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Ultrasound scanning figures and lambing rates of merino-type ewes

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Abstract

This study assessed ultrasound scanning as a proxy for observed reproduction records, quantified the effects of lambing year and ewe age, and estimated repeatability of traits to predict current-flock gains. Data for number of lambs recorded per ewe scanned, lambs born per ewe lambed, and embryonic losses per ewe scanned were available for 2338 Dohne Merino, 1159 SA Mutton Merino (SAMM), and 138 Merino ewes on the Mariendahl experimental farm of Stellenbosch University, with 7652, 3364, and 240 ewe-year records, respectively. Merino records spanned 1990–1992, whereas the other breeds had lambing records for 1990–2016. Scan records indicated that 89.2%–95.8% of ewes scanned pregnant with multiples also lambed multiples. Embryos lost per ewe at lambing were 0.00–0.05 in all breeds. ASReml was used to fit mixed models to the Dohne and SAMM data. Lambing year and ewe age significantly affected all reproductive traits, except for ewe age effects on embryonic losses. Two-year-old ewes were more likely to be barren than their mature contemporaries, irrespective of breed. Scanning and lambing rates were highly correlated at the ewe level, suggesting that scanning is a good proxy for lambing rate in the absence of full lambing data. Age effects confirmed that an optimal flock structure contributes to a desirable reproductive output. Results indicated that embryonic losses were random and not meaningfully related to fixed or random effects. Moderate repeatability estimates for reproductive traits support low-to-moderate current-flock gains for scanning and lambing rate. Ultrasound scanning may thus be used to optimise reproduction on farms without detailed reproduction records.

Keywords: Dohne Merino, current-flock selection, embryonic losses, flock dynamics, management aid, mutton merino

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Introduction

Large parts of South Africa are defined as arid or semi-arid and are predominantly suitable for extensive small-stock farming. The extensive production of lamb, mutton, and wool are thus the only viable enterprises in these areas (Snyman *et al.*, 1998a; Brand, 2000; Cloete *et al.*, 2014). In recent years, price considerations placed a premium on meat production, as opposed to wool production (Van der Merwe *et al.*, 2019). The increased cost of capital and operational inputs, as well as the ability to increase product outputs by intensive husbandry practices linked to high lamb and mutton prices, are pressuring small-stock producers to maximise the efficiency of their farming operations (Terblanche,

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2013; Brand *et al.*, 2014; Van Der Merwe *et al.*, 2020). Small-stock farmers have to be dynamic in implementing changes to their practices to meet the ever-changing demands of consumers, adapt to environmental changes, and meet their economic obligations (Van Wyk *et al.*, 2003). Reproductive performance is particularly important when lamb/mutton production is the primary objective, making this the most important economical trait complex in sheep production (Fourie & Heydenrych, 1982; Van Haandel & Visscher, 1995; Snyman *et al.*, 1998a; Cloete *et al.*, 2000; Abegaz *et al.*, 2002; Van Wyk *et al.*, 2003; Senger, 2012; Ali *et al.*, 2020). A successful and viable sheep industry is based on a good base level of reproduction, and it is undisputable that the ultimate worth of any farm animal lies within its ability to reproduce (Cloete, 1972).

The number of lambs born per ewe mated is the first measure of the reproductive potential of a sheep flock (Fourie & Heydenrych, 1982). However, reproduction is considered a composite trait, with conception rate, multiple-birth rate, and lamb survival as components (Cloete & Heydenrych, 1986). Other hard-to-measure traits, such as oestrus activity, ovulation rate, and embryo viability, also contribute to composite reproductive traits. Key factors defining the efficiency of lamb production in any environment are the reproduction rate and lamb survival rate (Falconer & Mackay, 1996; Snyman *et al.*, 1997). Reproduction can be enhanced by increasing the number and weight of lambs weaned per ewe per year, as well as minimising ewe and lamb wastage (Duguma *et al.*, 2002). Given the complexity of the reproductive process, numerous situations could prevent fertilisation and/or terminate pregnancy (Cloete, 1972). As in other mammals, the ewe carries the burden of the reproductive process, providing the environment for fertilisation, supporting foetal development until parturition, and offering post-partum maternal care until weaning (Cloete, 1972). Scanning ewes during pregnancy will provide an estimate of conception, as well as the anticipated litter size for each ewe (often only recorded as single versus multiple), thus allowing for the intensification of management of ewe groups, without the need for exhaustive record-keeping (Fourie & Cloete, 1993). The latter authors also noted the possibility of using such records, together with the wet-and-dry technique, to select for a potentially more reproductive ewe flock in the absence of detailed records.

Measures of female reproductive success are related to age in large mammals (Festa-Bianchet, 1988), and the efficiency of a breeding flock therefore depends strongly on the age structure of the breeding ewes within that flock (Turner & Young, 1969). The age at first breeding/lambing, litter size, length of a ewe's productive life, and frequency of lambing per year, are some of the most important contributors to overall or lifetime reproductive performance in sheep (Spicer *et al.*, 1993; Lafi *et al.*, 2009; Talafha & Ababneh, 2011). Changes in reproductive performance associated with age are important in planning an optimal flock structure for maximal production (Mullaney & Brown, 1969). Turner *et al.* (1968) used numerous patterns of change in reproduction rate with age in presenting various flock structures for achieving an improved total productivity. Turner & Dolling (1965) established a general pattern of change in reproductive performance with the age of the ewe. This and subsequent literature reported that reproductive potential, expressed as litter size and conception rate, and culminating in the number of lambs born per ewe, will increase with the age of the ewe, followed by a reduction in reproductive performance after roughly five lambing opportunities (Turner & Dolling, 1965; Mullaney & Brown, 1969; De Haas & Dunlop, 1969; Fourie & Heydenrych, 1982; Olivier, 1982; Cloete & Heydenrych, 1986). Two-year-old ewes are characterised by lower pregnancy rates (Schladweiler & Stevens, 1973; Ozoga & Verme, 1982), smaller litter sizes (Schladweiler & Stevens, 1973; Ozoga & Verme, 1982), and lower weaning rates (Ozoga & Verme, 1982). The extent to which embryonic losses as a source of reproductive wastage reduce production efficiency is not well documented in South Africa. Alosta *et al.* (1998) reported that ovine embryonic losses amounted to 17.2%, thus contributing markedly to reproductive failure in four sheep breeds (Suffolk cross, Cheviot, Grey-face, and Mountain).

