



Better odds of lamb survival in sheep at dry arid tropical region of India

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ABSTRACT

Lamb survival till first 28 days of life is critical as it increases the chances of economic gain in flock. Objective of the current study was to assess the incidence of neonatal mortality in lambs born in arid region of India and genetic and non-genetic factors affecting it. The present study was conducted using the data on 4,137 Magra and 4,595 Marwari sheep over 17 years (1999 to 2016). Incidence of neonatal mortality was very low in Magra (1.04%) and Marwari (2.48%) sheep, respectively in semi-intensive management system. Year and seasonal variation was observed for neonatal losses. Males had lower odds of survival as compared to females. Odds of survival were low if the lambs were born to dams of low body weight and in their first parity. It was observed that the lamb survival can be improved if due care of the lambs born with low birth weight (<2 kg) is taken. The heritability estimate was moderate in Magra sheep (0.17), indicating further scope for genetic improvement for lamb survival through selection. However, for Marwari sheep, the total heritability was 0.02, thus limiting the scope for selection. Arid region favoured the lamb survival. Hardiness of the Magra and Marwari sheep, their high lamb survival along with standard production potential is indicative of the good genetics of these sheep along with better management practices adopted at arid regional campus, thus reflecting better sheep welfare practices.

Keywords: Arid, Gibbs sampling, Heritability, Neonatal mortality, Sheep welfare

Lamb survival is critical aspect in sheep industry as it is directly related to the economics. Loss of lambs especially in their early life also alarms the livestock welfare practices. The neonatal mortality in sheep is a trait that is expressed from 0 to 28 days of the birth and is a complex problem that may result from a variety of climatic, nutritional, management, infectious, genetic and other unknown factors. Profitable sheep business demands better survival of the lambs from birth to weaning. Decreased and variable lamb survival is usually considered as a major constraint for efficient sheep production (Haughey 1991). Neonatal deaths are known to be highest in the first 3 days of life (Binns *et al.* 2002, Sharif *et al.* 2005, Everett-Hincks and Dodds 2008) and tend to be larger during the first week of life (Hatcher *et al.* 2009) suggesting that events occurring at this time are of particular importance in lamb survival. High rate of lamb losses (10 to 30%) during the neonatal stage had been reported in the most sheep producing countries (Gowane *et al.* 2018). This is indicative of the important economic loss for agrarian economy.

Infection causes such as naval ill, pneumonia, etc. are major reasons for lamb losses during early life. However, there are other non-infectious conditions that can also affect lamb mortality, viz. starvation and chilling exposure (Henderson 2000), mis-mothering, low birth weight of lamb (Dwyer *et al.* 2005, Gowane *et al.* 2018), breed differences (Mukasa-Mugerwa *et al.* 2000), age of ewe (Vatankhah and

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Talebi 2009), weight of the dam at lambing (Gowane *et al.* 2018), immunity acquired by the neonate through colostrums (Vihan 1986), parity of the dam and sex of the lamb (Binns *et al.* 2002, Gowane *et al.* 2018). Lamb survival is usually reported as the trait with low genetic variation. This indicates that the genetic improvement in the direction for improved lamb survivability will not be much fruitful. Genetic variability of low to moderate degree have been reported for the lamb survival (Hall *et al.* 1995, Lopez-Villalobos and Garrick 1999, Morris *et al.* 2000, Everett-Hincks *et al.* 2005, Safari *et al.* 2005, Brien *et al.* 2010, Everett-Hincks *et al.* 2014, Gowane *et al.* 2018). Lamb survivability is controlled by genetics of the animal, contributed by direct and maternal genetic effects and also by environmental factors. Knowledge of genetic parameters is required to predict the response to selection and also to obtain the estimated breeding values for the selection candidates. However, lamb survival being a threshold trait, it is also imperative to know appropriate approach such as Bayesian for estimation of genetic parameters.

Bikaner falls in the arid region of Rajasthan, India, demarcated as desert with peculiarities of intense summers, high diurnal variation in temperature, extremely low rainfall, low humidity and high evaporation. With such an extreme weather, livestock husbandry and sheep in particular survived as a backbone for livelihood resource, as dependence on the agricultural output is unreliable. Magra and Marwari sheep are well adapted to the harsh

climatic conditions of the region and thrive well with optimum production performance, viz. for Marwari sheep, the average live weight at 6 month was 25.92 kg and at 12 month it was 31.51 kg. Similarly, in Magra sheep, the live weight at 6 and 12 month was 25.18 kg and 30.35 kg, respectively (Annual Report NWPSI 2017) in farm condition. Hypothesis for the study was, adapted breeds in arid region should have better lamb survival given their prehistoric natural selection for survival and low environmental microbial load due to harsh climate. In the current study, investigations on the genetic and non-genetic factors affecting lamb survival or neonatal mortality on a farm condition in the arid region of Rajasthan India was been carried out. The genetics of the neonatal mortality was been further investigated to obtain estimates of (co) variance components and unbiased estimates of the genetic parameters.

