

Ultrasound scanning and body condition scoring as aids to reproduction management of sheep

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Declaration

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Summary

The body condition scoring (BCS) and ultrasound scanning of ewes with reference to their reproductive performance are management tools with potential to ease the management, nutrition and breeding of South African sheep. There is a paucity of data on condition scores and scanning figures of individual sheep in the local ovine genetic resource and relevant data were thus sourced from genetic resource flocks managed by science and research institutions. Data from the Elsenburg Merino, Dormer and South African Mutton Merino (SAMM) flocks were used to study genetic and environmental parameters for ewe mating weight, BCS at mating and lambing, as well as for correlations of these traits with reproduction. H Line Merino ewes were heavier than the L Line at mating, but no line differences were found for condition scores. The H Line was selected for reproduction while the L Line was selected against reproduction. Dormer ewes were heavier than SAMM ewes at mating, with the SAMM having higher condition scores. Ewe mating weight was highly heritable at 0.74 in Merinos, with lower estimates for BCS at mating (0.28) and lambing (0.18). Ewe mating weight was moderately heritable at 0.49 in Dormers and SAMMs, with lower estimates for BCS at mating (0.21) and lambing (0.27). Genetic correlations among these traits were positive and moderately high for all flocks, ranging from 0.58 to 0.93. Genetic correlations of mating weight and condition scores with reproduction were mostly negative (i.e. unfavourable) across ewe age groups and analyses, significantly so in some cases. The unfavourable genetic correlations are probably related to complex interactions of age and current and previous reproduction in mature ewes, as well as the relationship of reproduction with BCS being characterised by an intermediate optimum. Further studies are indicated. On the other hand, ultrasound scanning was studied in Dohne Merino and SAMM ewes of the Mariendahl flock. Lambing year had a significant effect on all reproductive traits with values oscillating in both breeds. Number of embryos lost per ewe present at lambing was generally low (0.00 to 0.05). Number of lambs scanned per ewe available was moderately repeatable at 0.11 to 0.16, depending on breed and modelling. A comparable range of 0.16 to 0.19 was found for number of lambs born per ewe lambed. Repeatability estimates for embryonic losses were not significant. Scanning and lambing rate were highly correlated on the ewe level, suggesting that scanning figures would act as a good proxy for lambing rate in the absence of complete lambing data. Both ewe BCS and the outputs of ultrasound scanning may have a role to play in managing reproductive performance at the flock level. However, further refinement is needed before these managerial aids can be used with confidence in the broader South African sheep flock.

Opsomming

Kondisiepunte en die ultraklankskandering vir dragtigheid kan as bestuursmiddels gebruik word om die bestuur van reproduksie, voeding en teling van Suid-Afrikaanse teelooie te beheer. Daar is 'n gebrek aan data aangaande kondisiepunte en skanderingsyfers van individuele diere in die nasionale kleinveehulpbron en data vir die studie is van genetiese hulpbronnkuddes onder institusionele bestuur bekom. Data van die Elsenburg Merino, Dormer en Suid-Afrikaanse Vleismerino (SAVM) kuddes is bekom om genetiese- en omgewingsparameters vir ooi paargewig, sowel as kondisiepunte by paring en lam te bestudeer. H-Lyn Merino-ooie was swaarder by paring as ooie in die L-lyn, maar daar was nie lynverskille vir kondisiepunte by paring of lam nie. Die H-Lyn was geselekteer vir reproduksie en in teenstelling was die L-Lyn geselekteer teen reproduksie. Dormerooie was swaarder as SAVMs by paring, maar SAVM-ooie het hoër kondisiepunte gehandhaaf. Ooi paargewig was hoogs oorerflik teen 0.74 in Merinos, met laer beramings vir kondisiepunt by paring (0.28) en lam (0.18). Ooi paargewig was matig oorerflik teen 0.49 in Dormers en SAVMs, met laer beramings vir kondisiepunt by paring (0.21) en lam (0.27). Genetiese korrelasies tussen die eienskappe was positief en matig-hoog in alle kuddes, met ramings wat tussen 0.58 en 0.93 gewissel het. Genetiese korrelasies van paargewig en kondisiepunte met reproduksie was meestal negatief (m.a.w. ongunstig) oor ooiouderdomsgroepe, met betekenisvolle korrelasies in sommige gevalle. Hierdie ongunstige genetiese korrelasies is waarskynlik die gevolg van ingewikkelde interaksies van ooi-ouderdom met huidige en vorige reproduksieprestasie in volwasse ooie, sowel as 'n verwantskap met 'n intermediêre optimum tussen kondisiepunt en reproduksie. Verdere studies word voorgestel. Aan die ander kant is ultraklankskandering met Dohne Merino- en SAVM-ooie van die Mariendahlkudde bestudeer. Lamjaar het al die skanderingseienskappe betekenisvol beïnvloed met waardes wat baie tussen jare gewissel het. Die getal embryos verloor per ooi bekikbaar by lam was laag (0.00 tot 0.05) in albei rasse. Die getal lammers geskandeer per ooi beskikbaar was matig herhaalbaar teen 0.11 tot 0.16, afhangend van die ras en die gepaste model. 'n Vergelykbare stel waardes van 0.16 tot 0.19 is gevind vir aantal lammers gebore per ooi gelam. Die herhaalbaarheid van embrionale verliese was nie betekenisvol nie. Skanderings- en lamtempo was hoogs gekorreleer op die ooivlak, wat daarop dui dat skanderingsresultate as 'n goeie aanduiding van lamtempo gebruik kan word as volledige lamrekords nie bygehou word nie. Ooikondisiepunt sowel as die uitsette van ultraklankskandering kan moontlik 'n belangrike rol in die reproduksiebestuur van skape op 'n kuddevlak speel. Daar is egter verdere verfyning van die tegnologie nodig voordat hierdie bestuurshulpmiddels met vertroue in die breër Suid-Afrikaanse skaapkudde toegepas kan word.

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List of abbreviations

BCS	Body Condition Score
CV %	Coefficient of variation
E	East
ERA	Ewe Rearing Ability
GPS	Global Positioning System
GnRH	Gonadotrophin releasing hormone
h^2	Direct additive heritability
ha	Hectare
H-Line	High Line
kg	Kilogram
km	Kilometre
L-Line	Low Line
LH	Luteinizing hormone
mm	Millimetre
MOET	Multiple Ovulation and Embryo Transfer
n	Number of records
NLB	Number of Lambs Born
NLW	Number of Lambs Weaned

PE	Permanent environment
pe ²	Animal permanent environment
r	Correlation coefficient
r _e	Environmental correlation
r _g	Genetic correlation
r _p	Phenotypic correlation
SAMM	South African Mutton Merino
S	South
SD	Standard deviation
SE	Standard error
TWW	Total Weight of Lamb Weaned
µm	Micrometre
σ ² _a	Direct additive variance
σ ² _e	Ewe variance
σ ² _p	Total phenotypic variance
σ ² _{ss}	Service Sire variance
%	Percent

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Chapter 1:

Introduction

1.1 Problem identification and possible solutions

The reproductive management of sheep must be as simple and uncomplicated as possible, without compromising efficiency. Day-to-day management practices aiding managerial decisions on ethical and sustainable production will become cumbersome if they are overcomplicated and time consuming. The current economic environment, agricultural philosophy and consumer expectations call for a balanced approach to ensure maximal reproductive outcomes, while adhering to stringent requirements as far as animal welfare and sustainable production is concerned. Tools to on-farm decision-making should thus be chosen with care and applied judiciously during routine operations.

Feed on offer and consumed by animals determines the nutrients that are available for production purposes (Kenyon *et al.*, 2014). The available nutrients are stored in various places in the body such as adipose tissue in the subcutaneous, intramuscular, and abdominal reserves to name a few. These nutrients can be mobilized when it is required (Rauw, 2008). It is known that, if there are limitations in the nutrient supply of an animal, sheep can use these stored body reserves in an attempt to meet their nutritional requirements (Kenyon *et al.*, 2014). The assessment of the total nutrient reserves of ewes can be challenging. One practical solution is to assess the subcutaneous fat and muscle reserves along the spine of a sheep by applying the body condition scoring (BCS) technique (Kenyon *et al.*, 2014). A sheep's BCS is assessed by the palpation of the lumbar region along the backbone (the loin region) of the animal, above the kidneys directly behind the last rib, to determine the degree of sharpness (as opposed to roundness) (Gunn *et al.*, 1969; Russel, 1984; White *et al.*, 1984). In short it is a subjective way to evaluate the degree of fatness of a live animal (Russel, 1984). This is an easily learned and practical technique, making it an extremely useful management tool to evaluate animal performance when used correctly by sheep farmers (Kenyon *et al.*, 2014). It is well reported in literature that the BCS of an ewe influences her reproductive performance (Gunn *et al.*, 1969; Bastiman, 1972; Gunn & Doney, 1975; Newton *et al.*, 1980; Rhind & McNeilly, 1986; Rondon *et al.*, 1996; Atti *et al.*, 2001; Abdel-mageed, 2009; Sejian *et al.*, 2010; Yilmaz *et al.*, 2011; Young *et al.*, 2011; Curnow *et al.*, 2011; Edwards *et al.*, 2011; Vatankhah *et al.*, 2012; Walkom *et al.*, 2014b, a; c).

Another management tool available to sheep farmers to facilitate reproduction management is ultrasound scanning. The early recognition of pregnancy enables farmers to manage their ewes according to pregnancy status to balance the available nutrients against their nutrient requirements, thereby allowing proper and effective resource management (Allworth *et al.*, 2017). The incorrect management of gestational needs of ewes during the reproduction cycle may result in marked economic losses (Ishwar, 1995). Ultrasound scanning can provide farmers with an indication of conception, as well as the projected litter size for each ewe, thus allowing for the intensification of management in ewe groups without the need for exhaustive record-keeping (Fourie & Cloete, 1993). Farm profitability can be elevated by optimizing nutritional decisions during late pregnancy on the basis of pregnancy status with the help of pregnancy scanning data of individual ewes (Young *et al.*, 2016).

Despite the importance and potential impact of these managerial interventions, they have been understudied in the South African scientific literature. This study used data from well-known South African resource flocks, described in the exhaustive review by Schoeman *et al.* (2010). The sheep flocks that were involved in the study are the Elsenburg Merino, Dormer and South African Mutton Merino flocks along with the Mariendahl Dohne Merino and South African Mutton Merino studs. Apart from having scarce individual data readily linked to pedigree records, the reasoning for using these flocks is the following: The Elsenburg Merino flock are well known for its divergence in reproduction potential (Cloete *et al.*, 2004; Nel *et al.*, 2021), thereby making it strategically important in any study on reproduction. The separation of ewes in this flock on two markedly distinct lines in terms of reproduction warrants research on understanding the interaction of BCS with ovine reproduction. The Elsenburg Dormer flock is the foundation flock of this breed. The Dormer was developed at Elsenburg in an effort to produce an excellent terminal sire breed (Muller, 2020). The Dormer is an appropriate breed to do reproductive studies on, as it is the most common terminal sire breed within South Africa (Zishiri, 2009; Zishiri *et al.*, 2012; Cloete *et al.*, 2014). Local wool sheep farmers rely both on meat production as well as wool production to ensure economic sustainability (Olivier, 1999; Huisman *et al.*, 2008). Therefore, South Africa is home to a number of dual-purpose breeds adapted to the production of both commodities. One such resource flock is the Elsenburg South African Mutton Merino (SAMM) flock which is also the foundation flock for the breed in South Africa (Muller, 2020), where it was bred from the erstwhile German Merino. The availability of BCS data as well as the status of these flocks in the South African ovine genetic resource make them amenable to study the effects of BCS on the reproduction management of terminal sire and dual-purpose breeds.

Lastly, the University of Stellenbosch maintains stud flocks of the Dohne Merino and SAMM breeds. These studs are maintained as demonstration flocks to guide South African sheep farmers in the management of sheep flocks. Production parameters of the flocks were described by Cloete *et al.* (1999), while Cloete *et al.* (2001) reported genetic parameters for body weight and wool traits. The availability of individual ultra-sound scanning data allowed for a first comprehensive analysis of ultrasound scanning as a diagnostic tool for managing reproduction of sheep in South Africa as it was applied in Australia (Bunter *et al.*, 2016).

Against this background, a comprehensive set of analyses were performed on the flocks listed above, as indicated by the availability of BCS and Ultra-sound scanning data. This information is expected to inform South African sheep farmers with regard to management options to farm in an ethical and sustainable manner by making use of all sources of variation available to them.

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Chapter 2:

Literature review

2.1 Introduction

The primary measure of the reproduction potential of a sheep flock is the number of lambs born per ewe mated (Fourie & Heydenrych, 1983). Nevertheless, reproduction is considered a composite trait, with conception rate, multiple birth rate, and lamb survival (just to name a few) as components (Cloete & Heydenrych, 1986). It is also significant to note that other hard-to-measure reproduction traits like oestrus activity, ovulation rate, embryo viability, etc. also contribute to composite reproduction phenotypes. Falconer & Mackay (1996) and Snyman *et al.* (1997) reported that reproduction rate and lamb survival are key factors defining the efficiency of lamb production in any environment. Reproduction could be enhanced in a number of different ways with the focus leaning towards increasing the number and weight of lambs weaned per ewe per year, as well as minimizing ewe wastage and lamb losses (Duguma *et al.*, 2002). Walkom *et al.* (2016) highlighted that lamb meat is the major component of sheep enterprises thus, the viability of the enterprise is greatly affected by the ability of the ewe to produce a lamb for slaughter each breeding season (Snowder & Fogarty, 2009). With the profitability of a sheep enterprise being significantly impacted by the total number and the weight of lambs weaned annually (Morel & Kenyon, 2006; Young *et al.*, 2010), increasing both the number of lambs and the total weight at weaning should increase revenue for producers (Kenyon *et al.*, 2004a). As in other mammals, the ewe carries the burden of the reproductive process, as she provides the environment for fertilization, the development of the foetus until parturition, maintaining the pregnancy as well as by providing post-partum maternal care until weaning (Cloete, 1972). Keeping this in mind there are numerous factors affecting reproduction. The ewe's reproduction cycle will be discussed in this chapter, as well as management strategies to optimize the reproduction rate of sheep.

2.2 Oestrous cycle and gestation

One of the basic aspects of lamb/sheep production enterprises, is to ensure that ewes become pregnant and successfully raise their lambs (Kennedy, 2012). Understanding the

basic physiological principals of the ewe's reproductive cycle is thus of outmost importance. At six to nine months of age sheep reach puberty (Kennedy, 2012; Schoenian, 2012; Senger, 2012; Menzies, 2015). After puberty, the ewe enters a period of reproductive cyclicity that continues throughout most of her life, known as the oestrous cycle (Senger, 2012). The oestrous cycle consists of a sequence of predictable reproductive events, beginning at oestrus and ending at the following oestrous (Senger, 2012). This continue throughout the adult ewe's life and are interrupted by pregnancy, nursing and by seasonality (Senger, 2012). According to Kennedy (2012), Senger (2012) and Edwards (2020) the oestrous cycle is defined as the series of physiological events occurring between periods of oestrous or the number of days between the start of two consecutive oestrous periods, during which oestrous is the time of sexual receptivity. The start of oestrous is considered to be when ovulation occurs (i.e. the egg is released) from the ovary (Kennedy, 2012). Oestrous cycles are categorized by the frequency by which they occur during one year (Senger, 2012). There are three types of oestrous cyclicity; namely polyoestrus, seasonal polyoestrus and mono-oestrus (Senger, 2012).

Polyoestrous females, like cattle, rodents, and swine, are characterized as having an unbroken distribution of oestrous cycles throughout the entire year. Females with this type of cyclicity can become pregnant throughout the year without regard to season (Senger, 2012). Seasonally polyoestrous females like mares (horses), sheep and goats display clusters of oestrous cycles that occur only during a certain season of the year (Senger, 2012). Sheep have a natural breeding season followed by a period of anoestrous (oestrous cycle stops). For example, mares are long-day breeders because they begin cycling as day length increases. In contrast, ewes are short-day breeders because they start cycling as day length decreases (Senger, 2012). Mono-oestrous females are defined as having only one oestrous cycle per year. Dogs, wolves and foxes are examples of animals that displays mono-oestrous reproduction (Senger, 2012).

The ewe's gestation length varies between 142 to 152 days, with the average being 147 days (Schoenian, 2012). This may vary between breeds, early maturing breeds tending to have shorter pregnancies, the opposite being true for late maturing breeds (Schoenian, 2012). The length of a ewe's oestrous cycle ranges from 14 to 19 days with the average being 17 days in sheep (Kennedy, 2012; Schoenian, 2012; Senger, 2012; Hafez & Hafez, 2013; Menzies, 2015; Edwards, 2020). The time an ewe is in oestrous (also known as heat) is between 24-48 hours. This is the window where fertilization take place, with ewe lambs tending to have shorter oestrous cycles than mature ewes (Kennedy, 2012; Schoenian, 2012; Senger,

2012; Menzies, 2015; Edwards, 2020). In case of a fertilization failure during the breeding season, small stock return to oestrus within 7 to 23 days (Goel & Agrawal, 1992).

Within most sheep production systems, ewes are mated over at least two to three oestrous cycles (34–51 days), whereas the weaning of lambs occurs over a compressed period, often as short as 1 day (Kenyon *et al.*, 2004a). The non-return to oestrous after breeding is one of the signs of pregnancy (Goel & Agrawal, 1992). The sign of non-return to oestrus due to pregnancy is similar from seasonal anoestrus at the end of the breeding season (Goel & Agrawal, 1992). There is an advantage in having the majority of ewes conceiving within the first 17 days of mating (first cycle) (Kenyon *et al.*, 2004a). This will lead to a smaller variation on the age of the lambs leading to a more consistent lamb crop (Kenyon *et al.*, 2004a).

2.3 Embryonic losses and postnatal lamb mortality

According to Farrell *et al.* (2019) ewe wastage is one of the primary factors that limits the productivity of a sheep flock. Reproductive wastage can occur as failure to conceive; ova loss; embryonic and foetal losses during gestation and peri- and post-natal lamb loss (Kenyon *et al.*, 2014). A major source of reproductive wastage within a sheep-production system is perinatal lamb mortality, particularly in twins (Robertson *et al.*, 2011). Prenatal mortality is not uncommon in mammals in general (Adams, 1959) and sheep in particular (Edey, 1966; Abecia *et al.*, 1999). Walker *et al.* (2003) reviewed literature indicating that lamb mortality from birth until weaning can be as high as 20–30% in singles and 30–40% in twins. The survival of twin lambs can be 20–40% lower than the survival of singles, especially during adverse weather conditions at lambing (Behrendt *et al.*, 2011). Perinatal lamb mortality is estimated to be in the range of 20–25% (Hatcher *et al.*, 2011; Hinch & Brien, 2014), with the majority of the losses occurring during the first week post-lambing (Abecia *et al.*, 1999; Kleemann & Walker, 2005a). Perinatal lamb mortality is an economic as well as a welfare concern for sheep producers (Allworth *et al.*, 2017). Ewes with poor body condition scores have been associated with higher prenatal (West *et al.*, 1989) and neonatal mortalities (Nordby *et al.*, 1986) as well as an impaired lamb viability/survival rate (Russel, 1984). The body condition score (BCS) and body weight of ewes at the time of lambing are important predictors of lamb survival (McClymont & Lambourne, 1958), while weight change during the peri-parturient period also have an impact (Oddy & Holst, 1991). Lamb survival is compromised where flock sizes are large and animals graze outdoors all year round, including the lambing season (Brien *et al.*, 2010). Poor lamb

survival also prevents achieving higher net reproductive rates, as the advantage of increasing the number of lambs born is often negated by decreases in lamb survival associated with increased multiple births (Slee *et al.*, 1991). The impact of genetic effects is uncertain. According to veterinary practitioners in rural practices, embryonic losses may be attributed to ewe age, nutrition, stress as well as possible infections. Strategies that aim to increase net reproductive rate should improve or at least maintain the number (or proportion/percentage) of lambs surviving (Brien *et al.*, 2010).

2.4 Ultrasound Scanning

Early recognition of pregnancy assists in management practices (culling or rebreeding of barren ewes), and offers a valuable tool for controlled breeding programs (Ishwar, 1995). In larger domestic animals (bovine and equine), palpation of the genital tract per rectum also allows early pregnancy diagnosis. This is not possible in small ruminants like sheep and goats (Ishwar, 1995). The early and accurate diagnosis of pregnancy facilitates livestock management (Goel & Agrawal, 1992). There are a number of methods available for diagnosing pregnancy in sheep and goats (Phillippo *et al.*, 1971; Snyder & Richard Dukelow, 1974; Phillippo & Rhind, 1977; Wani, 1982; Trapp & Slyter, 1983; Watt *et al.*, 1984; Buckrell, 1988; Freeman, 1989; Goel & Agrawal, 1990). Only a few of these methods are reliable and practical under field conditions. An inability to differentiate pregnant from non-pregnant ewes can result in substantial reproduction and production losses (Goel & Agrawal, 1992). Visual observation, abdominal palpation, service records and non-return rates to oestrous are not reliable methods of early pregnancy diagnosis in small stock (Ishwar, 1995). Real-time ultrasound pregnancy diagnosis (pregnancy scanning) enables farmers to identify and remove dry ewes, thereby managing limited feed resources more effectively (Allworth *et al.*, 2017). Failure to detect barrenness may result in uneconomical feeding of dry ewes (Ishwar, 1995). The non-return to oestrous following breeding may indicate pregnancy but is not accurate. Pathological conditions of the uterus, physiological anoestrous late in the breeding season and out of season breeding can also cause anoestrous in non-pregnant ewes (Ishwar, 1995).

Ultrasound pregnancy diagnosis also provides a tool to accurately derive reproductive wastage from early pregnancy (pregnancy scanning) to weaning (Allworth *et al.*, 2017). The accuracy of pregnancy scanning data depends on the experience of the operator, the timing of scanning relative to foetal age, and the equipment used (Wilkins & Fowler, 1982). An advantage of pregnancy scan data is that sheep farmers are able to collect data on

reproductive outcomes for much larger groups of pedigreed ewes whose lambing data do not regularly enter the genetic evaluation system, for example, ewes sold/culled pre-lambing and ewes producing crossbred lambs (Bunter et al., 2016). Ultrasound scanning of ewes during pregnancy provides an estimate of conception, as well as the anticipated litter size for each ewe (often only recorded as single vs. multiple), thus allowing for the intensification of management in ewe groups without the need for exhaustive record-keeping (Fourie & Cloete, 1993). Pregnancy scan data also offer an opportunity to directly obtain reproductive data for all ewes joined (Bunter et al., 2016). Fourie & Cloete (1993) also noted the possibility of using such records together with the wet-and-dry technique to select for a potentially more reproductive ewe flock without exhaustive record-keeping. Pinpointing dry ewes and accurate mothering up can be challenging in large flocks, or when ewe losses or predation are high. The same is true in flocks where multiple births and/or mis-mothering are common (Bunter et al., 2016). Pregnancy scanning has been promoted as a management tool to enable both improved culling decisions and to improve the flock's net reproduction rate (Lee et al., 2014). Pregnancy scan data offer a clear opportunity to advance data quality and quantity, providing that scan data contribute to reproductive outcomes (Bunter et al., 2016).

Ultrasound scanning for pregnancy status and litter size allows for more specific management of the nutrition of the ewe flock according to the different nutritional requirements of dry, single- and twin-bearing ewes (Jordan et al., 2006; Bunter et al., 2016; Young et al., 2016). This may increase production and survival of these ewes and their progeny (Young et al., 2016). An alternative to using poor reproductive data is to use pregnancy scan data obtained to add to reproductive data (Bunter et al., 2016). With incomplete or poor reproductive data, breeders cannot make sustained progress in selecting for reproductive performance within a flock due to inaccurate data (Bunter et al., 2016).

2.5 Genetics

In the past, reproductive performance has been largely ignored in ovine selection programmes (Snyman *et al.*, 1998). Improving ewe reproductivity is a major objective in the local small stock industry at present (Cloete *et al.*, 2017a). The exclusion of a measure of reproduction in selection programs could be due to the difficulty to record differences in reproductive performance owing to technical problems of recording and analysing reproduction data under extensive conditions (Snyman *et al.*, 1998). Sheep breeders are less interested to acquire maternal pedigrees (which requires mothering up) when the paternal

pedigree is already known, thereby limiting recordkeeping of reproduction data for ewes (Bunter *et al.*, 2016). Among reproductive traits, litter size can more easily be measured and reported, while it is also considered to have a higher heritability than other reproduction traits (Safari *et al.*, 2005). These advantages leads to litter size being favoured as a selection criterion in the past (Afolayan *et al.*, 2008). With direct selection for litter size it was suggested by Afolayan *et al.* (2008) that 80% of the overall response in total weight weaned by a ewe would be attributable to litter size. Such selection is expected to be more efficient in overall gains per generation per year than the combination of traits into an appropriate selection index (Afolayan *et al.*, 2008).