In the past, reproductive performance has been largely ignored in ovine selection programmes (Snyman *et al.*, 1998a). Improving ewe productivity is therefore a major objective in the local small-stock industry at present (Matebesi-Ranthimo *et al.*, 2017). The exclusion of a measure of reproduction in selection programmes could be because of the difficulty of recording differences in reproductive performance, owing to technical problems of recording and analysing reproduction data under extensive conditions (Snyman *et al.*, 1998a). Among reproductive traits, litter size can be more easily measured and reported, and is also considered to have a higher heritability than other reproductive traits (Safari *et al.*, 2005). These advantages lead to litter size being favoured as a selection criterion (Afolayan *et al.*, 2007). With direct selection for litter size, it was suggested by the latter authors that 80% of the overall response in total weight weaned by an ewe would be attributable to litter size. Such selection is expected to be more efficient in overall gains per generation or per year than combining traits into an appropriate selection index (Afolayan *et al.*, 2007). The fine balance between production, reproduction, and fitness and longevity traits needs to be kept in mind when a breeding plan is assessed (Zishiri *et al.*, 2013; Bunter *et al.*, 2019).

Selection for increased reproduction has two possible objectives: one, the selection of replacement progeny of both sexes to improve reproduction in future generations, and two, selection in the current flock to ensure that only the most productive ewes are retained on the farm. Option one hinges on the heritability of the reproductive trait to be improved, while repeatability is the parameter of importance for option two. Cloete *et al.* (2004) demonstrated that reproductive traits could be markedly improved by genetic selection, despite the low heritability often touted as a constraint to genetic progress. Cloete & Heydenrych (1987) also studied the repeatability of reproductive traits and made recommendations to achieve current-flock gains. Although repeatability is predicted to be low-to-moderate for most reproductive traits, it will still be possible to improve genetic capability if selection is done correctly (Cloete *et al.*, 2009; Hatcher *et al.*, 2010a). Hatcher *et al.* (2010b) reported that lamb survival can be increased using correct selection programmes. This study focuses on current-flock gains achievable by scanning, as was envisaged by Fourie & Cloete (1993).

In this context, the multiple objectives of this study were: one, to study the outcomes of ultrasound scanning in relation to observed reproduction records; two, to quantify the effects of lambing year and ewe age on scanning figures and lambing rate; and three, to derive repeatability estimates for scanning traits and lambing rate to enable recommendations, with reference to current-flock selection.

Materials and Methods

The study was conducted on the Merino, Dohne Merino, and SA Mutton Merino (SAMM) stud flocks maintained on the Mariendahl experimental farm of the University of Stellenbosch, as described by Cloete *et al.* (1999, 2001). Ethical clearance for the study was obtained from the Stellenbosch University ethical committee (clearance number ACU-2020-12955). Data were available for varying periods, namely 1990–1992 for Merinos and 1990–2016 for the other two breeds. However, there was an interval in 1993 and 1994 during which no scanning data were recorded for the latter two breeds. In total, the database available for analysis thus included 11256 repeated scanning records of 3635 ewes across breeds.

The farm Mariendahl (33°55’59” S; 18°49’18” E) is located about 14 km outside Stellenbosch in the Western Cape province of South Africa. It covers an area of 375 ha and is situated at an elevation of 165 m above sea level. The land used by the sheep is relatively flat, with only gentle slopes, and is largely devoid of trees. The farm lies within the Mediterranean climate zone of the Western Cape, characterised by hot, dry summers and mild, wet, and windy winters. Annual precipitation averages around 640 mm, with winter temperatures reaching a minimum of about 5 °C and summer temperatures peaking around 30 °C (J. Morris; unpublished farm data). Occasional frost may occur during winter after the passage of a cold front. During this study, grazing varied from crop stubble and dryland clover pastures to irrigated ryegrass, white clover, and kikuyu pastures, depending on the season.

The breeding season started in mid-October and ended in mid-November, after a 28- to 32-day mating period. Lambing thus took place from mid-March to mid-April. For the Dohne Merinos, one ram was used for 50 ewes, while one ram serviced 30 SAMM ewes. Mating involved single sires that were mated to groups of ewes as stated above on approximately 5 ha irrigated paddocks. At the cessation of mating, ewes were randomly allocated to groups of approximately 150 animals. Individual groups were moved to grain stubble camps (30 ha), where they stayed until a week before lambing. All ewes underwent ultrasound scanning once during pregnancy, performed by a veterinarian using a Mindray DP 30 V 7.5 MHz linear transducer, typically during the first week of January. This timing placed the scanning approximately 45 days after the rams were removed from the ewe flocks. Following the scan, the ewes were grouped according to their expected pregnancy status and managed accordingly. They were then returned to the crop-stubble camps.

The objectives of scanning were to determine whether specific ewes had multiple or single foetuses, or if they were barren. Most ewes that were scanned as barren were sold, while the remaining ewes were divided according to their scan status (single or multiple), meaning that ewes were pooled across sire groups. Since the scanner was only asked to identify multiples, without determining the actual number of lambs carried, the written records indicated two lambs in most cases. However, there were also several cases where triplets were differentiated from twins.

All the ewes lambed in small, irrigated kikuyu paddocks of approximately 2 ha, in groups of 20–30. Ewes were separated according to the breed and the expected birth rate (single or multiple) at this stage. Lambing rounds to mark newborn lambs and to identify them with their mothers took place twice daily at 08:00 and 16:00 throughout lambing. The identification of lambs with their dams allowed for pedigree information to be derived, while birth type, lamb sex, dam age, and birthweight of the lambs were simultaneously recorded. These records also allowed the derivation of the reproductive outcomes that were used for reconciliation with the scanning records. After spending three to five days with their lambs in the small camps, the ewes were moved to irrigated camps (kikuyu and clover) to graze. The camps were ca. 10 ha in size and supported 70 ewes each.

During the reconciliation of the lambing records with the scanning records, it became clear that ewes scanned as twins commonly had triplets, or even quadruplets, at birth. This result was expected, as the instruction to the scanner was to only scan for multiples. Embryonic mortality for such ewes was set to zero. There was also a minority of ewes scanned as singles that produced multiple lambs. As this outcome would also involve a net gain of foetuses (that is, embryonic mortality would become negative), embryonic mortality was set to zero for such ewes as well. Embryonic mortality was calculated by subtracting the number of lambs born from the number of lambs scanned on an individual ewe basis in those ewes not subject to the provisions described above. Embryonic losses were poorly distributed, with an excess of zero values and a low overall frequency. These data were therefore transformed to square roots after adding 0.5 prior to analysis, as suggested by Dickson & Sanford (2005).