MATERIALS AND METHODS

The data on two sheep breeds namely Magra and Marwari, native of arid region of Rajasthan were used in this study. The sheep flocks were located at the Arid Region Campus of the ICAR-Central Sheep and Wool Research Institute (ICAR-CSWRI), Bikaner, Rajasthan. Marwari breed of sheep is widely distributed in Jodhpur, Jalore, Nagaur, Pali, Sirohi and Barmer districts of Rajasthan and is reared for its medium and coarse quality carpet wool and mutton. However, the source of income from this breed depends mainly upon mutton production as earnings from its wool are of little value due to its coarse texture (Singh *et al.* 2016). Magra is an important carpet wool breed of western and southern Bikaner and adjoining area of Nagour, Churu and Jhunjhunu districts of Rajasthan (Acharya 1982).

Data: Data on 4,147 Magra and 4,596 Marwari sheep born since 1999 to 2016 were used for studying the incidence of neonatal mortality and factors affecting odds of lamb survival in sheep. If the lamb survived till 28 days of the birth, it was given a code 1 and for the lamb mortality till 28 days of life, the code 2 code was given. The data with regards to year and season of birth, dam's parity, dam's weight at lambing and lamb's birth weight were recorded from the database maintained at Arid Regional Campus of ICAR-CSWRI.

Management: All the animals in this flock were kept under semi-intensive management system (Singh *et al.* 2016). The concentrate mixture was provided *ad lib.* to suckling lambs from 15 days of age till weaning at around 90 days age. All the animals were grazed separately from their ewes in morning and evening. After weaning, all the animals were sent for grazing from 08:00 AM to 06:00 PM, except during summer months (April–September) when split grazing during cooler hours of the day was practiced from 06:00 AM to 12 noon and 03:00 PM to 07:00 PM. In addition to this, 300 g concentrate mixture was provided during post-weaning period. The pasture consisted primarily of grasses such as *Aristida fununculata* (Lampla) and *Cenchrus sagittarius*.

Table 1. Estimates of Wald statistics and β exponential for neonatal mortality in sheep

Factors	Magra			Marwari		
	Wald	Sig.	Exp(b)	Wald	Sig.	Exp(b)
Sex of lamb	1.66	0.20	1.51	3.98	0.05	1.49
<i>Year of birth</i>	7.72	0.97	–	51.05	0.00	–
1999	–	–	–	–	–	–
2000	0.33	0.57	1.56	–	–	–
2001	0.20	0.66	0.74	1.81	0.18	0.31
2002	0.47	0.49	1.82	1.74	0.19	4.41
2003	0.00	0.99	1.21	0.14	0.71	0.59
2004	0.00	1.00	0.92	0.00	0.99	1.04
2005	0.00	0.99	0.00	0.00	0.99	0.00
2006	0.36	0.55	2.13	0.00	0.99	2.88
2007	0.87	0.35	0.31	0.00	1.00	0.72
2008	0.00	0.99	2.11	0.00	0.99	0.00
2009	0.00	0.99	0.00	5.82	0.02	2.98
2010	1.98	0.16	0.35	17.78	0.00	0.18
2011	2.49	0.11	5.59	0.05	0.83	1.07
2012	0.00	0.99	4.54	1.64	0.20	1.90
2013	0.00	0.99	0.00	0.64	0.42	1.57
2014	0.59	0.44	1.80	0.00	0.95	1.03
2015	0.02	0.90	1.12	0.75	0.39	2.83
2016	0.00	0.99	1.18	–	–	–
Season of birth	0.01	0.93	0.96	6.59	0.01	1.89
<i>Parity of dam</i>	0.76	0.94	–	8.22	0.08	–
1	–	–	–	–	–	–
2	0.04	0.84	0.92	0.16	0.69	1.12
3	0.34	0.56	1.34	3.40	0.07	1.91
4	0.01	0.93	0.94	3.96	0.05	0.48
5	0.22	0.64	1.69	3.25	0.07	2.07
<i>Birth weight of lamb</i>	25.82	0.00	–	23.61	0.00	–
Up 2 kg	–	–	–	–	–	–
2–2.50 kg	5.96	0.02	3.31	2.33	0.13	1.73
2.51–3.00 kg	2.06	0.15	1.86	1.57	0.21	1.42
3.01–3.50 kg	4.23	0.04	3.43	4.17	0.04	1.73
>3.50 kg	0.94	0.33	0.51	0.75	0.39	1.38
<i>Dam weight at lambing</i>	9.57	0.02	–	1.43	0.70	–
≤25 kg	–	–	–	–	–	–
25.1–30 kg	1.35	0.25	0.53	0.00	0.99	0.00
30.1–35 kg	7.30	0.01	3.52	1.00	0.32	1.30
>35.1 kg	5.65	0.02	0.27	0.78	0.38	0.81
Constant	0.00	0.98	0.00	0.00	0.99	0.00

