Genetic parameters for ewe rearing performance

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ABSTRACT: This paper reports genetic parameters for ewe performance traits in sheep breeders’ flocks in New Zealand. Animal performance records from the AgResearch Lamb Survival Database and from Sheep Improvement Limited were used to generate data sets from 3 lambing years (2003 to 2005) in 24 flocks, and involving 31,651 ewes and many breeds and breed compositions (predominantly Romney, Coopworth, and Texel). The heritabilities and repeatabilities for the litter survival traits were very low. Litter weight traits had heritabilities ranging from 0.12 for BW of lamb weaned to 0.28 for total triplet litter weight at birth and repeatabilities ranging from 0.18 to 0.29. The repeatabilities of BCS and maternal behavior score were low to moderate. This study showed that there is little to be gained from including litter survival in sheep selection programs because heritabilities and repeatabilities for the litter survival traits were very low. However, genetic gains in BCS, maternal behavior score, litter weight at birth, and litter weight weaned are possible in this population. Incorporating these traits into sheep selection programs warrants investigation to improve ewe and therefore flock performance.

Key words: body condition, genetic parameter, lamb rearing ability, lamb survival, sheep

INTRODUCTION

In New Zealand, many sheep breeders have selected and bred ewes for increased fecundity over the last 2 decades because improved lambing percentage per ewe exposed to the ram is the biggest contributor to greater profits on New Zealand sheep farms (Geenty, 1997). The national mean lambing percentage (lambs weaned per ewe joined) in 2006 was 130%, which was significantly greater than the 2002 season record of 117% (Anonymous, 2006). Davis et al. (1983) reported that triplets replace singles as litter size increases above 1.7 lambs per ewe. The increased proportion of ewes having triplets is of concern to farmers and to industry as lamb mortality is greatest in triplets (Amer et al., 1999; Everett-Hincks and Dodds, 2008).

Lamb losses of 30% have been recorded between pregnancy scanning and tail docking at about 3 wk of age (Aspin, 1997; Anonymous, 2006). Above a litter size of 2.3 lambs born per ewe lambing, farmers can expect a reduction in farm profitability (Amer et al., 1999). Twin- and triplet-born lambs have greater mortality rates than singles (Johnson et al., 1982; Hinch et al., 1983; Scales et al., 1986; Hall et al., 1988). Many studies emphasize the importance of lamb birth weight, reporting decreased survival to weaning in lambs with BW less than 3 kg at birth (Hight and Jury, 1970; Dalton et al., 1980; Johnson et al., 1982; Nowak and Lindsay, 1992; Everett-Hincks and Dodds, 2008), but overall, the relationship between lambing rate (fecundity) and lamb survival in highly fecund ewes is poorly understood.

Selective breeding has been advocated as a means of improving ewe lamb-rearing ability and lamb survival under pastoral conditions (Haughey, 1983). Selective breeding for ewe lamb-rearing ability, defined as the ratio of lambs weaned to lambs born, has resulted in a reduction in lamb mortality (Haughey, 1983; Cloete and Scholtz, 1998; Everett-Hincks et al., 2005) and a reduction in the interval from standing to suckling (Cloete and Scholtz, 1998).

The ability of the ewe to rear her litter to weaning is determined by the successful execution of several processes. These processes are driven by genetics, management, and the environment. This paper provides an investigation into the genetic parameters for ewe...
performance traits on sheep breeders’ farms in New Zealand and investigates whether genetic improvement is possible as improved performance has economic and animal welfare benefits.

**MATERIALS AND METHODS**

Animal Ethics Committee approval was not obtained for this study because the data were obtained from an existing database.

Animal performance records from the AgResearch Lamb Survival Database and from Sheep Improvement Limited were used to generate data sets from 3 lambing years (2003 to 2005) in 24 flocks, and involving 31,651 ewes and many breeds and breed compositions (predominantly Romney, Coopworth, and Texel). The data have been used to calculate environmental and management factors as traits of the lamb and were reported in Everett-Hincks and Dodds (2008). The data were used in the current study to calculate genetic parameters for ewe performance traits of the pregnant ewe and dam.

