits under consideration is the pre-requisite in establishing a selection programme. Development of breeding objectives and effective genetic improvement programme require knowledge of the genetic variation (Forgarty, 1987) for economically important traits and the genetic covariation among these traits. The accuracy of estimates of variance components is dependent on the choice of data, methods and models (Misztal, 1992). The potential for genetic improvement of a trait is largely dependent upon its heritability and its genetic correlations with other traits. The heritability of the traits could vary with

the age of animals. Therefore, it becomes important to estimate heritabilities and correlations at various ages of animals to be selected (Bathaei, 1994). Traditionally, variance and covariance components are estimated by ANOVA and regression methods. The variance estimated by Handerson's Method 1, 2 and 3 are not appropriate for unbalance data. The main assumption of random sampling underlying standard ANOVA type procedure does not hold true. Therefore, the estimates of variance and covariance, obtained from these methods are expected to bias by selection (Robertson, 1977; Meyer and Thompson, 1984). Most of the reported heritabilities are based on the ratio of variance components estimated mainly by Handerson's Method 3. In India, least-squares method is generally used for analysis of animal breeding data. The scientific reports to estimate the genetic parameter using an animal model for growth and wool yield traits in Avikalin crossbred sheep are very little published.

In recent years, advance statistical methods used to estimate variance components have been greatly improved. In contrast with the analysis of variance estimators, Maximum Likelihood estimators seen to be free of some forms of selection bias (Schaeffer and Soong, 1979). A method for the simultaneous estimation of variance components due to several genetic and environmental effects from unbalanced data called restricted maximum likelihood (REML). The estimates obtained by evaluating the likelihood explicitly and using standard, derivative-free optimization procedures to locate its

maximum. The model of analysis, considered is called Animal model, which includes the additive genetic merit of animals as a random effect, and incorporates all information on relationship between animals (Meyer, 1989a).

Mostly, multiple traits of economic importance are recorded on each individual to collect as much information. The prediction of breeding values constitute an integral part of most breeding programmes for genetic improvements. A major constraint to using controlled reproductive technology in the development of efficient selection criteria has been lack of precise estimates of genetic parameters for ewe productivity. These estimates are also necessary to determine the relative emphasis that should be given to each of multiple traits to increase the accuracy of breeding values in selection of superior rams and ewes as replacement for the production of subsequent generations of offspring (Hansen and Shrestha, 1997). In practical animal breeding there are numerous complications to the estimation of breeding value. The individuals whose breeding value are to estimated may be related, some individuals may have repeated records and others only a single record, and most seriously, there may be systematic environmental differences between groups of individuals. The Best Linear Unbiased Prediction (BLUP) has become the most widely accepted method for genetic evaluation of livestock. Recently, there is a constant thrust to get Best Linear Unbiased Prediction evaluating single and multiple traits animal model, depending upon the goal of breeding programme (Lin and Lee, 1986; Ducrocque and Besbes, 1993).

In view of above consideration, it was planned to employ derivative free REML and Least-Square method for the analysis of growth and wool yield traits. The present study was conducted on Avikalin crossbred sheep with the following objectives:

1. To determine mean performance of various economic traits under the study.
2. To estimate genetic and non-genetic factors affecting growth and wool yield traits.
3. To determine variance-covariance components of various economic traits.
4. To estimate the heritability, genetic, phenotypic and environmental correlations among the various economic traits.
5. To compare estimated parameters obtained by different procedures.
6. To estimate BLUP value of sire
7. To find rank correlations among sires on the basis of BLUP Value.

Review of Literature

Animal model in evaluation of breeding value:

The use of ML and REML in animal breeding has brought about change in the random effects fitted in the infinitesimal additive genetic model (Henderson, 1988; Foulley, 1990). In traditional ANOVA and related methods, (co)variance are described in terms of random effect due to a single parent (e.g. sire model) or both parents (sire-dam model), uniquely partitioning the total sum of the squared deviations of the observations from the grand mean into sum of squares contributed by each factor in the design (Harville,1977; Shaw,1987). However, over the last decade considerable research effort has concentrated on the development of specialized and efficient algorithms. This has been closely linked to advances in the genetic evaluation of animals by Best Linear Unbiased Prediction (BLUP). However, ML and REML allow the random effect of models to be expressed in terms of the genetic merit or breeding value of animals. These models are called individual animal models (IAM) and incorporate information on relationship between all animals (Meyer, 1989b, 1991). Animal Model (AM) has influenced the use of mixed model methodology in the statistical analysis of animal breeding data considerably. The AM includes a random effect for the additive genetic merit of each animal, both for animals with records and animal, which are parents only, incorporating all known relationship information in the analysis. This requires the inverse of numerator relationship matrix A. Hence it gained practical importance with the

availability of procedure to obtain A^{-1} directly from a list of pedigrees (Henderson, 1976; Quaas, 1976), which made the AM computationally feasible for large data sets. Kennedy *et al.* (1988) discussed the genetic properties of animal models, outlining how the AM can account for change in genetic means and variances. Thus the AM allows an optimal analysis of data involving multiple generations arising, for instances, from selection experiments (Sorensen and Kennedy, 1986; Kennedy, 1988).

In terms of variance component estimation, the AM had changed thinking from the interpretation of covariances between relatives to a linear model framework where we determine variances directly by fitting corresponding random effects in the model of the analysis. Covariances between random effects for relatives are now taken into account by specifying the variance matrix of random effects accordingly. With the AM, the additive genetic variance is estimated as the variance of animals' additive genetic merit instead of, for example, four times the variance between sires or twice the covariance between parents and offspring. The basic assumptions of individual animal model (IAM) are : (i) σ_e^2 is the same for all observation, (ii) dominance genetic effects are not important and are part of σ_p^2, (iii) covariance between animal genetic effect and other random effects in the model are zero, (iv) the relative values of variances must be known, and (v) additive genetic effect can include individual without any observations, and in that case corresponding design matrix contain zero columns for those individuals. It is intuitively obvious that an IAM is more correct for animal breeding data since it exploits all known relationship and can therefore account for changes in genetic variance due to

both inbreeding and the established linkage disequilibrium (Kennedy and Sorensen, 1988; Henderson, 1990a). Furthermore, the use of an IAM allow more random effects to be fitted, such as maternal and dominance effect, which are known to bias some genetic estimates (Barlow, 1978; Falconer, 1989; Meyer, 1989a; Webb and Bampton, 1990). The other advantages of animal model are : (i) if data had been collected over many years then the possibility could arise that an individual female animal could appear as one of the measured individuals, but also as the dam of one or more other female animals. Thus, these equations combine information on an animal itself and on its progeny, (ii) in an animal model genetic merit of the female to which sires were mated is also considered whereas the same is ignored while evaluating sires solely on their female progeny, and (iii) if only selected animals were allowed to reproduce then biases due to selection can be avoided by use of numerator relationship matrix. The major disadvantage of an animal model is the larger order of the equations that need to be solved.

Wiggans and Misztal (1987) opined that the main advantage of an animal model over a sire model is that all additive genetic relationships among animals contribute to an animal's evaluation, which improves the accuracy of evaluation and avoids bias due to non-random mating and female selection. They mentioned the disadvantage that many more equations must be solved, and convergence may be slow because animal equations have off diagonal elements contributed by the relationship matrix. Meyer and Burnside (1988) mentioned that sire model ignores both the dams of the cow (sire's mate) and relationship between females, and therefore, sire proofs may be biased due to

non-random mating or selection of cows. On the other hand, animal model evaluate both the sires and cows simultaneously, animals without records (like sires in dairy cattle) are evaluated from the information on their relatives' records. The animal model takes into account all the relationship, adjusts for the non-random mating, account for selection bias and adds to the accuracy by taking information from the correlated traits. Canon and Cheshais (1989) enumerated following advantages of animal model : (i) permits the use of all additive genetic relationships among animals as 'a priori' information in animals' evaluation, (ii) the predicted genetic merit of sires is free from bias due to non-random mating since the genetic merit of dams of their progenies is taken in to account, and (iii) the need for grouping is decreased in order to account for genetic trends.

The available literature regarding relevant aspect of the current study has been reviewed and presented under the following heads for each economic traits.

1. Mean performance
2. Effect of genetic and non-genetic factors
3. Heritabilities
4. Comparison between estimates
5. Correlations
6. BLUP/Breeding values
7. Rank correlations

2.1 Birth weight

2.1.1 Mean performance

The body weight of a lamb is a measure of the cumulative growth and it is a indicator of its genetic constitution and adaptability to a specific environment. The proper growth is a pre-requisite for the future performance. Growth performance has direct bearing on its economics returns. Many workers have reported body weights at various ages in variety of sheep breeds and different crossbreds in India and abroad. The means performance of birth weight in different breed of sheep as reported by various workers is summarized in Table 2.1. The birth weight ranged from 2.26 ± 0.09 kg. (Arora *et al.*, 1975) to 3.97 kg. (Conington *et al.*, 1995).

Table 2.1: Least-squares means (±s.e.) of birth weight in various sheep breeds

Means (Kg.)	Breed (s)	Reference (s)
2.73 ± 0.03	Crossbred	AL-Shorepy (2001)
2.33 ± 0.05	Chokla	Acharya and Manimohan (1979)
2.37	-do-	Acharya (1982)
2.46 ± 0.02	-do-	Anonymous (1986)
2.70 ± 0.02	-do-	Anonymous (1993)
2.26 ± 0.07	-do-	Arora *et al.* (1975)
2.98 0.03	Avikalin	Arora *et al.* (1999)
3.92 ± 0.13	Iranian Mehraban	Bathaei (1994)
3.97	Hill sheep	Conington *et al* (1995)
2.81 ± 0.01	Chokla	Kumar (2000)
2.87 ± 0.04	-do-	Kushwaha (1994)
2.80 ± 0.02	-do-	Kushwaha *et al* (1997)
3.25 ± 0.13	R· M F1	Malik *et al* (1980)
2.66 ± 0.04	Avikalin	Singh and Dhillon (1992)
3.48 ± 0.07	Muzaffarnagri	Sinha and Singh (1997)
3.21 ± 0.08	Bharat Merino	Tomar *et al* (2000a)
3.42 ± 0.03	Bharat Merino	Tomar *et al* (2000b)

2.1.2. Effect of genetic and non-genetic factors

The economically important traits of sheep are influenced by genetic and non-genetic factors to a varying degree, and the knowledge of these factors on economic traits is a pre-requisite for the estimation of genetic and phenotypic parameters used in predicting the breeding values of the animals. The factors affecting to birth weight as reported by various workers are follow:

A. Sire

Kumar (2000) reported significant effect (P <= 0.05) of sires on birth weight in Chokla sheep.

Sinha and Singh (1997) observed that random effect of sire was highly significant (P<0.01) on birth weight in Muzzaffernagri sheep.

Swain *et al.* (1994) also observed significant effect (P < 0.05) due to sire on birth weight in Bharat Merino sheep.

Tomar *et al.* (2000a) estimated highly significant differences on birth weight due to sire in Bharat Merino sheep.

Vatalitya (1993) also reported highly significant (P<=0.01) difference of sire on birth weight in Patanwadi and crossbred sheep.

B. Season of birth

Arora *et al.* (1981) observed significant seasonal variation on birth weight in Nali and Chokla sheep. They attributed the reason of better management of ewes and availability of good pasture to ewes lambing in autumn season.

Malik *et al.* (1980) obtained that Autumn born (July- Sep.) lambs were heavier at birth as compared to Winter-born (Feb. - April) in crosses of Chokla, Malpura and Jaisalmeri with Rambouillet.

Singh *et al.* (1982) reported highly significant effect due to season on birth weight in Nali sheep.

Singh and Dhillon (1992) estimated that season of birth did not vary significantly on birth weight in Avikalin lambs.

Swain *et al.* (1994) also observed non-significant effect of season of birth on lambs birth weight in Bharat Merino sheep.

Tomar *et al.* (2000a and 2000b) reported that season of birth highly significantly affected to the birth weight in Bharat Merino sheep.

C. Sex of lamb

In general, irrespective of breed or breed groups, male lambs were heavier at birth and subsequently had higher body weights at later ages than female. This fact was reflected as highly significant or significant influence of sex of lambs on body weights of various breeds at birth.

Arora *et al.* (1983) observed non- significant effect of sex on birth weight in Bikaneri sheep.

Arora *et al.* (1999) reported highly significant source of variation due to sex on birth weight in Avikalin sheep.

Kandasamy *et al.* (1980) also reported non-significant sex effect on birth weight in Nali, Chokla and their crosses with Rambouillet and Merino.

Malik *et al.* (1971) obtained significantly differences due to sex on birth weight in Chokla sheep.

Malik *et al.* (1980) observed significantly differences of sex effect on birth weight in crosses of Chokla, Malpura and Jaisalmeri with Rambouillet.

Singh and Dhillon (1992) reported highly significant source of variation for sex on birth weight in Avikalin sheep.

Singh and Kushwaha (1995) also estimated highly significant differences due to sex on birth weight in Bharat Merino sheep.

2.1.3 Heritabilities

The genetic parameters are the pre-requisite for any selection programme because they not only provide the information regarding the type of gene effects influencing the inheritance of economic traits in the population, but also have an important role in predicting the response under a particular selection programme. Heritability is the most important single concept in the application of genetics to animal breeding. It is most often used to describe the amount of the superiority of parents above their contemporaries for a given trait which on an average is passed on to the offspring. The heritability estimates reported by various workers are presented in Table 2.2.

2.1.4 Correlations

Hazel (1943) introduced the concept of genetic correlation into animal breeding theory. Genetic correlation between two traits is defined as the correlation between genetic effects that influence the two traits and it is arise due to pleiotropy and linkage (Falconer and Mackay, 1996). The genetic, phenotypic and environmental correlations of birth weight with different traits as observed by various workers are summarized in table 2.3.

Table 2.2: Heritability estimates (± s. e.) of birth weight alongwith method of estimation in various breeds of sheep.

Heritability (± s.e.)	Method (s)	Breed (s)	Reference (s)
0.13 ± 0.03	PHS	SB	Atkins (1986)
0.35 ± 0.14	-do-	Iranian Mehraban	Bathaei (1994)
0.08 ± 0.01	REMLa	Suffolk	Barwick (1989)
0.07 ± 0.04	REMLs	SB	Conington *et al.* (1994)
0.13 ± 0.03	PHS	Merino	Davis (1987)
0.20 ± 0.02	REMLs	-do-	-do-
0.26	LS-MIVQUE	Barbary	Djemali and Aloulou (1996)
0.32	ML	-do-	-do-
0.43	REML	-do-	-do-
0.31 ± 0.10	PHS	Crossbred	Ercanbrack and Price (1972)
0.26 ± 0.13	PHS	Rambouillet	-do-
0.30 ± 0.10	PHS	Targhee	-do-
0.12 ± 0.11	PHS	Columbia	-do-
0.12 ± 0.09	PHS	Merino	Hancock *et al.* (1979)
0.31 ± 0.06	REML	Chokla	Kumar (2000)
0.24 ± 0.08	PHS	Avivastra	Kushwaha *et al.*(1995)
0.15 ± 0.14	REMLs	Dala	Olesen and Husabo (1994)
0.45 ± 0.17	PHS (good env.)	Targhee	Osman and Bradford (1965)
0.19 ± 0.07	PHS (poor env.)	-do-	-do-
0.21 ± 0.04	PHS	Merino	Piper and Bindon (1977)
0.04 ± 0.03	PHS	Marwari	Singh *et al.* (1998)
0.32 ± 0.10	PHS	Muzzaffernagri	Sinha and Singh (1997)
0.30	REML	Australian Merino	Vaez Torshzi *et al.* (1996)
0.42	REMLa	Elsenburg Dormer	Van Wyk *et al.* (1993)
0.13 ± 0.06	PHS	Suffolk	Yamaki (1994)

Table 2.3: Genetic, phenotypic and environmental correlation coefficients of birth weight with different traits in various breeds of sheep

Correlated traits	Correlation coefficients			Breed (s)	Reference (s)
	r_G	r_P	r_E		
WWT	- 0.07± 0.02	0.47	-	SB	Atkins (1986)
	0.45 ± 0.17	0.55	-	Iranian Mehraban	Bathaei (1994)
	0.48	0.36	-	SB	Conington *et al.* (1994)
	0.88 ± 0.26	0.25 ± 0.02	-	Merino	Davis (1987)
	0.55	0.48	0.47	Chokla	Kumar (2000)
	0.47	0.43	0.42	Avivastra	Kushwaha *et al.* (1995)
	0.67	0.65	-	Targhee	Osman and Bradford (1965)
	-0.04 ± 0.27	0.37	0.46	Bharat Merino	Tomar *et al.* (2000a)
	0.02 ± 0.19	0.28	0.39	-do-	Tomar *et al.* (2000b)
	0.37 ± 0.16	0.37 ± 0.03	-		Wuliji *et al.* (2001)
WT 6	0.39	0.34	0.69	Chokla	Kumar (2000)
	0.26	0.32	0.35	Avivastra	Kushwaha *et al.* (1995)
	0.06 ± 0.24	0.31	-	Targhee	Osman and Bradford (1965)
	-0.03 ± 0.21	0.28	0.42	Bharat Merino	Tomar *et al.* (2000a)
	0.02 ± 0.16	0.22	0.52	-do-	Tomar *et al.* (2000b)
WT 12	0.49	0.38	-	Various	Ercanbrack and Price (1972)
	-0.23 ± 0.18	0.25	0.56	Bharat Merino	Tomar *et al.* (2000a)
	-0.18 ± 0.15	0.19	0.65	-do-	Tomar *et al.* (2000b)
	0.37	0.34	-	Suffolk	Yamaki (1994)
GFY 1	0.44 ± 0.13	0.24 ± 0.03	-	Merino	Davis (1987)
	0.71	0.23	0.12	Chokla	Kumar (2000)
	0.49	0.21	0.06	Avivastra	Kushwaha *et al.* (1995)
	-0.02	0.28	-	Targhee	Osman and Bradford (1965)
	0.22 ± 0.28	0.11	-	Muzaffernagri	Sinha and Singh (1997)
	-0.05 ± 0.19	0.14	0.25	Bharat Merino	Tomar *et al.* (2000a)
	0.13 ± 0.19	0.34 ± 0.03	-	Merino	Wuliji *et al.* (2001)

2.2 Weaning weight

2.2.1 Mean performance

The mean performances of weaning weight in different breeds of sheep, as reported by various workers are presented in Table 2.4. The mean performance of weaning weight ranged between 10.26 ± 0.71kg (Arora *et al.*, 1975) to 32.10 ± 0.15 kg (Cloete *et al.*, 2001).

