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Estimation of (co)variance components for body weight traits in intercross synthetic sheep

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ABSTRACT

This study was carried out on the recently developed intercross sheep developed from Bharat merino and Gaddi sSynthetic in the temperate region in the state of Himachal Pradesh of India. Study aimed to estimate the genetic parameters and (co)variance components for body weights at birth (BW) and 3-month (3BW), 6-month (6BW), 9-month (9BW) and 12-month (12BW) month age in a closed flock of intercross sheep maintained at North Temperate Regional Station of ICAR-CSWRI, Garsa, India. Data records on 1505 sheep descended from 565 dams and 154 sires over the period of 10 years were utilized. Data were corrected for possible fixed environmental effects such as lambing year, parity, sex of lamb, ewe weight at lambing for further genetic analysis. The restricted maximum likelihood procedure fitting animal models with different combinations of direct and maternal effects were used for genetic analysis. Analysis revealed significant influences of lambing year, parity, sex of lamb and ewe weight at lambing on studied traits. Direct heritability estimates for BW, 3BW, 6BW, 9BW and 12BW were 0.14±0.04, 0.18±0.05, 0.00±0.04, 0.05±0.05 and 0.05±0.05, respectively. Maternal effects significantly influenced the BW and estimated maternal heritability for the trait was 0.17±0.03. The correlation among body weights were medium to high except between BW and 12BW and it ranged from 0.16±0.51 to 0.99±0.19. Results suggest that maternal effects were important for initial growth performance. The heritability estimates for weaning weight was moderate and its positive association with other growth traits indicated that the present selection practice at six months may be shifted to early selection at weaning weight for further genetic improvement.

Keywords: Body weights, Direct heritability, Genetic correlation, Intercross sheep, Maternal effects

Small ruminants are an integral part of rural agrarian economy, especially in hilly and mountainous areas. Poor marginal farmers and agricultural landless labourers depend upon small ruminants farming for their livelihood security (Kumar *et al.* 2021). The climate of Himalayan region in the North Western India is ideally suited for small ruminant farming. The Himalayan region of Himachal Pradesh possesses lush green meadows which help in rearing small ruminant populations particularly sheep in semi-intensive and migratory production systems. However, the productivity of native breeds in terms of mutton and wool yield is low due to their poor genetic potential (Dixit *et al*. 2006). Therefore, crossbreeding program for sheep in India was initiated to evolve synthetic sheep breeds of high genetic merit for mutton and wool production (Prince *et al*. 2010). Native sheep of Gaddi breed of Himachal Pradesh were crossed with exotic fine wool breeds, viz. Merino and Rambouillet to improve their growth, wool (yield and quality) and reproduction traits. As a result, a fast-growing and fine wool producing intercross sheep was developed in 2012 at North Temperate Regional Station (NTRS), ICAR-Central Sheep and Wool Research Institute (ICAR-CSWRI), Garsa by stabilizing the population with 75% exotic inheritance (Merino and Rambouillet). The animals of this synthetic strain are relatively medium-sized, well adapted to high ranges of Himalayan terrains and capable to travel long distances (Rahim *et al*. 2024). It yield large quantity of fine quality wool and have better growth than native sheep breeds (Rajaravindra *et al*. 2018).

Growth has direct association with wool yield, mature body weight, early reproduction and survivability (Narula *et al*. 2009, Gowane *et al*. 2010b, Lalit *et al*. 2017). Lamb growth is regulated by both direct additive and maternal genetic effects, which in turn, influence the economic viability of a commercial sheep flock (Mousa *et al*. 2013, Shiotsuki *et al*. 2014). Models which ignored the maternal genetic effects resulted in biased estimation of genetic parameters. Keeping this into consideration, the present

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study was undertaken to estimate genetic parameters and covariance components of growth traits in intercross sheep using animal model. The aim was also extended to devise a strategy for breeding program in the closed nucleus of intercross sheep.

MATERIALS AND METHODS

Description of data: The information utilized in the study was collected from the database of 1505 animals maintained during the period from 2012 to 2021. As the flock is institutional, the data size was limited. The research project was started in August 2009 with the aim to develop the fine wool sheep from existing breeds. Initially, Gaddi Synthetic (GS) and Bharat Merino (BM) sheep with same exotic inheritance (75%) were reciprocally crossed (BM rams × GS ewes and GS rams × BM ewes) with each other to produce F_1 (B and G genotype) animals. The crossbred genotypes (G and B) born were again crossed with each other to developed intercross (H genotypes), which were stabilized by intercrossing and flock was subsequently closed in next generation.