It needs to be considered that there is a fine balance between production, reproduction, fitness and longevity traits when a breeding plan is formulated (Zishiri *et al.*, 2013; Bunter *et al.*, 2019). The objective of selection for an increased reproduction could be two-fold: 1. Selection of replacement progeny of both sexes to improve reproduction in future generations; and 2. Selection in the current flock to ensure that only the most productive ewes are retained on the farm. Option 1 hinges on the heritability of the reproductive trait to be improved, while repeatability is the parameter of importance in Option 2. Cloete *et al.* (2004) demonstrated that reproduction traits could be improved quite markedly by genetic selection, despite its low heritability often touted as a constraint to genetic progress. Cloete & Heydenrych (1987) also studied the repeatability of reproduction traits and made recommendations to achieve current flock gains. Although repeatability was low to moderate for most reproductive traits, one will still be able to achieve current-flock gains if selection is done correctly (Cloete *et al.*, 2009; Hatcher *et al.*, 2010). Hatcher *et al.* (2011) reported that lamb survival can be increased with the correct selection programs.

Increasing productivity and reproductive performance of the female generally improves economic and biological efficiency of animal production enterprises (Snowder & Fogarty, 2009). This led to the selection for individual component traits of reproduction, such as ovulation rate or litter size at birth (Snowder & Fogarty, 2009). Prior to 2007, the phenotype for reproductive performance of breeding ewes analysed by Sheep Genetics Australia was a single record reflecting number of lambs weaned per lambing opportunity (Bunter *et al.*, 2009). In addition, this trait definition was vague, as it did not allow for important systematic and temporal effects influencing annual outcomes, it did not always capture lamb losses, and contemporary comparisons were also limiting (Bunter *et al.*, 2009). According to the definition of ewe productivity (Olivier, 1999), it is a complex composite trait that is influenced by many interdependent components including age at puberty, ovulation, oestrous, fertilization, embryo implantation, birth of a live lamb(s), survival to weaning and average weaning weight, to name

a few (Snowder & Fogarty, 2009). Knowledge of the nature of the relationships between ewe reproduction and other economically important wool traits is also thus essential to derive appropriate selection programs in the South African Merino industry (Cloete *et al.*, 2017a). Genetic improvement of reproduction has primarily been focusing on selection for the ability of ewes to rear multiple lambs (Atkins, 1980; Cloete & Scholtz, 1998; Cloete *et al.*, 2004a). Improvements in lamb survival are unlikely if litter size is increased through selection without considering if additional lambs born can be successfully reared (Barker *et al.*, 1982) as multiple lambs are more likely to succumb than singles (Hatcher *et al.*, 2009).

With selection towards a more prolific ewe through an increase in the number of lambs weaned and lamb weaning weight, the breeding ewe flock will experience an increased level of fluctuation in both ewe body weight and BCS (Walkom *et al.*, 2016). A positive genetic correlation exists between body BCS as well as pregnancy scan, fertility, fecundity and the number of lambs born (Walkom & Brown, 2017). The same authors reported that number of lambs weaned was positively correlated to BCS at joining, during pregnancy and at lambing, but negatively correlated with BCS at weaning. It is thus suggested that ewes which are fatter at weaning might have lost lambs during the present lactation and consequently put less resources into milk production, thus maintaining body condition. It is therefore recommended that ewes are joined at a BCS of 3 and should not drop below 2.5 (Edwards *et al.*, 2011). A series of papers by Walkom *et al.* (2014a; b; c) demonstrated that the additive genetic component for BCS persist across time. Selecting for better condition and fat scores in breeding ewes will improve condition and fat reserves across the reproduction/production cycle (Walkom *et al.*, 2016).

2.6 Nutrition

The sheep is a well-known seasonal breeder which reproductive activity is clearly driven by photoperiod and further modulated by nutritional status (Debus *et al.*, 2012). It is known that ovulation and lambing rates can be altered using nutrition in several sheep breeds (Lassoued *et al.*, 2004). Nutrition is the main non-genetic factor contributing to fertility. Pregnancy and lactation are known as the most critical periods in ovine nutrition (Durak & Altiner, 2006). Debus *et al.* (2012) states that suboptimal nutrition is associated with decreased reproductive performance during a given season, resulting in: 1. The delayed onset of puberty; 2. A blockade of ovulation or delayed postpartum ovulation and 3. An increased embryo mortality. The static and dynamic properties of nutrition on ovulation rate has been well

established in the ovine species, indicating that ewes heavier body weight and those offered optimal levels of nutrition prior to breeding are more likely to be multiple-bearing (Smith, 1991; Scaramuzzi *et al.*, 2006).

A low feed intake after mating will result in a higher embryo wastage (Lassoued *et al.*, 2004). The effects of energy on embryo survival in sheep have been detailed in the literature (Abecia *et al.*, 1997). The energy balance of an ewe is a significant factor in determining the number and weight of lambs weaned by that ewe (Scaramuzzi *et al.*, 2006). Lamb growth and survival to weaning are primarily determined by their milk intake (Doney & Peart, 1976; Snowden & Glimp, 1991). An increased dietary energy intake of ewes during lactation increases ewe milk production and lamb growth (Langlands, 1977; Jordan & Mayer, 1989). A reduced rate of embryo survival have been reported in both over- and underfed ewes (Abecia *et al.*, 1997). It is postulated that undernutrition can increase reproductive wastage by restricting embryo growth to the point of death. Overfeeding during the same time will also lead to a significant reduction in embryo survival and pregnancy rate, due to implantation failure (Lassoued *et al.*, 2004). After the second or third week of pregnancy, embryo survival rates will decline with undernutrition of the ewe (Abecia *et al.*, 1999).

The nutritional requirements of twin-bearing ewes are 25% higher than those of ewes bearing a single foetus during late pregnancy and nearly double that of non-pregnant ewes (Agriculture and Resource Management Council of Australia and New Zealand, 1990). The nutritional demands of lactation are often not met from pasture alone, resulting in mobilization of maternal fat reserves (Gibb & Treacher, 1982; Vernon & Finley, 1985). Ewe milk production and lamb growth to weaning is the greatest for ewes that have more fat to mobilize when maternal nutritional demands are not met (Brand & Franck, 2000; Lambe *et al.*, 2005). Feeding twin-bearing ewes differentially during late pregnancy so that they have similar body weight and condition to single-bearing ewes at lambing could reduce the differences in lamb survival, wool production and body weight between single- and twin-born progeny (Edwards *et al.*, 2011). Weaner lambs with a body weight below average have an increased risk of succumbing under adverse environmental conditions. This elevates the nutritional management of ewes and weaners to being the key factor in managing number of lambs born as well as lamb and weaner mortality (Jordan *et al.*, 2006).

The nutritional demands of ewes during gestation are determined primarily by the lamb weight (Freer *et al.*, 1997; Cannas *et al.*, 2004; NRC, 2005), resulting in highly prolific ewes experiencing greater periods of negative energy balance, therefore, a greater mobilisation of body weight and fat reserves (Walkom *et al.*, 2016). Ewes with a lower body weight carrying

twins would require a high level of nutrition throughout pregnancy, while a lower plane of nutrition would be sufficient for heavier ewes (Jordan *et al.*, 2006). The improvement of nutrition of the ewes is a strategy to minimize lamb losses, particularly in twin-bearing ewes during late pregnancy and early lactation (Thompson *et al.*, 2011a; Hinch & Brien, 2014). However, under practical management regimens, the improved level of nutrition would be applied to all twin-bearing ewes irrespective of their weight or condition score, adding to the financial cost of nutritional management (Jordan *et al.*, 2006).

Underfeeding of the ewe may cause acute short-term problems like pregnancy toxemia or a general reduction in reproductive potential (Webb *et al.*, 2010). Underfed ewes will experience body weight loss during late pregnancy. This can compromise the birthweight and survival of their lambs (Oldham *et al.*, 2011; Paganoni *et al.*, 2014), lamb weaning weight (Edwards *et al.*, 2011; Thompson *et al.*, 2011a; Paganoni *et al.*, 2014), offspring wool quantity and quality throughout their lifetime (Kelly *et al.*, 1996, 2006; Kelly, 2005; Thompson *et al.*, 2011b), ewe mortality at lambing (Edwards *et al.*, 2011) as well as ewe wool production as well as carryover reproductive performance at the subsequent joining (Ferguson *et al.*, 2011). Overfeeding a pre-pubertal female has a negative effect on mammary development, stemming from excess fat deposition in the udder. This will affect maternal milk production (Schoenian, 2012). This is where the management systems need to be correct for ensuring optimal production/reproduction. Adequate levels of protein, together with a good profile of amino acids, have been pointed out as essential, especially for the functioning of specific mechanisms integral to reproductive processes. This is needed to improve the energy balance of animals (reducing the synthesis of urea), as well as enhancing the synthesis of lipoproteins, essential agents for the transport of cholesterol which is necessary for steroidogenesis. Rodrigues *et al.* (2015) reported that adequate levels of protein can improve the energy balance of the animal. The utilization of different levels of dietary protein for ewes in the mating season has important implications for their metabolic and reproductive responses.

If the growth restriction of sheep before weaning is severe and prolonged muscle and bone formation may be impaired (Greenwood *et al.*, 1998, 2000; Tygesen *et al.*, 2007) ultimately restricting mature size (Everitt, 1967; Krausgrill *et al.*, 1997; Kelly *et al.*, 2006).

2.7 Age

Measures of female reproductive success are related to age in large mammals (Festa-Bianchet, 1988). The efficiency of a breeding flock depends strongly on the age structure of the breeding ewes (Turner & Young, 1969). Age at first breeding/lambing, litter size, the length of a ewe's productive life as well as the 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) clearly established a general pattern of change in reproductive performance with ewe age. This and subsequent literature reported that reproduction potential, expressed as litter size as well as 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; De Haas & Dunlop, 1969; Mullaney & Brown, 1969; Olivier, 1982; Fourie & Heydenrych, 1983; Cloete & Heydenrych, 1986). Two-year-old ewes were characterized 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 source of reproductive wastage reduces production efficiency is not well documented in South Africa. Alostia *et al.* (1998) reported that ovine embryonic losses amounted to 17.2%, thus contributing markedly to reproductive failure in four sheep breeds they studied (Suffolk cross, Cheviot, Grey-face and Mountain).

2.8 Body weight

The body weight of a sheep relative to its potential mature body weight offers an indication of its absolute energy reserves, while body weight change indicates whether the sheep is in either in a positive energy balance (body weight gain) or a negative energy balance (body weight loss) (Young & Corbett, 1972). Body weight also reflects the quality and quantity of available dry matter as well as the dry matter intake of the animal (Mahgoub *et al.*, 2000), this allows stocking rate to be determined relative to carrying capacity of the pasture (Lloyd

Davies & Southey, 2001). The monitoring of an ewe's body weight is particularly important as fleece-free and conceptus-free ewe body weight and body weight change can significantly affect the productivity of the ewe (Coop, 1962; Kenyon *et al.*, 2004a; Ferguson *et al.*, 2011) and her progeny (Behrendt *et al.*, 2011; Thompson *et al.*, 2011a; 2011b). Economic modelling has established that whole-farm profitability can be increased when ewe body weights are managed at optimal levels (Young *et al.*, 2011), which suggests that livestock farmers, assuming they monitor the body weight of their sheep, are able to recommend a feeding regime that leads to better whole-farm profitability. Detrimental effects on enterprise profitability can follow if the additional feed cost to increase ewe body weight is not compensated for by increased saleable lamb output (Brown *et al.*, 2015). This problem has been emphasized by modelling, showing that sheep enterprise profitability starts to decrease once ewes exceed an optimum body weight (Morel & Kenyon, 2006; Young *et al.*, 2011). The body weight profile of Merino ewes is related to the production of the ewe (Ferguson *et al.*, 2011) and her progeny (Oldham *et al.*, 2011; Thompson *et al.*, 2011b; a) as well as the profitability of the sheep industry (Young *et al.*, 2011). The body weight of an ewe may be perceived as an efficiency measure. It should thus be optimized, as opposed to maximized, for greater enterprise profitability (Brown *et al.*, 2015).

The body weight of ewes at breeding affects their subsequent litter size (Gordon, 1997) and productivity (Vatankhah & Salehi, 2010). There is substantial evidence in literature that the reproductive efficiency of sheep is affected by an ewe body weight (Newton *et al.*, 1980; Saul *et al.*, 2011), and that heavier ewes have more lambs per ewe (Brown *et al.*, 2005; Ferguson *et al.*, 2011). Heavier ewes are more likely to display oestrus and successfully join, especially at younger ages (Kenyon *et al.*, 2010). Hogget and adult ewes with heavier body weights at joining are more probable to mate in the first 17 days of the breeding season and are more likely to lamb multiples (Kenyon *et al.*, 2004a, 2005, 2006). Ewe lambs should not be bred if they are below 70 percent of their mature weight to prevent poor reproduction performance and even death (Schoenian, 2012). Having more ewes mating early in the breeding season allows for the lambing period to be shortened without compromising conception rates (Brown *et al.*, 2015). Heavier ewes attain puberty earlier (Stephenson *et al.*, 1980; Smith, 1982), display behavioural oestrus (Doney & Gunn, 1981), commence with ovulation (Knight, 1980; Rattray *et al.*, 1980, 1983; Smith, 1982, 1991), and display lower levels of barrenness (Smith, 1982). Ovulation rate, as a key driver of ewe fecundity, is sensitive to body weight in sheep (Rhind *et al.*, 1984a; Rowe, 2003).

Increasing body weight and growth rate will benefit ovulation rates of ewes and the survival of their lambs until weaning (Jordan *et al.*, 2006). Heavier ewes are less likely to

respond to enhanced levels of nutrition prior to breeding in terms of an increased ovulation rate (referred to as the dynamic effect) than lighter ewes (Smith, 1991). The relationship between body weight and ovulation rate is not linear but curvilinear, indicating that for each added kg of body weight, the relative gain in ovulation rate is reduced (Smith, 1991). Rowe (2003) reported that ewes weighing 55kg have a 45% higher ovulation rate than those weighing 15kg less, with an additional 11% increase in ovulation rate if the ewes are also gaining body weight at joining. Merino ewes between 35 kg and 53.5 kg responded by a 2% to 5% increase in ovulation rate for every additional 2.5 kg of body weight gained (Edey, 1968). A wide range of sheep breeds responded by an average of 2% increase in ovulation rates for every 1 kg increase in ewe body weight (Morley *et al.*, 1978). Ewe ovulation rates may fluctuate considerably due to fluctuations in body weight, thus this providing an opportunity to monitor and manage the ewe flock's body weight to increase fecundity (Brown *et al.*, 2015). Shorter lambing periods aid with the management of the ewe flock, but with twins becoming more prevalent this will require additional management to prevent high mortality rates (Brown *et al.*, 2015). Genetically heavier ewes were more fertile, had bigger litters and weaned more lambs (Safari *et al.*, 2005; Walkom & Brown, 2017). Ewes who lost or failed to gain weight in either joining to pregnancy or pregnancy to lambing were not as fertile and produced fewer lambs (Rose *et al.*, 2014; Walkom & Brown, 2017). Lamb survival is largely determined by the birthweight of the lamb (Holst *et al.*, 1986). Litter size is predominately influenced by lamb birthweight (Hinch *et al.*, 1985), while ewe body weight at joining and body weight fluctuations during pregnancy also influence lamb survival (Brown *et al.*, 2015). The optimum lamb birthweight ranged between 4kg and 6.5 kg, with lamb mortality rising sharply below and above this range (Hinch *et al.*, 1985; Hatcher *et al.*, 2009; Oldham *et al.*, 2011). Hinch *et al.* (1985), Brown *et al.* (2005) and Oldham *et al.* (2011) has indicated that lamb birthweight increased by 0.025 kg to 0.03kg for every 1 kg increase in ewe body weight at joining.

Ewes bearing twins tend to be lighter at lambing than single-bearing ewes if they are under the same management regimen during pregnancy (Ferguson *et al.*, 2011). Ewe body weight change during pregnancy has also been linked to lamb survival, predominantly those from multiple births (Edwards *et al.*, 2011; Oldham *et al.*, 2011). Lambs from Scottish half-bred ewes fed to gain weight between conception and lambing suffered 11.6% lamb mortality, compared to 23.4% in ewes fed to lose weight (Khalaf *et al.*, 1979). Lamb survival can thus be increased by managing ewe body weight both at joining and throughout pregnancy (Brown *et al.*, 2015). The general reproductive performance of low body weight ewes can be improved by providing supplementary feed, to increase their body weight (Brown *et al.*, 2015). Young *et al.* (2011) stated that feeding ewes during late pregnancy to recover any body weight lost

in early pregnancy was the most significant target to achieve during the reproductive cycle. The phenotypic relationship between ewe body weight and body condition and her reproductive performance is complex, with both traits contributing and being responsive to nutrition in nature (Walkom & Brown, 2017). It has been shown that a favourable phenotypic relationship exists, to where heavier and better conditioned ewes had an increased reproductive performance (Curnow *et al.*, 2011; Edwards *et al.*, 2011; Young *et al.*, 2011).

2.9 Body Condition Score

The body weight of the ewe has two components, the basic skeletal size of the sheep and the degree of fatness (body condition) of the ewe. Due to the difference in skeletal size between animals, body weight alone cannot indicate the degree of fatness of an animal. BCS is an estimation of muscle and fat development of an animal and is linked with the direct measurement of back fat depth or the amount of fat reserves in the body, thus allowing a clearer estimate than body weight alone (Russel *et al.*, 1969; Sanson *et al.*, 1993). Body condition scoring has become a common management tool on many farms (Kenyon *et al.*, 2004a). Sheep producers have enhanced weaning percentages by taking advantage of a favourable phenotypic relationship between ewe BCS and reproductive performance (Curnow *et al.*, 2011; Edwards *et al.*, 2011; Young *et al.*, 2011). BCS is a subjective way to evaluate the nutritional status of a flock, thus acting as a potential indicator for sheep producers to increase production efficiency in their flock (Sejian *et al.*, 2010). Sheep are given a BCS of 1 (emaciated) to 5 (obese), based on the level of muscling and fat deposition around the loin region (Russel, 1984). There is thus an optimum BCS for each ewe for each stage of the production/reproduction cycle (Vatankhah *et al.*, 2012). Farmers can improve reproduction through suitable management, one can also select for a better body condition and be confident that the ewe will be genetically inclined to higher subcutaneous fat reserves and condition across the reproduction/production cycle and throughout her breeding life (Walkom *et al.*, 2014a; b; c). There are numerous reports suggesting a positive correlation between BCS at mating and reproductive performance (Atti *et al.*, 2001; Abdel-mageed, 2009; Sejian *et al.*, 2010; Yilmaz *et al.*, 2011). Knowing the ideal BCS at mating, allows flock owners to make adjustments to the nutritional program to save money, to avoid problems attributed to ewe body condition and achieve optimal productivity by evaluating the nutritional status of the ewes (Vatankhah *et al.*, 2012). The BCS of ewes at mating affect seasonality (Forcada *et al.*, 1992; Rondon *et al.*, 1996), the number of large follicles present during the luteal phase (Rhind &

McNeilly, 1986; McNeilly *et al.*, 1987; Rhind *et al.*, 1989), ovulation rates (Gunn *et al.*, 1969; Bastiman, 1972; Gunn *et al.*, 1972; Rhind *et al.*, 1984a; McNeilly *et al.*, 1987; Forcada *et al.*, 1992; Rondon *et al.*, 1996), ova/embryo loss rates (Gunn & Doney, 1975), conception rates (Bastiman, 1972), fertility (Gunn *et al.*, 1972), and lambing percentage (Gunn *et al.*, 1969, 1972; Newton *et al.*, 1980).

BCS is generally positively related to ovulation rate (Kenyon *et al.*, 2014). A Merino across-flock analysis showed a positive relationship between average flock BCS and flock ovulation rate (Kleemann & Walker, 2005b). The relative improvement in ovulation rate might also be reduced since ewes in a higher BCS will be less responsive to improved nutrition in comparison with ewes of low BCS (Smith, 1991). The main objective from a reproduction perspective for sheep producers are often the number of lambs weaned per ewe present at breeding (Kenyon *et al.*, 2014). The ovulation rate of an ewe determines the potential for the number of lambs that can possibly be weaned per ewe per year. Knight *et al.* (1975); Lindsay *et al.* (1975); Kelly, (1982) and Knight (1990) reported that ovulation rate was the foremost determinant of variation in the number of lambs weaned. Post-ovulation, the goal should be to minimize flock reproductive wastage (Kenyon *et al.*, 2014). Ewes with a lower BCS will display reduced reproductive performance in comparison to ewes with a greater BCS (Kenyon *et al.*, 2014). Ewes with low body condition scores have been associated with a higher prenatal (West *et al.*, 1989), and neonatal lamb mortality (Nordby *et al.*, 1986) and a lower lamb viability/survival rate (Russel, 1984). BCS at breeding had a positive effect on number of lambs weaned per ewe in Lori-Bakhtiari ewes, but only up to a BCS of 3.0 before it plateaued (Vatankhah *et al.*, 2012). Ovulation rate increased in Cheviot ewes up to a BCS of 2.5 to 2.75, without a further increase in ovulation rate at higher body condition scores (Gunn *et al.*, 1991a). Ovulation rate continued to increase with higher body condition scores in Welsh Mountain ewes (Gunn *et al.*, 1991b), suggesting a differences in optimal BCS between breeds. The effect of BCS on ovulation might be less pronounced in highly fecund breeds (Russel, 1984).

Studies comparing two body condition scores, showed that the group with the higher BCS exhibited a higher ovulation rate (Gunn *et al.*, 1972 [Scottish Blackface]; Gunn & Doney, 1979 [Cheviot]; Rhind *et al.*, 1984a; b[Scottish Blackface and Scottish Blackface crossbred]; Rhind & McNeilly, 1986 [Scottish Blackface]; McNeilly *et al.*, 1987 [Scottish Blackface]; Forcada *et al.*, 1992 [Rasa Aragonesa]; Viñoles *et al.*, 2002 [Polwarth]). The ovulation rate of Beulah ewes increased with body condition score, but in Cheviot ewes it increased only to a BCS of 2.25 to 2.5 (Gunn *et al.*, 1988). This led to a belief that, similar to the static effect, the effect of feed intake on ovulation rate diminishes above a threshold body condition score.

Hence there is a BCS where feed intake is an important determinant of ovulation rate (Kenyon *et al.*, 2014). Increasing the level of feeding have a positive effect on ovulation rate in Scottish Blackface ewes with low body condition, with no effect in ewes with a high BCS (Gunn *et al.*, 1969).

Some studies have found that BCS had no effect on embryo mortality, with example in Merino cross and Merino ewes across a wide range of body condition scores (Cumming *et al.*, 1975). A similar finding was reported by comparing Scottish Blackface ewes with a BCS of 1.5 to 1.75 with those with a BCS of 2.75 to 3.0 (Rhind *et al.*, 1984a), with most studies reporting otherwise. Ewes with extreme body condition scores of 1.5 and 4.0 were more likely to lose pregnancies than ewes with intermediate body condition scores (Abdel-mageed, 2009). Scottish Blackface ewes with a BCS of 1.5 also had higher embryo mortality during the early stages of pregnancy than ewes with a BCS of 3.0, although BCS had no effect after 26 days of pregnancy (Gunn *et al.*, 1972). Supplementary feeding had no effect on embryo loss in ewes with a BCS of 1.5 but ewes with a moderate BCS of 2.5 responded by a reduced embryo loss to these elevated levels of feeding. Conversely, embryo survival was higher in Scottish Blackface cross ewes with a moderate BCS versus a high BCS (3.4 vs. 2.7) in another study (Rhind *et al.*, 1984b). Gunn & Doney (1975) compared Scottish Blackface ewes across a range of 1.5 to 3.0 body condition scores and stated that embryo loss decreased as BCS increased at mating. Ewes fed above maintenance demonstrated lower progesterone concentrations and were less likely to maintain their pregnancy (Parr, 1992), suggesting that the mechanism was probably increased liver blood flow, leading to an increased clearance of progesterone from circulation (Parr, 1992). In summary, these studies demonstrate that both high and low body condition scores in ewes can be detrimental to embryo survival.