Descriptive statistics were derived for various combinations of scanning and lambing outcomes to get an indication of the nature of the data used in downstream analyses. This analysis was performed for all three breeds. However, the records obtained for Merino ewes were dropped from further analyses, as this breed had too few records for meaningful analyses compared to the other breeds (see Table 1).

Three reproduction traits were considered, namely the number of embryos scanned per ewe present at scanning, the number of lambs born per ewe present at lambing and the number of embryos lost per ewe present at lambing. As the breeds were managed separately, these records were analysed within each breed. ASReml (Gilmour *et al.*, 2015) was used to analyse the data. Fixed effects included lambing year (1990–1992; 1995–2016) and ewe age (2–6+ years). Significance of fixed effects was declared at P <0.05. Random effects fitted to the data included individual breeding ewes and individual service sires (the ram the ewe was mated to in single-sire mating groups). The single-trait mixed model fitted to scanning, lambing, or embryo loss records was the following:

$$y_{ijklm} = \mu + yr_i + da_j + ewe_k + ss_l + e_{ijklm}$$

where: y_{ijklm} = the ijklmth record of the trait analysed;
μ = the overall mean of the trait analysed;
yr_i = the fixed effect of the ith lambing year (i = 1990–1992; 1995–2016);
da_j = the fixed effect of the jth dam age group (j = 2–6+ years);
ewe_k = the random effect of the kth Dohne Merino or SAMM ewe;
ss_l = the random effect of the lth Dohne Merino or SAMM service sire;
e_{ijklm} = the random error term associated with each record.

Both random effects were fitted by default to get an indication of the repeatability of sire and dam performance for those reproduction traits under consideration. In the absence of significant between-ewe and between-service sire variances for the number of embryos lost per ewe present at lambing (see Table 3), only the number of embryos scanned per ewe present at scanning and the number of lambs born per ewe present at lambing were analysed in two-trait analyses to derive between-ewe, between-service sire, and phenotypic correlations between these traits. These analyses partitioned the phenotypic covariance components between traits that were present at the level of individual ewes and individual service sires, and at the environmental level.

Additional analyses were conducted on the Dohne Merino and SAMM breeds to test whether the frequency of barrenness was higher in two-year-old ewes than in their mature flock-mates. These frequencies were compared within breeds using the online chi-square test made available by Preacher (2001).

Results

Across breeds, there were 11256 repeated scanning records for 3635 ewes, amounting to approximately 3.1 records per ewe. However, there were some differences between breeds, with 7652 scanning records for 2338 Dohne Merino ewes (3.28 records per ewe), 3364 scanning records for 1159 SAMM ewes (2.90 records per ewe), and 240 scanning records for 138 Merino ewes (1.74 records per ewe). The vast majority (between 89.2% in SAMMs and 95.8% in Merinos) of ewes scanned with multiple lambs were also recorded with multiple lambs at lambing (Table 1).

Table 1 Lambing outcomes per scanning classification and breed in the Mariendahl Dohne Merino, SA Mutton Merino (SAMM), and Merino flocks

Scanning classification		Outcome	Breed[1]		
			Dohne Merino	SAMM	Merino
Multiple		Multiple	91.04	89.15	95.80
		Single	8.20	9.72	3.36
		Barren	0.02	0.00	0.00
		No record	0.74	1.13	0.84
	Total[2]		4183	1770	119
Single		Multiple	15.66	16.04	2.17
		Single	82.68	82.21	95.65
		Barren	0.00	0.00	0.00
		No record	1.66	1.75	2.17
	Total[2]		2708	1197	92
Barren		Multiple	0.13	0.25	0.00
		Single	0.79	0.25	0.00
		Barren	0.00	0.00	0.00
		No record	99.08	99.50	100.00
	Total[2]		761	397	29
Grand total			7652	3364	240

[1]Outcomes are reported as a percentage of the total number of ewes per scanning classification per breed, [2]Total: total number of ewes per scanning classification per breed

Between 3.4% (Merinos) and 9.7% (SAMMs) of ewes scanned with multiples had single lambs at birth, and thus presumably lost one lamb during gestation (Table 1). Only a single Dohne Merino ewe that was scanned as being pregnant with multiple lambs was barren at lambing. Between 0.7% (Dohne Merino) and 1.1% (SAMM) of ewes scanned with multiples were not recorded further and were presumably lost prior to lambing. Between 2.2% (Merino) and 16.0% (SAMM) of ewes scanned with singles had multiples at birth, while the bulk of single-scanned ewes were correctly assigned single lambs at lambing (82.2% in SAMMs and 95.7% in Merinos). None of the ewes scanned with singles were barren at lambing, but between 1.7% (Dohne Merino) and 2.2% (Merino) of ewes were not recorded further. Only ten Dohne Merino and SAMM ewes that were scanned as barren had further records, as >99% of ewes scanned as barren were not recorded further. Most of these ewes were presumed to be culled based on their reproductive status, as was intended, and could therefore not contribute to further analyses.

The mean number of lambs scanned per ewe ranged from 1.41 in SAMM ewes to 1.45 in Dohne Merino ewes, with coefficients of variation (CVs) just below 50%. The number of lambs born per ewe at lambing ranged from 1.64 in SAMM ewes to 1.67 in Dohne Merino ewes, with CVs just exceeding 33%. In contrast, embryonic losses were low, with standard deviations exceeding the mean by a factor of at least 4. These results are presented in Table 2.