All ewes were scored for body condition (1 = emaciated to 5 = grossly fat at 0.5 intervals) at mid-pregnancy (MBCS) and again 2 wk before lambing (PBCS). Body condition scoring has been described by Jeffries (1961). Pasture-fed conditions meant that BCS had a mean of 3 (range 1.5 to 4.5); there were no emaciated or obese ewes, and therefore this trait was treated as a linear variable in all analyses. Maternal behavior score (MBS) was scored on a 5-point scale based on the distance the ewe retreated from her lambs when the farmer was tagging them (1 = ewe flees at the approach of the shepherd and does not return, 5 = ewe stays within 1 m of the shepherd). The MBS has previously been described by O’Connor et al. (1985), Everett-Hincks et al. (2005), and Everett-Hincks and Dodds (2008), where low MBS represented poor mothers and high MBS represented excellent mothers.

The following ewe traits were derived from lamb birth weight and weaning weight records: total litter weight at birth (TLWB, where the lamb weights of a litter of a ewe are summed and recorded in kilograms), average lamb weight at birth (ALWB, where the total litter weight at birth was divided by the number of lambs in the litter and recorded in kilograms) and litter weight of lamb weaned (LWW, where the lamb weights of a litter were summed and recorded in kilograms). The following ewe traits were derived from lamb survival and date of death records: litter survival at birth (LSB), litter survival to 1 d of age (LS1d), litter survival to 3 d of age (LS3d), litter survival to 3 wk of age (LS21d), and litter survival to weaning age (LSW, 100 d). All ewe litter survival traits were measured from birth and calculated by dividing the latter litter size by litter size at birth and recorded as a proportion.

Data from 3 lambing years were edited to remove missing records, and low subclass numbers and records were restricted to lambing ewes. Ewes 2 to 6 yr of age were included, and ewes older than 6 yr were grouped with age group 6. Ewes with litters larger than 3 lambs in a given year were removed. Litters with lambs fostered or hand reared or where the ewe aborted or was assisted with lambing, and litters resulting from embryo transfer breeding programs, were also removed.

Analyses were conducted using GLM (SAS Institute Inc., Cary, NC) to determine the significance of main effects and to define models for the genetic analyses. Main effects tested were contemporary group (farmer by breed by lambing year; some farms had more than one breed and data for up to 3 yr), age of ewe (5 classes as above), litter size, lambing day deviation from the contemporary group mean lambing day, the proportion of male lambs in the litter, and litter weight at birth as a quadratic term within litter size at birth. For LWW and LSW, birth-rearing rank (6 classes, combining litter size at birth and litter size weaned into a composite trait) was an additional effect fitted. All 2-way interactions were fitted, and only those fixed effects and interactions accounting for at least 2% of the total sums of squares were used in the genetic analyses. The large numbers of records in these analyses meant that almost all effects were significant; the 2% threshold was chosen to drop those effects that were not biologically significant. The final model effects for MBCS, PBCS, MBS, TLWB, ALWB, LWW, LSB, LS1d, LS3d, LS21d, and LSW are shown in Table 1. Management practices in the various contemporary groups were not identified, but common practices on sheep farms in New Zealand are to group ewes at lambing by age of ewe or litter size determined before lambing by the use of pregnancy scanning or both. Thus, litter size and age of ewe were nested within contemporary group to account for the possible different grazing groups managed by farmers. Lambing day deviation from the contemporary group mean lambing day was calculated to adjust for possible linear changes in feed availability and climatic conditions as lambing progressed from late winter into spring.

