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Slaughter and carcass characteristics of cross- and purebred lambs finished in a pasture-based system

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Abstract

One hundred and twelve cross- and purebred pasture-reared lambs were slaughtered at optimal backfat thickness (4 mm). Selected slaughter, carcass, and meat quality characteristics of these animals were assessed. Slaughter age, but not weight, was influenced by genotype, whereas rams were younger and heavier at slaughter than ewes. Throughout, the crossbred genotypes were younger at slaughter than their purebred contemporaries. Merinos had a lower dressing percentage (40.74%) than Dohne Merinos (43.89%), which in turn dressed out substantially lower than all crossbred combinations (~47%). Genotype did not influence the fat or bone percentage in the carcass, but differences existed for the meat percentage. Meat from all groups could be described as very tender (<32.96 N) and acceptable even to consumers not preferring pasture-produced lamb. The reduced slaughter age of crossbred lambs presents the possibility of shortening the production cycle of lamb while simultaneously increasing carcass yields.

Keywords: heterosis, lamb production, meat quality, sheep
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Introduction

Traditionally South African sheep meat producing systems have been extensive, grazing-based systems, often in the more arid parts of the country (Cloete & Olivier, 2010). In many cases sheep farming is complementary to cropping, with sheep utilizing crop residues and ley-crops as a feed source (Cloete & Olivier, 2010). Animals produced in these systems are almost exclusively pasture-fed and receive little to no supplementary feeding under normal conditions.

Meat produced by animals reared in such systems offers an attractive alternative to certain market segments due to consumer perceptions, even if these perceptions are not always correct (Meissner *et al.*, 2013; Stampa *et al.*, 2020). A shift is occurring in consumer preferences for meat, with buyers beginning to place more emphasis on the origin and quality of the products they buy (Erasmus *et al.*, 2017; Prache *et al.*, 2020). At the same time, they are becoming more aware of how the meat was produced and reservations regarding animal welfare, environmental impact, and sustainability could influence their buying choices (Conner *et al.*, 2005). This could lead to consumers discriminating against products from feedlot-reared animals. Pasture-finishing also affects the colour and appearance of meat (Prache *et al.*, 2022), an important factor in consumer acceptability.

Furthermore, consumers often believe that meat from pasture-reared animals is healthier than that of feedlot animals (Jacques *et al.*, 2011; Prache *et al.*, 2020; Stampa *et al.*, 2020). Given that there is scientific evidence that red meat consumption may increase the risk of contracting several chronic

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diseases (Wolk, 2017), consumers who are unwilling to cut out red meat from their diets completely may instead opt to consume pasture-reared meat.

Pasture-based systems also offer further advantages to producers. Zervas *et al.* (1999) stated that pasture-based production systems could be physically, biologically, and economically sustainable, all of which are important considerations for any livestock producer. These systems also provide farmers with a higher profit margin when compared to intensive finishing systems due to lower input costs and a potentially more valuable product being produced (Zervas *et al.*, 1999). Additionally, pasture-rearing offers the advantage of allowing for the production of heavier carcasses while still maintaining an acceptable level of carcass fat (Jacques *et al.*, 2011). Given that the best prices are paid for lamb carcasses with a moderate fat cover (graded A2/A3 in South Africa), it would be beneficial to producers to be able to produce heavier carcasses that still fall into this category to satisfy market requirements.

Another way in which market needs might be met, is through the use of crossbreeding (Malhado *et al.*, 2009). Crossing of two or more breeds with desirable traits could produce offspring that display the favourable traits of both parental lines and could help producers to maximise production output through the utilization of heterosis for production traits. Numerous studies have expounded on the benefits associated with crossbreeding. These include greater birth weights (Scales *et al.*, 2000; Özcan *et al.*, 2001; Cloete *et al.*, 2007), higher weaning weights (Sidwell & Miller, 1962; Özcan *et al.*, 2001; Kiyanzad, 2002; Cloete *et al.*, 2007), faster growth rates (Scales *et al.*, 2000; Kiyanzad, 2002; Souza *et al.*, 2013; de Sousa *et al.*, 2019), and improved lamb production (Carneiro *et al.*, 2007; de Sousa *et al.*, 2019) in comparison to pure breeds. The improvement in performance by the crossbred progeny relative to the pure breeds tends to be greater when breed dimorphism is present (Cloete *et al.*, 2004a). When a small-framed dam breed is crossed with a larger sire breed, the difference in size allows for maximal utilization of the concept of feeder–breeder dimorphism, as set out by Roux (1992). In essence it allows for the creation of a more feed-efficient and thus profitable flock, by producing larger, crossbred offspring (feeders) for sale out of smaller, more efficient dams (breeders). According to Cloete *et al.* (2004a), there is ample genetic variation that can be exploited within a structured crossbreeding system in order to improve profitability. Furthermore, Merino-type dam lines are considered as suitable for use as dams in a terminal crossing program due to their small size, good fibre production, and acceptable reproduction, which leads to them providing a good economic yield in such a system (Cloete *et al.*, 2004a). Although the benefits of crossbreeding are well-documented internationally (Carneiro *et al.*, 2007; Souza *et al.*, 2013; de Sousa *et al.*, 2019), very little information is available on crossbreeding in the South African flock (Cloete *et al.*, 2008) and more work needs to be done to determine the viability of crossbreeding. The majority of crossbreeding studies are also centred on intensive lamb production systems, rather than attempting to quantify the benefits of crossbreeding in extensive production and finishing systems.

Combining the lower input costs and potentially higher incomes from pasture-reared animals with the improved performance of crossbred animals has the potential to substantially improve the long-term profitability and, therefore, sustainability, of sheep meat producing systems. Against this background, this study aimed to assess slaughter, carcass, and meat quality traits of various crossbred animals to allow for comparison with purebred wool (Merino) and dual-purpose (Dohne Merino) sheep. It was expected that the crossbred animals would outperform their purebred contemporaries for various slaughter traits of economic importance.