Table 2 Descriptive statistics for the number of embryos scanned per ewe present at scanning, number of lambs born per ewe present at lambing, and number of embryos lost per ewe present at lambing for Dohne Merino and SA Mutton Merino (SAMM) ewes

Breed and trait	Records	Mean ± SD[1]	Range	CV[2]
Dohne Merino				
Number of lambs scanned	7652	1.45 ± 0.67	0–3	47.5
Number of lambs born	6822	1.67 ± 0.56	0–4	33.5
Number of embryos lost	6822	0.05 ± 0.22	0–2	440.0
SAMM				
Number of lambs scanned	3364	1.41 ± 0.71	0–3	49.6
Number of lambs born	2928	1.64 ± 0.55	0–3	33.5
Number of embryos lost	2928	0.06 ± 0.24	0–1	400.0

[1]Standard deviation; [2]CV: coefficient of variation

Lambing year had a significant effect on all reproduction traits in both breeds. The number of lambs scanned per ewe available and the number of lambs born per ewe present at lambing varied, at 1.3–1.6, and 1.6–1.9, respectively, in Dohne Merino ewes (Figure 1a). There was also a suggestion that both reproductive traits went through a slump between 1995 and 2014 in Dohne Merinos, with higher means in the early 1990s and towards the end of the recording period, in 2016. In contrast, the number of lambs scanned per ewe available declined from around 1.5–1.7 initially to 1.1–1.4 in the last years recorded for the SAMM flock (Figure 1b). The corresponding trend across birth years for the number of lambs born per ewe present at lambing similarly declined from around 1.7–1.9 initially to 1.4–1.6 in later years. The number of embryos lost per ewe present at lambing was mostly in the 0.00–0.05 range in both breeds. However, 2001 was marked by much higher embryonic losses of 0.115 in Dohne Merino ewes and 0.149 in SAMM ewes (Figures 1a and 1b). Dohne Merino ewes also had a relatively poor year in 2003, with embryonic losses of 0.074. Embryonic losses in both breeds were again comparatively high in 2006, at 0.073 in Dohne Merinos and 0.138 in SAMMs. Embryonic losses in SAMM ewes also exceeded 0.1 in 2008, at 0.114. Apart from a few years with relatively high embryonic losses in both breeds, losses appeared to be comparatively low during the initial years recorded, prior to 1999–2000, in both breeds. It should also be noted that means for embryonic losses in some years did not exceed zero, based on the standard errors provided in Figures 1a and 1b.

The frequency of two-year-old ewes that scanned barren was higher than for their mature contemporaries in both breeds. In Dohne Merino ewes, 283 of 1889 (0.150) two-year-old ewes scanned as barren, compared to 478 of 5763 (0.083) mature ewes (chi-square = 70.3, degrees of freedom = 1; P <0.01). Corresponding figures for SAMM ewes were 196 of 991 (0.198) two-year-old ewes versus 201 of 2373 (0.085) mature ewes (chi-square = 84.8, degrees of freedom = 1; P <0.01).

The number of lambs scanned per ewe available and the number of lambs born per ewe present at lambing increased from two-year-old to four-year-old ewes in both breeds, with the differences between the age groups being significant (Figures 2a and 2b). Subsequent differences between age groups were generally not significant, but there was a suggestion that reproductive performance started declining in the 6+-year-old ewes for both traits in SAMMs and for the number of lambs scanned in Dohne Merino ewes. The number of lambs born per ewe present at lambing trended above the number of lambs scanned per ewe available for both breeds. Square-root transformed embryonic mortality rates per ewe lambed were independent of ewe age in both breeds (P >0.20; Figure 2), with no clearly discernible age trend.

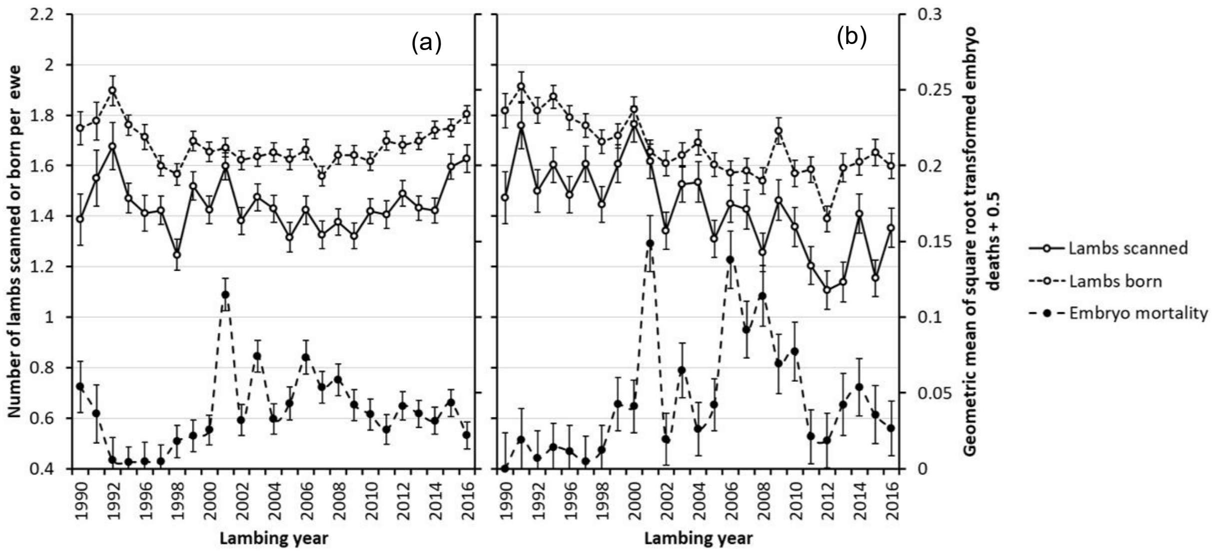

Figure 1 Line graphs representing the effects of lambing year on the number of lambs scanned per ewe available at scanning, number of lambs born per ewe present at lambing, and number of embryos lost per ewe present at lambing in Dohne Merino (a) and SA Mutton Merino (b) ewes (error bars indicate the standard errors of the means)

