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Genetic evaluation of growth performance of Rambouillet sheep in Jammu and Kashmir, India

NUSRAT NABI KHAN[1], MUBASHIR A RATHER[2], A HAMADANI[1]✉ and DIBYENDU CHAKRABORTY[3]

Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shuhama, Srinagar, Jammu and Kashmir 190 006 India

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ABSTRACT

The present study was conducted to genetically evaluate the growth performance in Rambouillet sheep. For this, data of 7,158 lambs born to 181 sires over a 16 year period from 2000 to 2015 were collected from Government Sheep Breeding Farm, Reasi, India. Random effect of sire as well as fixed effects of sex, genetic group, year, parity and birth type on the performance of this breed were evaluated. Ten traits were taken into consideration, viz. birth weight (BW), weaning-weight (WW), 6 months body weight (SMW), 12 month weight (YBW), average daily gain (birth to weaning) (ADG-1), metabolic mass at weaning age ($WW^{0.75}$), Kleiber ratio (birth to weaning) (KR-1), average daily gain (weaning to yearling age) (ADG-2), and metabolic mass at 12 months ($YBW^{0.75}$) and Kleiber ratio (weaning to 12 months) (KR-2). The overall least-squares means for BW, WW, SMW, YBW, ADG-1, $WW^{0.75}$, KR-1, KR-2, ADG-2, and $YBW^{0.75}$ were 3.16±0.05 kg, 13.79±0.16 kg, 18.81±0.22 kg, 28.00±0.26 kg, 116.93±1.72 g/day, 7.13±0.06 kg, 16.22±0.11, 4.38±0.10, 53.95±1.36 g/day, and 12.14±0.08 kg respectively. The sire and year effects of birth were significant. The genetic group was a non-significant source of variation for all traits under study. Sex effect was significant on most traits under study. Heritability ranged from low to moderate. Genetic and phenotypic correlations also ranged from low to very high. Genetic, phenotypic and environmental trends for BW, WW and $WW^{0.75}$, genetic trends for BW, WW, SMW and $WW^{0.75}$ and environmental trends for YBW, $YBW^{0.75}$ and KR-2 were negative. Our results indicate that most of the variation may be attributed to non-additive genetic effects and may also be influenced by the environment.

Keywords: BLUP, Genetic trends, Heritability, Kleiber ratio, Selection, Sheep

The agro-climatic conditions of Jammu and Kashmir, India, favours sheep husbandry. Despite this, the native sheep breeds do not have a high production potential. Also, rising demand for mutton in the Valley instigated animal breeders to adopt cross breeding as a policy for the improvement of production potential of the animals (Rather *et al.* 2019, 2020). This is the reason why Rambouillet sheep breed was imported from USA in 1951. This breed is since being managed at Government Sheep Breeding Farm, Reasi, India. Little importation has been practiced since then which includes the introduction of 256 superior Rambouillet ewes (2005–6) into the farm. Rambouillet produces high quality mutton, possesses great maternal ability, is adaptable to myriad of arid range conditions and is long-lived. It also possesses well developed flocking. The breed was originally developed in France and was developed as a dual-purpose breed in the US (Hultz *et al.* 1931). Rambouillet has been extensively used for cross breeding programs in India. Since its import, this breed has proven to be a valuable genetic resource, therefore, understanding its adaptability as well as genetic evaluation from time to time is important.

In this regard, growth is a manifestation of adaptability of a breed to changing environmental conditions as well as the changes in its genetic composition over time. Therefore, the evaluation of growth (body weights, growth efficiency, etc.) is a good indicator of the performance of the breed under the specific agro-climatic conditions of Jammu and Kashmir (J&K). The Kleiber ratio is great indicator of feed conversion and has been used as a selection criterion for growth efficiency (Koster *et al.* 1994) which is emphasized by the fact that feed conversion has high heritability (Bergh 1994). The metabolic mass signifies the portion of feed intake used by animal for its maintenance needs and is also an important indicator of growth.

Knowledge of the genetic parameters as well as estimation of breeding values (Hamadani *et al.* 2019) is critical for effective selection of any breed. These are essential for predicting response to selection and in

Present address: [1]Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shuhama, Jammu and Kashmir. [2]Department of Sheep Husbandry, Kashmir, Jammu and Kashmir. [3]Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, RS Pura, Jammu, Jammu and Kashmir. ✉Corresponding author email: escritor005@gmail.com

optimizing the method of selection for genetic improvement. Generating genetic, environmental, and phenotypic trends of a breed over time are also important for deciphering the effectiveness of any breeding program.

Few studies on this breed under the temperate agro-climatic conditions of J&K have been conducted in the past (Baba 2016, Hamadani *et al.* 2019, Rather *et al.* 2019a, 2019b, 2019c, Khan *et al.* 2020, Baba *et al.* 2020). Studies on the genetic evaluation of breeds under Indian conditions (Mallick *et al.* 2017, Kumar *et al.* 2018) are helpful for effective selection and genetic improvement of the breeds. This study comprehensively evaluates the performance of this breed over a period of 49 years to determine the optimal selection strategy to be adopted for its genetic improvement.

MATERIALS AND METHODS

Source of data: The data regarding 7,158 lambs born to 181 sires for 16 years (2000–2015) were collected from Government Sheep Breeding, Reasi, J&K, India, for genetic evaluation of growth performance of Rambouillet sheep. The birth records with missing pedigree information, deaths just after birth and anyabnormal lambing like still birth, etc. were excluded for the analysis. The information regarding pedigree and growth traits were collected from history sheet maintained at the farm.