All of the available ancestry data from the 31,651 ewes were used to construct a pedigree file (~387,000 records). Animal-model REML procedures were run with the ASReml package (Gilmour et al., 2006) to derive heritabilities and repeatabilities for each trait from univariate runs, with the models as described in Table 1. Random effects fitted were the direct genetic effect and the permanent environmental effect to account for repeated measures across years. Genetic and phenotypic correlations were estimated from bivariate runs. Genetic parameters were also estimated separately for TLWB in single, twin, and triplet litters with the effect of litter size at birth removed from these models. Litter survivals to 1, 3, and 21 d of age have been omitted from correlation analyses. Predicted means were derived for each subclass of litter size and age of ewe using the predict function in ASReml.
RESULTS

Environmental and Management Effects on Ewe Performance

Ewes 6 yr of age and older had decreased BCS (MBCS and PBCS) and greater, more favorable, MBS than younger ewes (Table 2). Better conditioned ewes had larger litter sizes and ewes with larger litter sizes had more favorable MBS (Table 2). Litter survival at all stages (LSB, LS3d, and LSW) was significantly greater for smaller litter sizes and younger ewes when adjusted for TLWB (Table 2). All estimates of litter survival have been adjusted for TLWB, resulting in a reduced range of values across litter sizes with values for triplet litters not too distant from that for twins and singles. The LSB, after adjusting for TLWB, has only a 2% range across ewe ages, but remains statistically significant at $P < 0.05$ due primarily to the large sample size ($n = 9,815$).

Two-year-old ewes had lighter TLWB at birth than older ewes (Table 3). The LWW was heaviest for 4-yr-old ewes and lightest for 2-yr-old ewes (Table 4). Ewes giving birth to triplet litters and rearing 2 lambs weaned less BW of lamb than ewes giving birth to twins and rearing twins (Table 4). Litter size at birth and litter size reared had significant effects on LWW ($P < 0.001$, Table 4).

Genetic Parameters for Ewe Performance

Variance estimates for the ewe traits are presented in Table 5. The heritabilities and repeatabilities for the litter survival traits were very low, whereas the herita-

### Table 1. Final model effects for ewe BCS, maternal behavior score, litter weight, and litter survival

<table>
<thead>
<tr>
<th>Trait</th>
<th>MBCS</th>
<th>PBCS</th>
<th>MBS</th>
<th>TLWB</th>
<th>ALWB</th>
<th>LWW</th>
<th>LS traits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed effects</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contemporary group</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Ewe age within contemporary group</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Litter size within contemporary group</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Litter size weaned within contemporary group</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Covariates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contemporary group by ewe lambing date deviation</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Litter weight at birth (quadratic) within litter size at birth within contemporary group</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Proportion of ram lambs in litter of ewe</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random effects fitted</td>
<td>Animal X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Permanent environment</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1MBCS = ewe BCS mid-pregnancy; PBCS = ewe BCS 2 wk before lambing; MBS = maternal behavior score; TLWB = total lamb BW in litter (kg); ALWB = average lamb BW in litter (kg); LWW = litter weight of lamb weaned (kg).
2LS traits include: LSB = litter survival at birth (proportion); LS1d = litter survival 1 d from birth (proportion); LS3d = litter survival 3 d from birth (proportion); LS21d = litter survival 21 d from birth (proportion); LSW = litter survival to weaning (proportion).
3Contemporary group = farmer by breed by lambing year.

* $P < 0.05$. Blank cells were not included in the final model; not significant and not logical were also not included. X = random effect included in final model.