Materials and methods

This trial was carried out with ethical clearance from the University of Stellenbosch's Research and Ethics Committee: Animal Care and Use under clearance number ACU-2020-14574.

For the trial, 112 pasture-reared lambs were slaughtered at Deli-Co commercial abattoir in Riebeeck-West, Western Cape. These lambs were a mix of pure- and crossbred lambs of both sexes sired out of Dohne Merino and Merino dam lines (Table 1).

Lambs were born between April and June (late autumn to early winter) on Langgewens Research Farm in the Swartland region of the Western Cape. Prior to weaning they had *ad libitum* access to creep feed, but no supplementation was provided after weaning and they were reliant upon wheat stubble and medics pastures (*Medicago truncutula, M. littoralis, and M. polymorpha)* for grazing. The stocking density was approximately 4.5 SSU/ha (Brand, 2017) while the medics pastures had herbage production in excess of 3000 kg dry matter per hectare (Swanepoel & Tshuma, 2017). The lambs were weaned when they attained approximately 31 kg live weight. At weaning they received anti-clostridial vaccinations and oral anthelminthic medication.

Table 1 Composition (genotype and sex) of the group of 112 pure and crossbred lambs slaughtered at optimal fat cover after pasture finsihing

Genotype	Sex		
	Ewes	Rams	Total
Dohne Merino	8	4	12
Dohne x Dorper	11	6	17
Dohne x Dormer	13	1	14
Dohne x Ile de France	2	6	8
Merino	7	7	14
Merino x Dorper	10	8	18
Merino x Dormer	12	9	21
Merino x Ile de France	4	4	8
Total	67	45	112

Lambs were weighed weekly from one month of age until slaughter. Slaughter readiness was determined by ultrasound scanning of backfat thickness at the 12–13th rib on the animal's right side. Once lambs achieved a body weight of 20 kg, they were scanned during the weekly weighing using a Mindray DP30V ultrasound scanner. They were considered to be slaughter ready when a backfat thickness of 4 mm, corresponding to a carcass class of A2 (Government Notice R. 863, 2006), was reached. This is considered to be the optimal carcass classification under the South African system. All lambs that attained this level of optimal fatness were slaughtered the following week.

Lambs were slaughtered at a commercial abattoir, following standard South African industry practices. Animals were transported to the abattoir on the day prior to slaughter (~45 minutes of travel) and held in lairage overnight. The animals were rendered unconscious by electrical stunning immediately prior to slaughter and exsanguinated. Carcasses were not electrically stimulated. During the slaughter process, various carcass components were collected and weighed. These components included the skins, red offal, full gastrointestinal tracts, kidneys, and kidney fat of the animals. Warm carcass weight, as measured by the abattoir, was taken to calculate dressing percentage from on-farm slaughter weight measurements. The pH and temperature of the right *longissimus thoracis et lumborum* muscle were also measured at the 12–13th rib 45 min after slaughter using an ACCSEN pH5 pH-meter. Carcasses were chilled in a commercial freezer at 5 °C.

The day after slaughter, the carcasses were transported in a refrigerated truck to a commercial butchery where further samples were taken. Carcass temperature and pH at 24 h post-slaughter were measured at the same site as before and the carcasses were weighed to determine cold carcass weight. The carcasses were then sawed through in the length and a three-rib cut and loin sample was taken from the right side of the carcass. The three-rib cut was made cranially to the 9th and 12th ribs to include the 9th, 10th, and 11th ribs and extended from the vertebrae to approximately the middle of the rib, where inward curvature started (Hankins & Howe, 1946). Carcasses were divided along the line of the three-rib cut (the 12th rib) and both halves were weighed to determine fore- and hindquarters weights.

The three-rib cuts were later dissected into muscle, bone, and fat and expressed as percentages of the whole to estimate carcass composition (Hankins & Howe, 1946; Brand *et al.*, 2018). The soft tissue (meat and fat) from these cuts were conserved and after being homogenized, a proximate analysis was performed on it to determine the moisture, ash, crude fat, and protein content of the sample (AOAC International, 2002). The crude fat content was determined using chloroform–methanol extraction; nitrogen content was determined using the LECO method (AOAC International, 2002).

A loin muscle sample was taken caudally from the site of the three-rib cut, i.e., extending backwards from the 12th rib to where the loin and leg primal cuts separate (approximately at the first and second lumbar vertebrae). This sample was taken to the laboratory where it was weighed and fat depth was measured using a digital calliper. The samples were allowed to bloom for an hour, after which the CIELAB colour parameters, lightness (L*), redness (a*), and yellowness (b*), were determined using a handheld BYK-Gardner 45/0 colorimeter as per Honikel (1998). Hue and chroma values were calculated from these measurements using the formulae:

$$\text{Hue} = \arctan\left(\frac{b*}{a*}\right), \text{ and} \quad (1)$$

$$\text{Chroma} = \sqrt{a*^2 + b*^2}. \quad (2)$$

The loin samples were then vacuum sealed and frozen at -8 °C. The fat was not trimmed from the samples as the aim was to determine freezing and cooking loss for the entire cut and not just the lean meat. Frozen samples were later allowed to thaw at 18 °C for 24 h in the sealed bags in a coldroom and were weighed after being patted dry to determine freezing loss. Thawed samples were subsequently cooked in a water bath at 80 °C for 1 h, allowed to dry off, and weighed to determine the percentage weight lost during cooking.