Farm details and flock management: The Government Sheep Breeding Farm, Reasi, is located at 33° 05″ N latitude and 74°5″ E longitude. The farm spans an area of ~418 acres and is surrounded by abundant green vegetation. The temperatures range from 5°C–45°C from winter–summer seasons respectively. This farm follows a semi-migratory and semi-intensive production system. The sheep were shifted to alpine pastures from mid-April to end of September, sub-alpine pastures from mid-March to mid-April and October to mid-December, and stall fed from mid-December to the end of February. The sheep were vaccinated against infectious diseases, like enterotoxaemia, PPR, FMD and sheep pox. The sheep were routinely drenched with anthelmintic and dipping to prevent ectoparasitic infestation was done twice a year. Ewes were divided in groups of 45 for mating in the month of August and September. New ewes were introduced for breeding at age of approximatly18 months.

Rams were selected on the basis of production performance and mating among close relatives was avoided to prevent inbreeding. The rams were changed after 21 days and breeding was completed in 42 days in two cycles. Lambs were weaned at the age of 4–5 months.

Statistical and biometrical analysis: The growth traits that were taken into consideration were birth weight (BW), weaning-weight (WW), 6 months body weight (SMW), 12 month weight (YBW), average daily gain (birth to weaning) (ADG-1), metabolic mass at weaning age ($WW^{0.75}$), Kleiber ratio (birth to weaning) (KR-1), average daily gain (weaning to yearling age) (ADG-2), and metabolic mass at 12 months ($YBW^{0.75}$) and Kleiber ratio (weaning to 12 months) (KR-2). Average daily gain (birth-weaning) (ADG1), average daily gain (weaning-12 months) (ADG2), metabolic weight (weaning) ($WW^{0.75}$), metabolic weight (12 months) ($W12^{0.75}$), Kleiber ratio (birth-weaning) (KR1) and Kleiber ratio (weaning to 12) (KR2) were calculated as:

ADG1 (GMs) = (WW–BW)/no. of days from birth to weaning

ADG2 (GMs) = (W12–W6)/no. of days from weaning to one year age

$KR1 = ADG1/W6^{0.75}$, $KR2 = ADG2/W12^{0.75}$.

The data were classified to study effects of non-genetic factors, viz. year (16), gender (male, female), parity (primiparous and pleuriparous), birth type (single, twin/triplet) and genetic groups (lambs born to purebred and crossbred dams). Descriptive statistics were computed using SPSS. To overcome non-orthogonality of data caused by unequal data indifferent groups, Mixed Model Least Squares and Maximum Likelihood algorithm PC-2 version of Harvey (Harvey 1990) was used to analyze the data. The model used for the present investigation to study the effect of various factors on afore mentioned growth traits was,

$$Y_{ijklmno} = \mu + R_i + Y_j + S_k + T_l + G_m + P_n + e_{ijklmno}$$

where $Y_{ijklmno}$, n^{th} lamb born to a dam in n^{th} parity of m^{th} genetic group in l^{th} birth type having k^{th} sex born in j^{th} year to i^{th}; μ, population mean and Y_j, S_k, T_l, G_m and P_n are fixed effects of year of birth, sex of lamb, birth type, genetic group and parity of dam, respectively. R_i, random effect of sire and $e_{ijklmno}$, error related with each observation.

The significance of fixed effects was verified by 'F' test. Duncan's multiple range test (DMRT), modified by Kramer (1957) was used for evaluating the differences between pairs of levels of effects of period. Genetic parameters were assessed using paternal half-sib correlation method (Becker, 1975). Genetic parameters were estimated using

$$Y_{ij} = \mu + s_i + e_{ij}$$

Y_{ij} being the observation of the j_{th} progeny of the i_{th} sire, μ is the overall mean, s_i is effect of the i^{th} sire, NID (0, σ^2s), $e_{ij;}$ random error NID (0, σ^2e). Standard errors of phenotypic correlations were also estimated. Phenotypic correlations were established by 't' test for significance.

Breeding values (EBVs) of sires were predicted by the Best Linear Unbiased Prediction (BLUP) procedure (Henderson 1975). Genetic and phenotypic trends were estimated by regressing breeding values and phenotypic values, respectively of the traits under study on periods of birth. This was done using the Minitab Statistical Software. Estimation of genetic and phenotypic trends was done from the slope. Phenotypic values minus the average breeding value and subsequent regression of those values on the birth period was taken to be the environmental trend (Roshanfekr *et al.* 2015).