2.2.2 Effect of genetic and non-genetic factors

A. Sire

Kumar (2000) found to be highly significant (P<0.01) sire effect on weaning weight in Chokla sheep.

Singh and Kushwaha (1995) estimated that random effect of sire was highly significant (P<0.01) on body weight at 3 month of age in Bharat Merino sheep.

Sinha and Singh (1997) also reported that random effect of sire was highly significant (P<0.01) on 3-month body weight in Muzzaffernagri sheep.

Swain *et al.* (1994) reported significant (P<=0.05) source of variation due to sire on weaning weight in Bharat Merino sheep.

Tomar *et al.* (2000a) observed highly significant (P<=0.01) differences on weaning weight due to sire in Bharat Merino sheep.

Vatalitya (1993) obtained non- significant effect of sire on weaning weight in Patanwadi and crossbred sheep.

Table 2.4: Least-squares means (± s.e.) of weaning weight in different breeds of sheep

Means (Kg.)	Breed (s)	Reference (s)
11.13	Chokla	Acharya (1982)
10.67 ± 0.09	-do-	Anonymous (1986)
12.95 ± 0.17	Crossbred	AL-Shorepy (2001)
10.26 ± 0.71	-do-	Arora *et al.* (1975)
15.53 ± 0.19	Avikalin	Arora *et al.* (1999)
22.34 ± 0.33	Mehraban	Bathaei (1994)
26.00 ± 0.17	African Merino	Cloete *et al* (2001)
30.10 ± 0.14	Dohne Merino	Cloete *et al* (2001)
32.10 ± 0.15	S. A. Meat Merino	Cloete *et al* (2001)
12.12 ± 0.11	Chokla	Kumar (2000)
13.43 ± 0.26	-do-	Kushwaha (1994)
12.90 ± 0.12	-do-	Kushwaha *et al* (1997)
15.36 ± 0.30	R· M F1	Malik *et al* (1980)
10.57 ± 0.23	-do-	Sahni (1985)
16.65 ± 0.21	Bharat Merino	Singh and Kushwaha (1995)
13.07 ± 0.23	Avikalin	Singh and Dhillon (1992)
16.82 ± 0.37	Muzaffarnagri	Sinha and Singh (1997)
16.20 ± 0.16	Bharat Merino	Tomar *et al* (2000a)
15.74 ± 0.45	-do-	Tomar *et al* (2000b)

B. Season of birth

Kishore *et al.* (1982) reported significant effect (P<0.05) due to season of birth on weaning weight in Avikalin sheep.

Malik and Acharya (1972) estimated that season of birth highly significantly (P<0.01) affected the weaning weight in various crosses of sheep.

Malik *et al.* (1980) observed significant effect on weaning weight due to season of birth in crosses of Chokla, Malpura and Jaisalmeri with Rambouillet.

Singh and Dhillon (1992) reported highly significant (P<0.01) seasonal variation on the weaning weight in Avikalin sheep.

Tomar *et al.* (2000b) obtained highly significant (P<=0.01) effect of season on weaning weight in Bharat Merino sheep.

Vatalitya (1993) estimated that weaning weight significantly differ due to season of birth in Patanwadi and crossbred sheep.

C. Sex of lamb

Arora *et al.* (1999) reported highly significant effect (P<0.01) of sex on weaning weight in Avikalin sheep.

Kumar (2000) also observed highly significant (P<0.01) influence of sex on weaning weight from model 2 and 8 of LSA in Chokla sheep.

Malik and Acharya (1972) estimated non-significant effect due to sex on weaning weight in various crossbred sheep.

Singh and Dhillon (1992) reported highly significant (P<0.001) source of variation of lamb sex on weaning weight.

Tomar *et al.* (2000a) also observed highly significant influence of sex on the weaning weight in Bharat Merino sheep.

2.2.3 Heritability

The heritability estimates of weaning weight in sheep breeds, as available in the literature are summarized in Table 2.5. The heritability estimates varied between 0.05 ± 0.04 (Arora and Kushwaha, 1996) in Avikalin sheep to 0.45 ± 0.07 (Brash *et al.* 1994d) in Coopworth sheep.

Table 2.5: Estimates of heritability (± s.e.) for weaning weight alongwith method of estimation in various breeds of sheep

Heritability (± s.e.)	Method (s)	Breed (s)	Reference (s)
0.05 ± 0.04	PHS	Avikalin	Arora and Kushwaha (1996)
0.13 ± 0.01	REMLa	Suffolk	Barwick (1989)
0.44 ± 0.19	PHS	Iranian Mehraban	Bathaei (1994)
0.34 ± 0.07	-do-	Corriedale	Brash *et al.* (1994c)
0.45 ± 0.07	-do-	Coopworth	Brash *et al.* (1994d)
0.13 ± 0.04	REMLs	Romney	Bissett *et al.* (1992)
0.18 ± 0.07	REMLs	Merino	Cloete *et al.* (2001)
0.21 ± 0.07	-do-	Dohne Merino	-do-
0.32 ± 0.09	-do-	SA meat Merino	-do-
0.14 ± 0.05	-do-	Scottish Blackface	Conington *et al.* (1994)
0.30 ± 0.05	PHS	Merino	Davis (1987)
0.32 ± 0.06	REMLs	-do-	-do-
0.35 ± 0.01	ROD	-do-	-do-
0.34 ± 0.04	ROS	-do-	-do-
0.21 ± 0.06	REML	Chokla	Kumar (2000)
0.34 ± 0.09	PHS	Avivastra	Kushwaha *et al.* (1995)
0.35 ± 0.18	-do-	Chokla	Kushwaha *et al.* (1998)
0.22 ± 0.08	REMLs	Coopworth Romney	Mc Ewan *et al.* (1991)
0.15 ± 0.14	REMLs	Dala	Olesen and Husabo (1994)
0.40 ± 0.17	PHS (good env.)	Targhee	Osman and Bradford (1965)
0.19 ± 0.08	PHS (poor env.)	-do-	-do-
0.43 ± 0.12	-do-	Muzzaffernagri	Sinha and Singh (1997)
0.25 ± 0.13	PHS	Bharat Merino	Singh and Kushwaha (1995)
0.13 ± 0.04	-do-	Marwari	Singh *et al.* (1998)
0.28	REML	Australian Merino	Vaez Torshizi *et al.* (1996)
0.34	REMLa	Elsenburg Dormer	Van Wyk *et al.* (1993)
0.34 ± 0.11	PHS	Suffolk	Yamaki (1994)

2.2.4 Correlation

The genetic, phenotypic and environmental correlation coefficients of weaning weight with other traits in various sheep breeds, as reported by various workers are presented in Table 2.6.

Table 2.6: Genetic, phenotypic and environmental correlation coefficients of weaning weight with different traits in various breeds of sheep

Correlated traits	Correlation coefficients			Breed (s)	Reference (s)
	r_G	r_P	r_E		
WT 6	0.73 ± 0.13	0.65 ± 0.01	-	Romney	Bissett *et al.* (1992)
	0.81	0.72	0.69	Chokla	Kumar (2000)
	0.79	0.67	0.61	Avivastra	Kushwaha *et al.* (1995)
	0.91 ± 0.05	0.70 ± 0.03	-	CRP	Mc Ewan *et al.* (1991)
	0.86 ± 0.05	0.69	-	Targhee	Osman and Bradford (1965)
	0.90 ± 0.11	0.74	0.71	Bharat Merino	Singh and Kushwaha (1995)
	0.62 ± 0.15	0.67	-	Muzaffernagri	Sinha and Singh (1997)
WT 12	0.77 ± 0.13	0.49 ± 0.04	-	Romney	Baker *et al.* (1979)
	0.73	0.72	-	Various	Ercanbrack and Price (1972)
	0.83 ± 0.05	0.63 ± 0.02	-	BLM	Gunawan *et al.* (1985)
	-0.87 ± 0.19	-0.05	0.47	Various	Maji *et al.* (1995)
	0.34 ± 0.31	0.57	-	Merino	Purvis *et al.* (1986)
	0.64 ± 0.10	0.66	-	Rambouillet	Shelton and Menzies (1968)
	0.66 ± 0.18	0.62	0.65	Bharat Merino	Singh and Kushwaha (1995)
	0.94 ± 0.05	0.84	-	Merino	Van Wyk *et al.* (1985)
GFY 1	0.16 ± 0.15	0.32 ± 0.02	-	Corridale	Brash *et al.* (1994c)
	0.40 ± 0.11	0.24 ± 0.02	-	Coopworth	Brash *et al.* (1994d)
	-0.60 ± 0.21	0.23 ± 0.02	-	Romney	Bissett *et al.* (1992)
	0.48 ± 0.12	0.22 ± 0.03	-	Merino	Davis (1987)
	0.82	0.38	0.25	Chokla	Kumar (2000)
	0.36	0.30	0.27	Avivastra	Kushwaha *et al.* (1995)
	0.27 ± 0.21	0.27 ± 0.03	-	CRP	Mc Ewan *et al.* (1991)
	-0.20	0.25	-	Targhee	Osman and Bradford (1965)
	0.26 ± 0.30	0.02	-0.12	Merino	Wuliji *et al.*(2001)

2.3 Body weight at 6 month of age

2.3.1 Mean performance

The performances of 6 month body weight in different breeds of sheep as estimated by various workers are summarized in table 2.7. The mean performance of 6 month body weight ranged between 11.69 ± 0.07kg. (Acharya and Manimohan, 1979) to 25.16 ± 0.41kg (Sinha and Singh, 1997).

Table 2.7: Least square means (± s. e.) of 6-month body weight in various breeds of sheep

Means (Kg.)	Breed (s)	Reference (s)
11.69 ± 0.07	Chokla	Acharya and Manimohan (1979)
13.46	-do-	Acharya (1982)
15.11 ± 0.12	-do-	Anonymous (1986)
13.51 ± 0.55	-do-	Arora *et al.* (1975)
21.94 ± 0.35	Avikalin	Arora *et al.* (1999)
22.34 ± 0.33	Iranian Mehraban	Bathaei (1994)
16.91 ± 0.13	Chokla	Kumar (2000)
17.59 ± 0.34	-do-	Kushwaha (1994)
17.40 ± 0.17	-do-	Kushwaha *et al* (1997)
19.89 ± 0.44	R· M F1	Malik *et al* (1980)
13.88 ± 0.28	-do-	Sahni (1985)
17.55 ± 0.34	Avikalin	Singh and Dhillon (1992)
23.44 ± 0.38	Bharat Merino	Singh and Kushwaha (1995)
25.16 ± 0.41	Muzaffarnagri	Sinha and Singh (1997)
22.03 ± 0.27	Bharat Merino	Tomar *et al* (2000a)
22.31 ± 0.91	-do-	Tomar *et al* (2000b)

2.3.2 Effect of genetic and non-genetic factors

A. Sire

Kumar (2000) reported highly significant (P<0.01) influence by sire on 6 month body weight in Chokla sheep.

Singh and Kushwaha (1995) also observed highly significant (P<0.01) effect due to sire on body weight at 6 month of age in Bharat Merino sheep.

Sinha and Singh (1997) estimated highly significantly (P<0.01) differences on 6 month body weight by sire in Muzzaffernagri sheep.

B. Season of birth

Malik and Acharya (1972) reported highly significant effect (P<0.01) of season of birth on 6 month body weight in various crosses of sheep.

Malik *et al.* (1980) also estimated significant seasonal variation of birth of weight on 6 month of age in Chokla, Malpura and Jaisalmeri with Rambouillet.

Singh and Dhillon (1992) observed non-significant differences due to season of birth on body weight at 6 month of age in Avikalin sheep.

Sinha and Singh (1997) reported highly significant effect (P<0.01) of season of birth on 6 month body weight in Muzzaffernagri sheep.

Tomar *et al.* (2000a) found that 6 month body weight highly significantly (P< = 0.01) affected by season of birth in Bharat Merino sheep.

C. Sex of lamb

Arora *et al.* (1999) observed highly significant (P<0.01) source of variation in 6 month body weight by the sex of lamb in Avikalin sheep.

Kishore *et al.* (1982) also reported highly significant (P<0.01) differences in 6 month body weight affected by sex of lamb in Avikalin sheep.

Malik and Acharya (1972) estimated that 6 month body weight highly affected by sex of lamb in various crosses of sheep.

Malik *et al.* (1980) found significantly effect of sex of the lamb on body weight at 6 month of age in crosses of Chokla, Malpura and Jaisalmeri with Rambouillet.

Singh and Dhillon (1992) observed highly significant (P<0.01) source of variation in 6 month body weight due to sex of lamb in Avikalin lambs.

2.3.3 Heritability

The inheritance of body weight at 6 month of age and later ages have been subjected to considerable study because of its relationship with the efficiency of wool production. The report on heritability estimates of body weight at 6 month of age in different sheep breeds are summarized in Table 2.8. The estimates of heritability varied 0.11 ± 0.04 (Bissett *et al.*, 1992) to 0.58 ± 0.16 (Singh and Kushwaha, 1995).

2.3.4 Correlation

The genetic, phenotypic and environmental correlation coefficients of 6 month body weight with other traits, as reported by various workers in different breed of sheep are presented in Table 2.9.

Table 2.8: Estimates of heritability (± s.e.) 6- month body weight alongwith method of estimation in sheep.

Heritability (±s.e.)	Method (s)	Breed (s)	Reference (s)
0.21 ± 0.13	PHS	Avikalin	Arora and Kushwaha (1996)
0.25 ± 0.07	-do-	Scottish Blackface	Atkins (1986)
0.23 ± 0.05	REMLs	Dorset	Atkins *et al.* (1991)
0.11 ± 0.04	-do-	Romney	Bissett *et al.* (1992)
0.20 ± 0.13	REMLa	Texel ± Oxford	Cameron and Bracken (1992)
0.32	LS-MIVQUE	Barbary	Djemali and Aloulou (1996)
0.27	ML	-do-	-do-
0.36	REML	-do-	-do-
0.19 ± 0.06	REMLs	Dorset	Gilmour *et al.* (1994)
0.32 ± 0.09	PHS	Avivastra	Kushwaha *et al.* (1995)
0.27 ± 0.17	-do-	Chokla	Kushwaha *et al.* (1998)
0.41 ± 0.05	REMLs	Suffolk	Mercer *et al.* (1994)
0.31 ± 0.05	-do-	Texel	-do-
0.42 ± 0.08	-do-	Charollais	-do-
0.27 ± 0.09	PHS	Muzaffernagri	Sinha and Singh (1997)
0.58 ± 0.16	PHS	Bharat Merino	Singh and Kushwaha (1995)
0.41 ± 0.08	-do-	Bharat Merino	Tomar *et al.* (2000a)
0.26 ± 0.10	REMLa	Suffolk	Young and Simm (1990)

Table 2.9: Genetic, phenotypic and environmental correlation coefficients of 6 month body weight with different traits in various sheep breeds

Correlated traits	Correlation coefficients			Breed (s)	Reference (s)
	r_G	r_P	r_E		
WT 12	0.68	0.70	0.71	Avikalin	Arora and Kushwaha (1996)
	0.42±0.28	0.77±0.01	-	Romney	Baker *et al.* (1979)
	0.80	0.81	-	Various	Ercanbrack and Price (1972)
	0.86±0.06	0.83±0.03	-	CRP	Mc Ewan *et al.* (1991)
	0.66±0.12	0.79	0.98	Bharat Merino	Singh and Kushwaha (1995)
	0.54±0.11	0.65	0.78	Bharat Merino	Tomar *et al.* (2000a)
	0.73±0.06	0.65	0.41	-do-	Tomar *et al.* (2000b)
GFY 1	0.44	0.47	0.49	Avikalin	Arora and Kushwaha (1996)
	0.47±0.15	0.53±0.03	-	Merino	Davis (1987)
	0.09±0.22	0.41±0.02	-	-do-	-do-
	0.54	0.49	0.48	Chokla	Kumar (2000)
	0.32	0.29	0.28	Avivastra	Kushwaha *et al.* (1995)
	0.28±0.23	-0.03	-0.41	Bharat Merino	Singh and Kushwaha (1995)
	0.14±0.30	0.35	-	Muzaffernagri	Sinha and Singh (1997)
	0.47±0.12	0.42	0.37	-do-	Tomar *et al.* (2000a)

2.4 Body weight at 12 month of age

2.4.1 Mean performance

The Least-squares means for 12 month body weight, reviewed from literature are summarized in Table 2.10. The mean performance of 12 month body weight ranged between 16.82 ± 0.37 (Singh and Kushwaha, 1995) to 65.20 ± 0.33 (Cloete *et al.*, 2001).

Table 2.10: Least square means (± s.e.) of 12-month body weight in different breeds of sheep

Means (Kg.)	Breed (s)	Reference (s)
28.70 ± 0.28	Avikalin	Arora *et al.* (1999)
49.80 ± 0.37	African Merino	Cloete *et al* (2001)
57.90 ± 0.29	Dohne Merino	Cloete *et al* (2001)
65.20 ± 0.33	S. A. Meat Merino	Cloete *et al* (2001)
25.13 ± 0.49	R· M F1	Malik *et al* (1980)
25.09 ± 0.51	R· M F2	-do-
25.11 ± 0.56	R· M 5/8	-do-
23.08 ± 0.55	R· M 3/4	-do-
22.39 ± 0.58	Avikalin	Singh and Dhillon (1992)
31.47 ± 0.46	Bharat Merino	Singh and Kushwaha (1995)
29.74 ± 0.34	Bharat Merino	Tomar *et al* (2000a)
30.26 ± 1.01	-do-	Tomar *et al* (2000b)

2.4.2 Effect of genetic and non-genetic factors

A. Sire

Singh and Kushwaha (1995) observed that random effect of sire was highly significant (P<0.01) on weight at 12 month of age in Bharat Merino sheep.

Tomar *et al.* (2000a) also reported a highly significant variation due to sire on body weight at 12 month of age in Bharat Merino sheep.

B. Season of birth

Malik and Acharya (1972) estimated significant differences in yearling weight existed between two seasons of birth in various crosses of sheep.