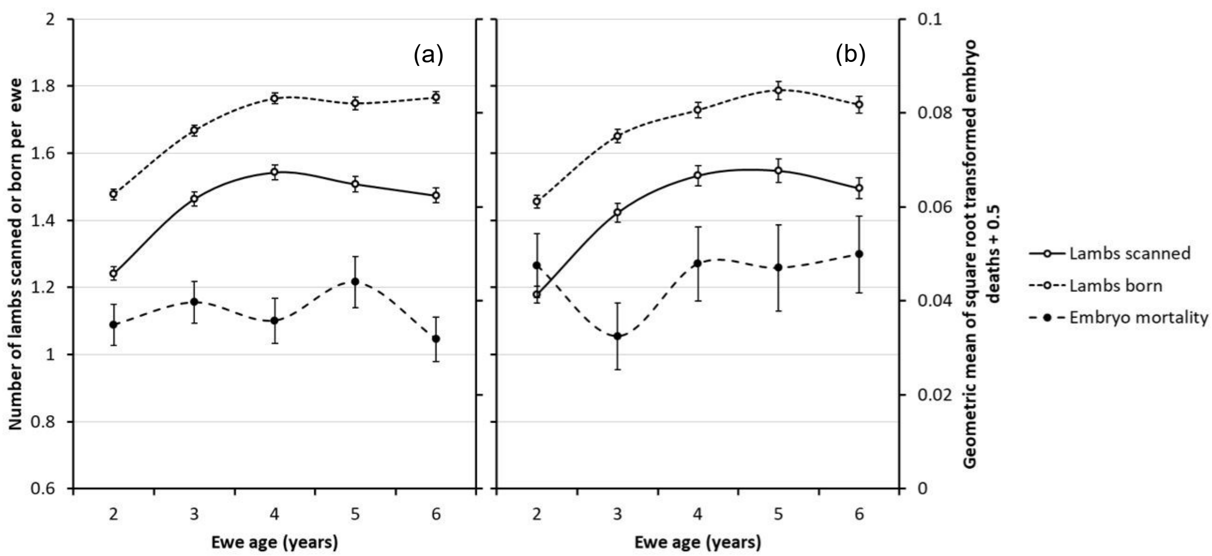

Figure 2 Line graphs representing the effects of ewe age on the number of lambs scanned per ewe available, number of lambs born per ewe present at lambing, and number of embryos lost per ewe present at lambing in Dohne Merino (a) and SA Mutton Merino (b) ewes (error bars indicate the standard errors of the means)

The single-trait variance components and ratios for the number of lambs scanned per ewe available at scanning, number of lambs born per ewe present at lambing, and square-root transformed number of embryos lost per ewe present at scanning are provided in Table 3 for Dohne Merino and SAMM ewes. Based on repeated ewe records for the number of lambs scanned per ewe present at scanning, repeatability was estimated as 0.11 for Dohne Merino ewes and 0.12 for SAMM ewes. Corresponding service sire variance ratios were 0.04 and 0.03, respectively, for the two breeds. Although the derived service sire variance ratios were low, at below 0.05, all estimates were significant, at more than double the corresponding standard error. Repeatability estimates for the number of lambs born per ewe present at lambing amounted to 0.17 for Dohne Merino ewes and 0.16 for SAMM ewes (Table 3). Corresponding service sire variance ratios were very low, at just above 0.01 for Dohne Merino service sires (P <0.05) but only 0.003 for SAMM service sires (P >0.05). In contrast with the other reproductive traits, between-ewe (SAMM) and between-service sire variance (both breeds) ratios were not significant for the number of embryos lost per ewe present at lambing.

Table 3 Single-trait variance components and ratios (± standard error) for the number of embryos scanned per ewe present at scanning, number of lambs born per ewe present at lambing, and number of embryos lost per ewe present at lambing for Dohne Merino and SA Mutton Merino ewes

Breed variance components and ratios	**Trait**		
	Number of lambs scanned	**Number of lambs born**	**Number of embryos lost**
Dohne Merino			
Variance components			
Ewe (σ^2_{ewe})	0.0486	0.0514	0.00018
Service sire (σ^2_{ss})	0.0192	0.0040	0.00003
Residual (σ^2_e)	0.3657	0.2451	0.01259
Phenotype (σ^2_p)	0.4336	0.3005	0.01280
Variance ratios:			
Repeatability	0.112 ± 0.012	0.171 ± 0.013	0.014 ± 0.010
Service sire	0.044 ± 0.008	0.013 ± 0.004	0.002 ± 0.003
SA Mutton Merino			
Variance components			
Ewe (σ^2_{ewe})	0.0542	0.0438	0.00022
Service-sire (σ^2_{ss})	0.0145	0.0007	0.00014
Residual (σ^2_e)	0.3741	0.2372	0.01420
Phenotype (σ^2_p)	0.4428	0.2818	0.01456
Variance ratios			
Repeatability	0.123 ± 0.020	0.156 ± 0.012	0.015 ± 0.015
Service sire	0.033 ± 0.010	0.003 ± 0.005	0.009 ± 0.007

According to the results in Table 3, the occurrence of embryo losses was random and not conclusively related to either ewes or service sires. These analyses were therefore followed up with breed-specific two-trait analyses involving the number of lambs scanned per ewe present at scanning and the number of lambs born per ewe present at lambing (Table 4). Repeatability estimates from the two-trait analyses were very similar to the corresponding single-trait results in Table 3 for Dohne Merinos and the number of lambs scanned per ewe available at scanning in SAMMs. In contrast, the repeatability of the number of lambs born per ewe present at lambing in SAMM ewes increased from 0.16 in the single-trait analysis to 0.19 in the two-trait analysis. The between-ewe correlations were equal to, or exceeded, 0.95 in both breeds. Notably, the service sire variance ratios were similar to the single-trait estimates for the number of lambs scanned per ewe available at scanning in both breeds (Tables 3 and 4). The between-service sire correlation between the two traits exceeded 0.96 in both breeds. However, service sire effects for the number of lambs born per ewe present at lambing increased from 0.01 to 0.03 in Dohne Merinos and from 0.00 to 0.02 in SAMMs. These results implied that scanning and lambing performance were practically the same trait at the level of individual ewes and individual service sires, as reflected by between-ewe and between-service sire correlations approaching unity. It was similarly clear that an environment favouring a high number of lambs scanned would also allow a high lambing rate, as reflected by environmental correlations between these two traits of 0.78 ± 0.01 in Dohne Merinos and 0.77 ± 0.01 in SAMMs. The phenotypic correlations were also high, at around 0.80.