Magra: Year: 1998–1999 merged together; Parity: 5 and more than 5 are merged together; Dam weight: group 1 and 2 are merged together; Marwari: Parity: 5 and more than 5 are merged together, Dam weight: group 1 and 2 are merged together. Method used for binary logistic regression is “Repeated”, where each category of the predictor variable except the first category is compared to the category that precedes it. Number of observations (N) equals 4,147 for Magra, and 4,596 for Marwari.

Statistical analysis: The responding variable was lamb survival (1) or non-survival (2). Logistic regression model was used to study the association of various non-genetic factors on the neonatal mortality. The statistical model used is as below:

$$\ln\left(\frac{P_{ijklmne}}{1-P_{ijklmne}}\right) = \beta_0 + \beta_1 S_i + \beta_2 Y_j + \beta_3 N_k + \beta_4 P_l + \beta_5 B_m + \beta_6 D_n + e_{ijklmne}$$

where $P_{ijklmne}$, probability that animal i survived; β_0 , intercept; S_i is the effect of i^{th} sex; Y_j is the effect of j^{th} year of birth; N_k is the effect of k^{th} season of birth; P_l is the effect of l^{th} parity of dam; B_m is the effect of m^{th} birth weight group; D_n is the effect of the n^{th} Dam weight group at lambing. Corresponding regression coefficients are indicated by β . $e_{ijklmne}$ is the residual error corresponding to responding variable. SPSS (2005) was used to carry out the statistical analyses.

Genetic analysis: A total of 4,137 records on Magra and 4,594 records of Marwari sheep were used for genetic analysis. Details of the pedigree used and inbreeding level in the flock are presented in Table 2. Neonatal mortality being a binary threshold trait, the genetic analysis was conducted by fitting univariate animal models using Bayesian approach (Gibbs sampling). All the significant factors influencing lamb survival were included in the genetic analysis model. The software used was THRGIBBS1F90 in the BLUPF90 family of programs (Misztal 2008). It is suitable for estimation of (co)variance components for threshold animal mixed models for any combination of categorical and continuous traits. The program POSTGIBBSF90 (Misztal 2008) was used for post-Gibbs analysis. Six different single-trait threshold models which accounts for the direct and maternal effects were initially fitted for each trait.

Table 2. Characteristics of data structure in neonatal mortality for genetic analysis

Trait	Magra	Marwari
No. of records for genetic analysis	4,137	4,595
Sires with progeny records	228	289
Dams with progeny records	1,294	1,331
Pedigree records	4,569	5,002
Average in breeding (%)	0.73	0.68

$$y = X\beta + Z_a a + \varepsilon \quad \dots (1)$$

$$y = X\beta + Z_a a + Z_m m + \varepsilon \text{ with Cov}(a_m, m_o) = 0 \quad \dots (2)$$

$$y = X\beta + Z_a a + Z_m m + \varepsilon \text{ with Cov}(a_m, m_o) = A\sigma_{am} \quad \dots (3)$$

$$y = X\beta + Z_a a + Z_{pe} pe + \varepsilon \quad \dots (4)$$

$$y = X\beta + Z_a a + Z_m m + Z_{pe} pe + \varepsilon \text{ with Cov}(a_m, m_o) = 0 \quad \dots (5)$$

$$y = X\beta + Z_a a + Z_m m + Z_{pe} pe + \varepsilon \text{ with Cov}(a_m, m_o) = A\sigma_{am} \quad \dots (6)$$

