ABSTRACT: Genotype effects on lamb growth, survival, and commercial finishing were estimated in a 5-yr study aimed at assessing potential benefits from introducing meat breeds into extensive sheep systems of northeastern Patagonia. Five ram (Corriedale: CO; Border Leicester: BL; Île de France: IF; Texel: TX; and synthetic CRIII (25% Merino, 37.5% IF, 37.5% TX)) and 5 dam (CO; synthetic CRIII; BLCO: BL × CO; IFCO: IF × CO; and TXCO: TX × CO) genotypes were represented in the study. Data were collected from 1,426 born and 1,258 weaned lambs of 9 resulting genotypes (CO × CO, BL × CO, IF × CO, TX × CO, CRIII × CO, CRIII × BLCO, CRIII × IFCO, CRIII × TXCO, and CRIII × CRIII). Birth weight was recorded on all lambs; subsequently, BW and BCS (scale 1 to 5) were recorded at regular intervals until weaning. Body weights were adjusted to 60 and 90 (weaning) d of age, and ADG were calculated from the adjusted BW for the periods 0 to 60 d and 60 to 90 d; BCS was adjusted to 90 d. Survival to weaning and percentage of lambs reaching commercial finishing (BW ≥ 23 kg and BCS ≥ 2.5 points) were also recorded. Significant (P < 0.05) genotype × litter size interactions were detected for birth weight and ADG 60 to 90 d. With the exception of CRIII × CO, crossbred and synthetic genotypes presented greater (P < 0.05) ADG 0 to 60 d and BW at 60 and 90 d than CO × CO lambs. Second cross lambs reared as singles presented greater ADG 60 to 90 d (P < 0.05) than BL × CO, TX × CO, and CRIII × CO, but less (P < 0.05) ADG 60 to 90 d, and no differences were observed for twins. The IF × CO, CRIII × BLCO, CRIII × IFCO, and CRIII × CRIII genotypes showed greater BCS at 90 d (P < 0.05) than CO × CO. The probability of greater commercial finishing for crossbred and synthetic genotypes relative to CO × CO was at least 79%. Probabilities of greater survival to weaning in CO × CO and CRIII × BLCO lambs relative to IF × CO, TX × CO, CRIII × CO, and CRIII × CRIII lambs were greater than 81%. Results indicate significant improvements in lamb BW and saleable lambs from the introduction of meat genotypes. Among the terminal sire breeds evaluated, BL and IF would produce the greatest impact. Differential nutritional management of pregnant ewes carrying twins and of twin lambs beyond 60 d should be implemented to mitigate litter size × genotype interactions constraining growth potential benefits, which may be critical for northeastern Patagonia conditions.

Key words: crossbreeding, extensive system, growth, lamb, survival

INTRODUCTION

Patagonian sheep farming has traditionally focused on fine wool; lamb and mutton production have been mainly confined to the milder, wetter areas along the Atlantic coast, the foothills of the Andes, and Tierra del Fuego (Müller, 2005). Depressed wool prices and a stable meat demand from overseas markets (Rees, 2009) and local packers from within the foot and mouth disease-free area (McCormick and Lynch, 2004) are motivating genotype switches in areas suitable for intensifying meat production. The dual-purpose Corriedale, still very popular in those latter areas, has been increasingly interbred with recently introduced meat or moderately prolific genotypes or both; synthetic and
composite genotypes are also spreading. Some experimental evaluation of available genetic resources is essential to assess their potential roles in these typically extensive sheep production systems. The work reports initial results of a long-term study aimed at characterizing genotype effects on growth traits, survival, and commercial finishing of lambs. Results are also reported on some environmental effects that may help identify possible targets for improved management. The study focused on coastal northeastern Patagonia although general findings are probably relevant for other, typically extensive sheep meat production systems around the world.

**MATERIALS AND METHODS**

Experimental protocols and animal management followed standards for the humane use and care of experimental animals (FASS, 1999).

**Study Site**

The study was conducted at the Patagones Research Station (40°39′ S, 62°54′ W), a research site in northeastern Patagonia located within the Monte (Cabrera, 1976), a semiarid region characterized by its shrubby natural vegetation. Long-term annual rainfall in the area averages 330 mm, and mean annual relative humidity is close to 60%. Mean annual temperature is about 14.5°C with minimum and maximum temperatures usually occurring in August and January, respectively (Giorgetti et al., 1997).