Management practices: The sheep flocks were maintained at North Temperate Regional Station (NTRS), Garsa, Kullu, Himachal Pradesh, a sub temperate region with optimum inputs under semi-intensive management system. The farm is located an altitude of 1400 to 2100 above average sea level with coordinates of 77.20°E longitude and 31.28°N latitude. The climate is sub-temperate with temperature ranging from -2°C in winter to 35°C in summer. The animals were allowed to graze during day time in Himalayan territory of Garsa valley, with six-hour grazing. The animals were stall-fed with 300 to 450 g concentrate feed according to their age, sex and physiological status. Tupping was carried out once a year and during breeding season between mid-August to ending September. The flock was a closed type where 150 breeding females were maintained every year. Breeding rams were selected on the basis of six months live weight, first six-monthly greasy fleece yield and wool quality. Top 10 to 15 rams of different sire lines were kept for breeding per year and retained in the flock for two years. Lambing usually commenced in January and terminated at the end of March. After birth, lambs were housed with their mothers in separate enclosures for three days. Concentrate feed was offered *ad lib* to lambs from 15 days after birth till weaning at three months of age. After weaning, the male and female lambs were segregated from dams and housed separately. Concentrate mixture @300 g was provided to each animal in addition to six hours grazing along with stall feeding of dry or green fodder or lopped fodder tree leaves as per availability. Various prophylactic measures, viz. drenching, dipping and vaccination against enterotoxemia were followed as per standard protocol.

Recorded growth traits: Lambs were weighed from birth to one year of age at an interval of three month. Birth weight of newly born lamb was taken within 12 h of birth and the remaining 3BW, 6BW, 9BW and 12BW were taken precisely on exact dates, when the particular animal attains that particular age.

Statistical analysis: Data were analyzed initially by least-squares analysis of variance to identify the fixed effects to be included in the model (IBM Corp, SPSS, 2019). The statistical model included the fixed effects of year of lambing (10 levels; 2012 to 2021), sex of lamb (male and female), parity of ewe (I, II, III, IV and >V) and dam weight at lambing (<30, 30-35, 35-40 and ≥40 kg) on different body weights. Only the significant ($P\leq 0.05$) effects were included in analysis to derive (co)variance components by Average Information Restricted Maximum Likelihood (AIREML) approach fitting an animal model using WOMBAT program (Meyer 2007). Six different animal models which accounted for the direct and maternal genetic effects were used as below:

$y = X\beta + Z_a a + e$
$y = X\beta + Z_a a + Z_m m + e$ with $Cov(a_m, m_o)=0$
$y = X\beta + Z_a a + Z_m m + e$ with $Cov(a_m, m_o)=A\sigma_{am}$
$y = X\beta + Z_a a + Z_{pe} pe + e$
$y = X\beta + Z_a a + Z_m m + Z_{pe} pe + e$ with $Cov(a_m, m_o)=0$
$y = X\beta + Z_a a + Z_m m + Z_{pe} pe + e$ with $Cov(a_m, m_o)=A\sigma_{am}$

Where; y, Phenotypic record vector; β, a, m, pe and *e,* Vectors for fixed, direct additive, maternal additive, maternal permanent environmental, and residual effects, respectively; X, Z_a, Z_m and Z_{pe}, Associated corresponding matrices; A, Numerator relationship matrix and σ_{am}, Covariance between direct and maternal direct effects. Assumptions for variance (V) and covariance (Cov) matrices involving random effects were $V(a)=A\sigma^2_a$; $V(m)=A\sigma^2_m$; $V(pc)=I\sigma^2_{pc}$; $V(e)=I\sigma^2_e$ and $Cov(a,m)\ A\sigma_{am.}$ Where; I, Identity matrix; $\sigma^2_a, \sigma^2_m, \sigma^2_{pc}, \sigma^2_e$, Direct additive, direct maternal, maternal permanent environmental and residual variances, respectively.