where y is the vector of records; β , a , m , pe and ε are vectors of fixed, direct additive animal genetic, maternal additive genetic, permanent environmental effects of the dam, and

residual effects, respectively; with association matrices X , Z_a , Z_m and Z_{pe} ; A is the numerator relationship matrix between animals; and σ_{am} is the covariance between additive direct and maternal genetic effects. Assumptions for variance (V) and covariance (Cov) matrices involving random effects were:

$$V(a) = A\sigma_a^2, V(m) = A\sigma_m^2, V(c) = I\sigma_c^2, V(e) = I\sigma_e^2 \text{ and Cov}(a, m) = A\sigma_{am}$$

where, I is an identity matrix and σ_a^2 , σ_m^2 , σ_c^2 and σ_e^2 are additive direct, additive maternal, maternal permanent environmental and residual variances, respectively. The direct maternal correlation (r_{am}) was computed as the ratio of the estimates of direct maternal covariance (σ_{am}) to the product of the square roots of estimates of σ_a^2 and σ_m^2 . Maternal across year repeatability for ewe performance ($t_m = (1/4)h^2 + m^2 + c^2 + mr_{am}h$) was calculated. The total heritability (h^2_t), was calculated using the formula $h^2_t = (\sigma_a^2 + 0.5\sigma_m^2 + 1.5\sigma_{am})/\sigma_p^2$ (Willham 1972). It is also assumed that both the systematic effects listed above and the (co)variance components included in the fitted model have a uniform a priori Gaussian distribution, whilst the conditional distributions of the direct additive, maternal, permanent environmental and residual variances present inverse Wishart distribution (Sorenson and Gianola 2002). The most appropriate model for each trait was selected using likelihood Ratio Tests (LRT) (Meyer 1992).

For the analysis, in all cases, a single chain of 500,000 cycles was run, with the first 200,000 cycles used as the burn-in period. Every 100th sample was stored after 200,000 iterations. Samples generated were used for the computation of posterior means and posterior SD, as well as 95% highest posterior density (HPD) confidence intervals. Point estimates were calculated as the posterior mean of the specific variance component, using the results from the samples as set out above. Convergence was monitored using the serial correlations from the output that should reach zero.

RESULTS AND DISCUSSION

The data recorded over 18 years for Magra and 16 years for Marwari sheep revealed very low neonatal mortality incidence in Magra (1.04%) and Marwari sheep (2.48%). Breed difference was observed, however, the differences were not significant. Lamb survival was excellent as compared to the already available reports by several authors for neonatal mortality, viz. 3.66% (Vatankhah 2013) and 3.77% (Vatankhah and Talebi 2009) in Lori-Bakhtiari lambs, 4.29% in Avikalin, 5.17% in Chokla and 4.07% in Malpura sheep (Gowane *et al.* 2018) up to 1 month of age and 8% lamb mortality up to 3 days of age (Everett-Hincks *et al.* 2014). The average annual relative humidity of 42.7% at Bikaner that ranges from 25% in April to 61% in August (<https://www.weatheronline.in>) along with temperature extremes lowers the incidence of microbial load that may be pathogenic to lambs and hence better odds of survival are expected for adapted breeds of this region. Favourable lamb survival in arid region was also reported by Gowane

et al. (2018), where shifting a flock of Chokla sheep from semi-arid to the arid region of Rajasthan resulted in decline in the incidence of neonatal mortality from 5.48% to 2.49%. Low lamb mortality of Magra and Marwari in current study also indicated sincere efforts towards management of the flock especially during lambing and post lambing period along with good genetic potential of the germplasm.

Non-genetic factors affect the neonatal mortality: Sex of the animal influenced the survival outcome for the lambs till first 28 days of their life, where females had better survival as compared to males. These differences were significant for Marwari sheep (P=0.05) and non-significant for Magra sheep. In all mammals, young males have greater risk of death as compared to females (Petersson and Danell 1985, Nash *et al.* 1996, Mukasa Mugerwa *et al.* 2000, Sawalha *et al.* 2007, Mandal *et al.* 2007, Vatankhah and Talebi 2009, Maxa *et al.* 2009, Everet-Hincks *et al.* 2014). Differences in lamb survival between the sexes is not yet determined, however, Oldham *et al.* (2011) reported that the survival of male lambs decreased more rapidly with increasing chill index than survival of female lambs. Arid winter is severe and the same factor might have also affected the lamb survival in breeds studied.

