Pakistan J. Zool., pp 1-11, 2022. **DOI**: https://dx.doi.org/10.17582/journal.pjz/20220302060325

Estimates of Phenotypic and Genetic Parameters for Traits of Reproductive Efficiency in Kajli Sheep in Punjab, Pakistan

Asad Ali[1]*, Khalid Javed[1], Imran Zahoor[1], Khalid Mahmood Anjum[2], Numan Sharif[1], Imtiaz Ahmad[3] and Aftab Hussain Aftab[3]

[1]*Department of Animal Breeding and Genetics, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan*
[2]*Department of Wildlife and Ecology, University of Veterinary and Animal Sciences, Lahore 54000, Pakistan*
[3]*Livestock Experiment Station Khushab, Punjab, Pakistan*

ABSTRACT

The objectives of this study were to evaluate non-genetic and genetic effects as well as heritabilities and repeatabilities for seven reproductive traits using phenotypic records from an experimental Kajli flock in Punjab, Pakistan. Phenotypic data comprised 2501 records of litter size at birth (LSB), cumulative litter weight at birth (LWB), and mean litter weight at birth/ lamb born (LMWB), 1657 records of litter size at weaning (LSW), cumulative litter weight at weaning (LWW), and mean litter weight at weaning/ lamb weaned (LMWW), and 1674 records of lambing interval (LI) from Kajli sheep housed at the Livestock experiment station Khushab from 2007 to 2018. Least squares procedures (SAS, 9.1) were used to assess the effect year of service (YOS), season of service (SOS), parity of dam, and breeding ram on the expression of all reproductive traits. A derivative free REML algorithm was used to estimate heritabilities and repeatabilities with software WOMBAT®. The overall least squares means ± standard error for LSB, LWB, LMWB, LSW, LWW, LMWW and LI were 1.19±0.03, 5.75±0.17 kg, 4.88±0.06 kg, 1.17±0.05, 20.77±0.91 kg, 17.87±0.57 kg, 330.69±20.48 days, respectively. The YOS had significant ($p \leq 0.01$) impact on LSB, LWB, LMWB, LWW and LMWW. However, SOS did not affect any reproductive trait except for LI ($p \leq 0.01$). Parity significantly affected LMWB ($p<0.05$) as well as LSB, LWB, LSW and LWW ($p \leq 0.01$), but not LMWW and LI. Breeding ram influenced LSB, LSW and LWW significantly ($p \leq 0.01$). Genetic parameter estimates were very low due to large values of environmental variances for all reproductive traits. Estimates of heritability were low for all traits (0.08±0.05, 0.01±0.02, 0.02±0.02, 0.01±0.01, 0.04±0.03, 0.07±0.05 for LSB, LWB, LMWB, LSW, LWW and LMWW, respectively). The heritability for LI was zero. Repeatability estimates were also low for all traits (0.09±0.05, 0.02±0.02, 0.06±0.03, 0.02±0.01, 0.04±0.02, 0.09±0.06, 0.01±0.01 for LSB, LWB, LMWB, LSW, LWW, LMWW and LI, respectively). Regression of estimated breeding values for all reproductive traits on year of breeding yielded no significant genetic trends during the 12 years of the study.

Article Information
Received 02 March 2022
Revised 05 November 2022
Accepted 22 November 2022
Available online 23 February 2023 (early access)

Authors' Contribution
Concept, design, proof reading and submission, KJ, AA. Data collection and analysis, AA, KJ. Data maintenance and animal management, IA, AHA. Drafting and formatting of manuscript, AA, NS, IZ, KMA.

Key words
Breeding value, Environment, Genetic trend, Kajli, Reproduction

INTRODUCTION

Mediterranean and Asian wild sheep are both the ancestors of present-day sheep breeds (Waheed *et al*., 2016). The ancestors of Pakistani sheep breeds are most likely Urial (Ovis vignei), Argali (Ovis ammon) and Marco Polo sheep of China. Pakistan is endowed with a diverse small ruminant genetic pool. There are 30.9 million sheep in Pakistan that produce 46.8 metric tons of wool and contribute significantly to the 732 metric tons of lamb and chevon along with a goat population of 76.1 million (GOP, 2019). Kajli sheep are well recognized for their juicy mutton; rams are particularly nurtured for trade on Eid-ul-Adha as sacrificial animals (Qureshi *et al*., 2010). Kajli has become the most promising sheep breed of Pakistan due to its huge market acceptance. Kajli lambs are very popular for their growth rate and aesthetic traits (roman nose, black circle around eyes, and white colored wool). Autochthonous breeds of livestock species have a high biological value because they have developed an optimal set of adaptive characteristics over time in response to environmental pressures (Waheed *et al*., 2016).

---

* Corresponding author: asad@uvas.edu.pk
0030-9923/2022/0001-0001 $ 9.00/0

The overall genetic progress of a breeding program largely depends on amounts of genetic variation associated with selection traits and on genetic correlations among these traits. Understanding of non-genetic factors underlying reproductive traits included in a genetic improvement scheme is crucial to devise a suitable management strategy. Similarly, knowledge of genetic parameters for composite traits in selection indexes helps to predict direct and indirect selection responses as well as determine optimal trait weights in multiple-trait selection programs.

Previous research with Kajli sheep has involved non-genetic and genetic sources of variation underlying performance characteristics (Qureshi *et al*., 2010), change in physiological and blood parameters in new born lambs (Saddiqi *et al*., 2011), morphometric measurements (Iqbal *et al*., 2014), pathophysiology of peste des petitis (Khan *et al*., 2018) and polymorphism of Calpastatin (Khan *et al*., 2012), Leptin (Qureshi *et al*., 2015), Callipyge (Shah *et al*., 2018), Myostatin and Beta-3 Adrenergic Receptor genes (Ali *et al*., 2021). However, detailed and comprehensive information about environmental effects, genetic effects, and variance components for composite reproductive traits in Kajli sheep is lacking.

Genetic variation for reproductive traits does exist among individuals but large environmental differences make the assessment of such genetic differences very challenging (Abegaz *et al*., 2002). Moreover, phenotypic selection of large sized ewe lambs is a common practice in most sheep production systems. Therefore, the estimation of environmental and genetic influences underlying ewe performance becomes unavoidable to make unbiased breeding decisions (Borg *et al*., 2009). The success of a sheep enterprise depends largely on the reproductive efficiency of the flock. Thus, enhancement of reproductive performance is a vital objective in sheep breeding. This can be achieved through a selection program for reproductive traits such as number of lambs born and weaned per ewe per year. Implementation of a selection program requires comprehensive information on genetic and environmental factors influencing reproductive traits as well as genetic parameters associated with these traits. Thus, the objectives of this study were to evaluate nongenetic and genetic effects as well as heritabilities and repeatabilities for seven reproductive traits i.e., litter size at birth (LSB), cumulative litter weight at birth (LWB), mean litter weight at birth/lamb born (LMWB), litter size at weaning (LSW), cumulative litter weight at weaning (LWW), mean litter weight at weaning/lamb weaned (LMWW) and lambing interval (LI) using phenotypic records from an experimental Kajli flock.