**Animals**

Five ram genotypes [Corriedale (CO), Border Leicester (BL), Île de France (IF), Texel (TX), and synthetic CRIII] and 5 dam genotypes [CO, synthetic CRIII, BLCO (BL × CO), IFCO (IF × CO), and TXCO (TX × CO)] were represented in the study. Corriedale ewes were obtained from representative commercial flocks in the area (Miñón et al., 2000a, 2001a). The CRIII genotype is a synthetic formed at the Valle Inferior Agriculture Experiment Station (VIAES, located nearby the Patagones research station) by crossing and back-crossing of IF and TX rams on Merino dams followed by lamb ram selection, primarily based upon weaning weight, among lambs born and reared as twins. Synthetic CRIII dams are comparatively heavier (~60 kg) than CO (~53 kg) dams and have an approximate blend of 25% Merino, 37.5% IF, and 37.5% TX (Miñón et al., 2000a). This synthetic breed has not been evaluated before for terminal crossing; it also has potential for straight breed lamb production.

From 2002 to 2006, CO ewes (n = 182 to 240) were mated to CO, BL, IF, or TX rams every year; CRIII ewes (n = 98 to 113) were mated to CRIII rams from 2003 to 2006 (Table 1). Female lambs born to CO dams (i.e., BLCO, IFCO, and TXCO genotypes) were retained and mated to CRIII rams in 2004, 2005, and 2006. Corriedale, BL, IF, and TX rams were obtained from local studs (3 different breeders); the CRIII rams came from the experimental VIAES flock. A total of 5 CO, BL, IF, and TX rams and 12 CRIII rams were used in the experiment.

**Table 1. Number of progeny born (weaned) by genotype and year**

<table>
<thead>
<tr>
<th>Genotype \ Year</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO × CO</td>
<td>54 (51)</td>
<td>51 (47)</td>
<td>36 (32)</td>
<td>29 (25)</td>
<td>29 (26)</td>
<td>199 (181)</td>
</tr>
<tr>
<td>BL × CO</td>
<td>46 (40)</td>
<td>46 (42)</td>
<td>43 (39)</td>
<td>41 (36)</td>
<td>21 (20)</td>
<td>197 (177)</td>
</tr>
<tr>
<td>IF × CO</td>
<td>47 (43)</td>
<td>53 (46)</td>
<td>30 (27)</td>
<td>19 (15)</td>
<td>32 (27)</td>
<td>181 (158)</td>
</tr>
<tr>
<td>TX × CO</td>
<td>72 (70)</td>
<td>45 (37)</td>
<td>23 (21)</td>
<td>24 (20)</td>
<td>22 (19)</td>
<td>186 (167)</td>
</tr>
<tr>
<td>CRIII × CO</td>
<td>15 (14)</td>
<td>14 (13)</td>
<td>18 (16)</td>
<td>16 (14)</td>
<td>20 (18)</td>
<td>91 (75)</td>
</tr>
<tr>
<td>CRIII × BLCO</td>
<td>17 (15)</td>
<td>28 (24)</td>
<td>40 (37)</td>
<td>57 (49)</td>
<td>63 (57)</td>
<td>85 (76)</td>
</tr>
<tr>
<td>CRIII × IFCO</td>
<td>15 (14)</td>
<td>20 (18)</td>
<td>28 (25)</td>
<td>30 (27)</td>
<td>32 (27)</td>
<td>63 (57)</td>
</tr>
<tr>
<td>CRIII × TXCO</td>
<td>23 (22)</td>
<td>31 (26)</td>
<td>27 (24)</td>
<td>30 (27)</td>
<td>32 (27)</td>
<td>81 (72)</td>
</tr>
<tr>
<td>CRIII × CRIII</td>
<td>101 (90)</td>
<td>86 (77)</td>
<td>63 (59)</td>
<td>93 (80)</td>
<td>433 (395)</td>
<td>1,426 (1,258)</td>
</tr>
</tbody>
</table>

1 Sire breed listed first: CO = Corriedale; BL = Border Leicester; IF = Île de France; TX = Texel; CRIII = Synthetic III.
kg of DM·ha−1·yr−1) from lambing to weaning, and oat stubbles during the dry period. No supplements were offered.

Ewe BW and BCS [on a 1 (emaciated) to 5 (obese) scale; Jeffries, 1961] were determined once per year, immediately before the service period; all animals were treated at the same time against internal and external parasites (ivermectin 3%, Vermectin Premium LA, OVER Labs, Buenos Aires, Argentina; 1 cm3·50 kg of BW−1 subcutaneously). Shearing was prelambing, 20 d in advance of the expected date of first lambings.

