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Introduction of sheep meat breeds in extensive systems: Lamb carcass characteristics

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ABSTRACT

Genotype effects on lamb carcass traits were investigated in a 4-year study aimed at assessing potential benefits from introducing meat breeds into the wool-oriented extensive sheep systems of northeastern Patagonia, Argentina. 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 436 male lambs of 9 genotypes (CO × CO, BL × CO, IF × CO, TX × CO, CRIII × CO, CRIII × BLCO, CRIII × IFCO, CRIII × TXCO, and CRIII × CRIII). Hot carcass weights and dressing yields were determined after slaughtering. Carcasses were given conformation and subcutaneous fat scores using the EUROP system [scale varying from E (best) to P (poorest) for conformation, and from 1 (lean) to 5 (overfat) for subcutaneous fat]. Linear measurements of carcass length and width were recorded and carcass compactness indices were calculated from those. Purebred CO acted as a standard for comparisons. On a constant liveweight basis, genotypes CRIII × IFCO and CRIII × CRIII presented higher ($P < 0.05$) carcass weight and dressing yield than CO × CO and BL × CO. Crossbred and synthetic genotypes showed higher ($P < 0.05$) carcass width than CO × CO. With the exception of BL × CO the remaining genotypes showed higher ($P < 0.05$) carcass width/length ratio than CO × CO. The probability that carcasses of crossbred and synthetic lambs presented better conformation than CO × CO was higher than 84%. Carcasses of CRIII × IFCO lambs were given the best conformation scores. The probability that BL × CO carcasses presented higher subcutaneous fat than the remaining genotypes exceeded 79%. Our results indicate significant improvements in carcass conformation arising from crossing. Sheep farmers in extensive systems could take advantage of the higher fatness of BL crossbred lambs to produce light carcasses with adequate fat cover, a crucial industry requirement. Terminal crossbreeding with Île de France, Texel, and CRIII rams could be implemented to improve carcass conformation thus matching market demand for heavy carcasses with limited fat content. Second cross schemes did not improve carcass commercial traits over the best terminal cross or the synthetic CRIII breed.

1. Introduction

Patagonian sheep farming has historically focussed on fine wool; lamb and mutton production has been confined

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to the wetter areas of the region (e.g. foothills of the Andes, Atlantic coast and Tierra del Fuego). Meat demand from overseas markets and local packers within the foot-and-mouth disease-free area is increasing. In this new scenario meat production has potential for improving farm income substantially thus contributing to economic and social sustainability of Patagonian sheep farming. However, new markets demand lean heavy carcasses (Rees, 2009) and this is fostering genotype changes in areas suitable for intensifying meat production. Synthetic meat genotypes are gradually spreading and dual-purpose Corriedales, the traditional resource for meat production, are being increasingly interbred with meat and prolific genotypes (Álvarez et al., 2010). Identifying crosses matching particular markets and production systems is required for getting leaner carcasses at optimum slaughter weights (Kirton et al., 1995). An evaluation of available genetic resources is essential to assess their potential for crossing systems exploiting both heterosis and complementarity to meet specific production and market goals. This work reports results on carcass traits from a long-term study aimed at characterizing genotype effects on growth traits, survival, and commercial finishing of lambs (Álvarez et al., 2010). We also report results on some non-genetic effects that may help identify possible strategies for improving management. The study focused on northeastern Patagonia but general findings are probably relevant for other extensive sheep production systems around the world.

2. Materials and methods

Experimental protocols and animal management were carried out in accordance with EU Directive 2010/63/EU for animal experiments (http://ec.europa.eu/environment/chemicals/lab_animals/legislation_en.htm).

2.1. Study site

The study was conducted at the Patagones Research Farm located in northeastern Patagonia (40°39′S, 62°54′W, 40 m a.s.l.), within the phytogeographical Province of the Monte (Cabrera, 1976), Argentina. This is a semi-arid region characterized by shrubby natural vegetation and long-term annual rainfall averages of approximately 300 mm. The mean annual temperature is 14.5 °C with minimum and maximum temperatures usually occurring in August and January, respectively.