MATERIALS AND METHODS

Resource flock and site

The resource flock consisted of 652 Kajli ewes housed at the Livestock Experiment Station, Khushab (LES Khushab), Pakistan (coordinates: 32.296667, 72.3525). The climate in Khushab is classified as BSh (Steppe climate; Köppen-Geiger classification), commonly known as semi-arid, with an average temperature of 24.3°C and an annual rainfall of about 400 mm. Kajli sheep is native to Khushab; it was brought into LES Khushab in the 1980s (Ali *et al*., 2020a). The LES Khushab spans 971 acres of land, 930 acres of canal irrigated, 10 acres of forest, and 30 acres of roads and buildings. Selection of Kajli ewes in LES Khushab was based on growth performance and breed characteristics. Rams selected for breeding were either produced within LES Khushab or purchased from other flocks to provide genetic heterogeneity. Mature male and female sheep were housed in separate open type buildings except during breeding days. Generally, breeding occurred in the fall (August-October) and spring (February-April) seasons. However, to meet the high demand for male lambs, ewes which did not breed in the fall and spring were bred in the summer (May-July) and winter (November-January) months, respectively. Breeding was practiced in small groups of 25 to 30 ewes/ram (Ali *et al*., 2020b). Lambs were ear tagged and weighed at birth, and allowed to stay with their dams until weaning (90 to 120 days of age). Animals at LES Khushab were weighed on an electronic scale at the end of each month. Monthly body weight records were maintained in registers (Ali *et al*., 2020b). The feeding and housing conditions at LES Khushab have remained the same since the start of the Kajli flock. Feeding consisted of 7 to 8 h/day of grazing on seasonal crop remains in the canal irrigated plains or similar number of hours of grazing on naturally grown wild trees in the forested areas. Clean drinking water was provided *ad libitum* in cement troughs. In addition, a concentrate supplement (300 to 500 g/day/female and 500 to 750 g/day/male) was provided during breeding, lambing, and seasons of scarcity. Kajli sheep were vaccinated against pleura-pneumonia, enterotoxaemia, sheep pox, foot and mouth disease, and peste des petits. Drenching with anthelmintic medicines to avoid internal parasites was given every four months, and dipping to prevent external parasites was practiced twice a year.

Data description

Data used in this study included pedigree, birth date, birth type, sex and weight records at different ages collected at LES Khushab during a period of 12 years (2007 to 2018). Data consisted of 2501 lambing from 652 dams and 25 rams. Lambs were 51.61% male, 48.39% female, 71.96% single-born, 27.14% twins, and 0.89% triplets. The pedigree structure of selected animals is laid out in Table I. The reproductive traits were litter size at birth (LSB), cumulative litter weight at birth (LWB), mean litter weight at birth/lamb born (LMWB), litter size at weaning (LSW), cumulative litter weight at weaning (LWW), mean litter weight at weaning/lamb weaned (LMWW) and lambing interval (LI). The overall data description is provided in Table II. Lambs were allowed to stay with their dams until they were four months of age. The age of 120 days was adopted as weaning age. Weaning weights were adjusted to 120 days of age using the following equation (Akhtar *et al*., 2012).

Body weight adjusted to 120 days (LWWT) = X+[(Y-X)/Z]*120

Where X is birth weight; Y is actual weight; Z is actual age (days).

Table I. Pedigree structure of Kajli sheep at LES Khushab.

Category	N
No. of base animals	361
No. of animals with records	859
No. of animals with unknown sire	328
No. of animals with unknown dam	326
No. of sires with progeny records	25
No. of dams with progeny records	354
No. of grand sires with progeny records	25
No. of grand dams with progeny records	171

N, number of individuals.

Statistical analysis

Least squares analyses were used to evaluate the fixed effects of year of service (YOS), season of service (SOS), parity, and breeding ram using linear model procedures from the statistical analysis software (Cody, 2015). The fixed effect model was as follows:

$$Y_{ijklm} = \mu + YOS_i + SOS_j + P_k + R_l + e_{ijklm} \quad \text{(Model 1)}$$

Where Y_{ijklm} is phenotypic value of each trait, μ is population mean; YOS_i is year of service (i=1,2,3...12; 1 to 12); SOS_j is season of service {j=S1, S2, S3, S4; S1 (February, March, April), S2 (May, June, July), S3 (August, September, October), S4 (November, December, January)}, P_k is parity (k=1,2,3...7; 1 to 7), R_l is breeding ram (l=1,2,3...25; 1 to 25), ε_{ijklm} is random residual associated with Y_{ijklm} assumed to be NID ~ mean zero, variance σ^2_ε.

Table II. Descriptive statistics for reproductive traits in Kajli sheep.

Trait	N	Mean±SE (Range)	h^2	R
LSB (No.)	2501	1.16±0.007 (1-3)	0.08±0.05	0.09±0.05
LWB (kg)	2501	5.57±0.031 (1.50-12.00)	0.01±0.02	0.02±0.02
LMWB (kg)	2501	4.84±0.017 (1.50-07.40)	0.02±0.02	0.06±0.03
LSW (kg)	1657	1.13±0.008 (1-3)	0.01±0.01	0.02±0.01
LWW (kg)	1657	20.13±0.167 (7.48-56.55)	0.04±0.03	0.04±0.02
LMWW (kg)	1657	18.04±0.101 (7.48-32.23)	0.07±0.05	0.09±0.06
LI (days)	1674	342.80±160.91 (164-1661)	0.00±0.00	0.01±0.01

LSB, litter size at birth; LWB, cumulative litter weight at birth; LMWB, mean litter weight at birth/ lamb born; LSW, litter size at weaning; LWW, cumulative litter weight at weaning; LMWW, mean litter weight at weaning/ lamb weaned; LI, lambing interval; N, number of animals; SE, standard error; h^2, heritability; R, repeatability.

Variance components were estimated with restricted maximum likelihood (REML) procedures (Gilmour *et al*., 1995) by fitting an animal mixed linear model in software WOMBAT® (Meyer, 2007). Pedigree information was traced as back as possible and was included in the additive relationship matrix to minimize biases due to selection and non-random mating. The values of the convergence criteria (-2 log likelihood) for genetic parameters were 1×10^{-8}.

Univariate analyses were run to estimate heritabilities for performance traits. Only those fixed effects found to be significant in the initial analyses (Model-1) were included in the animal mixed linear model. The following model was used to compute variance components and heritabilities:

$$Y_{ijk} = \mu + F_i + A_j + e_{ijk} \quad \text{(Model 2)}$$

Where Y_{ijk} is the actual value of a particular trait, μ is the population mean, F_i represents fixed effects found significant in model 1 (Table III), A_j is the random additive genetic effect of the j^{th} animal with mean zero and variance σ^2_A, and e_{ijk} is the random residual assumed to be NID (0, σ^2_e).

Estimates of repeatabilities for reproductive traits were obtained with the following model:

$$Y_{ijkl} = \mu + F_i + A_j + E_k + e_{ijkl} \quad \text{(Model 3)}$$

Where Y_{ijkl} is the observation for a particular trait, μ is the population mean, F_i is the i^{th} fixed effect considered in Model 2 (Table III), A_j is the random additive genetic effect of the j^{th} animal with mean zero and variance σ^2_A, E_k is the random permanent environmental effect of the k^{th} ewe, e_{ijkl} is the random error associated with Y_{ijkl}, assumed to be NID (0, σ^2_e). However, estimates of the common environment ratio (c^2) were obtained as follows:

$$c^2 = \sigma^2_{PE} / \sigma^2_P$$

where σ^2_{PE} is permanent environment variance, σ^2_P is phenotypic variance.

Repeatability estimates were obtained as follows:

$$\text{Repeatability} = (\sigma^2_A + \sigma^2_{PE}) / \sigma^2_P$$

where σ^2_A is additive genetic variance, σ^2_{PE} is permanent environment variance, and σ^2_P is phenotypic variance.

Table III. Fixed effects fitted for the estimation of heritability (Model-2) and repeatability (Model-3).

Trait	Fixed effects			
	Year of service	**Season of service**	**Parity**	**Serving ram**
LSB (No.)	X		X	X
LWB (kg)	X		X	
LMWB (kg)	X		X	
LSW (kg)			X	X
LWW (kg)	X		X	X
LMWW (kg)	X			
LI (days)		X		

For abbreviation, see Table II.