The direct animal and maternal effect correlation (r_{am}) was estimated as $\sigma_{am}/(\sigma_a \times \sigma_m)$. The maternal repeatability across the year for ewe performance was calculated for all the traits as $t_m=[(¼)\ h^2 + m^2 + c^2 + r_{am}\sqrt{m^2}\sqrt{h^2}]$ (Al-Shorepy 2001). The total heritability (h^2_t) was calculated using the formula $h^2_t=(\sigma^2_a + 0.5\ \sigma^2_m + 1.5\ \sigma_{am})/\sigma_p^2$ (Willham 1972). For selecting the best univariate model, Likelihood Ratio Test (LRT) was employed for each trait (Meyer 2007). An effect was considered to have significant influence when its inclusion caused a significant increase in log likelihood, compared with the model in which it was ignored. Significance was tested at $P<0.05$ by comparing differences in log-likelihoods to values for a chi-square distribution with degrees of freedom equal to the difference in the number of (co)variance components fitted for the two models. Subsequently, bivariate analyses were performed from best model to estimates the correlations among the studied traits.

RESULTS AND DISCUSSION

The characteristic of data structure in intercross sheep along with descriptive analysis for the traits under study are

Table 1. Characteristics of data structure for body weight in intercross synthetic sheep

Trait	BW	3BW	6BW	9BW	12BW
Number of records	1505	1415	940	840	743
Number of sires with progeny	154	153	141	141	139
Number of dams with progeny	565	549	464	440	414
Mean (kg)	3.56	15.72	21.91	24.83	28.20
Standard error of the mean	0.01	0.08	0.14	0.14	0.19
Standard deviation	0.54	2.91	4.23	4.09	5.20
Coefficient of variation (%)	15.23	18.53	19.31	16.46	18.44
R^2 (%)	0.20	0.18	0.32	0.35	0.50

Where; BW, Birth weight; 3BW, 3 Months body weight; 6BW, 6 Months body weight; 9BW, 9 Months body weight; 12BW, 12 Months body weight; R^2, Coefficients of determination.

presented in Table 1. Number of animals in the pedigree was found to be 1505, and sires and dams with known progeny are 154 and 565, respectively. In the studied population, 49.24% of the lambs were male and 50.76% were female. In general, the coefficient of variation (CV) for the studied traits ranged from 15.23% (BW) to 19.31% (6BW). The CV for BW is less than other growth traits, which is an indication of the minor effect of environment on BW. The coefficients of determination for fitted models ranged from 20 to 50 %.

The estimated least squares means (LSM) and standard errors (SE) for BW, 3BW, 6BW, 9BW and 12BW was 3.55±0.02, 15.61±0.10, 21.29 ±0.16, 24.19±0.16 and 27.90 ±0.19 kg, respectively. The overall LSM obtained in present study were well in agreement with the earlier studies of Gowane *et al*. (2010a) in Bharat Merino sheep and Rajaravindra *et al*. (2018) for this intercross sheep. Least squares analysis of variance revealed significant ($P<0.05$) effect of year of lambing, sex of the lamb and dam weight at lambing on all studied traits, whereas, parity of dam was significant on BW only (Table 2). Similar findings have been reported by various researchers in other sheep breeds (Gowane *et al*. 2010a, Abbasi *et al*. 2012, Kumar *et al*. 2017, Mallick *et al*. 2021, Ehsaninia, 2021,

Table 2. Least-squares means along with standard error of body weights at different ages in intercross synthetic sheep