2.2. Animals

The gamut of sheep meat breeds readily available in Argentina is rather limited. Genotypes included in the study were those locally available at the time. 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. Experimental CO ewes came from commercial flocks with production records representative of the breed. The CRIII genotype is a synthetic originated at the Valle Inferior Agriculture Experiment Station (VIAES, located nearby the Patagones Research Farm) by crossing and backcrossing of IF and TX rams on Merino dams. Synthetic CRIII dams are usually heavier (~60 kg) than CO (~53 kg) dams and have an approximate blend of 25% Merino, 37.5% IF, and 37.5% TX (Álvarez et al., 2010). This breed has not been evaluated before for straight breeding nor for terminal crossing.

From 2002 to 2006, CO ewes ($n = 182–240$) were mated to CO, BL, IF, or TX rams every year. First cross females born in 2002–2004 (i.e., BLCO, IFCO, and TXCO genotypes) were retained and mated to CRIII rams in 2004, 2005, and 2006; CRIII ewes ($n = 98–113$), in turn, were mated to CRIII rams from 2003 to 2006 (Table 1). Five rams of each CO, BL, IF, and TX breeds and 12 CRIII rams were used in the study. Corriedale, BL, IF, and TX rams were obtained from 3 different local breeders. The CRIII rams came from the experimental VIAES flock. As data were connected across years by ram breed and by rams within ram breed, the design allowed for comparisons among 9 lamb genotypes: CO × CO, BL × CO, IF × CO, TX × CO, CRIII × CO, CRIII × BLCO, CRIII × IFCO, CRIII × TXCO, and CRIII × CRIII; see Álvarez et al. (2010) for further details of experimental design and connectedness.

2.3. Flock management and data recording

Flock management mimicked the annual spring lambing system typical of local flocks. On average, mating started on 25 March and lasted for 34 days. Starting as 18-month-old, ewes were assigned every year to a randomly chosen ram breed and to a random ram within that breed. Animals were treated against internal and external parasites (ivermectin 3%, Vermectin Premium LA, OVER Labs, Buenos Aires, Argentina; 1 cm^3/50 kg bodyweight s.c.) before the onset of the mating season. All ewe genotypes were managed as one flock. Feeding was exclusively grass-based; year-round grazing mirrored a sequence of forage resource use typical of local flocks. During the mating and gestation periods ewes grazed native grassland (~560 kg dry matter/ha per year) and improved wheatgrass pastures (~950 kg dry matter/ha per year), respectively. Two times a day recently lambed ewes and newborn lambs were moved to an oats winter crop paddock (~1800 kg dry matter/ha per year) where they joined previously lambed ewes. Dry ewes grazed oats stubbles.

Ewes were shorn 20 days in advance of the expected date of onset of lambing (19 August on average). Ewe–lamb pairs were identified at birth, and date of birth, sex, birthweight and litter size were recorded. Thereafter and every fortnight until weaning (90 days) lambs were weighed and assessed for body condition score [on a 1 (emaciated) to 5 (obese) scale; Jefferies, 1961]. Starting in 2003, male lambs reaching at weaning both 23 kg or higher and 2.5 points or a higher condition score were considered commercially finished and shipped for slaughtering; female lambs were retained for reproduction.

2.4. Slaughtering and carcass evaluation

Male lambs were slaughtered in a local abattoir following standard procedures including humane desensitization. Individual hot carcass weights were recorded after slaughtering and a dressing yield was calculated as 100 × carcass weight (kg)/liveweight (kg). Carcasses were given conformation and subcutaneous fat scores using the EUROP system (de Boer, 1992) which varies from E (best) to P (poorest) for conformation, and from 1 (lean) to 5 (overfat) for subcutaneous fat. Classes 3 and 4, in turn, admit 2 subclasses each (H for high and L for low fatness). Two different measurements of length and width were recorded (Timon and Bichard, 1965) and used in three indices of leg and carcass compactness. Carcasses were suspended on a gamble to keep a constant separation between the legs and the following linear measures were recorded: carcass length (from tail base to neck base), leg length (from the perineum to the tarsal–metatarsal articular surface), bottom width (width at the level of the proximal edge of the patellae) and carcass width (maximum carcass width at chest height). Indices of carcass compactness (carcass weight/length), leg compactness (bottom width/leg length) and carcass width/length ratio (Bibe et al., 2002) were calculated for each carcass.