After this, the fat was trimmed from the samples and six cores of 1×1×2.5 cm were taken parallel to the muscle fibres in each sample. These cores were subjected to the Warner–Bratzler shear force test using an Instron universal testing machine (Instron model 4444/H1028, Apollo Scientific CC., South Africa) to determine shear force as an indication of tenderness. Six repetitions were performed for each animal. A triangular cutting blade, operating at a speed of 200 mm/min was used to cut perpendicularly to the fibres to determine shear force values.

Statistical analysis was performed using the Statistica 14 software package (Tibco Statistica, 2020). The significance level was set to $P \leq 0.05$ and tendencies to differ were discussed from $P \leq 0.1$. Data points deviating more than three standard deviations from the mean were considered as outliers and discarded from the dataset. The carcass component weights were converted to percentage of slaughter weight to correct for potential differences in slaughter weight.

After preparation of the data, two-way analysis of variance tests were performed with genotype and sex set as main effects. Age was initially included as a covariate in these analyses but, as it was found that it had no significant influence on the results, it is excluded from the results presented here. Variables were tested for homoscedasticity using Levene's test over main and interaction effects and residuals were tested for normality. *Post-hoc* interaction effects were evaluated using Fisher's LSD multiple comparison tests. In the case of non-significant interactions, Fisher's LSD multiple comparisons tests were performed on the main effects and not production groups.

Results

Least squares means with standard errors for the slaughter characteristics are given in Table 2. No significant interactions were observed between main effects (sex and genotype) for any trait and therefore main effects are reported separately. Since no interactions were observed, no animal records were discarded as both the sex (n rams, n = 45; ewes, n = 67) and genotypic (n >8) groups showed sufficient repetitions to allow for accurate comparisons. This is despite some production groups having very limited numbers, which would have prevented accurate comparisons being made between production groups.

Slaughter age differed between both sex ($P < 0.001$) and genotype ($P < 0.001$). Rams were younger at slaughter than ewes (116 days vs 132 days) while purebred Merinos were the oldest group (157 days) at slaughter. They were followed by Dohne Merinos, which only differed markedly from Dohne × Dorper (113 days) and Merino × Ile de France (108 days), the two youngest groups. The remaining groups did not differ from each other ($P > 0.05$). Crossbred Dohne Merino offspring were younger than purebred Dohne Merinos at slaughter, although the differences were not statistically significant. Crossbred Merino offspring were, however, substantially younger than purebred Merinos. The crossbred lambs therefore outperformed their purebred counterparts from their maternal lines with regards to slaughter age.

Slaughter weight was not influenced by genotype, but rams were heavier ($P = 0.001$) than ewes. The opposite was found for dressing percentage, where sex had no influence, but differences occurred among genotypes ($P < 0.001$). Purebred Merinos had the lowest dressing percentage (40.74%), markedly lower than all other groups, followed by Dohne Merinos, which did not differ substantially from the Dohne × Dormer group. In turn, Dohne × Dormer did not differ from any of the other groups, among which no differences existed. The lower dressing percentages of the purebred Merinos could potentially be attributed to their greater wool production in comparison to the other breeds. This would result in an increase in slaughter weight due to higher fleece weights but would not translate to higher carcass weights. As with slaughter age, the crossbred groups performed better than their respective purebred maternal lines.

Calliper-measured fat depth at the 13th rib differed markedly between sexes and genotypes. Ewes were fatter (4.66 mm) than rams (3.43 mm) and therefore received a higher average classification (2.16 vs. 1.95; $P = 0.004$). The greatest fat depth was found in the Merino × Dormer combination (4.62 mm), which only differed substantially from purebred Dohne Merinos (3.45 mm) and Merinos (3.03 mm), the latter being the group with the least fat. Purebred Merinos did not differ from the purebred Dohnes or the Dohne × Dormer cross. Dohne × Dormer was intermediate and did not differ from any other group, while no differences existed among the remaining groups (Dohne × Dorper, Dohne × Ile de France, Merino × Dorper, Merino × Ile de France). Carcass classification was not influenced by genotype (*P* =0.210).

Table 2 Slaughter characteristics (least squares means ± S.E.) of cross- and purebred lambs raised on pasture and slaughtered at optimal fat cover (4 mm)

Main effects	Slaughter age (days)	Slaughter weight (kg)	Dressing percentage	Fat depth at 13th rib (mm)	Average carcass classification
Ram	116 ±4	42.8±1.1	45.90±0.49	3.43±0.25	1.95±0.08
Ewe	132 ±3	39.1±1.1	46.67±0.39	4.67±0.20	2.16±0.06
P-value	*<0.001*	*0.001*	*0.220*	*<0.001*	*0.004*
Dohne Merino	134^{b} ±7	43.6±1.9	43.90^{b} ±0.81	3.45^{bc} ±0.41	1.94±0.13
Dohne × Dorper	114^{c} ±6	37.6±1.6	47.91^{a} ±0.67	4.14^{ab} ±0.34	2.05±0.11
Dohne × Dormer	119^{bc} ±12	42.7±3.2	46.99^{ab} ±1.38	4.12^{abc} ±0.70	2.04±0.22
Dohne × Ile de France	115^{bc} ±9	44.3±2.5	48.18^{a} ±1.08	4.62^{ab} ±0.55	1.92±0.18
Merino	157^{a} ±6	39.3±1.5	40.74^{c} ±0.74	3.03^{c} ±0.36	1.92±0.17
Merino × Dorper	125^{bc} ±6	38.8±1.5	46.91^{a} ±0.62	4.01^{ab}±0.32	2.04±0.10
Merino × Dormer	123^{bc} ±5	41.1±1.4	46.75^{a} ±0.58	4.62^{a}±0.30	2.26±0.09
Merino × Ile de France	108^{c} ±8	40.2±2.2	48.90^{a} ±0.94	4.34^{ab} ±0.51	2.25±0.15
P-value	*<0.001*	*0.160*	*<0.001*	*0.040*	*0.210*

Means with different superscripts ($^{a-c}$) in the same column differ significantly (*P* ≤0.05)

Regarding carcass components (Table 3), differences existed between sexes for red offal (*P* <0.001), kidney (*P* <0.001), and kidney fat (*P* =0.021) weights relative to slaughter weight. With the exception of kidney fat, rams had heavier weights for these traits than ewes. Gastrointestinal tract weight did not differ between sexes or genotypes, although there was a tendency to differ between genotypes (*P* =0.091). Kidney fat (*P* =0.306) and red offal weight (*P* =0.076) were not influenced by genotype either, while skin and kidney weight differed substantially between genotypes.