RESULTS

The least squares means (LSM) for year of service (YOS), season of service (SOS), parity of dam, and breeding ram on LSB, LWB, LMWB, LSW, LWW, LMWW, and LI revealed significant differences among YOS for all observed traits (p≤0.01), except for LSW and LI (p>0.05). Higher LSM for LSB (1.43±0.03) and LWB (6.97±0.15 kg) and lower LSM for LI (266.07±9.16 days) were obtained in 2017. The LSM values revealed near linear improvement in LSB of Kajli across years. The SOS only affected LI (p≤0.01). Higher LSM for LWB (5.84±0.05 kg) and lower LSM for LSB (1.17±0.01 kg) were observed in S1 (spring). Dam parity number affected LSB, LWB, LMWB, LSW (p≤0.01) and LWW (p≤0.05), but not LMWW and LI. Analysis showed a gradual increase in LSM values for LSB from the 1st (1.09±0.01) to the 6th parity (1.27±0.04). The number of individuals, least squares means (LSM), and standard errors (SE) for YOS, SOS and parity computed for each of the reproductive traits (LSB, LWB, LMWB, LSW, LWW, LMWW, and LI) are presented in Table IV. Table V shows the breeding ram LSM for LSB, LWB, LMWB, LSW, LWW, LMWW, and LI. LSM for LSB differed across years (p≤0.01); differences of up to 0.56 lambs per breeding ram were observed over the years. Similarly, differences among breeding rams (p≤0.01) existed for LSW (up to 0.36 lambs) and LWW (up to 8.99 kg).

Heritability and repeatability estimates for LSB, LWB, LMWB, LSW, LWW, LMWW, and LI are presented in Table II. Estimates were low for all observed traits. Heritability estimates ranged from 0 (LI) to 0.08±0.05 (LSB). Repeatability estimates ranged from 0.01±0.01 for LI to 0.09±0.06 for LMWW. Trends for estimated breeding values (EBV) of Kajli sheep for LSB, LWB, LMWB, LSW, LWW, LMWW, and LI from 1999 to 2018 are plotted in Figure 1. Genetic trends for LSB, LWB, LMWB, LSW, LMWW, and LI were essentially flat, although LSW and LWW exhibited improvement and decline in different years of production.

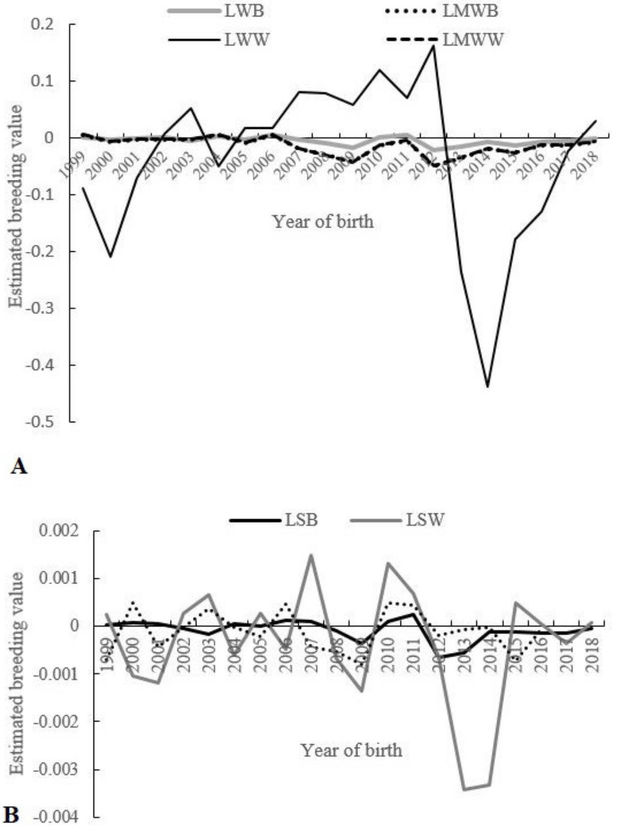

Fig. 1. (a) Genetic trends for litter size at birth (LSB), litter size at weaning (LSW) and lambing interval (LI). (b) Genetic trends for cumulative litter weight at birth (LWB), mean litter weight at birth/ lamb born (LMWB), cumulative litter weight at weaning (LWW) and mean litter weight at weaning/ lamb weaned (LMWW).

Table IV. Least squares means (LSM±SE) for non-genetic effects affecting reproductive traits in Kajli sheep.

Effect	No.	LSB (No.)	LWB (kg)	LMWB (kg)	No.	LSW (No.)	LWW (kg)	LMWW (kg)	No.	LI (days)
Year of service										
2007	58	1.11±0.03^{e}	5.67±0.09^{e}	5.17±0.09^{bc}	21	1.18±0.05	20.43±0.82^{e}	17.24±0.64^{d}	44	352.81±34.23
2008	196	1.16±0.02^{cde}	5.70±0.06^{de}	5.01±0.06^{bc}	104	1.21±0.02	20.31±0.50^{e}	16.68±0.30^{d}	151	344.21±13.37
2009	215	1.10±0.02^{de}	5.41±0.05^{e}	4.97±0.05^{bc}	107	1.12±0.01	18.71±0.30^{e}	16.44±0.25^{d}	160	316.59±12.66
2010	225	1.06±0.02^{de}	4.53±0.08^{f}	4.26±0.08^{e}	127	1.17±0.01	18.54±0.34^{e}	15.65±0.28^{d}	171	319.52±11.68
2011	212	1.05±0.02^{de}	5.37±0.09^{e}	5.09±0.09^{bc}	135	1.16±0.02	20.78±0.43^{d}	17.87±0.30^{c}	170	312.37±12.47
2012	251	1.15±0.02^{bcd}	5.80±0.08^{c}	5.07±0.08^{b}	178	1.19±0.02	21.54±0.41^{d}	18.30±0.32^{c}	210	331.20±12.66
2013	257	1.21±0.03b	5.88±0.09^{c}	4.94±0.09^{bc}	199	1.16±0.02	21.96±0.44^{cd}	18.89±0.26^{bc}	201	378.95±12.63
2014	261	1.13±0.02^{bcde}	5.37±0.06^{e}	4.77±0.06^{d}	205	1.19±0.02	21.29±0.43^{d}	18.09±0.31^{c}	164	405.72±13.22
2015	195	1.21±0.03^{bc}	5.68±0.10^{cd}	4.75±0.10^{cd}	147	1.17±0.03	22.46±0.60^{bc}	19.31±0.33^{ab}	126	330.31±7.19
2016	349	1.31±0.02^{b}	6.03±0.09^{c}	4.68±0.09^{bc}	230	1.19±0.02	22.15±0.50^{bc}	19.05±0.26^{ab}	219	293.44±7.72
2017	191	1.43±0.03^{a}	6.97±0.15^{a}	4.90±0.15^{a}	134	1.09±0.04	19.84±0.77^{ab}	18.41±0.37^{a}	58	266.07±9.16
2018	91	1.36±0.05^{a}	6.59±0.21^{b}	4.93±0.21^{a}	70	1.17±0.06	21.27±1.05^{a}	18.50±0.54^{a}	--	--
Season of service										
S1 (Spring)	836	1.17±0.01	5.84±0.05	4.98±0.03	569	1.18±0.01	21.18±0.30	18.30±0.16	546	332.76±7.69^{ab}
S2 (Summer)	72	1.18±0.03	5.70±0.05	4.83±0.11	50	1.16±0.05	20.79±1.17	17.70±0.52	46	359.63±25.55^{a}
S3 (Fall)	1427	1.21±0.01	5.68±0.05	4.77±0.02	920	1.17±0.01	20.93±0.23	18.03±0.14	974	336.14±4.78^{ab}
S4 (Winter)	166	1.18±0.02	5.78±0.05	4.84±0.08	118	1.16±0.02	20.21±0.53	17.45±0.40	108	319.17±15.00^{b}
Parity										
1	789	1.09±0.01^{d}	5.29±0.04^{d}	4.88±0.03^{a}	502	1.11±0.01^{b}	19.51±0.30^{c}	17.70±0.17	580	357.63±6.65
2	613	1.14±0.01^{cd}	5.63±1.04^{c}	4.98±0.03^{a}	397	1.12±0.01^{b}	20.24±0.31^{bc}	18.15±0.20	443	245.31±7.77
3	441	1.20±0.02^{bc}	5.83±2.04^{bc}	4.93±0.04^{a}	291	1.18±0.02^{ab}	21.26±0.44^{ab}	18.08±0.26	302	327.20±8.01
4	306	1.19±0.02^{bc}	5.78±1.04^{bc}	4.92±0.05^{a}	203	1.13±0.02^{ab}	20.75±0.50^{ab}	18.32±0.28	184	328.50±13.26
5	183	1.24±0.03^{ab}	6.03±2.04^{a}	4.89±0.06^{a}	132	1.21±0.03^{a}	21.47±0.69^{a}	17.80±0.37	97	314.40±16.46
6	99	1.27±0.04^{a}	5.95±2.04^{ab}	4.73±0.08^{b}	79	1.21±0.05^{a}	20.79±0.78^{a}	17.24±0.41	45	337.72±25.99
7	70	1.20±0.05^{abc}	5.74±2.04^{c}	4.81±0.10^{ab}	53	1.21±0.05^{a}	21.40±0.99^{a}	17.80±0.58	23	312.74±29.33