2.5. Statistical analyses

Basic edits eliminated records of lambs with unknown parents and implausible lambing or weight records (usually associated with mismothering; less than 1% of cases). Data from 436 male lambs slaughtered from 2003 to 2006 were available for analyses.

All linear measurements plus carcass weight and dressing yield were analyzed using linear mixed models. Exploratory analyses identified main factors and interactions to be included in the reduced models. In commercial farms lambs are shipped for slaughtering at a target liveweight. Hence we decided to include liveweight or carcass weight in the statistical models to identify factors other than weight contributing to differences between genotypes. Liveweight and carcass weight showed non-linear relationships with some traits; they were quantized into four levels (1: value $< \mu - \sigma$; 2: $\mu - \sigma \leq$ value $< \mu$; 3: $\mu \leq$ value $< \mu + \sigma$; 4: value $\geq \mu + \sigma$) for inclusion as fixed effects. Not unexpectedly, factors usually affecting lamb growth traits such as lambing period or dam body condition (Álvarez et al., 2010), did not reach statistical significance after liveweight or

Table 1
Number of lambs by genotype and levels of environmental effects.

Genotype[a]	Year				Liveweight[b]				Carcass weight[c]				Litter size	
	2003	2004	2005	2006	1	2	3	4	1	2	3	4	Single	Twins
CO × CO	17	13	10	11	14	17	12	8	15	17	12	7	37	14
BL × CO	17	14	14	10	8	18	15	14	9	19	15	12	38	17
IF × CO	17	12	10	11	9	13	14	14	9	14	14	13	36	14
TX × CO	15	10	12	10	9	16	14	8	8	14	14	11	31	16
CRIII × CO		9	12	11	8	10	7	7	8	9	8	7	20	12
CRIII × BLCO		11	10	13	6	8	10	10	7	11	9	7	21	13
CRIII × IFCO		9	11	12	6	9	8	9	6	7	10	9	20	12
CRIII × TXCO		11	11	10	7	8	11	6	7	7	11	7	20	12
CRIII × CRIII	28	27	22	26	20	32	28	23	21	33	27	22	66	37
Total	94	116	112	114	87	131	119	99	90	131	120	95	289	147

[a] Sire breed listed first: BL, Border Leicester; CO, Corriedale; IF, Île de France; TX, Texel; CRIII, synthetic III.

[b] Level 1: liveweight $<$ 24.6 kg; level 2: 24.6 kg $\leq$ liveweight $<$ 29.0 kg; level 3: 29.0 kg $\leq$ liveweight $<$ 33.3 kg; level 4: liveweight $\geq$ 33.3 kg.

[c] Level 1: carcass weight $<$ 11.0 kg; level 2: 11.0 kg $\leq$ carcass weight $<$ 13.4 kg; level 3: 13.4 kg $\leq$ carcass weight $<$ 15.9 kg; level 4: carcass weight $\geq$ 15.9 kg.

carcass weight was included in the models. No significant interactions were detected.