RESULTS AND DISCUSSION

Descriptive statistics: The descriptive statistics for

Table 1. Descriptive details of data set of Rambouillet sheep

Trait	N	Mean	Std. Deviation	CV%
BW	7158	3.39±0.01	0.88	26.03
WW	6450	14.19±0.03	2.53	17.84
SMW	6491	19.50±0.04	3.42	17.53
YBW	4542	28.63±0.06	4.12	14.40
ADG1	6450	118.45±0.33	26.37	22.26
$WW^{0.75}$	6450	7.29±0.01	0.98	13.48
KR-1	6450	16.08±0.02	1.80	11.17
ADG2	4542	54.65±0.29	19.56	35.78
$YBW^{0.75}$	4542	12.35±0.02	1.35	10.91
KR-2	4542	4.37±0.02	1.36	31.21

different growth traits of Rambouillet observed in the present study is given in Table 1. Constant decrease in number of lambs with increase in age was observed in the present study. The coefficient of variation (CV %) and therefore, variability of the traits under study was low to medium. Among the body weight traits, average daily gain from weaning to yearling age (ADG-2) had the highest coefficient of variation (35.78%). This shows that there is an excellent scope for improvement of this trait through scientific selection. Similar estimates for raw means and CV % were reported by Khan *et al.* (2020) in Correidale sheep and Rather (2019a, 2019b) in Kashmir Merino sheep. Das *et al.* (2014) in Kashmir Merino sheep also reported similar estimates of raw means and CV% for BW and WW. However, lesser estimates were reported by Venkataramanan (2013) in Nilagiri and Sandyno sheep with the greatest CV % for WW among body weight traits.

Least squares means: The least squares means (LSM's) along with standard errors (SE) for the body weight and growth efficiency traits are presented in Tables 2, 3, respectively to recognize the effect of sire and non-genetic factors on these traits. Similar estimates for body weight traits were also observed by Rather (2019a) in Kashmir Merino sheep. However, lower estimates for body weight

Table 2. Least squares means along with standard errors for growth traits and wool traits

Effect	BW (kg)		WW (kg)		SMW (kg)		YBW	
	N	Mean±SE (kg)	N	Mean±SE (kg)	N	Mean±SE (kg)	N	Mean±SE (kg)
Sire	P value	0.000**		0.000**	P value	0.000**		0.000**
Overall	7158	3.16±0.05	6450	13.79±0.16	6921	18.81±0.22	4583	28.00±0.26
Year	P value	0.000**		0.000**	P value	0.000**		0.000**
2000	518	2.53±0.09^{b}	396	12.43±0.34^{b}	504	19.08±0.45^{cd}	43	24.40±1.13a
2001	388	2.52±0.09^{b}	273	12.76±0.33^{b}	370	18.17±0.43^{ab}	41	27.99±1.12^{d}
2002	428	2.74±0.08^{bc}	351	13.04±0.28^{b}	413	19.15±0.37^{bcd}	125	26.36±0.57^{d}
2003	232	2.90±0.08^{c}	211	13.64±0.29^{c}	217	19.48±0.41^{cd}	165	30.21±0.49^{f}
2004	405	2.55±0.07^{a}	381	14.14±0.26^{d}	392	19.72±0.36^{de}	292	28.72±0.44^{e}
2005	418	2.67±0.08^{bc}	411	13.89±0.26^{d}	401	19.23±0.36^{cde}	387	29.10±0.42^{e}
2006	411	2.91±0.07^{d}	408	14.77±0.25^{e}	393	18.77±0.34^{abc}	399	28.78±0.39^{e}
2007	327	3.45±0.08^{e}	327	14.66±0.27e	308	19.88±0.37^{def}	307	33.09±0.41^{g}
2008	466	2.88±0.09^{d}	463	13.98±0.30^{d}	452	18.63±0.41^{de}	423	31.09±0.44^{f}
2009	519	2.89±0.09^{d}	511	14.37±0.31^{e}	506	19.24±0.43^{efg}	400	26.09±0.46^{bc}
2010	264	3.62±0.11^{g}	264	14.30±0.36^{e}	250	18.23±0.53^{g}	111	28.14±0.59^{e}
2011	524	3.56±0.10^{ef}	421	13.83±0.35^{d}	510	19.55±0.49^{h}	344	29.96±0.52^{f}
2012	601	3.71±0.10^{g}	527	14.85±0.35^{f}	590	19.34±0.49^{h}	438	27.50±0.52^{d}
2013	625	3.82±0.10^{g}	554	14.81±0.36^{f}	611	18.27±0.50^{fg}	427	26.08±0.53^{bc}
2014	481	3.87±0.11f^{g}	405	13.47±0.37^{cd}	468	18.39±0.52^{g}	338	26.42±0.55^{c}
2015	551	3.88±0.11^{ef}	547	11.67±0.39^{a}	536	15.79±0.54^{a}	343	24.01±0.59^{a}
Sex	P value	0.000**		0.000**	P value	0.000**		0.000**
Male	3578	3.21±0.05	3245	13.90±0.17	3458	19.10±0.23	2255	28.89±0.26
Female	3580	3.10±0.05	3205	13.68±0.17	3563	18.51±0.23	2328	27.11±0.27
Birth type	P value	0.000**		0.000**	P value	0.015**		0.399
Single	6990	3.37±0.04	6307	13.74±0.17	6770	19.13±0.19	4461	28.21±0.20
Multiple	168	2.94±0.07	143	13.83±0.16	151	18.48±0.32	102	27.78±0.39
Parity	P value	0.000**		0.220 N	P value	0.065N		0.198N
Primiparous	2844	3.11±0.05	2524	13.74±0.17	2744	18.72±0.23	1609	27.92±0.27
Pleuriparous	4314	3.21±0.05	3926	13.83±0.16	4177	18.89±0.22	2954	28.07±0.26
Genetic group	P value	0.982N		0.098 N	P value	0.168N		0.256N
Purebred	6902	3.16±0.04	6206	13.92±0.14	6665	18.97±0.19	4365	28.09±0.23
Upgraded	256	3.16±0.06	244	13.65±0.22	256	18.64±0.30	198	27.91±0.35

Means with different superscript in a column differ significantly. NS, non-significant; *, significant at 5% level; **, significant at 1% level.