Year of birth of the animal influenced the neonatal mortality significantly in Marwari sheep (P<0.01), however effect was non-significant for Magra sheep. In the Magra sheep, year 1999 to 2001 showed incidence of neonatal mortality between 2.33 to 3.55%, however after that the estimates never crossed more than 1.90% (Fig. 1), thus resulting in overall 1.04% neonatal mortality. The differences between the years were non-significant. For Marwari sheep, during year 2008, 2010 and 2011 higher estimates of 4.84, 6.43 and 3.94% were observed, and for all the other years, neonatal mortality was below 3%, resulting in overall estimate of 2.48%. During year 2007, suspected *peste des petits ruminants* (PPR) or sheep pox vaccination outbreak occurred across Rajasthan and affected the neonatal mortality in several pockets across Rajasthan, however it was not confirmed diagnostically in Marwari sheep flock under study. Year to year variation occurred due to uneven rainfall that affects pasture development and hence variation in the body condition scores of pregnant ewes. Odds of survival were better for the year succeeding

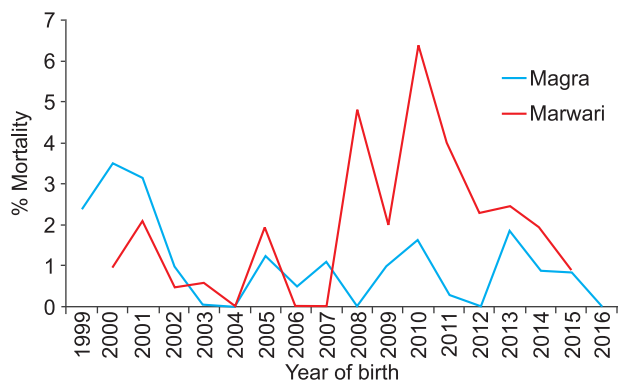


Fig. 1. Per cent neonatal mortality of lambs from 1999 till 2016.

a year with high neonatal mortality. Season of birth was non-significant source of variation in Magra sheep, however it was significant (P=0.01) in Marwari sheep. Results however, revealed that the differences were of not high magnitude.

Animal effects viz. parity of dam, dam's weight at lambing and lamb's weight at birth also influenced the odds of survival of lambs in early life. Overall analysis of parity revealed that lambs born to primi-parous ewes were at higher risk and had low odds of survival (Fig. 2), with relatively better odds in the subsequent parities. For Magra and Marwari sheep, the parity of dam was non-significant source of variation for neonatal mortality. Although, the overall neonatal mortality was low, the lamb losses can be further reduced if more care is taken of pregnant ewes and lambs born to ewes in their first parity. Similar findings were reported by Gowane *et al.* (2018) for Malpura and Avikalin sheep. Southey *et al.* (2001) and Sawalha *et al.* (2007) observed that lamb mortality reduced with increasing ewe age. Smith (1977) reported that yearling ewes had lambs with lower birth weight, lower vigour, and higher mortality rates than lambs from older ewes. Vatankhah and Talebi (2009) reported higher lamb losses for lambs born to the younger ewes and in contrast to our finding to the older ewes too (>5 year-old).

Birth weight of lamb was a highly significant source of variation (P=0.00) for neonatal mortality across two breeds studied. Higher estimates of per cent neonatal mortality were observed for lambs born with less than 2 kg birth

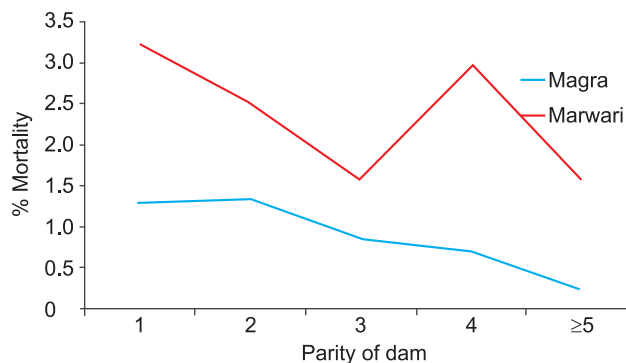


Fig. 2. Per cent neonatal mortality for lambs born to dams with varying parities.