LSB, litter size at birth; LWB, cumulative litter weight at birth; LMWB, mean litter weight at birth/ lamb born; LSW, litter size at weaning; LWW, cumulative litter weight at weaning; LMWW, mean litter weight at weaning/ lamb weaned; LI, lambing interval; SE, standard error; LSM, least squares mean (LSM values for each trait with different superscripts within columns differ significantly ($P<0.05$) from each other; LSM values without superscripts do not differ significantly ($p\geq0.05$); SE, standard error; S1, (February, March, April); S2, (May, June, July); S3, (August, September, October); S4, (November, December, January), --, no record.

DISCUSSION

Year of service

The LSM for LSB (1.16) in Kajli was lower than the values of 1.77 in Polypay (Hanford *et al*., 2006), 1.56 in Pelibuey (Tec-Canché *et al*., 2015), 1.50 in Abera (Marufa *et al*., 2017), 1.43 in Bonga sheep (Tera *et al*., 2021) 1.28 in Baluchi (Yadollahi *et al*., 2019), 1.29 in Baluchi (Jafaroghli *et al*., 2019) and 1.45±0.010 in Bonga sheep (Areb *et al*., 2021). Further, the LSM for LSB (1.14) in Menz and Horro sheep was lower than the LSB in Kajli (Mukasa-Mugerwa *et al*., 2002). The significant effect of YOS on LSB in Kajli was contrary to the non-significant impact of year on LSB in Santa Inês (Riofrio *et al*., 2016). However, the LSB in Pelibuey sheep was significantly associated with year (Tec-Canché *et al*., 2015). The LSM for LWB in Kajli was higher than values reported in Baluchi (5.39kg) (Yadollahi *et al*., 2019) and Awassi (5.32kg) (Haile *et al*., 2019) but lower than the value in Lori Bakhtiari (5.70kg) (Vatankhah *et al*., 2008) sheep. The significant influence of year on LWB in Kajli was similar to earlier findings by Tec-Canché *et al*. (2015) in Pelibuey but dissimilar to the report on Saint Croix sheep (Sánchez-Dávila *et al*., 2015). Moreover, the significant impact of year on LSB and LWB was similar to

Table V. Least squares means (LSM±SE) for breeding ram effects on reproductive traits in Kajli sheep.

Ram ID	No.	LSB (No.)	LWB (kg)	LMWB (kg)	No.	LSW (No.)	LWW (kg)	LMWW (kg)	No.	LI (days)
200411005	92	1.22±0.02^{bc}	5.57±0.13	4.60±0.10	63	1.05±0.01^{f}	18.66±0.51^{ijk}	17.88±0.43	69	334.05±17.74
200510002	35	1.58±0.06^{a}	5.78±0.13	4.58±0.14	17	1.09±0.06^{ef}	18.74±1.27^{ijk}	17.25±0.77	30	348.61±37.79
200510003	88	1.20±0.03^{bc}	5.67±0.07	4.78±0.08	46	1.14±0.04^{def}	19.06±0.70^{jk}	16.92±0.44	66	375.39±25.36
200510005	193	1.22±0.02^{bc}	5.72±0.09	4.77±0.06	105	1.08±0.02^{ef}	18.26±0.50^{hijk}	16.92±0.36	150	328.48±12.47
200510007	61	1.25±0.04^{bc}	5.67±0.11	4.59±0.10	29	1.05±0.03^{f}	17.26±0.60^{k}	16.53±0.52	50	344.49±23.23
200510008	237	1.17±0.02^{cd}	5.57±0.07	4.83±0.05	149	1.08±0.02^{ef}	18.06±0.39^{ghijk}	16.99±0.35	182	337.98±12.49
200510009	296	1.31±0.02^{b}	5.67±0.07	4.78±0.05	201	1.15±0.02^{cdef}	19.27±0.42^{fghij}	16.91±0.28	226	330.50±12.74
200611008	112	1.27±0.03^{b}	5.72±0.14	4.54±0.10	75	1.08±0.03^{f}	18.58±0.50^{ijk}	17.37±0.40	89	359.28±15.93
200611009	87	1.25±0.03^{bc}	5.88±0.14	4.81±0.12	55	1.11±0.04^{def}	18.98±0.83^{ghijk}	17.19±0.40	64	368.01±22.81
200710063	15	1.17±0.00^{cd}	5.53±0.23	4.70±0.23	10	1.39±0.16^{a}	25.73±1.44^{a}	19.76±1.49	12	360.53±47.14
200710064	79	1.18±0.02^{cd}	5.43±0.13	4.68±0.12	45	1.03±0.00^{f}	18.65±0.47^{ijk}	18.19±0.47	65	354.63±18.86
200710066	93	1.21±0.03^{bc}	5.78±0.15	4.78±0.10	49	1.02±0.00^{f}	17.36±0.48^{k}	17.05±0.48	73	352.74±19.46
201110588	203	1.28±0.03^{b}	5.65±0.09	4.86±0.05	158	1.16±0.03^{bcdef}	19.69±0.53^{efgh}	17.15±0.34	123	299.39±13.22
201110594	159	1.24±0.03^{bc}	5.76±0.10	4.72±0.07	127	1.16±0.03^{bcdef}	20.08±0.56^{efg}	17.55±0.34	113	319.05±16.15
201310761	72	1.17±0.05^{cd}	5.79±0.20	4.99±0.09	46	1.10±0.04^{def}	19.30±1.04^{efghi}	17.28±0.60	49	332.43±21.99
201310775	84	1.19±0.05^{cd}	5.87±0.19	4.94±0.07	58	1.16±0.05^{bcdef}	20.52±0.96^{cdef}	17.55±0.55	62	298.68±12.49
201310862	48	1.24±0.06^{bc}	5.91±0.22	4.83±0.10	33	1.30±0.08^{abc}	22.60±1.39^{abcd}	17.54±0.77	27	325.99±12.98
201310864	101	1.12±0.04^{d}	5.62±0.16	5.00±0.06	75	1.10±0.03^{def}	20.20±0.70^{def}	18.29±0.42	71	298.27±13.36
201411001	51	1.05±0.04^{de}	5.45±0.19	5.10±0.08	38	1.15±0.05^{cdef}	19.91±1.12^{efgh}	16.94±0.61	29	301.33±16.01
201411002	109	1.09±0.04^{de}	5.70±0.18	5.21±0.07	79	1.20±0.05^{bcdef}	22.04±0.83^{bcdef}	18.38±0.45	44	322.02±14.52
201411003	88	1.02±0.04^{de}	5.42±0.21	5.22±0.04	54	1.24±0.05^{bcdef}	23.34±1.19^{abcde}	18.64±0.58	33	322.50±12.86
201411004	97	1.13±0.05^{cd}	6.13±0.21	5.37±0.08	59	1.38±0.06^{abc}	25.38±1.26^{ab}	18.39±0.48	44	289.47±8.85
201411007	49	1.22±0.07^{bc}	6.09±0.29	5.04±0.12	41	1.38±0.07^{ab}	26.25±1.44^{a}	19.38±0.81	--	--
201411008	31	1.23±0.10^{bc}	6.06±0.40	5.04±0.20	27	1.32±0.09^{abcd}	25.49±1.66^{abc}	19.75±0.77	--	--
201411009	21	1.22±0.11^{bc}	6.29±0.45	5.19±0.20	18	1.27±0.10^{bcde}	25.96±1.84^{a}	20.90±1.24	3	330.44±62.60