Fixed effects for the analysis of carcass weight and dressing yield included: lamb genotype, year (2003–2006), litter size (single, twins), and liveweight class (1: liveweight $<$ 24.6 kg; 2: 24.6 kg $\leq$ liveweight $<$ 29.0 kg; 3: 29.0 kg $\leq$ liveweight $<$ 33.3 kg; 4: liveweight $\geq$ 33.3 kg). The same fixed effects were included in models of carcass linear measurements except that carcass weight class substituted for liveweight class (1: carcass weight $<$ 11.0 kg; 2: 11.0 kg $\leq$ carcass weight $<$ 13.4 kg; 3: 13.4 kg $\leq$ carcass weight $<$ 15.9 kg; 4: carcass weight $\geq$ 15.9 kg). The PEST software (Groeneveld et al., 1990) was applied for both estimation of fixed and prediction of random effects. Contrasts between levels of each effect were tested against an F distribution, and it was assumed that levels differed from each other when $P<0.05$ or more extreme. Variance ratios reported by Bibe et al. (2002) were used for all carcass traits and compactness indices. Scores of conformation, subcutaneous and kidney fat were analyzed via threshold models using a Bayesian approach (Gianola and Foulley, 1983). Observations of conformation were grouped into four classes (E, U, R, O–P) and those of subcutaneous fat into three (2, 3L-3H, 4L-4H; no carcasses were assigned to the 1 or 5 classes). It was assumed that each animal had an unknown liability (l_i) for each trait and that the liabilities, conditional to all effects, were independently and normally distributed. The animal model included the same effects applied to analyze carcass linear measurements. Marginal posterior distributions were estimated using Gibbs sampling with bounded flat priors for all parameters. Following exploratory analyses, it was decided to use 400,000-iteration chains rejecting the first 100,000 (burning) and saving 1 out of 10 of the remaining ones (i.e., marginal posterior distributions were made up of 30,000 samples). Convergence was tested using the Z criterion (Geweke, 1992). Inferences were made in the liability scale and samples were then back-transformed using the probit function to estimate marginal posterior means and deviations in the observable scale.

3. Results and discussion

The objective of the study was to assess differences between genotypes after removing weight-mediated effects. Environmental effects were considered to better understand factors affecting carcass traits and to identify promising management strategies; least squares means are only reported when relevant for those purposes. For conformation and subcutaneous fatness, preplanned comparisons involving genotype are presented as differences relative to the CO × CO genotype (Table 3); other pair-wise genotype comparisons, among the 36 possible for each trait, are mentioned when relevant.

3.1. *Environmental effects*

Year affected all variables studied ($P<0.05$). Year effects on conformation and carcass fatness are usually mediated by ill-defined factors (e.g. nutritional level, protein and energy content of the diet, photoperiod) that affect daily gain and carcass composition (Kirton et al., 1998). Those factors were not controlled for in our experiment and as their effects are typically not repeatable they were not studied further.

Carcass weight increased with liveweight ($P<0.05$) but no liveweight effect was detected on dressing yield ($P>0.05$). Several studies reported higher dressing yields in medium and heavy lambs compared with light lambs (Kirton et al., 1995; Kremer et al., 2004). However, lambs in our study were unshorn at slaughter and wool weight may have masked fattening differences. Wool growth of the heavier, probably older lambs could have neutralized any effect of liveweight on dressing yield mediated by a higher fat content. Carcass linear measurements and carcass and leg compactness indices increased ($P<0.05$) with carcass weight. Heavier carcasses were given higher conformation and subcutaneous fat scores. The influence of carcass weight on linear measurements and compactness indices, conformation, and subcutaneous fat has been widely reported and explained by the differential growth rates of bone, muscle and fat.

Twinning reduced ($P<0.05$) both carcass weight and dressing yield with no further effects on carcass linear measurements or compactness indices. The effects of litter size on carcass characteristics are mainly mediated through liveweight and carcass weight (Fogarty et al., 2005). However, our results showed that factors other than liveweight or carcass weight could have contributed to the differences observed. For single lamb carcasses the probability of obtaining higher conformation and subcutaneous fat scores than twin lamb carcasses was 85% and 90%, respectively. A limited milk supply and a more developed rumen from earlier forage consumption could significantly contribute toward lower dressing yields in twins (Ryan et al., 1993) whereas a lower growth rate may promote less carcass fatness.

