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Genetic and Non-genetic Factors Affecting Mortality in Lori-Bakhtiari Lambs

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ABSTRACT : Data and pedigree information for Lori-Bakhtiari sheep used in this study were 6,239 records of lamb mortality from 246 sires and 1,721 dams, collected from 1989 through 2007 from a Lori-Bakhtiari flock at Shooli station in Shahrekord. The traits investigated were cumulative lamb mortality from birth up to 7 days, up to 14 days, up to 21 days, and up to 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 months of age. The models included fixed factors that had significant effects and random direct genetic, maternal genetic and maternal permanent environmental effects. Variance components were estimated using the restricted maximum likelihood procedure applying three animal models with and without maternal and common environmental effects. The overall mean of cumulative lamb mortality rate was 22.95% from birth to 1 year of age, while the overall mortality rate up to 3 and from 3 to 6 months of age was 6.14% and 12.76%, respectively. The mortality rate after 6 months of age declined as the lambs grew older. The age of dam had no important effect on lamb mortality. The type of birth was more important during the preweaning period than at later ages, and lamb mortality rate was higher in twins. The year of birth, month of birth and sex of lamb significantly ($p\leq 0.01$) affected the cumulative lamb mortality rate at all ages. The least square mean of mortality during the final one-third of the lambing period was higher than the first and middle one-third of the lambing period. Male lambs were found to be at a higher risk of mortality than females. Birth weight of the lamb had a highly significant ($p\leq 0.01$) effect on lamb mortality at all ages as a quadratic regression. Direct and maternal heritability estimates of lamb mortality ranged from 0.01 to 0.13 and 0.01 to 0.05, respectively. Direct heritability increased with age of lamb, while maternal effects (genetic and common environmental) were important in the preweaning period. These results indicate that lamb mortality can be reduced first through farm management practices and secondly by genetic selection. Both animal and maternal effects should be considered in breeding programmes for reducing lamb mortality at preweaning. (**Key Words :** Heritability, Non-genetic Factors, Lamb Mortality, Lori-Bakhtiari Sheep)

INTRODUCTION

Improved ewe productivity is a major objective for the sheep industry in Iran. This objective can be achieved by increasing the number of lambs successfully reared per ewe in a given year. Lamb mortality is the major cause of lower productivity of sheep. Diseases are a major cause of lamb mortality and low productivity in sheep (Yapi et al., 1990). Fogarty et al. (1985) reported the survival of lambs from birth to weaning to be a major factor affecting the number of lambs weaned per lambing and found it to be highly correlated with lamb weight weaned per lambing. Several studies have shown that approximately 5-59% of lambs die by 1 year of age in different agro-climatic conditions with neonatal lambs being at greater risk (Yapi et al., 1990; Green and Morgan, 1993; Nash et al., 1996; Mukasa-Mugerwa et al., 2000; Sawalha et al., 2007).

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Lori-Bakhtiari sheep are one of the most common native breeds in the south-western part of Iran (the Zagros Mountains), with a population of more than 1.7 million head having the largest fat-tail size among all breeds in Iran. The animals are mostly kept in villages under a semi-intensive system. The Ministry of Jahad-Agriculture in Iran has found it important to increase the efficiency of sheep production, because the output of sheep in this system is low (Vatankhah, 2005). Due to the fact that reproductive traits (e.g. number of lambs weaned per ewe exposed) were the most important in all sheep production systems (Gallivan, 1996; Vatankhah, 2005), increasing the efficiency of sheep production (output) by improving reproductive traits is economically important.

A significant reduction in lamb mortality rate increases the profitability at farm level which can be achieved by identifing the genetic and non-genetic factors that influence lamb mortality and including them in breeding programmes. Lamb mortality is a complex trait that is influenced by the ewe's maternal ability and the lamb's capability for survival, in addition to management practices and environmental variables at the time of birth and during the rearing period (Morris et al., 2000; Southey et al., 2001). Various studies have reported how lamb mortality is influenced by fixed effects such as age of dam, type of birth, sex of lamb, season and year of birth, birth weight, body weight of dam and rearing system (Morris et al., 2000; Mandal et al., 2007; Sawalha et al., 2007). Estimates of heritability published in the literature for lamb mortality are mostly small and within the range of 0.00 to 0.11 (Fogarty, 1995; Lopez-Villalobos and Garrick, 1999). The main objective of this study was to estimate genetic and non-genetic factors affecting mortality in Lori-Bakhtiari lambs at different ages.