### Table 2. Predicted least squares means (±SE) for ewe traits recorded between mid-pregnancy and lamb weaning

<table>
<thead>
<tr>
<th>Item</th>
<th>MBCS</th>
<th>PBCS</th>
<th>MBS</th>
<th>LSB</th>
<th>LS3d</th>
<th>LSW</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of records</td>
<td>12,850</td>
<td>12,566</td>
<td>4,389</td>
<td>9,815</td>
<td>9,815</td>
<td>9,886</td>
</tr>
<tr>
<td>Litter size at birth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Singles</td>
<td>2.9 ± 0.014</td>
<td>2.6 ± 0.015</td>
<td>3.9 ± 0.038</td>
<td>0.98 ± 0.006</td>
<td>0.94 ± 0.007</td>
<td>0.92 ± 0.009</td>
</tr>
<tr>
<td>Twins</td>
<td>3.0 ± 0.013</td>
<td>2.6 ± 0.011</td>
<td>4.1 ± 0.031</td>
<td>0.96 ± 0.005</td>
<td>0.94 ± 0.006</td>
<td>0.91 ± 0.008</td>
</tr>
<tr>
<td>Triplets</td>
<td>3.1 ± 0.021</td>
<td>2.7 ± 0.019</td>
<td>4.3 ± 0.068</td>
<td>0.93 ± 0.006</td>
<td>0.89 ± 0.008</td>
<td>0.83 ± 0.009</td>
</tr>
<tr>
<td>$P$-value</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
<tr>
<td>Ewe age, yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3.1 ± 0.014</td>
<td>2.7 ± 0.014</td>
<td>3.7 ± 0.04</td>
<td>0.97 ± 0.005</td>
<td>0.94 ± 0.007</td>
<td>0.90 ± 0.009</td>
</tr>
<tr>
<td>3</td>
<td>3.0 ± 0.014</td>
<td>2.7 ± 0.015</td>
<td>4.0 ± 0.043</td>
<td>0.97 ± 0.005</td>
<td>0.94 ± 0.006</td>
<td>0.91 ± 0.008</td>
</tr>
<tr>
<td>4</td>
<td>3.0 ± 0.015</td>
<td>2.8 ± 0.016</td>
<td>4.1 ± 0.049</td>
<td>0.96 ± 0.005</td>
<td>0.93 ± 0.007</td>
<td>0.89 ± 0.008</td>
</tr>
<tr>
<td>5</td>
<td>2.9 ± 0.018</td>
<td>2.6 ± 0.017</td>
<td>4.3 ± 0.054</td>
<td>0.95 ± 0.006</td>
<td>0.91 ± 0.007</td>
<td>0.88 ± 0.009</td>
</tr>
<tr>
<td>+6</td>
<td>2.8 ± 0.028</td>
<td>2.4 ± 0.019</td>
<td>4.5 ± 0.062</td>
<td>0.95 ± 0.006</td>
<td>0.91 ± 0.008</td>
<td>0.86 ± 0.010</td>
</tr>
</tbody>
</table>

1MBCS = ewe BCS mid-pregnancy; PBCS = ewe BCS 2 wk before lambing; MBS = maternal behavior score; TLWB = total lamb BW in litter (kg); ALWB = average lamb BW in litter (kg); LWW = litter weight of lamb weaned (kg).

* $P < 0.05$. ***$P < 0.001$. **P**
abilities and repeatabilities for the litter weight traits were moderate. The repeatabilities for BCS (MBCS and PBCS) and MBS traits were low to moderate.

Genetic and phenotypic correlations for the ewe traits are presented in Table 6. The phenotypic correlations between the BCS traits and litter survival traits were very low. The MBS also had low phenotypic correlations with the traits TLWB, LSB, LSW, and LWW. However, the phenotypic correlation between TLWB and LSB was positive and moderate and the phenotypic correlations between LSB and LSW and LSB and LWW were also positive and moderate. Ewes with greater LSB have greater LSW and greater BW of lamb weaned.

The genetic correlation between MBCS and LSB was large and positive, whereas the genetic correlation between MBCS and TLWB was close to zero. The genetic correlation between TLWB and LWW was positive and moderate.

**DISCUSSION**

Published estimates of genetic parameters for ewe performance and lamb-rearing ability in highly fecund sheep are limited. This is the first known genetic analysis reporting heritabilities for ewe BCS, litter weight at birth, and genetic correlations for ewe performance traits in the same study.