Purebred Merinos had heavier (*P* <0.001) skins than all other genotypes except Merino × Dormers. The latter group only differed markedly from the Dohne × Dorper, Dohne × Dormer, and Merino × Dorper genotypes. The Dohne × Dorper cross had the lightest skins (8.93% of slaughter weight). The heaviest kidneys were found in the Dohne × Ile de France group (0.47% of slaughter weight), which did not differ substantially from the Dohne Merino or Merino × Ile de France combinations. Merino and Merino × Dorper did not differ and had the lowest kidney weights at 0.36% of slaughter weight.

Results pertaining to cold carcass weights and fore- and hindquarter weights are given in Table 4, along with the muscle, fat, and bone percentages of the carcass as estimated from three-rib cuts. As expected, both sex (*P* =0.020) and genotype (*P* <0.001) influenced cold carcass weight. Rams had heavier carcasses than ewes (19.5 kg vs 18.0 kg) with purebred Merino carcasses being substantially lighter (15.7 kg) than all other groups. They were followed by the Merino × Dorper and Dohne × Dorper groups which were not substantially lighter than any of the other groups, bar Dohne × Ile de France (21.1 kg), which was the heaviest. Neither the percentage fore- nor hindquarter yield in the carcasses differed between genotypes. Only the percentage forequarter varied between sexes, with rams having more weight (*P* =0.001) in their forequarters.

Carcass composition differed between sexes, with rams having a substantially greater percentage of muscle and bone than ewes, but less fat. Genotype influenced the percentage muscle in the carcass (*P* =0.020), but not fat (*P* =0.070) or bone (*P* =0.270). Purebred Dohne Merinos (51.62%) and the Merino × Dorper (52.16%) cross had the highest percentage of muscle in the carcass, substantially more than Dohne × Dormer (46.67%) and Merino × Dormer (47.85%). There was a tendency (*P* =0.070) for fat percentage to differ between genotypes, where Merino × Ile de France (30.06%) and purebred Merinos (24.17%) had the highest and lowest absolute percentage of fat respectively.

Table 3 Various carcass components given as percentage of slaughter weight (±S.E.) of pasture-reared lambs slaughtered at 4-mm backfat cover

Main effects	Skin	Red offal	Gastrointestinal tract	Kidneys	Kidney fat
Ram	11.47±0.44	5.98±0.20	22.54±1.24	0.45±0.02	0.544±0.05
Ewe	10.62±0.34	4.98±0.16	21.66±0.97	0.38±0.01	0.707±0.04
P-value	*0.128*	*<0.001*	*0.577*	*<0.001*	*0.021*
Dohne Merino	11.74^{ab}±0.72	5.38±0.33	27.03±2.04	0.44^{ab} ±0.03	0.55±0.09
Dohne × Dorper	8.93^{d} ±0.59	5.27±0.27	20.54±1.69	0.41^{bc} ±0.02	0.55±0.07
Dohne × Dormer	11.31^{bcd}±1.21	6.12±0.55	22.12±3.45	0.45^{bc} ±0.04	0.54±0.15
Dohne × Ile de France	10.99^{abc}±0.96	5.95±0.43	21.93±2.72	0.47^{a} ±0.04	0.77±0.12
Merino	12.47^{a} ±0.63	4.66±0.28	24.60±1.78	0.36^{c} ±0.02	0.59±0.08
Merino × Dorper	9.34^{cd} ±0.56	5.24±0.25	21.56±1.58	0.36^{c} ±0.02	0.66±0.07
Merino × Dormer	12.10^{a} ±0.52	5.78±0.23	19.68±1.47	0.40^{bc} ±0.02	0.76±0.06
Merino × Ile de France	11.48^{ab} ±0.83	5.42±0.38	19.38±2.35	0.41^{abc}±0.03	0.59±0.10
P-value	*<0.001*	*0.076*	*0.091*	*0.044*	*0.306*

Means with different superscripts ($^{a-c}$) in the same column differ significantly (*P* ≤0.05)

Table 4 Percentage fore- and hindquarter carcass yields as well as carcass composition as estimated from three-rib cuts (least square means ± S.E.)