Malik *et al.* (1980) also observed significant seasonal variation of birth on 12-month body weight in crosses of Chokla, Malpura and Jaisalmeri with Rambouillet.

Singh and Dhillon (1992) reported non-significant effect in 12-month body weight existed between two season of birth in Avikalin lambs.

Tomar *et al.* (2000a) estimated significant (P<0.01) effect due to season of birth on weight at 12 month of age in Bharat Merino sheep.

C. Sex of lamb

Arora *et al* (1999) reported highly significant (P<0.01) effect of sex on 12 month body weight in Avikalin sheep.

Malik *et al.* (1971) also estimated that sex of lamb is a highly (P<= 0.01) significant source of variation for 12 month weight in Chokla sheep.

Malik and Acharya (1972) observed significant differences due to sex on body weight at 12 month of age in various crosses of sheep.

Singh and Dhillon (1992) reported sexually a highly significant (P<0.01) effect for 12 month body weight in Avikalin sheep.

Singh and Kushwaha (1995) estimated that sex of lamb is a highly significant effect on body weight at 12 month of age in Bharat Merino sheep.

2.4.3 Heritability

The heritability estimates for 12 month body weight, reviewed from literature are summarized in Table 2.11. The heritability estimates for 12 month body weight were found to be low to high in magnitude with a range of 0.11 ± 0.06 (Gilmour *et al.*,1994) to 0.82 ± 0.26 (Bissttel *et al.*, 1992).

Table 2.11: Heritability estimates (±s.e.) of 12- month body weight alongwith method of estimation in sheep

Heritability (± s.e.)	Method (s)	Breed (s)	Reference (s)
0.20 ± 0.13	-do-	Avikalin	Arora and Kushwaha (1996)
0.21 ± 0.08	-do-	Scottish Blackface	Atkins (1986)
0.82 ± 0.26	-do-	Rambouillet	Bissett *et al.* (1992)
0.13 ± 0.04	REMLa	Corriedale	Brash *et al.* (1994c)
0.38 ± 0.07	-do-	Coopworth	Brash *et al.* (1994d)
0.30 ± 0.07	REMLs	Merino	Cloete *et al.* (2001)
0.33 ± 0.07	-do-	Dohne Merino	-do-
0.45 ± 0.07	-do-	S A Meat Merino	-do-
0.44 ± 0.26	-do-	Crossbred	Ercanbrack and Price (1972)
0.57 ± 0.15	-do-	Rambouillet	-do-
0.25 ± 0.10	-do-	Targhee	-do-
0.55 ± 0.14	-do-	Columbia	-do-
0.11 ± 0.06	REMLs	Dorset	Gilmour *et al.* (1994)
0.49 ± 0.18	-do-	Romney	Mc Ewan *et al.* (1984)
0.29 ± 0.09	REMLs	CRP	Mc Ewan *et al.* (1991)
0.56 ± 0.09	PHS	Bharat Merino	Tomar *et al.* (2000)
0.41 ± 0.15	PHS	Merino	Van Wyk *et al.* (1985)
0.66 ± 0.22	PHS	Suffolk	Yamaki (1994)
0.53 ± 0.14	ROD	Merino	Young *et al.* (1960b)

2.4.4 Correlation

Arora and Kushwaha (1996) reported genetic, phenotypic and environmental correlations between 12 month body weight and GFY 1 to be 0.01, 0.35 and 0.48, respectively, in Avikalin sheep.

Koots *et al.* (1994b) reported that large differences between genetic and phenotypic correlations occurred only when the genetic correlation was estimated with low precision.

Singh and Kushwaha (1995) observed genetic, phenotypic and environmental correlations between 12 month body weight and GFY 1 to be –0.41 0.23, -0.13 and 0.22, respectively, in Bharat Merino sheep.

Tomar *et al.* (2000a) computed genetic, phenotypic and environmental correlations between 12 month body weight and GFY 1 to be –0.07 0.15, 0.23 and 0.56, respectively in Bharat Merino sheep.

2.5. First greasy fleece yield at 6 month of age

2.5.1 Mean performance

The mean performances of GFY1 in various breeds of sheep, as reviewed in literature are summarized in Table 2.12. The least squares means for GFY1 varied from 0.82 ± 0.02 kg. (Tomar *et al.*, 2000a) in Bharat Merino to 1.37 kg. (Acharya, 1982) in Chokla sheep.

Table 2.12: Least square means (± s.e.) of first six monthly greasy fleece yield in different breeds of sheep

Means (Kg.)	Breed (s)	Reference (s)
0.89 ± 0.38	Chokla	Acharya and Manimohan (1979)
1.37	-do-	Acharya (1982)
0.93 ± 0.01	-do-	Anonymous (1986)
0.85 ± 0.03	-do-	Anonymous (1993)
1.19 ± 0.02	Avikalin	Arora *et al.* (1999)
0.95 ± 0.02	Chokla	Kumar (2000)
0.97 ± 0.01	-do-	Kushwaha *et al* (1997)
0.86 ± 0.03	Bharat Merino	Singh and Kushwaha (1995)
0.82 ± 0.02	Bharat Merino	Tomar *et al* (2000a)

2.5.2. Effect of genetic and non-genetic factors

A. Sire

Kumar (2000) observed highly significant effect (P<0.01) due to sire on GFY 1 in Chokla sheep.

Singh and Kushwaha (1995) also reported highly significantly (P<0.01) influence of sire on GFY 1 in Bharat Merino sheep.

Tomar *et al.* (2000a) estimated significant effect of sire on GFY 1 in Bharat Merino sheep.

Sinha and Singh (1997) reported that random effect of sire was highly significant (P<0.01) on GFY 1 in Muzzaffernagri sheep.

B. Season of birth

Batalitya (1993) reported highly significant (P<0.01) influence to due season of birth on GFY 1 in Patanwadi and crossbred sheep.

Tomar *et al.* (2000a) also observed highly significant (P<0.01) seasonal variation in GFY 1 existed between two seasons of birth in Bharat Merino sheep.

C. Sex of lamb

Kumar (2000) observed significant effect (P<0.05) of sex on GFY 1 under model 8 of LSA where as non- significant effect under model 2 of LSA in Chokla sheep.

Singh and Kushwaha (1995) reported highly significant (P<0.01) influence due to sex on GFY 1 in Bharat Merino sheep.

Tomar *et al.* (2000a) estimated non-significant effect of sex on GFY 1 in Bharat Merino sheep.

2.5.4 Heritability

The heritability estimates for GFY1, reviewed form literatures are presented in Table 2.13. The heritability estimates for GFY1 were found to be low to high in magnitude with a range of 0.11 ± 0.06 **(Kumar, 2000)** in Chokla to 0.84 ± 0.33 **(Osman and Bradford, 1965)** in Targhee sheep.

Table 2.13: Estimates of heritability (± s.e.) for GFY 1 alongwith method of estimation in various breeds of sheep

Heritability (± s.e.)	Method (s)	Breed (s)	Reference (s)
0.35 ± 0.15	PHS	Avikalin	Arora and Kushwaha (1996)
0.49 ± 0.09	-do-	Scottish Blackface	Atkins (1986)
0.41 ± 0.09	REMLs	Romney	Bissett *et al.* (1992)
0.17 ± 0.05	REMLa	Border Leicester	Brash *et al.*(1994b)
0.32 ± 0.07	-do-	Corriedale	Brash *et al.*(1994c)
0.28 ± 0.05	-do-	Coopworth	Brash *et al.*(1994d)
0.48 ± 0.10	PHS	Merino	Davis (1987)
0.65 ± 0.11	REMLs	-do-	-do-
0.16 ± 0.20	-do-	Poll Dorset	Hall *et al.* (1994)
0.11 ± 0.06	-do-	Chokla	Kumar (2000)
0.44 ± 0.09	PHS	Avivastra	Kushwaha *et al.* (1995)
0.64 ± 0.20	-do-	Chokla	Kushwaha *et al.* (1998)
0.56 ± 0.13	REMLs	CRP	Mc Ewan *et al.* (1991)
0.38 ± 0.21	-do-	Dala	Olesen and Husabo (1994)
0.84 ± 0.33	PHS (good env.)	Targhee	Osman and Bradford (1965)
0.50 ± 0.17	PHS (poor env.)	-do-	-do
0.19 ± 0.08	PHS	Kashmir Merino	Sheikh and Dhillen (1992)
0.52 ± 0.15	PHS	Bharat Merino	Singh and Kushwaha (1995)
0.52 ± 0.06	-do-	Marwari	Singh *et al.* (1998)
0.15 ± 0.07	-do-	Muzaffernagri	Sinha and Singh (1997)
0.20	REML	Merino	Snyman *et al.* (1996)
0.49 ± 0.09	PHS	Bharat Merino	Tomar *et al.* (2000a)

2.6 Comparison between parameter estimates

2.6.1 Heritability

Few results have been reported on comparison of genetic parameter estimates on the basis of REML fitted with IAM and traditional sire model based on ANOVA and its types for sheep in general. Young (1989) and Conington *et al.* (1995) in an experiment based on sheep selection spanned approximately two generations, over sires and few on ewes, but they explain their failure to demonstrate the superiority of individual animal model over sire model. A review of Koots *et al.* (1994b) based on beef animals, having few pedigree data, spread over few years, or both, hence their failure to find out differences between ANOVA and ML based methods. A further likely explanation of this discrepancy is that, if there is no effect of selection in an experiment, then, there will be no reduction in genetic variance. Therefore, genetic parameter estimates will not be affected by the method of analysis (Koots *et al.* 1994a). In addition, to demonstrate the superiority of REML individual animal model mathematical properties, it requires long term selection experiment with large pedigree data.

Bulmer (1971) observed that lower heritabilities for data from more resent year indicated reduced genetic variation caused by increased gametic phase disequilibrium due to increase selection intensity.

Burfenning and Kness (1993) have described that higher h^2 estimates from model 2 using paternal half sibs may be due to common environmental factors among paternal half sib.

Conigton *et al.* (1995) reported similar heritability 0.08, 0.07 for birth weight and 0.12, 0.14 for weaning weight by univariate and sire model, respectively.

Dong *et al.* (1998) reported that estimates of heritability from REML with an animal model were considerably smaller if relationship were from sire only as compared with from more complete relationships and the estimates could be larger if more relationship were included with REML and an animal model.

Kumar (2000) reported comparison of heritability estimates based on REML univariate animal model and model 2 and 8 of least squares methods in Chokla sheep. The results are summarized in Table 2.14. He reported much difference between heritability obtained by above two procedures. He explained that higher heritability estimated from REML method than the least square method may be due to exclusion of maternal effect in univariate animal model.

Table 2.14: Comparison between heritability estimates for various traits in Chokla sheep

S. No.	Traits	Heritabilities		
		Model 2	Model 8	Univariate AM
1	BWT	0.138 ± 0.070	0.147	0.306
2	WWT	0.238 ± 0.079	0.185	0.204
3	WT6	0.245 ± 0.080	0.161	0.240
4	GFY1	0.242 ± 0.080	0.144	0.103

Hansen and Shrestha (1997) reported comparison on h^2 estimates for ewe productivity traits in three breeds of sheep using least squares analysis (LSA) and REML procedures. The results are presented in Table 2.15.

Table 2.15: Comparison of heritability estimation by LSA and REML for ewe productivity traits in three different breeds of sheeps

Breed	Heritability	
	LSA	REML
Fertility		
Canadian	0.12	0.08
Outaouais	0.16	0.10
Rideau	0.14	0.07
Prolificacy		
Canadian	0.16	0.10
Outaouais	0.20	0.23
Rideau	0.15	0.13
Multiple birth		
Canadian	0.11	0.07
Outaouais	-0.04	0.00
Rideau	0.06	0.02
Fecundity		
Canadian	0.12	0.06
Outaouais	0.14	0.16
Rideau	0.08	0.06
Ewe weight at breeding (kg)		
Canadian	0.18	0.17
Outaouais	0.03	0.14
Rideau	0.21	0.33

Maria *et al.* (1993) reported that the influence of the non-permanent environmental factors become important after weaning.

Notter and Hough (1997) observed that genetic parameters for body weights showed the expected increase in importance of additive effects with increase of compositional maturity and body weight.

Raheja (1992) reported that h^2 estimated from use of residual and sire variances, obtained from single trait Handerson Model 3, were over estimated by about 15-20 per cent.

Snyman *et al.* (1995) reported more importance of direct additive genetic effects than maternal genetic effects for BWT, WWT and clean fleece yield traits.

2.6.2 Correlation between h^2 and coefficient of variation

Kumar (2000) estimated positive correlation between h^2 and coefficient of variation for body weight traits under model 8 and negative correlation between h^2 and coefficient of variation for body weight traits in univariate animal model.

2.7 Breeding values

Genetic improvement of a trait in a particular flock/herd mainly depends on genetic superiority of the sires used for breeding purpose. If the sire selected for breeding purpose possess superior combinations of genes with respect to production/reproduction traits, then only, the desired genetic improvement could be achieved in stipulated time period.

Traditionally, in the absence of selection and random mating, the breeding values are estimated as the individual or progeny deviation from contemporary performance within an environment (Dalton, 1985; Falconer, 1989 and Nicholas, 1993) after adjusting for most identifiable environmental sources, viz. Birth rank, rearing rank, age of dam and age of the individual. Estimation of breeding value would be biased from traditional method in selected population

and or animals are compared across environments or are assortatively mated. Recently, best linear unbiased prediction (BLUP) developed by Henderson (1949, 1973), is the better method (Henderson, 1973, 1980; Kennedy, 1981; Falconer, 1989; Nicholas, 1993), particularly, when IAM has been employed for the analysis. The model of analysis under BLUP takes into account the fixed effects and relatedness between animals, therefore, breeding values estimated from this methods are less biased (Falconer, 1989; Henderson, 1973, 1990b and Nicholas, 1993).

Kumar (2000) evaluated top 10 sires out of 110 sires, on the basis of their breeding values estimated from model 8 (BLUP 1) and univariate animal modle (BLUP 2) for BWT, WWT, 6WT and GFY 1 in chokla sheep. The BLUP values ranged between 0.1224 to 0.0702, 0.668 to 0.3802, 0.836 to 0.4703 and 0.0851 to 0.0381 for BWT, WWT, 6WT and GFY 1, respectively, in model 8. In univariate animal model (BLUP 2) the breeding values ranged from 0.5262 to 0.2985, 2.2562 to 1.2801, 2.9029 to 2.0222 and 0.1429 to 0.0781 for the traits.

However, literature revealed that, through the LSM and BLUP procedures of estimating the ESM of sires are easy from the view point of computations involved. The BLUP procedure is better and has minimum prediction error variance, provided the true variance of random effects are know. Hence, BLUP method could be treated as best, if and only if, the exact ratio of residual to sire variance or heritability is known, however, LSM procedure could be treated Conigton *et al.* (1995) reported similar heritability 0.08, 0.07 for birth weight and 0.12, 0.14 for weaning weight by univariate and sire model, respectively.

Dong *et al.* (1988) reported that estimates of heritability from REML with an animal model were considerably smaller if relationship were from sire only as compared with from more complete relationships and the estimates could be larger if more relationship were included with REML and an animal model.

2.8 Rank correlation

Kumar (2000) observed highly significant rank correlations for BWT, WWT, WT6 and GFY1 under model 8 and univariate animal model. Rank correlation of model 8 was lower than univariate animal models.

Material and Methods

3.1 Experimental data and location

Data in present study were recorded over a period of 22 years (1980-2001), from data base of 1313 Avikalin crossbred sheep, maintained at Central Sheep and Wool Research Institute, Avikanagar, District Tonk, Rajasthan.

The Institute was established in 1962 near Tehsil Malpura of District Tonk , Rajasthan. It is located about 85 km away from Jaipur on Jaipur-Toda Rai Singh road and campus is known as Avikanagar. The institute is located at 26^0- 17′ N and 75^0-22′ E with elevation of 326 m above mean sea level. The annual rainfall varies from 11.16 cm (in 1987) to 39.21 cm (in 1977). The farm is spread over an area of 1251 hectares. The soil is sandy loam. The maximum temperature goes as high as 46^0C during the month of May and June and falls to the level of 0.5^0C during winter months.

3.2 Management of the flock

3.2.1 Housing

Animal were housed according to their age, size, physiological and health status in the housing complex providing standard floor space of ten square feet per sheep. All the sheds and corrals were disinfected frequently with lime.

3.2.2 Feeding

3.2.2.1 Grazing

The grazing area was available about 375 acres for sheep grazing. Till 1985, conventional grazing system was followed by regular mazdoors. Since 1986, contractual grazing system was being followed. Under contractual grazing system, the grazing hours were 6.30 A.M. to 6.30 P.M. during April to Sept., 8.00 AM to 6.00 PM during Oct to Feb. and from 7.30 AM to 6.00 PM during March. The rotational grazing system was also followed.

3.2.2.2 Supplementary feeding

Cenchrus, cowpea, pala leaves and khejri leaves were provided to the animals. Concentrate was supplemented to different category of animals at the recommended rates. Ewes were supplemented with 250 g. concentrate in the last month of pregnancy and first two months of lactation. Lambs were weaned at 3 month of age. Weaner lambs were offered concentrate mixture @ 300 g. /day up to age of 1 year. Mineralized salts licks were also provided to the animals.

3.2.2.3 Health cover

Various prophylactic measures viz. drenching, dipping and vaccinations were followed as per the recommendation of sheep health scientists. To maintain hygienic condition in sheep sheds and corrals, 6″ soil was scrapped and replaced with the new soil mixed with lime, twice a year. The sick animals were isolated form the flock and kept separately in sick wards for treatments.

3.3 History of Avikalin strain

Avikalin, a carpet wool sheep has been created out by stabilizing the crossbred population of Rambouillet × Malpura at 50% exotic inheritance. It was evolved in the year 1977 with the objectives to produce 2 Kg. annual fleece yield, around 30 micron fibre diameter and 30% medullation. During the initial years and up to 1992 ram lambs /breeding lambs were selected following the sequential selection based on WWT, WT6, WT12, GFY1, GFY2 and wool quality traits viz. staple length at 6 month of age and fibre diameter at yearling stage. The objectives of wool quality traits have been achieved and since 1993 the animals were selected based on an index incorporating 6 month body weight and GFY1. During the selection, main emphasis being on 6 month body weight and GFY1. Avikalin sheep is a promising strain of sheep for carpet wool and produces 80% more wool than the native Malpura sheep. This strain has shown considerable improvement with regards to greasy fleece production and wool quality. Further improvement is being made through selection and inter-se-mating. Avikalin sheep can be used as improver breed for cross breeding of coarse wool breeds of sheep to increase carpet wool production and it has potential to be developed as dual-purpose sheep. Moreover, recent hike in meat price and scope for exporting mutton, it was evolved for carpet wool as well as mutton production since 1992.