A positive relationship was found between pregnancy rate and a range of body conditions body condition scores in Manchega (Molina *et al.*, 1994), Barbarine (Atti *et al.*, 2001) and Merino (Kleemann & Walker, 2005b) sheep maintained under commercial feeding conditions. The same issue was approached in a different way by demonstrating that pregnant ewes had a higher mean body condition than their barren counterparts (Gonzalez *et al.*, 1997; Esmailizadeh *et al.*, 2009). The same trend was reported in Romney and Kivircik ewes with body condition scores of respectively 2.0 and 2.5 at breeding that were more likely to get pregnant than ewes lower body condition scores (Kenyon *et al.*, 2004a; Yilmaz *et al.*, 2011). In the previously cited studies involving Romney and Kivircik ewes, there was no further improvement in pregnancy rate above a BCS of 2.5 (Kenyon *et al.*, 2004a; Yilmaz *et al.*, 2011). In manipulative studies, ewes were fed to attain a specific body condition score, ewes with a BCS of 3.0 had higher pregnancy rates at first mating than ewes with a BCS of 2.0 (Gunn &

Doney, 1979). The number of Ossimi lambs per ewe mated plateaued after a BCS of 2.5 and later declined as body condition increased above 3.5 (Abdel-mageed, 2009). No further increase was also found in Chokla ewes above body condition scores of 3.5 (Maurya *et al.*, 2009). Body condition scores either side of an intermediate optimum have the potential to negatively influence ovulation rate, ova and embryonic loss, conception rates and failure to conceive, which are all components of whether a ewe will be pregnant or not (Kenyon *et al.*, 2014).

There was a positive relationship between ewe flock body condition and the number of foetals per Merino ewe in an across-flock comparison (Kleemann & Walker, 2005b). Number of lambs born per ewe was independent of ewe BCS in Merino, Suffolk, Afshari and various other breeds (McInnes & Smith, 1966; Geisler & Fenlon, 1979; Rozeboom *et al.*, 2007; Aliyari *et al.*, 2012). In contrast, other authors reported a positive correlation between ewe BCS and number of lambs born in Scottish Black Face, Masham and several other breeds (Gunn *et al.*, 1969; Pollott & Kilkenny, 1976; Newton *et al.*, 1980). A possible explanation for the differences in these studies is that the positive relationship between ewe body condition and the number of lambs born is not linear but curvilinear instead (Kenyon *et al.*, 2014). There have been reports of a plateau in the positive relationship between BCS and number of lambs born in Icelandic, Latxa and Lori-Bakhtiari ewes (Adalsteinsson, 1979; Oregui *et al.*, 2004; Vatankhah *et al.*, 2012). To complicate this matter further, a high ewe BCS was also related to a decline in the number of lambs born (Rhind *et al.*, 1984b; Gunn *et al.*, 1991b; Atti *et al.*, 2001; Abdel-mageed, 2009; Aliyari *et al.*, 2012). Collectively, these results confirm a curvilinear relationship between ewe body condition and the number of lambs born. There thus appears to be a threshold for each breed above which there is a negative effect of ewe body condition on lambing rate (Kenyon *et al.*, 2014). Thus, the BCS objective for optimal reproductive efficiency need to be established for different breeds, with some breeds having a lower optimal BCS than other breeds (Kenyon *et al.*, 2014).

It is expected that a ewe with a low body condition would yield less milk than ewes with higher body conditions (Kenyon *et al.*, 2014). Up to a third of milk production by a ewe is achieved by mobilizing body fat and protein reserves during early lactation (Cannas *et al.*, 2004). Because ewe body condition is bound to change during pregnancy it is expected that pre-lambing ewe body condition had a positive effect on milk production as well as on lactation length, whereas ewe body condition measured pre-breeding had no effect (Hossamo *et al.*, 1986). Under conditions where ewes lost body weight during lactation, ewes with a lower body condition tended to produce less milk than ewes with a higher body condition score, indicative of a positive effect of ewe body condition during late pregnancy on milk production

(Gibb & Treacher, 1980; Hossamo *et al.*, 1986). At insufficient levels of feeding, the milk production of ewes with more body fat (higher body condition score) was less affected than in ewes with less body fat (Cannas, 2004). When lactating ewes had access to satisfactory nutrition, ewe body condition had no influence on milk production (Gibb & Treacher, 1982). The same trend for body weight was also true for body condition, with ewes producing the most lambs also losing the most condition during lactation (Walkom & Brown, 2017). Ewes that were genetically more fertile lost condition between joining and pregnancy as well as between pregnancy and lambing while still having a greater fecundity (Walkom & Brown, 2017), while ewes that were able to maintain or gain condition had a higher lamb survival. Ewes in better condition at lambing due to enhanced nutrition during pregnancy have more fat to mobilize (McNeill *et al.*, 1997) and it is rational to expect that they will produce more milk and have lambs with higher weaning weights, especially when nutritional demands during lactation are not met (Thompson *et al.*, 2011a). When farmers are aiming to improve ewe body condition it is wise to base selection on joining condition scores to avoid the impact of reproduction on the ewe's phenotype (Walkom & Brown, 2017).

While there is a positive relationship between lamb growth and ewe body condition, there are also a suggestion that there may be a plateau above which no further improvements are made, and that the number of lambs a ewe rears affect the relationship reported (Kenyon *et al.*, 2014). The body condition of ewes can thus be used as a management tool to ensure an improved lamb survival (Kenyon *et al.*, 2014). There exists a positive curvilinear relationship between singleton lamb survival and ewe body condition score, with a weakening response as body condition increased above 3.0 in Merino ewes (Kleemann & Walker, 2005b). In contrast, this relationship remained linear in ewes with twins. Ewe body condition either have no influence on lamb growth to weaning (Gibb & Treacher, 1982; Litherland *et al.*, 1999; Thompson *et al.*, 2011a) and weaning weight (Al-Sabbagh *et al.*, 1995; Litherland *et al.*, 1999; Aliyari *et al.*, 2012; Verbeek *et al.*, 2012), or ewe body condition do have a positive effect on lamb growth (Gibb & Treacher, 1980; Kenyon *et al.*, 2004b, 2011; Mathias-Davis *et al.*, 2013) and weaning weight (Molina *et al.*, 1991).

2.10 Animal resources utilised

The success of a study like this hinge on the availability of high quality phenotypic data that were obtained from reputable sources. Based on the availability of data, the study focussed upon ewes from several resource flocks maintained under institutional control, as

reviewed by Schoeman *et al.* (2010). A brief account of the history of each of these flocks, as well as previous studies utilising the resource is provided below:

2.10.1 The Elsenburg Merino flock

The Merino resource flock project at Elsenburg began in 1986 and involved divergent selection for and against reproduction from a common base flock (Cloete & Scholtz, 1998). Maternal ranking values for the number of lambs reared per joining were initially used as selection criterion for both male and female replacements (Turner, 1977). The two different fertility lines were selected from a Merino flock initially selected for an increased wool secondary:primary follicle ratio (Heydenrych *et al.*, 1984). This selection experiment is extremely well documented in literature (Cloete & Scholtz, 1998; Cloete *et al.*, 1998b, 2001, 2004). Cloete *et al.* (2004a, 2017) reported marked divergent responses in reproduction approximately 2% per annum on the upward direction and 1% per annum in the downward direction within the flock. Divergent responses were also reported for body weight and fold score (Cloete *et al.*, 2005), behaviour in responses to the stress of being separated from flock mates (Cloete *et al.*, 2020) as well as maternal and offspring behaviour (Cloete *et al.*, 2021a). The line selected against reproduction also exhibited a lower resistance to breech blowfly strike than the line selected for an improved reproduction line (Scholtz, 2010). The flock also formed the basis for molecular genetic studies on SNPs (Nel *et al.*, 2021). There are numerous studies illustrating the difference in production traits between these lines (Cloete & Scholtz, 1998; Cloete *et al.*, 1998, 2001b; 2001a, 2004a, 2005, 2009, 2010; Scholtz, 2010; Cloete *et al.*, 2017a; 2017b, 2020, 2021a; Nel *et al.*, 2021). The results from Elsenburg Merino research flock had a major impact on the perceptions of sheep farmers to selection for reproduction. Responses in number or weight of lamb weaned in the National flock reported by Olivier & Cloete (2007) and Schoeman *et al.* (2010) can directly be linked to the demonstration in these lines that selection for reproduction is successful.

This flock provided data on the effect of BCS and mating weight on the reproduction of Merinos ewes. The marked differences in the two lines making up the flock provided an opportunity to better understand the impact of these traits in Merinos differing in their reproductive ability.

2.10.2 The SAMM

The SAMM is a dual-use breed that was bred from the imported German Merino by selection from the 1930's (Vosloo, 1967). In 1932 the South Africa Department of Agriculture

imported ten German Merino ewes also known as Deutsche Merinofleischschaf from Germany for experimental purposes (Cloete, 1998). These ten ewes were maintained on the Elsenburg Research Farm in the Western Cape of South Africa, where they formed part of crossbreeding and breed comparison experiments. Based on the performance of the German Merino the Department of Agriculture as well as private breeders imported more animals to contribute to the newly established breed. Based on the German Merino's high lambing percentage in autumn, superior wool production and improved disease resistance compared other breeds, it was the breed of choice among those sheep breeds tested (Vosloo, 1967). The German Merino Breeder's Society was established on 30 October 1946 and was incorporated in the South African Stud Book Association in 1951. The name South African Mutton Merino (SAMM) was adopted by breeders in 1970 as dedicated breeders asserted that the locally developed breed had diverged from its German Merino ancestors.

The SAMM was developed to produce good quality slaughter lambs with an excellent slaughter weight at early ages, while continuing to produce wool of a good quality. The breed was initially known for its fertility while producing a medium to strong white wool (22 to 23 microns). There are numerous reports (Zemuy, 2002; South African Mutton Merino Breeders' Society, 2009; Van der Merwe *et al.*, 2020) stating that the SAMM is an efficient feed converter that excels in feedlot and pasture systems because of its ability to utilize low quality roughage. The breed has non-selective grazing habits and causes minimal trampling of pastures thus, simplifying fodder flow management (Zemuy, 2002). The SAMM utilizes energy efficiently which in turn leads to optimal wool-and meat-production, especially in grain producing areas (Burger *et al.*, 2013; Van der Merwe *et al.*, 2020). According to Cloete *et al.* (2007a) the SAMM excelled in crossbreeding programs with woolled-type sheep breeds to develop composite breeds because of its enhanced conformation, hardiness, fertility and adaptability. The SAMM contributed to the development of South African composite breeds such as the Afrino, Dormer and Dohne Merino; while seed stock has also been exported to other countries (Van der Merwe, 1976; Erasmus *et al.*, 1995; Cloete *et al.*, 2001b).

Vosloo (1967) was the first author to publish a dissertation on production and reproduction traits of German Merinos. Nesper *et al.* (2000) estimated non-genetic factors and genetic parameters for growth traits using 387600 pedigree and 126477 performance records from the national SAMM database from 1974 to 1999. Studies using field data were limited due to different breeders recording weights at different ages while they did not regularly supply all the records to the database. However, the study of Nesper *et al.* (2000) provided valuable information on operational models and genetic parameters to predict breeding values that are important for selection purposes in early growth traits. Genetic parameters for early growth

traits in addition to phenotypic and genetic parameters for hogget weight and wool traits for the Elsenburg SAMM flock were estimated by Zemuy (2002). Genetic and environmental trends for all the traits were also estimated. These studies were carried out from 1955 to 2002 which concluded that non-genetic factors were significant sources of variation in the traits. During these studies it was observed that the heritability estimates for birth and weaning weight were low while the heritability for hogget weight were moderate while being high for wool traits. Genetic improvement by selection for these traits should thus be easily obtainable. In addition to this it was found that selection responses in most traits were slow. It was contended that selection for growth and wool traits were not primary selection objectives in the Elsenburg flock genetic gain for all the traits tended to be small over the study period (Zemuy, 2002). Emphasis on visually assessed traits such as conformation was listed as a possible reason for the small positive genetic trends that were observed. Neser *et al.* (2000) focused on the estimation of (co)variance components for early growth and body weight growth of the SAMM breed.

Two SAMM flocks contributed data to this study, namely the Elsenburg and Mariendahl resource flocks (see Schoeman *et al.*, 2010). The Stellenbosch University's Mariendahl flock SAMM flock was used for the estimation of breed effects for lamb traits and yearling body weight traits (Cloete *et al.*, 1999) as well as for estimating genetic variance ratios for hogget weight, clean fleece weight and fibre diameter (Cloete *et al.*, 2001b). This flock contributed to the chapter on ultrasound scanning traits in South African sheep.

The Elsenburg SAMM flock provided information on the effect of ewe BCS on ewe reproduction. Cloete *et al.* (2004b) previously estimated genetic and environmental (co)variance components and ratios for hogget weight and wool traits in this resource flock and suggested that their study laid the foundation for wool to be emphasized in future selection programs. Selection for multiple births received a lot of attention in the Elsenburg SA Mutton Merino flock. This resulted in the flock having a very high reproduction rate in the late 1990's and early 2000's which was linked to a high lamb mortality rate (Cloete, 1992). The net reproduction rate of the flock, defined as weight of lamb weaned per ewe mated was thus not optimal. This is worrying since reproduction was identified as a key contributor to the economic success of local small stock farmers (Olivier, 1999). Genetic progress in excess of 1 % of the overall phenotypic mean per annum was found for number of lambs weaned per ewe mated (Cloete *et al.*, 2004a, 2017a). At this stage it is unsure if the same progress will be achieved in a breed like the SA Mutton Merino which is reputed to be a more prolific breed. There is little knowledge of genetic (co)variances in Elsenburg SA Mutton Merinos apart from the studies of Zemuy (2002), Cloete *et al.* (2004b) and Muller (2020). These studies mostly

involved traits in the growth and wool complexes and did not report on the importance of mating weight or condition scores in the flock. The lack of genetic correlations involving other traits of economic importance remains a limitation to the formulation of a scientifically based breeding strategy for the breed.

2.10.3 The Dormer

During the 1940's the Dormer breed was developed at the Elsenburg Research Farm. With the objective to establish a composite, synthetic breed, Dorset Horn rams were crossed with German Merino ewes to form the foundation of this breed (Cloete, 1998). The objective with the formation of the breed was to develop a fast-growing white-wool breed for terminal crossbreeding on Merino-type ewes (De Villiers & Cloete, 1984). The Dormer adapted well to this role and produced slaughter lambs of the desired quality when used on Merino type dams (Erasmus *et al.*, 1983; Cloete *et al.*, 2004c). Van der Merwe *et al.* (2019) reported that the Dormer displayed favourable growth and meat production characteristics with it having the reputation of a coarse wool breed. The Dormer is by far the most numerous terminal sire breed in South Africa as reflected by the number of records submitted to the National Small Stock Improvement Scheme (Zishiri, 2009; Zishiri *et al.*, 2012; Cloete *et al.*, 2014).

The first evaluation of the Elsenburg Dormer flock was by Van der Merwe (1976) then followed by (Van Wyk *et al.*, 1993c; d, b; a). Each evaluation had more data available, and the more recent studies used updated techniques for the analyses. The flock remained a closed flock until after the second study by Van Wyk *et al.* (1993c; d, b; a) in the early 1990's. This resulted to an increase in inbreeding as the initial cross between Dorset Horn rams and German Merino ewes were from unrelated breeds. Variance components and heritabilities for early growth traits for this flock was initially estimated by (Van Wyk *et al.*, 1993d). The genetic, phenotypic and environmental correlations among early growth traits were also evaluated for the closed flock (Van Wyk *et al.*, 1993b). The effect of an increase in inbreeding, the effect of inbreeding depression and the effect of ignoring inbreeding vs. considering inbreeding coefficients of the animal and dam on (co)variance estimates and breeding values were subsequently quantified for early growth and reproduction traits (Van Wyk *et al.*, 2009). Genetic parameter estimates for the Dormer resource flock were updated in a study that was crucial due to the inevitable increase in inbreeding (Fair, 2002). Granting that Van der Merwe (1976) evaluated reproduction, the methods had become outdated since. Consequently, the study done by Fair (2002) re-estimated genetic parameters for reproduction traits that was eventually published by Van Wyk *et al.* (2003). Selection in Elsenburg Dormers was so far more like a programme for a dual-purpose breed with emphasis also placed on traits such as

reproduction and conformation. Heritability estimates for reproduction in the Elsenburg Dormer flock were low (Fair, 2002; Van Wyk *et al.*, 2003). The estimated values were, however, consistent with those in a Merino flock where worthwhile genetic progress in reproduction was reported (Cloete *et al.*, 2004a).

This flock also contributed mating weight and BCS data to this study. Since the Elsenburg SAMM and Dormer flocks were managed as a single flock during the period of the study, it provided an opportunity to study ewe BCS and mating weight in a dual-purpose and terminal sire breed managed as a single flock.

2.10.4 The Dohne Merino

The Dohne Merino is an important wool breed with dual-purpose characteristics that were developed in South Africa from the German Merino and the Merino (Cloete *et al.*, 1999, 2001b). Previous large-scale studies on the breed involved breed analyses on yearling body weight and wool traits (Van Wyk *et al.*, 2008) and on ewe reproduction traits (Cloete *et al.*, 2021b). The flock used in the study was the Dohne Merino flock maintained at the Mariendahl farm of Stellenbosch University, where detailed individual records of ultrasound scanning were recorded. The flock was used alongside with the Mariendahl SAMM flock in the studies of Cloete *et al.* (1999; 2001) briefly described before. The availability of scanning records in both flocks, as well as the Merino flock initially maintained on the same property, allowed for the comparison of these breeds for scanning traits. However, the Merino flock was phased out early and only served the purpose of providing data pertaining to the distribution of scanning records (Chapter 5). The Dohne Merino and SAMM flocks provided a greater number of records, allowing detailed analyses on the effects of lambing year and ewe age on average performance records. Repeated records across years also allowed the estimation of repeatability estimates for scanning traits, parameters not yet recorded in South African sheep. Current-flock gains can be estimated from these parameters.

Finally, it is foreseen that this thesis will contribute to and update previous literature describing ultrasound scanning, mating weight and body condition scores as tools to the reproductive management of sheep with particular reference to South Africa. It should be noted that we are not aware of comparable publications on South African sheep studying these traits. As the study utilised data obtained from the reputable Elsenburg Merino, South African Mutton Merino and Dormer flocks as well as the Stellenbosch University Dohne Merino and SAMM studs, it is assumed that the quality of the data used is beyond doubt. We would thus

like to contend that robust results for South African sheep can thus be obtained from this unique blend of ovine genetic resources.

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Chapter 3:

Effects of ewe body weight and body condition score on reproductive performance in Merino ewes divergently selected for reproduction

3.1 Abstract

Ewe reproduction determines selection intensity as well as the number of surplus lambs to be sold and is therefore important in a meat-producing enterprise. Literature indicates that reproduction in sheep depends both on size and body condition (fatness). As ewe size is also indicative of maintenance requirements, it is important to understand the relative contribution of ewe body size and condition to reproduction. Data of the Elsenburg Merino flock from 2017 to 2020 were used to study genetic and environmental parameters for ewe mating weight, BCS (subjectively assessed on a 5-point scale) at mating and lambing, as well as correlations of these traits with reproduction. The Elsenburg flock was divergently selected from the same base for number of lambs weaned per ewe mated (NLW) since 1987. The line selected for NLW (High or H Line) is well separated on reproduction from the line selected against NLW (Low or L Line), resulting in an opportunity to study body weight and reproduction in this divergent resource. H Line ewes were heavier than the L Line at mating, but no line differences were found for the condition scores. Using an animal repeatability model, it was found that ewe mating weight was highly heritable at 0.74, with lower estimates for BCS at mating (0.28) and lambing (0.18). Genetic correlations among these traits were positive, ranging from 0.58 between mating weight and BCS at mating to 0.93 between the condition scores. Repeatability model genetic correlations of mating weight and condition scores with reproduction were mostly negative, significantly so with ewe conception rate (all traits) as well as lambing and twinning rate (BCS at mating). This unexpected trend was apparently due to high condition scores in barren ewes, particularly in H Line ewes aged five and six years. In contrast, two-year-old maiden H line ewes that conceived had a higher BCS at mating than their barren flock mates. Across age groups, the best reproductive performance was found in ewes with an intermediate BCS of two to three. Further research on the interface between ewe age, mating weight, BCS and reproduction is warranted.

3.2 Introduction

The main wool producing sheep within South Africa is the Merino, a breed universally recognised for its apparel wool production (Cottle, 2010; Cloete *et al.*, 2014). The South African national sheep flock steadily declined during the last three decades without affecting the local production as well as the consumption of lamb and mutton (DAFF, 2019). Since the total number of sheep declined without a change in the demand for lamb and mutton, it is foreseen that the demand will exceed the supply of sheep meat, resulting in a value change for lamb and mutton (Pride & Ferrel, 2006). Thus Brand *et al.* (2014) predicted a change within the South African ovine meat trade. Huisman & Brown (2008) and Van der Merwe *et al.* (2019) reported a premium for meat production over wool production, suggesting that currently carcass attributes and reproduction are favoured over wool production in the sheep industry. This relative increase in the value of sheep meat resulted in farmers in wool producing regions rather selling replacement stock for slaughter, as they are more valuable in the meat market (Huisman & Brown, 2008).

The most important economical trait complex in sheep is reproductive performance, particularly when lamb and mutton are the primary products (Fourie & Heydenrych, 1983; Van Haandel & Visscher, 1995; Snyman *et al.*, 1998; Cloete *et al.*, 2000; Abegaz *et al.*, 2002; Van Wyk *et al.*, 2003; Senger, 2012; Ali *et al.*, 2020). A viable and sustainable sheep industry with meat production as a major component hinges on an excellent base level of reproduction to ensure maximal genetic progress as well as surplus offspring for marketing (Cloete, 1972; Snowder & Fogarty, 2009; Walkom *et al.*, 2016). Minimizing wastage and increasing the number of lambs and weight of lamb weaned per ewe per year results in an increased efficiency (Duguma *et al.*, 2002). The value of a commercial farm animal is directly proportional to their ability to reproduce under optimal conditions.

The breeding efficiency of a sheep flock was conclusively related to the ewe age structure (Turner & Young, 1969). A clear and well defined trend has been established for the change in reproductive performance linked to dam age (Turner & Dolling, 1965). Low pregnancy rates (Schladweiler & Stevens, 1973; Ozoga & Verme, 1982), small litter sizes (Schladweiler & Stevens, 1973; Ozoga & Verme, 1982), and low weaning rates (Ozoga & Verme, 1982) are all characteristics of two-year-old maiden ewes. Reproduction potential, expressed as litter size, conception rate and culminating in the number of lambs born and weaned per ewe increased with dam age, subsequently followed by a reduction in reproductive performance after roughly five lambing opportunities (Turner & Dolling, 1965; De

Haas & Dunlop, 1969; Mullaney & Brown, 1969; Olivier, 1982; Fourie & Heydenrych, 1983; Cloete & Heydenrych, 1986; Hatcher *et al.*, 2009, 2011).

Monitoring the body weight of ewes is important, as body weight and body weight change can appreciably affect ewe reproduction (Coop, 1962; Kenyon *et al.*, 2004; Ferguson *et al.*, 2011). It is well known that the body weight of ewes at mating has a profound effect on litter size (Gordon, 1997) as well as ewe productivity in the subsequent breeding season (Vatankhah & Salehi, 2010). The reproductive efficiency of a sheep flock is affected by the ewe's body weight as ewes with higher body weights tend to have more lambs (Newton *et al.*, 1980; Cloete & Heydenrych, 1986; Brown *et al.*, 2005; Ferguson *et al.*, 2011; Saul *et al.*, 2011). An increased body weight at mating will increase ovulation rates of ewes and the survival of their lambs until weaning (Rhind *et al.*, 1984; Rowe, 2003; Jordan *et al.*, 2006). Ewes that are genetically heavier are more fertile, have bigger litters and wean more lambs per ewe per season (Safari *et al.*, 2005; Walkom & Brown, 2017). As an indicator of maintenance requirements (Bedier *et al.*, 1992), ewe body weight can also be perceived as an efficiency measure, and thus should be optimized as opposed to maximized, for an even greater profitability (Brown *et al.*, 2015). Thus an often considered question is: Is it more profitable to have fewer "larger" ewes or relatively more "smaller" ewes on a per farm unit basis (Kenyon *et al.*, 2009)? A balance needs to be found for optimum production.

The body weight of ewes has two components, namely the degree of fatness (body condition) of the ewe as well as its basic skeletal size. Body condition score (BCS) is linked with the back fat depth measurement or the fatness of the animal; therefore it provides additional information above body weight as a primary measure of size (Russel *et al.*, 1969; Sanson *et al.*, 1993). There have been numerous reports of a positive correlation between body condition score (BCS) at mating and reproductive performance (Atti *et al.*, 2001; Abdelmageed, 2009; Sejian *et al.*, 2010; Yilmaz *et al.*, 2011). These results suggest that a farmer can select for an increased body condition and be confident that the ewe will be genetically predisposed to higher subcutaneous fat reserves and a better condition during the reproductive season and throughout her breeding life (Walkom *et al.*, 2014a; b; c). Sheep farmers can increase the weaning percentages of their breeding flocks by using this knowledge (Curnow *et al.*, 2011; Edwards *et al.*, 2011; Young *et al.*, 2011). The phenotypic relationships that exist among body weight, BCS and reproduction traits are complex, resulting in difficulty to differentiate between cause and effect among these traits (Walkom & Brown, 2017). Yet it is accepted that heavier ewes and ewes in a better conditioned are expected to have an improved reproductive performance (Curnow *et al.*, 2011; Edwards *et al.*, 2011; Young *et al.*, 2011).