Factors	N	BW(kg)	3BW(kg)	6BW(kg)	9BW(kg)	12BW(kg)
Overall	1505	3.55±0.02	15.61±0.10	21.29±0.16	24.19±0.16	27.90±0.19
Year of lambing		**	**	**	**	**
2012	156	3.55^{bc}±0.05	16.86^{a}±0.26	26.26^{a}±0.37	26.93^{a}±0.37	33.95^{a}±0.43
2013	161	3.43^{cd}±0.04	16.85^{a}±0.24	22.37^{b}±0.39	25.70^{ab}±0.43	31.42^{a}±0.87
2014	196	3.55^{bc}±0.04	15.43^{bc}±0.23	17.81^{c}±0.80	20.22^{c}±0.68	24.72^{cd}±0.79
2015	121	3.28^{d}±0.05	14.70^{c}±0.26	19.56^{c}±0.40	22.52^{c}±0.43	26.72^{bcd}±0.50
2016	136	3.42^{cd}±0.04	14.88^{c}±0.24	19.57^{c}±0.38	24.39^{b}±0.40	27.66^{b}±0.45
2017	154	3.59^{bc}±0.04	15.06^{c}±0.22	18.62^{c}±0.32	21.95^{c}±0.35	25.16^{c}±0.39
2018	119	3.63^{ab}±0.05	16.35^{ab}±0.26	21.75^{b}±0.40	25.03^{b}±0.42	27.07^{bcd}±0.49
2019	136	3.80^{a}±0.04	15.28^{bc}±0.25	22.01^{b}±0.37	24.61^{b}±0.37	27.53^{b}±0.42
2020	155	3.67^{ab}±0.04	15.27^{c}±0.22	22.43^{b}±0.33	24.97^{b}±0.34	27.01^{bd}±0.38
2021	171	3.59^{bc}±0.04	15.43^{bc}±0.21	22.50^{b}±0.30	25.56^{ab}±0.30	27.72^{b}±0.35
Parity of dam		**	NS	NS	NS	NS
Parity I	566	3.43^{b}±0.02	15.33±0.13	21.05±0.22	24.60±0.23	27.99±0.28
Parity II	392	3.54^{a}±0.03	15.66±0.15	21.30±0.25	24.24±0.25	28.16±0.31
Parity III	274	3.56^{a}±0.03	15.74±0.17	21.66±0.27	24.07±0.27	27.81±0.32
Parity IV	162	3.63^{a}±0.04	15.58±0.23	21.69±0.35	24.42±0.36	28.25±0.42
Parity V or above	111	3.60^{a}±0.05	15.73±0.27	20.75±0.41	23.60±0.42	27.27±0.48
Sex of lamb		**	**	**	**	**
Males	741	3.63^{a}±0.02	16.02^{a}±0.12	22.22^{a}±0.20	25.85^{a}±0.20	30.27^{a}±0.24
Females	764	3.48^{b}±0.02	15.20^{b}±0.12	20.36^{b}±0.19	22.53^{b}±0.19	25.52^{b}±0.23
Ewe weight at lambing		**	**	**	**	**
30 kg	177	3.27^{d}±0.04	14.47^{c}±0.24	20.17^{b}±0.38	22.86^{b}±0.40	26.21^{c}±0.46
30-35	417	3.53^{c}±0.03	15.12^{c}±0.15	20.91^{b}±0.24	23.62^{b}±0.24	27.62^{b}±0.29
35-40	556	3.63^{b}±0.02	15.83^{b}±0.12	21.81^{a}±0.21	24.77^{a}±0.21	28.61^{a}±0.25
>40	355	3.78^{a}±0.03	17.02^{a}±0.15	22.28^{a}±0.24	25.49^{a}±0.24	29.15^{a}±0.30

Where; BW, Birth weight; 3BW, 3 Months body weight; 6BW, 6 Months body weight; 9BW, 9 Months body weight; 12BW, 12 Month body weight; LSM±SE in same column with different superscripts differ significantly (** $P<0.01$).

Table 3. (Co)variance components and genetic parameter estimates of growth traits in intercross synthetic sheep