3.4 Collection of data

The data used in the present study were taken from the database of Avikalin crossbred sheep lambed during 1980-2001. The following information were recorded:

- Animal No
- Sire No.
- Dam No.
- Date of lambing
- Sex
- Birth weight (BWT)
- Weaning weight at 3 month of age (WWT)
- Weight at 6 month of age (WT6)
- Weight at 12 month of age (WT12)
- First greasy fleece yield at 6 month of age (GFY1).

Under the present analyses Birth (BWT), weaning (WWT), six month (WT6), 12 month (WT12) and first six monthly greasy fleece weights (GFY1) were considered for the study.

3.5 Standardization of records

The animals with known pedigree and complete records on all target traits, viz. birth weight, weaning weight, 6 month weight, 12 month weight and 1st greasy fleece yield were considered for the present study. The sires with less than 4 progenies had been deleted from the analysis. A total of 1313 observations on Avikalin crossbred sheep were used for the present investigation.

3.6 Statistical Analyses

Least-squares analysis (LSA) and derivative-free Restricted Maximum Likelihood (DFREML) methods were used for the estimation of genetic and phenotypic parameters and variance -covariance components.

3.6.1 Least-squares analysis of variance (LSA) method

The LSMLMW and MIXMDL package of Harvey (1990) under different models were carried out for the analysis. A total of two models were considered to examine the effect of genetic and non-genetic factors on various body weight traits and on first greasy fleece yield.

3.6.1.1 Model 2

This model considered was from Harvey (1990), which consists one set of cross-classified non-interacting random effect. All five traits were analyzed simultaneously with the following statistical model :

$$y_{ijkl} = \mu + S_i + C_j + Y_k + e_{ijkl}$$

where,

y_{ijkl} is observation on i^{th} progeny of ith sire of jth sex in k^{th} year,

μ is the overall mean,

S_i is random effect of ith sire ($i = 1,2, \ldots, 106$),

C_j is the fixed effect of the jth sex ($j=1,2$),

Y_k is the fixed effect of kth season of birth ($k=1,2$), and

e_{ijkl} is the random error which is normally and independently distributed with mean 0 and variance σ^2_e.

The analyses computed with the mixed model least-squares program utilizes the Method 3 of Henderson (1953).

3.6.1.2 Model 8

This model considered was from Harvey (1990) which also consists one set of cross-classified non-interacting random effect. The same model was fitted on all the traits and the traits were analyzed separately. The general formulation of the mixed model fitted on the observation, comprised the following:

$$y_{ijkl} = \mu + S_i + C_j + Y_k + e_{ijkl}$$

where, all the abbreviations are same as described in model 2.

The formulation of the model in matrix notation is as follows:

$$y = l\mu + Xb + Za + e$$

where,

l is the column vector of One's

μ is an overall mean,

b is a column vector of fixed effects,

a is a column vector of random effect,

Z is an incidence matrix of 0′ s and l′s,

X is an incidence matrix of 0′ s, l′s & - l′s and X-$\overline{X}$ values for the discrete effects, and

e is a column vector of the random errors.

This model is same as model 2, except the random effects may be correlated. Henderson's mixed model equations are used by MIXMDL program of Harvey (1990) to estimate Best Linear Unbiased Predictions (BLUP) of random effects, Best Linear Unbiased Estimates (BLUE) of the fixed effects and the MINQUE estimates of variance component. In this analysis, MINQUE estimates of the variance components are computed and the REML option may be used to obtain restricted maximum likelihood estimates of variance components from iterative MINQUE.

Mixed model equations are:

$$\begin{bmatrix} N & I'Z & I'X \\ Z'I & Z'Z + kA^{-1} & Z'X \\ X'I & X'Z & X'X \end{bmatrix} \begin{bmatrix} \hat{\mu} \\ \hat{a} \\ \hat{b} \end{bmatrix} = \begin{bmatrix} y. \\ Z'y \\ X'y \end{bmatrix}$$

where,

$k = (1 - REP) / REP = \sigma^2_e / \sigma^2_a$,

A^{-1} is an inverse of the relationship matrix, and

REP = intra-class correlation

Now let the inverse segment for the random set of effects ($Z'Z + kA^{-1}$ section) from the inverse of the coefficient matrix be designed as Caa.

MINQUE estimates of variance components:

The MINQUE quadratics form, from Henderson (1984) is:

$$Q_1 = \hat{a}' A^{-1} \hat{a}$$

$$Q_2 = \hat{e}'\hat{e}$$

where, $\hat{e} = y - X\hat{b} - Z\hat{a}$

and $E(Q_1) = E(\hat{a}' A^{-1} \hat{a}) = tr\,[A^{-1}\, Var\,(\hat{a})] = T_{11}\,\sigma^2_a + T_{12}\sigma^2_e$

$$T_{11} = s - 2k\, tr\,(A^{-1}\, Caa) + k^2\, tr\,(A^{-1}Caa\, A^{-1}Caa)$$

$$T_{12} = tr\,(A^{-1}Caa) - k\, tr\,(A^{-1}Caa\, A^{-1}Caa)$$

$$E(Q_2) = E\,(\hat{e}'\hat{e}) = tr\,[\,Var\,(e)] = T_{21}\,\sigma^2_a + T_{22}\,\sigma^2_e$$

$$T_{21} = k^2\, T_{12}$$

$$T_{22} = N - p - s + k^2\, tr\,(A^{-1}Caa\, A^{-1}Caa)$$

The MINQUE equations are:

$$\begin{pmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{pmatrix} \begin{pmatrix} \sigma^2_a \\ \sigma^2_e \end{pmatrix} = \begin{pmatrix} Q_1 \\ Q_2 \end{pmatrix}$$

where,

tr = trace,

s = number of random classes,

N = total number of observations, and

p = number of degrees of freedom for fixed effects including one for μ.

The sum of squares of solutions to the MME (mixed model equations) with the expectations calculated from the inverse of the coefficient matrix for the MME could be used to obtain MINQUE estimates of variance components. Iterative MINQUE with normality is the same as REML.

3.6.1.3 Estimation of parameters

The estimates of h^2 and genetic, phenotypic and environmental correlations were computed from sire components of variance and covariance using LSMLMW and MIXMDL computer program PC-2 (Harvey, 1990). Estimates of heritabilites and all correlations were based upon variance and covariance components using the method of paternal half-sibs correlations. The theoretical expectations and causal components for variances and covariances among families used in this study are shown in Table3.1.

Table 3.1: Simultaneous equations to estimate causal components of variance from observed family variances under model 2 and 8

Observed family components	Statistical model used	Causal components							
		Additive			Dominance			σ^2_{EC}	σ^2_e
		σ^2_{AD}	σ^2_{AM}	σ^2_{ADAM}	σ^2_{DD}	σ^2_{DM}	σ^2_{DDDM}		
$\sigma^2_{s(PHS)}$	Model 2	1/4	0	0	0	0	0	0	0
$\sigma^2_{w(PHS)}$	Model 2	0	0	0	0	0	0	0	3/4
$\sigma^2_{s(PHS)}$	Model 8	1/4	0	0	0	0	0	0	0
$\sigma^2_{w(PHS)}$	Model 8	0	0	0	0	0	0	0	3/4

where, σ^2_{AD} additive direct, σ^2_{AM} additive maternal, σ^2_{ADAM} additive direct maternal, σ^2_{DD} dominance direct, σ^2_{DM} dominance maternal , σ^2_{DDDM} dominance direct maternal, $_{PHS}$ paternal half sibs, σ^2_{EC} permanent maternal environmental, and σ^2e random environmental.

3.6.1.3.1 Estimation of heritability:

3.6.1.3.1.1 Under model 2

The heritability for the traits under study were computed by the paternal half-sib correlation method. The expected mean squares (EMS) for various effects are:

ANOVA Table

S.V	D.F	M.S	E(MS)
Between sire	s-1	MS_s	$\sigma^2_e + k_1 \sigma^2_s$
Between sex	c-1	MS_c	$\sigma^2_e + kk_2\sigma^2_c$
Between season	y-1	MS_y	$\sigma^2_e + kk_2\sigma^2_y$
Error	N-s-c-y+2	MS_e	σ^2_e
Total	N-1		

The components of variance were estimated as follows:

$$\hat{\sigma}^2_e = MS_e \qquad \hat{\sigma}^2_s = (MS_s - MS_e)/k_1$$

and $$k_1 = \frac{1}{s-1}[N - \frac{\sum_{i=1}^{s} n_i^2}{N}]$$

$$h^2 = \frac{[(1 - NR1)\hat{\sigma}^2_s]}{[((1 - NW)/NR1) * \hat{\sigma}^2_s + \hat{\sigma}^2_e]}$$

where,

$\hat{\sigma}^2_s$ is cross classified sire variance component estimate,

$\hat{\sigma}^2_e$ is error variance estimate,

NR1 is the decimal percentage of additive genetic variance in σ^2s. NR1 is between variance component and is equal to 0.25, and

NW is the decimal percentage of additive genetic variance in σ^2e in random mating population. NW is within variance component and is equal to 0.75.

3.6.1.3.1.2 Under model 8

The heritability estimated by Model 2 analyses was divided by 4 and then the value obtained was used as intra-class correlation in REP option for respective trait in Model 8 analysis. This method also used paternal half-sib correlations method to estimate the h^2. Therefore, the intra-class correlation was estimated by using VAR (A) and VAR (E), estimated under MINQUE, and then this correlation value was multiplied by 4 to obtain h^2.

$$t = \hat{\sigma}^2_s / (\hat{\sigma}^2_s + \hat{\sigma}^2_e)$$

$$h^2 = 4t$$

where,

t is intra-class correlation among half sibs,

$\hat{\sigma}^2_s$ is the between sire component of variance, and

$\hat{\sigma}^2_e$ is the within sire component of variance or error variance.

3.6.1.3.2 Estimation of correlations

$$r_g(hh') = \frac{Cov_s(hh')}{\sqrt{\hat{\sigma}_s^2(h) * \hat{\sigma}_s^2(h')}}$$

$$r_e(hh') = \frac{\hat{\sigma}_e(hh') - [(NW / NR1)\ \hat{\sigma}_s(hh')]}{\sqrt{[\hat{\sigma}_e^2(h) - (NW / NR1)\hat{\sigma}_s^2(h)][\hat{\sigma}_e^2(h') - (NW / NR1)\hat{\sigma}_s^2(h')]}}$$

$$r_p(hh') = \frac{\hat{\sigma}_e(hh') + \{[(1-NW) / NR1]\ \hat{\sigma}_s(hh')\}}{\sqrt{[\hat{\sigma}_e^2(h) + ((1-NW) / NR1)\hat{\sigma}_s^2(h)][\hat{\sigma}_e^2(h') + ((1-NW) / NR1)\hat{\sigma}_s^2(h')]}}$$

where,

Cov_s is sire or family covariance,

h refers to h^{th} trait and h' refers to another trait respectively,

$\hat{\sigma}^2_s$ refers among variance or covariance components, and

$\hat{\sigma}^2_e$ refers within variance or covariance components.

3.6.1.3.3 Estimation of standard error

The standard error of h^2 was estimated using the formula of Swiger *et al.* (1964) which is as follows:

$$S.E\ (h^2) = \frac{4\sqrt{2(N-1)(1-t)^2(1+(k-1)t)^2}}{\sqrt{k^2(N-s)(s-1)}}$$

where,

t is intra-class correlation,

s is the number of sires,

N is the total number of observations, and

k is the average number of progenies per sire.

The standard error of genetic correlation was estimated by the formula as given by Robertson (1959):

$$S.E\ (r_g) = \frac{1-r_g^2}{\sqrt{2}} * \frac{\sqrt{S.E(h_x^2) * S.E(h_y^2)}}{\sqrt{h_x^2 * h_y^2}}$$

where,

h^2_x and h^2_y are the h^2 estimates of trait x and y, respectively,

S.E is the standard error, and

r_g is genetic correlation.

The standard error of phenotypic correlation was estimated by the formula as given by Panse and Sukhatme (1967):

$$S.E\ (r_p) = \frac{\sqrt{1-r^2_{p(xy)}}}{\sqrt{N-2}}$$

where,

$r_{p(xy)}$ is the phenotypic correlation between trait x and trait y, and

N is the total number of observations.

The significance of phenotypic correlation was tested from the Table of Snedecor and Cochran (1967) at (N-2) degrees of freedom.

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3.6.2 Restricted Maximum Likelihood (REML) method

For REML estimation of variance components, data were analyzed by derivative free Restricted Maximum Likelihood (DFREML) program of Meyer (1998) under univariate animal model. Derivative free restricted maximum likelihood (DFREML) was described by Smith and Graser (1986) and Meyer (1989b). The program attempts to locate the likelihood function (L) without using information from derivative of L. The derivative free algorithm, for use in REML (co)variance component estimation in animal or reduced animal model, does not require matrix inversion, instead it uses dimensional search involving the variant part of the log likelihood to find the maximum of the function. Computational strategies used and problems associated with this kind of analysis have been discussed by Meyer (1992a. 1993a).

Variances components were estimated by REML using a derivative free algorithm, fitting an animal model throughout and incorporating all available pedigree information (Meyer, 1989, 1991, and 1998). Variance matrices were estimated by derivative free REML (Smith and Gracer, 1986; Gracer *et al.*, 1987) and popularized by Meyer (1988, 1989band 1991). The single trait DFREML program developed by Meyer (1998) was used. Heritability estimates were subsequently obtained by using the derivative-free REML procedure (DFREML) of Meyer (1998) using animal model. The heritability was categorized as direct in animal model where only a direct effect was fitted. The model includes all animals, even without records, but as parents in the base

population. It, therefore, take all information into account for the estimation of variance components (Sorenson and Kennedy, 1986). Full pedigree were available, but parents with only a single link to one offspring were treated as unknown, as they did not contribute any information and unnecessarily increased the number of effects in the analysis (Meyer, 1994).

3.6.2.1 Single trait model

In univariate analysis, birth weight (BW), weaning weight (WWT), 6 month weight (WT6), 12 month weight (WT12) and 1st six monthly greasy fleece yield (GFY1) were analyzed separately. The same model was fitted on all five traits. The general formulation of the mixed model fitted on the observations, comprised the following:

$$y_{ijkl} = \mu + A_i + C_j + Y_k + e_{ijkl}$$

where,

y_{ijkl} is the observation on i^{th} trait of ith animal of jth sex in k^{th} year,

μ is the overall mean,

A_i is random effect of ith animal (i = 1,2, ..., 1478),

C_j is the fixed effect of the jth sex (j=1,2),

Y_k is the fixed effect of kth season of birth (k=1,2) and

e_{ijkl} is the random error which is normally and independently distributed with mean 0 and variance σ^2_e.

The formulation of general single trait animal model, in matrix notation, is:

$$y = Xf + Za + e$$

where,

y is a vector of N x 1 records (i = 1,2,3,4),

f is a vector of fixed environmental effects of sex (1,2) and season(1,2). No covariable was taken here,

a is a vector of breeding values for additive direct genetic effects fitted which is random,

X is a N * NF design matrix for fixed effects with column ranks $N * F^*$,

Z is a N * NR design matrix for random animal effects, where Z = I, and

e is a vector of N random residual errors.

Assumptions of the model are:

$$E[y] = Xf$$

$$E[a] = E[e] = 0$$

with variances,

$$Var(a) = A\,\sigma^2_a = G$$

$$Var(e) = I\,\sigma^2_e = R$$

$$Cov(a, e') = 0$$

$$Var(y) = ZAZ'\,\sigma^2_a + I\,\sigma^2_e = ZGZ' + R = V$$

where,

A is numerator relationship matrix,

σ^2_a is direct additive genetic variance,

σ^2_e is residual variance, and

I represents identity matrix.

All the covariances are assumed to be null. This is simple animal model fitting animals' direct additive genetic effect only (i.e., ignoring any maternal effects). Additionally, inbreeding was excluded from vector f but included in A. Starting values for h^2 given was taken from estimate of model 8 of least-squares analysis. The left-hand bracket was given as 0.1 and right hand as 0.5.

3.6.2.3 Evaluating the Likelihood

Assuming the above model in which y has a multivariate normal distribution with mean Xb and variance V, the log of the likelihood function (L) to be maximized is then (Meyer, 1993):

$$\log L = -\frac{1}{2}[const + \log|V| + \log|X^{*'}V^{-1}X^{*}| + (y - X\hat{b})'V^{-1}(y - X\hat{b})]$$

where,

X^* (of order N * NF^*) denotes a full column rank sub-matrix of X, and

$X^* = X^0$

Alternatively, the log likelihood can be expressed as a function of covariance matrices of the random effects in the model of analysis (Harville, 1977; Searle, 1979):

$$-2\log L = const + \log|R| + \log|G| + \log|C| + y'Py$$

where,

$$P = V^{-1} - V^{-1}X(X'V^{-1}X)^{-}X'V^{-1}$$

$$= V^{-1} - V^{-1}X^{*}(X^{*'}V^{-1}X^{*})^{-1}X^{*'}V^{-1}$$

R is the residual covariance matrix associated with random effects,

C is the coefficient matrix of the general mixed model equations, and

$y'Py$ is a generalized residual sum of squares.

Maximum likelihood estimation consists of obtaining the parameters (i.e. variance components) that maximize the likelihood function (L). Maximizing likelihood function is same as maximizing the log L or minimizing the -2log L.