The heritabilities and repeatabilities for the litter survival traits were very low. The litter weight traits had heritabilities ranging from 0.12 for LWW to 0.28 for TLWB in triplet litters and repeatabilities ranging from 0.18 to 0.29. The repeatabilities of the BCS (MBCS and PBCS) and MBS traits were low to moderate.

Heritability estimates for ewe performance from birth to weaning and BW of lamb weaned have been reviewed by Safari et al. (2005). The heritabilities in the current study were similar to previous reports for BW of lamb weaned, ewe rearing performance to weaning (Safari et al., 2005), and MBS (Lambe et al., 2001). Everett-Hincks et al. (2005) recently reported the heritability and repeatability for ewe LSW to be very low (0.0 and 0.1 respectively) for a Coopworth flock. The inference that ewe rearing performance is heritable has been confirmed in a few studies with Merinos (Haughey, 1983; Haughey et al., 1985; and a review by Piper and Bond, 1982). The repeatability of rearing performance has been estimated at 10% by Haughey (1983), similar to the repeatabilities reported in the current study (litter survival traits, 0 to 6%). Purser and Young (1983) reported that ewe rearing performance was a repeatable trait; the more lambs were reared, the better the sub-

<table>
<thead>
<tr>
<th>Item</th>
<th>All</th>
<th>Singles</th>
<th>Twins</th>
<th>Triplets</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of records</td>
<td>11,556</td>
<td>2,068</td>
<td>7,707</td>
<td>1,781</td>
</tr>
<tr>
<td>Litter size at birth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reared as a single</td>
<td>8.9 ± 0.054</td>
<td>6.1 ± 0.040</td>
<td>9.4 ± 0.059</td>
<td>11.3 ± 0.145</td>
</tr>
<tr>
<td>Reared as a twin</td>
<td>5.6 ± 0.055</td>
<td>6.1 ± 0.056</td>
<td>9.5 ± 0.072</td>
<td>11.3 ± 0.195</td>
</tr>
<tr>
<td>Reared as a triplet</td>
<td>6.2 ± 0.062</td>
<td>6.2 ± 0.062</td>
<td>9.8 ± 0.074</td>
<td>11.6 ± 0.205</td>
</tr>
<tr>
<td>Ewe age, yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>7.8 ± 0.069</td>
<td>5.6 ± 0.055</td>
<td>8.4 ± 0.071</td>
<td>10.0 ± 0.223</td>
</tr>
<tr>
<td>3</td>
<td>8.8 ± 0.066</td>
<td>6.1 ± 0.056</td>
<td>9.5 ± 0.072</td>
<td>11.3 ± 0.195</td>
</tr>
<tr>
<td>4</td>
<td>9.2 ± 0.069</td>
<td>6.2 ± 0.062</td>
<td>9.8 ± 0.074</td>
<td>11.6 ± 0.205</td>
</tr>
<tr>
<td>5</td>
<td>9.3 ± 0.073</td>
<td>6.3 ± 0.069</td>
<td>9.7 ± 0.083</td>
<td>11.6 ± 0.210</td>
</tr>
<tr>
<td>+6</td>
<td>9.2 ± 0.081</td>
<td>6.3 ± 0.078</td>
<td>9.7 ± 0.090</td>
<td>11.8 ± 0.238</td>
</tr>
</tbody>
</table>