Lambing started on average on August 19 and ended on October 7. Ewe-lamb pairs were identified at birth, and date of birth, sex, BW, and litter size were recorded. Thereafter lambs were weighed and assessed for BCS every 14 d until weaning (90 d). Male lambs were not castrated. Body weights adjusted to 60 (BW60) and 90 d of age (BW90), and BCS adjusted to 90 d (BCS90) were calculated for each lamb by linear interpolation. Average daily gains until 60 d of age (ADG0–60) and between 60 and 90 d (ADG60–90) were calculated from the adjusted BW. Lambs weighing 23 kg or more and with a BCS of 2.5 or greater were considered commercially finished. Survival to weaning (SW) and commercial finishing (CF) were recorded and treated as binary traits.

Statistical Analyses

Growth traits were analyzed using linear mixed models (Henderson, 1984). Exploratory analyses were performed screening for main effects and interactions to be included in the reduced models. An animal model with permanent environmental effects was selected. The model for birth weight included the fixed effects of lamb genotype (CO × CO, BL × CO, IF × CO, TX × CO, CRIII × CO, CRIII × BLCO, CRIII × IFCO, CRIII × TXCO, and CRIII × CRIII), dam parity (1 = first, 2 = second, 3 = third to fifth parity), a combined 15-level effect of year (2002 to 2006) by birth period (3 periods of approximately 15 d each), dam BCS (1: BCS < 3.0; 2: 3.0 ≤ BCS < 3.5; 3: BCS ≥ 3.5), sex (female, male), litter size (single, twins), and the interaction of genotype by litter size (18 levels). Because only small differences were detected among the other growth traits, a model was selected that included the same fixed effects and interactions considered for birth weight plus the interaction of dam BCS by litter size (6 levels). Data from 1,426 born and 1,258 weaned lambs remained in the data set (Table 1) after basic edits eliminated records of lambs with unknown parents, implausible birth dates, or deviant, extremely light BW (usually associated with mismothering; less than 1% of cases in the data set). Because data were connected (Weeks and Williams, 1964) by sire genotypes across years (Table 2), and by sires within sire genotype, the design allowed for comparisons among the 9 lamb genotypes generated in the study: CO × CO, BL × CO, IF × CO, TX × CO, CRIII × CO, CRIII × BLCO, CRIII × IFCO, CRIII × TXCO, and CRIII × CRIII.

The model in matrix notation was

\[ y = X\beta + Zu + Wp + e, \]

where \( y \) = vector of observations; \( X \) = incidence matrix for fixed effects; \( \beta \) = vector of fixed effects; \( Z \) = incidence matrix for random additive effects; \( u \) = vector of random additive effects of the lambs related through sires and dams; \( W \) = incidence matrix of permanent environmental random effects; \( p \) = vector of permanent environmental random effects of the dams; and \( e \) = vector of residuals.
Fixed effects were estimated and random effects predicted using the PEST software (Groeneveld et al., 1990). Contrasts between levels within main effects were tested against an F distribution, and it was assumed that levels differed from each other when \( P < 0.05 \) or more extreme. Variance components were initially estimated from the same data set using REML methodology (Gianola et al., 1986). However, some of the estimates obtained were comparatively less than average estimates from the literature. To adhere to a more conservative standard when comparing genotypes, it was decided to use the variance ratios reported by Safari and Fogarty (2003) and Safari et al. (2005) instead of the original estimates.

Survival to weaning and CF were analyzed via threshold models using a Bayesian approach (Gianola and Foulley, 1983). For SW, a sire-maternal grandsire model was selected that included lamb genotype, dam parity, dam BCS at service, year-birth period, litter size, sex, a genetic additive effect of sire and maternal grandsire of the lamb, and a permanent environmental effect of the dam. For CF, genotype and litter size were treated as one combined effect. For both traits, it was assumed that each animal had an unknown liability (i) and that the liabilities, conditional to all effects, were independent and normally distributed. To facilitate calculations, the threshold was fixed at 0 and the residual variance at 1. Then the conditional probability that lamb \( i \) survived or reached commercial finishing at weaning given \( \beta, u, \) and \( p \) was

\[
P(y_i = 1 \mid \beta, u, p) = P(l_i > t \mid \beta, u, p) = 1 - \Phi \left( \frac{t - (x_i' \beta + z_i' u + w_i' p)}{\sigma} \right)
\]

\[
= 1 - \Phi \left( \frac{0 - (x_i' \beta + z_i' u + w_i' p)}{\sigma} \right)
\]