For abbreviations and statistical details, see Table IV.

the significant ($p\leq 0.01$) effect of year of lambing on litter size and birth weight in Kermani (Mokhtari *et al*., 2010) and Rambouillet (Khan *et al*., 2017) sheep. Differences observed among studies may be attributed to intra-breed and interbreed genetic differences among animals as well as differences in climatic conditions, availability of fodder/feed, and managerial skills of farm staff.

The effect of year of service was significant ($p\leq 0.01$) for all observed traits of Kajli sheep except LSW and LI. The LSM for LSW (1.13) and LWW (20.13kg) in Kajli were lower than 1.24 (LSW), 29.11kg (LWW) in Baluchi sheep (Yadollahi *et al*., 2019). Similar to this study, the effects of year were significant ($p\leq 0.01$) for weight at weaning in Baluchi sheep (Yadollahi *et al*., 2019). The significant effect of year on LWW ($p\leq 0.01$) is supported by Piwczynski *et al*. (2011) and Sanchez-Davila *et al*. (2015).

The LSM for LI (330.69±20.48 days) in Kajli was higher than 242.62 days in Djallonke sheep (Gbangboche *et al*., 2006), 253.5 in Bonga sheep (Tera *et al*., 2021), 259.4 days in Pelibuey sheep (Tec-Canché *et al*., 2015), 283 days in Bonga sheep (Areb *et al*., 2021), 288 days in Abera sheep (Marufa *et al*., 2017), 307.41 days in Brazillian Santa Ines sheep (Aguirre *et al*., 2017), 264 days in Pakistani Harnai sheep (Zaborski *et al*., 2019) and lower than 363 days in Santa Ines (Riofrio *et al*., 2016). The substantial influence of service year on reproductive efficiency traits in this study ($p\leq 0.01$) may be linked to climatic conditions, particularly annual rainfall in different years of production.

Season of service

Season of service was inconsequential for all reproductive traits (LSB, LWB, LMWB, LSW, LWW and LMWW), except for LI ($p\leq 0.05$). Analysis revealed that dams bred in S3 (fall) had larger litter sizes than of dams bred in S1 (spring) but LMWB of dams bred in spring were higher than LMWB from ewes bred in fall. These results indicated that LMWB decreased as LSB increased in Kajli sheep, in agreement with reports on Mexican Saint Croix hair (Sanchez-Davilla *et al*., 2015), Iranian Mehraban (Yavarifard *et al*., 2015), and Chinese small tail han (Lv *et al*., 2016) breeds of sheep. The overall non-significant differences in LSB due to SOS were contrary to significant ($p \leq 0.05$) differences in litter sizes of fat tailed sheep (Ferda *et al*., 2009) and Bonga sheep (Tera *et al*., 2021), but in accordance ($p > 0.05$) to Mukasa-Mugerwa *et al*. (2002) for Menz and Horro sheep.

LSM differences for LWB, LMWB, LSW, LWW and LMWW among dams bred in different seasons were statistically non-significant. Availability of good quality fodder throughout the gestation period of dams bred in spring (S1) yielded high LSM values for LWB, LMWB, LSW, LWW and LMWW. Seasons were non-significantly associated with LWB, but significantly associated with LWW in Saint Croix hair sheep (Sanchez-Davilla *et al*., 2015). The significant impact of lambing season on LI in Djallonke ($p \leq 0.01$; Gbangboche *et al*., 2006) and Pelibuey ($p \leq 0.05$; Tec-Canché *et al*., 2015) support the findings on Kajli sheep. The absence of reproductive seasonality in Kajli may be due to the tropical climate of the region, because seasonality of reproduction is mostly observed in sheep of temperate climates (Ortavant *et al*., 1988). Furthermore, reproduction is primarily influenced by non-genetic factors (feeding, housing, management of breeding and lambing ewes), thus a uniform year-round reproductive management of Kajli at LES Khushab may be one of the reasons for the non-seasonality of reproductive traits in this breed.

Parity

The LSM for litter size at birth in Kajli varied with parity ($p \leq 0.01$); minimum value (1.09±0.01) in the 1st parity and maximum value (1.27±0.04) in the 6th parity. The gradual increase in litter size after each parity can be related to the fact that during early parities dams were still growing in size, increase in uterine capacity, multiple ovulations, and maternal behavior traits associated with reproductive efficiency (Fogarty *et al*., 2000; Abegaz *et al*., 2002; Benyi *et al*., 2006; Gbangboche *et al*., 2006). Tec-Canché *et al*., (2015) reported a similar increase in litter size from the 1st to the 6th parity in Pelibuey sheep to the one observed in Kajli sheep here. Litter size of 3rd-parity dams was higher ($P < 0.05$) than that of 1st-parity dams, congruent with reports for various sheep breeds (Red karaman and Tuj sheep; Koycegiz *et al*. (2009), Pelibuey sheep; Macías-Cruz *et al*. (2009), and Saint Croix sheep; Sanchez-Davila *et al*. (2015)). Differences among LSM for LWB, LWW and LSW due to parity in Kajli were significant ($p \leq 0.01$). The differences ($p \leq 0.01$) in LWB and LWW for ewes of different parity were likely due to differences in body sizes at different ages, maternal care, and experience of lamb grooming. The impact of parity or maternal uterine environment on LMWB decreased until weaning and parity did not significantly ($p > 0.05$) affect LMWW (Sanchez-Davila *et al*., 2015). These results agree with reports on Marwadi sheep (Nirban *et al*., 2015), Small tail han sheep (Lv *et al*., 2016) and Avikalin sheep (Mahala *et al*., 2019), establishing the significant impact of parity on LWB. However, in Avikalin sheep the differences ($p < 0.05$) in body weight of lambs due to parity continued until 6 months of age (Mahala *et al*., 2019). Parity did not affect ($p > 0.05$) LI in Kajli sheep, contrary to the significant impact of parity on LI found in Djallonke (Gbangboche *et al*., 2006), Moghani (Rashidi *et al*., 2011), Shall (Posht-e-Masari *et al*., 2013), Ghezel (Nabavi *et al*., 2014), Lori (Mohammadi *et al*., 2015) and Santa Ines (Aguirre *et al*., 2017) sheep.