3.6.2.4 Calculation of $\log|C|$ and $y'Py$

These two terms viz., $\log|C|$ and $y'Py$, require 'factorization' of the coefficient matrix of the MME. The factorization was done by Cholesky decomposition (Boldman & Van vleck, 1991). Coefficient matrix (C) can be decomposed in to the product of a lower triangular matrix (L ={l_{ij}} with l_{ij} = 0 for j>i) and its transpose.

$$LL' = C$$

C, to be decomposed, should be positive definite and of full rank.

then, $\log|C| = 2 \sum_{i=1}^{NR+NF^*} l_{ii}$

Therefore, the determinant of a triangular matrix is simply the product of its diagonal elements. Solutions for fixed and random effects fitted are obtained by solving the two triangular systems by simple forward / backward substitutions, i.e. Lv = r and L'w = v;

where, r is the vector of RHS in the MME.

The solutions are used to determined $y'Py$ as (Harville, 1977):

$$y'Py = y'R^{-1}y - y'R^{-}X^{*}\hat{b}^{*} - y'R^{-1}Z\hat{a}$$

3.6.2.5 Calculation of $\log|R|$

$$\log|R| = \sum_{w=1}^{W} Nw \log|Ew|$$

where,

R is block diagonal for animal when cov(ee') = 0,

W is the possible combinations of traits recorded,

N*w* represents number of animals having records for combinations of traits *w*,

E*w* is the sub-matrix of variance-covariance matrix for the trait *w* (*w*<=q),

Obtained by deleting rows and columns pertaining to missing records.

3.6.2.6 Calculation of $\log|G|$

$$\log|G| = NA\log|T| + q\log|A|$$

where,

G = T * A

T is the additive genetic covariance matrix between traits, of size q * q,

NA is the total number of animals,

q is the number of traits,

A is the numerator relationship matrix between animals, and

* is the direct matrix product.

$\log|A|$ does not depend on the parameters to be estimated and is not required in order to maximize log L.

3.6.2.7 Univariate analyses

For this analysis, R = σ^2_E I and the error variance can be estimated directly from the residual sum of squares as:

$$\sigma^2_E = y'Py \ / \ (N-r(X))$$

Hence the likelihood can be maximize with respect to remaining parameters expressed as a function of the original variances and σ^2_E, i.e. the dimension of the search is reduced by one (Graser *et al.*, 1987; Meyer, 1989b).

3.6.2.8 Maximizing the likelihood

In DFREML, the quadratic approximation, as described by Graser *et al.* (1987), method was used for single trait models, which required one-dimensional search. They compared AI-REML with other methods and in their example found it to reach convergence five times faster than with a derivative free algorithm and 15 times faster than with an expectation-maximization algorithm. The algorithm is a Newton method that uses first and second derivatives to find estimates of genetic parameters that maximize the likelihood function. Solutions for fixed and random effects (generalized least squares) are presented and discussed. The program does not, however, present individual predicted breeding values of animals.

3.6.2.9 Convergence criteria

The convergence criterion was the variance of the likelihood function values. The convergence criterion was taken as the variance among the function values; convergence was assumed when this variance was less than less than 10^{-8}. In other words, convergence was considered to be obtained when mean squared differences between (co)variances matrices in consecutive rounds was 10^{-8}. Iterations were assumed to have converged when the differences in the variance of successive log likelihood was less than 10^{-8}. A value of 10^{-8} gives a good accuracy of estimation.

3.6.2.10 Global Maximization

After convergence, it was again verified that the maximization attained is global and not local. This was done by researching the parameter space within the range of 10% of the values obtained at convergence in the previous run.

3.6.2.11 Standard error of the estimates

The standard errors of the genetic parameters for single trait models were estimated as described by Meyer (1989b). Approximate standard errors of the estimated variance components were obtained by an approach similar to that of Smith and Graser (1986). Standard errors for correlations were calculated as described by Falconer and Mackay (1996).

3.7 Sire Evaluation

Sires with a minimum of four progenies were considered for analysis and sire evaluation. Solutions obtained after analyzing the data with Model 8 (taking only sires as random effect) and with univariate REML using animal model (taking animals with and without records as random effects) were BLUP values. On the basis of these BLUP values animals were ranked.

The Spearman's rank correlation between BLUP values, obtained by above methods, was worked out (Steel and Torrie, 1980) as follows:

$$r = 1 - \frac{6\sum_i d_i^2}{(n-1)n(n+1)}$$

where,

r is the rank correlation,

n is the number of sires,

d_i is the difference between rank of the sire ranked by two methods.

The significance of the rank correlation was tested by student's t-test as:

$t = r\sqrt{(n-2)/(1-r^2)}$ with n-2 degrees of freedom.

Results and Discussion

The growth and wool production traits were studied in the present investigation. Summary of number of records, sires, grand sires and grand dams for BWT, WWT, WT6, WT12 and GFY1 of Avikalin sheep are presented in Table 4.1. The general means and S.D. for various traits have been presented in Table 4.2.

Table 4.1 : Characteristics of data for all traits

No. of records	1313
No. of years	22
No. of base animals	299
No. of animals with records	1313
No. of animals with unknown/pruned sire	0
No. of animals with unknown/pruned dam	134
No. of sires with progeny records	106
No. of grand sires with progeny records	135
No. of grand dams with progeny records	303

Table 4.2 : General means (±S.D.) for BWT. WWT, WT6, WT12 and GFY1 in Avikalin sheep

S. No.	Traits	Mean (kg)	S.D. (kg)
1.	BWT	2.95	0.6701
2.	WWT	15.43	2.701
3.	WT6	21.17	3.623
4.	WT12	26.02	4.304
5.	GFY1	1.06	0.234

The results of the present study have been presented and discussed under following headings to confirm the objectives.

4.1 Mean Performances

4.2 Effect of Genetic and Non-genetic Factors

4.3 Heritability

4.4 Comparison between Estimates

4.5 Genetic, Phenotypic and Environmental Correlations

4.6 BLUP/Breeding Values

4.7 Rank Correlation

4.1 Mean Performance

4.1.1 Birth weight

The least-squares means (±s.e.) estimated by model 2 and model 8 for different growth and first six monthly greasy fleece yield have been presented in Table 4.3 and 4.4. The least squares means estimated by model 2 and models 8 were found to be 2.91 ± 0.045 kg and 2.89 ± 0.037 kg respectively. The least squares means, estimated by model 8, were slightly lower than the means estimated by model 2.

The least-squares means of birth weight in the present study were in close agreement with those reported by Kushwaha (1994), Kushwaha *et al.* (1997) and Kumar (2000) in various breeds of sheep. However, lower values than the present study were reported by Arora *et al.* (1975), Acharya and Manimohan (1979), Acharya (1982), Singh and Dhillon (1992) Arora *et al.*

Table 4.3: **Least squares mean (±S.E.) of sex and season of birth for BWT, WWT, WT6, WT12 and GFY1 under model 2 in Avikalin sheep**

S. No.	Particulars	No. of observations	Least squares means ± S.E. (kg)				
			BWT	WWT	WT6	WT12	GFY1
1.	Overall mean (μ)	1313	2.91 ± 0.045	15.57 ± 0.184	20.98 ± 0.249	26.13 ± 0.304	1.06 ± 0.018
2.	**Sex**						
	Male	481	3.08 ± 0.051	16.57 ± 0.211	22.51 ± 0.279	28.19 ± 0.335	1.11 ± 0.021
	Female	832	2.73 ± 0.046	14.72 ± 0.191	19.45 ± 0.256	24.06 ± 0.311	1.02 ± 0.019
3.	**Season of birth**						
	1 (January-June)	1214	3.01 ± 0.039	15.67 ± 0.164	21.68 ± 0.227	26.65 ± 0.281	1.07 ± 0.017
	2 (July-December)	99	2.82 ± 0.072	15.46 ± 0.294	20.27 ± 0.378	25.61 ± 0.443	1.04 ± 0.027

Table 4.4 : Least square mean (±S.E.) of sex and season of birth for BWT, WWT, WT6, WT12 and GFY1 under model 8 in Avikalin sheep

S. No.	Particulars	No. of observations	Least squares means ± S.E. (kg)				
			BWT	WWT	WT6	WT12	GFY1
1.	Overall mean (μ)	1313	2.89 ± 0.037	15.58 ± 0.152	20.86 ± 0.196	26.03 ± 0.228	1.06 ± 0.014
2.	**Sex**						
	Male	481	3.17 ± 0.045	16.43 ± 0.181	22.43 ± 0.232	28.16 ± 0.268	1.11 ± 0.016
	Female	832	2.71 ± 0.038	14.75 ± 0.155	19.31 ± 0.201	23.88 ± 0.234	1.02 ± 0.014
3.	**Season of birth**						
	1 (January-June)	1214	3.03 ± 0.024	15.71 ± 0.098	21.68 ± 0.132	26.64 ± 0.158	1.07 ± 0.009
	2 (July-December)	99	2.77 ± 0.067	15.47 ± 0.273	20.05 ± 0.345	25.41 ± 0.396	1.05 ± 0.025

(1999), and Al-Shorepy (2001) and in different breeds of sheep. Whereas, higher mean values than the present study were reported by Bathaei (1994), Connigton *et al.* (1995), Sinha and Singh (1997), Tomar *et al.* (2000a and 2000b) and Malik *et al.* (1980) in various breeds of sheep.

4.1.2 Weaning weight

The least-squares means for weaning weight estimated by model 2 and model 8 were found to be 15.57 ± 0.184 kg and 15.58 ± 0.152 kg, respectively, in Avikalin sheep (Table 4.3 and 4.4). The mean estimated by model 2 was slightly lower from the mean estimated by model 8. The estimates of similar magnitude have been reported by Malik *et al.* (1980), Arora *et al.* (1999) and Tomar *et al.* (2000b). However, lower mean values were reported by Arora *et al.* (1975). Acharya (1982), Sahni (1985), Singh and Dhillon (1992), Kushwaha (1994), Kushwaha *et al.* (1997), Kumar (2000) and Al-Shorepy (2001). While higher mean values have been observed by Bathaei (1994), Sinha and Singh (1997), Tomar *et al.* (2000a) and Cloete (2001) in different breeds of sheep.

4.1.3 Weight at 6 moth of age

The least-squares means of 6 months body weight estimated by model 2 and model 8 were found to be 20.98 ± 0.249 kg and 20.86 ± 0.196 kg respectively. The mean estimated by model 8 was slightly lower from the mean estimated by model 2. These results of present study are in close agreement with the findings of Malik *et al.* (1980) and Arora *et al.* (1999), whereas lower values for WT6 have been reported by Arora *et al.* (1975),

Acharya and Manimohan (1979), Acharya (1982), Sahni (1985), Singh and Dhillon (1992), Kushwaha (1994), Kushwaha *et al.* (1997) and Kumar (2000). However, higher means have been observed by Bathaei (1994), Singh and Kushwaha (1995), Sinha and Singh (1997) and Tomar *et al.* (2000a, b) in different breeds of sheep.

4.1.4 Weight at 12 months of age

The least squares means of 12 month body weight estimated by mode 2 and model 8 were found to be 26.13 ± 0.304 kg and 26.03 ± 0.228 kg, respectively, in Avikalin sheep (Table 4.3 and 4.4). The least squares mean estimated by model 8 was slightly lower from the mean estimated by model 2. The least squares mean for WT12 in this study was lower than those reported in the literature by the most workers. However, lower values for WT12 have been reported by Malik *et al.* (1980) and Singh and Dhillon (1992) in different breeds of sheep.

4.1.5 First six-monthly greasy fleece yield

The least squares means for six-monthly greasy fleece yield estimated by model 2 and model 8 were found to be 1.06 ± 0.018 kg and 1.06 ± 0.014 kg respectively, in Avikalin sheep. The lower estimates than the present finding were reported by Acharaya and Monimohan (1979), Singh and Kushwaha (1995), Kushwaha *et al.* (1997), Kumar (2000) and Tomar *et al.* (2000a). However, Acharaya (1982) and Arora *et al.* (1999) reported higher values for GFY1.

The coefficient of variations (Table 4.5) were slightly lower in model 8 than the univariate. The coefficient of variation decreases from BWT to WT12 with increase in age of the animal. The C.V. was almost similar for GFY1 under models 8 and univariate. The BWT and GFY1 had maximum variation followed by WWT, WT6 and WT12 under model 8 and univariate methods. The decreasing trend in coefficient of variation may be due to culling of lambs from time to time that may have reduced the variation. Moreover, the weights become more uniform after the maternal influence and weaning stress passed as reported by Bathaei and Leroy (1998), thereby reducing the variation. Higher values of C.V. at GFY1 because of the fact that all the animals were practically, not shorn at the similar age i.e. 6 month of age. This variation in shearing age may have increased the C.V. Fogarty (1995) reported declining trend in the mean coefficient of variation for live weights with increasing age from birth (17%) to weaning (15%), yearling (11%) and hogget (10%). He reported little consistency among coefficient of variation. In general REML analysis using animal model explained more variation than the model 8 of least squares analyses. Kumar (2000) reported lower C.V. for BWT but higher values for WWT, WT6 and GFY1 in case of Chokala sheep than the present study. Malik *et al.* (1971) had also reported lower values of C.V. (17%) for birth weight in Chokla than the present study. However, higher C.V. had reported by Chaudhary and Malik (1972) and Arora *et al.* (1981) for WWT, WT6 and GFY1 than the present study in Avikalin sheep.

Table 4.5: Coefficient of variation (C.V.%) for BWT, WWT, WT6, WT12 and GFY1 under model 8 and univariate REML animal model in Avikalin sheep

S.No.	Traits	Coefficient of variation	
		Model8	Univariate
1.	BWT	21.17	21.92
2.	WWT	16.25	16.76
3.	WT6	14.70	15.33
4.	WT12	13.52	14.23
5.	GFY1	20.75	21.76

4.2 Genetic and non-genetic factors affecting growth and wool yield traits

4.2.1 Sire

The random effect of sires had highly significant ($p<0.01$) effect on BWT, WWT, WT6, WT12 and GFY1 under model 2 (Table 4.6), which indicating sizable genetic difference among sires. Highly significant source of variation due to sires were also reported by Vatalitya (1993), Kushwaha (1995), Singh and Kushwaha (1995), Sinha and Singh (1997), Kumar (2000) and Tomar *et al.* (2000a) for BWT, WWT, WT6, WT12 and GFY1, respectively, in case of various breeds of sheep.

The significant effect of sires on all the traits studied indicated that superior sires could be used effectively for improvement of these traits.

Sire of lambs, under model 2 of LSA, accounted for 5.07, 5.77, 7.81, 9.78 and 9.21% of total variation for BWT, WWT, WT6, WT12 and GFY1, respectively. The corresponding values, under model 8 were 1.29, 1.48, 2.13, 2.68 and 2.42% respectively (Table 4.8).

Table 4.6 : Analysis of variance for BWT, WWT, WT6, WT12 and GFY1 under model 2 of LSA

S. No.	Source of variation	d.f.	Mean squares				
			BWT	WWT	WT6	WT12	GFY1
1.	Sire	105	0.64**	10.97**	19.72**	28.94**	0.11**
2.	Sex	1	32.78**	736.72**	2419.61**	4410.23**	2.05**
3.	Season	1	2.63**	3.15 NS	137.82**	74.42*	0.06 NS
4.	Error	1205	0.38	6.28	9.65	12.38	0.05

NS = not significance; ** = $p < 0.01$; * = $p < 0.05$

Table 4.7: Analysis of variance for BWT, WWT, WT6, WT12 and GFY1 under model 8 of LSA

S. No.	Source of variation	d.f.	Mean squares				
			BWT	WWT	WT6	WT12	GFY1
1.	Sex	1	41.48**	805.41**	2765.78**	5121.37**	2.24**
2.	Season	1	5.43**	4.63 NS	215.87**	119.87*	0.03 NS
3.	Error	1310	0.38	6.29	9.68	12.37	0.05

NS = not significance; ** = $p < 0.01$ * = $p < 0.05$

Table 4.8 : Observed between and within sire variance for various traits under model 2 and 8 of LSA (expressed as percentage of phenotypic variation)

Observed family components	Model used	Traits									
		BWT		WWT		WT6		WT12		GFY1	
		BWT	Per cent	WWT	Per cent	WT6	Per cent	WT 12	Per cent	GFY1	Per cent
σ_S^2 (PHS)	Model 2	0.0207	5.07	0.3807	5.77	0.8173	7.81	1.3434	9.78	0.0049	9.21
σ_W^2 (PHS)	Model 2	0.3877	94.93	6.2815	94.28	9.6496	92.19	12.3831	90.22	0.0483	90.79
σ_S^2 (PHS)	Model 8	0.0051	1.29	0.0945	1.48	0.2102	2.13	0.3411	2.68	0.0012	2.42
σ_W^2 (PHS)	Model 8	0.3889	98.71	6.293	98.52	9.6845	97.87	12.3701	97.32	0.0484	97.58

where, σ_S^2 (PHS) = between sire component of variance

σ_W^2 (PHS) = within sire component of variance

PHS = parental half sibs

Burferning and Kress (1993) also reported 8.3 and 8.8% variation in BWT and WWT, respectively due to sire in sheep. The sire had accounted more variation under model 2 than model 8 for all the traits. With the advance of age the variation accounted by sire was increased under model 2 and same trend also observed under model 8 of analysis. Since all the traits were analysed simultaneously under model 2, therefore there may be some confounding among traits, which increased sire contribution in total variation with the advance of age. But that was not in the case of model 8, as all the traits were analysed separately. Kumar (2000) also reported same trend of variation under model 2 and model 8 of LSA.

The coefficients of multiple determination (R^2) (Table 4.9) obtained under model 8 were 13.50, 13.90, 26.40, 33.30 and 12.10%, respectively, for BWT, WWT, WT6, WT12 and GFY1. For the growth traits, as the age of lambs advanced the R^2 increased. The higher variation at 12 month weight indicates the need for applying intense selection pressure at the age of 12 month. Similar trend also reported by Kumar (2000) incase of Chokla sleep.