Traits	Model	σ^2_a	σ^2_m	σ_{am}	σ^2_c	σ^2_e	σ^2_p	h^2±SE	m^2±SE	c^2±SE	r_{am}	h^2_t	t_m	Log L
BW	1	0.065	-	-	-	0.176	0.241	0.27±0.05	-	-	-	0.27	0.07	318.169
	2	**0.034**	**0.042**	**-**	**-**	**0.168**	**0.243**	**0.14±0.04**	**0.17±0.03**	**-**	**-**	**0.22**	**0.21**	**334.682**
	3	0.032	0.040	0.002	-	0.168	0.243	0.13±0.05	0.16±0.05	-	0.063	0.23	0.21	333.102
	4	0.044	-	-	0.037	0.159	0.240	0.18±0.04	-	0.15±0.03	-	0.18	0.20	332.521
	5	0.037	0.023	-	0.018	0.163	0.241	0.15±0.05	0.10±0.05	0.08±0.05	-	0.20	0.21	334.389
	6	0.033	0.018	0.006	0.019	0.165	0.241	0.14±0.05	0.08±0.06	0.23±0.48	0.080	0.21	0.21	334.511
3BW	**1**	**1.265**	**-**	**-**	**-**	**5.813**	**7.078**	**0.18±0.05**	**-**	**-**	**-**	**0.18**	**0.04**	**-2088.085**
	2	0.716	0.528	-	-	5.868	7.112	0.10±0.04	0.07±0.03	-	-	0.14	0.10	-2088.522
	3	1.053	1.197	-0.768	-	5.616	7.098	0.15±0.06	0.16±0.06	-	-0.684	0.23	0.10	-2086.598
	4	0.737	-	-	0.657	5.688	7.081	0.10±0.04	-	0.09±0.03		0.10	0.12	-2086.552
	5	0.727	0.039	-	0.625	5.691	7.083	0.10±0.04	0.01±0.04	0.09±0.04		0.11	0.12	-2086.554
	6	0.977	0.556	-0.518	0.524	5.533	7.072	0.14±0.05	0.08±0.06	0.07±0.05	-0.703	0.07	0.11	-2085.395
6BW	**1**	**0.001**	**-**	**-**	**-**	**12.105**	**12.106**	**0.00±0.04**	**-**	**-**	**-**	**0.00**	**0.00**	**-1651.353**
	2	0.001	0.524	-	-	11.598	12.122	0.00±0.05	0.04±0.04	-	-	0.02	0.04	-1650.659
	3	0.119	0.848	-0.316	-	11.472	12.123	0.01±0.06	0.07±0.06	-	-0.996	0.01	0.05	-1650.503
	4	0.001	-	-	0.353	11.755	12.109	0.00±0.04	-	0.03±0.04	-	0.00	0.03	-1651.093
	5	0.001	0.523	-	0.001	11.599	12.124	0.00±0.05	0.04±0.05	0.00±0.06	-	0.02	0.04	-1650.660
	6	0.117	0.849	-0.313	0.012	11.473	12.126	0.01±0.05	0.07±0.09	0.00±0.06	-0.996	0.01	0.05	-1650.501
9BW	**1**	**0.592**	**-**	**-**	**-**	**10.407**	**10.999**	**0.05±0.05**	**-**	**-**	**-**	**0.05**	**0.01**	**-1433.004**
	2	0.601	0.001	-	-	10.403	11.005	0.06±0.06	0.00±0.04	-	-	0.05	0.01	-1433.005
	3	0.712	0.016	-0.102	-	10.378	11.003	0.07±0.07	0.00±0.06	-	-0.968	0.05	0.01	-1432.960
	4	0.598	-	-	0.001	10.406	11.005	0.05±0.05	-	0.00±0.04	-	0.05	0.01	-1433.005
	5	0.601	0.001	-	0.001	10.407	11.010	0.06±0.05	0.00±0.06	0.00±0.06	-	0.05	0.01	-1433.007
	6	0.713	0.015	-0.101	0.001	10.380	11.008	0.07±0.06	0.00±0.08	0.00±0.06	-0.967	0.05	0.01	-1432.971
12BW	**1**	**0.714**	**-**	**-**	**-**	**12.899**	**13.610**	**0.05±0.05**	**-**	**-**	**-**	**0.05**	**0.01**	**-1346.224**
	2	0.678	0.075	-	-	12.860	13.613	0.05±0.06	0.01±0.04	-	-	0.06	0.02	-1346.218
	3	0.941	0.660	-0.655	-	12.662	13.607	0.07±0.06	0.05±0.08	-	-0.832	0.02	0.02	-1346.027
	4	0.613	-	-	0.352	12.649	13.613	0.05±0.06	-	0.03±0.05		0.05	0.04	-1346.107
	5	0.616	0.001	-	0.354	12.643	13.615	0.05±0.06	0.00±0.07	0.03±0.08	-0.999	0.05	0.04	-1346.107
	6	0.955	0.338	-0.567	0.468	12.416	13.610	0.07±0.07	0.03±0.11	0.03±0.08	-	0.02	0.03	-1345.879

Where; h^2, Direct heritability; Log-L, Log-likelihood value; S.E., Standard error; σ^2_a, Direct genetic variance; σ^2_c, Maternal common (permanent) environmental variance; σ^2_e, Residual variance; σ^2_m, Maternal additive genetic variance; σ^2_p, Phenotypic variance. m^2, σ^2_m/σ^2_p; c^2, σ^2_c/σ^2_p; t_m, Maternal across year repeatability for ewe performance; r_{am}, Direct–maternal correlation; h^2T, Total heritability. Bold rows represent the estimates from best model as per log ratio.