Table 3. Least squares means along with standard errors for growth performance traits

Effect	ADG-1		$WW^{0.75}$	KR-1	ADG-1		$WW^{0.75}$-1 (kg)	KR-1
	N	Mean±SE (g/day)	Mean±SE (kg)	Mean±SE (kg)	N	Mean±SE (gm/d)	Mean±SE (kg)	Mean±SE
Sire		0.000**	0.000**	0.000**		0.000**	0.000**	0.000**
Overall	6450	116.93±1.72	7.13±0.06	16.22±0.11	4583	53.95±1.36	12.14±0.08	4.38±0.10
Year	P value	0.000**	0.000**	0.000**		0.000**	0.000**	0.000**
2000	396	108.51±3.60^{b}	6.62±0.13^{b}	16.37±0.23^{f}	43	67.52±5.91^{e}	10.97±0.37^{b}	5.96±0.43^{g}
2001	273	111.70±3.44^{b}	6.75±0.13^{b}	16.49±0.22^{efg}	41	67.98±5.92^{d}	12.14±0.37^{e}	4.37±0.43^{e}
2002	351	113.35±2.92^{b}	6.85±0.11^{b}	16.43±0.19^{f}	125	58.37±2.98^{f}	11.60±0.19^{d}	4.91±0.22^{f}
2003	211	118.31±3.01^{c}	7.08±0.11^{c}	16.59±0.20^{g}	165	60.94±2.58^{d}	12.87±0.16^{ef}	4.65±0.19^{f}
2004	381	127.65±2.69^{e}	7.27±0.10^{d}	17.36±0.18^{i}	292	50.39±2.31^{c}	12.39±0.14^{e}	4.02±0.17^{bc}
2005	411	123.71±2.75^{de}	7.17±0.10^{d}	17.02±0.18^{h}	387	52.89±2.22^{cd}	12.51±0.14^{e}	4.16±0.16^{cd}
2006	408	130.60±2.62^{e}	7.51±0.10^{f}	17.20±0.17^{h}	399	47.71±2.03^{c}	12.41±0.13^{e}	3.78±0.15^{bc}
2007	327	123.60±2.81^{cd}	7.47±0.10^{f}	16.36±0.18^{de}	307	64.53±2.16^{f}	13.78±0.14^{f}	4.63±0.16^{ef}
2008	463	122.30±3.12^{cd}	7.20±0.12^{de}	16.77±0.20^{fg}	423	58.88±2.28^{e}	13.15±0.14^{f}	4.41±0.17^{ef}
2009	511	126.53±3.26^{e}	7.34±0.12^{ef}	16.86±0.21^{fg}	400	38.62±2.39^{a}	11.51±0.15^{bc}	3.29±0.17^{a}
2010	264	117.57±3.83^{c}	7.33±0.14^{f}	15.85±0.25^{c}	111	47.75±3.08^{c}	12.20±0.19^{e}	3.87±0.22^{bc}
2011	421	112.40±3.70^{b}	7.16±0.14^{d}	15.65±0.24^{bc}	344	63.67±2.73^{f}	12.79±0.17^{e}	4.94±0.20
2012	527	122.67±3.72^{e}	7.54±0.14^{g}	16.06±0.24^{d}	438	50.24±2.73^{c}	11.98±0.17^{d}	4.12±0.20^{b}
2013	554	121.08±3.78^{e}	7.53±0.14^{g}	15.91±0.25^{de}	427	47.34±2.78^{b}	11.52±0.17^{cf}	4.09±0.20^{bc}
2014	405	105.31±3.93^{b}	7.02±0.15^{d}	15.01±0.26^{b}	338	56.33±2.91^{ad}	11.63±0.18^{c}	4.80±0.21^{de}
2015	547	85.62±4.12^{a}	6.29±0.15^{a}	13.53±0.27^{a}	343	44.01±3.11^{a}	10.82±0.19^{a}	4.02±0.23^{a}
Sex	P value	0.042	0.000**	0.813 N		0.000**	0.217N	0.689N
Male	3245	117.56±1.74	7.18±0.06	16.21±0.11	2255	56.67±1.37	12.43±0.09	4.50±0.10
Female	3205	116.30±1.76	7.09±0.06	16.22±0.11	2328	51.22±1.40	11.85±0.09	4.25±0.10
Birth type		0.078N	0.601 N	0.080 N		0.503N	0.589N	0.756N
Single	6307	117.00±1.81	7.12±0.07	16.25±0.12	4461	54.32±1.06	12.21±0.07	4.37±0.08
Multiple	143	116.86±1.71	7.15±0.06	16.18±0.11	102	53.57±2.07	12.07±0.13	4.38±0.15
Parity	P value	0.849 N	0.143 N	0.098 N		0.156N	0.536N	0.256N
Primiparous	2524	117.00±1.81	7.12±0.07	16.25±0.12	1609	53.56±1.42	12.12±0.09	4.36±0.10
Pleuriparous	3926	116.86±1.71	7.15±0.06	16.18±0.11	2954	54.33±1.36	12.17±0.08	4.40±0.10
Genetic group	P value	0.088 N	0.116 N	0.126 N		0.254N	0.125N	0.236N
Purebred	6206	118.42±1.51	7.19±0.06	16.30±0.10	4365	53.60±1.18	12.17±0.07	4.35±0.09
Upgraded	244	115.45±2.28	7.08±0.08	16.13±0.15	198	54.29±1.81	12.11±0.11	4.41±0.13