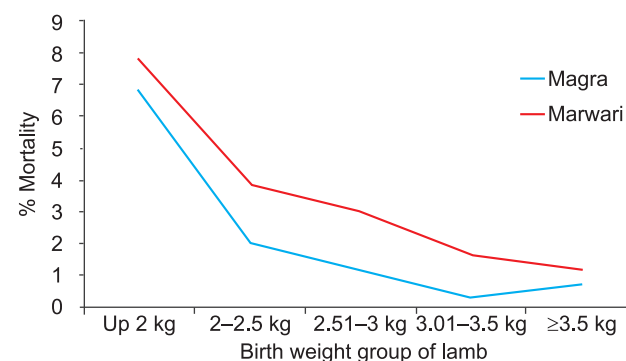


Fig. 3. Per cent neonatal mortality of lambs born with low to high birth weight.

weight (6.85 to 7.81%). There was a linear decline in the per cent neonatal mortality with increase in the birth weight of the lambs (Fig. 3). Lambs with birth weight of 3 kg and more had higher survival rate. Results indicate that critical care of the lambs born with low birth weight is essential to reduce the lamb losses in first one month that emphasizes the colostrum feeding, suckling of milk and proper housing for prevention from the cold climate and wind during winter. Smith (1977) concluded that birth weight had a large influence with most early deaths occurring in lambs with birth weights below the mean. Vatankhah and Talebi (2009) also reported the similar observation. Dam's weight at lambing affected the lamb survival significantly in Magra sheep ($P=0.001$), and non-significantly in Marwari sheep. Results revealed that in Magra and Marwari sheep, there was better odds of lamb survival for lambs born to dams with 30 to 35 kg weight at lambing (Fig. 4). Dams with low weight have low odds of lamb survival. Care and supplementary feeding is important for the pregnant ewes with lower body weight, so that lambs born to them have better odds of survival during first 28 days of life.

Genetic analysis: Although the odds of survival till first 28 days of life in both the breeds was higher, there were certain non-genetic factors as discussed above, which influenced the outcome. Apart from these factors, genetics of the animals plays a crucial role in determining the fate of

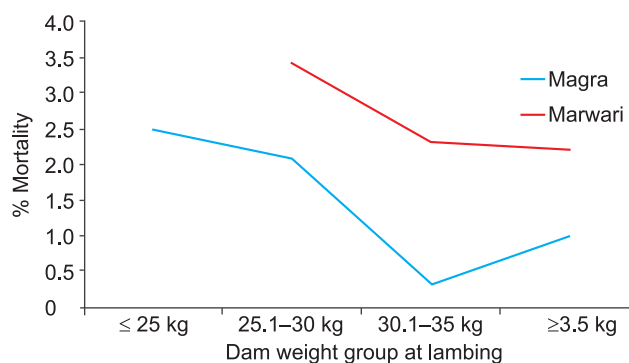


Fig. 4. Per cent neonatal mortality of lambs born to dams with low to high weight at lambing.

lambs in the flock. Study revealed different levels of genetic influences for neonatal mortality in Magra and Marwari sheep. Magra sheep revealed moderate additive genetic variance for the neonatal mortality (Table 3). Model-1 was the best model for explaining the genetic estimates due to increased likelihood over all other models ($P<0.05$) as per LRT. The h^2 for neonatal mortality was 0.17 ± 0.02 . Similar estimate of h^2 (0.17 ± 0.02) was reported for Avikalin sheep (Gowane *et al.* 2018). This was in contrast to most of the earlier reports where low additive genetic variance for the lamb survival was reported (Olivier *et al.* 1998, Snyman *et al.* 1998, Lopez-Villalobos and Garrick 1999, Cloete *et al.*

Table 3. Estimates of (co)variance components and genetic parameters for neonatal mortality in Magra sheep