This study utilised a well-known South African Merino resource flock that was divergently selected for and against number of lambs weaned per lambing opportunity (NLW). Marked differences between the line selected for NLW (High or H Line) and the line selected against NLW (Low or L Line) were found for the component traits of conception and twinning rate, as well as for the composite traits number of lambs born and weaned per ewe mated (Cloete *et al.*, 2004, 2017). Lamb mortality was also recently demonstrated to differ markedly between the H and L lines (Nel *et al.*, 2021). It is unsure if these differences were related to changes in the size or body condition of the ewes in the respective lines.

Against this background, a study was designed to shed light on the effects of ewe age on reproduction, mating weight and BCS in the H and L lines. Additionally, estimate the genetic (co)variances among these traits in the resource population using single and multi-trait repeated records animal models we used. An additional objective was to derive genetic correlations of mating weight and BCS with both component and composite reproduction traits.

3.3 Materials and Methods

3.3.1 Animal resources, the environment and management

This study was conducted on the Merino resource flock that is maintained on the Elsenburg Research farm of the Western Cape Department of Agriculture over the period from 2017 to 2020. The farm (33°51'S and 18°50'E) is situated roughly 14km north of Stellenbosch in the Western Cape province of South Africa and is approximately at an elevation of 177m above sea level. The farm is situated on fairly even terrain with gentle slopes and is largely lacking trees. Minimum winter temperature is around 5°C and maximum summer temperatures around 30°C. The Western Cape of South Africa is known for its Mediterranean climate, characterised by hot, dry summers and mild, wet winters. Annual rainfall can be expected to be around 600mm.

Since 1986, Merino ewes from the same base population were divergently selected to form two distinct selection lines (Cloete & Scholtz, 1998). Maternal ranking values were used as selection criteria for and against number of lambs weaned per joining (NLW) (Turner, 1977). These lines were selected from a Merino population selected for an increased wool secondary:primary follicle ratio (Heydenrych *et al.*, 1984). The ranking values were derived as follows:

$$(\hat{G} - GO) = 0.5h^2 \times \{k/[1 + (k - 1)t]\} \times (PD - P\mu)$$

$(\hat{G} - GO)$ is the ranking value for an individual under selection, h^2 is heritability of number of lambs weaned per joining, t is repeatability of number of lambs weaned per joining, k is number of times the dam of the individual has been joined, $PD = K/k$, with K the total number of lambs weaned to the dam, and $P\mu$ is the mean number of lambs weaned per joining for the flock under consideration, for ewes up to and including the present age group of the dam. The parameters used in the above equation were obtained from the Merino flock on the Tygerhoek experimental farm. This flock was a good representation of a typical South African Merino flock at that stage (Cloete & Heydenrych, 1986).

An intuitive representation of the selection procedure would be that male and female offspring preferred as replacements in the selection line for NLW (High or H Line) would be descended from ewes rearing more than 1 lamb per joining (i.e., reared twins at least once when their offspring are available as replacements). For the selection line against NLW (Low or L Line), replacement animals were preferred to be from ewes rearing less than 1 lamb per joining (i.e., were barren or lost all lambs born, at least once in their lifetime). These selection decisions were informed by at least three or more maternal lambing opportunities in the case of males. Primarily the maternal phenotype was initially considered during the selection of individual animals, with no additional information used. Based on results reported by Cloete *et al.* (2004), single-trait repeatability model breeding values were used to supplement and later on to replace the initial ranking values based on dam performance (Nel *et al.*, 2021). Once an ewe was selected, she remained in the breeding flock for at least five joinings, except if she had teeth or udder defects or death. Thus, no selection on reproductive traits was directed at the current flock once ewes were selected. Originally, approximately 120 breeding ewes represented each selection line. As time passed the H Line was allowed to grow up to 130–180 breeding ewes, while the L Line decreased to 60–80 breeding ewes. Twenty-eight ewes born in 1991 and 1992 from a multiple ovulation and embryo transfer (MOET) programme were added to the H Line (Cloete *et al.*, 1998a). A second MOET programme resulted in both lines being supplemented by nn ewes (mm H Line and oo L Line) during the period from 2009 to 2014 (Burger, 2019). Wherever possible, male replacement animals were selected to represent all the sires present in their offspring group. The outcomes of this selection experiment is extremely well documented in literature (Cloete & Scholtz, 1998; Cloete *et al.*, 1998b, 2001, 2004; Nel *et al.*, 2021).

Ewes from both selection lines were kept in a single flock throughout the experiment. The exception to this was during joining in single-sire groups. Ewes were joined in the summer;

thus, lambing took place in winter (June–July) of the same year. Dryland lucerne and medic pastures were largely used at the research farm, although medics have in recent years been phased out. Small grain crops (mostly oats) were grazed in winter, while small grain crop residues and standing oat hay were seasonally available (spring and early summer). During joining and lambing, irrigated kikuyu paddocks were utilised (Cloete & Scholtz, 1998). Ewes were shorn before lambing annually. Ten to twenty ewes were lambed in random groups distributed over small kikuyu paddocks of 0.3–0.4 ha each (Cloete & Scholtz, 1998). Lambed ewes were joined in groups of 20–40 ewes with their lambs on 1.0 to 1.5 ha irrigated lucerne paddocks after they were allowed at least three days for the establishment of a firm dam-offspring bond (Cloete & Scholtz, 1998). As the kikuyu paddocks became depleted, these groups were joined in larger groups on dryland lucerne, medic and oat paddocks.

3.3.2 Data recording

3.3.2.1 Ewe body condition scoring (BCS)

BCS was subjectively recorded according to a linear 5-point scale graded from the leanest (1) to most fat (5) (Kenyon *et al.*, 2014). The BCS of ewes was assessed by the palpation of the lumbar region specifically on and around the backbone in the loin area, immediately behind the last rib and above the kidneys to examine the degree of sharpness or roundness (Jeffries, 1961; Phythian *et al.*, 2012). Table 3.1 denotes the scoring grades, as well as a description for each grade.

Table 3.1: The description of the condition scoring technique*

Grade	Description
Score 1	The spinous processes are prominent and sharp. The transverse processes are also sharp, with fingers passing easily under the end of the process. The eye muscle areas are shallow with little to no fat cover.
Score 2	The spinous processes are smooth but still prominent. The individual processes can still be felt but only as fine corrugations. The transverse processes are smooth and rounded. However, it is still possible to pass the fingers under the ends of the processes with some pressure. The eye muscle areas are of moderate depth but have sparse fat cover.
Score 3	The spinous processes are smooth and rounded, and individual bones can only be felt with some pressure applied. The transverse processes are also smooth and are well covered. Firm pressure is required to feel over the ends. Eye muscle area is full and covered by a moderate degree of fat.
Score 4	With pressure applied, the spinous processes can just be detected, although the ends of the transverse processes cannot be felt. Eye muscle areas are full with a thick fat cover.
Score 5	Even with firm pressure applied, the spinous processes cannot be detected. Due to a high level of fat adjacent to the spinous process, a depression directly above where the spinous processes would normally be felt may be present. It is not possible to detect the transverse processes. The eye muscle areas are very full with very thick fat cover. It is possible to have significant deposits of fat cover over the rump and tail.

*The table was adapted from Russel *et al.* (1969); Russel (1984); Kenyon *et al.* (2014).

3.3.2.2 Mating

Before the breeding season all of the animals were inspected to see if they are fit for mating, without any complications. This took place in November of each year and ewes with obvious teeth and udder malfunction were culled. Mating of the ewes generally started within the first week of January annually. At this time, ewes were weighed determining mating weight while a BCS at mating was recorded simultaneously. The rams that were used stayed with their group of ewes for a 35 day period during which each ram had 10 to 50 ewes to service. Once 35 days has passed and the rams were removed, the ewes were joined in a single flock and maintained on dryland and irrigated lucerne and kikuyu paddocks as described.

3.3.2.3 Lambing

The lambing season started at the beginning of June and lasted eight to nine weeks. Ewes were mustered one to two days before lambing and put through a crush. BCS at lambing was recorded and the ewes were separated into small groups on lambing paddocks as described previously. Each lambing paddock was inspected each morning and afternoon for new births. The number of lambs born per ewe was recorded and individual lambs weighed while lambs were identified with their dams to allow tracing back to the selection line and service sire (Cloete *et al.*, 2004).

3.3.2.4 Weaning

Weaning of the lambs took place during mid to late September when the oldest lambs were approximately 100 days of age. Number of lambs and weight of lamb weaned per ewe were documented, the latter corrected for lamb age and sex as described by Cloete *et al.* (2004). The lambs were separated from the ewes and are moved to larger lucerne camps, while the ewes were maintained on Kikuyu pastures.

3.3.2.5 Statistical analyses

The ASREML program (Gilmour *et al.*, 2015) was used to estimate fixed effects and variance components for mating weight and the condition scores in single-trait analyses. Year of lambing (2017 - 2020), selection line (H and L) and ewe age (2 - 6 years) were fitted as fixed effects. Significant effects in these preliminary analyses were retained in subsequent analyses. Random terms were then added to the operational model, resulting in the following genetic models for analyses (in matrix notation):

$$y = Xb + Z_1a + e \quad (1)$$

$$y = Xb + Z_1a + Z_2c_{ewe} + e \quad (2)$$

Where: y was a vector of observations for ewe traits, b , a and c_{ewe} were vectors of fixed effects, direct genetic effects and ewe permanent environmental effects respectively. Vectors X , Z_1 , and Z_2 denoted the corresponding incidence matrices relating the respective effects to y , while e was the vector of randomly distributed residuals that summed to zero.

It was assumed that:

$$V(a) = A\sigma_a^2; V(c_{PE}) = I\sigma_{ewe}^2; V(e) = I\sigma_e^2,$$

Where: A was the numerator relationship matrix, I an identity matrix; σ_a^2 , σ_{ewe}^2 and σ_e^2 the direct genetic variance, the ewe permanent environmental variance and the environmental (residual) variance respectively. All analyses included the full pedigree file, consisting of 4351 individuals, the progeny of 216 sires and 1107 dams.

The random effects fitting the data best for each trait were identified, using the log likelihood ratios obtained from the respective analyses (Snyman *et al.*, 1996). Subsequently, a three-trait animal model was fitted to all traits. All relevant genetic and ewe permanent environmental correlations (where applicable) were derived from these analyses, together with the relevant standard errors (Gilmour *et al.*, 1995). Further analyses estimated genetic correlations of mating weight and condition scores with ewe reproduction traits. Detailed information on the analyses of reproduction traits are not provided, since it was previously reported on larger databases (Cloete *et al.*, 2004, 2017). In additional analyses, reproduction outcomes were related to specific BCS classes to assist in the interpretation of some results.

Finally, ethical clearance for the study was obtained from the Stellenbosch University ethical committee; with clearance number ACU-2020-12955.

3.4 Results

3.4.1 Descriptive statistics

For the Elsenburg Merino flock between 2017 to 2020, 1031 repeated mating weight records, 776 body condition scores taken at mating and 1024 body condition scores at lambing were available (Table 3.2). The average mating weight of the ewes were 49.1 kg with a 7.8 kg standard deviation and a range of between 21.0 and 75.5 kg. The average BCS of ewes at mating was 2.38 with a standard deviation of 0.72 and a range of 1 to 5. Corresponding values at lambing were 2.28, 0.73 and 1 to 4.5. Coefficients of variation were below 20% for mating weight and higher than 30% for the conditions scores.

Table 3.2: Descriptive statistics for mating weight, body condition score at mating and body condition score at lambing for the Elsenburg Merino flock.

Trait	n	Mean	SD	CV (%)	Range
Mating weight (kg)	1031	49.1	7.8	15.8	21.0-75.5
Body condition score at mating (n)	776	2.38	0.72	30.3	1-5
Body condition score at lambing (n)	1024	2.28	0.73	31.9	1-4.5

n: Number of records
SD: Standard deviation
CV % : Coefficient of variation
kg: Kilogram

3.4.2 Environmental effects denoted by predicted fixed effect means

Selection line had a significant effect on ewe mating weight, H Line ewes being 7.6% heavier than their L line contemporaries at mating (50.8 vs. 47.2 kg; $P < 0.01$; Table 3.3). Body condition scores at mating and lambing were however independent of selection line ($P > 0.10$).

Lambing year had a significant ($P < 0.05$) effect on all the traits in the study (Table 3.3). The ewes were about 2.8 kg lighter in 2020 than during the other years at mating (Table 3.3). Body BCS at mating was lowest during 2019, followed by 2020 with 2017 having the highest body condition score. BCS at lambing was the lowest for 2020, followed by 2019 with 2017 and 2018 having the highest means.

Table 3.3: Predicted means \pm SE of the fixed effects fitted for ewe mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Merino flock.

Effects and level	Mating weight (kg)	Body condition score at mating (n)	Body condition score at lambing (n)
Selection line			
High-line	50.8 \pm 0.2 ^B	2.68 \pm 0.02	2.41 \pm 0.02
Low-line	47.2 \pm 0.4 ^A	2.67 \pm 0.04	2.33 \pm 0.04
P-value	0.001	0.21	0.12
Year			
2017	49.7 \pm 0.41 ^B	2.94 \pm 0.04 ^C	2.61 \pm 0.05 ^C
2018	49.9 \pm 0.05 ^B	-	2.68 \pm 0.05 ^C
2019	49.4 \pm 0.40 ^B	2.45 \pm 0.04 ^A	2.36 \pm 0.04 ^B
2020	46.8 \pm 0.40 ^A	2.63 \pm 0.04 ^B	1.83 \pm 0.04 ^A
P-value	0.001	0.001	0.001
Ewe age			
2	41.1 \pm 0.50 ^A	2.49 \pm 0.04 ^A	2.16 \pm 0.05 ^A
3	48.4 \pm 0.50 ^B	2.71 \pm 0.04 ^B	2.42 \pm 0.05 ^{BC}
4	51.2 \pm 0.50 ^C	2.77 \pm 0.05 ^B	2.53 \pm 0.05 ^C
5	51.9 \pm 0.50 ^C	2.65 \pm 0.06 ^B	2.45 \pm 0.06 ^{BC}
6+	51.9 \pm 0.60 ^C	2.75 \pm 0.05 ^B	2.29 \pm 0.06 ^{AB}
P-value	0.001	0.001	0.001

^{ABC} – Means with different superscripts are significantly different ($P < 0.05$)

n: Number of records

kg: Kilogram

Ewe age also had a pronounced effect on all the traits studied (Table 3.3). Four-year-old and older ewes were heavier compared to their younger counterparts. Two-year-old ewes were the lightest, with three-year olds being intermediate between the two-year-old and ewes older than three years (all $P < 0.05$). The BCS at mating was only different for the two-year old ewes, being lower compared to all the older age groups. Two- and six-year-old ewes had lower body condition scores at lambing compared to four-year old ewes ($P < 0.05$). Ewes in the three-, five- and six-year age groups had a similar BCS at lambing. Means were also similar for three-, four- and five-year-old ewes ($P > 0.05$).

The next objective was to investigate the effect of selection line on the age trends for BCS in the Elsenburg Merino flock (Figure 3.1). BCS at mating trended lower ($P < 0.10$) at two-year-old in the L Line compared to the H Line (Figure 3.1a). After an increase in BCS at mating from two- to three-year-old ewes ($P < 0.05$) in both the L and H Lines, no further increase or line differences were observed. BCS at lambing increased from two- to three-year-old ewes in both lines ($P < 0.05$), with no line differences at two and three years (Figure 3.1b). BCS at lambing subsequently stabilised at the higher levels in the H Line. In contrast, BCS at lambing

trended lower in the L Line for ewes aged 5 years and older, the line difference in favour of the H Line being significant ($P < 0.05$) in ewes aged 6 years.

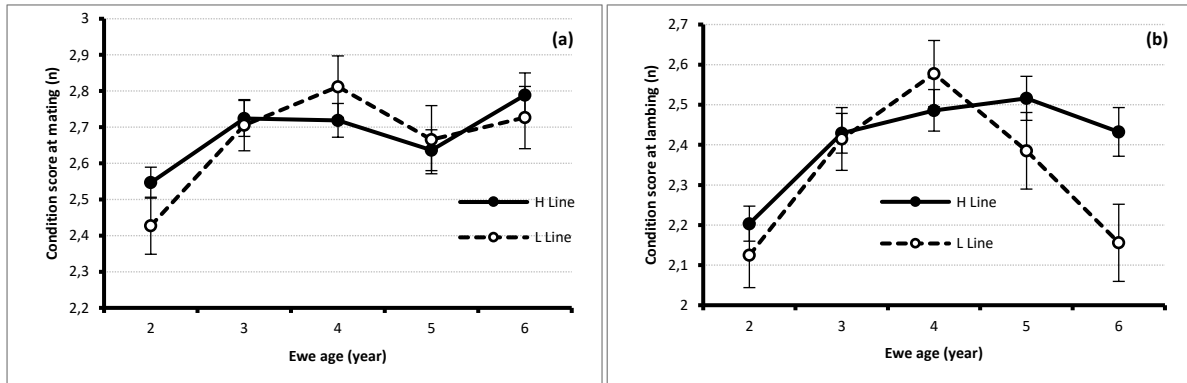


Figure 3.1: Line graphs representing the effect of ewe age on body condition score at mating (a) or at lambing (b) for the High (H) and Low (L) selection lines of the Elsenburg Merino flock (SE's are around means).

Figure 3.2 is a line graph that displays age trends in condition scores at mating in ewes that were either barren or conceived, irrespective of selection line. At two years of age, barren ewes tended to have a lower condition score. Two-year-old ewes that conceived had an average BCS of 2.5. For three- and four-year-old ewes, average BCS were independent of conception status. Average BCS at mating trended higher ($P < 0.05$) in barren ewes aged five and six years than in ewes that conceived. The graph clearly illustrates that barren older ewes presented with BCS higher than 2.8 at mating. In contrast, BCS at mating of ewes that conceived were consistently between 2.6 and 2.8.

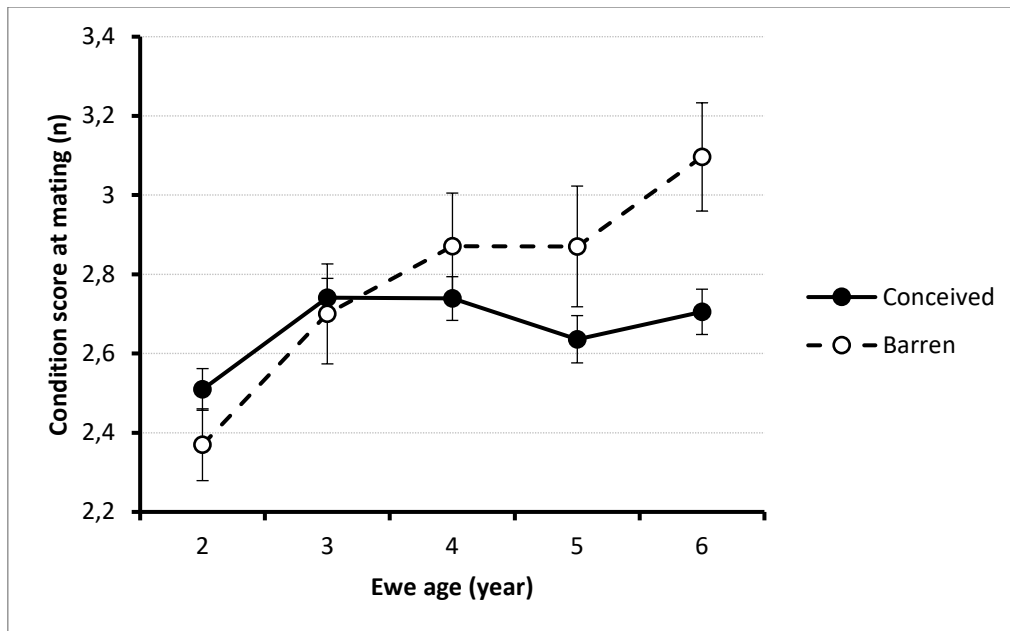


Figure 3.2: A line graph representing the effect of ewe age and body condition score at mating in ewes that were either barren or conceived across selection lines in the Elsenburg Merino flock (SE's are around means).

3.4.3 Genetic analyses

3.4.3.1 Log likelihood values

Table 3.4 summarise the log likelihoods for random effects in single-trait models fitted to mating weight, BCS at mating and BCS at lambing. The random effects fitted to these traits indicated that Model 1 (with direct genetic effects as the only random term) was the best model for mating weight as well as for BCS at mating (Table 3.4). In contrast, Model 2 (incorporating direct genetic and ewe permanent environmental effects) fitted the data best for BCS at lambing (Table 3.4).

Table 3.4: The log likelihood ratios for random effect models fitted to mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Merino flock. The best model in bold.

Model	(Co)variance components	Mating weight	Body condition score at mating	Body condition score at lambing
Operational model	Fixed effects	-2401.400	73.807	-64.612
1	+ h^2	-2143.530	91.793	-19.841
2	+ h^2 + PE	-2142.860	91.980	-16.625

3.4.3.2 Single- and multi-trait heritability estimates

Table 3.5 summarise the single-trait variance components and ratios for mating weight as well as for condition scores at mating and at lambing. All three traits analysed were moderately-highly heritable. The h^2 of mating weight was high at 0.74 (Table 3.5). The h^2 of BCS at mating and BCS at lambing ranged from 0.18 to 0.28 (Table 3.5). In contrast to results for mating weight and BCS at mating, where the animal permanent environmental effect was excluded, the log likelihood values in Table 3.4 indicated that the animal permanent environmental effect should also be modelled for BCS at lambing. The corresponding variance ratio amounted to 0.15, resulting in a repeatability of 0.34 (Table 3.5).

Table 3.5: Single trait variance components and ratios \pm SE for mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Merino flock.

Single trait	Mating weight	Body condition score at mating	Body condition score at lambing
Variance components			
Additive (σ^2_a)	32.331	0.0813	0.0722
Animal PE (σ^2_{PE})	-	-	0.0603
Phenotype (σ^2_P)	43.885	0.2932	0.3954
Variance ratios			
Heritability (h^2)	0.74 \pm 0.02	0.28 \pm 0.05	0.18 \pm 0.07
Animal PE (pe^2)	0.000	0.000	0.15 \pm 0.06
Repeatability (t)	0.74 \pm 0.02	0.28 \pm 0.05	0.34 \pm 0.04

Table 3.6 presents the three-trait analysis for mating weight, BCS at mating and BCS at lambing. In the three-trait analysis the heritability estimates were 0.74 for mating weight 0.28 for BCS at mating and 0.33 for BCS at lambing (Table 3.6). In this analysis, the variance attributed to the animal permanent environment for BCS at lambing repartitioned to the direct genetic effect, resulting in a heritability of 0.33 instead of the value of 0.18 reported in Table 3.5. The phenotypic variance components in the three-trait analysis were 43.77 for mating weight, 0.2967 for BCS at mating and 0.4148 for BCS at lambing (Table 3.6).

Mating weight was highly correlated to the condition scores of the ewes, the genetic correlations amounting to 0.58 for BCS at mating and 0.65 for BCS at lambing (Table 3.6). The corresponding phenotypic correlations amounted to respectively 0.43 and 0.38. At 0.93,

the genetic correlation between the two condition scores did not differ from unity, but the corresponding phenotypic correlation amounted to 0.35.

Table 3.6: Three trait (co)variance components and ratios \pm SE for mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Merino flock.

Trait	Mating weight (kg)	Body condition score at mating (n)	Body condition score at lambing (n)
h^2 on diagonal and r_g below diagonal			
Mating weight	0.74 \pm 0.02		
Body condition score at mating	0.58 \pm 0.08	0.28 \pm 0.05	
Body condition score at lambing	0.65 \pm 0.06	0.93 \pm 0.07	0.33 \pm 0.04
σ_p^2 on diagonal r_E above diagonal and r_P below diagonal			
Mating weight	43.77	0.37 \pm 0.04	0.14 \pm 0.04
Body condition score at mating	0.43 \pm 0.03	0.2967	0.09 \pm 0.04
Body condition score at lambing	0.38 \pm 0.03	0.35 \pm 0.03	0.4148

n: Number of records

kg: Kilogram

r_e: Environmental correlation

r_g: Genetic correlation

r_P: Phenotypic correlation

σ_p^2 : Total phenotypic variance

h²: Direct additive heritability

3.4.3.3 Genetic correlations with reproduction traits

Table 3.7 presents the estimated correlations for mating weight with reproductive traits. The only genetic correlation that reached significance was the estimate of -0.26 with number of ewes conceived per ewe mated. The genetic correlation of mating weight with ewe rearing ability per ewe lambled was also sizable at -0.20. It should be noted that all environmental correlations of mating weight with reproductive traits were positive ($P < 0.05$), indicating that an environment favouring mating weight will also favour an increased reproductive performance. Phenotypic correlations oscillated around zero and were not significant ($P > 0.05$), barring the correlations with twinning rate and total weight weaned.