Means with different superscript in a column differ significantly. NS, non-significant; *, significant at 5% level; **, significant at 1% level.

and growth efficiency traits were reported in Nilagiri and Sandyno sheep by Venkataramanan (2013). However, Kumar *et al.* (2017) in Deccani Sheep reported ADG1 and ADG2 of 97.22±1.71 and 45.28±0.85 g, whereas KR1 and KR2 of 15.44±0.14 and 9.07±0.04, respectively. The higher ADGs (116.93±1.72 g/day) and lower metabolic mass up to weaning (7.13±0.06 kg), lower post weaning average daily weight gains (53.95±1.36 g/day) and higher metabolic mass (12.14±0.08 kg) indicate that the animal's maintenance requirements increase and that the production potential decreases with increase with age.

Effects of non-genetic factors: Analysis of variance reflected that the effects of sire and year of birth were highly significant ($p<0.01$) source of variation where as that of genetic group was non-significant source of variation on all the traits under study. Parity had significant effect ($p<0.05$) on BW only, whereas birth type had a significant effect ($p<0.01$) on growth traits up to six months age only. Effect of sex was significant on all body weights, ADG-1, $WW^{0.75}$-1 and ADG-2 traits (Tables 1, 2). However, sexual dimorphism was observed in favour of males with respect to all traits except for KR-1. Significant effect of period, sire and sex on different growth traits was also reported by Khan *et al.* (2020) and Rather *et al.* (2019) in Corriedale and Kashmir Merino sheep breeds. Venkataramanan (2013) in Nilagiri and Sandyno also found significant effects of sex on body weights, ADG-1, $WW^{0.75}$-1 and $WW^{0.75}$-2 and so did Talebi (2011) in Karakul sheep for sex on various body weight traits. Baba (2016) in Corriedale, Tohidi *et al.* (2017) in Iran-Black breed and Kumar *et al.* (2018) in Harnali sheep also reported similar effects for birth year and sex of lamb on BW, WW, SW and YBW. However, Mallick *et al.* (2017) in Bharat Merino observed significant effects of year and sex on BW, SMW and YBW only. Kumar *et al.* (2017) in Deccani sheep found significant effect of sex on ADG2 and KR2 whereas non-significant in ADG1 and KR1. Dixit *et al.* (2001) in Bharat Merino lambs observed that year, sex of lamb and type of birth as significant sources of variation for lamb weights and pre and post weaning daily gains at different ages.

Rather *et al.* (2019a, b) in Kashmir Merino sheep reported significant effects of birth period, sire, and sex of lambs. The significant variation among performance of sire indicated existence of variation between sire which can be used for further improvement of the breed with respect to growth traits. Our study revealed significant difference in performance of Rambouillet Sheep flock under study between different years which might be attributed to difference in availability of grazing pastures, variation in rainfall, climate, management differences and selection of rams. Unsurprisingly, male animals were significantly heavier than females which is established in literature (Baba 2016, Mallick *et al.* 2017, Rather 2019). This variation between two sexes may be due to difference in sex chromosomes, positional difference of genes related to growth and differences in the secretion of hormones leading to difference in growth of long bones. somatic cell growth, and muscles. In consonance with our results, Momoh *et al.* (2013) in Uda and Balami breeds reported non-significant effect of parity on SMW. The lambs born to primiparous ewes were lighter at all ages. Rather (2019) in Kashmir Merino also reported similar results. Single born lambs were seen to perform better than twins for all traits except $WW^{0.75}$ and $YBW^{0.75}$. This may be due to the competition for nutrients and uterine space during prenatal stage between twins. However, twins/triplets often demonstrated compensatory growth after weaning. Similar findings were also observed by Momoh *et al.* (2013) in Balami and Uda sheep breeds. However, Rather (2019) found otherwise.

Genetic parameters: Heritabilities along with respective standard errors for traits under study are given in Table 4. The heritability for all traits ranged from low to moderate corresponding to low to moderate genetic variability. More or less similar estimates of heritability were also reported by Dixit *et al.* (2001) for Bharat Merino sheep for different growth traits. Low heritability estimates were also observed by Venkataramanan (2013) in Nilagiri and Sandyno sheep for BW, WW, SMW, YBW, ADG-1, ADG-2, KR-1 and KR-2. However, high estimates of heritability were reported by Jeichitra (2009) for YBW and ADG-2 in Mecheri, Talebi (2011) for KR-1 in Karakul sheep, Kumar *et al.* (2018) for SMW in Harnali and Rather (2019) in Kashmir Merino sheep for SMW and YBW. Moderate estimations of heritability were stated by Talebi (2011) for BW, WW, SMW, ADG-1, and $WW^{0.75}$ in Karakul sheep, Kumar *et al.* (2018) for BW, WW, YBW and ADG-2 in Harnali. The minimal approximations of heritability for various performance traits in the present study indicate that most of the variation may be due to non-additive genetic variance and/or be influenced by environment. So, these characters may be improved through better management practices.