MATERIALS AND METHODS

Data and flock management

The data used in this study were collected from 6,239 lambs born between 1989 and 2007, with the lambs under investigation being the progeny of 246 rams and 1,721 ewes from a Lori-Bakhtiari research flock at Shooli station in Shahrekord. The flock was managed under a semi-migratory or village system. The flock was generally kept from December to May at the station and during this period was fed alfalfa, barley and wheat stubble indoors. The sheep grazed on rangeland and cereal pastures during the rest of the year. The breeding period extended from late August to late October (ewes were assigned randomly to the rams) and consequently, lambing started in late January. Lambs suckled their mothers and from 15 days of age they had access to creep feed *ad-libitum* and they were weaned at an average age of 90±5 days. After weaning male and female lambs were separated. Male lambs chosen for fattening were separated from the rest of the animals. Female lambs were kept on a pasture of cultivated alfalfa, while the rest of the males were kept indoors and fed a maintenance and growth ration to 12 months of age. The animals were monitored daily and dates of death of lambs were recorded. Traits studied were cumulative lamb mortality from birth up to 7 days, up to 14 days, up to 21 days, and up to 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 months of age.

Statistical analysis

For each time of mortality, a lamb attained a score of 1 if it died during this period and 0 if otherwise. The GLM procedure of SAS (1996) was applied to identify important fixed effects to be considered in the final model. The statistical model included age of dam, month of birth, type of birth, sex of lamb and year of birth. All the two-way interaction effects were included in the initial model. The birth weight of the lamb and weight of the ewe at lambing were fitted as linear and quadratic covariate in the model. All non-significant interaction effects were removed from the final model, which was as follows:

$$y_{ijklmn} = \mu+AD_i+MB_j+TB_k+SL_l+YB_m+b_1(X_{ijklmn}-X_{000000}) +b_2(X_{ijklmn}-X_{000000})^2+MBYB_{jm}+TBYB_{km} +MBTB_{jk}+e_{ijklmn}$$

Where, y_{ijklmn} is the record for the *n*th lamb; μ is the overall mean; AD_i is the effect of *i*th age of dam ($\leq$2, 3, 4, 5, 6 and $\geq$7); MB_j is the effect of *j*th month of birth (Jan-Feb, Feb-March, March-April); TB_k is the effect of *k*th type of birth (Single, Twin); SL_l is the effect of *l*th sex of lamb (Male, Female); YB_m is the effect of *m*th year of birth (1989 to 2007); b_1 is the linear regression coefficient for weight of lamb; b_2 is the quadratic regression coefficient for weight of lamb; X_{ijklmn} is the birth weight of *n*th lamb; $MBYB_{jm}$ is the interaction between *j*th month of birth with *m*th year of birth; $TBYB_{km}$ is the interaction between *k*th type of birth with *m*th year of birth; $MBTB_{jk}$ is the interaction between *j*th month of birth with *k*th type of birth and e_{ijklmn} is the residual error.

Variance components were estimated from an animal model in a univariate analysis using the restricted maximum likelihood method (WOMBAT program of Meyer, 2006). Three different animal models (M_1, M_2 and M_3) with and without maternal and common environmental effects were used. Each random effect was tested using log likelihood ratio tests after including the effect (excluding residual) to the fixed effects model. An effect was considered in the model when the model had a larger log likelihood value compared with other alternate models. A Chi-square distribution for α = 0.05 and appropriate degree of freedom was used as the critical test statistic. When -2 times the difference between log likelihood was greater than the critical value the inclusion of the effect was considered significant. When differences between log likelihoods were not significant the model with the fewest random effects was chosen. The following univariate animal models were fitted:

$$\mathbf{y = Xb+Z_1a+e} \quad (M_1)$$

$$\mathbf{y = Xb+Z_1a+Z_2m+e} \quad (M_2)$$

$$\mathbf{y = Xb+Z_1a+Z_2m+Z_3c+e} \quad (M_3)$$

where, **y**, **b**, **a**, **m**, **c** and **e** are the vectors of observations, fixed effects, direct additive genetic effects, maternal additive genetic effects, maternal common environmental effects and residual random effects, respectively. Incidence matrices **X**, $\mathbf{Z_1}$, $\mathbf{Z_2}$ and $\mathbf{Z_3}$ related the observations with the respective effects. The average information (AI) REML algorithm was use to maximize the likelihood (convergence