Kannan *et al*. 2023). Weights of the lambs was significantly ($P<0.01$) influenced by period of lambing, with some years performing better than others at certain phases. The differences could be attributed due to variation in late gestational nutrition of ewes and body score condition of ewe prior to conception, which is dictated by grazing pattern, breeding strategy, diseases outbreaks and other managemental and feeding practices during study period. Results on similar lines were also reported by Illa *et al*. (2019) in Nellore sheep, Ehsaninia (2021) in Sagsari sheep and Kannan *et al*. (2023) in Mecheri sheep. Birth weights ($P<0.01$) showed significant ($P<0.05$) variation in the dam's parity and similar finding was also reported by Kannan *et al*. (2023) in Mecheri sheep. Primiparous ewes produce lambs with lower birth weight than multiparous ewes. Also, higher birth weight was observed with an increase in parity number. Ewes in their advanced parity attain adequate body capacity and better mothering ability leading to better development of fetal growth (Gowane *et al*. 2011, Abbasi *et al.* 2012). However, parity had non-significant impact on body weight at later age which can be attributed to decrease in the maternal environment components and expression of the individual's own phenotype as the dominant entity. Male lambs were significantly ($P<0.05$) heavier than the female lambs at all ages. Differences in sexes were prominent with advancement of age due to differences in their endocrine system (Ehsaninia 2021). The males become more aggressive for suckling and feeding due to anabolic effect of androgen hormone resulting in higher intake of nutrient and consequently higher growth (Kumar *et al*. 2018). Significant ($P\leq 0.01$) effects of dam weight at lambing was observed on all body weights (Table 2). Heavier lambs were born to heavier weight ewes followed by medium-weight ewes and lighter ewes. This might be due to more nutrition and uterine space offered by heavier dams to developing fetuses. The lambs delivered by heavier dams had heavier live weights at successive ages.

Estimation of (co)variance components analyzed by univariate models using AIREML method for different body weights are presented in Table 3. The best model was chosen using LRT (Meyer 2007). As 1 degree of freedom at 5% level of significance leads to critical value of 3.841. Any significant difference between all the 6 models for all the traits except BW could not be seen. Model 2 with animal and maternal genetic effects was found to be more suitable for birth weight, however model-1 was most suitable for rest of the live weights.

Birth weight (BW): Results of different animal models fitted to birth weight revealed that, model 1 tends to overestimate (0.27±0.05) as compared to other models. The incorporation of maternal genetic effect in model 2 significantly improved the value of log-likelihood and reduced the direct h^2 by 48% (0.14±0.05) as the genetic variance was further partitioned into the maternal genetic variance component (m^2=0.17±0.03). This estimate of direct heritability for BW from best model was in agreement with earlier reports of Mandal *et al*. (2006a) in Muzaffarnagari (0.15), Prince *et al*. (2010) in Malpura (0.14), and Rajendran *et al*. (2022) in Mecheri (0.15) sheep breeds. However, heritability values were higher than findings of Gowane *et al*. (2010a) in Bharat Merino, Bangar *et al*. (2020) in Harnali and Kumar *et al.* (2017) in Nellore sheep. Further, the estimate was lower than Prince *et al*. (2010) in Avikalin, Khorsand *et al*. (2014) in Afshari and Ehsaninia (2021) in Sangsari sheep. Maternal effects are a heritable component of phenotypic variance and that arises from allelic differences between individual mothers at loci affecting offspring phenotype (Ghafouri-Kesbi 2013). The maternal heritability for this trait was in accordance with the findings of Gowane *et al*. (2010b) in Malpura (0.23), Singh *et al*. (2016) in Marwari (0.21) and Bangar *et al.* (2020) in Harnali (0.16) sheep. Moderate estimate of direct heritability suggests further scope for improvement of BW due to selection in the flock. Direct heritability estimate was increased to 0.18±0.04 when direct additive and maternal permanent environmental effect (c^2) were included in model 4. However, it did not increase the log likelihood value. The more comprehensive model 5 gave estimates of h^2, m^2 and c^2 as 0.15±0.05, 0.10±0.05 and 0.08±0.05, respectively, indicating that the maternal effect constitutes little more of the direct effect rather than permanent environment effects. The maternal effect had a significant impact on growth performance up to weaning period indicating the importance of maternal ability for early expressed traits. Addition of covariance between direct and maternal effects yield positive estimate of r_{am} in models 3 and 6 for birth weight, which were similar to earlier findings of Gowane *et al*. (2010a) in Bharat Merino sheep. The estimates of repeatability of ewe performance (t_m) for birth weight in current study ranged from 0.07 to 0.21. The total heritability (h_t^2) ranged from 0.18 to 0.27 over different models. However, based on LRT we report h^2_t estimate of 0.22 for BW.