The genetic correlations were positive and ranged from moderate (0.27±0.21, between WW and YBW) to high (0.65±0.08, between BW and WW). The genetic correlation of BW with all other traits were positive except KR-1, ADG-

Table 4. Estimated genetic parameters along with standard errors among performance

Trait	BW	WW	ADG-1	WW0.75	KR-1	SMW	YBW	ADG-2	YBW0.75	KR-2
BW	0.28±0.04	0.65±0.08	0.34±0.12	0.65±0.08	−0.19±0.13	0.30±0.14	0.45±0.17	−0.26±0.16	0.44±0.16	−0.45±0.13
WW	0.32±0.01**	0.18±0.03	0.93±0.02	0.99±0.00	0.0±0.08	0.37±0.15	0.27±0.21	−0.68±0.22	0.28±0.22	-0.87±0.21
ADG-1	−0.03±001*	0.94±0.01**	0.13±0.03	0.93±0.02	0.85±0.04	0.29±0.18	0.07±0.25	−0.73±0.27	0.10±0.24	−0.86±0.26
WW0.75	0.34±0.01**	1.00±0.01**	0.94±0.03**	0.19±0.03	0.61±0.08	0.36±0.15	0.27±0.20	−0.68±0.22	0.28±0.20	−0.86±0.20
KR-1	−0.44±0.01**	0.70±0.01**	0.90±0.01**	0.70±0.04**	0.13±0.03	0.07±0.18	−0.14±0.23	−0.48±0.36	−0.12±0.23	0.50±−0.22
SMW	0.25±0.01**	0.36±0.01**	0.29±0.01**	0.37±0.01**	0.17±0.1**	0.12±0.03	0.52±0.19**	0.07±0.20	0.52±0.18	−0.07±0.18
YBW	0.10±0.01**	0.24±0.01**	0.22±0.02**	0.25±0.01**	0.17±0.01**	0.34±0.01**	0.06±0.02	0.52±0.17	0.99±0.00	0.24±0.21
ADG-2	−0.05±0.02**	−0.35±0.01**	−0.34±0.03**	−0.34±0.01**	−0.26±0.03**	0.12±0.01**	0.83±0.01**	0.09±0.02	0.51±0.17	0.95±0.02
YBW0.75	0.10±0.03**	0.25±0.01**	0.22±0.01**	0.25±0.01**	0.18±0.01**	0.34±0.01**	01.00±0.01**	0.83±0.03**	0.06±0.03	0.24±0.21
KR-2	−0.12±0.01**	−0.57±0.02**	−0.55±0.03**	−0.57±0.01**	−0.42±0.01**	0.01±0.05N	0.65±0.03**	0.96±0.02**	0.65±0.04**	0.13±0.03

Table 5. Average breeding value (BV) of Corriedale sires for different production traits.

Trait	No of Sires	Average BV	Minimum BV (% below average)	Maximum BV (% above average)	No. of sires (below average %)	No. of sires (above average %)
BW	151	3.33±0.02	2.86±0.07 (14.11)	3.94±0.15 (18.32)	70 (46.36)	81(53.64)
WW	151	14.61±0.05	12.22±0.32(13.39)	15.52±0.31 (12.22)	74 (49.01)	77 (50.99)
SMW	151	19.64±0.23	17.20±1.20(17.27)	23.15±0.99 (14.18)	80 (52.98)	71 (47.02)
YBW	151	28.58±0.25	26.40±0.68 (7.63)	31.36±1.82 (9.73)	69 (45.70)	82 (54.30)
ADG-1	151	118.26±0.56	103.63±3.73(12.37)	134.15±3.40(13.43)	72 (47.68)	79 (52.32)
$WW^{0.75}$	151	7.26±0.02	7.94±.0.13 (9.23)	6.48±0.12 (10.74)	72 (47.68)	79 (52.32)
KR-1	151	16.14±0.0.03	15.44±0.22 (4.38)	17.02±0.22 (5.45)	74 (49.01)	77 (50.99)
ADG-2	151	52.44±0.99	43.36±4.75 (17.32)	64.33±3.41 (22.67)	65 (43.05)	86 (56.95)
$YBW^{0.75}$	151	12.34±0.08	11.17±0.0.31 (9.48)	12.93±0.0.70 (4.78)	69 (45.70)	82 (54.30)
KR-2	151	4.186±0.06	3.59±0.18 (14.24)	4.66±0.0.36 (11.32)	67 (44.37)	84 (55.63)

2 and KR-2. The genetic relationship of BW with other traits was in range of –0.45±0.13 with KR-2 to 0.65±0.08 (high) with $WW^{0.75}$. Similarly, WW also had low genetic association of –0.68±0.22 with ADG-2 and high genetic association of 0.99±0.00 with $WW^{0.75}$. The genetic correlation between SMW and YBW was 0.52±0.19 (high and positive). The genetic relationship of SMW with growth performance traits was positive except with KR-2 (–0.07±0.18). The genetic correlation between growth performance traits was in range of –0.86±0.26 (among ADG-1 and KR-2) to 0.99±0.00 (between ADG-1 and 0.99±0.00). The phenotypic association of BW with other body weight traits, $WW^{0.75}$ and $YBW^{0.75}$ was positive in direction whereas it was negative with KR-1, KR-2, ADG-1 and ADG-2. The phenotypic association of WW with ADG-1, $WW^{0.75}$, KR-1, SMW, YBW and $YBW^{0.75}$ was positive. However, WW had negative phenotypic correlation with ADG-2 and KR-2. The phenotypic relationship of SMW with YBW and growth performance traits was positive in direction. Venkataramanan (2013) in Nilagiri and Sandyno also reported positive genetic and phenotypic associations between body weights except the genetic association between BW and YBW in Nilagiri which was negative. Negative phenotypic relationship between AGR-1 and AGR-2, and between KR- and KR-2 was also observed by Venkataramanan (2013) in Nilagiri sheep and Khan *et al.* (2020) in Corriedale sheep. The positive genetic and phenotypic associations among different body weight traits were presented by Kumar *et al.* (2018) in Harnali, Umeel *et al.* (2018) in Munjal, Rather (2019) in Kashmir Merino and Khan *et al* (2020) in Corriedale. Significant and desirable correlations were also reported by Dixit *et al.* (2001) in Bharat Merino lambs. This genetic relation of SMW with other traits indicates that selection for body weight traits and growth rate at six months would be beneficial for selection due to its correlated response with other traits.