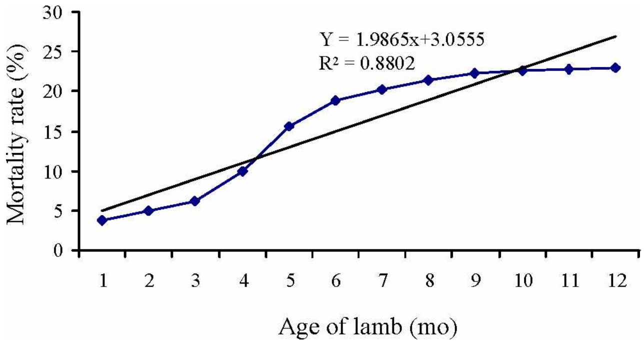

Figure 1. Cumulative mortality pattern from 1 up to 12 months of age in Lori-Bakhtiari lambs.

criterion was 10^{-8}) and additional restarts were performed until no further improvement in log likelihood occurred (Rashidi et al., 2008).

RESULTS AND DISCUSSION

Mortality pattern

The pattern of cumulative mortality in Lori-Bakhtiari lambs from 1 to 12 months of age is depicted in Figure 1. The overall mean of lamb mortality rate was 22.95% from birth to 1 year of age (1.99% per month). With respect to overall mortality of the flock, 6.14%, 12.76%, 3.36% and 0.69% of lambs died before 3 months of age, during 3 and 6 months, 6 and 9 months, and 9 and 12 months of age, respectively. The overall rate of lamb mortality recorded in this study was in range in the literature for different breeds of sheep (Yapi et al., 1990; Green and Morgan, 1993; Nash et al., 1996; Mukasa-Mugerwa et al., 2000; Mandal et al., 2007; Sawalha et al., 2007). These values were lower when compared to values obtained for some sheep breeds such as Menz and Horro (Mukasa-Mugerwa et al., 2000). The overall lamb losses up to 7 days were lower (1.94%) than rates reported for Menz, Horro and Muzaffarnagari breeds (Mukasa-Mugerwa et al., 2000; Mandal et al., 2007). The overall mortality rate up to 3 months of age was 6.14%, which is in accordance to Muzaffaranagari sheep (Mandal et al., 2007), but is the lowest mortality limit reported (6.8% to 28.8%) compared to some sheep breeds such as Menz, Horro and Muzaffarnagari (Mukasa-Mugerwa et al., 2000; Mandal et al., 2007). The highest mortality rate occurred during 3 to 6 months of age (4.25% per month), which is in accordance with values reported for Menz and Horro sheep (Mukasa-Mugerwa et al., 2000), but higher than values reported for some breeds of sheep such as Scottish Blackface and Muzaffarnagari (Sawalha et al., 2007; Mandal et al., 2007). This is due to extreme environmental changes in this period, because lambs were weaned at 90±5 days of age and weaned lambs were kept on a pasture of cultivated alfalfa. The mortality rate of the surviving lambs substantially decreased after 6 months of age.

Estimates of non-genetic factors on lamb mortality

The least-squares means for cumulative mortality of lambs for different levels of non-genetic factors at different ages are shown in Table 1 and 2. The lamb losses were higher in lambs born to the younger and older ewes compared to 5-year-old ewes; however, these differences were not significant ($p>0.05$) for all age groups except up to 4 and 5 months of age. Smith (1977) reported that yearling ewes had lambs with smaller birth weight, lower vigor, and higher mortality rates than lambs from older ewes. Ewe age effects on lamb mortality have been shown to reduce lamb mortality with increasing ewe age (Southey et al., 2001; Sawalha et al., 2007), although Morris et al. (2000) showed slight decreases in survival of lambs born to ewes greater than 5 years of age.

Month of birth had a significant effect ($p\leq0.01$) on lamb mortality at all ages. Sawalha et al. (2007) found a similar effect for month of birth in Scottish Blackface sheep. The least square means of lamb mortality increased with month of birth at all ages; however, the differences between these values were not significant ($p>0.05$) for the first and middle one-third of the lambing period (Jan-Feb and Feb-March), but significant ($p<0.05$) during the final one-third of the lambing period (March-April). On the other hand, mortality rates were highest for lambs that were born in the final month of the parturition period of ewes. This may be attributed to poor management at the end of the lambing period and that ewes with low body condition conceived at the end of the breeding period.