Weaning weight (3BW): For weaning weight, model 1 was found to be most suitable among all animal models based on LRT. Heritability estimate from model 1 was 0.18±0.05. However, estimates ranged from 0.10±0.04 to 0.18±0.05 over different models, due to inclusion or exclusion of maternal effect. This estimate was in accordance with estimates reported by Mokhtari *et al*. (2013) in Arman (0.15±0.02) and Dixit *et al*. (2001) for Bharat Merino (0.14) sheep. However, it was higher than reports of Ekiz *et al*. (2004) for Turkish Merino (0.06); Mandal *et al*. (2006b) in Muzaffarnagari (0.09) sheep and Gowane *et al*. (2010a) in Bharat Merino (0.04±0.02) sheep. Moderate estimate of genetic variability can be exploited for further improvement of weaning weight through direct selection. In present flock, selection at weaning age provides higher genetic gain per unit of time rather than selection at six months of age. In higher models, estimate of m^2 were lower than the m^2 for BW and c^2 estimate (0.07±0.04) indicates the decline of maternal effect from birth to weaning in intercross sheep. Similar declining results were also obtained by Kumar *et al.* (2017) in

Nellore, Abbasi *et al.* (2012) in Iranian Baluchi and Dhakad *et al*. (2022) for Malpura sheep. Addition of covariance between direct and maternal effect has shown negative estimate of r_{am} in models 3 and 6 and yield higher estimates of h^2 in comparison, which is just an inflated estimate. The negative covariance arises due to antagonistic pleiotropy among the traits (Roff 2002). The total heritability (h^2_t) was high in magnitude (0.18) and in accordance with earlier findings of Gowane *et al*. (2010a) in Bharat Merino sheep. Moderate direct h^2 estimate for 3BW indicate further scope of genetic improvement of weaning weight through selective breeding.

Post weaning body weights (6BW, 9BW and 12BW): Among all animal models, model 1 was found to be more appropriate model for post weaning body weights as per LRT. The direct heritability obtained from best model for 6BW, 9BW and 12BW were 0.00±0.04, 0.05±0.05 and 0.05±0.05, respectively. Higher models that included maternal effects revealed that estimates of maternal heritability were 0.07±0.06, 0.00±0.06 and 0.03±0.06, respectively. Similarly, low estimates for post weaning body weights were also reported by Gowane *et al*. (2010a) for fine wool Bharat Merino (0.00 for 6BW; 0.03±0.03 for 9BW and 0.09±0.05 for 12BW) Sheep. These values were lower than the estimates of Mandal *et al*. (2006b) in Muzaffarnagri (0.06 for 6BW, 0.10 for 9BW and 0.14 for 12BW) and Rajenddran *et al.* (2022) in Mecheri (0.07 for 6BW, 0.11 for 9BW, and 0.07 for 12BW) sheep breed. The negligible estimates for these traits indicate poor genetic variability in population due to possibility of exhaustion of additive genetic variance. This trait has been under selection for several generations and hence logical reduction in additive genetic variance is possible, especially for 6BW. The intercross sheep is developed from Bharat merino and Gaddi synthetic and maintained only at regional station under sub-temperate environment. The flock was genetically closed since the development of this strain which restricted the scope for increasing genetic variability in the flock by influx of outside germplasm. Also, since the population is being continuously selected for early favorable trait, additive genetic variability in the population may have declined over the years. Maternal heritability estimates were low in magnitude and shows decreasing trends for post-weaning weights as compared to birth (0.17) and weaning (0.08) weight. Present findings were in agreement with the reports of Prince *et al*. 2010 in Avikalin sheep, Kumar *et al*. 2017 in Nellore sheep and Dhakad *et al*. 2022 in Malpura sheep, where maternal effects were found to be declining with the advancement of age. Very low or zero estimates of maternal heritability indicates that maternal genetic effects lost its impact during post-weaning stage and animals completely rely upon their own genotype for better growth rate. For all post weaning traits, there was a strong negative correlation between animal and maternal genetic effects and it ranged from − 0.967 to −0.999. The negative r_{am} would not be possible from a biological perspective and this may arises due to poor nutrition, management and environmental conditions and low number of progenies per ewe (Maniatis and Pollott 2003, Meyer 2007). Significant effect of maternal common environment was noticed only on 12BW (0.03±0.05). The estimates of total heritability for post weaning body weighs over different models ranged from 0.01 (6BW) to 0.06 (12BW). Similarly, repeatability of ewe performance estimates obtained in present study ranged between 0.00 (6BW) and 0.05 (6BW). Both the estimates of h^2_t and t_m were very low in present finding and were similar with the earlier studies of Gowane *et al*. (2010a) for Bharat merino (0.00 and 0.11 for 6BW, 0.03 and 0.09 for 9BW and 0.09 and 0.02 for 12BW) sheep, indicating negligible or little scope for further improvement in these traits.