Breeding values: The mean superiority of sires along with their numbers is presented in Table 5. Similar breeding values were obtained by Khan *et al.* (2020) in Corriedale. However, higher breeding values for BW, WW, SMW and YBW were reported by Umeel *et al.* (2018) in Munjal Sheep. Jeichitra *et al.* (2015) used BLUP in Mecheri for body weight and found that the EBV's ranged from –0.199, –1.195, –1.079, –1.682 to 0.228, 1.133, 0.902, 1.459 for BW, WW, MW and YBW. Mallick *et al.* (2016) also estimated the estimated breeding values for Bharat Merino and reported breeding values as 0.067, 0.008, 0.036, –0.003 for BW, WW, SMW and for GFW.

The variation of EBVs was greater for body-weights and lesser for growth traits. It was higher for early growth traits than later body weights. Venkataramanan (2013) in Sandyno also described greater variability of EBVs for the early body weights.

Good quality sires had a superiority over average breeding value (%) of 18.32, 12.22, 14.18, 9.73, 13.43, 10.74, 5.45, 22.67, 4.78 and 11.32 for BW, WW, SMW, YBW, ADG-1, $WW^{0.75}$, KR-1, ADG-2, $YBW^{0.75}$ and KR-2 respectively. Similarly, low ranking sires had breeding values (%) of 14.11, 13.39, 17.27, 7.63, 12.37, 9.23, 4.38, 14.24, 17.32, and 9.48 than average breeding value for BW, WW, SMW, YBW, ADG-1, $WW^{0.75}$, KR-1, KR-2, ADG-2, and $YBW^{0.75}$ correspondingly. The findings were in consonance with the report of Khan *et al.* (2020) in Corriedale. About 81 (53.64), 77 (50.99), 71 (47.02), 82 (54.30), 79 (52.32), 79 (52.32), 77 (50.99), 86 (56.95), 82 (54.30) and 84 (55.63) sires had breeding values above the average breeding value for BW, WW, SMW, YBW, ADG-1, $WW^{0.75}$, KR-1, KR-2, ADG-2, and $YBW^{0.75}$ respectively. Similarly, 70 (46.36), 74 (49.01), 80 (52.98), 69 (45.70), 72 (47.68), 72 (47.68), 74 (49.01), 69 (45.70), 67 (44.37), and 65 (43.05) sires had less than the average breeding values for BW, WW, SMW, NMW, YBW, ADG-1, $WW^{0.75}$, KR-1, KR-2, ADG-2, and $YBW^{0.75}$ respectively. It was observed that a greater number of sires with above average breeding values was used during the study period. Different findings were reported by Umeel *et al.* (2018) in Munjal and Khan *et al.* (2020) in Corriedale sheep.

Genetic, phenotypic and environmental trends: Trend estimation depicts change in production performance of a breed per unit of time caused by change to change in overall performance of the breed (Harville and Henderson 1966). Therefore, it depicts the direction of progress made in different economic traits. The factors responsible for

Table 6. Genetic, phenotypic and environmental trends

Trait	Type of trend (gm/period)	Trend/ period	F value	P value	R^2
BW	Phenotypic (kg)	0.1050	75.76	0.000	0.84
	Genetic (kg)	0.1020	82.18	0.000	0.85
	Environmental (kg)	–0.0017	0.21	0.654	0.15
WW	Phenotypic (kg)	0.0436	0.70	0.417	0.05
	Genetic (kg)	–0.0680	2.03	0.179	0.13
	Environmental (kg)	–0.0295	21.86	0.000	0.61
SMW	Phenotypic (kg)	–0.09332	3.70	0.075	0.21
	Genetic (kg)	0.02441	0.17	0.685	0.12
	Environmental (kg)	–0.1177	0.12	0.0005	0.45
YBW	Phenotypic (kg)	–0.0881	0.43	0.522	0.03
	Genetic (kg)	–0.1358	1.07	0.319	0.07
	Environmental (kg)	0.04769	5.81	0.030	0.29
ADG-1	Phenotypic (g/day)	–0.6626	1.21	0.290	0.08
	Genetic (g/day)	–0.3268	0.39	0.541	0.03
	Environmental (g/day)	–0.3396	13.71	0.002	0.50
$WW^{0.75}$	Phenotypic (kg)	0.01557	0.59	0.454	0.04
	Genetic (kg)	0.02562	1.93	0.186	0.12
	Environmental (kg)	–0.01175	17.91	0.001	0.56
KR-1	Phenotypic	–0.1335	11.89	0.004	0.46
	Genetic	–0.1148	11.67	0.004	0.45
	Environmental	–0.01863	5.29	0.037	0.27
ADG-2	Phenotypic (g/day)	–1.011	6.02	0.028	0.30
	Genetic (g/day)	–0.6902	2.65	0.126	0.16
	Environmental (g/day)	–0.3206	0.55	0.470	0.04
$YBW^{0.75}$	Phenotypic (kg)	–0.02919	0.44	0.516	0.03
	Genetic (kg)	–0.04487	1.09	0.315	0.07
	Environmental (kg)	0.01568	5.54	0.034	0.28
KR-2	Phenotypic (kg)	–0.00588	0.05	0.820	0.04
	Genetic (kg)	–0.04788	4.71	0.048	0.26
	Environmental (kg)	0.04200	4.31	0.057	0.24