3.2. Genotype effects

Genotypes CRIII × IFCO and CRIII × CRIII presented higher ($P < 0.05$) carcass weight and dressing yield than CO × CO and BL × CO (Table 2). Comparatively lower dressing yield in BL crossbred lambs, even at the same age of other crosses, has been previously reported and attributed to higher intestine and gut fat weights (Kirton et al., 1995). Higher wool and skin weights may have also contributed to the lower dressing yield of CO × CO and BL × CO lambs (Kirton et al., 1995). The higher dressing yield of second cross lambs is in agreement with reports in other recent studies (Fogarty et al., 2005).

Genotypes CRIII × IFCO and CRIII × CRIII presented higher carcass width ($P < 0.05$) than the remaining genotypes. Carcasses from CRIII × CRIII, CRIII × IFCO and CRIII × TXCO lambs showed comparatively higher compactness indices ($P < 0.05$, Table 2) and IF × CO lambs presented higher leg compactness ($P < 0.05$). With the exception of BL × CO, the remaining genotypes showed higher carcass width/length ratios than CO × CO ($P < 0.05$, Table 2).

A positive relationship between conformation and saleable meat yield has been reported in some studies, but correlations were low and predictions uncertain (Purchas and Wilkin, 1995). A relatively high muscle:bone ratio is a common finding in carcasses with the best conformations. However, conformation is not a reliable predictor of carcass composition (Kempster et al., 1981). Hence, it must be worth considering in what circumstances a good carcass conformation effectively represents a benefit for producers and packers, and how differences among genotypes could be exploited to match market demand.

Differences between good vs. poor carcass conformations are reflected in saleable meat yield only when the steaking method is used for processing. On a constant weight and fattening basis, carcasses with higher conformation scores had more weight and area of leg and loin steaks than carcasses with low conformation scores (MLC, 1987). Shorter, wider carcasses have a more compact appearance which seems to be attractive to consumers due to a preference for cuts with more muscle area (Texeira et al., 2004). Carcasses with high conformation scores are highly valued and receive better prices in Patagonian export markets, the EU in particular. As it has been pointed out before (Jones and Lewis, 2003) farmers should produce heavy carcasses with conformation scores higher than R, and with subcutaneous fat scores not higher than 3. Hence, conformation could be important per se, not just as an indicator of lean content (Nsoso et al., 2000). Fatness, in contrast, would be a better indicator of carcass composition since fat and muscle percentages are inversely related (Taylor et al., 1989).

Differences between breeds for conformation and fatness were noticeable in our study. The probability that carcasses of crossbred and CRIII × CRIII lambs presented better conformation than CO × CO was higher than 84% and the probability that IF × CO carcasses presented better conformation than BL × CO, TX × CO and CRIII × CO was more than 77%. Carcasses of CRIII × IFCO lambs were given the best conformation scores (Tables 3 and 4). Higher growth

Table 2
Least square means and average standard errors of the genotypes on carcass traits.

Genotype[a]	Carcass weight (cm)	Dressing yield (%)	Linear measurements				Carcass compactness (kg/cm)	Leg compactness	Carcass width/length ratio
			Carcass length (cm)	Leg length (cm)	Bottom width (cm)	Carcass width (cm)			
CO × CO	12.8a	44.3a	55.9ab	25.5ab	25.9	19.3a	0.235a	1.018ab	0.344a
BL × CO	12.8a	44.0a	56.5b	25.4ab	26.0	20.1b	0.236ab	1.025ab	0.355ab
IF × CO	13.0a	44.5ab	55.4a	25.1b	26.1	20.4b	0.240abc	1.042b	0.368b
TX × CO	13.2abc	45.9abc	55.3a	25.4ab	26.4	20.2b	0.243bcd	1.039ab	0.365b
CRIII × CO	13.1ab	45.4ab	55.7ab	25.4ab	26.1	20.3b	0.241abc	1.030ab	0.365b
CRIII × BLCO	13.2abc	45.6abc	55.7ab	25.4ab	25.7	20.4b	0.242abcd	1.014ab	0.367b
CRIII × IFCO	13.8c	47.2c	54.9a	25.4ab	26.0	21.2c	0.247cd	1.024ab	0.386c
CRIII × TXCO	13.5abc	45.7abc	55.8ab	25.3ab	26.2	20.4b	0.246cd	1.037ab	0.366b
CRIII × CRIII	13.5bc	46.2bc	55.3a	25.6a	25.9	21.2c	0.247d	1.013a	0.381c
Average s.e.	0.2	0.8	0.3	0.2	0.3	0.3	0.003	0.013	0.005

Within trait means without a common letter differ (at least $P < 0.05$).