\[
= \Phi \left( \frac{x_i' \beta + z_i' u + w_i' p}{\sigma} \right).
\]

where \( \Phi \) is the cumulative normal standard distribution; \( x_i, z_i, \) and \( w_i \) are the rows of the respective incidence matrices; \( t \) is the threshold; and \( \sigma \) is the residual deviation. Marginal posterior distributions were estimated using Gibbs sampling with bounded flat priors for all variables (Sorensen and Gianola, 2002). After some exploratory analyses, it was decided to use 400,000-iteration chains rejecting the first 100,000 and saving 1 out of 10 of the remaining ones (i.e., the marginal posterior distributions consisted of 30,000 samples). Convergence was tested using the Z criterion of Geweke (Geweke, 1992). Samples were transformed using the probit function; inferences are reported in the observable scale.

RESULTS

All variables studied were affected by the combined year-birth period effect. Because these effects are mostly unsystematic, hardly repeatable, and typically associated with unknown causes, they were not studied further. Least squares means are reported for the remaining environmental effects of dam parity, dam BCS, sex, and litter size (Table 3) and for the genotype effect. For SW and CF, preplanned comparisons involving genotype are presented as differences relative to the CO × CO genotype; other pair-wise genotype comparisons among the 36 possible for each trait are mentioned when relevant. Relevant interactions are presented graphically.

Environmental Effects

Dam parity only affected birth weight (Table 3); lambs born to adult ewes (parity levels 2 and 3) were heavier (\( P < 0.05 \)) than lambs born to first parity dams. Lambs reared by BCS2 and BCS3 dams presented greater ADG0–60 (\( P < 0.001 \)) and BW60 (\( P < 0.001 \)) than lambs from BCS1 dams (Table 3). Dams in the highest BCS class induced greater BW gains during the 60 to 90 d period (Table 3), but this effect was mainly due to greater BW gains of twin lambs (Figure 1). The combined effects of dam BCS on lamb growth rates in both periods induced BW90 differences that mirrored the preservice BCS of the dams (Table 3). Greater BW at 90 d did not translate into greater BCS of the lambs; BCS2 and BCS3 dams weaned lambs with greater BCS90 than BCS1 dams.

Not unexpectedly, male lambs were 0.3 ± 0.1 kg heavier (\( P < 0.05 \)) at birth than females and showed greater ADG0–60, BW60, ADG60–90, and BW90 (\( P < 0.001 \)). In contrast, females were fatter (\( P < 0.001 \)) than males when both sexes reached average weaning age (Table 3). At birth twin lambs were systematically lighter than singles (\( P < 0.001 \)) and had less ADG in both periods; consequently, they also showed lighter BW at 60 and 90 d of age (\( P < 0.001; \) Table 3).

Features of the marginal posterior distributions of the differences between levels of environmental effects are presented in Table 4 along with the probability for such differences to be greater than 0. In Bayesian analysis, that is the actual probability of the difference between levels (i.e., the reader should judge whether or not that represents sufficient evidence).

Dam parity did not affect SW or CF of lambs (Table 4). In contrast, greater dam BCS were associated with a marginally improved survival to weaning and with greater percentages of commercially finished lambs (Table 4). The probability of greater SW of lambs reared by dams with BCS3 relative to dams with smaller BCS was greater than 90% (Dam BCS 1 to 3, 2 to 3; Table 4). The probability of observing greater CF in lambs reared by dams with BCS3 relative to lambs reared...
by dams with BCS1 or BCS2 was greater than 97%, and the probability of greater CF in lambs from dams with BCS2 relative to lambs from dams with BCS1 was greater than 99% (Table 4). Male and female lambs had similar chances of surviving to weaning; males and singles had greater chances of reaching commercial finishing; and singles had greater chances than twins of surviving to weaning (Table 4). The mean difference in CF was 16% between sexes and 49% between singles and twins.