Type of birth had a significant ($p\leq0.05$) effect on lamb mortality from birth to 4 months of age. Twin-born lambs had higher least square mean mortality rates than singletons, but these differences between twins and singletons were not significant ($p>0.05$) from 5 to 12 months of age. Birth weights are normally lower for lambs born in larger litters (Smith, 1977; Morris et al., 2000; Sawalha et al., 2007) and therefore these lambs may be at greater risk of illnesses. Lambs born to multiple litters may also have higher mortality due to limitation in milk production by the dam, either as a result of low genetic potential for milk production or restricted nutrient intake in limiting environments (Snowder and Knight, 1995). The smaller difference of mortality rates between twins and singletons after 4 months of age was attributed to lack of dependence of the lamb on mother's milk.

Male lambs were found to have a significantly ($p\leq0.01$) higher mortality rates than females at all ages. The higher mortality in male lambs compared to females is in agreement with other findings (Nash et al., 1996; Mukasa-Mugerwa et al., 2000; Sawalha et al., 2007; Mandal et al., 2007). Higher mortality in male lambs may be due to sex-linked determinants which have not yet been identified (Mandal et al., 2007).

Table 1. Least-squares means (%) of cumulative lamb mortalities for different levels of non-genetic factors during the period from birth to 4 months of age in Lori-Bakhtiari sheep

Effects	n	Up to 7 d	Up to 14 d	Up to 21 d	Up to 1 mo	Up to 2 mo	Up to 3 mo	Up to 4 mo
Overall mean	6,239	1.94±0.17	2.87±0.21	3.27±0.22	3.77±0.24	4.90±0.27	6.14±0.29	9.95±0.35
Age of ewe		NS	NS	NS	NS	NS	NS	*
≤2	1,645	2.09±0.47	3.33±0.57	4.03±0.61	4.87±0.65	6.56±0.74	8.62±0.81	13.42±0.96^{b}
3	1,331	2.90±0.47	4.14±0.56	4.62±0.60	5.33±0.64	6.87±0.73	9.04±0.79	14.32±0.95^{ab}
4	1,239	2.36±0.47	3.45±0.56	4.25±0.60	5.10±0.64	6.93±0.72	8.73±0.79	13.65±0.94^{b}
5	938	1.94±0.52	3.11±0.63	3.56±0.67	4.30±0.72	5.81±0.81	7.57±0.89	12.99±1.06^{b}
6	676	3.29±0.59	4.50±0.71	5.13±0.76	5.96±0.82	7.36±0.92	9.93±1.01	16.45±1.20^{a}
≥7	410	3.38±0.74	4.90±0.89	5.89±0.95	6.42±1.01	9.28±1.15	11.38±1.25	17.21±1.49^{a}
Month of birth		**	**	**	**	**	**	**
Jan-Feb	2,827	1.43±0.40^{b}	2.72±0.49^{b}	3.22±0.52^{b}	3.99±0.56^{b}	5.39±0.63^{b}	5.84±0.69^{b}	7.57±0.82^{c}
Feb-March	2,752	1.92±0.37^{b}	2.74±0.45^{b}	3.08±0.48^{b}	3.57±0.51^{b}	5.40±0.58^{b}	6.26±0.63^{b}	9.96±0.75^{b}
March-April	660	4.63±0.79^{a}	6.26±0.96^{a}	7.45±1.02^{a}	8.43±1.09^{a}	10.61±1.20^{a}	15.53±1.35^{a}	26.49±1.60^{a}
Type of birth		*	*	*	**	**	*	**
Single	4,388	2.01±0.35^{b}	3.11±0.42^{b}	3.61±0.45^{b}	4.25±0.48^{b}	5.71±0.55^{b}	8.22±0.60^{b}	12.55±0.71^{b}
Twin	1851	3.31±0.54^{a}	4.70±0.65^{a}	5.55±0.69^{a}	6.40±0.74^{a}	8.56±0.84^{a}	10.21±0.92^{a}	16.80±1.09^{a}
Sex of lamb		**	**	**	**	**	**	**
Male	3,135	3.16±0.37^{a}	4.54±0.45^{a}	5.27±0.47^{a}	6.21±0.51^{a}	8.21±0.57^{a}	10.66±0.63^{a}	16.54±0.75^{a}
Female	3,104	2.16±0.38^{b}	3.27±0.46^{b}	3.90±0.49^{b}	4.45±0.52^{b}	6.06±0.59^{b}	7.77±0.65^{b}	12.80±0.77^{b}
Year of birth		NS	*	*	*	**	**	**
Birth weight of lamb[1]		**	**	**	**	**	**	**
Linear		-12.82±1.90	-19.15±2.30	-18.86±2.44	-19.79±2.61	-22.73±2.95	-24.10±3.23	-29.73±3.82
Quadratic		1.13±0.19	1.72±0.23	1.68±0.25	1.74±0.27	2.00±0.30	2.10±0.33	2.63±0.39