Main effects	Cold carcass weight (kg)	Forequarter (%)	Hindquarter (%)	Carcass muscle (%)	Carcass fat (%)	Carcass bone (%)
Ram	19.5±0.5	49.60±0.29	50.30±0.27	51.08±0.71	24.46±1.00	23.88±0.69
Ewe	18.0±0.4	48.64±0.23	50.59±0.21	48.61±0.56	30.51±0.78	20.15±0.54
P-value	*0.020*	*0.001*	*0.410*	*<0.001*	*<0.001*	*<0.001*
Dohne Merino	18.9^{ab} ±0.8	49.25±0.48	50.23±0.45	51.62^{a} ±1.16	25.13±1.63	22.33±1.14
Dohne x Dorper	18.0^{b} ±0.7	49.66±0.40	50.68±0.37	50.10^{abc} ±0.96	28.02±1.35	21.05±0.94
Dohne x Dormer	19.9^{ab} ±1.4	48.27±0.80	51.15±0.75	46.67^{bc} ±1.97	27.57±2.77	24.04±1.92
Dohne x Ile de France	21.1^{a} ±1.1	48.52±0.63	50.52±0.59	50.44^{abc} ±1.59	29.60±2.23	21.53±1.51
Merino	15.7^{c} ±0.7	49.57±0.41	49.93±0.39	50.78^{ab} ±1.01	24.17±1.42	23.98±0.99
Merino x Dorper	18.0^{b} ±0.6	49.32±0.37	50.73±0.36	52.16^{a} ±0.90	26.14±1.26	20.83±0.88
Merino x Dormer	19.0^{ab} ±0.6	49.39±0.34	50.25±0.32	47.85^{c} ±0.84	29.21±1.18	21.55±0.82
Merino x Ile de France	19.4^{ab} ±0.9	48.98±0.54	50.07±0.51	49.12^{abc} ±1.34	30.06±1.88	20.81±1.31
P-value	*<0.001*	*0.670*	*0.690*	*0.020*	*0.070*	*0.270*

Means with different superscripts $^{(a-c)}$ in the same column differ significantly (*P* ≤0.05)

Table 5 Meat quality characteristics as least squares means ± S.E. of right *longissimus thoracis et lumborum* muscle samples

Main effects	pH at 45 min	Temperature at 45 min (ºC)	pH at 24 h	Temperature at 24 h (ºC)	Freezing loss (%)	Cooking loss (%)	Warner–Bratzler shear force (N)
Ram	6.81±0.04	32.0±0.4	5.68±0.46	6.1±0.3	5.17±0.24	24.18±1.31	20.79±1.162
Ewe	6.75±0.03	33.3±0.3	5.78±0.04	6.9±0.2	4.98±0.19	25.22±1.03	19.83±1.068
P-value	*0.190*	*0.001*	*0.100*	*0.020*	*0.560*	*0.530*	*0.540*
Dohne Merino	6.88^{a} ±0.06	33.2^{ab} ±0.7	5.75^{ab} ±0.08	7.0^{abc} ±0.5	6.68^{a} ±0.40	24.05±2.16	17.42^{b} ±1.913
Dohne × Dorper	6.75^{ab}±0.05	31.8^{b} ±0.5	5.73^{ab} ±0.06	5.9^{cd} ±0.4	4.61^{c} ±0.33	23.40±1.79	18.55^{b} ±1.585
Dohne × Dormer	6.98^{a} ±0.11	29.2^{c} ±1.1	5.76^{abc} ±0.13	5.2^{d} ±0.8	4.93^{bc} ±0.67	22.85±3.65	27.30^{a} ±3.242
Dohne × Ile de France	6.66^{b} ±0.09	34.1^{a} ±0.9	5.71^{abc} ±0.10	7.2^{abc} ±0.6	5.88^{ab} ±0.53	28.56±1.88	15.89^{b} ±3.374
Merino	6.87^{a} ±0.06	33.5^{a} ±0.6	5.88^{a} ±0.07	7.4^{a} ±0.4	4.27^{c} ±0.34	23.51±1.67	24.62^{a} ±1.670
Merino × Dorper	6.63^{b} ±0.05	33.1^{ab}±0.5	5.71^{bc} ±0.06	7.1^{ab} ±0.4	5.15^{bc} ±0.32	24.16±1.55	18.01^{b} ±1.482
Merino × Dormer	6.71^{b} ±0.05	33.5^{a} ±0.4	5.55^{c} ±0.06	6.6^{abcd} ±0.3	4.56^{c} ±0.29	24.16±1.55	19.90^{b} ±1.377
Merino × Ile de France	6.77^{ab}±0.07	32.9^{ab}±0.8	5.72^{abc} ±0.09	5.9^{bcd} ±0.5	4.46^{bc} ±0.45	22.09±2.49	20.81^{ab} ±2.209
P-value	*<0.001*	*<0.001*	*0.030*	*0.040*	*<0.001*	*0.220*	*0.010*

Means with different superscripts ($^{a-d}$) in the same column differ significantly ($P \leq 0.05$)

Selected meat quality characteristics are given in Table 5. Temperature and pH were considered as both traits relate to meat quality in terms of colour and perceived tenderness. Sex did not influence pH at either 45 min or 24 hours h post-slaughter, but temperature did differ, with rams having lower (*P* <0.05) carcass temperatures in both cases. Temperature and pH were both influenced by genotype at 45 min and 24 h post-slaughter. The Dohne × Ile de France, Merino × Dorper, and Merino × Dormer (~6.66) groups had a substantially lower pH than the purebreds and the Dohne × Dormer genotype (~6.91) at 45 min. At 24 h, the Merino × Dormer group had the lowest pH (5.55), significantly lower than purebred Dohne Merinos and the Dohne × Dorper and Dohne × Dormer groups. Purebred Merinos had the highest pH (5.88), which differed from the Merino × Dorper and Merino × Dormer genotypes (*P* =0.030).

Dohne × Ile de France (34.1 °C), Merino (33.5 °C), and Merino × Dormer (33.5 °C) carcasses were warmer at 45 min than Dohne × Dorper (31.8 °C) and Dohne × Dormer (29.2 °C), with the latter two groups also differing from one another (*P* <0.01). The highest temperatures at 24 h were observed in Merinos (7.4 °C) while Dohne × Dormer carcasses were the coldest (5.2 °C). The Dohne Merino, Dohne × Ile de France, and Merino × Dorper groups did not differ from purebred Merinos. The Dohne × Dormer, Dohne × Dorper, and Merino × Ile de France crosses in turn did not differ from one another while the Merino × Dormer group did not differ from any other group (*P* >0.05).