Table 4 Two-trait variance components and (co)variance ratios (± standard error) for the number of embryos scanned per ewe present at scanning and number of lambs born per ewe present at lambing for Dohne Merino and SA Mutton Merino ewes

Breed (co)variance components and ratios	Trait	
	Number of lambs scanned	Number of lambs born
Dohne Merino		
Repeatability[1] and the between-ewe correlation[2]		
Number of lambs scanned	**0.111 ± 0.012**	
Number of lambs born	0.950 ± 0.016	**0.167 ± 0.013**
Between-service sire variance ratios[1] and the service sire correlation[2]		
Number of lambs scanned	**0.044 ± 0.008**	
Number of lambs born	0.979 ± 0.016	**0.035 ± 0.007**
Phenotypic variance components (σ^2_p)[1] and the phenotypic correlation[2]		
Number of lambs scanned	**0.4333**	
Number of lambs born	0.808 ± 0.005	**0.4290**
SA Mutton Merino		
Repeatability[1] and the between-ewe correlation[2]		
Number of lambs scanned	**0.126 ± 0.020**	
Number of lambs born	0.963 ± 0.023	**0.190 ± 0.021**
Between-service sire variance ratios[1] and the service sire correlation[2]		
Number of lambs scanned	**0.034 ± 0.010**	
Number of lambs born	0.968 ± 0.050	**0.020 ± 0.008**
Phenotypic variance components (σ^2_p)[1] and the phenotypic correlation[2]		
Number of lambs scanned	**0.4433**	
Number of lambs born	0.799 ± 0.007	**0.4079**

[1]In bold on the diagonal; [2]below the diagonal

Discussion

As seen in Table 1, ultrasonic methods accurately predicted multiples (89%–95%) and singles (82%–96%) in all three breeds studied. The accuracy of barrenness diagnostics could not be confirmed, as the bulk of barren ewes (99%–100%) were not followed to lambing. However, Plant (1980) used a rectal probe to accurately diagnose barrenness in 96.9% of ewes in a flock. With recent advances in ultrasonography, there is no reason to believe that the accuracy in the flocks studied would be worse than this. Trapp & Slyter (1983) determined that pregnancy diagnosis using ultrasonic devices is better for animal welfare and remains highly accurate. They reported a correct diagnosis of multiples with an accuracy of 89.1%–98.8%, which closely corresponded with the figures reported in Table 1.

The means for the number of lambs scanned per ewe available were 1.45 in Dohne Merinos and 1.41 in SAMMs, with CVs exceeding 45% (Table 2). White *et al.* (1984) reported a higher range, of 1.50–1.80 lambs scanned per ewe present in English sheep breeds, at an accuracy rate of 95%–99%. McLaren *et al*. (2023) reported a slightly lower mean of 1.28 for Scottish Blackface ewes, with a CV of 51.6%. Safari *et al.* (2005) reported CVs for lambs born per ewe joined of 52.7%, and embryo survival of 26.8%. The former estimate is consistent with those in Table 2, but the latter is not comparable. However, McLaren *et al*. (2023) reported that the standard deviation of foetal losses exceeded the mean of 0.07 by a factor of 4.4. This value is quite consistent with those in Table 2. The corresponding means for the number of lambs born per ewe available at lambing amounted to 1.64 in SAMM ewes to 1.67 in Dohne Merino ewes, with CVs just exceeding 33%. This is in agreement with Safari *et al.* (2005), who reported a CV for the number of lambs born per ewe at lambing of 34.1%, based on 36 literature estimates. A study done on Zimbabwean Sabi sheep reported CV values of 36.5% for fertility and 30.4% for prolificacy (Matika *et al.*, 2001).

The higher numbers of lambs born than numbers of lambs scanned in this study stem from two causes. Firstly, although triplets were occasionally identified in the scanning records, the primary intention was only to discern between singles and multiples. It was thus not surprising that a substantial number of triplets, and a quadruplet, were born to ewes scanned as having multiples (or twins). Secondly, scanning figures included ewes scanned as barren, the vast majority of which were not maintained until lambing and were thus not included in the lambing records.

The number of lambs born per ewe available at lambing was much higher than reported in previous studies. Fourie & Cloete (1993) and Kleemann & Walker (2005) both reported lower fecundity percentages, ranging from 122% to 140%, for Dohne Merinos and SAMMs. Older papers by Knight *et al.* (1975a; 1975b) reported even lower performance levels in Western Australian flocks than the figures reported by Fourie & Cloete (1993). From the literature sources cited above, a clear trend can be seen, with fecundity increasing over time. This may be because of genetic gains, but the impacts of improved managerial practices and intensification cannot be ruled out. The two breeds in question are also known for their high fertility (Campher *et al.*, 1998; SA Dohne Merino Breed Society, 2019). Dohne Merinos and SAMMs are exceptionally well adapted to the South African climate/country, according to Van der Merwe *et al.* (2019), because they were developed within the region by the South African Department of Agriculture in 1932 and 1938, respectively. Moreover, at the Mariendahl experimental farm, most barren ewes are not maintained until lambing, which makes the selection process for reproduction very strict.

From the results given in Table 1, it is evident that the percentage of ewes that scanned barren amounted to 9.9% in Dohne Merinos, 11.8% in SAMMs, and 12.1% in Merinos. Turner & Dolling (1965) reported similar results, with the proportion of ewes failing to lamb ranging from 8%–18%, and Kleemann & Walker (2005) reported a percentage of 13.2%. Both of these studies used South Australian Merino sheep. Knight *et al.* (1975b) reported much higher losses, of 20.1%–26.4%, owing to barrenness in Merino and Corriedale ewes in Western Australia. The low levels of embryonic losses, of 5%–6% in this study (Table 1), are also in general agreement with the literature (Dolling & Nicholson, 1967; Alosta *et al.*, 1998; Kleemann & Walker, 2005; McLaren *et al.*, 2023).

Marked year-to-year variation in the reproduction of sheep, as shown in Figure 1, is not surprising. Mullaney & Hyland (1967) reported that there was marked seasonal variation in the reproductive performance of Australian sheep flocks. These changes were also not in the same direction each year, and Mullaney & Hyland (1967) ascribed these results to variable weather conditions. A study done on Ethiopian Horro sheep similarly showed that year had a significant effect on reproduction (Abegaz *et al.*, 2002). Therefore, this significant effect of lambing year can putatively be ascribed to differences in weather conditions. The resultant change in annual grazing potential would affect the condition of the ewe at mating and at lambing, and during lactation, since these production phases rely on the ewe's body condition (Kenyon *et al.*, 2014). This seems to be a plausible explanation for the situation as found in the Dohne Merino flock, where the year-to-year variation did not follow a clear trend (Figure 1a). However, changes in the management of the flocks could also have potentially affected the reproductive potential of the ewes. This could be a plausible explanation for the decline in the number of lambs scanned per ewe available, from around 1.5–1.7 initially to 1.1–1.4 in the last years recorded for the SAMM flock. The corresponding trend across birth years for the number of lambs born per ewe present at lambing similarly declined, from around 1.7–1.9 initially, to 1.4–1.6 in later years. The reasons for the different trends in the number of lambs born with the effect of year are not apparent, but could be related to the differential management of the flocks.