Table 4.9: Coefficient of multiple determination (R^2) for BWT, WWT, WT6, WT12 and GFY1 under model 8 in Avikalin sheep

S.No.	Traits	R^2
1.	BWT	13.50
2.	WWT	13.90
3.	WT6	26.40
4.	WT12	33.30
5.	GFY1	12.10

4.2.2 Season of birth

The fixed affect of season of lambing had highly significant ($p<0.01$) effect on BWT and WT6 and significant ($P<0.05$) effect on WT12 under model 2 (Table 4.6) and model 8 (Table 4.7). However, non-significant differences were found for weaning weight and GFY1 under model 2 and model 8 in Avikalin sheep. Highly significant effect due to season of birth also reported by Singh *et al.* (1982) Tomar *et al.* (2000a and 2000b) for birth weight; Malik and Acharya (1972), Singh and Dhillon (1992) and Tomar *et al.* (2000b) for weaning weight; Malik and Acharya (1972), Sinha and Singh (1997) and Tomar *et al.* (2000a) for WT6; Tomar *et al.* (2000a) for WT12 and Vatalitya (1993) and Tomar *et al.* (2000a) for GFY1 in various breeds of sheep. Non-significant effect due to season of birth have been reported by Singh and Dhillon (1992) and Swain *et al.* (1994) for birth weight and Singh and Dhillon (1992) for 6 and 12 month of body weights in Avikalin sheep.

The means estimated for season 1 (January-June) showed higher values than the estimated for season 2 (July-December) under model 2 and model 8 of LSA. The significant effect of season of lambing on the BWT, WT6 and WT12 under the present study revealed that lambing in seasons 1 were mostly concentrated during January to February and the lambs were born to those ewes, who have completed 3-4 months of their initial pregnancy during the second half of an year i.e. seasons 2, in which the fodder availability is upto mark due to onset of mansoon during June-July. The better fodder availability to pregnant ewes during second half of a year reflected higher weight during season 1 than season 2. Due to this lambs born in winter were heavier at all the age and grew faster than their counterparts.

4.2.3 Sex of lamb

Analysis of variance showed that sex of lambswere important ($p<0.01$) source of variation for live weights in all ages and first greasy fleece weight under both models (2 and 8) of analysis (Table 4.6 and 4.7). Male lambs were significantly ($p<0.01$) heavier at all ages and GFY1 was produced more than female lambs. Significant effect of sex of lamb for all the traits under present study have been reported by various researchers sited in the literature, which are in consonance with the present findings. However, non-significant effect due to sex of lamb observed by Kandasamy *et al.* (1980) on birth weight; Malik and Acharya (1972) for weaning weight; Kumar (2000) under model 2 of LSA and Tomar *et al.* (2000a) on GFY1.

The heavier body weight of male lambs may be due to differences in their endocrine profile and in their culling level practiced at different ages (Dixit *et al.,* 2001).

4.3 Heritability and variance components

The heritability and variance components were estimated by model 2 and 8 of Harvey (1990) package. Both the models were included the fixed effect of sex, season of birth and random effect of sires. Single trait animal model were also used to estimate h^2 and variance components by REML method for the same records, using DFREML Package of Meyer (1998). The h^2 and variance components estimated by model 2, 8 and univariate REML have been presented in Table 4.10, 4.11 and 4.12.

Table 4.10 : Estimates of heritability and variance components for various traits in Avikalin sheep under model 2

S. No.	Traits	Heritability ± S.E.	Variance components			
			σ_p^2	σ_a^2	σ_s^2	σ_e^2
1.	BWT	0.203 ± 0.070	0.4084	0.0828	0.0207	0.3877
2.	WWT	0.229 ± 0.072	6.6622	1.5228	0.3807	6.2815
3.	WT6	0.312 ± 0.081	10.4669	3.2692	0.8173	9.6496
4.	WT12	0.391 ± 0.089	13.7265	5.3736	1.3434	12.3831
5.	GFY1	0.373 ± 0.087	0.0532	0.0196	0.0049	0.0483

Table 4.11 : Estimates of heritability and variance components for various traits in Avikalin sheep under model 8

S. No.	Traits	Heritability	Variance components			
			σ_p^2	σ_a^2	σ_s^2	σ_e^2
1.	BWT	0.197	0.3940	0.0202	0.0051	0.3889
2.	WWT	0.227	6.3876	0.3779	0.0945	6.2931
3.	WT6	0.319	9.8947	0.8408	0.2102	9.6845
4.	WT12	0.397	12.7112	1.3643	0.3411	12.3701
5.	GFY1	0.374	0.0496	0.0049	0.0012	0.0484

Table 4.12 : Estimates of heritability and variance components for various traits in Avikalin sheep under univariate REML analysis

S. No.	Traits	Heritability	Variance components			
			σ_p^2	σ_a^2 (direct)	σ_e^2	Log L
1.	BWT	0.265	0.4167	0.1105	0.3063	-58.05
2.	WWT	0.138	6.6935	0.9282	5.7654	-1897.60
3.	WT6	0.188	10.5399	1.9894	8.5505	2187.62
4.	WT12	0.243	13.7088	3.3217	10.3872	-2350.52
5.	GFY1	0.104	0.5325	0.5548	0.4770	1264.37

4.3.1 Birth weight

The h^2 estimates of birth weight were found to be 0.203 ± 0.070, 0.197 and 0.265 by model, 2, 8 and univariate analysis, respectively, in Avikalin sheep. The h^2 estimates from model 2 and 8 were almost similar for birth weight. The univariate REML method estimated higher h^2 than the least squares methods. Since maternal effect had not been fitted in univariate animal model, therefore it might had inflated the direct effect which resulted into higher h^2 at birth weight whereas in least squares models the paternal half sib does not included maternal effect. That might be reason of higher h^2 estimates under REML procedure. Conington *et al.* (1995) reported that almost half of the observed phenotypic variation in live weight is due to maternal effect at birth. The medium heritability estimates with relatively small C.V. suggested that BWT alone would not be appropriate trait for evaluation of animals. Therefore, the BWT may considered in combination of other important traits for better evaluation of animals. The similar observation have also been reported by Osman and Bradford (1965), Davis (1987), Kushwaha *et al.* (1995), Djemali and Aloulou (1996) and Piper and Bindon (1977) in various breeds of sheep. Lower h^2 for BWT were observed by Atkins (1986), Davis (1987), Barwick (1989), Conington *et al.* (1994) in Merino, Ercanbrack and Price (1972) in Columbia, Hancock *et al.* (1979), Olesen and Husabo (1994), Yamaki (1994) and Singh *et al.* (1998) in Suffolk sheep. However, higher h^2 were estimated by Osman and Bradford (1965), Ercanbrack and Price (1972), Van Wyk *et al.* (1993), Bathaei (1994), Djemali and Aloulou (1996), Vaez Torshzi *et al.* (1996), Sinha and Singh (1997) and Kumar (2000) in different breeds of sheep.

4.3.2 Weaning weight

The h^2 estimated by three ways for weaning weight were ranged from 0.138 (REML univariate) to 0.229 (model 2). The model 2 (0.229) and model 8 (0.227) had almost similar estimates of h^2 for WWT (Table 4.10 and 4.11). The values estimated in the present study were well within the range of h^2 estimates for weaning weight as reviewed by Fogarty (1995) in the exotic breeds. The recorded h^2 for WWT are in accordance with that obtained by Osman and Bradfored (1965), Barwick (1989), Mc.Ewan *et al.* (1991), Bissett *et al.* (1992), Olesen and Husabo (1994), Conington *et al.* (1994), Singh and Kushwaha (1995), Vaez Torshizi *et al.* (1996), Singh *et al.* (1998), Kumar (2000) and Cloete *et al.* (2001) in different breeds of sheep, but higher estimates of h^2 were observed by Davis (1987), Van wyk *et al.* (1993), Bathaei *et al.* (1994), Brash *et al.* (1994c and 1994d), Yamaki (1994), Kushwaha *et al.* (1995), Kushwaha *et al.* (1998) and Sinha and Singh (1997) in different breeds of sheep. The h^2 estimated under univariate REML for WWT was lower than the BWT, which might be due to reduced maternal effect.

4.3.3 Weight at 6 month of age

The heritability estimated by three methods for WT6 ranged 0.188 (univariate) to 0.319 (model 8). Model 2 (0.312) and model 8 (0.319) analyses estimated almost similar heritability. The heritability estimated by univariate analyses for WT6 was lower than the BWT, which might be due to increased influence of the non-permanent environmental factors. As Maria *et al.* (1993)

had reported that the influence of the non-permanent environmental factors become more important after weaning. The similar estimates of h^2 were also reported by Atkins (1986), Atkins *et al.* (1991) Young and Simm (1990), Cameron and Bracken (1992), Gilmour *et al.* (1994), Mercer *et al.* (1994), Arora and Kushwaha (1996), Djemali and Aloulou (1996) and Sinha and Singh (1997) in various breeds of sheep. Moreover higher values of h^2 were estimated by Mercer *et al.* (1994), Singh and Kushwaha (1995) and Tomar *et al.* (2000a), whereas lower h^2 observed by Bissett *et al.* (1992) in Romney sheep and Kumar (2000) in Chokla sheep.

4.3.4 Weight at 12 month of age

The estimates of h^2 for WT12 by three methods (model 2, 8 and univariate REML) were 0.391 ± 0.089, 0.397 and 0.243, respectively, in Avikalin sheep. Similar results of heritability for weight at 12 month were obtained by Ercanbrack and Price (1972), McEwan *et al.* (1991), Brash *et al.* (1994d) and Cloete *et al.* (2001) in different breeds of sheep. However, higher values were observed by Young *et al.* (1960b), Van wyk *et al.* (1985), Mc Ewan *et al.* (1984), Bissett *et al.* (1992), Yamaki (1994), Ercanbarck and Price (1972), Tomar *et al.* (2000a) and Cloete *et al.* (2001). Whereas lower h^2 estimates were reported by Brash *et al.* (1994c) and Gilmour *et al.* (1994) in Corriedale and Dorset sheep, respectively.

4.3.5 First greasy fleece weight

The h^2 estimates for GFY1 ranged from 0.104 (univariate REML) to 0.374 (model 8). Model 2 (0.373) and model 8 (0.374) of LSA were estimated

almost similar heritability (Table 4.10, 4.11 and 4.12). Model 2 and model 8 of LSA had higher estimates of h^2 than the univariate REML procedure (0.104).

It becomes difficult to compare results from the literature because estimates from different authors were obtained from the flock of different genetic background, different management conditions and different genetic model of analysis (animal or sire models). So, the estimates of the present study were generally compared with the same breed but due to insufficient literature, comparison had also been made with exotic breeds.

The lower heritabilities estimates in the present study than the reported estimates in the literature may be due to rearing of Avikalin animals in the harsher climate. Conington *et al.* (1995) had also observed that the harsher rearing environment inflates the error variance, Flock had also undergone for selection for the traits under study that may also have reduced the genetic variability. Kushwaha *et al.* (1998) had also reported higher value of h^2 for GFY1 in Chokla sheep than the present study.

4.4 Comparison between estimates

4.4.1 Heritability

For body weight, heritability increase with age from birth weight (0.203) to weight at 12 months (0.391) under model 2. Heritability estimated by model 8 also displayed the same tendency as h^2 from the model 2 for all live weights, it increased as animal age is advanced in both the models. From Table 4.13 it is evident that heritability estimates from univariate animal model for body

weights, on the other hand, decreased from birth weight (0.265) to weaning weight (0.138), where after it increased gradually upto body weight at 12 months of age (0.243). The heritability estimates of GFY1 by model 2 and model 8 were similar whereas lower heritability estimated by univariate REML animal model. These higher h^2 estimates from model 2 using paternal half sibs, indicate that this may be due to common environment effects among paternal half sibs (Burfenning and Kress, 1993). Raheja (1992) stated that the heritabilities calculated from use of residual and sire variances, obtained from single trait Handerson Model-3, were over estimated by about 15-20 per cent. Notter and Haugh (1997) reported that genetic parameters estimated for body weights showed the expected increase in importance of additive effects with increasing compositional maturity and body weight. Model 8 displayed the same tendency as model 2 for all live weights in the present study.

Table 4.13 : Comparison between heritability (±S.E.) estimates obtained by different methods

Models	BWT	WWT	WT6	WT12	GFY1
Model 2	0.203 ± 0.070	0.229 ± 0.072	0.312 ± 0.081	0.391 ± 0.089	0.373 ± 0.087
Model 8	0.197	0.227	0.319	0.397	0.374
Univariate AM	0.265	0.138	0.188	0.243	0.104

Model 2 had higher h^2 estimates among all three methods employed for all traits, except BWT. Hansen and Shrestha (1997) also reported lower h^2 estimates by restricted maximum likelihood procedures than the paternal half sib based on least squares mixed model methodology. Low h^2 estimates for BWT under model

2 and model 8 there may be genetic reason for low additive heritabilities, such as maternal effect (Van wyk *et al.*, 1993). Maternal effects may confounded with animal effects as reported by Van wyk *et al.* (1993). Since maternal effect had not been fitted in univariate animal model, therefore, it might have inflated the direct additive genetic effect. Because of joint effect additive and maternal variances, the h^2 at birth weight is higher than WWT, WT6, WT12 and GFY1, as also reported by Conington *et al.* (1995). This may be the reason for higher estimate of h^2 at birth under univariate animal model. Conigton *et al.* (1995) reported that almost half of the observed phenotypic variation in live weight was due to maternal effects at birth. On the contrary Snyman *et al.* (1995) reported more importance of direct additive genetic effects than maternal genetic effects for birth, wearing weight and clean fleece weight.

The model 2 and model 8 used did not take into account all relationships between animals but the animal model fitted does. Since sire was the random effect in model 2 and model 8, using paternal half-sibs, therefore, there was no maternal effect included. Van wyk *et al.* (1993) reported higher estimates of h^2 under animal model than sire models using REML. Snyman *et al.* (1995) stated that the differences in higher/lower estimates of direct heritability could partly be explained through the use of different models of analysis. It seemed that the more detailed animal model yielded higher h^2 estimate than the simpler sire model. On the contrary, Conington *et al.* (1995) reported almost identical heritabilities estimates by sire and animal models for BWT and weaning weight in sheep.

In the present study two trends in h^2 estimates for various traits were found while using different estimation methods. In model 2 and model 8 BWT had lowest h^2 but at subsequent ages the heritability increased. While in animal model, BWT had the highest h^2 and WWT, WT6 and GFY1 had lower estimates than BWT. The reduction in h^2 values after birth weight under REML procedure may be due to declining the maternal effect on WWT, WT6 and GFY1. Bathaei and Leroy (1998) reported that after weaning, maternal effect gradually diminished and h^2 of weight increased. Nottor and Hough (1997) had also reported that the importance of maternal effects correspondingly decline with increasing maturity. Kumar (2000) reported that BWT had the highest h^2 estimate followed by WT6 and WWT, while GFY1 had lowest h^2 estimate under univariate REML.

Conington *et al.* (1995) reported decreasing importance of the maternal component with lamb age to around 0.1 for all measurements at weaning (at the age 17 weeks). This pattern corresponds to the findings of Atkins (1986), working with Scottish Blackface sheep. Decreasing trend in maternal h^2 with age confirms the proposal that maternal effects in mammals are substantial in young animals but diminish with age (Nasholm and Danell, 1996). Bathaei and Leroy (1998) gave the consequences that the selection for increased growth or maturing rate tend to decrease mature weight.

For GFY1, the h^2 estimated by univariate REML animal model were lower than model 2 and model 8. So, there may not be maternal effect of

fleece yield. Snyman *et al.* (1995) also reported that clean fleece weight (CFW) was significantly influenced only by the additive genetic effect. There are contradictory results about maternal effects on ovine fleece weight. In Australian Merinos, significant maternal effects on genetic parameters were observed for fleece weight at weaning (Swan and Hickson, 1994), and at the age of 15 months (Mortimer and Atkins, 1994). However, in the South African Merino, Van Wyk *et al.* (1994) did not detect any significant maternal genetic effects for fleece weight.

The results in the present study showed that different estimates of heritabilities could be obtained for growth and wool traits in sheep using different estimation procedures with same and/or different models. There may be model effect for difference in h^2 values obtained by different methods for BWT. Van Wyk *et al.* (1993) found important role of model specification in the accuracy of estimation. There was small effect of method of estimation on h^2 estimates for WWT and 6WT but significant effect for GFY1. Koots *et al.* (1994a) reported significant effect of method of estimation on h^2 estimates for weaning weight (direct).

Where relationship trace back to the base populations, estimates of h^2 by animal model are expected to be estimates of variance prior to selection of therefore to be higher than other methods. But no evidence was found here that animal model estimates were higher than the other estimates, perhaps indicating insufficient pedigree data or lack of effective selection; and hence no

reduction in genetic variance (Koots *et al.,* 1994a). Estimates of heritability from REML with an animal model were considerably smaller if relationships were from sires only as compared with from more complete relationships and the estimates would be larger if more relationship were included with REML and an animal model (Dong *et al.*, 1998). There was no tendency of h^2 estimates derived from animal model analyses (which estimate parameters in the base population) to be higher than those from population, which have not been selected, although most of the h^2 estimates studied were for growth traits, which have undergone some selection. It is likely, however, that pedigree did not, in most of the cases, trace back to an unselected base population. It is also possible that h^2 estimates derived from an animal model failed to be higher than those from other estimation methods, because recent animal models which would tend to have better statistical models fitted (e.g. more fixed effects) than earlier estimates.

The trend towards lower heritabilities for data from more recent year might indicate reduced genetic variation caused by increased gametic phase disequilibrium (Bulmer, 1971) due to increased selection intensity.

Using the estimates of heritabilities from animal model, one could expect improved rates of response by selection of additive genetic value (Van Wyk *et al.,* 1993). REML methodology combined the information from between and within lines, parent-offspring and the relationship between collateral relatives for an efficient estimate of response to selection (Thompson and

Atkins, 1990). If selection is to be made on direct effects alone, breeding value based on the estimates of the variance components under a sire model, using REML procedure, are preferable to those from an animal model accounting for direct effects only (Van Wyk *et al.,* 1993).

The standard errors of h^2 estimates ranged between 0.07 (for BWT under model 2) to 0.089 (for WT12 under model 2). Although, there were not significant differences in standard errors of h^2 among different methods, but model 2, in general, had higher standard errors for all traits. With experimental data, the standard error of estimate of h^2 is an obvious criterion for comparing the precision, but not the bias of the estimation procedure (Raheja, 1992).

4.4.2 Correlation between h^2 and coefficient of variation

There was positive correlation between C.V. and heritability estimates in univariate animal model. BWT had highest C.V. and highest h^2 among all traits. However, WWT, WT6 and WT12 had negative correlation between C.V. and h^2. GFY1 had highest C.V. but lowest heritability which indicate negative correlation between C.V. and h^2 for GFY1.