Freezing and cooking loss and shear force were also assessed as these relate to consumer experience and preference. None of these traits were influenced by sex, however differences were found between genotypes for freezing loss and shear force. Dohne Merino had a higher (*P* <0.001) freezing loss percentage than any other genotype. The lowest freezing losses were observed in the Dohne × Dorper, purebred Merino, and Merino × Dormer genotypes. These losses were not substantially lower than those of the Dohne × Dormer, Merino × Dorper, and Merino × Ile de France groups, while the Dohne × Ile de France genotype did not differ markedly from purebred Dohne Merinos. The Dohne × Dormer (27.30 N) and purebred Merinos (24.62 N) had the highest shear force values. Apart from the Merino × Ile de France group (20.81 N), all the other genotypes had lower shear force values (*P* =0.010).

The CIELAB colour parameter values of the loin muscle samples are given in Table 6. No marked differences existed between sexes for any of the parameters (*L**, *a**, *b**, hue or chroma). For genotype, only the *b** (yellowness) parameter, was found to differ (*P* =0.029), with Dohne × Dormer (5.51) and purebred Merinos (6.03) having lower values than Merino × Ile de France (10.83). All other groups were intermediate and do not differ from the extremes.

Finally, a proximate analysis was performed on the soft tissue gathered from the three-rib cuts during dissection (Table 7). A number of samples were removed from the analysis due to their being unsuitable for further analysis and the new group sizes are given in the table. No differences were found among genotypes for dry matter, ash, total lipid, or protein percentages and only dry matter was influenced by sex (*P* <0.001), with ewes having a higher dry matter percentage than rams.

Table 6 Least squares means ± S.E. of CIELAB colour parameters of loin muscle samples from pasture-reared slaughter lambs

Main effects	*L**	*a**	*b**	Hue	Chroma
Ram	42.07±0.75	9.72±0.57	7.34±0.55	37.12±3.33	12.91±0.42
Ewe	40.65±0.59	8.69±0.45	7.89±0.43	42.88±2.62	12.22±0.33
P-value	*0.140*	*0.500*	*0.440*	*0.180*	*0.190*
Dohne Merino	43.02±1.23	8.49±0.95	6.98^{b} ±0.91	40.25±5.49	11.37±0.69
Dohne × Dorper	41.54±1.02	8.65±0.78	8.02^{ab}±0.75	43.12±4.55	12.22±0.57
Dohne × Dormer	40.44±2.09	10.46±1.60	5.51^{b} ±1.54	29.20±9.31	12.68±1.17
Dohne × Ile de France	38.89±1.64	10.91±1.26	7.72^{ab}±1.21	35.33±7.32	13.49±0.92
Merino	40.84±1.07	9.47±0.83	6.03^{b} ±0.79	32.77±4.79	11.97±0.60
Merino × Dorper	42.01±0.95	9.48±0.73	7.73^{ab}±0.70	40.85±4.25	13.08±0.53
Merino × Dormer	43.13±0.89	8.49±0.68	8.09^{ab}±0.65	43.55±3.95	12.17±0.50
Merino × Ile de France	41.00±1.42	7.67±1.09	10.83^{a}±1.05	54.91±6.34	13.53±0.79
P-value	*0.340*	*0.160*	*0.029*	*0.170*	*0.330*

Means with different superscripts ($^{a-c}$) in the same column differ significantly (*P* ≤0.05)

Table 7 Results of the proximate analysis (least squares means ± S.E.) of the soft tissue (muscle and fat) from the three-rib cuts of crossbred pasture-reared lambs

Main effects	n	Dry matter (%)	Ash (%)	Total lipid (%)	Protein (%)
Ram	34	45.90±1.22	0.77±0.03	24.25±1.58	19.60±0.93
Ewe	55	50.03±0.90	0.78±0.02	27.27±1.17	20.27±0.69
P-value		*<0.001*	*0.720*	*0.130*	*0.560*
Dohne Merino	8	49.93±2.39	0.76±0.06	27.23±3.10	19.99±1.80
Dohne × Dorper	14	47.98±1.63	0.81±0.04	26.48±2.13	18.91±1.24
Dohne × Dormer	11	47.18±3.07	0.74±0.07	28.80±3.99	17.34±2.34
Dohne × Ile de France	6	47.62±2.53	0.79±0.06	23.24±3.30	21.99±1.93
Merino	12	47.09±1.69	0.82±0.04	23.13±2.20	21.31±1.29
Merino × Dorper	15	48.07±1.54	0.79±0.04	25.71±2.01	20.24±1.18
Merino × Dormer	16	47.10±1.47	0.77±0.03	24.28±1.92	20.67±1.12
Merino × Ile de France	7	48.14±2.23	0.70±0.05	27.18±2.91	19.02±1.70
P-value		*0.990*	*0.720*	*0.830*	*0.680*