***P < 0.001.

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**Table 4.** Predicted least squares means (±SE) for the effects of litter size at birth, ewe age, and ewe age within litter size at birth on total litter weight at birth (kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>All</th>
<th>Singles</th>
<th>Twins</th>
<th>Triplets</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of records</td>
<td>22,209</td>
<td>4,331</td>
<td>15,077</td>
<td>2,801</td>
</tr>
<tr>
<td>Litter size at birth</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reared as a single</td>
<td>34.0 ± 0.136</td>
<td>32.3 ± 0.171</td>
<td>32.3 ± 0.171</td>
<td>30.4 ± 0.409</td>
</tr>
<tr>
<td>Reared as a twin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reared as a triplet</td>
<td>58.7 ± 0.139</td>
<td>57.1 ± 0.328</td>
<td>57.1 ± 0.328</td>
<td>57.1 ± 0.328</td>
</tr>
<tr>
<td>Ewe age, yr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>44.9 ± 0.158</td>
<td>33.3 ± 0.156</td>
<td>43.2 ± 0.173</td>
<td>52.2 ± 0.440</td>
</tr>
<tr>
<td>3</td>
<td>49.1 ± 0.16</td>
<td>34.9 ± 0.195</td>
<td>46.6 ± 0.173</td>
<td>57.4 ± 0.369</td>
</tr>
<tr>
<td>4</td>
<td>50.1 ± 0.162</td>
<td>34.8 ± 0.200</td>
<td>47.5 ± 0.179</td>
<td>58.8 ± 0.361</td>
</tr>
<tr>
<td>5</td>
<td>48.8 ± 0.174</td>
<td>33.9 ± 0.227</td>
<td>46.5 ± 0.212</td>
<td>57.0 ± 0.381</td>
</tr>
<tr>
<td>+6</td>
<td>47.0 ± 0.201</td>
<td>33.2 ± 0.264</td>
<td>44.8 ± 0.253</td>
<td>55.5 ± 0.450</td>
</tr>
</tbody>
</table>

***P < 0.001.
### Table 5. Estimated variance components and genetic parameters for ewe traits recorded between mid-pregnancy and lamb weaning

<table>
<thead>
<tr>
<th>Item</th>
<th>Units</th>
<th>No. of animals</th>
<th>Trait, mean ± RSD</th>
<th>Σ² phenotypic</th>
<th>Heritability</th>
<th>Repeatability</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBCS</td>
<td>score (1–5)</td>
<td>12,850</td>
<td>3.07 ± 0.46</td>
<td>0.21 ± 0.003</td>
<td>0.16 ± 0.02</td>
<td>0.31 ± 0.02</td>
</tr>
<tr>
<td>PBCS</td>
<td>score (1–5)</td>
<td>12,566</td>
<td>2.66 ± 0.42</td>
<td>0.18 ± 0.003</td>
<td>0.18 ± 0.02</td>
<td>0.34 ± 0.02</td>
</tr>
<tr>
<td>TLWB all litters</td>
<td>kg</td>
<td>10,588</td>
<td>9.25 ± 1.88</td>
<td>3.61 ± 0.054</td>
<td>0.17 ± 0.02</td>
<td>0.18 ± 0.02</td>
</tr>
<tr>
<td>TLWB single litters</td>
<td>kg</td>
<td>1,867</td>
<td>5.89 ± 0.92</td>
<td>0.74 ± 0.027</td>
<td>0.18 ± 0.07</td>
<td>0.29 ± 0.12</td>
</tr>
<tr>
<td>TLWB twin litters</td>
<td>kg</td>
<td>7,099</td>
<td>9.63 ± 1.84</td>
<td>3.45 ± 0.063</td>
<td>0.18 ± 0.03</td>
<td>0.18 ± 0.03</td>
</tr>
<tr>
<td>TLWB triplet litters</td>
<td>kg</td>
<td>1,622</td>
<td>12.03 ± 2.74</td>
<td>7.59 ± 0.301</td>
<td>0.28 ± 0.09</td>
<td>0.28 ± 0.09</td>
</tr>
<tr>
<td>ALWB all litters</td>
<td>kg</td>
<td>11,599</td>
<td>4.90 ± 0.92</td>
<td>0.83 ± 0.012</td>
<td>0.19 ± 0.02</td>
<td>0.23 ± 0.02</td>
</tr>
<tr>
<td>MBS</td>
<td>score (1–5)</td>
<td>4,389</td>
<td>4.00 ± 0.81</td>
<td>0.65 ± 0.015</td>
<td>0.13 ± 0.03</td>
<td>0.38 ± 0.03</td>
</tr>
<tr>
<td>LSB</td>
<td>proportion</td>
<td>9,815</td>
<td>0.93 ± 0.15</td>
<td>0.02 ± 0.000</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>LS1d</td>
<td>proportion</td>
<td>9,886</td>
<td>0.84 ± 0.25</td>
<td>0.06 ± 0.001</td>
<td>0.01 ± 0.01</td>
<td>0.05 ± 0.03</td>
</tr>
<tr>
<td>LS21d</td>
<td>proportion</td>
<td>9,815</td>
<td>0.89 ± 0.20</td>
<td>0.04 ± 0.001</td>
<td>0.00 ± 0.00</td>
<td>0.02 ± 0.00</td>
</tr>
<tr>
<td>LS3d</td>
<td>proportion</td>
<td>9,815</td>
<td>0.87 ± 0.22</td>
<td>0.05 ± 0.001</td>
<td>0.01 ± 0.01</td>
<td>0.06 ± 0.00</td>
</tr>
<tr>
<td>LSW</td>
<td>proportion</td>
<td>22,656</td>
<td>49.20 ± 6.10</td>
<td>38.50 ± 0.413</td>
<td>0.12 ± 0.01</td>
<td>0.22 ± 0.01</td>
</tr>
<tr>
<td>LWW</td>
<td>kg</td>
<td>10,588</td>
<td>9.25 ± 1.88</td>
<td>3.45 ± 0.063</td>
<td>0.18 ± 0.03</td>
<td>0.18 ± 0.03</td>
</tr>
</tbody>
</table>