The negative correlation between C.V. and h^2 for BWT, WWT, WT6 and WT12 were observed under model 8. For body weight, heritability increase with age from birth to weight at 12 months but C.V. decreases as age advanced. Similar observations also reported by Kumar (2000) in case of Chokla sheep.

4.5 Genetic, phenotypic and environmental correlations among growth and wool yield traits

The estimates of genetics phenotypic and environmental correlations among the various traits computed from different components of variance and covariance under model 2 are presented in Table 4.15.

The genetic correlation of BWT with WWT estimated by model 2 was found to be highly positive (0.48 ± 0.18) in Avikalin sheep. The corresponding phenotypic and environmental correlations between these traits were also observed to be highly positive (0.55) and (0.57), respectively. Similar findings have also been reported by Bathaei (1994), Conington *et al.* (1994) and Kushwaha *et al.* (1995).

High genetic correlations among these traits indicating that the mass selection for birth weight could successfully be done for weights expressed beyond WT3. High phenotypic and environmental correlations between BWT and WWT indicating that good management, feeding and other environmental conditions tend to enhance growth and increase body weight. Thus, emphasis on good feeding and management is needed and should be considered besidesselection in order for ewe lambs for higher body weight at an earlier age. Genetic correlations (Table 4.15) between birth weight and weight at 6 months of age and 12 months of age were 0.315 ± 0.192 and 0.303 ± 0.185 respectively. The estimates of genetic correlations (-0.051 ± 0.209) between birth weight and first greasy fleece weight was very low and negative, which

Table 4.14 : Variance and covariance matrices for BWT, WWT, WT6, WT12 and GFY1 under model 2 in Avikalin sheep

Traits		BWT	WWT	WT6	WT12	GYF1
BWT	A[a]	0.083				
	E[b]	0.387				
	P[c]	0.408				
WWT	A[a]	0.171	1.523			
	E[b]	0.867	6.283			
	P[c]	0.909	6.663			
WT6	A[a]	0.164	1.609	3.269		
	E[b]	0.952	5.332	9.649		
	P[c]	0.993	5.734	10.467		
WT12	A[a]	0.203	1.575	3.049	5.374	
	E[b]	0.903	4.687	8.067	12.383	
	P[c]	0.954	5.081	8.829	13.726	
GFY1	A[a]	-0.002	0.088	0.176	0.019	0.019
	E[b]	0.038	0.143	0.272	0.048	0.048
	P[c]	0.038	0.165	0.316	0.053	0.053

where A[a] = indicate additive genetic variances (diagonal) and covariances (below diagonal)
E[b] = indicate environmental variances (diagonal) and covariances (below diagonal)
P[c] = indicate phenotypic variances (diagonal) and covariances (below diagonal)

Table 4.15 : Genetic, phenotypic and environmental correlations among BWT, WWT, WT6, WT12 and GFY1 under model 2 of LSA

Traits		BWT	WWT	WT6	WT12
WWT	ra	0.479 ± 0.180			
	rP	0.552 ± 0.023			
	rE	0.572			
WT6	ra	0.315 ± 0.192	0.721 ± 0.105		
	rP	0.480 ± 0.024	0.687 ± 0.020		
	rE	0.541	0.678		
WT12	ra	0.303 ± 0.185	0.550 ± 0.141	0.728 ± 0.085	
	rP	0.403 ± 0.025	0.531 ± 0.023	0.737 ± 0.018	
	rE	0.456	0.535	0.745	
GFY1	ra	-0.051 ± 0.209	0.510 ± 0.166	0.693 ± 0.117	0.620 ± 0.120
	rP	0.257 ± 0.026	0.278 ± 0.026	0.423 ± 0.025	0.400 ± 0.025
	rE	0.384	0.185	0.255	0.264

where A^a = indicate additive genetic variances (diagonal) and covariances (below diagonal)
E^b = indicate environmental variances (diagonal) and covariances (below diagonal)
P^c = indicate phenotypic variances (diagonal) and covariances (below diagonal)

indicates ewe lambs grew faster and were of heavier body weight, produce small quantity of greasy fleece yield.

Phenotypic and environmental correlations between birth weight and weight at 6 and 12 months of age and first greasy fleece weight (Table 4.15) were highly positive, indicated improvement in early observable weights would long lasted to body weights of subsequent stages of lambs. Therefore, besides selection, management and other impacts need to be improved for better growth increment and wool weight. Very low to moderate genetic, phenotypic and environmental correlations were reported by Osman and Bradford (1965), Kushwaha *et al.* (1995) and Tomar *et al.* (2000b) in different breeds of sheep; whereas very low and negative genetic correlations was reported by Tomar *et al.* (2000a) in Bharat Merino sheep. However, higher values of genetic, phenotypic and environmental correlations was reported by Kumar (2000) in Chokla sheep.

Genetic correlations between weaning weight and weight at 6 and 12 months of age and first greasy fleece weight were all significant, positive and relatively high. The estimates of genetic correlations between these traits (Table 4.15) are of general interest in selection for these characters in Avikalin sheep. Low genetic correlations was found by Tomar *et al.* (2000a & b) in Bharat Merino sheep, but Ercanbrack and Price (1972), Yamaki (1994), Bathaei (1994) and Kumar (2000) reported very high genetic correlations among weights of different ages and weaning weight which support the present findings.

Phenotypic and environmental correlations between weaning weight and weight at 6 and 12 months of age and fleece weight were all significant and positive (Table 4.15), indicating that ewe lambs weaned at heavy body weight, growing most rapidly after weaning, tend to be heavier at later ages and produce more fleece yield. The phenotypic and environmental correlations between these traits indicate that good management, feeding and other environmental conditions tend to enhance growth and increase body weight and fleece yield. Thus, emphasis on good feeding and management is needed and should be considered beside selection in order for ewe lambs for higher growth at an earlier age. Similar estimates were reported by Ercanbrack and Price (1972), Yamaki (1994), Bathaei (1994) and Kumar (2000) in different breeds of sheep.

Genotypic, phenotypic and environmental correlations between weight at 6 and 12 month and first greasy fleece yield were moderate to high under model 2 of LSA. Estimates of genetic correlations between weight at 6 moths and weight at 12 months of age and first greasy fleece yield were 0.728 and 0.693 respectively (Table 4.15). These results suggest that weight at 6 month and weight at 12 month and first greasy fleece yield are genetically correlated, so that selection for 6 months weight might result in increase in genetic merit for the other traits.

The estimates of positive and significant phenotypic and environmental correlations indicated presence of desirable association among growth traits and fleece yield. The positive correlations between body weights are probably

due to greater similarly of environment and managemental conditions as well as automatic correlation between adjacent records. The estimates of genotypic and phenotypic correlations were in agreement with those reported by Davis (1987), Kushwaha *et al.* (1995), Arora and Kushwaha (1996), Sinha and Singh (1997), Tomar *et al.* (2000b) and Kumar (2000). However, higher values were reported by Ercanbrack and Price (1972) and Mc Ewan *et al.* (1997) in different breeds of sheep.

Estimates of genetic correlation between weight at 12 month and fleece yield (0.620 ± 0.120) was highly positive and significant. Generally positive genetic correlation between weight at 12 months and fleece yield was inferred from the positive phenotypic response in weight at 12 month during long term, selection for weight at 12 month during long term selection for weight at 12 month of age.

Estimate of phenotypic correlation between weight at 12 month and fleece yield was (0.400) highly positive. The high, positive and significant phenotypic correlation between weight at 12 months and first greasy fleece yield showed the existence of high degree of association between the two traits and indicated that increased weight at 12 months is associated with increase in fleece yield.

The environmental correlation between weight at 12 months and greasy fleece yield was positive, implying thereby that improvement in the environment and management of lambs specially nutritional status and the

health cover would help in increasing the body weights and greasy fleece weights. Arora and Kushwaha (1996) reported lower values of genotypic and phenotypic correlations than the present study in Avikalin sheep.

In general, the genetic correlations tend to be slightly higher than their phenotypic counterparts in all traits except genetic correlations of birth weight with other traits under the present study. Large differences between genetic and phenotypic correlations tend to occur only when the genetic correlation was estimated with low precision, suggesting that in general genetic correlations are the same or similar to phenotypic correlations for many traits (Koots *et al.,* 1994b). The magnitude of genetic correlations among all the traits in general were higher than the environmental correlations which indicates that phenotypic correlations among these traits were more due to genetic causes.

The correlations among body weight traits indicate that body weight at given age played an important role in determining the body weights at subsequent ages. It suggest the need for efficient management for ensuring good growth and more wool production throughout the growth period of the lambs. The positive environmental correlations imply that improvement in the environment and the management of lambs, would help in improvement of body weights and fleece yields.

4.6 Sire evaluation

As per the objectives, the sires have been ranked on the basis of solution obtained through univariate REML animal model and BLUP value for sire effects under model 8. The sire effect and list of ten top ranking sires are presented in Tables 4.16 to 4.19. Rank correlations (Table 4.20) between these values worked out to evaluate the efficiency of sire evolution.

Details of sire evaluations under different methods

Two solutions for sire evolution were used. Best linear unbiased prediction (BLUP 1) values of model 8 and univariate (BLUP 2) solutions of REML. All the methods were based on progeny testing. BLUP 2 was based on an animal model, which utilized information from all the known relationship under univariate animal model no sire effect was fitted. The sire solution was sorted out from the solution of all the animals and used for comparison with BLUP values obtained under model 8.

The raw means estimated by the different methods were same, therefore, the sire effects taken as deviation of the sires value from the raw mean and have been presented and discussed from the purpose of sire evaluation and comparison under model 8 and univariate methods. A total of 106 sires were evaluated for BWT, WWT, WT6, WT12 and GFY1 in Avikalin sheep. The information on sire evaluation viz. per cent of sire with positive and negative effects, sire effect for the top ranking and bottom ranking sires and per cent superiority/inferiority of top/bottom under model 8 (BLUP 1) and univariate animal model (BLUP 2) are presented in Table 4.16 and 4.18.

Table 4.16 : Range of solution (LSC) for sire effect of BWT, WWT, WT6, WT12 and GFY1 under model 8 in Avikalin sheep

S. No.	Traits	Best sire			Worst sire			% of sire with	
		Sire code	Value	% of mean	Sire code	Value	% of mean	Positive effect	Negative effect
1.	BWT	GC 1349	0.253	8.58	GC 2035	-0.239	-8.12	52.83	47.17
2.	WWT	GC 3016	1.104	7.15	GC 3255	-0.896	-5.81	45.28	54.72
3.	WT6	GC 3016	2.391	11.29	GC 1335	-1.520	-7.18	50.95	49.05
4.	WT12	GC 2928	2.273	8.74	GC 1377	-1.980	-7.61	49.06	50.94
5.	GFY1	GC 3016	0.128	12.07	GC 1337	-0.113	-10.66	41.51	58.49

Table 4.17 : Ranking of sire effect of top 10 sires for BWT, WWT, WT6, WT12 and GFY1 under model 8 in Avikalin sheep

Rank	Traits									
	BWT		WWT		WT6		WT12		GFY1	
	Sire	LSC	Sire	LSC	Sire	LSC	Sire	LSC	Sire	LSC
1.	GC 1349	0.253	GC 3016	1.104	GC 3016	2.391	GC 2928	2.273	GC 3016	0.128
2.	GC 1587	0.197	GC 2975	0.954	GC 2975	1473	GC 2975	1.845	GC 2911	0.119
3.	GC 1675	0.174	GC 2917	0.857	GC 2838	1.434	GC 2911	1.743	GC 751	0.115
4.	GC 1843	0.169	GC 3063	0.811	GC 2948	1.347	GC 3016	1.487	GC 2975	0.111
5.	GC 2975	0.155	GC 133	0.762	GC 3063	1.335	GC 2917	1.366	GC 3007	0.101
6.	GC 3244	0.154	GC 1349	0.729	GC 2215	0.968	GC 1637	1.292	GC 2917	0.094
7.	GC 1637	0.142	GC 1493	0.593	GC 1843	0.912	GC 3520	1.284	GC 2838	0.184
8.	GC 3063	0.114	GC 785	0.572	GC 2917	0.894	GC 2781	1.267	GC 3026	0.082
9.	GC 2309	0.109	GC 2838	0.537	GC 2911	0.877	GC 2215	1.253	GC 3063	0.081
10.	GC 1493	0.101	GC 3244	0.525	GC 785	0.792	GC 1587	1.169	GC 2948	0.079

Where, LSC = Least squares constant.

Table 4.18 : Range of solution (LSC) for sire effect of BWT, WWT, WT6, WT12 and GFY1 under univariate animal model in Avikalin sheep

S. No.	Traits	Best sire			Worst sire			% of sire with	
		Sire code	Value	% of mean	Sire code	Value	% of mean	Positive effect	Negative effect
1.	BWT	GC 1349	0.487	16.73	GC 1030	-0.496	16.84	56.61	43.39
2.	WWT	GC 133	1.383	8.96	GC 1420	-1.155	7.48	52.83	47.17
3.	WT6	GC 2975	2.989	14.12	GC 1335	-2.109	9.96	69.81	30.19
4.	WT12	GC 3205	4.122	15.84	GC 1377	-2.286	8.78	71.69	28.31
5.	GFY1	GC 3016	0.127	11.98	GC 1337	-0.075	7.07	61.32	38.68

Table 4.19 : Ranking of sire effect of top 10 sires for BWT, WWT, WT6, WT12 and GFY1 under univariate animal model in Avikalin sheep

Rank	Traits									
	BWT		WWT		WT6		WT12		GFY1	
	Sire	Solution	Sire	Solution	Sire	Solution	Sire	Solution	Sire	Solution
1.	GC 1349	0.487	GC 133	1.383	GC 2975	2.989	GC 3205	4.122	GC 3016	0.127
2.	GC 1637	0.455	GC 2975	1.286	GC 3016	2.971	GC 2928	3.988	GC 2911	0.109
3.	GC 1843	0.441	GC 3063	1.069	GC 2838	2.028	GC 2975	3.926	GC 2906	0.104
4.	GC 1675	0.441	GC 3016	1.028	GC 3063	2.115	GC 3520	3.583	GC 3007	0.099
5.	GC 1337	0.383	GC 2948	0.919	GC 2638	1.983	GC 3016	3.304	GC 3667	0.097
6.	GC 133	0.372	GC 3244	0.906	GC 2948	1.961	GC 2911	3.035	GC 2975	0.097
7.	GC 2309	0.339	GC 1843	0.898	GC 2917	1.838	GC 2638	2.889	GC 3621	0.096
8.	GC 2215	0.326	GC 1349	0.752	GC 133	1.807	GC 3316	2.549	GC 3199	0.093
9.	GC 1535	0.285	GC 2829	0.729	GC 3316	1.753	GC 2917	2.513	GC 2917	0.093
10.	GC 1428	0.282	GC 2215	0.705	GC 3244	1.573	GC 2404	2.421	GC 3561	0.080

4.6.1 Birth weight

The estimated general mean of birth weight (2.946 kg) was used for BLUP 1 and BLUP 2 in Avikalin sheep. More than half of the sires (52.83%) were superior to the population mean under BLUP 1. The corresponding values were slightly higher (56.61%) under BLUP 2.

The range of sire effects of birth weight were -0.239 to 0.253 and -.0496 to 0.87, respectively, under BLUP 1, and BLUP 2. The range of sire effects was higher in BLUP 2 than the BLUP 1. The superiority of best sire (as per cent of the general mean) were 8.58 and 16.53, respectively under BLUP 1 and BLUP 2 whereas corresponding values of inferiority of the worst sire were -8.12 and –16.84, under BLUP 1 and BLUP 2. BLUP 2 had shown maximum value in terms of superiority and/or inferiority. The upper limit of sire effects for BWT was increased from 0.253 kg (BLUP 1) to 0.487 kg in BLUP 2 whereas, lower limit reduced from 0.239 kg in BLUP 1 and 0.496 kg in BLUP 2. Upper limit and lower limit of sire effect under BLUP 1 was almost half of the BLUP 2 method.

4.6.2 Weaning weight

The estimated average WWT of 15.43 kg was used BLUP 1 and BLUP 2. For weaning weight less than half of the sires (45.83%) were superior to the population mean under BLUP 1. The corresponding values slightly higher and more than half of the sires (52.83%) were superior to the population mean under BLUP 2 in Avikalin sheep.

The range of sire effects for WWT were -0.896 to 1.104 and –1.155 to 1.383 under BLUP 1 and BLUP 2, respectively. The superiority of best sire were 44.34 and 52.83 per cent, respectively, under BLUP 1 and BLUP 2, whereas corresponding values of inferiority of the worst sire were 55.66 and 47.13 per cent. BLUP 2 had shown maximum values in terms of superiority and/or inferiority of the sire effect.

The upper limit of sire effects for weaning weight was increased from 1.104 kg (BLUP 1) to 1.383 kg in BLUP 2 whereas lower limits were reduced from 0.896 kg (BLUP 1) to 1.155 kg in BLUP 2.

4.6.3 Weight at 6 month of age

The general mean (21.44 kg) of 6 month body weight was used for BLUP 1 and BLUP 2. About half of the sires (50.95%) were superior under BLUP 1. The corresponding values was much higher (69.81%) under BLUP 2.

The range of sire effects for WT6 were -1.520 to 2.391 and -2.109 to 2.989, respectively, under BLUP 1 and BLUP 2. The range of sire effects under BLUP 2 was slightly higher than BLUP 1. The superiority of the best sire were (as per cent of general mean) were 11.29 and 14.12, respectively, under BLUP 1 and BLUP 2, whereas inferiority of worst sires for corresponding values were -7.18 and -9.96. BLUP 2 had shown maximum value in terms of superiority and/or inferiority of the sire.

The upper limit of sire effects for WT6 was increased from 2.391 kg (BLUP 1) to 2.975 kg (BLUP 2) whereas lower limits were reduced from 1.520 in BLUP 1 to 2.109 in BLUP 2.

4.6.4 Weight at 12 month of age

The general mean of WT12 (26.02 kg) was used in BLUP 1 and BLUP 2. About half of the (49.06) sires were superior under BLUP 1. The corresponding value was much higher (71.69%) under BLUP 2.