Discussion

When looking at the slaughter characteristics, age, weight, and dressing percentage, two important observations were made. Firstly, crossbred animals were younger than purebred animals from the same maternal line when slaughter readiness was reached. Secondly, no statistical differences existed between cross- and purebred lambs for slaughter weight when slaughtered at a specified level of fatness, but crossbred lambs had higher dressing percentages. Previous studies have also reported that crossbred animals reached slaughter-readiness sooner than purebreds (Scales *et al.*, 2000; Kiyanzad, 2002; Cloete *et al.*, 2006, 2007; Schiller *et al.*, 2015), although Khaldari & Ghiasi (2018) did caution that the superiority of crossbred lambs was dependant on the pubertal weights of the breeds involved. Dressing percentage was also improved by crossbreeding in this study, concurring with the results of Scales *et al.* (2000) and Kremer *et al.* (2004), but contradicting that of Güngör *et al.* (2022). Therefore, crossbred slaughter lambs appear to be more profitable from a meat-producing perspective than their purebred contemporaries as they can be sold off in a shorter time, and at similar live weights, produce a higher percentage of saleable carcass meat. Although this study did not find any statistical differences between genotypes for slaughter weight, literature points to such differences existing (Scales *et al.*, 2000; Kiyanzad, 2002; Cloete *et al.*, 2006; Kader Esen *et al.*, 2020; Karimi *et al.*, 2022). The superiority of crossbred lambs for these traits is likely attributable to heterosis and the levels of dimorphism between the sire and dam breeds. It has been indicated elsewhere (Cloete *et al.*, 2004a) that small maternal size contributes to the efficiency of terminal crossbreeding, which explains why the Merino crosses generally displayed greater gains in performance for the various traits. The Dohne Merino is a heavier breed than the Merino (Cloete *et al.*, 2004a; Van der Merwe *et al.*, 2019) and therefore the degree of breed dimorphism between the dam and sire lines is not as great as for Merinos. Khaldari & Ghiasi (2018) pointed out that the performance of crossbred progeny relative to purebred lambs was influenced by the mature weights of the purebred parental lines and therefore the greater the difference in mature weight between the dam and sire lines, the better the crossbred progeny will perform relative to the smaller, purebred dam line.

Comparing the purebred lines in this study to that of Van der Merwe *et al.* (2020) showed that both the Merinos and Dohne Merinos in this study were older and lighter at slaughter with lower dressing percentages, likely due to the animals in that study being finished off in a feedlot environment and not on pasture. Further comparison with the study of Cloete *et al.* (2004a), where Dormer and Suffolk rams were crossed with five different Merino lines, shows that the crossbred animals in this trial were generally younger and heavier at slaughter while achieving higher dressing percentages than the crossbred animals in that study. The purebred Merinos in this trial had particularly low dressing percentages. This is potentially due to Merinos having heavier skins than the other genotypes due to increased wool production, meaning more of their live weight is made up by non-carcass components.

Marked differences were observed between sexes for slaughter age and weight, with rams being younger and heavier at slaughter. This concurs with previous findings on the subject (Fahmy *et al.*, 1972; Kiyanzad, 2002) and producers can therefore expect that it will be more profitable to finish off rams than ewes. Rams also had substantially heavier red offal and kidney weight relative to slaughter weight than ewes. The reason for this difference is unclear. Ewes had more kidney fat than rams, likely as a result of the higher carcass fat level found in ewes (Kremer *et al.*, 2004; Cloete *et al.*, 2007). This reasoning is consistent with findings from this trial, where ewes had a greater fat depth at the 13th rib and therefore received higher average carcass classifications. This greater fat depth can be ascribed to ewes having a higher rate of fat deposition than rams. There was a time lapse of five days between the final ultrasound scan and slaughter dates and it is possible that ewes deposited sufficient fat in this period to lead to significant differences in measured post-slaughter fat depth. A previous study by Van der Merwe *et al.* (2020) found that the comparable sex difference was not significant in intensively-reared lambs slaughtered at a fixed fat level.

Marked differences in cold carcass weights existed between sexes and genotypes, although for different reasons. Rams had higher carcass weights as a result of being heavier than ewes at slaughter, although they did not dress out substantially higher. All genotypes had similar slaughter weights, but the crossbred lambs had higher dressing percentages and therefore higher carcass weights. This held true for all groups, except the Dohne × Dorper, which had lower carcass weights than purebred Dohne Merinos, probably attributable to their lower absolute slaughter weights.

Neither genotype nor sex influenced the percentage hindquarter yield but rams had a higher percentage carcass weight in their forequarters. The absolute fore- and hindquarter weights were converted to percentage of carcass weight in order to compare the proportion of potentially high value cuts between ram and ewe carcasses instead of just absolute carcass yield, which rams would have dominated by virtue of their greater cold carcass weights. The majority of the high value cuts (e.g., loin, rump) comes from the hindquarters and therefore, a higher percentage yield from the hindquarters would potentially indicate a higher carcass value. However, although forequarters yield differed between sexes (rams had a higher percentage weight in the forequarter), sex did not influence the percentage hindquarter yield.

The cuts designated as the hindquarters in this study differ from the commercial hindquarter cuts and therefore the results from this study may not be directly comparable to published literature. It is, however, still worth contrasting the results from this study to published literature to determine whether the different procedures had a substantial impact on relative yields. It has been reported (Cloete *et al.*, 2004b; c, 2008, 2012) that rams have heavier necks and shoulders than ewes. All of the aforementioned studies, except Cloete *et al.* (2008), found that rams also had heavier absolute hindquarter weights than ewes. The findings from Cloete *et al.* (2008) concur with the results from this study, namely, that no difference exists between the relative hindquarter weights of rams and ewes.

Rams had a substantially higher percentage of muscle and bone in the carcass, whereas ewes had a higher percentage of fat. This is due to physiological differences between the sexes, with ewes depositing more fat at an earlier age. Previous studies also found that ewes produce fatter carcasses (Cloete *et al.*, 2007) with a lower percentage of bone (Kremer *et al.*, 2004). The animals in both of these studies were slightly older than the lambs slaughtered in the current study. In contrast to the studies of Kiyanzad (2002) and de Sousa *et al.* (2019), muscle percentage differed between genotypes. However, this result concurred with findings by Khaldari & Ghiasi (2018). Fat percentages were similar among genotypes, concurring with results from Kiyanzad (2002) but differing from the results of de Sousa *et al.* (2019). Bone percentages did not differ either, agreeing with Khaldari & Ghiasi (2018) but differing from the results of de Sousa *et al.* (2019). The animals used by de Sousa *et al.* (2019) were older than the animals in the current trial, which may help explain the difference in results. However, given the contradictions that were found in the literature cited, it was difficult to evaluate the results of this study in relation to previous research.