1MBCS = ewe BCS mid-pregnancy; PBCS = ewe BCS 2 wk before lambing; MBS = maternal behavior score; TLWB = total litter weight at birth (kg); ALWB = average litter weight at birth (kg); MBS = maternal behavior score; TLWB = total litter weight at birth (kg); LSB = litter survival at birth (proportion); LS1d = litter survival to 1 d of age (proportion); LS21d = litter survival to 21 d of age (proportion); LS3d = litter survival 3 d from birth (proportion); LSW = litter survival to weaning (proportion); LWW = BW of lamb weaned (kg).

2RSD = residual SD.

sequent performance appeared to be. If a lamb was not reared from the first parity of the ewe, lamb mortality at age 3 and parity 2 was 26.8%, but if the previous lamb was reared, the mortality was only 13.5% (Purser and Young, 1983). However, Dalton et al. (1980) suggested that culling 2-yr-old ewes that were not pregnant would have a greater effect on improving flock lamb survival than culling ewes that had lost a lamb. Environmental variances due to permanent maternal effects (e.g., uterine capacity, pelvic width, milking, and maternal ability) were found to contribute mostly to the repeatability of ewe rearing performance, providing evidence that improved lamb survival has to be seen mainly as a successful partnership between mother and offspring throughout pregnancy, parturition, and lactation (Morris et al., 2000).

There has been selection for behavior traits thought to improve lamb survival; however, these studies are scarce (Lambe et al., 2001; Cloete et al., 2002). The heritability and repeatability reported in the current study (0.13 and 0.38, respectively) were nearly identical to those reported by Lambe’s team (0.13 and 0.32, respectively; Lambe et al., 2001). Everett-Hincks et al. (2000) reported lesser estimates for MBS in a flock where breeding ewes had been selected for nearly 30 yr for the traits and resulting flock variation in the trait was reduced (heritability and repeatability were both 0.09). Cloete et al. (2002) showed that the time from birth to standing and the time from standing to nursing have a genetic component, which differs between breeds.