**Genotype Effects**

Differences between genotypes were detected for BW at the 3 stages (birth, 60 d, and 90 d) and BW gains in the 2 periods (Table 5). With the exception of CRIII × CO, crossbred and synthetic genotypes presented greater ADG0–60, BW60, and BW90 ($P < 0.05$) than CO × CO lambs (Table 5). Some of the observed differences, however, were not homogeneous across litter size. Significant ($P < 0.05$) genotype × litter size interactions were detected for birth weight (Figure 2) and ADG60–90 (Figure 3). Single lambs of the IF × CO, TX × CO, and CRIII × CRIII genotypes presented greater ($P < 0.05$) birth weights than single CO × CO lambs, but no such differences ($P > 0.05$) were observed among twins (Figure 2). A similar pattern was noticeable when CRIII × BLCO and CRIII × TXCO genotypes were compared with CRIII × IFCO lambs. Second cross lambs reared as singles had greater ADG60–90 ($P < 0.05$) than BL × CO, TX × CO, and CRIII × CO (Figure 3), but smaller ADG60–90 or no differences were observed for twins. The IF × CO, CRIII × BLCO, CRIII × IFCO, and CRIII × CRIII genotypes showed greater BCS90 ($P < 0.05$) than CO × CO (Table 5).

Although individual comparisons against the CO × CO genotype did not reach extreme probability values in any case, the general trend of SW in Table 6 suggest

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**Table 3.** Least squares means and average SEM of dam parity, dam BCS, sex, and litter size effects for growth traits

<table>
<thead>
<tr>
<th>Effect</th>
<th>Birth BW, kg</th>
<th>Period 0–60 d</th>
<th>Period 60–90 d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADG, g/d</td>
<td>ADG, g/d</td>
<td>ADG, g/d</td>
</tr>
<tr>
<td></td>
<td>BW, kg</td>
<td>BW, kg</td>
<td>BW, kg</td>
</tr>
<tr>
<td>Dam parity$^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.7</td>
<td>233.1</td>
<td>18.6</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
<td>236.1</td>
<td>19.0</td>
</tr>
<tr>
<td>3</td>
<td>5.0</td>
<td>235.6</td>
<td>19.0</td>
</tr>
<tr>
<td>Average SEM</td>
<td>0.1</td>
<td>3.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Dam BCS$^3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4.8</td>
<td>221.8</td>
<td>18.0</td>
</tr>
<tr>
<td>2</td>
<td>4.9</td>
<td>238.7</td>
<td>19.2</td>
</tr>
<tr>
<td>3</td>
<td>4.9</td>
<td>244.3</td>
<td>19.6</td>
</tr>
<tr>
<td>Average SEM</td>
<td>0.1</td>
<td>3.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>4.7</td>
<td>228.5</td>
<td>18.4</td>
</tr>
<tr>
<td>Male</td>
<td>5.0</td>
<td>241.3</td>
<td>19.4</td>
</tr>
<tr>
<td>Average SEM</td>
<td>0.1</td>
<td>2.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Litter size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td>5.2</td>
<td>263.7</td>
<td>21.1</td>
</tr>
<tr>
<td>Twins</td>
<td>4.6</td>
<td>204.1</td>
<td>16.7</td>
</tr>
<tr>
<td>Average SEM</td>
<td>0.1</td>
<td>3.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

$^a$Within trait and source of variation, means without a common superscript differ (at least $P < 0.05$).

$^b$BW = BW at the end of the period, BCS on a scale of 1 (emaciated) to 5 (obese) at the end of the period.

$^c$Level 1 = first parity; level 2 = second parity; level 3 = third to fifth parity.

$^d$Level 1: BCS < 3.0; level 2: 3.0 ≤ BCS < 3.5; level 3: BCS ≥ 3.5.
a slight but consistent negative effect of using non-CO rams on CO dams (first 4 genotypes listed).

The probability of observing a greater percentage of commercially finished lambs of crossbred and synthetic genotypes relative to CO × CO was at least 79% (Table 6). Among the rest of the 36 possible pair-wise contrasts tested, the probability of a greater CF for BL × CO and IF × CO relative to TX × CO and CRIII × CO was greater than 93%.

**DISCUSSION**

The primary objective of the study was to assess possible genotype effects on lamb growth, survival, and commercial finishing. Depending upon the particular trait considered, those effects may be induced by direct and maternal additive components or heterosis or combinations thereof. We also focused on some environmental effects to improve the understanding of factors affecting the traits and to identify possible ways of improving management or mitigating constraints.

Not unexpectedly, we detected significant effects of the combined year-birth period effect for all traits studied. Several factors may contribute to the year-to-year variation, which usually cannot be controlled and are typically not repeatable. Birth period effects, in contrast, are expected to be more systematic because they are usually associated with changes in the quality of forage as the growing season progresses (e.g., Fogarty et al., 1984; Sušiće et al., 2005). Some of the effects we detected were most probably of this type.