In this study, embryonic losses were low, at 5%–6% (Table 2). However, these losses exceeded 10% in several lambing years in both breeds (Figure 5.1). The reason for the higher levels of embryonic losses in some years is not apparent. In the late 1990s, the funding for the experimental farm was limited, leading to a lack of resources. During this time, the ewes did not receive flush feeding. Dolling & Nicholson (1967) accordingly reported ewes that were expected to lamb but failed to do so, ranging from 0.034 to 0.053 in Australian Merinos. Alosta *et al.* (1998) also reported embryonic losses of 0.172 in four Irish sheep breeds (Suffolk cross, Cheviot, Grey-face and Mountain). Both studies sacrificed animals to conduct an abattoir survey on the ewes' reproductive tracts. Foetal losses from scanning to lambing averaged 7% in the Scottish study by McLaren *et al.* (2023) on Scottish Blackface sheep.

According to Wilkins & Croker (1990), several factors can influence embryonic losses, including genotype, ovulation rate, management of the flock, toxins ingested from pastures/feed, and stress. This makes it difficult to pinpoint the exact cause of these losses. In the current study, the year of lambing had an obvious effect on embryonic losses, but the causes of these losses were not clear. Recently harvested grain stubble paddocks at Mariendahl (see Material and Methods) are expected to fulfil the needs of ewes during early pregnancy, making nutritional stress an unlikely cause of embryonic losses. Handling stress during scanning was presumably spread equally across all ewes within the groups and was unlikely to result in the observed year-to-year variation. Further studies are therefore indicated to better understand the causes of such losses. Two-year-old ewes were proportionally more likely to be barren than their mature contemporaries, which was expected, based on reports in the literature (Turner & Dolling, 1965; Mullaney & Hyland, 1967; Mullaney & Brown, 1969; Cloete & Heydenrych, 1986).

The graphs for number of lambs born per ewe present at lambing trended above those for number of lambs scanned per ewe available for both breeds (Figure 3). This result suggests that there was a net gain in embryos, which is not biologically feasible; however, it can be traced back to the reasons already stated in the Results section. Kleemann & Walker (2005) reported a 9.3% decline in lambs born from South Australian Merino ewes compared to records obtained from ultrasonography, thus reflecting a net loss. In contrast to the bulk of the literature, including the present results, Kleemann & Walker (2005) reported that neither the age of the ewe nor the year affected fertility significantly. Other contradictory results were reported by Mullaney & Brown (1969) in Australian Merino sheep, where a steady decrease in lambing rate was reported with an increase in ewe age. However, the results from the other breeds evaluated by Mullaney & Brown (1969) agree with the findings of the present study.

Ewe reproduction improved from two to four years of age and plateaued as the ewes got older, prior to a suggestion of a decline in ewes six years or older (Figure 2). This result is consistent with the bulk of the results in the literature. Cloete & Heydenrych (1986) reported an increase in fecundity (number of lambs born per ewe lambed) with the age of the ewe in the Tygerhoek Merino flock, South Africa, with six-year-old ewes having the highest fecundity. Other literature also indicates that a strong relationship exists between a flock's age structure and reproductive traits (Turner & Dolling, 1965; Mullaney & Hyland, 1967; Mullaney & Brown, 1969; Abdel-Moneim *et al.*, 2009). Younger ewes require better management to ensure good lambing performance, as they have lower reproductive potential than older ewes. Optimal flock age structure and management are thus of great importance to ensure optimal economic returns from self-replacing ewe flocks. It is also well documented in the literature that ewe body weight has an effect on reproductive performance (McLaughlin, 1970; Cloete & Heydenrych, 1986; Molina *et al.*, 1994; Gordon, 1997; Snyman *et al.*, 1998a; Vatankhah & Salehi, 2010; Aktaş *et al.*, 2015). Aktaş *et al.* (2015) reported that younger ewes had lower body weights than older ewes, possibly contributing to the age effect on reproduction. A high positive correlation between body weight and reproduction exists, implying that heavier ewes are more productive (i.e. they produced a higher number of lambs born and a higher total weight of lambs weaned) (Cloete & Heydenrych, 1986; Snyman *et al.*, 1998a; Zishiri *et al.*, 2013). No mating weights were recorded in this study, and the expected effects of age and mating weight could therefore not be studied.

With reference to the suggestion that reproduction will start declining after six years of age for both traits in SAMM ewes and for the number of lambs scanned in Dohne Merino ewes, it is notable that most previous studies investigated more ewe age groups than we did in the current study. However, it was clear that a decline in reproductive performance as the ewes grew older was in general agreement with several literature sources, suggesting that the observed trend may well be real (Turner & Dolling, 1965; Mullaney & Hyland, 1967; Mullaney & Brown, 1969; Festa-Bianchet, 1988; Snyman *et al.*, 1998b; Notter, 2000; Abegaz *et al.*, 2002; Abdel-Moneim *et al.*, 2009; Aktaş *et al.*, 2015). As modern sheep flocks seldom include ewes older than six years, this result may be of greater academic than practical value.

The square-root transformed embryonic mortality per ewe lambed was independent of ewe age in both breeds (P >0.20; Figure 2). Kleemann & Walker (2005) similarly reported that total reproductive losses did not vary significantly with either age of the ewe or season of mating in South Australian Merinos.

Estimates of repeatability cited from the literature in this section were sometimes derived from the sum of heritability and ewe permanent environment when repeatability was not explicitly derived. Repeatability in this study was estimated as 0.15–0.19 for the number of lambs born per ewe lambed (Tables 3 and 4), and this would be able to support low-to-moderate current-flock gains in the sheep flocks used. These values were consistent with a repeatability of 0.17 reported by Hebart *et al.* (2010) for the number of lambs born per ewe joined in the South Australian Merino resource flock and the South Australian selection demonstration flocks. Other literature sources reported lower repeatability estimates for the number of lambs born per ewe lambed. Using cross-bred sheep, Dzakuma *et al.* (1982) reported a repeatability estimate of 0.14 in the United States. Fogarty *et al.* (1976) reported a 0.13 repeatability estimate in Australian Border Leicester ewes. Researching New Zealand Romney ewes, Rae & Ch'ang (1955) reported a repeatability estimate of 0.12, while a repeatability estimate of 0.11 was obtained by Inskeep *et al.* (1967) for various American breeds. Polish Romney Marsh ewes yielded a repeatability estimate of 0.11 (Radomska *et al.*, 1976), and Bunter *et al.* (2021) reported a repeatability estimate of 0.10 for litter size in Australian Merinos. In a study on South African Dormers, Van Wyk *et al.* (2003) reported a repeatability estimate of 0.133 for the number of lambs born per ewe exposed. Parental half-sib repeatability estimates for ewe prolificacy (defined as the number of lambs born per ewe at lambing) and fecundity (defined as the number of lambs born per 100 ewes exposed), ranged from 0.11 to 0.19 and from 0.12 to 0.13, respectively (Hansen & Shrestha, 1997) in three different sheep breeds (Canadian, Outaouais, and Rideau Arcotts) from the Centre for Food and Animal Research, Canada.