The range of sire effects for WT12 were -1.980 to .273 (BLUP 1) and -2.286 to 4.122 in BLUP 2. The range of sire effects for WT 12 under BLUP 2 was much higher than BLUP 1. The superiority of best sire were (per cent of general mean) 8.74 and 15.84, respectively, under BLUP 1 and BLUP 2 whereas inferiority of worst sires for corresponding values were -7.61 and -8.78. The BLUP 2 had shown maximum values in terms of superiority and/or inferiority of the sire.

The upper limit of sire effect for WT12 was increased from 2.273 kg in BLUP 1 to 4.122 kg under BLUP 2 whereas lower limits were reduced from 1.980 (BLUP 1) to 2.286 in BLUP 2.

4.6.5 First six monthly greasy fleece yield

The estimated general mean (1.061 kg) of GFY1 was used for BLUP 1 and BLUP 2. Under BLUP 1, 41.51 per cent sires were superior to the population mean. The corresponding value was much higher (61.32%) under BLUP 2.

The range of sire effect for GFY1 were -0.113 to 0.128 (BLUP 1) and -0.075 to 0.127 under BLUP 2. The superiority of the best sire (per cent of general mean) were 12.07 and 11.98, respectively, under BLUP 1 and BLUP 2 whereas corresponding values of inferiority of the worst sire were -10.66 and -7.07. The upper limit of sire effect for GFY 1 was increased from 0.127 kg (BLUP 2) to 0.128 kg in BLUP 1, whereas lower limits were reduced from 0.075 (BLUP 2) to 0.113 in BLUP 1. It was observed that the top ranking sire for GFY 1 was same (i.e. GC 3016) under the both BLUP methods.

The higher percentage of superior sire to population mean for all the traits except GFY1 was under BLUP 2, this might be due to non-fitting of sire effect in the model. In BLUP 2 sires were sorted out from the animal solutions and then ranked on the basis of breeding values. It can be concluded from the results that the range of sire effects was more under BLUP 2. Kumar (2000) reported that the range of sire effects, per cent sires superior to population mean and the superiority of best sire was more under BLUP 2 (univariate) than the BLUP1 (model 8). Therefore, REML, using animal model, could be used to evaluate the sires.

4.7 Rank correlation

A total 106 sires were ranked on the basis of solution obtained under BLUP 1 (model 8) and BLUP 2 (univariate animal mode) for BWT, WWT, WT6, WT12 and GFY1 in Avikalin sheep. The rank correlation coefficients for among methods within trait and among traits within method are presented in Table 4.20.

Table 4.20 : Rank correlation coefficients between model 8 and univariate animal model for BWT, WWT, WT6, WT12 and GFY1 in Avikalin sheep

	Traits	Model 8				
		BWT	WWT	WT6	WT12	GFY1
	BWT	**0.806**	0.459	0.381	0.341	0.129
	WWT	0.551	**0.815**	0.638	0.557	0.309
Univariate	WT6	0.435	0.671	**0.789**	0.732	0.419
	WT12	0.304	0.513	0.802	**0.887**	0.432
	GFY1	0.297	0.281	0.537	0.541	**0.803**

Figures in bold letters are 'among method within traits' rank correlation coefficients

Above diagonal values are among traits within method rank correlation coefficient under model 8 and below diagonals are among traits within method rank correlation coefficient under univariate animal model

The rank correlation among method was highly significant. The rank correlations between the two methods were though high and significant ($P<0.01$), yet not perfect, revealing that ranking of sires by different methods were not similar.

The rank correlations 'among traits within method' were low than 'among methods within traits'. In 'among traits within method', the ranking of sires changed resulting into decreased rank correlation coefficients. The change in ranking of sires with increase in age or weights of their daughter might be due to non-unity in genetic correlations between different weights. Within the method, the rank correlation ranged from 0.129 (between BWT and GFY1, in model 8) to 0.802 (between WT12 and WT6, in univariate animal model). All the correlation coefficients were significant, except between BWT and GFY1 in model 8. In general, WT6 and WT12 had highest rank correlation in model 8 and univariate and ranging from 0.732 and 0.802, respectively. Kumar (2000) also reported highly significant correlations for BWT, WWT, WT 6 and GFY 1 under model 8 and univariate animal model. This rank correlation may be due to high genetic correlation between these two traits.

Summary and Conclusion

Chapter 5 SUMMARY AND CONCLUSION

Data used in the present study were recorded over a period of 22 years from 1980-2001 from data base of 1313 Avikalin crossbred sheep, maintained at Central Sheep and Wool Research Institute, Avikanagar, Rajashtan. Avikalin, a carpet wool sheep has been created out by crossing and stabilizing of Rambouillet × Malpura at 50 per cent inheritance. It was evolved in the year 1977 with the objectives to produce 2 kg annual fleece yield, around 30 micron fiber diameter and 30 per cent medullation.

The traits studied were BWT, WWT, WT6, WT12 and GFY1. The data were subjected to LSMLMW and MIXMDL package of Harvey (1990) and derivative free REML package of Meyer (1998). Same model was fitted to taking sex and season of birth of lamb as fixed effect and sire as random effect.

The least squares means (±se) of weight at birth, weaning, 6 months, 12 month and 1st GFY clipped at 6 month of age were 2.91 ± 0.045 kg, 15.57 ± 0.184kg, 20.98 ± 0.249 kg, 26.13 ± 0.304 kg and 1.06 ± 0.018 kg respectively, under model 2 and 2.89 ± 0.037 kg, 15.58 ± 0.152 kg, 20.86 ± 0.196 kg, 26.03 ± 0.228 kg and 1.06 ± 0.014 kg, respectively under model 8.

The least squares means, estimated by model 8 were slightly lower than the means estimated by model 2. The coefficient of variations were slightly lower in model 8 than the univariate. The coefficient of variation decreases from BWT to WT12 with increase in age of the animal. The C.V. was almost similar for GFY1

under model 8 and univariate. The BWT and GFY1 had maximum variation and followed by WWT, WT6 and WT12 under model 8 and univariate methods.

The random effect of sires had highly significant ($P<0.01$) effect on BWT, WWT, WT6, WT12 and GFY1 under model 2, which indicating sizable genetic difference among sires. The significant effect of sires on all the traits studied indicated that superior sires could be used effectively for improvement of these traits.

Sire of lambs under model 2 of LSA accounted 5.07, 5.77, 7.81, 9.78 and 9.21 per cent of total variation for BWT, WWT, WT6, WT12 and GFY1 respectively. The corresponding values under model 8 were 1.29, 1.48, 2.13, 2.68 and 2.42 per cent respectively. The sire had accounted more variation under model 2 than model 8 for all the traits. With the advance of age the variation accounted by sire was increased under model 2 and same trend also observed under model 8 of analysis.

The coefficient of multiple determination (R^2) obtained under model 8 were 13.50, 13.90, 26.40, 33.30 and 12.10 per cent respectively for BWT, WWT, WT6, WT12 and GFY1. For the growth traits, as the age of lambs advanced the R^2 increased. The higher variation at 12 month weight indicates the need for applying intense selection pressure at the age of 12 month.

The fixed effect of season of lambing had highly significant effect ($P<0.01$) on BWT, WT6 and WT12 under model 2 and model 8. However, non significant differences were found for weaning weight and GFY1 under model 2

and model 8. The means estimated for season 1 (January-June) showed higher values than the estimated for season 2 (July-December) under model 2 and model 8. The differences in body weight at birth, weaning, 6 month, 12 month and first greasy fleece yield due to sex was highly significant ($P<0.01$) under model 2 and model 8. Male lambs were significantly heavier at all ages and produced more wool yield than the female lambs.

Additive (direct), phenotypic and environmental variances were estimated by model 2 and 8 and univariate animal model. Variance estimated from model 2 and 8 and univariate REML analysis were agreed for phenotypic and environmental variance for BWT, WWT, WT6 and WT12. For GFY1, univariate REML analysis had highest value of phenotypic and environmental variance. Model 2 and model 8 had similar values of phenotypic and environmental variances for BWT, WWT, WT6, WT12 and GFY1 but lower than the values of univariate analysis.

Additive (direct) variances estimated from univariate animal model were higher than estimates of model 2 and 8 for all the traits under study. Model 8 had slightly higher values of additive variances for all traits than the model 2.

The h^2 estimates for birth weight were 0.203 ± 0.070, 0.197 and 0.265 respectively under model 2, model 8 and univariate REML analysis. The medium h^2 estimates with relatively small C.V. suggested that birth weight alone would not be appropriate for evaluation of animals. The h^2 estimated for weaning weight by model 2, model 8 and univariate animal model were 0.229 ± 0.081,

0.227 and 0.138 respectively. The h^2 estimated under univariate animal model for WWT was lower than BWT, which might be due to reduced maternal effect.

The heritability estimated by three methods for weight at 6 month ranged from 0.188 (univariate) to 0.319 (model 8). Model 2 (0.312) and model 8 (0.319) analyses estimated almost similar heritability. The h^2 estimated by univariate analysis for WT6 was lower than the BWT, which might be due to increased influence of the non permanent environmental factors.

The estimates of h^2 for weight at 12 month by model 2, model 8 and univariate REML were 0.319 ± 0.089, 0.397 and 0.243 respectively. The h^2 estimates for first greasy fleece yield ranged from 0.140 (univariate REML) to 0.374 (model 8). Model 2 (0.373) and model 8 (0.374) were estimated almost similar heritability. Model 2 and model 8 had higher estimates of h^2 than the univariate REML procedure.

There was positive correlation between C.V. and h^2 estimates in univariate animal model. BWT had highest C.V. and h^2 among all the traits. However, WWT, WT6, WT12 and GFY1 had negative correlation between C.V. and h^2.

The negative correlation between C.V. and h^2 for BWT, WWT, WT6, WT12 and GFY1 were observed under model 8. For body weight heritability increases with age from birth weight to weight at 12 month but C.V. decreases as age advanced.

The genetic correlations of birth weight with weaning weight, weight at 6 month and 12 month were 0.48 ± 0.180, 0.135 ± 0.192 and 0.303 ± 0.185 respectively under model 2. The estimates of genetic correlations (-0.051 ± 0.209) between birth weight and first greasy fleece weight was very low and negative.

Genetic correlations between weaning weight and weight at 6 month (0.721 ± 0.105), 12 month (0.550 ± 0.141) and first fleece yield (0.510 ± 0.116) were all significant, positive and relatively high. Genetic correlation of weight at 6 month with weight at 12 month and first fleece yield were very high. The genetic correlation between weight at 12 month and first fleece yield was very high (0.620 ± 0.120).

The phenotypic and environmental correlations of birth weight with weaning weight, 6 month, 12 month and first fleece yield were observed positive and from medium to very high. The phenotypic and environmental correlations of weaning weight with weight at 6 and 12 month and first fleece yield were positive and moderate to very high. The phenotypic and environmental correlations of weight at 6 month with weight at 12 month and fleece yield were also showed same trend. The phenotypic and environmental correlation between weight at 12 month and first fleece yield were also positive and medium.

In general, the genetic correlations tend to be slightly higher than their phenotypic counterparts in all traits except genetic correlations of birth weight with other traits. The correlations among body weight traits indicate that body weight at live age played an important role in determining the body weights in subsequent ages. It suggest the need for efficient management for ensuring better growth and more wool production through out the growth period of the lambs.

Two solutions for sire evaluation were used. Best linear unbiased prediction (BLUP 1) values of model 8 and univariate (BLUP 2) solutions of REML. The raw means estimated by the different methods were same, therefore, the sire effects taken as deviation of the sires value from the raw mean. A total of 106 sires were evaluated for BWT, WWT, WT6, WT12 and GFY1 in Avikalin sheep. More than 50 per cent of sires (52.83%) were superior to the population mean under BLUP 1. The corresponding values were slightly higher (56.61%) under model 2 for birth weight. Whereas, corresponding values of inferiority of the worst sire were -8.12 and -16.84 per cent under BLUP 1 and BLUP 2. For weaning weight less than half of the sires (45.83%) were superior to the population mean under BLUP 1. The corresponding values were slightly higher (52.83%) under BLUP 2. The superiority of best sire were 44.34 and 52.83 per cent respectively, under BLUP 1 and BLUP 2, whereas, corresponding values of inferiority of the worst sires were 55.66 and 47.13 per cent, respectively, under BLUP 1 and BLUP 2. BLUP 2 had shown maximum values in terms of superiority and/or inferiority.

About 50 per cent sires were superior under BLUP1 for weight at 6 month. The corresponding value was much higher (69.81%) under BLUP 2. The superiority of the best sires were 11.29 and 14.12 per cent, respectively, under BLUP 1 and BLUP 2, whereas corresponding inferiority values of worst sires were -7.18 and -9.96 per cent respectively. About half of the (49.06%) sires were superior for weight at 12 month under BLUP 1. The corresponding value under BLUP 2 was much higher (71.69%). The superiority of best sire were 8.74 and 15.84 per cent respectively under BLUP 1 and BLUP 2, whereas

corresponding values of inferiority of worst sires were -7.61 and -8.78, respectively. The BLUP 2 had shown maximum values in terms of superiority and/or inferiority of sire.

Under BLUP 1, 41.51 per cent of sires were superior for first greasy fleece yield to the population mean. The corresponding value was much higher (61.32%) to the population mean under BLUP 2. The superiority of the best sire (as per cent of raw mean) were 12.07 per cent under BLUP 1 and 11.98 per cent under BLUP 2 for first fleece weight. It was observed from the present results that the range of sire effects, per cent sires superior to the population mean and the superiority of best sire was more under BLUP 2 than the BLUP 1. Therefore, REML using an animal model, could be used to evaluate sires.

The rank correlations for BWT, WWT, WT6, WT12 and GFY1 under model 8 and univariate animal model were highly significant. The rank correlations among methods within traits were high and significant (<0.01), yet not perfect, revealing that the ranking of sires by different methods were not similar. The rank correlations 'among traits within method' were low than 'among method with traits'. All the rank correlation coefficients within method were significant, except between BWT and GFY1, in mode 8. Univariate animal model had higher rank correlations among traits as compared to model 8. In general, WT6 and WT12 had highest rank correlation in model 8 and univariate animal model and ranging from 0.732 to 0.802, respectively.

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G. B. Pant Univ. of Ag. & Tech., Pantnagar

Author's Biography

AUTHOR'S BIOGRAPHY

The author was born on 15th July, 1974 at Arjunpur, district Sultanpur, U.P. He passed his High School and Intermediate Examinations form Janta Intermediate College, Belhari, Sultanpur in 1990 and 1992, respectively. He did his B.Sc. (Ag.) from Udaipratap College (Deemed University), Varanasi in 1997. Thereafter, he joined G.B. Pant University of Agriculture and Technology, Pantnagar in Master degree programme in Animal Breeding. He joined same University for his Ph. D. progrramme.

Permanent Address:

Maroof Ahmad
S/o Janab Mohd. Rauf
Village – Arjunpur
P.O. – Belhari-228 133
Distt. – Sultanpur (U.P.)

ABSTRACT

Name	:	**Maroof Ahmad**	**Id. No.**	:	**24694**
Semester & year of admission	:	**Ist, 1999-2000**	**Degree**	:	**Ph. D.**
Major	:	**Animal Breeding**	**Department**	:	**Animal Science**
Minor	:	**Molecular Biology & Biotechnology**			

Thesis title : "GENETIC EVALUATION OF GROWTH AND WOOL YIELD TRAITS USING ANIMAL MODEL IN AVIKALIN CROSSBRED SHEEP"

Advisor : Dr. C V Singh

Data consisting of 1313 lambs records of Avikalin sheep, maintained at CSWRI, Avikanagar, Rajasthan over the period 1980-2001, were used for present study. The traits studied were BWT, WWT, WT6, WT12 and GFY1. The data were subject to LSMLMW and MIXMDL package of Harvey (1990) and derivative free REML package of Mayer (1990). Same model taking sex and season of lamb as fixed effect and sire as random effect.

The least squares means ±s.e. of BWT, WWT, WT6, WT12, and GFY1 were 2.91 ± 0.045 kg, 15.57 ± 0.184 kg, 20.98 ± 0.249 kg, 26.13 ± 0.304 kg and 1.06 ± 0.018 kg, respectively, under model 2 and 2.89 ± 0.051 kg, 15.58 ± 0.152 kg, 20.86 ± 0.196 kg, 26.03 ± 0.228 kg, and 1.06 ± 0.014 kg respectively, under model 8. Least squares means estimated by model 8 were slightly lower than the means estimated by model 2. The C.V. were slightly lower in model 8 than the univariate for all the traits.

The random effect of sire had highly significant ($P<0.01$) effect on all the traits under model 2. The sire had accounted more variation under model 2 than model 8 for all the traits. The coefficient of multiple determination (R^2) obtained under model 8 were 13.50, 13.90, 26.40, 33.30 and 12.10 per cent, respectively, for BWT, WWT, WT6, WT12 and GFY1. The fixed effect of season of lambing had highly significant ($P<0.01$) on BWT, WT6 and WT12 under model 2 and 8. However, non-significant differences were found for WWT and GFY1 under model 2 and 8. The differences in body weight at, birth, weaning, 6 month, 12 month and GFY1 due to sex was highly significant ($P<0.01$) under model 2 and 8. Male lambs were significantly heavier at all the ages and produced more wool yield than the female lambs.

The heritability estimated under model 2, model 8 and univariate REML analysis were 0.203, 0.197 and 0.265, respectively for birth weight, 0.229, 0.227 and 0.138, respectively for weaning weigh; 0.312, 0.319 and 0.188, respectively for WT6; 0.319, 0.397 and 0.243 respectively for WT12; and 0.373, 0.374 and 0.140 respectively for GFY1. Model 2 and model 8 had higher estimates of h^2 than the univariate REML procedure. The genetic, phenotypic and environmental correlations among all the traits under study were observed positive and from moderate to very high. In general, the genetic correlations tend to be slightly higher than their phenotypic counter parts in all the traits. Under BLUP1, the percentage of superior sires to the population mean was 50 per cent or less than 50 per cent for the traits studied. Corresponding values were above 55 per cent under BLUP 2. The superiority of the best sire (as per cent of raw mean) was higher in BLUP 2 than the BLUP 1 for all the traits. It was also observed that range of sire effects was more under BLUP 2, therefore, univariate REML an animal model could be used for sire evaluation. The rank correlations for BWT, WWT, WT6, WT12 and GFY1 under model 8 and univariate animal model were highly significant.

(C V Singh)
Advisor

(Maroof Ahmad)
Author