Lighter birth weights from first parity dams are a frequent finding (e.g., Afolayan et al., 2007). In most commercial sheep enterprises, ewes have yet to reach full

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Birth BW, kg</th>
<th>Period 0 to 60 d</th>
<th>Period 60 to 90 d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADG, g/d</td>
<td>BW, kg</td>
<td>ADG, g/d</td>
</tr>
<tr>
<td>CO × CO</td>
<td>4.6^a</td>
<td>211.3^a</td>
<td>17.3^a</td>
</tr>
<tr>
<td>BL × CO</td>
<td>4.9^bcd</td>
<td>236.2^bc</td>
<td>19.1^bcd</td>
</tr>
<tr>
<td>IF × CO</td>
<td>4.7^abc</td>
<td>246.7^c</td>
<td>19.6^c</td>
</tr>
<tr>
<td>TX × CO</td>
<td>4.8^bcd</td>
<td>227.9^bc</td>
<td>18.5^bc</td>
</tr>
<tr>
<td>CRIII × CO</td>
<td>4.8^abc</td>
<td>224.2^ab</td>
<td>18.2^ab</td>
</tr>
<tr>
<td>CRIII × BLCO</td>
<td>5.1^d</td>
<td>239.1^bc</td>
<td>19.4^d</td>
</tr>
<tr>
<td>CRIII × IFCO</td>
<td>4.9^bcd</td>
<td>248.1^bc</td>
<td>19.6^d</td>
</tr>
<tr>
<td>CRIII × TXCO</td>
<td>5.0^d</td>
<td>252.5^bc</td>
<td>19.0^bcd</td>
</tr>
<tr>
<td>CRIII × CRIII</td>
<td>4.8^ab</td>
<td>245.7^bc</td>
<td>19.5^d</td>
</tr>
<tr>
<td>Average SEM</td>
<td>0.1</td>
<td>6.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

^a–eWithin trait means without a common superscript letter differ (at least P < 0.05).

1BW = BW at the end of the period, BCS on a scale of 1 (emaciated) to 5 (obese) at the end of the period.

2Sire breed listed first: CO = Corriedale; BL = Border Leicester; IF = Île de France; TX = Texel; CRIII = Synthetic III.
development by the time they lamb for the first time. Body weight records of individual ewes across years in our data set (data not shown) support this possible cause for the observed effect.

It has been widely reported that changes in BW and BCS of the ewes during gestation are associated with variation in lamb birth weight (Holst et al., 1986; Geenty, 1997; Smeaton et al., 1999). Our results do not support those findings with the caveat that the BCS of the dams was assessed before service (i.e., well ahead of the nutritionally critical period of advanced gestation). However, other results from northeastern Patagonia (e.g., Miñón et al., 2001b) suggest that, in well-managed local flocks, ewes usually maintain BCS between mating and parturition. This, in turn, may explain why we detected an association between the BCS of the dams and all growth endpoints evaluated beyond birth weight. This suggests that, under the prevailing management conditions, ewe BCS at mating could be an indicator of milk production potential in early lactation; this relationship would be justified in the capacity to mobilize body reserves for milk production (Smeaton et al., 1999).

The effect of the BCS of the dams on BW gain was modulated by the size of the litter. Gardner and Hogue (1964) and Treacher (1989) observed that ewes rearing twins produced more milk with little or no increase in lactation persistence. Snowden and Glimp (1991) confirmed that ewes rearing twins produced more milk and lose more BW during the first 42 d of lactation than ewes rearing singles. In spite of the greater milk production of twin-rearing dams, twin lambs usually gain less BW and reach lighter weaning weights than singles (Black, 1989), as observed in our study. The interaction between litter size and BCS of the dams was probably mainly induced by the greater than expected growth rate of twin lambs reared by ewes in the greatest BCS class; this effect may has been mediated by sustained mobilization of body reserves in that class of ewes beyond d 60.

Results concerning the effects of sex on growth variables are in agreement with previous findings (e.g., Langlands et al., 1984; Notter et al., 1991). The greater BCS90 observed in females is also in agreement with reports by other authors (Fogarty et al., 1992; Saiuño et al., 1998; Vergara and Gallego, 1999). This is usually attributed to enhanced lipogenic enzymatic activity and greater size of adipocytes in females (Mendizábal et al., 1997).

Litter size was the most influencing factor in determining lamb growth. Most lambs born and reared as twins reached lighter BW90 and BCS90 than required by local buyers; only 36.4% of twins reached CF by d 90 compared with 84.6% in singles. This seriously compromises the chances of successful commercialization of twin lambs. To capitalize on the advantage of the greater prolificacy of some genotypes, some form of differential nutritional management (e.g., creep feeding) should be implemented for twin-rearing dams soon after parturition.