The number of lambs scanned per ewe present at scanning had a lower repeatability estimate (0.11 for Dohne Merino ewes and 0.12 for SAMM ewes) than reported elsewhere. Hebart *et al.* (2010) reported a corresponding value of 0.17 for the number of ultrasound-scanned foetuses per ewe joined in ewes from the South Australian Merino resource flock and the South Australian selection demonstration flock. However, a more recent study based on half a million records from MERINOSELECT in Australia (which is the most comprehensive database to date) by Bunter *et al.* (2021), reported results that were in strong agreement with this study, with repeatability estimates of 0.10 for scanned litter size and 0.12 for conception rate of ewes. A subsequent study by McLaren *et al*. (2023) on Scottish Blackface ewes reported a comparable repeatability estimate of 0.15 for litter size at pregnancy scanning.

Although the derived service sire variance ratios for the number of lambs scanned per ewe present at scanning were low, at below 0.05 for both breeds, all estimates were significant, at more than double the corresponding standard error. Safari *et al.* (2007) derived a service sire variance ratio from data from several Australian resource flocks that was consistent with the current study, at 0.032. Service-sire variance ratios were very low, at just above 0.01 for Dohne Merino service sires (P <0.05), but only 0.003 for SAMM service sires (P >0.05), for the number of lambs born per ewe present at lambing. These results are lower than reported in the literature, a finding possibly related to the exclusion of barren ewes from further analyses. Hansen & Shrestha (1997) determined parental half-sib estimates for sires for productivity traits (prolificacy and fecundity), with prolificacy ranging from 0.0192 to 0.0452, while fecundity ranged from 0.0264 to 0.0578, using the same three breeds as mentioned above. Safari *et al.* (2007) reported a service sire variance for litter size from the data of several Australian resource flocks (0.001) that is in better agreement with our study.

In contrast with the other reproductive traits, neither the between-ewe nor between-service sire variance ratios were significant for the number of embryos lost per ewe present at lambing (Table 2). The occurrence of embryonic losses was thus random and not conclusively related to either ewes or service sires. If repeatability is regarded as the upper boundary of heritability, it is worth mentioning that Safari *et al.* (2005) reported a heritability of 0.01, based on four literature estimates. The recent study by McLaren *et al*. (2023) also reported a repeatability of 0.023 for foetal losses in Scottish Blackface sheep. These estimates are consistent with the values in Table 3.

The between-ewe correlations for scanning outcome and lambing rate were equal to or exceeded 0.95 in both breeds. Since 95% confidence intervals for SAMM ewes included unity and came close to unity in Dohne Merino ewes, it can be accepted that the number of lambs scanned and the number of lambs born are very similar traits at the ewe level. Scanning figures can thus be used to great effect as a proxy for lambing rate in cases where lambs born cannot be recorded accurately, as suggested by Fourie & Cloete (1993). Derived 95% confidence intervals for the between-service sire correlation likewise included unity for both breeds (Table 4), indicating that the traits are effectively the same at the service sire level. A study done on Australian Merinos found that the number of lambs born and number of lambs scanned were highly correlated, with genetic correlations ranging from 0.88 to 1.0 and phenotypic correlations being between 0.80 and 0.92 (Bunter *et al.*, 2016). This means that scanning data and lambing data would supply the same genetic information. Environmental factors would solely affect the phenotypic outcome, as phenotypes could be affected by scanning errors or embryonic losses. The service sire variance ratio for number of lambs born per ewe present at lambing increased from the single-trait analysis to the two-trait analysis in both breeds. Information in the number of lambs scanned per ewe available at scanning thus unlocked some service sire variance in number of lambs born per ewe lambed. The correlation with the number of lambs scanned possibly captured some between-ewe variance in barrenness, on which information on the number of lambs born was very scant as most barren ewes were not recorded post-scanning.

It was clear from the environmental correlations in the text that an environment favouring a high number of lambs scanned would also allow a high lambing rate. The phenotypic correlations between the two traits were likewise high, at around 0.80. Sometimes lambing data is not complete, with regards to lambs born or the number of lambs born dead, as mentioned in the previous paragraph. In these instances, available scanning data can be used to compensate for this loss – while it cannot replace the lambing data, it can help with predictions. This high correlation between the two traits enables the farmer to predict with good accuracy the number of lambs they expect to be born. This will aid them in management decisions regarding nutrition (fodder flow), as well as financial planning for the flock.

Conclusion

This study confirmed previous literature that reproduction was influenced by year-to-year variation. Age effects were consistent with literature results, confirming that reproductive output depended on an optimal flock structure. Embryonic losses were random and not meaningfully related to either the fixed or random effects tested. Moderate repeatability estimates for reproductive traits indicated low-to-moderate current-flock gains for scanning and lambing rates. High between-ewe and phenotypic correlations between numbers of lambs born and scanned confirmed that scanning and lambing records supplied similar information at the individual ewe level. Ultrasound scanning is therefore a valuable management aid to optimise reproduction in the absence of detailed reproduction records. Considering all the component traits of reproduction will further facilitate genetic selection for lamb output to weaning. Studies where the between-ewe variances of the traits studied are partitioned into genetic and permanent environmental components should be conducted urgently.

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Authors' contributions

WHG and SWPC were responsible for statistical analysis, interpretation of the results and writing the manuscript. SWPC, TSB and JHCvZ collaborated in conceptualising the hypothesis, designing the experiment, interpreting the results, and reviewing the final manuscript critically. JM was responsible for maintaining the genetic resources and the recording of data for the study. JEC assisted with revising and editing the manuscript and preparing it for submission. All authors read and approved the manuscript.

Conflict of interest declaration

The authors declare that there are no conflicts of interest concerning this submission. Ethical clearance for this study was obtained from the University of Stellenbosch Research Ethics Committee: Animal Care and Use (ACU-2020-12955).

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