Breeding ram

The goal to evaluate the influence of the breeding ram on LSB, LWB, LMWB, LSW, LWW, LMWW and LI in Kajli was to document its effect on these reproductive traits as it had never been evaluated in Kajli. There is some evidence in the literature on the influence of breeding ram on LSB (Sanchez-Davila *et al*., 2015). The influence of serving ram was significant on LSB, LSW and LWW ($p \leq 0.01$) but non-significant ($p > 0.05$) on LWB, LMWB, LMWW and LI. The LSM for LSB by breeding ram ranged from 1.02±0.04 to 1.58±0.06 lambs born per parturition. Breeding plans to improve fertility rely on ram estimated breeding values for litter size (Afolayan *et al*., 2008; Sanchez-Davila *et al*., 2015). Intense selection of rams with high genetic merit for litter size can bring from 8 to 10% progress in reproductive efficiency of flocks (Aguirre *et al*., 2007; Vanimisetti *et al*., 2007; Sanchez-Davila *et al*., 2015). Breeding of prolific rams with genetically unrelated females results in a quick increase in litter size in a flock of sheep (Sanchez-Davila *et al*., 2015). Breeding Romanov rams exhibited detectable ($p < 0.05$) differences for LSB (Schmidova *et al*., 2016). However, Mohammadi *et al*. (2012) reported significant ($p < 0.05$) association of ram with LWB and non-significant ($p > 0.05$) with LSB.

Genetic parameters

The estimates of heritability and repeatability for LSB in Kajli were 0.08±0.05 and 0.09±0.05, respectively. The heritability estimate for LSB in Kajli was in conformity with values from 0.078 to 0.092 in Romanov sheep (Schmidova *et al*., 2016) and 0.08 (Tera *et al*., 2021) but lower than the 0.09 (Yadollahi *et al*., 2019) and 0.10 (Jafaroghli *et al*., 2019) values in Baluchi sheep and the 0.1 value in five different sheep breeds (Rosati *et al*., 2002). The estimates of heritability in Kajli for all reproductive traits were very low, ranging from 0 (LI) to 0.08±0.05 (LSB). Heritability estimates for reproductive traits here were lower than estimates for lambing interval (0.06), litter weight at birth (0.15), and litter weight at weaning (0.11) in meat type sheep (Lobo *et al*., 2009). Yadollahi *et al*. (2019) estimated heritability (0.12) for litter mean weight per lamb born (LMB) and (0.05) for litter mean weight per lamb weaned (LMW), while very high values for LMB (0.47) and LMW (0.40) were obtained in Shall sheep (Posht-e-Masari *et al*., 2013). Estimated repeatability values for all reproductive traits in Kajli were lower than values for litter size (0.34), LMB (0.25), and LMW (0.21) in Baluchi sheep (Yadollahi *et al*., 2019). The heritability estimate for LSB was higher than the estimate for LWW, in agreement with published reports (Bromley *et al*., 2000; Olivier *et al*., 2001; Piwczynski *et al*., 2011). If repeatability is the upper level of heritability, then the low repeatability values for reproductive traits in Kajli indicate that little improvement can be achieved through direct selection for these traits.

Mean yearly estimated breeding values for reproductive traits in Kajli showed minor changes across years, except for LSW and LWW which oscillated around the horizontal axis, indicating no significant genetic changes for reproductive traits over time. Studies on additive genetic trends for composite reproductive traits in sheep are scanty. However, significantly positive additive genetic trends for LSB and LSW were reported in Polypay sheep (Hanford *et al*., 2006). No significant improvement in genetic worth indicates little focus on reproductive traits in breeding programs of Kajli. Improvement in husbandry practices (environmental conditions) may be an option to increase reproductive efficiency in Kajli sheep.

CONCLUSION

Season of breeding had little impact on reproductive performance of Kajli sheep, thus year-round breeding plans can be implemented to obtain a higher number of lambs per ewe per year. Litter size is usually considered as a dam trait. However, a significant effect of breeding ram on litter size existed in Kajli sheep. Thus, selection for prolific rams may also be effective to enhance reproductive efficiency in Kajli sheep at LES Khushab, Pakistan.

ACKNOWLEDGEMENT

Authors are thankful to the farm staff at Livestock Experiment Station Khushab for their support in data collection.

Funding

This research received no external funding.

IRB approval

This study was approved by Advanced Studies and Research Board (ASRB) of University of Veterinary and Animal Sciences in its 48th meeting held on 11-05-2018.

Ethical statement

The study was approved by Ethical Review Committee of University of Veterinary and Animal Sciences, Lahore.

Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

Abegaz, S., Duguma, G., Negussie, E., Gelmesa, U., Terefe, F., and Rege, J.E.O., 2002. Factors affecting reproductive performance and estimates of genetic parameters of litter size in Horro sheep. *J. agric. Sci*., **139**: 79-85. https://doi.org/10.1017/S0021859602002265

Afolayan, R.A., Fogarty, N.M., Gilmour, A.R., Ingham, V.M., Gaunt, G.M., and Cummins, L.J., 2008. Reproductive performance and genetic parameters in first cross ewes from different maternal genotypes. *J. Anim. Sci*., **86**: 804-814. https://doi.org/10.2527/jas.2007-0544

Aguirre, E.L., Mattos, E.C., Eler, J.P., BarretoNeto, A.D., and Ferraz, J.B., 2017. Genetic parameters and genetic trends for reproductive traits of Santa Ines sheep kept in extensive environments in Brazil. *J. Anim. Sci. Livest. Prod*., **1**: 1-7.

Aguirre, V., Orihuela, A., and Vázquez, R., 2007. Effect of semen collection frequency on seasonal variation in sexual behaviour, testosterone, testicular size and semen characteristics of tropical hair rams (*Ovis aries*). *Trop. Anim. Hlth. Prod*., **39**: 271-277. https://doi.org/10.1007/s11250-007-9010-8

Akhtar, M., Javed, K., Abdullah, M., Ahmad, N., and Elzo, M.A., 2012. Environmental factors affecting preweaning growth traits of Buchi sheep in Pakistan. *J. Anim. Pl. Sci*., **22**: 529-536.

Ali, A., Javed, K., Zahoor, I., and Anjum, K.M., 2020a. Determination of the best non-linear function to describe the growth of Kajli sheep. *S. Afr. J. Anim. Sci*., **50**: 452-459. https://doi.org/10.4314/sajas.v50i3.12

Ali, A., Javed, K., Zahoor, I., and Anjum, K.M., 2020b. Analysis of non-genetic and genetic influences underlying the growth of Kajli lambs. *S. Afr. J.*

Anim. Sci., **50**: 613-625. https://doi.org/10.4314/sajas.v50i4.13

Ali, A., Javed, K., Zahoor, I., Anjum, K.M., and Sharif, N., 2021. Identification of polymorphisms in the MSTN and ADRB3 genes associated with growth and ultrasound carcass traits in Kajli sheep. *Anim. Biotech*., 1-16. https://doi.org/10.1080/10495398.2021.2000428

Areb, E., Getachew, T., Kirmani, M., Gsilase, T., and Haile, A., 2021. Estimation of co-variance components, genetic parameters, and genetic trends of reproductive traits in community-based breeding program of Bonga sheep in Ethiopia. *Anim. Biosci*., **34**: 1451-1459. https://doi.org/10.5713/ajas.20.0413

Benyi, K., Norris, D., Karbo, N., and Kgomo, K.A., 2006. Effects of genetic and environmental factors on pre-weaning and post-weaning growth in West African crossbred sheep. *Trop. Anim. Hlth. Prod*., **38**: 547-554. https://doi.org/10.1007/s11250-006-4416-2

Borg, R.C., Notter, D.R., and Kott, R.W., 2009. Phenotypic and genetic associations between lamb growth traits and adult ewe body weights in western range sheep. *J. Anim. Sci*., **87**: 3506-3514. https://doi.org/10.2527/jas.2008-1622

Bromley, C.M., Snowder, G.D., and Van Vleck, L.D., 2000. Genetic parameters among weight, prolificacy, and wool traits of Columbia, Polypay, Rambouillet, and Targhee sheep. *J. Anim. Sci*., **78**: 846-858. https://doi.org/10.2527/2000.784846x

Cody, R., 2015. *An introduction to SAS® university edition*. SAS Institute Inc., Cary, pp. 92-106.