Table 3.7: Estimated correlations of ewe mating weight with number of ewes conceived, number of lambs born, twinning percentage, ewe rearing ability, number of lambs weaned, and total weight weaned in the Elsenburg Merino flock.

Correlated traits	r_g	r_E	r_P
Ewes conceived/Ewe mated	-0.26 ± 0.10	0.10 ± 0.04	-0.06 ± 0.04
Number of lambs born/Ewe mated	-0.03 ± 0.11	0.14 ± 0.04	0.05 ± 0.04
Twinning percentage/Ewe lambled	0.06 ± 0.10	0.14 ± 0.04	0.09 ± 0.04
Ewe rearing ability/Ewe lambled	-0.20 ± 0.12	0.09 ± 0.04	-0.02 ± 0.04
Number of lambs weaned/Ewe mated	-0.05 ± 0.12	0.13 ± 0.04	0.05 ± 0.04
Total weight weaned/Ewe mated	0.06 ± 0.11	0.13 ± 0.04	0.08 ± 0.04

r_e : Environmental correlation

r_g : Genetic correlation

r_p : Phenotypic correlation

The genetic correlations of ewe BCS at mating with the reproductive traits analysed were all negative in absolute direction (Table 3.8). The genetic correlations involving the number of ewes that conceived per ewe mated, number of lambs born per ewe mated and twinning rate per ewe lambled were significant ($P < 0.05$), as indicated by a magnitude of more than double the corresponding standard error. As with correlations involving mating weight, all environmental correlations, barring the correlation with ewe conception rate and rearing ability/ewe lambled, were positive ($P < 0.05$). This result again served to demonstrate that an environment that would lead to a higher BCS would also be conducive to a better reproduction rate. Phenotypic correlations were variable in sign, small in magnitude and not significant ($P > 0.05$).

Table 3.8: Estimated correlations of body condition score at mating with the number of ewes conceived, number of lambs born, twinning percentage, ewe rearing ability, the number of lambs weaned, and the total weight weaned in the Elsenburg Merino flock.

Correlated traits	r_g	r_E	r_P
Ewes conceived/Ewes mated	-0.38 ± 0.18	0.06 ± 0.05	-0.04 ± 0.04
Number of lambs born/Ewes mated	-0.51 ± 0.19	0.14 ± 0.05	-0.00 ± 0.04
Twinning percentage/Ewes lambled	-0.46 ± 0.20	0.15 ± 0.05	0.02 ± 0.04
Ewe rearing ability/ Ewes lambled	-0.16 ± 0.21	0.07 ± 0.05	0.03 ± 0.04
Number of lambs weaned/Ewes mated	-0.30 ± 0.20	0.13 ± 0.05	0.04 ± 0.04
Total weight weaned/Ewes mated	-0.13 ± 0.17	0.11 ± 0.05	0.05 ± 0.04

r_e : Environmental correlation

r_g : Genetic correlation

r_p : Phenotypic correlation

The genetic correlations of ewe BCS at lambing with the reproductive traits analysed were all negative in sign and variable in magnitude (Table 3.9). Only the correlation for the

number of ewes that conceived per ewe mated reached significance ($P < 0.05$), as the correlation was more than double the standard error. In contrast with results on mating weight and ewe BCS at mating all environmental correlations were also negative, barring correlations with ewe rearing ability and total weight weaned. This finding seemed to suggest that an environment favouring subsequent reproduction would be associated with a lower BCS at lambing. Accordingly, phenotypic correlations were also negative with the same exceptions as for the environmental correlations.

Table 3.9: Estimated correlations for body condition score at lambing with the number of ewes conceived, number of lambs born, twinning percentage, ewe rearing ability, the number of lambs weaned, and the total weight weaned in the Eisenburg Merino flock.

Correlated traits	r_g	r_E	r_P
Ewes conceived/Ewes mated	-0.39 ± 0.12	-0.14 ± 0.04	-0.20 ± 0.03
Number of lambs born/Ewes mated	-0.22 ± 0.13	-0.27 ± 0.04	-0.25 ± 0.03
Twinning percentage/Ewes lambing	-0.05 ± 0.14	-0.26 ± 0.04	-0.20 ± 0.03
Ewe rearing ability/ Ewes lambing	-0.18 ± 0.15	-0.02 ± 0.04	-0.05 ± 0.04
Number of lambs weaned/Ewes mated	-0.13 ± 0.15	-0.15 ± 0.04	-0.14 ± 0.03
Total weight weaned/Ewes mated	-0.07 ± 0.14	-0.07 ± 0.04	-0.07 ± 0.04

r_e : Environmental correlation

r_g : Genetic correlation

r_p : Phenotypic correlation

The consistently unfavourable genetic correlations of condition scores with ewe conception rate (Tables 3.8 and 3.9) warrant further attention. Overall age trends on ewes that conceived or were barren revealed that the average BCS of two-year-old ewes that conceived trended higher ($P < 0.10$) than that of ewes that were barren. In contrast, barren ewes aged five years and older had higher condition scores at mating than their contemporaries that conceived (Figure 3.2). This result appeared to be primarily driven by the trend observed in the H line (Figure 3.3a), where the BCS of barren two-year-old ewes averaged 8.5% lower ($P < 0.05$) than in two-year-old ewes that conceived. After a significant increase from two to three years of age ($P < 0.05$), no further increase in the BCS of lambing H Line ewes were observed with age. In contrast, the condition scores of barren ewes exceeded those of ewes that conceived by 19.7% in five-year-old ewes and by 17.7% in six-year-old ewes. The BCS at mating of L Line ewes that conceived also increased from two- to three-year-old ewes ($P < 0.05$; Figure 3.3b), but the trend for barren ewes was more variable. The difference in favour of barren ewes for BCS at mating in five-year-old dams also approached significance by 11.2% ($P < 0.10$), but no conclusive differences were found ($P > 0.05$).

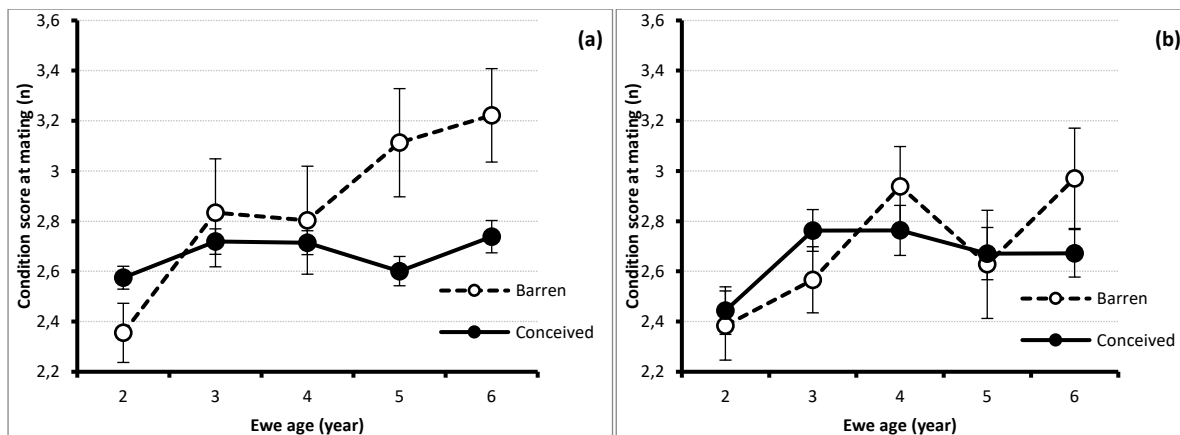


Figure 3.3: Line graphs representing the effect of ewe age of ewes that were either barren or conceived on body condition score at mating in the H Line (a) or in the L Line (b) of the Elsenburg Merino flock (SE's are around means).

When BCS at lambing was related to ewe conception rate (Figure 3.4a) and number of lambs weaned per ewe mated (Figure 3.4b) it was evident that ewes at a BCS of two performed best in the H Line. High Line ewes in the best condition category of 4+ had a worse performance for both traits than those scored 2 and 3 ($P < 0.05$). In the L Line, ewe conception rate also declined above a score of 2, substantially at a score of 4+ ($P < 0.05$). In contrast, number of lambs weaned in the L Line was less markedly affected by ewe BCS at lambing, with only the difference between a score of 3 and of 4+ reaching significance (Figure 3.4b; $P < 0.05$). The marked line differences in reproduction between the H and L lines were evident at all condition scores, with no conclusive line difference in conception rate at a BCS at lambing of one the only exception.

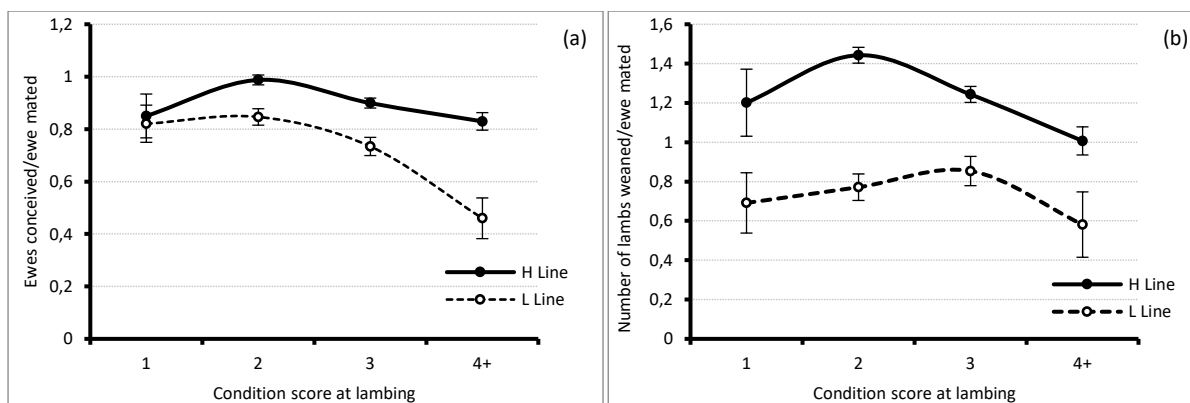


Figure 3.4: Line graphs representing the effect of body condition score at lambing on ewes conceived per ewe mated (a) and on number of lambs weaned per ewe mated (b) in the Elsenburg Merino flock (SE's are around means).

3.5 Discussion

3.5.1 Descriptive statistics

The average mating weight of the ewes were 49.1 kg with a 7.8 kg standard deviation and ranged between 21.0 and 75.5 kg. Cloete *et al.* (2004) reported ewe joining weight of the same flock to be above 60 kg during 1987 and 1988; between 1989 and 2001 it oscillated between 50 and 55 kg, before declining to 45 kg in 2002. Brown & Swan (2014) reported a standard deviation of 12.3 kg in their study. The average BCS of ewes at mating was 2.38 with a standard deviation of 0.72 and a range of 1 to 5. Corresponding values at lambing were 2.28, 0.73 and 1 to 4.5. Kenyon *et al.* (2004) reported an average BCS of 2.52 and 2.80 for two different flocks. Coefficients of variation were below 20% for mating weight and higher than 30% for the conditions scores. All these descriptive statistics agree with literature.

3.5.2 Environmental effects denoted by predicted fixed effect means

The higher body weight of H line ewes relative to their L Line contemporaries could be the result of intense selection within this flock for and against reproduction. The studies of Cloete & Scholtz (1998); Cloete *et al.* (2004; 2009; 2017) and Nel *et al.* (2021) indicate a number of traits that were significantly different between these two selection lines. As body weight has not been a primary selection objective during selection for reproduction, it can be

concluded that the line difference in mating weight resulted from a correlated response to selection. This reasoning seems to contrast the results of Table 3.7, which suggests general negative genetic correlations between mating weight and reproductive traits. In contrast, support for a correlated response in body weight stemming from selection on number of lambs weaned stems from the paper by Cloete *et al.* (2005). This paper reported that body weight at yearling age diverged in the selection lines, H line yearlings becoming heavier and L Line yearlings lighter. This line difference was carried through to mature ewes for their first two mating opportunities, after which line differences became smaller and disappeared (Cloete *et al.*, 2003). The latter authors ascribed the latter trend to the increased burden placed on mature H Line ewes by the demands of pregnancy and lactation as they grew older. In contrast to body weight, selection line did not affect BCS at mating or at lambing. An exhaustive slaughter study on yearlings of the two lines accordingly did not report significant line differences in the subcutaneous fat depth of the two lines (Cloete *et al.*, 2021). Due to the difference in skeletal size between the ewes of each selection line (Cloete *et al.*, 2005), body weight alone cannot indicate the degree of fatness of an animal. BCS is an estimation of muscle and fat development of an animal and is linked with the direct measurement of back fat depth or the amount of fat in the animal. BCS thus provides a more succinct estimate of the condition of an animal compared to body weight alone (Russel *et al.*, 1969; Sanson *et al.*, 1993). As the animals within this trial were managed as one flock it is to be expected that the condition of ewes would be similar, if not affected by the selection regime.

Lambing year had a significant effect on all of the traits in this study (Table 3.3). Year-to-year variation in body weight and condition depends on the unique conditions provided by climatic conditions and managerial decisions and are unlikely to be repeatable (Blumer *et al.*, 2015). Such changes are not necessarily in the same direction each year. According to Kenyon *et al.* (2014) the subsequent change in grazing potential from year-to-year would affect the body weight and condition of the ewe at mating, lambing and during lactation, since these production phases can rely on the ewe's body condition.

As can be seen in Table 3.3, the age of the ewe had a significant ($P < 0.05$) effect on all traits under investigation. There was an increase in body weight and condition scores as ewes aged, but both traits tended to stabilise at older ages. These results were in line with findings of Rose *et al.* (2014) in Australian Merinos, Semakula *et al.* (2020) in Romney ewes and Aktaş *et al.* (2015), who studied Central Anatolian Merino sheep. This age trend is due to the two-year-old ewes still being in a growth phase before the attainment of maturity (Rose *et al.*, 2014). Snyman *et al.* (1996) also reported very low body weights for 18-month-old Merino ewes. The literature reported a decline in BCS with an increase in age at mating for Merino

and Corriedale ewes (Gonzalez *et al.*, 1997 in). The results reported in the current study are contradictory to these literature sources; with two-year-old ewes having the poorest BCS at mating. However, the results of this study are well in alignment with those of Mchugh *et al.* (2019), who reported an increase in ewe condition scores as the age of an ewe increased across all stages of the annual production cycle in mature mixed sheep breeds as well as in crossbred ewes.

Generally, the selection lines followed the same trend for condition scores at mating and lambing (Figure 3.1), with a few exceptions, namely a tendency towards a better condition of two-year-old H Line ewes at mating and a poorer condition at lambing in six-year-old L Line ewes. These results are in general agreement with literature involving Merino and Corriedale ewes (Gonzalez *et al.*, 1997). The latter authors reported that ewe BCS increased with age at mating, lambing, and the weaning of their lambs. As in the current study, condition scores reached a plateau later in life. This plateau was achieved at around 3 years in the current study (Figure 3.1), in comparison to around 55 months of age, or around 4-5 years, in the study by Gonzalez *et al.* (1997). The only obvious benefit of having a better BCS at mating was for conception rate of two-year-old H line ewes (Figure 3.3a), a finding that was not consistent with the L Line (Figure 3.3b). In older ewes, there was strong evidence of a reduced reproduction in ewes with an increased BCS at mating (Figures 3.2), particularly in the H Line (Figure 3.3). These trends are difficult to explain, given a lack of significant line effects in subcutaneous fat depth in yearling (Cloete *et al.*, 2021) or hogget (Cloete *et al.*, 2005) slaughter animals. The line difference at six years of age for BCS at lambing is even more difficult to explain, as it was thought that the generally lower reproduction of L Line ewes would allow them to maintain better condition scores later in life, analogous to the opposite effect in body weight in the study of Cloete *et al.* (2003). It is feasible that the lower ewe numbers in the L Line could have resulted in more spurious results when compared to the H Line, which is represented by more ewes. However, it is clear that more research on this topic is warranted.

Across selection lines, BCS at mating trended ($P < 0.10$) lower in barren two-year-old ewes than in two-year-old ewes that conceived (Figure 3.2). This result seems to be mainly related to the trend in the H Line in Figure 3.3a. Such a difference seems reasonable, as two-tooth ewes in a positive energy balance (with BCS serving as a proxy) seems more likely to conceive (Esmailzadeh *et al.*, 2009). On the contrary, the reduced conception and weaning rates at a BCS of 4+ at mating likely reflects the impact of a minority of ewes subject to repeated reproductive failure. It should not be surprising that these ewes should be fatter with an increased BCS (Walkom *et al.*, 2014a), and also considering the low-moderate repeatability of conception rate and lamb weaning rate in sheep (Cloete & Heydenrych, 1987; Bromley *et*

al., 2000). This is a more than likely explanation for the trends in Figure 3.4 that were fairly consistent across lines. The higher BCS of barren five- and six-year-old ewes is consistent with results from Yilmaz *et al.* (2011), who studied Kiviricik sheep. In the latter study it was found that a BCS of between 2.0 and 3.0 had the highest rates of pregnancy (optimal), while condition scores above 3.5 would lead to a reduced pregnancy rate. Atti *et al.* (2001) also reported that fat-tailed Barbarine ewes with a higher BCS were less likely to fall pregnant and produce a lamb than ewes in an intermediate body condition. A study on Ossimi ewes reported that ewes with a BCS of 1.5 and lower as well as those with condition scores of 3.5-4.0 and higher did not exhibit oestrus (Abdel-mageed, 2009). From the present results as well as the literature stated it is reasonable to contend that mature ewes with high BCS at mating could be compromised as far as reproductive output is considered, an assertion borne out by Figure 3.4. In accordance, Bocquier *et al.* (1993) reported that excessive fat accumulation in ewes (higher body condition scores) had deleterious effects on their oestrus activity.

The current study indicates that low condition scores at mating of two-year-old ewes are associated with lower conception and thus, reproduction potential. The reason for the lowered conception rate in ewes with low body conditions might be the reduced gonadotrophin releasing hormone (GnRH) production in undernourished ewes, which will affect the pre-ovulatory luteinizing hormone (LH) surge, fertilization and early embryonic development (Schneider, 2004; Wade & Jones, 2004). From the literature, it is expected that two-year-old ewes would more likely to be barren than their older counterparts (Turner & Dolling, 1965; Mullaney & Hyland, 1967; Mullaney & Brown, 1969; Cloete & Heydenrych, 1986), resulting in an increased benefit of a positive energy balance on conception. However, it is unclear whether older ewes have a higher BCS because of not conceiving or if they do not conceive because they have higher condition scores. Figures 3.2 and 3.3a clearly illustrated that older ewes with a BCS at mating higher than 2.8 were more likely to be barren. These graphs also illustrate that the target BCS at mating, irrespective of age, should be between 2.6 and 2.8; with only well-conditioned two-year-old benefiting from mean condition scores below 2.6.

3.5.3 Genetic analysis

3.5.3.1 Log likelihood values

The log likelihood values for random effects models fitted to mating weight, BCS at mating as well as BCS at lambing indicated that direct genetic effects were important for all

traits. In fact, the animal permanent environmental variance for BCS at lambing also repartitioned to additive effects in the three-trait model involving condition scores and mating weight. The study of Cloete *et al.* (2004) also reported log likelihood values for random effects models to mating weight on the same flock of sheep only using a much larger data set. Their results indicated that ewe permanent environment also needs to be included in the model for mating weight, as this would lead to a model with a better fit. The number of records in the present study probably contributed to a reduced ability to partition animal and animal permanent environmental variances.

It need to be stated that these results were consistent with the literature, as Brown & Swan (2014) reported variation with regards to ewe BCS during the same year. Atti *et al.* (2001) and Saul *et al.* (2011) reported a very different distribution of ewes with regard to body condition scores between years. They postulated that this was a result of poor nutrition, which resulted in ewes having a low body weight and BCS (Atti *et al.*, 2001). This can be driven by the varying energy demands of ewes which results from changes in stocking rate and supplementary feeding (Hatcher *et al.*, 2011). Walkom *et al.* (2014a) reported that seasonal and year effects on feed supply, thereby having the greatest influence on fluctuations in weight and fat. The production environment and the stress of reproduction markedly influence on the weight and condition of the breeding ewe (Walkom *et al.*, 2014c, b). Vatankhah *et al.* (2012) and Thompson *et al.* (2011) attributed this variation to the nutritional status of the animal. Pregnant breeding ewes lose condition during the last trimester of pregnancy and during lactation because nutritional demands exceed the ewe's physical ability to consume feed (Walkom *et al.*, 2014c). During times when pasture is plentiful, ewes can gain weight and condition, while during harsh conditions she will rely on her body reserves to meet her reproductive demands (Walkom *et al.*, 2014c). Environmental variation was a major influence on the fluctuation in weight and fat across time (Walkom *et al.*, 2014a). The latter authors also stated that autumn-joined ewes were lighter at joining than their spring-joining flock mates. They also experienced greater fluctuations in weight, most likely stemming from differences in seasonal pasture supply (Walkom *et al.*, 2014a). Annual variation in rainfall and pasture growth is most likely the key drivers of variation in environmental effects reflected as differences among years, with age and thus the growth stage of the animal also accounting for a large proportion of the environmental variation.

3.5.3.2 Single- and multi-trait heritability estimates as well as correlations for and among body weight and condition scores

All three traits analysed in this study were moderately to highly heritable. The heritability of mating weight was high at 0.74 when using a model that only included the direct genetic effect (Table 3.5). The literature accordingly reports heritability estimates for body weight at mating varying from 0.70 to 0.78 (Brown & Swan, 2014; Rose *et al.*, 2014). The study of Safari *et al.* (2005) reported a much lower heritability of 0.41 for wool breeds. It is thus reasonable to conclude that the present estimate is consistent with other studies, suggesting our dataset is appropriate to study correlations between mating weight and reproductive traits. In a previous study on the same flock Cloete *et al.* (2004) reported the heritability of mating weight as 0.48, with an animal PE variance ratio of 0.27. When summed to a repeatability of 0.73, this between-ewe variance ratio is consistent with the present heritability estimate. Current-flock gains, as well as genetic improvement in mating weight are therefore highly achievable. It has to be remembered however that a heavier ewe will have an increased maintenance requirement (Freer *et al.*, 1997; Walkom *et al.*, 2014b). It might thus not be economical to select for excessively large (heavy/fat) ewes.

The phenotypic variation in the three-trait analysis in the current study for mating weight amounted to 43.77 (Table 3.6). This value is at the higher end of the range between 36.26 and 41.53 for the phenotypic variance of mating weight in the literature (Brown & Swan, 2014; Walkom *et al.*, 2014b). The phenotypic variance of BCS at mating in this study is 0.30. The phenotypic variance of pre-joining BCS varied between 0.239 and 0.266 in an Australian study (Bunter *et al.*, 2019). Walkom *et al.* (2014b) accordingly reported a phenotypic variance of 0.55 for pre-joining condition score. The phenotypic variance for BCS at lambing was higher at 0.42 in this study. Walkom *et al.* (2014b) accordingly reported a phenotypic variance component of 0.48 for BCS during mid pregnancy and of 0.59 for BCS at weaning. The derived parameters were thus generally consistent with expectations based on the literature results. The tendency of higher phenotypic variance components for BCS during pregnancy in the present study, as well as in the literature, is not surprising. Condition scores of dry ewes at mating are not expected to be impacted on by the demands of pregnancy as well as by variation in lambing dates as experienced in those ewes assessed at lambing.

The heritability estimates of BCS at mating for this study were moderate at 0.28 (Table 3.5). An Australian study reported a slightly lower heritability of 0.15 for BCS at joining (Brown & Swan, 2014). Bunter *et al.* (2020) accordingly reported the heritability for condition score, irrespective of production stage, as 0.20 in Merinos. It was also reported that the heritability

for pre-joining BCS were 0.18 (Bunter *et al.*, 2019). Linked to a coefficient of variation exceeding 30%, it is clear that BCS at mating would respond positively to directed selection.

In contrast to BCS at mating, the best single-trait model for BCS at lambing also included the animal permanent environment (PE). Heritability was estimated at 0.18 and the animal PE variance ratio amounted to 0.15, resulting in a repeatability of 0.34 (Table 3.6). This heritability of BCS is consistent with estimates ranging from 0.15 to 0.20 in the Australian literature (Brown & Swan, 2014; Bunter *et al.*, 2019; 2020). It is reasonable to assume that the ewe permanent environment would be more prominent at lambing because of variation attributable to pregnancy status and stage of gestation, which is not applicable to BCS at mating. The heritability estimates for mating weight and condition scores reported are fairly accurate despite the limited number of records. This is possibly a testimony to the higher levels of genetic variation in these traits compared to reproductive traits.