Previous studies have reported greater SW in females (Dalton et al., 1980; Oltenacu and Boylan, 1981; Bunge...
et al., 1990). Gama et al. (1991) pointed out that the leading causes of greater mortality in males are respiratory problems and starvation as indirect results of more frequent dystocia. In the present study, no differences in SW between sexes were detected, probably due to the slight sex difference on birth weight (0.3 ± 0.1 kg).

Singles presented 11.4% greater SW than twins. Most litter size effects on survival are mediated by differences in birth weight (Gama et al., 1991; Holst et al., 2002). Nevertheless, litter size still explained a significant amount of variation in survival after accounting for birth weight differences (Rodríguez Iglesias, 1983; Gama et al., 1991). Lambs born in multiple litters present a slower evolution of neonatal behavioral abilities and have more difficulties suckling (Dwyer, 2003), which may have contributed to the observed difference.

The effect of the genotype on birth weight was modulated by the size of the litter. Fogarty et al. (2005) also reported that differences between genotypes for birth weight decreased or disappeared in twin or triplet litters. Litter size modulates the expression of fetal growth, and in general, differences in birth weight have been detected only when paternal breeds differed markedly in mature BW (Bianchi et al., 2001; Freking and Leymaster, 2004; Fogarty et al., 2005) or when the environment did not impose a restriction on the greater nutritional requirements of twin-carrying ewes (Bianchi et al., 2002). Our results emphasize, for typically extensive systems, the need for differential nutritional management of ewes carrying twins.

Previous reports have shown greater loss of BCS and BW in crossbred ewes compared with CO and CRIII ewes during the period 0 to 60 d after lambing (Müñón et al., 2001b). Such a loss may be expected to reduce the body reserves available for mobilization beyond d 60, which, in turn, may affect milk production. The genotype × litter size interaction detected for ADG60–90 could be explained by a similar pattern of mobilization of fat reserves in crossbred ewes. However, our data cannot be applied in support of this hypothesis because dam BCS and BW were only recorded once, just before service.

Differences among first cross genotypes for growth rate and weaning weight were detected. Lambs of the IF × CO genotype presented greater BW90 than TX × CO and CRIII × CO. Wolf et al. (1980) did not detect differences between IF and TX when simultaneously evaluated as paternal breeds. More recent studies, however, have shown smaller ADG in TX cross lambs compared with other meat breeds (Cruickshank et al., 1996; Ellis et al., 1997; Bianchi et al., 2003). Less general appetite and efficiency in TX lambs was postulated as the cause of the decreased ADG observed in several studies (Kremer et al., 2004).

The synthetic CRIII has a moderate growth potential, which may explain why no differences were detected when compared against CO, as a terminal ram breed. Performance of BL × CO lambs was similar to previous reports, ranking among the genotypes with greater ADG (Kirtton et al., 1995). Second cross lambs had similar BW90d than first cross lambs from BL, IF, and TX rams.

Preweaning ADG is very dependent upon ewe milk production (Carson et al., 1999). In this study, lamb growth was evaluated in similar conditions for all dam genotypes; thus, differences between first cross genotypes and CO × CO would be indicative of better feed conversion efficiency or greater capacity to extract resources from their mothers among first cross lambs or both. This is supported by previous studies that showed greater conversion efficiency in crossbred lambs sired by rams of meat breeds compared with purebred lambs of wool breeds (Rui de Castro et al., 2003; Dwyer, 2008). Differences in growth between second cross and CRIII × CRIII lambs vs. the remaining genotypes include direct and maternal additive effects, heterosis effects, or both. Improved milk production in crossbred and CRIII dams as well as greater growth efficiency of second cross lambs may have contributed toward the observed differences in lamb growth. However, our