Given that meat pH did not differ between sexes at either 45 min or 24 h, it was expected that freezing and cooking loss and shear force would also be similar, despite ewes having higher carcass temperatures in both cases. This expectation was borne out by the results, with no differences existing between sexes for these traits. The higher carcass temperature displayed by ewes at both 45 min and 24 h post-slaughter may be due to their greater fat depth. Smith *et al.* (1976) found that fatter lamb carcasses chill more slowly than leaner carcasses, whereas Aalhus *et al.* (2001) noted that thicker backfat corresponded with a slower decline in carcass temperatures in cattle. It was speculated by Smith *et al.* (1976) that this may be due to the insulating properties of fat or because fatter carcasses may be heavier than leaner ones. Since ewes had substantially lighter carcasses than rams in the current study, the difference in temperature between sexes is likely due to the increased insulation offered by the greater fat depth on ewe carcasses. The variation in carcass temperatures across all groups may be due to differences in environmental temperature at time of slaughter since the animals were slaughtered at different times. All genotypes were fairly evenly distributed in the various slaughter groups and therefore the results of any particular group would not be unduly influenced by this natural variation.

Genotype influenced pH and temperature at both 45 min and 24 h and this translated to substantial differences in freezing loss and shear force. This is in contrast to the results of Cloete *et al.*

(2008), who found no differences in shear force between crossbred genotypes. It is possible that the shear force values could have been affected by freezing the samples and this may explain the difference in results. Due to logistical issues, the freezing times could unfortunately not be standardised. All shear force values in this study were below 32.96 N and therefore all genotypes produced meat that could be considered as very tender (Destefanis *et al.*, 2008).

Of the CIELAB colour parameters that were assessed, only the *b** (yellowness) parameter differed substantially among genotypes. Cloete *et al.* (2008) had found that the *a** (redness) and not the *b** parameter differed between crossbred lambs, where it was influenced by dam line but not sire breed. Crossbred lambs out of Merino dams selected for increased fleece weight had the highest *a** value in that study (12.5). Another study (Cloete *et al.*, 2006), found marked differences between crossbred genotypes for both the *a** and *b** parameters where a single dam line (Merino) was mated to six different sire breeds. No differences were present between sexes for colour parameters. Khliji *et al.* (2010) suggested that the *a** parameter was the most appropriate colour parameter to judge colour acceptability for consumers and set a value of 9.5 as the minimum value at which consumers would be satisfied with the appearance of the meat. The average *a** value of the meat samples in the current study was only 9.2, therefore below the threshold value for acceptance by consumers. Khliji *et al.* (2010) did, however, state that the *a** value must be higher (14.5) to have 95% confidence that a random consumer will find meat acceptable and therefore it seems unlikely that an untrained consumer will be able to discriminate against meat from this study relative to the threshold of 9.5. When comparing the threshold *L** (lightness) value of 34 set by Khliji *et al.* (2010) to the average value of 41.36 from this study, consumer standards are met for the lightness of the meat as consumers prefer meat with an *L** value exceeding 34.

When comparing the results of the proximate analysis, only dry matter differed between sexes and no differences were found between genotypes. Rams had a lower dry matter percentage than ewes, possibly due to the lower percentage of fat in ram carcasses. This concurs with results of Cloete *et al.* (2004b), Kemp *et al.* (1976), and Karimi *et al.* (2022), who found that ewes had lower moisture percentages than rams or wethers. The findings of Cloete *et al.* (2004b) for protein and ash content also concurred with that of this study, namely that no statistical differences existed between sexes. Karimi *et al.* (2022), however, found that ewes had lower crude protein levels and higher ash contents than rams.

Since muscle has a higher water content than fat, it follows that an animal with a higher percentage of carcass muscle would have less dry matter in the carcass tissue. Given that ewes had a substantially higher percentage of fat in the carcass as determined from the three-rib cut, it was expected that they would also have a substantially higher percentage of total lipids in the proximate analysis, as was found by Cloete *et al.* (2004b). However, although their total lipid values were higher in absolute terms, the difference was not statistically significant, similar to Kemp *et al.* (1976) and Karimi *et al.* (2022).The lipid values found in this study exceeded that of Cloete *et al.* (2004b) due to the inclusion of subcutaneous and intermuscular fat in the samples used in this study.

Conclusion

Crossbreeding is a viable option to increase meat output since crossbred animals reach slaughter readiness sooner than their purebred contemporaries, thereby shortening the production cycle. Crossbred lambs also produce a higher proportion of saleable carcass meat due to higher dressing percentages. Coupled with the previously discussed benefits of pasture rearing, this offers a practical solution to improve the profitability of commercial meat production enterprises.

The meat produced in the study was very tender according to shear force values and met consumer standards for lightness. It can thus be assumed that even consumers who do not have a preference for pasture-reared meat would find it acceptable. The pasture finishing of crossbred lambs for slaughter lamb production may therefore be a viable alternative to the traditional feedlotting of pure breeds if sufficient grazing of adequate quality is available.

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Author contributions

PGT was responsible for execution of the trial, data collection, statistical analysis, and initial write-up. The study was conceptualized, designed, and funding obtained by TSB and SWPC. TSB, SWPC, JHCvZ, and PES were responsible for supervision of the trial. All authors were involved in finalization of the manuscript and all authors have read and approved the final manuscript.

Declaration of competing interest

No conflicts of interest have been identified with this study. The opinions, findings, and conclusions in this study are that of the authors and do not necessarily reflect that of any of the funders.

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