Đuričić, D., Benić, M., Žaja, I.Ž., Valpotić, H., and Samardžija, M., 2019. Influence of season, rainfall and air temperature on the reproductive efficiency in Romanov sheep in Croatia. *Int. J. Biometeorol*., **63**: 817-824. https://doi.org/10.1007/s00484-019-01696-z

Ferda, K., Emsen, E., Diaz, C.A.G., and Kutluca, M., 2009. Effects of lambing season, lamb breed and ewe parity on production traits of fat tailed sheep and their lambs. *J. Anim. Vet. Adv*., **8**: 195-198.

Fogarty, N.M., Hopkins, D.L., and Van de Ven, R., 2000. Lamb production from diverse genotypes 1. Lamb growth and survival and ewe performance. *Anim. Sci*., **70**: 135–145. https://doi.org/10.1017/S1357729800051675

Gbangboche, A.B., Adamou-Ndiaye, M., Youssao, A.K.I., Farnir, F., Detilleux, J., Abiola, F.A., and Leroy, P.L., 2006. Non-genetic factors affecting the reproduction performance, lamb growth and productivity indices of Djallonke sheep. *Small Rumin. Res*., **64**: 133-142. https://doi.org/10.1016/j.smallrumres.2005.04.006

Gilmour, A.R., Thompson, R., and Cullis, B.R., 1995. Average information REML: An efficient algorithm for variance parameter estimation in linear mixed models. *Biometrics*, **51**: 1440-1450. https://doi.org/10.2307/2533274

GOP, 2019. *Economic survey of Pakistan (2018-19)*. Economic Advisers Wing, Finance Division, Government of Pakistan, Islamabad.

Haile, A., Hilali, M., Hassen, H., Lobo, R.N.B., and Rischkowsky, B., 2019. Estimates of genetic parameters and genetic trends for growth, reproduction, milk production and milk composition traits of Awassi sheep. *Animal,* **13**: 240-247.

Hanford, K.J., Van-Vleck, L.D., and Snowder, G., 2006. Estimates of genetic parameters and genetic trend for reproduction, weight, and wool characteristics of Polypay sheep. *Livest. Sci*., **102**: 72-82. https://doi.org/10.1016/j.livsci.2005.11.002

Iqbal, Z.M., Javed, K., Abdullah, M., Ahmad, N., Ali, A., Khalique, A., Aslam, N., and Younas, U., 2014. Estimation of body weight from different morphometric measurements in Kajli lambs. *J. Anim. Pl. Sci*., **24**: 700-703.

Jafaroghli, M., Safari, A., Shadparvar, A.A., and Ghavi Hossein-Zadeh, N., 2019. Genetic analysis of ewe productivity traits in Baluchi sheep. *Iran. J. appl. Anim. Sci.*, **9**: 651-657.

Khan, A., Saleemi, M.K., Ali, F., Abubakar, M., Hussain, R., Abbas, R.Z., and Khan, I.A., 2018. Pathophysiology of peste des petits ruminants in sheep (Dorper and Kajli) and goats (Boer and Beetal). *Microb. Pathog*., **117**: 139-147. https://doi.org/10.1016/j.micpath.2018.02.009

Khan, N.N., Assad, N., Kumar, N., Chakraborty, D., Ayaz, A., Ali, A., Dar, M.A., and Wani, S.Y., 2017. Non-Genetic factors effecting reproduction traits in Rambouillet sheep. *Int. J. Curr. Microbiol. appl. Sci*., **6**: 3698-3704. https://doi.org/10.20546/ijcmas.2017.608.446

Khan, S., Riaz, M.N., Ghaffar, A., and Khan, M.F.U., 2012. Calpastatin (CAST) gene polymorphism and its association with average daily weight gain in Balkhi and Kajli sheep and Beetal goat breeds. *Pakistan J. Zool*., **44**: 377-382.

Koycegiz, F., Emsen, E., Diaz, C.A.G., and Kutluca, M., 2009. Effects of lambing season, lamb breed and ewe parity on production traits of fat tailed sheep and their lambs. *J. Anim. Vet. Adv*., **8**: 195-198.

Lobo, A.M.B.O., Lobo, R.N.B., Paiva, S.R., de Oliveira, S.M.P., and Faco, O., 2009. Genetic parameters for growth, reproductive and maternal traits in a multibreed meat sheep population. *Genet. mol. Biol.*, **32**: 761-770. https://doi.org/10.1590/S1415-47572009005000080

Lv, S.J., Yang, Y., and Li, F.K., 2016. Parity and litter size effects on maternal behavior of small tail han sheep in China. *Anim. Sci. J.*, **87**: 361-369. https://doi.org/10.1111/asj.12441

Macías-Cruz, U., Álvarez-Valenzuela, F.D., Correa-Calderón, A., Molina-Ramírez, L., González-Reyna, A., Soto-Navarro, S., and Avendaño-Reyes, L., 2009. Pelibuey ewe productivity and subsequent pre-weaning lamb performance using hair-sheep breeds under a confinement system. *J. appl. Anim. Res.*, **36**: 255-260. https://doi.org/10.1080/09712119.2009.9707071

Mahala, S., Saini, S., Kumar, A., Prince, L.L.L., and Gowane, G.R., 2019. Effect of non-genetic factors on growth traits of Avikalin sheep. *Small Rumin. Res.*, **174**: 47-52. https://doi.org/10.1016/j.smallrumres.2019.03.006

Marufa, E., Taye, M., Abebe, G., Tera, A., and Jimma, A., 2017. Effect of non-genetic factors on reproductive and growth performance of Abera sheep under community-based breeding program in SNNPRS Ethiopia. *J. Adv. Dairy Res.*, **5**: 1000196. https://doi.org/10.4172/2329-888X.1000196

Meyer, K., 2007. WOMBAT® a tool for mixed model analyses in quantitative genetics by restricted maximum likelihood (REML). *J. Zhejiang Univ. Sci. B.*, **8**: 815-821. https://doi.org/10.1631/jzus.2007.B0815

Mohammadi, H., Shahrbabak, M.M., and Shahrbabak, H.M., 2012. Genetic analysis of ewe productivity traits in Makooei sheep. *Small Rumin. Res.*, **107**: 105–110. https://doi.org/10.1016/j.smallrumres.2012.04.019

Mohammadi, K., Arpanahi, R.A., Amraei, F., Mohamadi, E.M., and Rashidi, A., 2015. Genetic parameter estimates for growth and reproductive traits in Lori sheep. *Small Rumin. Res.*, **131**: 35-42. https://doi.org/10.1016/j.smallrumres.2015.07.029