[a] Sire breed is listed first: CO, Corriedale; BL, Border Leicester; IF, Île de France; TX, Texel; CRIII, synthetic breed III.

Table 3
Features of the marginal posterior distributions of the differences relative to Corriedale for each genotype.

Genotype[a]	Conformation				Subcutaneous fat			
	Mean[b]	s.d.	HDP95%[c]	$P > 0$[d]	Mean[b]	s.d.	HDP95%[c]	$P > 0$[d]
BL × CO	−0.195	0.175	−0.531, 0.157	0.130	−0.127	0.165	−0.440, 0.210	0.216
IF × CO	−0.454	0.171	−0.794, −0.122	0.004	−0.005	0.155	−0.312, 0.297	0.484
TX × CO	−0.269	0.187	−0.631, 0.101	0.072	0.136	0.169	−0.210, 0.455	0.794
CRIII × CO	−0.329	0.183	−0.690, 0.023	0.034	0.100	0.169	−0.234, 0.425	0.723
CRIII × BLCO	−0.215	0.212	−0.638, 0.192	0.152	0.315	0.196	−0.064, 0.698	0.950
CRIII × IFCO	−0.533	0.222	−0.962, −0.095	0.006	0.204	0.203	−0.188, 0.612	0.845
CRIII × TXCO	−0.480	0.219	−0.914, −0.055	0.014	0.083	0.201	−0.307, 0.480	0.661
CRIII × CRIII	−0.488	0.171	−0.823, −0.153	0.002	0.216	0.157	−0.095, 0.524	0.919

[a] Sire breed listed first: BL, Border Leicester; CO, Corriedale; IF, Île de France; TX, Texel; CRIII, synthetic III.
[b] Positive values indicate greater posterior means for Corriedale.
[c] Posterior high density interval with a 95% of probability.
[d] Probability for the difference to be greater than 0.

Table 4
Mean and standard deviation of the marginal posterior distributions of the genotypes for conformation and subcuntaneous fat score, in the observable scale.

Genotype[a]	Conformation (%)[b]				Subcutaneous fat (%)[c]		
	E	U	R	O–P	2	3L–3H	4L–4H
CO × CO	2.1 ± 1.2	42.9 ± 7.6	46.9 ± 6.0	8.1 ± 3.4	8.0 ± 3.5	54.7 ± 6.0	37.3 ± 8.5
BL × CO	4.0 ± 2.0	52.8 ± 6.4	38.7 ± 6.2	4.5 ± 2.1	5.2 ± 2.5	49.0 ± 6.5	45.8 ± 8.3
IF × CO	8.6 ± 3.1	62.8 ± 4.7	26.7 ± 5.6	1.9 ± 1.0	7.7 ± 2.9	54.8 ± 5.0	37.5 ± 7.0
TX × CO	5.1 ± 2.5	55.9 ± 6.7	35.4 ± 7.0	3.6 ± 2.0	12.1 ± 4.7	59.1 ± 4.7	28.8 ± 7.8
CRIII × CO	6.1 ± 2.8	58.5 ± 5.9	32.5 ± 6.6	2.9 ± 1.6	10.8 ± 4.1	58.3 ± 4.9	30.9 ± 7.7
CRIII × BLCO	4.5 ± 2.6	53.4 ± 8.0	37.7 ± 7.9	4.4 ± 2.6	19.6 ± 7.3	60.9 ± 3.9	19.5 ± 7.4
CRIII × IFCO	11.1 ± 5.2	63.9 ± 5.1	23.5 ± 7.5	1.5 ± 1.1	14.8 ± 6.4	60.1 ± 4.5	25.1 ± 8.6
CRIII × TXCO	9.7 ± 4.8	62.7 ± 5.7	25.8 ± 7.8	1.8 ± 1.4	10.6 ± 5.2	57.2 ± 5.9	32.2 ± 9.8
CRIII × CRIII	9.4 ± 3.1	63.8 ± 4.2	25.2 ± 5.1	1.6 ± 0.8	14.8 ± 4.1	61.2 ± 3.6	24.0 ± 5.6