The current study showed that ewes with greater LSB have greater LSW and greater BW of lamb weaned; however, this was primarily due to environmental factors because the genetic variance of the survival traits was very low and the high genetic correlation is partly due to LSB setting the upper limit for LSW. A high genetic correlation was reported between MBCS and LSB, suggesting that selection for ewes with superior MBCS produces ewes with superior genes for the survival of their litter to birth. Everett-Hincks and Dodds (2008) reported the importance of environmental effects of MBCS on lamb survival and death risk traits and showed a positive relationship between MBCS and lamb birth weight. The genetic correlation between TLWB and LWW was positive and moderate, and therefore, selection for improved litter weight at birth is likely to increase BW of lamb weaned, which has

### Table 6. Genetic and phenotypic correlations for ewe traits recorded between mid-pregnancy and lamb weaning

<table>
<thead>
<tr>
<th>Trait</th>
<th>MBCS</th>
<th>PBCS</th>
<th>TLWB</th>
<th>MBS</th>
<th>LSB</th>
<th>LSW</th>
<th>LWW</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBCS</td>
<td>0.39 ± 0.01</td>
<td>0.05 ± 0.01</td>
<td>−0.03 ± 0.02</td>
<td>0.02 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.11 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>PBCS</td>
<td>0.95 ± 0.03</td>
<td>0.01 ± 0.01</td>
<td>−0.02 ± 0.02</td>
<td>0.00 ± 0.01</td>
<td>0.01 ± 0.01</td>
<td>0.12 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>TLWB</td>
<td>−0.01 ± 0.09</td>
<td>−0.13 ± 0.08</td>
<td>0.13 ± 0.02</td>
<td>0.35 ± 0.01</td>
<td>0.38 ± 0.01</td>
<td>0.27 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>MBS</td>
<td>0.11 ± 0.16</td>
<td>−0.05 ± 0.16</td>
<td>−0.07 ± 0.15</td>
<td>0.05 ± 0.02</td>
<td>0.08 ± 0.02</td>
<td>0.02 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>LSB</td>
<td>0.73 ± 0.36</td>
<td>0.47 ± 0.30</td>
<td>0.21 ± 0.27</td>
<td>0.20 ± 0.41</td>
<td>0.64 ± 0.00</td>
<td>0.66 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>LSW</td>
<td>0.39 ± 0.19</td>
<td>0.48 ± 0.18</td>
<td>0.39 ± 0.16</td>
<td>−0.09 ± 0.29</td>
<td>0.95 ± 0.26</td>
<td>0.93 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>LWW</td>
<td>0.09 ± 0.08</td>
<td>0.08 ± 0.08</td>
<td>0.14 ± 0.07</td>
<td>0.05 ± 0.14</td>
<td>0.59 ± 0.23</td>
<td>0.93 ± 0.00</td>
<td></td>
</tr>
</tbody>
</table>

1r_g = genetic correlations below the diagonal, and r_p = phenotypic correlations above the diagonal.

2MBCS = ewe BCS mid-pregnancy; PBCS = ewe BCS 2 wk before lambing; MBS = maternal behavior score; TLWB = total litter weight at birth (kg); LSB = litter survival at birth (proportion); LSW = litter survival to weaning (proportion); LWW = BW of lamb weaned (kg).
economic benefits. Incorporation of MBCS and litter weight traits into sheep selection programs warrants investigation.

Sheep farmers have a range of options to influence the genetic capability of their flock. New sheep breeds and the genes they can contribute to the national sheep flock can provide an opportunity to improve ewe performance. However, the selection process is constrained because ewe performance is a sex-limited trait. Further research is needed to determine the heritabilities of lamb and ewe behaviors that relate to lamb survival.

This study showed that there is little to be gained from including litter survival in sheep selection programs because heritabilities for the litter survival traits were very low. However, genetic gains in BCS, MBS, litter weight at birth, and litter weight weaned are possible in this population. These traits warrant investigation in other populations before breeding program implementation. Body condition score at mid pregnancy and litter weight at birth show the most promise to genetically improve ewe lamb rearing performance at weaning.

**LITERATURE CITED**