Genetic correlations of mating weight with BCS at mating of 0.58 and with BCS at lambing of 0.65 indicated a high genetic correlation of frame size with fatness. Brown & Swan (2014) reported genetic correlations of mating weight with BCS at mating and lambing to be respectively 0.65 and 0.63. The results obtained in this study are thus in general agreement with this literature source. Corresponding phenotypic correlations amounted to respectively 0.43 and 0.38 between mating weight and BCS at mating and at lambing in this study. Comparable correlations in mature Australian Merinos amounted to respectively 0.32 and 0.40 (Brown & Swan, 2014). Walkom *et al.* (2014b) reported a phenotypic correlation of 0.33 between mating weight and pre-joining BCS of mature crossbred ewes. The same authors reported a phenotypic correlation between weight and condition scores during mid pregnancy as well as at weaning of their lambs at respectively 0.25 and 0.46 (Walkom *et al.*, 2014b). At 0.93, the genetic correlation between the two condition scores did not differ from unity, but the corresponding phenotypic correlation amounted to only 0.35. Our results are in general agreement with the results cited from the literature.

3.5.3.3 Genetic correlations with reproduction traits

Apart from the significant unfavourable genetic correlation of -0.26 between mating weight and ewe conception rate, other genetic correlations of reproduction traits with mating weight rarely exceeded an absolute value of 0.10. Walkom & Brown (2017) reported genetic correlations of respectively 0.17 and -0.08 of joining weight with pregnancy scanning outcome and fertility. Corresponding genetic correlations amounted to 0.36 for fecundity, -0.07 for number of lambs weaned and -0.21 for litter survival. Huisman & Brown (2009) reported

genetic correlations with adult mating weight to be 0.02 for the number of lambs born and -0.01 for the number of lambs weaned. These weak/negative genetic correlations of reproductive traits with mating weight suggest that, mating weight is of limited use as an indirect genetic indicator for reproductive traits. Safari *et al.* (2005) derived a genetic correlation of 0.15 for adult ewe weight with number of lambs born per ewe joined from the existing ovine literature, and a 0.40 genetic correlation of adult ewe weight with fertility. The Cloete *et al.* (2004) paper reported genetic correlations with mating weight of 0.13 for number of lambs born (NLB), 0.41 for number of lambs weaned (NLW) and 0.81 for total weight weaned (TWW).

On a phenotypic level this study only reported negative correlations for ewes conceived per ewes mated (-0.06) and ewe rearing ability (-0.02) with ewe mating weight, with positive phenotypic correlations with NLB (0.05), twinning percentage (0.09), NLW (0.05) and TWW (0.08) per ewe mated (Table 3.7). Walkom & Brown (2017) reported a negative phenotypic correlation of mating weight with fertility (-0.01), number of lambs weaned (-0.01) and litter survival (-0.03), and positive correlations for pregnancy scan (0.03), Fecundity (0.07) and NLB (0.03). These results are in general alignment. All the environmental correlations of mating weight with reproductive traits were positive, indicating that during this study an environment favouring mating weight will also favour and increase the reproductive performance of the ewes. These results could not be verified against the available literature.

Genetic correlations of ewe BCS at mating with the reproduction traits investigated were all negative in direction and significant for conception rate, number of lambs born and twinning rate (Table 3.8). Walkom *et al.* (2016) reported a generally similar pattern as nearly all of the reproductive traits in their study were negatively correlated with condition score. They reported comparable genetic correlations of -0.15 for scan fertility, -0.19 for fertility, -0.19 for fecundity, -0.20 for number of lambs born, -0.19 for number of lambs weaned and 0.30 for litter survival.

These substantive unfavourable negative genetic correlations are most likely due to some mature ewes suffering from repeated reproductive failure becoming over-fat. This line of reasoning is supported by results in Figures 3.2, 3.3 and 3.4 as well as the study by Walkom *et al.* (2016). It could be argued that the overall genetic association of BCS with reproduction across age groups could differ from correlations within age groups, as was reported on the phenotypic level for mating weight by Cloete & Heydenrych (1986). Based on the results in Figures 3.2 and 3.3a, it could be contemplated that the genetic relationship of BCS at mating with 2-year-old reproduction is likely to be favourable. However, substantially more data would

be needed to test this assertion scientifically. The phenotypic correlations reported in this study for BCS at mating on the reproductive traits were all positive except for ewes conceived per ewe mated and NLB (Table 3.7). The available literature has also reported negative phenotypic correlations for NLW (-0.01) and litter survival (-0.02) (Walkom & Brown, 2017). The same authors reported positive correlations for pregnancy scan (0.01), fertility (0.01), fecundity (0.00) and NLB (0.01).

All environmental correlations were positive for BCS at mating with the reproductive traits analysed. This result again served to demonstrate that an environment that would lead to a higher BCS would also be conducive to a better reproduction rate. No comparable reports were found in the literature.

The results of this study concluded that the BCS at lambing had a clear negative genetic correlation with all the reproductive traits analysed (Table 3.9). This is in agreement with the study done in Australia by Walkom & Brown (2017). These scientists reported negative genetic correlations for BCS at lambing with pregnancy scan (-0.22), fertility (-0.13), fecundity (-0.16), number of lambs born (-0.23), and for number of lambs weaned (-0.23). A possible reason for these negative correlations for BCS at lambing might be that ewes which have higher condition scores at lambing might not have conceived or may have lost their lambs during the pregnancy. Consequently, ewes that partition less resources into maintaining the pregnancy and more into maintaining body condition will be fatter at lambing. The genetic relationship between ewe body condition and reproduction traits are poorly reported in literature.

Phenotypic correlations between ewe BCS at lambing and the reproductive traits investigated were all negative for this study (Table 3.9). Although these correlations were negative in their absolute direction they were small in magnitude and not significant ($P > 0.05$). Walkom & Brown (2017) reported some positive correlations for fertility (0.00), NLW (0.00) and litter size (0.06) with BCS at lambing. The same authors reported negative phenotypic correlations for BCS at lambing with pregnancy scan (-0.12), fecundity (-0.14) and NLB (-0.14).

Contradictory to mating weight and ewe BCS at mating; all of the environmental correlations were negative. This finding solidifies that ewes due to reproducing are likely to be in a poorer condition in comparison to their flock mates that are barren or have lost their pregnancies. The poorer body condition of pregnant ewes most probably results from such ewes using body resources to maintain pregnancy and prepare for lactation. Thus, barren ewes with a reduced metabolic demand for maintaining pregnancy will become fatter than

those needing to maintain a pregnancy (Freer *et al.*, 1997; Cannas *et al.*, 2004; Rose *et al.*, 2014; Walkom *et al.*, 2014b; a). The consistently unfavourable genetic correlation of condition scores with ewe conception rate (Tables 3.8 and 3.9) warrants further attention. If sheep farmers are aiming to improve adult ewe body condition it is desirable to base the selection on mating body condition scores not to be confounded by the impact of reproduction on the phenotype of the ewe.

Overall age trends on ewes that conceived or were barren revealed the average BCS of two-year-old ewes that conceived trended higher than those of ewes that were barren (Figure 3.3). Walkom *et al.* (2014b) reported that they forced the majority of their first-cross ewes to be fatter than required to avoid the reproductive thresholds reported by (Kenyon *et al.*, 2004). The observed low condition among barren ewes at first mating may be explained by the fact that lighter and leaner ewes are less likely to conceive.

During this study it was evident that ewes at a BCS of 2 or 3 performed best (Figure 3.4). This result was consistent with results from Yilmaz *et al.* (2011) who studied Kivircik sheep. They found that ewes with body condition scores of between 2.0 and 3.0 had peak rates of pregnancy (optimal), while condition scores below 2.0 and above 3.5 would lead to a reduction in pregnancy rate. Results reported in Figure 3.4 accorded with these results. Hatcher (2007) similarly reported that maintaining Merino ewes at a BCS of 3.0 to 3.5 during pregnancy ensured optimum lambing rates. Sejian *et al.* (2010) reported that the highest lambing rate they had achieved was recorded in the group with a BCS of 3.0 to 3.5. A study on Ossimi ewes indicated that ewes with condition scores of 1.5 and lower as well as of 3.5-4.0 and higher did not exhibit oestrus (Abdel-mageed, 2009). These results confirmed that body condition scores at mating of 2 to 3 are in the optimal range for reproduction.

Ewes in the highest condition category of 4+ had a worse performance for both traits than those scored 2 and 3 (Figure 3.4). This is in alignment with results of Yilmaz *et al.* (2011) and Vatankhah *et al.* (2012) who also reported that ewes with a BCS greater than 4 at breeding have a higher frequency of barrenness. The same trend was noted by Atti *et al.* (2001) on fat-tailed Barbarine sheep. The decreasing trend of these traits following a BCS higher than 3.5 again could be attributed to an increased maintenance requirement of the ewe, as ewes with a BCS of 4 were heavier than animals with a lower BCS (Vatankhah *et al.*, 2012). Unnecessary fat accumulation in ewes with higher body condition scores impaired the oestrus activity of these ewes (Bocquier *et al.*, 1993). It is thus undefined if animals do not produce lambs because they are excessively fat or have a higher BCS because of not conceiving.

This study clearly demonstrated that an environment which favours body weight at mating as well as BCS at mating favoured all reproductive traits analysed. If ewe body weight cannot be measured, BCS of the ewe can therefore be a valuable management tool with regards to reproduction. BCS can occasionally be easier to work with as some sheep flock live in harsh environments, such flock are far away from scales, and it can be impossible to take a scale to the flock. In these cases, BCS is the best option. It is recommended that ewes enter joining at BCS 3 and do not drop below 2.5. With the majority of the young (first mating) ewes being little fatter than required to avoid decreased reproductive rates. While selection for amplified genetic merit for BCS will help take advantage of the positive relationship between ewe BCS and reproduction, the benefit of increased genetic merit for BCS is likely to be insignificant if ewes are managed correctly and, in some cases, may become detrimental if ewes are allowed to get too fat. However, the inclusion of ewe body condition in the selection program has some merit to help with improving maternal reproductive performance during harsh conditions; and possibly reducing feeding costs. The role and economic importance of ewe body condition requires further exploration. BCS is highly influenced by the environmental factors that the sheep have to endure. This leads us to believe that proper management with regards to BCS will benefit reproduction of the whole flock and increase the financial aspect of the ovine enterprise.

3.6 Conclusion

The results of this study are pertinent, as many sheep producers include body weight measurements into their management regimes. Body weight is of limited use for indirectly predicting sheep reproduction and should only be used as a last resort when direct selection is infeasible/unpractical. This study confirmed that body weight, BCS at mating and at lambing are indeed heritable traits that should respond to selection. Nevertheless, it should be born in mind that bigger ewes have a higher maintenance requirement than smaller animals. Options for indirect selection was constrained by largely unfavourable genetic correlations with the reproduction traits analysed. Correlations that are age specific may be of greater value; especially in 2-year-olds. More data are needed to test this hypothesis.

3.7 References

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Chapter 4:

Genetic evaluation of body weight and body condition score in relation to the reproductive performance of a dual-purpose and a terminal sire sheep breed

4.1 Abstract

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 maximize the efficiency of farming operations. Literature specifies that reproduction in sheep depends on size and body condition score. As the size of an ewe is also suggestive of her maintenance requirements, it is important to understand the contribution of ewe size and body condition towards reproduction. Data of the Elsenburg Dormer and SAMM flocks from 2018 to 2021 were used to study the genetic and environmental parameters for ewe mating weight, BCS (assessed on a 5-point scale) at mating and at lambing. The correlations were also assessed with regards to mating weight and condition scores at mating and at lambing with reproduction. Dormer ewes were heavier than the SAMM ewes at mating, with the SAMM having higher BCS at mating and at lambing. Both lambing year and ewe age had significant effects on the three traits studied. Using an animal repeatability model, revealed that ewe mating weight was moderately heritable at 0.49, with some lower estimates for BCS at mating (0.21) and BCS at lambing (0.27). The genetic correlations among these traits were positive, ranging from 0.64 between mating weight and BCS at lambing to 0.68 between mating weight and BCS at mating, with the condition scores correlation being 0.66. The repeatability model for genetic correlations of mating weight and both the condition scores with reproduction were all negative. This unexpected result was seemingly due to ewes with lower mating weights and BCS producing better reproductive outputs. Further research on the topic of mating weight, condition scores and reproduction are warranted.

4.2 Introduction

Body weight of production ewes is important, as body weight can affect the reproduction of ewes (Coop, 1962; Kenyon *et al.*, 2004; Ferguson *et al.*, 2011). It is known that the body weight of ewes at mating has an effect on reproduction (Gordon, 1997) as well as ewe productivity in the following breeding season (Vatankhah & Salehi, 2010). Ewes with higher body weights tend to produce more lambs (Newton *et al.*, 1980; Brown *et al.*, 2005; Ferguson *et al.*, 2011; Saul *et al.*, 2011). This is due to an increase in body weight at mating that will increase ovulation rates of ewes and the survival of their lambs until weaning (Rhind *et al.*, 1984; Rowe, 2003; Jordan *et al.*, 2006). Consequently ewes that are genetically heavier are more fertile, have bigger litters and wean more lambs annually (Safari *et al.*, 2005; Walkom & Brown, 2017). A ewe's body weight can also be perceived as an efficiency measure, and thus should be optimized as opposed to maximized, for an even greater profitability (Brown *et al.*, 2015). The body weight of ewes has two components, namely the degree of fatness (body condition) of the ewe as well as the basic skeletal size of the sheep. Body condition score (BCS) provides additional information above body weight as a primary measure of size (Russel *et al.*, 1969; Sanson *et al.*, 1993). There are reports that a positive correlation between BCS at mating and reproductive performance exists (Atti *et al.*, 2001; Abdel-mageed, 2009; Sejian *et al.*, 2010; Yilmaz *et al.*, 2011). Price ratios between wool and mutton tolerated fluctuations during recent times thus, resulting in a continuous change on the emphasis between the two income lines (Olivier, 1999; Huisman *et al.*, 2008). Van der Merwe *et al.* (2019) stated that during recent years, a premium was placed on meat as opposed to wool production due to price considerations. Reproductive performance is particularly important when meat production is the prime objective, making of this the most important economical trait complex within sheep production (Fourie & Heydenrych, 1983; Van Haandel & Visscher, 1995; Snyman *et al.*, 1998; Cloete *et al.*, 2000; Abegaz *et al.*, 2002; Van Wyk *et al.*, 2003; Senger, 2012; Ali *et al.*, 2020). A producer can thus select for an improved body condition and be confident that the ewe will be genetically predisposed to a better condition during the reproductive season and throughout her breeding life (Walkom *et al.*, 2014a; b; c). Sheep producers can boost the reproduction rate of their breeding flocks by using this knowledge (Curnow *et al.*, 2011; Edwards *et al.*, 2011; Young *et al.*, 2011). The phenotypic relationships that exist among body weight, BCS and reproduction traits are complex, resulting in difficulty to differentiate between cause and effect between the earlier traits (Walkom & Brown, 2017). Yet it is accepted that heavier ewes and ewes in a better condition have an improved reproductive performance (Curnow *et al.*, 2011; Edwards *et al.*, 2011; Young *et al.*, 2011). Accurate environmental and

genetic parameter estimates for breeds are needed before changes are made to selection criteria to accommodate these factors and changes (Muller, 2020).

This study utilised well-known resource flocks. The Elsenburg SAMM and Dormer flocks are recognized as the foundation flocks of the respective breeds (Muller, 2020). The SAMM has developed as a prominent dual-purpose breed in South Africa, while the Dormer is the most important terminal sire breed (Cloete *et al.*, 2014; Van Der Merwe *et al.*, 2020). The SAMM was developed to produce prime slaughter lambs with an excellent slaughter weight at early ages, while continuing to produce wool of a good quality. The emphasis within the SAMM breed selection program and branding of the breed was on optimising mutton production; this rendered it suitable for its present dual-purpose role (Vosloo, 1967). The objective with the formation of the Dormer was to develop a fast-growing white-wool breed for terminal crossbreeding on Merino-type ewes (De Villiers & Cloete, 1984). The Dormer adapted sound to the role of producing slaughter lambs of the desired quality when used on Merino type dams (Erasmus *et al.*, 1983; Cloete *et al.*, 2004a). The Dormer is by far the most abundant terminal sire breed in South Africa as it is reflected by the number of records submitted to the National Small Stock Improvement Scheme (Zishiri, 2009; Zishiri *et al.*, 2012; Cloete *et al.*, 2014).

Against this background, we designed a study to quantify the effects of ewe age on reproduction, mating weight and BCS in the above mentioned resource flocks. Additionally, the genetic (co)variances in these traits in the resource populations were estimated.

4.3 Materials and Methods

4.3.1 Animal resources, the environment and management

The Elsenburg Dormer and SAMM flocks are important local resource flocks and are described thoroughly in the literature (Van der Merwe, 1976; Brand *et al.*, 1985; Van Wyk *et al.*, 1993c; d; a; b; Zemuy, 2002; Cloete *et al.*, 2004b; Schoeman *et al.*, 2010; Muller, 2020). Since 1989, the Elsenburg SAMM and Dormer flocks were managed as a single population, initially to allow the studies on ewe and lambing behaviour (Cloete *et al.*, 2002), and since to compare the breeds under similar conditions (Muller, 2020). The flocks were maintained on the Elsenburg Research Farm throughout the study. Elsenburg is situated close to Stellenbosch in the Western Cape of South Africa. This location falls into a winter rainfall

environment with an average annual rainfall of ± 650 mm, with most of the rain expected between April and September. GPS coordinates of Elsenburg is $33^{\circ} 51' S$ and $18^{\circ} 30' E$ and the farm is approximately 177 m above sea level.

The Dorper flock consisted of approximately 120 breeding ewes and the SAMM flock of approximately 60 breeding ewes. Ewes grazed on irrigated *Pennisetum clandestinum* (kikuyu) paddocks of approximately 0.5 ha during mating and lambing. Rams were individually mated to groups of between 15 and 30 ewes during October and November (spring), using a single-sire mating system. The ewes subsequently lambed in these kikuyu paddocks the following year during March and April (autumn) (Cloete, 1992; Cloete *et al.*, 1993). After lambing in the smaller camps, the ewes along with their lambs were moved off to irrigated *Medicago sativa* (lucerne) paddocks after 3 to 14 days post lambing. After tail docking the ewes and their offspring were joined in bigger groups and moved to bigger dryland paddocks, grazing on *Medicago sativa* (lucerne) and occasionally oat fodder crops. The rest of the production cycle up until weaning took place on these dryland pastures. The ewe flock was maintained on irrigated kikuyu during the dry period.

4.3.2 Data recording

Body condition score (BCS) was subjectively recorded according to a linear 5-point scale graded from the leanest (1) to the fattest (5). The BCS of ewes was assessed by the palpation of the lumbar region specifically on and around the backbone in the loin area, immediately behind the last rib and above the kidneys to examine the degree of sharpness or roundness. Table 4.1 below denotes the scoring grades, as well as the description for each grade.

Table 4.1: The description of the condition scoring technique*.

Grade	Description
Score 1	The spinous processes are prominent and sharp. The transverse processes are also sharp, with fingers passing easily under the end of this process. The eye muscle areas are shallow with little to no fat cover.
Score 2	The spinous processes are smooth but still prominent. The individual processes can still be felt but only as fine corrugations. The transverse processes are smooth and rounded. However, it is still possible to pass the fingers under the ends of the processes with some pressure. The eye muscle areas are of moderate depth but have sparse fat cover.
Score 3	The spinous processes are smooth and rounded, and individual bones can only be felt with some pressure applied. The transverse processes are also smooth and are well covered. Firm pressure is required to feel over the ends. Eye muscle area is full and covered by a moderate degree of fat.
Score 4	With pressure applied, the spinous processes can just be detected, although the ends of the transverse processes cannot. Eye muscle areas are full with a thick fat cover.
Score 5	Even with firm pressure applied, the spinous processes cannot be detected. Due to a high level of fat adjacent to the spinous process, a depression directly above where the spinous processes would normally be felt may be present. It is not possible to detect the transverse processes. The eye muscle areas are very full with very thick fat cover. It is possible to have significant deposits of fat cover over the rump and tail.

*The table was adapted from Russel *et al.* (1969); Russel (1984); Kenyon *et al.* (2014).

At mating the ewes were weighed and had a BCS assessment as they were grouped into single-sire mating groups; all this information was documented. The BCS was not recorded for the 2020 lambing season due to the global pandemic. At lambing lambs were identified together with their dams and weighed within 24 hours of birth. Prior to lambing, ewes had their body condition scores taken before being randomly distributed to small lambing groups on the kikuyu lambing paddocks.

4.3.3 Statistical analyses

The ASREML program (Gilmour *et al.*, 2015) was used to estimate fixed effects and variance components for mating weight and the conditions scores in single-trait analyses. Year of lambing (2018 - 2021), breed (Dormer and SAMM) and ewe age (2 - 6 years) were fitted as fixed effects. Significant effects in these preliminary analyses were retained in subsequent analyses. Random terms were then added to the operational model so derived, resulting in the following genetic models for analyses (in matrix notation):

$$y = Xb + Z_1a + e \quad (1)$$

$$y = Xb + Z_1a + Z_2c_{ewe} + e \quad (2)$$

y was a vector of observations for ewe traits, b , a and c_{ewe} were vectors of fixed effects, direct genetic effects and ewe permanent environmental effects respectively. X , Z_1 , and Z_2 denoted the corresponding incidence matrices relating the respective effects to y , while e was the vector of randomly distributed residuals that summed to zero.

It was assumed that:

$$V(a) = A\sigma_a^2; V(c_{PE}) = I\sigma_{ewe}^2; V(e) = I\sigma_e^2,$$

A was the numerator relationship matrix, I an identity matrix; σ_a^2 , σ_{ewe}^2 and σ_e^2 the direct genetic variance, the ewe permanent environmental variance and the environmental (residual) variance respectively. All analyses included the full pedigree file, consisting of 28069 individuals, the progeny of 700 sires and 5590 dams.

Log likelihood tests were used to identify the best model for each trait in single-trait analyses. The random effects fitting the data best for each trait best were identified, using the log likelihood ratios obtained from the respective analyses (Snyman *et al.*, 1996). Subsequently, a three-trait animal model was fitted to all traits, including the identified fixed and random effects. All relevant genetic and ewe permanent environmental correlations (where applicable) were derived from these analyses, together with their standard errors (Gilmour *et al.*, 1995). In further analyses, we estimated genetic correlations of mating weight and BCS with ewe reproduction traits. In additional analyses, reproduction outcomes were related to specific BCS classes to assist in the interpretation of some results.

Finally, ethical clearance for the study was obtained from the Stellenbosch University ethical committee; with clearance number ACU-2020-12955.

4.4 Results

4.4.1 Descriptive statistics

Between 2018 to 2021, 703 repeated mating weight records, 519 body condition scores taken at mating and 666 body condition scores at lambing were recorded for the Elsenburg Dormer and SAMM flocks combined (Table 4.2). The average mating weight of for combined dataset was to 73.3 kg with an 8.6 kg standard deviation and a range of between 49.0 kg and 98.5 kg. The average BCS of the ewes at mating was 3.65 with a standard deviation of 1.12 with a range of 1 to 5. The corresponding values at lambing were 3.26, a standard deviation of 0.81 and ranged between 1 and 5. Coefficients of variation were below 15% for mating weight and higher or around 25% for the condition scores.

Table 4.2: Descriptive statistics for mating weight, body condition score at mating and body condition score at lambing for the combined data of the Elsenburg Dormer and SAMM flocks.

Trait	n	Mean	SD	CV (%)	Range
Mating weight	703	73.3	8.6	11.7	49.0-98.5
Body condition score at mating	519	3.65	1.12	30.7	1-5
Body condition score at lambing	666	3.26	0.81	24.8	1-5

n: Number of records

SD: Standard deviation

CV % : Coefficient of variation

4.4.2 Predicted fixed effects

The breed of the ewe affected mating weight significantly, Dormer ewes were 6.3% heavier than their SAMM contemporaries at mating (76.5 kg vs 71.7 kg; $P < 0.05$; Table 4.3). Breed also had a significant effect on BCS at mating. On average, SAMM ewes had a 11% higher BCS at mating than the Dormer ewes (3.90 vs 3.47; $P < 0.05$; Table 4.3). Finally, the SAMMs had a 6% better BCS at lambing than the Dormers (3.33 vs 3.14; $P < 0.05$; Table 4.3).

Lambing year had a significant ($P < 0.05$) effect on both condition scores (at mating and at lambing); but had no effect on mating weight ($P > 0.05$) (Table 4.3). The lowest BCS at mating were recorded during the 2018 season followed by 2019, with 2021 having the highest BCS at mating. BCS at lambing was the lowest for 2020 followed by 2019 with 2021 and 2018 having the highest means for body BCS at lambing.