Items	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ_a^2	0.24±0.04 (0.003–0.66)	0.58±0.09 (0.039–1.53)	10.41±6.70 (0.013–53.29)	0.34±0.04 (0.000–0.97)	0.51±0.05 (0.009–1.28)	3.57±2.66 (0.019–28.41)
σ_m^2	–	0.33±0.04 (0.031–0.68)	1.42±0.64 (0.032–5.96)	–	0.29±0.02 (0.037–0.65)	0.66±0.20
σ_{am}	–	–	-3.49±2.11 (-17.50–0.28)	–	–	-1.26±0.76
σ_c^2	–	–	–	0.24±0.03 (0.000–0.65)	0.24±0.02	0.23±0.02
σ_e^2	1.00±0.00 (0.941–1.06)	1.00±0.00 (0.938–1.07)	0.83±0.12 (0.186–1.07)	0.09±0.72 (0.941–1.06)	1.00±0.97 (0.940–1.07)	0.95±0.05 (0.363–1.09)
σ_p^2	1.25±0.04 (0.95–1.67)	1.91±0.10 (1.157–2.90)	9.18±5.12 (1.096–42.45)	1.58±0.05 (1.065–2.37)	2.04±0.06 (1.248–3.05)	4.15±2.05 (1.071–22.81)
h^2	0.17±0.02 (0.003–0.40)	0.27±0.03 (0.036–0.55)	0.60±0.15 (0.105–1.32)	0.19±0.02 (0.000–0.45)	0.23±0.02 (0.006–0.46)	0.43±0.07 (0.051–1.25)
m^2	–	0.17±0.02 (0.015–0.33)	0.22±0.02 (0.038–0.50)	–	0.14±0.95	0.19±0.02
r_{am}	–	–	-0.90	–	–	-0.82
c^2	–	–	–	0.14±0.02 (0.000–0.33)	0.11±0.00 (0.003–0.26)	0.10±0.01 (0.000–0.27)
h_t^2	0.17±0.02 (0.003–0.40)	0.35±0.03 (0.113–0.61)	0.31±0.09 (-0.007–0.78)	0.19±0.02 (0.000–0.45)	0.30±0.02 (0.071–0.51)	0.20±0.05 (-0.011–0.73)
t_m	–	0.24	0.04	0.19	0.31	0.16
-2logL	11993.90	12365.34	12302.49	12046.41	12094.26	12164.26

* σ_a^2 , σ_c^2 , σ_e^2 and σ_p^2 are additive direct, maternal permanent environmental, residual variance and phenotypic variance, respectively; h^2 is heritability; c^2 is σ_c^2/σ_p^2 ; t_m is maternal across year repeatability for ewe performance; h_t^2 is total heritability and log L is log likelihood for the model obtained from BLUPF90.

*Table 4. Estimates of (co)variance components and genetic parameters for neonatal mortality in Marwari sheep

Items ⁺	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
σ^2_a	0.10±0.00 (0.000–0.27)	0.10±0.01 (0.006–0.30)	0.20±0.04 (0.016–0.47)	0.08±0.01 (0.009–0.22)	0.13±0.02 (0.042–0.27)	0.30±0.05 (0.088–0.61)
σ^2_m	–	0.11±0.00 (0.026–0.23)	0.22±0.04 (0.042–0.51)	–	0.10±0.03 (0.009–0.22)	0.18±0.03 (0.021–0.38)
σ_{am}	–	–	–0.19±0.03 (–0.423–0.02)	–	–	–0.18±0.02 (–0.384–0.04)
σ^2_c	–	–	–	0.07±0.01 (0.003–0.17)	0.04±0.02 (0.000–0.15)	0.04±0.02 (0.000–0.16)
σ^2_e	1.00±0.00 (0.944–1.06)	1.00±0.00 (0.944–1.06)	1.00±0.00 (0.941–1.05)	1.00±0.00 (0.947–1.06)	1.00±0.00 (0.949–1.08)	1.00±0.00 (0.950–1.07)
σ^2_p	1.10±0.00 (0.958–1.29)	1.22±0.01 (1.031–1.46)	1.23±0.03 (1.033–1.50)	1.15±0.02 (1.014–1.33)	1.29±0.02 (1.123–1.45)	1.34±0.05 (1.116–1.59)
h^2	0.09±0.00 (0.000–0.21)	0.08±0.00 (0.005–0.21)	0.16±0.03 (0.015–0.32)	0.07±0.01 (0.008–0.17)	0.10±0.01 (0.031–0.19)	0.21±0.03 (0.071–0.38)
m^2	–	0.09±0.00 (0.022–0.17)	0.17±0.03 (0.041–0.35)	–	0.08±0.02 (0.008–0.17)	0.13±0.02 (0.017–0.26)
r_{am}	–	–	–0.91	–	–	–0.77
c^2	–	–	–	0.06±0.00 (0.003–0.13)	0.03±0.01 (0.000–0.11)	0.03±0.02 (0.000–0.11)
h^2_t	0.09±0.00 (0.000–0.21)	0.13±0.00 (0.024–0.25)	0.02±0.01 (–0.014 – 0.09)	0.07±0.01 (0.008–0.17)	0.14±0.01 (0.060–0.22)	0.08±0.03 (0.004–0.19)
t_m	–	0.11	0.06	0.08	0.14	0.08
–2logL	13398.76	13360.44	13280.54	13364.25	13291.38	13310.81

* σ^2_a , σ^2_c , σ^2_e and σ^2_p are additive direct, maternal permanent environmental, residual variance and phenotypic variance, respectively; h^2 is heritability; c^2 is σ^2_c/σ^2_p ; t_m is maternal across year repeatability for ewe performance; h^2_t is total heritability and log L is log likelihood for the model obtained from BLUPF90.