[a] Sire breed listed first: BL, Border Leicester; CO, Corriedale; IF, Île de France; TX, Texel; CRIII, synthetic III.
[b] Scale from E = best conformed to P = poorest conformed.
[c] Scale from 1 = lean to 5 = overfat. H, high; L, low.

rate is associated to proportionally more increase in width rather than length dimensions (Jeremiah et al., 1997) which explains the higher values for leg and carcass compactness indices and conformation scores observed in crossbred lambs.

The probability of BL × CO carcasses presenting higher subcutaneous fat than the remaining genotypes was more than 79% (Table 4). In contrast, higher conformation scores in other crossbred genotypes relative to CO × CO were not associated with higher subcutaneous fat (Tables 3 and 4). With the exception of BL × CO, IF × CO, and CRIII × TXCO, the probability that CO × CO carcasses presented higher subcutaneous fat than the rest of genotypes was more than 72% (Table 3).

During a fattening phase, fat percentages increase at the expense of muscle and bone percentages. As a result of variation in mature size, differences in fatness are more evident when comparing breeds. Breeds of large mature size initiate fattening at higher weights than smaller ones (Taylor et al., 1989). However, our results showed that, in spite of their larger mature size, BL crossbred lambs initiated fattening earlier than the remaining genotypes. This may indicate that the BL breed does not fit the general relationship between mature size and fattening and this is supported by previous findings (Kirton et al., 1995; Fogarty et al., 2005). As stated above, heavy and medium carcasses with excess fat receive lower prices. In contrast, achieving a minimum fattening grade is essential for light lamb production in arid and semiarid rangeland systems, since the forage growing season is usually short. Optimization of breed resources should take into account the ability of different genotypes to reach commercial finishing during a limited growing season. Our results indicate that producers could benefit from mating BL rams to CO ewes for light lamb production since BL crossbred lambs showed higher growth rates than most genotypes, and a high percentage of the lamb crop reached commercial finishing at weaning (Álvarez et al., 2010). Other breeds, on the other hand, could be used for medium and heavy lamb production in order to match consumer preferences. For markets requesting heavy carcasses with limited fat, terminal crossbreeding with breeds such as Île de France, Texel, and CRIII, should be implemented. No advantages on conformation score or subcutaneous fat were observed for second crosses when compared with the best terminal crosses or the CRIII breed. Previous work has shown no additional advantages for second cross lambs on growth rate, survival or commercial finishing (Álvarez et al., 2010). Thus, the decision of implementing multiple or terminal crossbreeding schemes should be based on traits other than carcass conformation or fatness.

Although it was adequate for our purposes to compare genotypes at a given marketing liveweight, it is clear that part of the differences we report could have been induced by differences in the degree of maturity of the genotypes rather than by their genetic makeup per se. The exception to this caveat would be terminal BL crosses that entered their fattening phase lighter and younger than other genotypes of smaller mature sizes.

4. Conclusions

More work will be needed to identify management strategies for extensive rangeland systems capable of mitigating year effects and litter size constrains.

Matching market demands on the basis of combining readily available dam genotypes with meat sires under adequate management has potential to improve farm income and long-term sustainability of extensive sheep raising.

Crossbreeding and the use of the CRIII breed increased carcass weight and dressing yield and improved carcass width/length ratio and conformation. Those changes may contribute to higher acceptance, better prices, and improved income.

Among the options available to match market demand, Border Leicester rams would be the choice for siring light lambs whereas Île de France, Texel, and CRIII sires should be considered for producing heavy, lean carcasses.

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