There was a pronounced effect observed of ewe age on mating weight and BCS at mating; with no significant effect on BCS at lambing (Table 4.3). Ewes four-year-old and older were heavier compared to their younger contemporaries at mating. The three-year-old ewes were intermediate between two-year-old and four plus year-old ewes, leaving the two-year-old ewes (the youngest age group) to be the lightest at mating ($P < 0.05$). With regards to BCS at mating the only differences were for the two-year-old ewes, being lower than the three- and five-year-old ewes ($P < 0.05$) and did not differ from the four and six-plus-year-old ewes.

Table 4.3: Predicted means \pm SE of the fixed effects fitted for Mating weight, Body condition score at mating and Body condition score at lambing in the Elsenburg Dormer and SAMM flocks.

Effects and level	Mating weight	Body condition score at mating	Body condition score at lambing
Breed			
Dormer	76.5 \pm 0.3 ^B	3.47 \pm 0.04 ^A	3.14 \pm 0.03 ^A
SAMM	71.7 \pm 0.4 ^A	3.90 \pm 0.05 ^B	3.33 \pm 0.04 ^B
P-value	0.001	0.001	0.01
Year			
2018	73.6 \pm 0.6	2.88 \pm 0.06 ^A	3.67 \pm 0.05 ^C
2019	74.6 \pm 0.5	3.80 \pm 0.05 ^B	3.01 \pm 0.04 ^B
2020	74.2 \pm 0.5	-	2.59 \pm 0.05 ^A
2021	73.9 \pm 0.5	4.36 \pm 0.06 ^C	3.67 \pm 0.05 ^C
P-value	0.312	0.001	0.001
Ewe age			
2	65.6 \pm 0.5 ^A	3.81 \pm 0.06 ^A	3.17 \pm 0.04
3	72.2 \pm 0.6 ^B	3.58 \pm 0.06 ^B	3.28 \pm 0.05
4	77.3 \pm 0.6 ^C	3.71 \pm 0.08 ^{A,B}	3.33 \pm 0.06
5	76.6 \pm 0.6 ^C	3.60 \pm 0.08 ^B	3.28 \pm 0.06
6+	78.6 \pm 0.7 ^C	3.72 \pm 0.09 ^{A,B}	3.11 \pm 0.07
P-value	0.001	0.001	0.128

^{ABC} – Means with different superscripts are significantly different ($P < 0.05$)

Furthermore, one of the objectives was to investigate the interactions of sheep breed with age and lambing year for condition scores and mating weight in the Elsenburg flocks (Figure 4.1, 4.2 and 4.3). BCS at lambing increased from two- to four-year-old ewes for the

SAMM ($P < 0.05$), where it stabilized in contrast, BCS at lambing for the Dormers decreased markedly from two to three years of age, where it stabilized before again increasing to six years of age ($P < 0.05$).

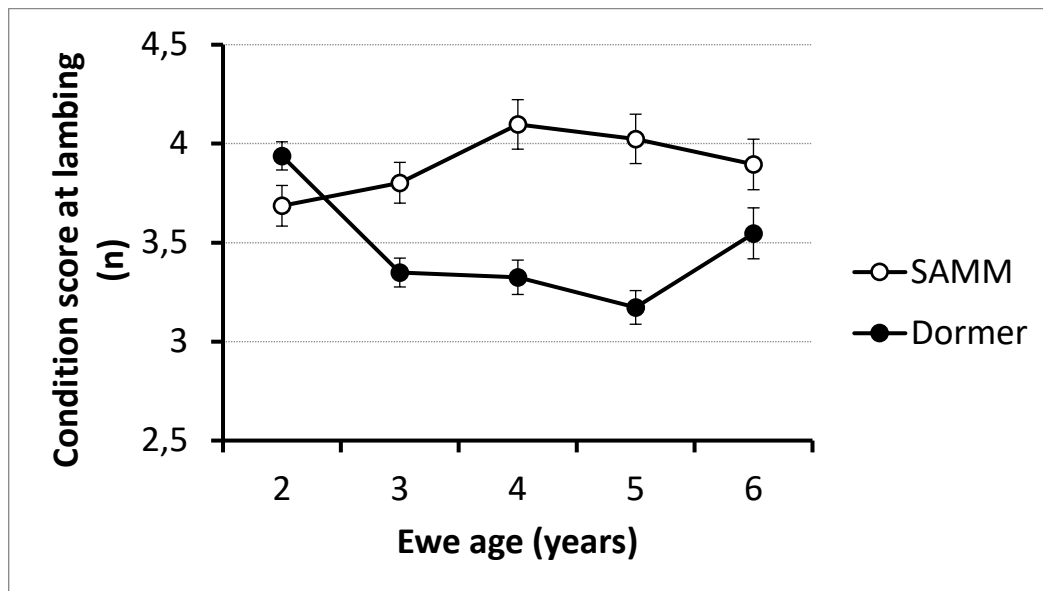


Figure 4.1: Line graph representing the effect of ewe age on body condition score at lambing for the Elsenburg Dormer and SAMM flocks (SE's are around means).

The interaction of ewe breed with lambing year for mating weight is displayed in Figure 4.2. Mating weight generally increased from 2018 to 2021 for SAMM ewes; with the only significant difference being that in 2018 the ewes were lighter at mating ($P < 0.05$). There was no difference between 2018 and 2019 for Dormer ewes ($P > 0.05$), but mating weight declined in subsequent years, although no difference was once again demonstrated from 2020 to 2021 ($P > 0.05$).

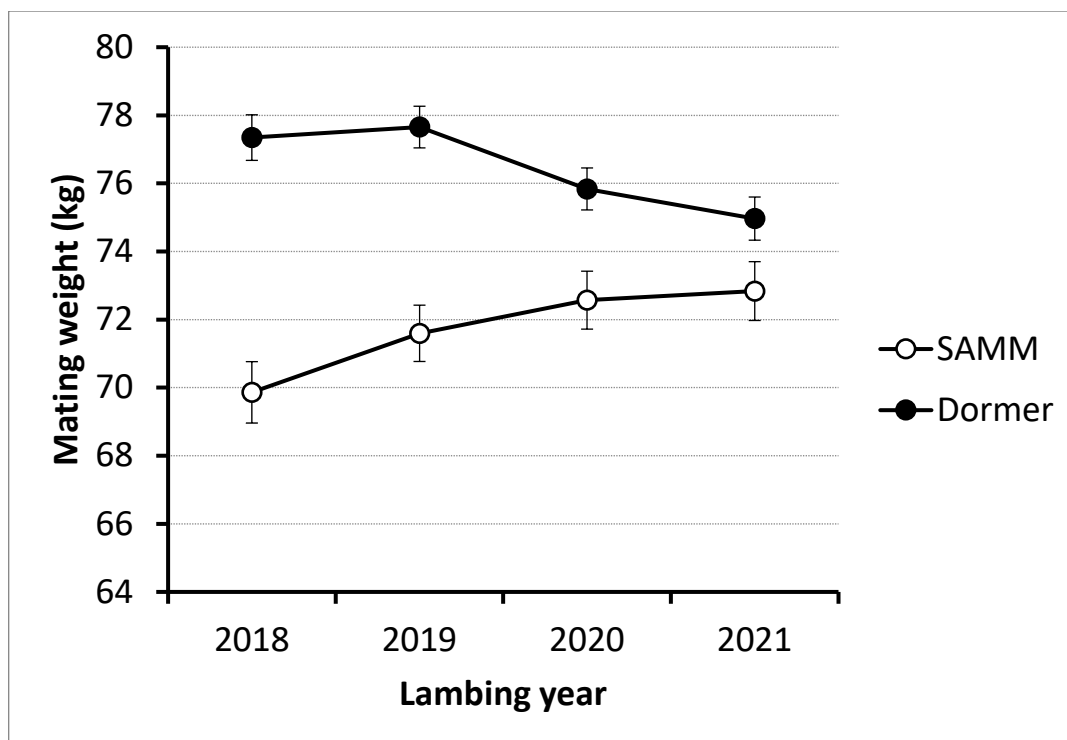


Figure 4.2: Line graph representing the effect of lambing year on mating weight for the Elsenburg Dormer and SMMM flocks (SE's are around means).

Ewe breed interacted with lambing year for BCS at lambing ($P < 0.05$; Figure 4.3). Dormer ewes had a high BCS of about four at lambing in 2018, followed by a marked reduction to about three in 2019 and about two in 2020. During 2021, the BCS once again increased to 3.65, which did not differ from the 2018 condition scores ($P > 0.05$). SMMM ewes followed the same general trend observed in the Dormers, but with lower increments of change and no reduction in BCS from 2019 to 2020 ($P > 0.05$). Breed differences were in favour of Dormers in 2018 and in favour of SMMMs in 2020, with no significant differences in the other years (2019 and 2021).

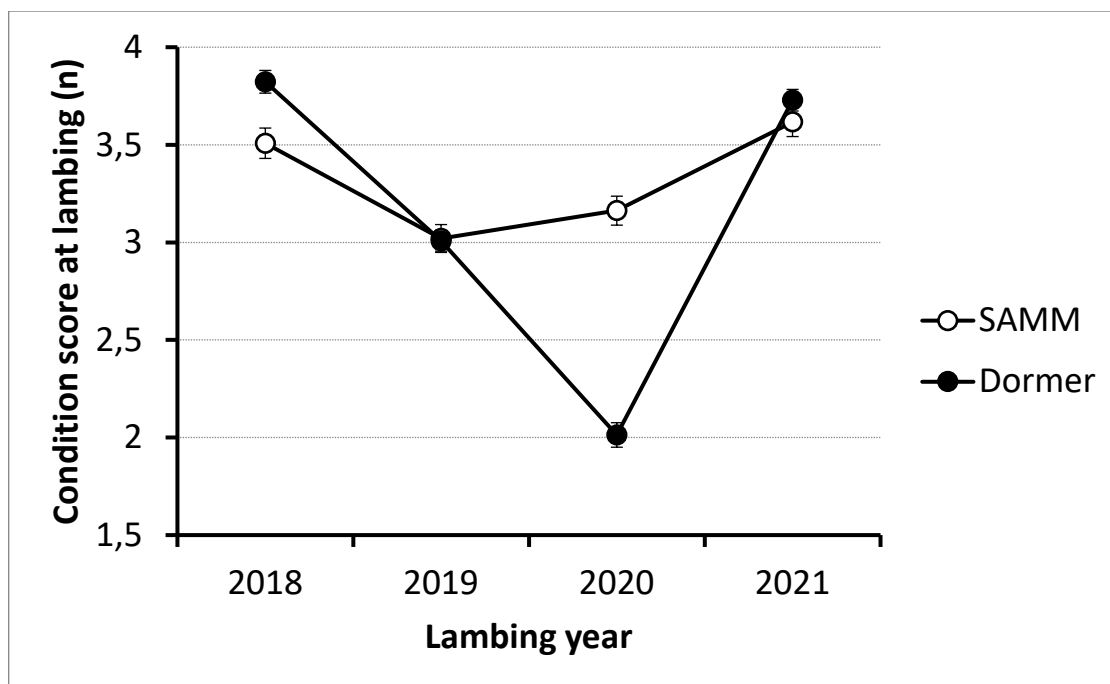


Figure 4.3: Line graph representing the effect of lambing year on body condition score at lambing for the Elsenburg Dormer and SAMM flocks (SE's are around means).

4.4.3 Genetic analysis

4.4.3.1 Log likelihood values

Log likelihoods values for adding random effects to the operational model in single-trait models fitted to mating weight, BCS at mating and BCS at lambing are provided in Table 4.4. These values indicated that Model 2 (with direct genetic effects and ewe permanent environment as random terms) was the most suitable model for mating weight (Table 4.4). Model 1 (incorporating only the direct genetic effects as only random term) fitted the data best for both condition scores.

Table 4.4: The log likelihood ratios for random effect models fitted to mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Merino flock. The best model in bold.

Model	(Co)variance components	Mating weight	Body condition score at mating	Body condition score at lambing
0	Fixed effects	-1667.76	-85.006	12.707
1	+ h^2	-1554.31	-77.545	38.653
2	+ h^2 + PE	-1546.44	-77.545	38.653

4.4.3.2 Single- and multi-trait heritability estimates

Table 4.5 provides the single-trait variance components and ratios for mating weight, BCS at mating as well as BCS at lambing. All three traits were moderately heritable. The heritability (h^2) of all traits was moderate, 0.21 for BCS at mating, 0.27 for BCS at lambing to 0.36 for mating weight (Table 4.5).

Table 4.5: Single trait variance and ratios \pm SE for mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Dormer and SAMM flocks.

Single trait	Mating weight	Body condition score at mating	Body condition score at lambing
(Co)variance components			
σ^2_a	16.121	0.10087	0.08834
σ^2_{PE}	13.287	-	-
σ^2_p	44.297	0.47548	0.32563
Variance ratios			
h^2	0.36 \pm 0.09	0.21 \pm 0.07	0.27 \pm 0.05
PE^2	0.30 \pm 0.09	-	-
Repeatability	0.66 \pm 0.09	0.21 \pm 0.07	0.27 \pm 0.05

σ^2_p : Total phenotypic variance

σ^2_a : Total additive variance

σ^2_{pe} : Total physical environment variance

h^2 : Direct additive heritability

The three-trait analysis for mating weight and BCS at mating and at lambing are presented in Table 4.6. The h^2 of mating weight was 0.49 in the three-trait analysis, with estimates of 0.17 for BCS at mating and 0.30 for BCS at lambing (Table 4.6). Some of the variance ascribed to animal permanent environment for mating weight in the single-trait analysis repartitioned to the direct genetic resulting in a somewhat lower animal permanent environmental variance ratio of 0.17 \pm 0.05 in the three-trait analysis.

Mating weight was strongly correlated to both condition scores (at mating and at lambing). A genetic correlation of 0.68 between mating weight and BCS at mating was estimated and the corresponding correlation BCS at lambing and mating weight was 0.64 (Table 4.6). The corresponding phenotypic correlations were 0.37 for BCS at mating and 0.32 for BCS at lambing. The genetic correlation between the two condition scores were to 0.66 with a corresponding phenotypic correlation of 0.31 (Table 4.6).

Table 4.6: Three trait (co)variance components and ratios \pm SE for mating weight, body condition score at mating and body condition score at lambing in the Elsenburg Dormer and SAMM flocks.

Trait	Mating weight (kg)	Body condition score at mating (n)	Body condition score at lambing (n)
h^2 on diagonal and r_g below diagonal			
Mating weight	0.49 \pm 0.08		
Body condition score at mating	0.68 \pm 0.12	0.17 \pm 0.05	
Body condition score at lambing	0.64 \pm 0.10	0.66 \pm 0.15	0.30 \pm 0.05
σ_p^2 on diagonal r_E above diagonal and r_P below diagonal			
Mating weight	38.19	0.32 \pm 0.05	0.16 \pm 0.05
Body condition score at mating	0.37 \pm 0.04	0.4696	0.21 \pm 0.05
Body condition score at lambing	0.32 \pm 0.04	0.31 \pm 0.04	0.3329

n: Number of records

kg: Kilogram

r_e: Environmental correlation

r_g: Genetic correlation

r_p: Phenotypic correlation

σ_p^2 : Total phenotypic variance

h²: Direct additive heritability

4.4.3.3 Genetic correlations with reproduction traits

The estimated correlations for mating weight with reproductive traits are presented in Table 4.7. All the genetic correlations of mating weight with the reproductive traits were negative and significant except for twinning percentage per ewes lambing. All the environmental correlations of mating weight with reproductive traits were positive ($P < 0.05$). This indicates that an environment that favours mating weight will also favour an increased reproductive performance. Phenotypic correlations fluctuated around zero and were not significant ($P < 0.05$); except for the correlation with total weight weaned per ewes mated amounting to -0.22.

Table 4.7: Estimated correlations of ewe mating weight with the number of ewes conceived, number of lambs born, twinning percentage, ewe rearing ability, the number of lambs weaned, and the total weight weaned in the Elsenburg Merino flock.

Correlated traits	r_g	r_E	r_P
Ewes conceived/Ewes mated	-0.46 ± 0.13	0.05 ± 0.01	-0.01 ± 0.02
Number of lambs born/Ewes mated	-0.33 ± 0.14	0.14 ± 0.05	-0.01 ± 0.01
Twinning percentage/Ewes lambled	-0.08 ± 0.18	0.17 ± 0.05	0.01 ± 0.05
Ewe rearing ability/ Ewes lambled	-0.66 ± 0.27	0.12 ± 0.05	-0.01 ± 0.01
Number of lambs weaned/Ewes mated	-0.55 ± 0.14	0.17 ± 0.05	-0.01 ± 0.01
Total weight weaned/Ewes mated	-0.49 ± 0.13	0.18 ± 0.05	-0.22 ± 0.04

r_e : Environmental correlation

r_g : Genetic correlation

r_p : Phenotypic correlation

Table 4.8 presents the estimated correlations for BCS at mating with reproductive traits. Most of the genetic correlations were significant except twinning percentage per ewe lambled and ewe rearing ability per ewe lambled. All the environmental correlations of BCS at mating with reproductive traits were positive but not significant. The phenotypic correlations fluctuated around zero and were not significant ($P < 0.05$).

Table 4.8: Estimated correlations of body condition score at mating with the number of ewes conceived, number of lambs born, twinning percentage, ewe rearing ability, the number of lambs weaned, and the total weight weaned in the Elsenburg Merino flock.

Correlated traits	r_g	r_E	r_P
Ewes conceived/Ewes mated	-0.71 ± 0.16	0.05 ± 0.05	-0.01 ± 0.02
Number of lambs born/Ewes mated	-0.42 ± 0.19	0.04 ± 0.05	-0.01 ± 0.01
Twinning percentage/Ewes lambled	0.14 ± 0.26	0.02 ± 0.05	-0.01 ± 0.01
Ewe rearing ability/ Ewes lambled	-0.46 ± 0.35	0.04 ± 0.05	-0.01 ± 0.01
Number of lambs weaned/Ewes mated	-0.50 ± 0.20	0.05 ± 0.05	-0.01 ± 0.01
Total weight weaned/Ewes mated	-0.49 ± 0.19	0.02 ± 0.05	-0.22 ± 0.12

r_e : Environmental correlation

r_g : Genetic correlation

r_p : Phenotypic correlation

The genetic correlations of ewe BCS at lambing with the reproductive traits analysed were all negative and variable in magnitude (Table 4.9). Only the correlation for twinning percentage per ewes lambled and ewe rearing ability (ERA) per ewes lambled did not reach significance ($P < 0.05$), as these correlations were less than double the standard error. In strong contrast with the results on mating weight and ewe BCS at mating all environmental correlations were negative, but not different from zero. Accordingly, phenotypic correlations were also negative.

Table 4.9: Estimated correlations for body condition score at lambing with the number of ewes conceived, number of lambs born, twinning percentage, ewe rearing ability, the number of lambs weaned, and the total weight weaned in the Elsenburg Merino flock.

Correlated traits	r_g	r_E	r_P
Ewes conceived/Ewes mated	-0.39 ± 0.16	-0.01 ± 0.05	-0.02 ± 0.02
Number of lambs born/Ewes mated	-0.39 ± 0.15	-0.02 ± 0.05	-0.10 ± 0.01
Twinning percentage/Ewes lambled	-0.27 ± 0.20	-0.01 ± 0.05	-0.11 ± 0.01
Ewe rearing ability/ Ewes lambled	-0.47 ± 0.27	-0.01 ± 0.05	-0.07 ± 0.01
Number of lambs weaned/Ewes mated	-0.57 ± 0.14	-0.01 ± 0.05	-0.02 ± 0.02
Total weight weaned/Ewes mated	-0.56 ± 0.14	-0.05 ± 0.04	-0.50 ± 0.01

r_e : Environmental correlation

r_g : Genetic correlation

r_p : Phenotypic correlation

4.5 Discussion

4.5.1 Descriptive statistics

With the two flocks combined the average mating weight of the ewes to 73.3 kg and a CV % of 11.7% and falling within a range of between 49.0 kg and 98.5 kg (Table 4.2). Cloete & Haughey (1990) accordingly reported CV % of 11.9% for mature SAMMs and 14.0% for Dormers, but with a much smaller sample size. Condition scores averaged at 3.66 for mating and 3.26 for lambing (Table 4.2). No comparable literature sources reporting descriptive statistics for condition scores of specifically mature SAMM and Dormer ewes were found. Kenyon *et al.* (2004) reported lower average condition scores of 2.52 for Romney ewes and 2.80 for composite breed ewes during pregnancy.

4.5.2 Predicted fixed effects

Overall, Dormers were 6.7% heavier than SAMMs at mating (Table 4.3). The overall mean of 71.7 kg in mature SAMM ewes was within a range of comparable means of 82.2 kg (Cloete & Haughey, 1990), 74.7 to 74.9 kg (Cloete, 1994), 67.1 kg (Cloete *et al.*, 1998) and 67.4 kg (Cloete *et al.*, 2004b) in the literature. The average of 76.5 kg in Dormer ewes were within a close band of literature values, namely 79.1 kg (Cloete & Haughey, 1990), 71.7 to 76.0 kg (Cloete, 1994) and 68.3 kg (Cloete *et al.*, 1998). The breeds were directly comparable in the studies of Cloete & Haughey (1990), Cloete (1994) and Cloete *et al.* (1998), where no

clear breed effect emerged. The difference in favour of Dormers is thus a bit perplexing. However, the study of Van der Merwe *et al.* (2019) modelled growth in both these breeds using four nonlinear model approaches. The most credible predictions from the Gompertz and Logistic models suggested adult weights of 90.9 to 98.9 kg for SAMM ewes and 96.9 to 105.9 kg for Dormer ewes. This study modelled growth under feedlot conditions, hence the higher predicted adult weights. It thus seems that the breed difference in favour of the Dormers may be real if this reference is considered. The overall means for the respective breeds were complicated by an interaction with lambing year, though. The breed difference was reduced, but still significant ($P < 0.05$) in favour of the Dormers, in 2020 and 2021 (Figure 4.2). The reason for the interaction is unclear, unless it can be related to the selection regime for weaning weight in Dormers, as described by (Muller, 2020). Clearly, more research is needed on this topic.

SAMM ewes had an 11% higher BCS at mating and a 6% higher BCS at lambing than Dormers (Table 4.3). This result is counter-intuitive when the results of Muller (2020) that yearling Dormers had a thicker fat cover than SAMMs is considered. If it is assumed that the Dormer matures earlier than the SAMM breed, as suggested by the latter study as well as by Cloete *et al.* (2012). These results are therefore in contrast to those of Lawrie & Ledward (2014) which states that early-maturing sheep breeds tend to gain fat more readily. This line of reasoning would suggest a thicker fat cover in mature Dormers compared to SAMMs. Moreover, the interaction of breed with lambing year for BCS at lambing is difficult to explain. As the breeds were maintained in the same flock, except at mating in single sire groups, the exceptionally lower BCS of Dormers during 2020 is difficult to understand (Figure 4.3). It is expected that a clearer picture might emerge as more data accrue. It was also evident that the BCS of ewes declined somewhat from mating to lambing (Table 4.2). Thompson *et al.* (2011) and Vatankhah *et al.* (2012) attributed this to the nutritional status of the pregnant ewe. Breeding ewes lose condition during the last trimester of their pregnancy and during lactation because the nutritional demands of pregnancy and lactation surpass the ewe's physical capability to consume feed (Walkom *et al.*, 2014c). Thus the ewes' pregnancy status will influence her nutritional demands and whether she needs to use her stored fat reserves for maintenance/pregnancy requirements. Ewes with lower pregnancy demands thereby use less of their body reserves.

The year of lambing had a pronounced effect on both condition scores (at mating and lambing) (Table 4.3). The lowest BCS at lambing were recorded during 2020, with 2021 producing the highest BCS at mating. Annual variation in mating weight and body condition depends on the unique circumstances provided by managerial decisions and climatic

conditions. Therefore, these conditions are unlikely to be repeatable (Blumer *et al.*, 2015). Mullaney & Hyland (1967) stated that they observed marked seasonal variation in performance of Australian flocks. These decisions and climatic changes are not necessarily in the same direction from year-to-year. The subsequent change in grazing potential from year-to-year would affect the body weight and condition of the ewe during the entire reproduction cycle since these production phases rely on the ewe's body condition (Mullaney & Hyland, 1967; Kenyon *et al.*, 2014). The previous mentioned statements are possibly the reason for the variation in BCS at mating and at lambing with regards the lambing year.

Ewe age had a pronounced effect on mating weight and BCS at mating (Table 4.3). A clear trend is visible in that ewes became heavier up to four years, before stabilising. This is in line with literature as a study done on Central Anatolian Merino sheep reported that younger ewes had lower body weights compared to older ewes (Aktaş *et al.*, 2015). With regards to BCS at mating the only differences were that two-year-old ewes had a lower BCS than older ewes. The two- and six-year-old ewes displayed the lowest condition scores at lambing (Table 4.3). These results are in agreement with the findings of Rose *et al.* (2014), Aktaş *et al.* (2015) and Semakula *et al.* (2020). It is generally expected that two-year-old ewes are lighter due to still being in a growth phase before the reaching maturity (Rose *et al.*, 2014). Mchugh *et al.* (2019) also reported an increase in ewe body condition scores as ewe aged across all stages of the annual production cycle.