Means with different superscripts (a-c) are significantly different (p≤0.05) from each other.
NS = Not significant (p≤0.05). * Significant (p≤0.05). ** Significant (p≤0.01).
[1] Regression coefficient of mortality on birth weight of lamb.

Table 2. Least-squares means (%) of cumulative lamb mortalities for different levels of non-genetic factors during the period from 4 to 12 months of age in Lori-Bakhtiari sheep

Effects	n	Up to 5 mo	Up to 6 mo	Up to 7 mo	Up to 8 mo	Up to 9 mo	Up to 10 mo	Up to 11 mo	Up to 12 mo
Overall mean	4,079	15.57±0.54	18.90±0.57	20.25±0.59	21.50±0.60	22.26±0.61	22.62±0.62	22.80±0.62	22.95±0.62
Age of ewe		*	NS	NS	NS	NS	NS	NS	NS
≤2	1,075	20.26±1.46^{b}	22.52±1.56	24.55±1.60	25.72±1.64	26.06±1.67	26.28±1.68	26.56±1.68	26.54±1.69
3	895	21.25±1.44^{b}	23.43±1.54	25.30±1.57	26.02±1.61	26.37±1.64	26.61±1.65	27.04±1.65	27.31±1.66
4	829	20.24±1.44^{b}	23.08±1.54	24.57±1.58	25.29±1.62	26.16±1.65	26.78±1.66	26.95±1.66	26.90±1.67
5	610	18.21±1.62^{b}	20.77±1.73	22.96±1.78	23.75±1.82	24.16±1.85	24.56±1.86	24.82±1.87	24.95±1.87
6	448	22.05±1.83^{ab}	24.83±1.96	26.37±2.01	26.61±2.06	28.23±2.09	28.48±2.11	28.59±2.11	28.79±2.12
≥7	222	27.46±2.46^{a}	29.70±2.64	31.77±2.70	31.65±2.77	32.15±2.81	32.10±2.83	32.21±2.84	32.23±2.84
Month of birth		**	**	**	**	**	**	**	**
Jan-Feb	1,949	16.12±1.18^{b}	19.79±1.26^{b}	20.66±1.30^{b}	21.77±1.39^{b}	23.02±1.35^{b}	23.42±1.36^{b}	23.57±1.36^{b}	23.68±1.36^{b}
Feb-March	1,762	18.27±1.08^{b}	20.27±1.15^{b}	20.81±1.18^{b}	21.53±1.33^{b}	22.06±1.23^{b}	22.61±1.24^{b}	22.73±1.24^{b}	23.03±1.25^{b}
March-April	368	30.34±1.08^{a}	32.10±2.49^{a}	35.87±2.56^{a}	35.83±2.62^{a}	36.11±2.66^{a}	36.01±2.68^{a}	36.39±2.68^{a}	36.39±2.68^{a}
Type of birth		NS	NS	NS	NS	NS	NS	NS	NS
Single	2,958	21.68±1.08	23.88±1.16	26.08±1.19	26.68±1.22	27.20±1.23	27.60±1.24	27.71±1.25	27.89±1.25
Twin	1,121	21.48±1.48	24.23±1.59	25.76±1.63	26.33±1.67	27.18±1.70	27.34±1.71	27.69±1.71	27.69±1.71
Sex of lamb		**	**	**	**	**	**	**	**
Male	1,593	27.51±1.21^{a}	30.31±1.29^{a}	32.05±1.33^{a}	32.41±1.36^{a}	32.98±1.38^{a}	33.35±1.39^{a}	33.62±1.39^{a}	33.83±1.40^{a}
Female	2,486	15.64±1.12^{b}	17.80±1.20^{b}	19.79±1.23^{b}	20.60±1.26^{b}	21.40±1.28^{b}	21.59±1.29^{b}	21.77±1.29^{b}	21.77±1.30^{b}
Year of birth		**	**	**	**	**	**	**	**
Birth weight of lamb[1]		**	**	**	**	**	**	**	**
Linear		-33.84±6.07	-33.62±6.50	-33.83±6.67	-34.31±6.83	-35.70±6.93	-36.92±6.98	-38.09±6.98	-37.71±7.01
Quadratic		2.73±0.62	2.70±0.66	2.65±0.68	2.69±0.70	2.78±0.71	2.88±0.71	3.01±0.71	2.96±0.72