2009). The moderate estimate is indicative of the scope for selection for the better lamb survivability, if breeding program is targeted in this direction.

The genetic analysis of Marwari sheep for neonatal mortality revealed low additive genetic variance. Model 3 was the best model as per LRT for explaining the genetic estimates of (co)variance (Table 4). Analysis revealed that the estimate of h^2 was 0.16±0.03, that was highly inflated due to negative and high r_{am} (–0.91). Therefore unbiased estimates of heritability was obtained ($h^2_T=0.02±0.01$), which resulted in low genetic variance. Results indicate no further scope for improvement of this trait through direct selection in Marwari sheep. Maternal genetic effect was found to be equivalent to the direct genetic effect in magnitude. Higher models explained 3 to 6% of the phenotypic variance due to maternal permanent environment effect (c^2). Similar to current study, the low estimates of h^2 were also reported by several workers for lamb survival at birth (Safari *et al.* 2005, Maxa *et al.* 2009, Cloete *et al.* 2009, Vatankhan 2013, Everett-Hincks *et al.* 2014). Our study on Chokla sheep also reported low estimate of h^2 (0.05±0.00) for neonatal mortality (Gowane *et al.* 2018). The lamb survival being a composite trait with multitude of factors leading to outcome is bound to have huge residual component of variance leading to low estimates of heritability (Riggio *et al.* 2008). Although

improving a lamb’s survival is of a great significance in breeding flock, the potential for genetic improvement through within flock selection is minimum due to low heritability estimates. However, Marwari sheep revealed moderate estimate of maternal effect for lamb survival up to one month. In contrast to our finding, low estimates of maternal effect (m^2 and c^2) were observed for lamb survival till 24 h (Maxa *et al.*, 2009), till 1 month (Vatankhah and Talebi 2009), till 3 days or till weaning (Everett-Hincks *et al.* 2014) and from birth to 1 year (Vatankhah 2013). Significant maternal components (0.26 for m^2 and 0.14 for c^2) were reported by Cloete *et al.* (2009) for lamb survival at birth that persisted till weaning. Current study indicates the importance of maternal effect, for accurate estimates of genetic parameters. Including the maternal heritability along with direct heritability can be useful for positive genetic selection of the lamb survival in Marwari sheep.

In our study high and unfavorable estimates (–0.91) of direct-maternal genetic correlations for lamb survival (r_{am}) were observed for neonatal mortality or lamb survival up to 28 days post birth in Marwari sheep. Similar unfavorable estimates of r_{am} were also reported earlier such as –0.74 by Everett-Hincks *et al.* (2005), –0.75 by Welsh *et al.* (2006), –0.60 to –0.61 by Cloete *et al.* (2009), –0.52 to –0.79 by Maxa *et al.* (2009) in Texel and Shropshire sheep, –0.59 to –0.96 in Avikalin, Malpura and Chokla sheep by Gowane

et al. (2018). The direct-maternal genetic correlations for lamb survival were also reported to be within a range of -0.03 to -0.34 (Lopez-Villalobos and Garrick 1999, Morris *et al.* 2000). High negative correlation between animal and dam's direct effects should have (co)evolutionary reasons. The genes of lamb and the dam do not seem to have coherence for lamb survival. Looking in to the evolutionary perspective, it seems that dam has a significant drain on her energy resources for the new born lamb in terms of milk and other maternal care. Thus it would always be beneficial for the dam if she gets rid of the lamb as soon as possible so that she can divert the resources for her own benefit. This genomic urge to get rid of the newborn might have set the high and negative correlation between dam and lamb's genes for lamb survival.

In the arid region, the incidence of neonatal mortality was low, indicating favorable environment for lamb survival, good genetics as well as better management practices carried out at the farm. Our study concludes the complex nature of the neonatal mortality in sheep. Underlying quantitative scale of this trait makes it further susceptible to be affected by many genetic and non-genetic factors. Apart from year-to-year variation, special care to the lambs born with low weight and born to dams with low weight and during their first parity is required to reduce the lamb losses. Although the flock has standard level of lamb survival, existence of moderate genetic variance assures genetic improvement through selection in Magra but not in Marwari sheep.

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