<table>
<thead>
<tr>
<th>Genotype1</th>
<th>Mean2</th>
<th>SD</th>
<th>HDP95%3</th>
<th>P &gt; 04</th>
</tr>
</thead>
<tbody>
<tr>
<td>BL × CO</td>
<td>0.008</td>
<td>0.032</td>
<td>−0.052, 0.076</td>
<td>0.615</td>
</tr>
<tr>
<td>IF × CO</td>
<td>0.030</td>
<td>0.035</td>
<td>−0.038, 0.103</td>
<td>0.822</td>
</tr>
<tr>
<td>TX × CO</td>
<td>0.037</td>
<td>0.038</td>
<td>−0.038, 0.116</td>
<td>0.847</td>
</tr>
<tr>
<td>CRIII × CO</td>
<td>0.039</td>
<td>0.046</td>
<td>−0.051, 0.133</td>
<td>0.812</td>
</tr>
<tr>
<td>CRIII × BLCO</td>
<td>−0.002</td>
<td>0.057</td>
<td>−0.114, 0.113</td>
<td>0.466</td>
</tr>
<tr>
<td>CRIII × IFCO</td>
<td>0.018</td>
<td>0.062</td>
<td>−0.104, 0.146</td>
<td>0.605</td>
</tr>
<tr>
<td>CRIII × TXCO</td>
<td>0.036</td>
<td>0.068</td>
<td>−0.097, 0.174</td>
<td>0.711</td>
</tr>
<tr>
<td>CRIII × CRIII</td>
<td>0.054</td>
<td>0.059</td>
<td>−0.061, 0.175</td>
<td>0.848</td>
</tr>
</tbody>
</table>

1Sire breed listed first: BL = Border Leicester; CO = Corriedale; IF = Île de France; TX = Texel; CRIII = Synthetic III.
2Positive values indicate greater posterior means for Corriedale.
3Posterior high density interval with a 95% of probability.
4Probability for the difference to be greater than 0.

Table 6. Features of the marginal posterior distributions of the differences relative to Corriedale for each genotype for survival to weaning and commercial finishing.
results suggest that crossbred ewes should be mated to rams from breeds of greater growth potential than CRIII to take advantage of any greater milk production of crossbred ewes.

Survival is a complex trait that synthesizes the competence of the lamb and the maternal ability of its dam. It is closely related to birth weight (Fogarty et al., 1985) but is also influenced by behavioral components (Cloete, 1993; Dwyer et al., 1996). When alternative genotypes are compared, a main role in survival is generally attributed to dystocia associated with differences in birth weight (Leymaster and Jenkins, 1993; Fogarty et al., 2005). Although there were differences in birth weight among the genotypes evaluated, their relevance for lamb survival could hardly be established without a more in-depth analysis of presumable causes of death, which were not available for this data set.

In arid and semi-arid rangeland systems, the herdage growing season is usually short. The optimization of breed resources in this kind of systems should take into account not only the differences in weaning weight but also the ability of different genotypes to reach commercial finishing during the limited growing season. In spite of its relevance, little attention has been traditionally devoted to the percentage of commercial finishing achieved in sheep crossbreeding studies. In the typical extensive systems of northeastern Patagonia, lambs still unfinished around weaning cannot remain in the farm because of forage constraints and are usually sold at a markedly reduced price, which affects economic efficiency. Alternatively, maintaining those lambs on-farm across the summer usually implies losses due to health issues, less forage for the dam flock, and lack of premium prices for the lambs in spite of their achieving comparatively heavy BW in early fall. In our study only 42% of CO × CO reached commercial finishing compared with 53 to 82% for crossbred lambs. Differences in CF were also observed among first cross genotypes. Thus, our results indicate that significant improvements could be expected in weaning weight and percentage of lambs sold at weaning from introducing rams from BL and IF breeds into local CO flocks. The use of TX or synthetic CRIII as terminal breeds would be less advantageous. The synthetic breed, on the other hand, could be used to improve weaning weight and commercial finishing without the added complexity associated with crossbreeding schemes.

Second cross lambs failed at achieving greater weaning weights and commercial finishing percentages than the best first cross genotypes or the CRIII purebred lambs. Thus, the decision of implementing a multiple or terminal crossbreeding scheme should be based on other performance traits such as prolificacy. Reproduction of crossbred and CRIII ewes was also part of the study, and main findings are being reported elsewhere. Nevertheless, upon examination of records, differences among genotypes for BW90, CF, and SW were mainly associated with the mean prolificacy (data not reported) of CRIII (1.32) and crossbred ewes (1.44) relative to purebred CO dams (1.22). It has been proposed that the advantage in reproduction traits from incorporating more prolific genotypes would be accentuated under management systems that use nursery facilities (Casas et al., 2004). In spite of the constraints typical of extensive systems, our results highlight that differential nutrition of ewes carrying twins and of twin lambs themselves should be implemented to take advantage of the more prolific genotypes.

A final general caveat applies to our results: lack of true spatial replication. Although between-year variation probably exceeds spatial variability among the typically resource-constrained farms and ranches of northern Patagonia, extrapolation to similar production systems in other arid or semi-arid regions should be done cautiously.

LITERATURE CITED

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