Means with different superscripts (a-c) are significantly different (p≤0.05) from each other.
NS = Not significant (p≤0.05). * Significant (p≤0.05). ** Significant (p≤0.01) respectively.
[1] Regression coefficient of mortality on birth weight of lamb.

Table 3. Genetic parameter estimates for lamb mortalities fitting most appropriate model (Bold) during the period from birth to 12 months of age in Lori-Bakhtiari sheep

Mortality of lamb	M1		M2			M3			
	h_a^2 ±SE	Log L	h_a^2 ±SE	h_m^2 ±SE	Log L	h_a^2 ±SE	h_m^2 ±SE	c_m^2 ±SE	Log L
Up to 7 d	0.02±0.01	9,184.79	0.01±0.01	0.04±0.01	9,190.00	**0.01±0.01**	**0.01±0.01**	**0.04±0.01**	**9,198.16**
Up to 14 d	0.03±0.01	7,999.13	0.01±0.01	0.04±0.01	8,000.95	**0.01±0.01**	**0.01±0.01**	**0.04±0.01**	**8,008.75**
Up to 21 d	0.05±0.01	7,603.11	**0.02±0.01**	**0.05±0.01**	**7,612.07**	0.01±0.01	0.02±0.01	0.04±0.01	7,613.46
Up to 1 mo	0.04±0.01	7,171.00	**0.01±0.01**	**0.04±0.01**	**7,178.89**	0.01±0.01	0.01±0.01	0.04±0.01	7,179.62
Up to 2 mo	0.07±0.02	6,412.15	**0.03±0.01**	**0.03±0.01**	**6,420.07**	0.03±0.01	0.01±0.01	0.03±0.01	6,420.27
Up to 3 mo	0.09±0.02	5,802.20	**0.05±0.02**	**0.02±0.01**	**5,809.82**	0.05±0.01	0.01±0.01	0.02±0.01	5,809.95
Up to 4 mo	**0.12±0.02**	**4,572.54**	0.10±0.02	0.02±0.01	4,573.85	0.09±0.02	0.01±0.01	0.01±0.01	4,574.07
Up to 5 mo	**0.12±0.03**	**2,177.67**	0.08±0.03	0.04±0.02	2,180.80	0.07±0.02	0.01±0.01	0.06±0.02	2,183.73
Up to 6 mo	**0.12±0.03**	**1,933.16**	0.11±0.03	0.01±0.01	1,933.41	0.09±0.03	0.00±0.01	0.03±0.02	1,934.77
Up to 7 mo	**0.10±0.02**	**1,821.36**	0.08±0.02	0.01±0.01	1,821.69	0.07±0.02	0.00±0.01	0.04±0.02	1,823.98
Up to 8 mo	**0.10±0.02**	**1,718.37**	0.08±0.02	0.01±0.01	1,718.47	0.07±0.02	0.00±0.01	0.03±0.02	1,720.00
Up to 9 mo	**0.11±0.02**	**1,663.61**	0.10±0.02	0.01±0.01	1,663.62	0.08±0.02	0.00±0.01	0.03±0.02	1,665.04
Up to 10 mo	**0.12±0.03**	**1,639.95**	0.11±0.03	0.01±0.01	1,640.04	0.09±0.02	0.00±0.01	0.03±0.02	1,641.87
Up to 11 mo	**0.13±0.02**	**1,630.72**	0.11±0.03	0.01±0.01	1,630.86	0.09±0.02	0.00±0.01	0.03±0.02	1,632.65
Up to 12 mo	**0.13±0.02**	**1,620.78**	0.11±0.03	0.01±0.01	1,620.81	0.09±0.02	0.00±0.01	0.03±0.02	1,622.37

h_a^2 = Direct heritability; h_m^2 = Maternal heritability; c_m^2 = Maternal common environmental variance as proportion of phenotypic variance.