the change in overall performance could be of genetic or environmental origin or observed at phenotypic scale (Nirban 2013). The trends obtained in the present study are presented in Table 6. The study revealed that all trends (i.e. genetic, phenotypic and environmental) for BW, WW and $WW^{0.75}$; genetic trends for BW, WW, SMW and $WW^{0.75}$ and environmental trends for YBW, $YBW^{0.75}$ and KR-2 were negative in direction. The trends were usually non-significant except the genetic, and phenotypic trends for BW and KR-1 and environmental trend for WW and SMW, YBW, $WW^{0.75}$ and $YBW^{0.75}$ which were significant ($p<0.05$) (Table 6). Khan *et al.* (2020) also reported negative trends for body weight and growth performance traits except environmental trends for WW, SMW, NMW, YBW, ADG-1, $WW^{0.75}$ and KR-1. Hamadani *et al.* (2019) and Khan *et al.* (2020) in Rambouillet and Corriedale, respectively also reported non-significant trends for body weight and growth traits. Singh and Dhillon (1991) in Indian Avivastra sheep and Shrestha *et al.* (1996) in Suffolk and Finn sheep reported negative genetic trends of –0.136 kg/year and 0.013 kg/year, respectively. Gray *et al.* (1999) observed negative genetic trend for WW, AGR and KR in South-African Mutton Merino sheep. Negussie *et al.* (2002) in Ethiopian fat-tailed Horro sheep reported negative phenotypic trends and positive genetic trends (kg/year) of 0.006, 0.056, and 0.094 with respect to for BW, SMW and YBW traits. Dixit *et al.* (2002) in Bharat Merino, found the annual genetic trends of –0.064 kg for BW, –0.327 kg for WW, –0.335 kg for SMW and –0.180 kg for YBW, respectively. The corresponding phenotypic trends were 0.018 kg, 0.137 kg, 0.603 kg and –0.249 kg respectively. Arora *et al.* (2010) estimated positive genetic trends and negative environmental trends for BW, SMW and YBW in Malpura sheep using the method described by Smith (1962). Positive and highly significant ($p<0.01$) genetic trends were reported by Mostafa *et al.* (2011) for BW and 6 SMW with values of 2 and 8 g/year, respectively. However, non-significant phenotypic trends for BW and SMW were reported by Day and Poonia (2006) in a Nali sheep. Balasubramanyam *et al.* (2012) in Madras observed high phenotypic trend. Asgar (2006) reported static genetic trends for BW, WW, SMW and YBW in Thalli sheep. El-Wakel and Elsayed (2013) in Barki sheep reported genetic trend (g/year) of 15 and 448, phenotypic trend (g/year) of –18 and –322 for BW and YBW, respectively. Di *et al.* (2014) in Chinese superfine Merino sheep reported non-significant genetic progress for BW and YBW. Mokhtari and Rashidi (2010) reported positive and significant genetic trends in Kermani breed of sheep for BW, WW, SMW, NMW and YBW and the estimated values (kg) for YBW were 0.002, 0.125, 0.091, 0.081 and 0.156 kg/year, respectively. Venkataramanan (2013) reported genetic trends (kg) of 0.000 for BW, 0.011 for WW, 0.006 for SMW, 0.016 for NMW and 0.011 for YBW, correspondingly in Nilagiri sheep. The corresponding values (kg) for Sandyno sheep were 0.001, 0.013, 0.011, 0.017 and 0.017. Jeichitra *et al.* (2015) also estimated genetic trends of Mecheri sheep for BW, WW, SMW and YBW which varied from –0.15 to 0.23, –0.61 to 0.85, –1.12 to 0.91 and –1.50 to 4.31 kg respectively. Arora *et al.* (2010) found to be declining significant environmental trends (kg) for BW, WW, SMW, NMW and YBW. Rather *et al.* (2019) also reported all negative for BW, SMW and YBW in Kashmir-Merino sheep. Umeel *et al.* (2018) in Munjal breed of Sheep reported the genetic trend for BW, WW, SMW and YBW as negative too.

The significant variation in all traits under study due to non-genetic factors along with low estimates of heritability for various performance traits obtained in the present study indicate that most of variation in traits may be due to non-additive genetic effects. Therefore, individual selection based on individual performance may not improve the performance of this flock. More attention should be paid to the performance of collateral relatives and progeny. Optimal environmental conditions should be provided to obtain more genetic progress in order to coincide the phenotypic trend with genetic one. The use of modern ICT based breeding tool for data management and real time data analysis and decision making is also highly recommended.

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