Genetic correlation: The bivariate analysis for estimation of correlation between different growths traits of intercross Synthetic sheep are presented in Table 4. Estimates for direct genetic correlation (r_g) between BW and body weight at different ages were low to high except very low of 0.05 between BW and 12BW. It ranged from 0.16 between BW and 9BW to 0.75 between BW and 6BW. Our results fall within the range as reported by Bangar *et al.* (2020) in Harnali sheep for BW with 3BW (0.57), 6BW (0.02), 9BW (0.41) and 12BW (0.59). Similarly, the r_g of 3BW with 6BW (0.99), 9BW (0.58) and 12BW (0.79) were high and in accordance with the estimates reported by Kumar *et al*. (2017) in Nellore sheep for 6BW (0.93), 9BW (0.84) and 12BW (0.79). The genetic correlation between 6BW-9BW, 6BW-12BW and 9BW-12BW were very high and ranged from 0.90 (6BW-9BW) to 0.99 (9BW-12BW). Similar to present estimates, several authors reported positive and medium to high genetic correlation in different breeds of sheep (Yazdi *et al.* 1997, Gowane *et al*. 2010a, Gowane *et al.* 2010b, Khorsand *et al.* 2014). The phenotypic correlations between body weights at various ages were positive and medium to high, which ranged from 0.17 (BW-9BW) to 0.78 (6BW-9BW). In accordance with current findings higher phenotypic and genetic correlation among different body weight has been reported in sheep breed (Gowane *et al*. 2010a; Gowane *et al*. 2010b, Mokhtari *et al*. 2013, Prakash *et al*. 2012 and Kumar *et al*. 2017). Positive and moderate to high correlation between different economically important traits suggest that selection of any growth early trait will have its positive consequence over the other correlated trait at later ages (Bangar *et al.* 2020, Mangotra *et al.* 2021). Therefore, early selection in intercross sheep could be advantageous since selection for weaning weight would lead to the overall genetic improvement of later expressed growth traits. In addition, this will also help in culling of surplus and less productive animals to increase the selection intensity and accuracy of selection for profitable sheep farming.

In conclusion, the results of the present investigation demonstrated the moderate heritability estimates for weaning weight and its positive association with other growth traits. This will help to replace the current practice

Table 4. Estimates of genetics (above diagonal) and phenotypic (below diagonal) correlation body weight in inter cross synthetic sheep

Trait	BW	3BW	6BW	9BW	12BW
BW	-	0.24±0.16	0.75#	0.16±0.51	0. 05±0.35
3BW	0.30±0.03	-	0.99±0.64	0.58±0.22	0.40±0.29
6BW	0.24±0.03	0.64±0.02	-	0.99±0.57	0.90#
9BW	0.17±0.03	0.58±0.02	0.70±0.02	-	0.99±0.19
12BW	0.18±0.04	0.50±0.03	0.66±0.02	0.78±0.02	-

[#]Indicates that the approximation used to define standard errors of parameter estimates failed.

of selection at six months to selection at weaning age for further genetic improvement in growth of intercross sheep.

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