The least square means of mortality for different years of birth at different ages was omitted from the results as it was thought to be of less interest and hence excluded from Table 1 and 2. However, there was significant ($p \leq 0.01$) variation in lamb losses between years, but no clear trend in mortality rate was observed for the 18 years of study. These significant variations from birth to 12 months of age in different years may be attributed to variation in the environmental conditions, differences in feed availability and other managerial factors. Similarly, Berhan and Van Arendonk (2006) and Mandal et al. (2007) observed significant effects of year of birth for lamb mortality rates.

This study also revealed a quadratic relationship between birth weight and lamb mortality rate (Tables 1 and 2), with lower rates of mortality initially associated with increases in birth weight until birth weight eventually reached a level associated with increased dystocia. This intermediate optimum range for birth weight has been presented in many evaluations of lamb survival (Smith, 1977; Lopez-Villalobos and Garrick, 1999; Morris et al., 2000; Sawalha et al., 2007). Smith (1977) concluded that birth weight had a large influence with most early deaths occurring in lambs with birth weights below the mean. Morris et al. (2000) found similar results with a larger proportion of dead lambs with light birth weights. One possible explanation for the elevated mean mortality rate at birth for lambs with the smallest birth weight is hypothermia, whilst dystocia can be a cause of mortality for lambs with the heaviest birth weights (Sawalha et al., 2007). Consequently, selection for optimal birth weight, rather than maximum birth weight, should be practiced when viability and birth weight are to be improved simultaneously.

Genetic parameter estimates

Genetic parameter estimates for lamb mortalities fitting the most appropriate model (in bold) from log-likelihood ratio tests during the period from birth to 12 months of age are given in Table 3. Model 3, which included a direct genetic effect, a maternal genetic effect and a maternal common environmental effect, was the most appropriate model for lamb mortality rate from birth to 14 days of age. The maternal common environmental effect (c_m^2) in this period was 4 times direct and maternal heritability, indicating that to reduce lamb mortality from birth up to 14 days of age, non-additive genetic effects should be improved. Model 2, which included a direct as well as maternal genetic effect, was the most appropriate model for lamb mortality rate from 21 days to 3 months of age. Model 1, which included a direct genetic effect, was the most appropriate model for lamb mortality rate from 3 to 12 months of age. The comparison between direct heritability and maternal effects (genetic and common environmental) showed that the maternal effect had more influence on lamb mortality at birth to 2 months of age, while direct genetic effects from 3 to 12 months of age were larger than maternal effects. This pattern is in agreement with other findings in different breeds of sheep (Morris et al., 2000; Southey et al., 2001; Southey et al., 2003; Sawalha et al., 2007). Direct heritability estimates ranged from 0.01 to 0.13 and increased with age of lamb, while maternal heritability estimates changed from 0.00 to 0.05 and decreased with age of lamb. Heritability estimates for lamb mortality similar to results of this study ranged from 0.00 to 0.11 in different breeds of sheep (Fogarty, 1995; Safari et al., 2005). As reducing lamb mortality has a great economical importance, because its heritability estimate, especially for preweaning mortality rate, is low, the potential for genetic improvement by within-flock selection would be less effective (Zhu et al., 2008).

CONCLUSION

The present investigation revealed environmental effects such as weather and management, as well as other non-genetic factors like ewe age, month of birth, birth type, litter size, sex of lamb, and birth weight have a large impact on lamb mortality. Lamb mortality at all ages is a heritable trait, but estimates of direct heritability were low. Maternal effects (genetic and environmental) were important for preweaning lamb mortality. In practice, management strategies should be employed when possible to preferentially treat lambs that are born in these unfavorable non-genetic groups in order to reduce lamb mortality rates. To reduce lamb mortality by genetic means, selection indices should include lamb mortality as a trait of the lamb and the dam together.

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