Mokhtari, M.S., Rashidi, A., and Esmailizadeh, A.K., 2010. Estimates of phenotypic and genetic parameters for reproductive traits in Kermani sheep. *Small Rumin. Res.*, **88**: 27-31. https://doi.org/10.1016/j.smallrumres.2009.11.004

Mukasa-Mugerwa, E., Anindo, D., Sovani, S., Lahlou-Kassi, A., Tembely, S., Rege, J.E.O., and Baker, R.L., 2002. Reproductive performance and productivity of Menz and Horro sheep lambing in the wet and dry seasons in the highlands of Ethiopia. *Small Rumin. Res.*, **45**: 261-271. https://doi.org/10.1016/S0921-4488(02)00155-4

Nabavi, R., Alijani, S., Taghizadeh, A., Rafat, S.A., and Bohlouli, M., 2014. Genetic study of reproductive traits in Iranian native Ghezel sheep using Bayesian approach. *Small Rumin. Res.*, **120**: 189-195. https://doi.org/10.1016/j.smallrumres.2014.05.008

Nirban, L.K., Joshi, R.K., Narula, H.K., Singh, H., and Bhakar. S., 2015. Genetic and non-genetic factors affecting body weights in Marwari sheep. *Indian J. Small Ruminant.*, **21**: 106-108. https://doi.org/10.5958/0973-9718.2015.00029.X

Olivier, W.J., Snyman, M.A., Olivier, J.J., Van Wyk, J.B., and Erasmus, G.J., 2001. Direct and correlated responses to selection for total weight of lamb weaned in Merino sheep. *S. Afr. J. Anim. Sci.*, **31**: 115-122. https://doi.org/10.4314/sajas.v31i2.3837

Ortavant, R., Bocquier, F., Pelletier, J., Ravault, J.P., Thimonier, J., and Volland-Nail, P., 1988. Seasonality of reproduction in sheep and its control by photoperiod. *Aust. J. biol. Sci.*, **41**: 69-86. https://doi.org/10.1071/BI9880069

Piwczynski, D., Kowaliszyn, B., and Mroczkowski, S., 2011. Heritability and repeatability of the number of lambs born and reared estimated using linear and threshold models. *Arch. Anim. Breed.*, **54**: 271-279. https://doi.org/10.5194/aab-54-271-2011

Posht-e-Masari, H.A., Shadparvar, A.A., Zadeh, N.G.H., and Tavatori, M.H.H., 2013. Estimation of genetic parameters for reproductive traits in Shall sheep. *Trop. Anim. Hlth. Prod.*, **45**: 1259-1263. https://doi.org/10.1007/s11250-013-0357-8

Qureshi, M.A., Babar, M.E., and Ali, A., 2010. Environmental and genetic factors influencing performance traits of Kajli sheep in Pakistan. *Pakistan J. Zool.*, **42**: 339-343.

Qureshi, Z.I., Farid, A.H., Babar, M.E., and Hussain, T., 2015. Leptin gene polymorphism in Lohi, Kajli and Spili breeds of sheep. *Pak. Vet. J.*, **35**: 321-324.

Rashidi, A., Mokhtari, M.S., Esmailizadeh, A.K., and Fozi, M., 2011. Genetic analysis of ewe productivity traits in Moghani sheep. *Small Rumin. Res.*, **96**: 11-15. https://doi.org/10.1016/j.smallrumres.2010.11.001

Riofrio, E.A., Ferraz, J.B.S., and Mattos, E.C., 2016. Influence of non-genetic factors on growth and reproductive traits of sheep Santa Inês in extensive systems. *Livest. Res. Rural Dev.*, **28**: http://www.lrrd.org/lrrd28/7/agui28121.html

Rosati, A., Mousa, E., Van Vleck, L.D., and Young, L.D., 2002. Genetic parameters of reproductive traits in sheep. *Small Rumin. Res*., **43**: 65–74. https://doi.org/10.1016/S0921-4488(01)00256-5

Saddiqi, H.A., Nisa, M., Mukhtar, N., Shahzad, M.A., Jabbar, A., and Sarwar, M., 2011. Documentation of physiological parameters and blood profile in newly born Kajli lambs. *Asian-Austral. J. Anim. Sci*., **24**: 912-918. https://doi.org/10.5713/ajas.2011.10336

Sanchez-Davila, F., Bernal-Barragán, H., Padilla-Rivas, G., Bosque-González, A.S., Vázquez-Armijo, J.F., and Ledezma-Torres, R.A., 2015. Environmental factors and ram influence litter size, birth, and weaning weight in Saint Croix hair sheep under semi-arid conditions in Mexico. *Trop. Anim. Hlth. Prod*., **47**: 825-831. https://doi.org/10.1007/s11250-015-0795-6

Schmidova, J., Milerski, M., Svitakova, A., and Vostry, L., 2016. Effects of service ram on litter size in Romanov sheep. *Small Rumin. Res*., **141**: 56-62. https://doi.org/10.1016/j.smallrumres.2016.05.018

Shah, A., Aziz, A., Ghafoor, A., Zahur, A.B., Yousaf, M., Ishaq, R., Abass, N., and Suleman M., 2018. Molecular analysis of callipyge gene mutation (C. 267A> G) in Kajli, Lohi and Thalli sheep breeds of Pakistan. *Russ. J. Genet*., **54**: 848-852. https://doi.org/10.1134/S1022795418070141

Tec-Canché, J.E., Monforte, J.G.M., and Correa, J.C.S., 2015. Environmental effects on productive and reproductive performance of Pelibuey ewes in Southeastern México. *J. appl. Anim. Res*., **44**: 508-512. https://doi.org/10.1080/09712119.2015.1102730

Tera, A., Getachew, T., Melesse, A., Rekik, M., Rischkowsky, B., Mwacharo, J.M., Abate, Z., and Haile, A., 2021. Estimates of genetic parameters and trends for reproduction traits in Bonga sheep, Ethiopia. *Trop. Anim. Hlth. Prod*., 53: 1-8. https://doi.org/10.1007/s11250-020-02445-w

Vanimisetti, H.B., Notter, D.R., and Kuehn, L.A., 2007. Genetic (co) variance components for ewe productivity traits in Katahdin sheep. *J. Anim. Sci*., **85**: 60-68. https://doi.org/10.2527/jas.2006-248

Vatankhah, M., Talebi, M.A. and Edriss, M.A., 2008. Estimation of genetic parameters for reproductive traits in Lori-Bakhtiari sheep. *Small Rumin. Res.,* **74**: 216-220.

Waheed, A., Eyduran, E., Tariq, M.M., Ahmad, S., Hameed, T., and Bukhari, F.A., 2016. Comparison of the non-linear models defining the growth of Thalli sheep under desert conditions. *Pakistan J. Zool*., **48**: 423-426.

Yadollahi, S., Gholizadeh, M., and Hafezian, H., 2019. Bayesian inference on genetic parameters for some reproductive traits in sheep using linear and threshold models. *Small Rumin. Res*., **170**: 149-153. https://doi.org/10.1016/j.smallrumres.2018.12.001

Yavarifard, R., Hossein-Zadeh, N.G., and Shadparvar, A.A., 2015. Estimation of genetic parameters for reproductive traits in Mehraban sheep. *Czech J. Anim. Sci*., **60**: 281-288. https://doi.org/10.17221/8242-CJAS

Zaborski, D., Ali, M., Eyduran, E., Grzesiak, W., Tariq, M.M., Abbas, F., Waheed, A., and Tirink, C., 2019. Prediction of selected reproductive traits of indigenous Harnai sheep under the farm management system via various data mining algorithms. *Pakistan J. Zool*., **51**: 421-431. https://doi.org/10.17582/journal.pjz/2019.51.2.421.431