As stated that one of the objectives was to investigate the effect of breed on the age trends for condition scores in the Elsenburg flocks. The interaction involving breed and ewe age for mating weight is difficult to explain, as SAMM and Dormer breeds followed completely opposite trends from one another with regards to BCS at lambing. As the SAMM followed the same trend as the combination of breeds mentioned above thus, it will not be discussed here (Figure 4.1). On the other hand, the Dormer showed that BCS at lambing was lowest in those age groups of three to five years (Figure 4.1). Although this trend is not as common as for the SAMM breed, there is literature that supports a decline in BCS with an increased age at mating in Merino and Corriedale ewes (Gonzalez *et al.*, 1997; Semakula *et al.*, 2020). It is assumed that clearer trends will emerge as more data becomes available.

4.5.3 Genetic analyses

4.5.3.1 Log likelihood values

The log likelihood values for random effects fitted to mating weight, BCS at mating and BCS at lambing indicated that direct genetic effects were important for all the traits analysed (Table 4.4). The permanent environmental variance of the animal was only important for mating weight, but not for condition scores. Cloete *et al.* (2004a) used a similar model when they analysed mating weight in Merino ewes.

4.5.3.2 Single- and multi-trait heritability estimates as well as correlations for and among body weight and condition scores

All three traits analysed in this study were moderately heritable. The heritability of mating weight was moderately-high at 0.36 in the single-trait analysis and high at 0.49 in the three-trait analysis with the condition scores (Tables 4.5 and 4.6). These findings are in line with the findings of Safari *et al.* (2005) who reported a heritability of 0.41 for adult weight in wool breeds and 0.40 for dual-purpose breeds. This also agrees with Cloete *et al.* (2004) who reported a heritability (h^2) of 0.48 for mating weight in a flock of Merinos. However, there are literature reporting even higher heritability estimates for body weight at mating, varying from 0.70 to 0.78 (Brown & Swan, 2014; Rose *et al.*, 2014). It is thus not unreasonable to conclude that the present estimate for adult weight is consistent with other studies, suggesting that the dataset used is indeed appropriate to study correlations between mating weight, condition scores and reproductive traits. Genetic improvement with regards to mating weight are therefore achievable, while keeping in mind that a heavier ewe will have an increased maintenance requirement (Freer *et al.*, 1997; Walkom *et al.*, 2014b). Thus might not be the best economical decision to select for excessively large (heavy/fat) ewes. The ewe permanent environmental effect was 0.30 in the single-trait model and 0.17 in the three-trait analysis. These values are either side of the estimate of 0.27 reported for Merino ewes by Cloete *et al.* (2004). It is reasonable that results contained in the condition scores could assist with the accurate partitioning of these variances.

The phenotypic variation in the three-trait analysis in the present study for mating weight was 38.19 (Table 4.6). This value falls within the range of 36.26 and 41.53 for the phenotypic variance of mating weight reported in the literature (Brown & Swan, 2014; Walkom

et al., 2014b). BCS at mating had a phenotypic variance of 0.47 in the current study. This value is similar to Walkom *et al.* (2014b) who reported a phenotypic variance of 0.55 for pre-joining condition score. There were, however, lower phenotypic variances reported for pre-joining condition score, varying between 0.239 and 0.266 (Bunter *et al.*, 2019). The phenotypic variance for BCS at lambing was lower at 0.33 in the present study. This result is lower than values reported in literature. Walkom *et al.* (2014b) stated a phenotypic variance of 0.48 for BCS during mid pregnancy and 0.59 for BCS at weaning. The derived h^2 estimates were thus generally consistent with results stated in literature. The trend towards a higher phenotypic variance for BCS during pregnancy in the literature is not surprising. Condition scores of non-pregnant ewes at mating will not be impacted on by the demands of pregnancy. The difference in lambing dates as experienced in those ewes assessed at lambing may also impact upon the phenotypic component. The h^2 estimates of BCS at mating in the present study were moderate to low at 0.21 in the single-trait model and 0.17 for the three-trait model (Tables 4.5 and 4.6). The study by Brown & Swan (2014) reported a comparable h^2 of 0.15 for BCS at mating. A h^2 of 0.20 for BCS irrespective of production stage were also reported for Merinos Bunter *et al.* (2020). Bunter *et al.* (2019) reported a pre-joining BCS h^2 of 0.18 in their study. These moderate h^2 estimates for BCS at mating linked to a high coefficient of variation suggest that this trait would respond positively to directed selection. The h^2 for BCS at lambing were estimated at 0.27 in the single-trait model (Table 4.5). The h^2 estimate for BCS at lambing is above comparable estimates reported in literature ranging from 0.15 to 0.20 (Brown & Swan, 2014; Bunter *et al.*, 2019; 2020). The higher than expected h^2 in the present study may suggest that the estimate is inflated by animal permanent environmental effects that could not be partitioned from direct genetic effects in the present analysis. It stands to reason that ewe permanent environment could be more prominent at lambing because of variation due to pregnancy status and stage of gestation, which is not applicable to BCS at mating. These results highlight the need for more work on this topic to accurately estimate h^2 for BCS at lambing.

Mating weight had a genetic correlation of 0.68 with BCS at mating and 0.64 with BCS at lambing (Table 4.6). These strong correlations indicate a high genetic correlation of ewe body size with degree of fatness. These values are in strong agreement with literature which reports genetic correlations of 0.65 for BCS at mating and 0.63 for BCS at lambing with mating weight (Brown & Swan, 2014). Phenotypic correlations amounted to 0.37 between mating weight and BCS at mating and 0.32 between mating weight and BCS at lambing. Brown & Swan (2014) reported corresponding correlations of respectively 0.32 and 0.40 for Merinos. A phenotypic correlation of 0.33 was estimated between mating weight and pre-joining BCS (Walkom *et al.*, 2014b). Walkom *et al.* (2014b) reported phenotypic correlations with adult

body weight of 0.25 with mid-pregnancy BCS as 0.25 of and 0.46 with BCS at weaning. The genetic correlation between the two condition scores amounted to 0.66 with the corresponding phenotypic correlation amounting to only 0.31.

4.5.3.3 Genetic correlations with reproduction traits

Only twinning percentage did not have a significant negative genetic correlation with mating weight (Table 4.7). The unfavourable genetic correlations of reproductive traits with mating weight reported in this study suggest that, mating weight is of limited use as an indirect selection criterion for the reproductive traits analysed. Literature results suggest that genetic correlations of mating weight with reproductive traits would be expected to be favourable. Genetic correlations of ewe weight were 0.15 with number of lambs born per ewe mated and 0.40 with fertility (Safari *et al.*, 2005). Cloete *et al.* (2004) reported the genetic correlations with mating weight with number of lambs born as 0.13, with number of lambs weaned as 0.41 and with total weight weaned as 0.81. These differences may indicate that the flocks under investigation might have exceeded the minimum mating weight required for optimal reproduction. This study only reported a favourable correlation for twinning rate (0.01) with ewe mating weight. The rest of the traits had unfavourable correlations with mating weight on a phenotypic level (Table 4.7). These results are in general agreement with the literature as unfavourable phenotypic correlations of mating weight with fertility (-0.01), number of lambs weaned (-0.01) and litter survival (-0.03) were also reported by Walkom & Brown (2017). The same authors reported favourable correlations of body weight with pregnancy scan (0.03), fecundity (0.07) and number of lambs born (0.03) (Walkom & Brown, 2017). The environmental correlations of mating weight with reproductive traits were all favourable. An environment favouring mating weight will thus also favour the reproductive performance of the ewes. These results could not be verified against the available literature, but it stands to reason than an environment allowing ewes to be in a positive energy balance at mating will also promote reproduction.

The genetic correlations of ewe BCS at mating with the reproduction traits investigated were all negative except for twinning percentage per ewes lambed (Table 4.8). A nearly similar pattern can be seen in the work done by Walkom *et al.* (2016) who reported that most of the reproductive traits they studied were also negatively correlated with condition score. Walkom *et al.* (2016) reported negative genetic correlations for BCS with fertility at scanning (-0.15), fertility (-0.19), fecundity (-0.19), number of lambs born (-0.20), number of lambs weaned (-

0.19) and litter survival (-0.30). Phenotypic correlations reported for BCS at mating on the reproductive traits in this study were also negative (Table 4.7). Within the literature available to us there are reports of negative and positive phenotypic correlations. Walkom & Brown (2017) reported negative phenotypic correlations for the number of lambs weaned (-0.01) and litter survival (-0.02); with positive phenotypic correlations for pregnancy scan (0.01), fertility (0.01), and the number of lambs born (0.01). The environmental correlations were all positive for BCS at mating with the reproductive traits studied, suggesting that an environment leading to a higher BCS at mating would also allow a better reproduction rate. There were no comparable results in the literature.

BCS at lambing had negative genetic correlations with all the reproductive traits studied (Table 4.9). Walkom & Brown (2017) reported similar results. Genetic correlations of BCS at lambing with pregnancy scan (-0.22), fertility (-0.13), fecundity (-0.16), number of lambs born (-0.23), and number of lambs weaned (-0.23) were all negative. A possible explanation for these negative correlations of BCS at lambing with reproductive traits is that ewes which have higher condition scores at lambing might have suffered early embryonic mortality or did not conceive at all. Such ewes arguably partitioned more resources towards maintaining their body condition, resulting in a greater fatness level, as they did not need to sustain a pregnancy. Overall the genetic relationships between ewe body condition and reproduction traits are not well documented in literature. All of the reproductive traits studied had negative phenotypic correlations with ewe BCS at lambing (Table 4.9). Literature results suggested that BCS at lambing is zero and low positively related to fertility (0.00), number of lambs weaned (0.00) and litter size (0.06) (Walkom & Brown, 2017). In contrast, negative correlations were found for pregnancy scan (-0.12), fecundity (-0.14) and number of lambs born (-0.14). All environmental correlations for BCS at lambing with reproduction traits were negative (Table 4.9). It stands to reason that barren ewes will be in a better condition at this stage as they only have to maintain body weight. Ewes will use body resources to maintain pregnancy and to prepare for lactation resulting in a poorer body condition compared to their barren counterparts. Freer *et al.* (1997); Cannas *et al.* (2004); Rose *et al.* (2014) and Walkom *et al.* (2014b; a) all stated that barren ewes having a reduced metabolic demand for maintaining pregnancy, resulting in barren ewes becoming fatter than those using body reserves to maintain a pregnancy. Cloete (1994) allocated ewes to “good” or “poor” mothers and reported results that were, in broad terms, consistent with the results reported here.

4.6 Conclusion

The findings of this study are relevant, as many sheep farmers include body weight measurements into their management and selection regimes. Ewe body weight and condition scores were not good indications of the reproduction of individuals on a genetic basis. Thus body weight or blanket condition scores should not be used as indicator traits to select for reproduction in the flocks studied. It should also be considered that bigger ewes also have a higher maintenance requirement than smaller ewes. The role of mating weight and condition scores in assessing reproduction in SAMM and Dormer sheep thus requires further attention. This information is required to inform sheep producers with regard to sustainable aids to ensure welfare of animals while also promoting sustainable production practices.

4.7 References

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Chapter 5:

Ultrasound scanning figures and lambing rate of Merino-type ewes in relation to flock management and current flock selection

5.1 Abstract

Successful and viable sheep farming is based on a good base level of reproduction, as it is undisputedly agreed that the ultimate worth of any farm animal lies within its ability to reproduce. Year-to-year variation is common in reproduction, while reproduction is also constrained in maiden ewes. This study assessed ultrasound scanning as a proxy for observed reproduction records, quantified the effects of lambing year and ewe age on and estimated the repeatability of traits to predict current flock gains. The study was conducted on the Dohne Merino and SA Mutton Merino studs maintained on the Mariendahl experimental farm of Stellenbosch University. Data of number of lambs recorded per ewe scanned, number of lambs born per ewe lambing and embryonic losses per ewe scanned were available for respectively 7652 and 3364 ewe-year records of respectively 2338 and 1159 individual ewes lambing from 1990 to 2016. Ethical clearance was obtained from the Stellenbosch University ethical committee (ACU-2020-12955). ASReml was used to fit a series of mixed models to the data. Fitted fixed effects included lambing year and ewe age, while individual ewes within breeds were fitted as random to derive repeatability estimates for the traits analysed. Lambing year had a significant effect on all reproduction traits with values oscillating in both breeds. Number of embryos lost per ewe present at lambing were low (0.00 to 0.05) in both breeds. However, 2001 marked much higher embryonic losses of 0.115 in Dohne Merinos and 0.149 in SAMM ewes. Two-year-old ewes were proportionally more likely to be barren than their mature contemporaries irrespective of breed. For Dohne Merinos, 15% of 2-year-olds scanned barren compared to 8.3% of mature ewes (Chi-square=70.3, degrees of freedom=1; $P<0.01$). SAMM figures were 19.8% for two-year-olds vs. 8.5% in mature ewes (Chi-square=84.8, degrees of freedom=1; $P<0.01$). Number of lambs scanned per ewe available was moderately repeatable at 0.11 to 0.16, depending on breed and modelling. A comparable range of 0.16 to 0.19 was found for number of lambs born per ewe lambing. Repeatability estimates for embryo losses were not significant. Scanning and lambing rate were highly correlated on the ewe level, suggesting that scanning figures would act as a good proxy for lambing rate in the absence of complete lambing data. Reproduction was influenced by fluctuating environmental

factors and varied annually. Age effects were consistent with literature results, confirming that an optimal flock structure would contribute to a desirable reproductive output. Results indicated that the occurrence of embryo losses was random and not meaningfully related to either fixed or random effects. Moderate repeatability estimates for reproduction traits would support low-moderate current-flock gains for scanning and lambing rate. Ultrasound scanning may thus be used as a valuable management aid to optimize reproduction on an on farm level when detailed reproduction records are not kept.

5.2 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 maximize the efficiency of farming operations (Terblanche, 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, to adapt to environmental change, and to meet their economic obligations (Van Wyk *et al.*, 2003). Reproductive performance is particularly important when lamb/mutton production is the primary objective, making of this the most important economical trait complex in sheep production (Fourie & Heydenrych, 1983; 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). While it is clear that a successful and viable sheep industry is based on a good base level of reproduction, it is also undisputedly agreed 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 reproduction potential of a sheep flock (Fourie & Heydenrych, 1983). However, reproduction is considered a composite trait, with conception rate, multiple birth rate, and lamb survival as components (Cloete & Heydenrych, 1986). It should also be noted that other hard-to-measure traits also contribute to composite reproduction traits, i.e. oestrus activity, ovulation rate, embryo viability, etc. Key factors defining the efficiency of lamb production in any environment are reproduction

rate and lamb survival (Falconer & Mackay, 1996; Snyman *et al.*, 1997). Reproduction could be enhanced by increasing the number and weight of lambs weaned per ewe per year, as well as minimizing ewe and lamb wastage (Duguma *et al.*, 2002). Given the complexity of the reproduction process there are numerous situations that could prevent fertilization and/or terminate pregnancy (Cloete, 1972). As in other mammals, the ewe carries the burden of the reproductive process, as she provides the environment for fertilization, the development of the foetus until parturition as well as providing post-partum maternal care until weaning (Cloete, 1972). Scanning of ewes during pregnancy will give one an estimate of conception, as well as the anticipated litter size for each ewe (often only recorded as single vs. multiple), thus allowing for the intensification of management in 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 exhaustive record-keeping.

Measures of female reproductive success are related to age in large mammals (Festa-Bianchet, 1988). The efficiency of a breeding flock depends largely on the age structure of the breeding ewes within that flock (Turner & Young, 1969). The age at first breeding/lambing, litter size, the length of a ewe's productive life as well as the 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) clearly established a general pattern of change in reproductive performance with the age of the ewe. This and subsequent literature reported that reproduction potential, expressed as litter size as well as 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; De Haas & Dunlop, 1969; Mullaney & Brown, 1969; Olivier, 1982; Fourie & Heydenrych, 1983; Cloete & Heydenrych, 1986). Two-year-old ewes are characterized 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 source of reproductive wastage reduces production efficiency is not well documented in South Africa. Alostia *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 a major objective in the local small stock industry at present (Cloete *et al.*, 2017). The exclusion of a measure of reproduction in selection programs could be due to the difficulty to record 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 more easily be measured and reported, while it is also considered to have a higher heritability than other reproduction traits (Safari *et al.*, 2005). These advantages leads to litter size being favoured as a selection criterion (Afolayan *et al.*, 2008). With direct selection for litter size it was suggested by Afolayan *et al.* (2008) that 80% of the overall response in total weight weaned by a ewe would be attributable to litter size. Such selection is expected to be more efficient in overall gains per generation per year than to combine traits into an appropriate selection index (Afolayan *et al.*, 2008). It needs to be considered that there is a fine balance between production, reproduction, fitness and longevity traits when a breeding plan is considered (Zishiri *et al.*, 2013; Bunter *et al.*, 2019).

The objective of selection for an increased reproduction could be two-fold: 1. Selection of replacement progeny of both sexes to improve reproduction in future generations; and 2. Selection in the current flock to ensure that only the most productive ewes are retained on the farm. Option 1 hinges on the heritability of the reproductive trait to be improved, while repeatability is the parameter of importance in Option 2. Cloete *et al.* (2004) demonstrated that reproduction traits could be improved quite markedly by genetic selection, despite its low heritability often touted as a constraint to genetic progress. Cloete & Heydenrych (1987) also studied the repeatability of reproduction traits and made recommendations to achieve current flock gains. Although repeatability is predicted to be low to moderate for most reproductive traits, one will still be able to improve genetic capability if selection is done correctly (Cloete *et al.*, 2009; Hatcher *et al.*, 2010). Hatcher *et al.* (2011) reported that lamb survival can be increased with the correct selection programs. This study focusses on current flock gains achievable by scanning, as was envisaged by (Fourie & Cloete, 1993).

Against this background, the multiple objectives of this study were to: 1. Study the outcomes of ultrasound scanning in relation to observed reproduction records; 2. Quantify the effects of lambing year and ewe age on scanning figures and lambing rate; and 3. Derive repeatability estimates for scanning traits and lambing rate to enable recommendations with reference to current flock selection.

5.3 Materials and Methods

5.3.1 Animals and location

The study was conducted on the Merino, Dohne Merino and SA Mutton Merino studs maintained on the Mariendahl experimental farm of the Stellenbosch University, as described by (Cloete *et al.*, 1999, 2001). Data were available for varying periods, namely 1990 to 1992 for Merinos and 1990 to 2016 for the other breeds. There was an interval in the latter breeds when no scanning data were recorded during 1993 and 1994. In total, the database used included 11256 repeated scanning records of 3635 ewes across breeds that were available for analysis.

The farm Mariendahl (33° 55' 59"S; 18° 49' 18"E) is located about 14 km outside of Stellenbosch in the Western Cape province of South Africa. The experimental farm is 375 ha in size and situated at 165m above sea level. The area utilised by the sheep are on relatively even terrain with only gentle slopes and is largely devoid of trees. The farm falls within the Mediterranean region of Western Cape and is characterised by hot, dry summers and mild, wet and windy winters. The annual precipitation is around 640mm with the minimum winter temperature being around being 5 °C and the maximum summer temperatures around 30 °C. Occasional frost may rarely occur during winter after the passing of a cold front. During this study, the grazing available varied from crop stubble, clover pastures to irrigated pastures consisting of ryegrass, white clover and kikuyu, depending on the season of usage.

The breeding season started during mid-October and ended during mid-November after a 28 to 32-day mating period during the course of this study. Lambing therefore 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 5ha irrigated paddocks. After the mating period the ewes were grouped together in groups of approximately 150 ewes and moved to grain stubble camps (30ha) where they stayed until a week before lambing was due. All ewes were subjected to ultrasound scanning by a veterinarian using a Mindray DP 30V 7.5 MHz linear transducer once during pregnancy, usually during the first week of January. This timing made scanning about 45 days after the rams were removed from the ewe flocks. After scanning of the ewes took place they were grouped on expected pregnancy status and managed accordingly, they would go back to the camps with the crop stubble. The objective of scanning was to determine if specific ewes had: 1. Multiple or single foetuses; 2. If they were barren. The vast majority of ewes that scanned barren were sold, while the remaining

ewes were divided according to their scan status (single/multiple) thus meaning that ewes were pooled across sire groups. Since the operator was asked to only identify multiples without regarding the actual number of lambs carried, the written records indicated two lambs in the vast majority of cases. However, there were also a number of cases where triplets were differentiated from twins.

All the ewes lambbed in small, irrigated kikuyu paddocks of approximately 2 ha in groups of 20-30. Ewes were separated on breed and the expected birth rate (single or multiple) at this stage. Lambing rounds to mark new-born lambs and to identify them with their mothers took place twice daily throughout at 08:00 and 16:00 throughout lambing. The identification of lambs with their dams allowed for the pedigree information to be derived while birth type, sex, dam age and birth weight were recorded simultaneously. These actions also allowed the derivation of reproduction 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 are about 10ha with 70 ewes in them.

During the reconciliation of the lambing records with scanning records it became clear that ewes scanned as twins commonly had triplets and up to quadruplets at birth. This result was not unexpected as the instruction to the operator 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 actually produced multiple lambs. As this outcome would also involve a net gain of foetuses (i.e. 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.

5.3.2 Statistical analyses

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 involved all three breeds. However, the records obtained from Merino ewes were dropped from further analyses, as the breed was represented by too few records for meaningful further analyses compared to the other breeds (see Table 5.1).

Three reproduction traits were considered, namely number of embryos scanned per ewe present at scanning, number of lambs born per ewe present at lambing and the number of embryos lost per ewe present at lambing as detailed above. As the breeds were managed separately, these records were analysed within breeds. ASReml (Gilmour *et al.*, 2015) was used to fit a series of mixed models to the data. Fixed effects included were lambing year (1990-1992; 1995-2016) and ewe age (2-6+ years). 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). 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 number of embryos lost per ewe present at lambing (see Table 5.3) only number of embryos scanned per ewe present at scanning and 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 to that present at the level of individual ewes, 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 2-year-old ewes than in their mature flock-mates. These frequencies were compared within breeds by using the online Chi-square test made available by Preacher (2001).

Finally, ethical clearance for the study was obtained from the Stellenbosch University ethical committee; with clearance number ACU-2020-12955.

5.4 Results

5.4.1 Scanning figures and outcomes

Across breeds, there were 11256 repeated scanning records of 3635 ewes, amounting to about 3.1 records per ewe. There were some differences between breeds, with 7652 scanning records of 2338 Dohne Merino ewes, or 3.28 records per ewe on average. Corresponding figures were 3364 scanning records, 1159 ewes and 2.90 records per ewe in SAMM ewes and 240 scanning records, 138 ewes and 1.74 records per ewe in Merinos. 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 5.1). Between 3.4% (Merinos) and 8.7% (SAMMs) scanned with multiples had single lambs at birth and presumably lost one lamb during gestation. Only a single Dohne Merino ewes scanned with a multiple was barren at lambing. Between 0.7% (Dohne Merino) and 1.1% (SAMM) 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 singles at lambing (between 82.2% in SAMMs and 95.7% in Merinos). No ewes scanned with singles were barren at lambing but between 1.7% (Dohne Merino) and 2.2% (Merino) ewes were not recorded further. Only 10 Dohne Merino and SAMM ewes that scanned barren had further records, while >99% of ewes scanned barren were not recorded further. The vast majority of these ewes were presumed to be culled on the basis of their reproductive status as was intended and could therefore not contribute to further analyses.

Table 5.1. Scanning figures per scanning classification and breed in the Mariendahl Dohne Merino, SAMM and Merino flocks

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

5.4.2 Descriptive statistics

Means for number of lambs scanned per ewe available at scanning ranged from 1.41 in SAMM ewes to 1.45 in Dohne Merino ewes, with a coefficient of variation (CV %) of just below 50%. Number of lambs born per ewe available at lambing amounted to 1.64 in SAMM ewes to 1.67 in Dohne Merino ewes with CV % just exceeding 33%. In contrast, means for embryo losses were low and characterised with CV % that exceeded the mean by a factor of at least 4. These results are presented in Table 5.2.

Table 5.2. Descriptive statistics for 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 SAMM ewes

Breed and trait	Number of records	Mean±SD	Range	CV %
<u>Dohne Merino:</u>				
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
<u>SAMM:</u>				
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

SD : Standard Deviation

CV % : Coefficient of Variation

5.4.3 Effects of lambing year on ewe reproduction

Lambing year had a significant effect on all reproduction traits in both breeds. Number of lambs scanned per ewe available and number of lambs born per ewe present at lambing oscillated between respectively 1.3 and 1.5 and 1.6 and 1.8 in Dohne Merino ewes (Figure 5.1a). There was a suggestion that both reproduction traits went through a slump during the early 2000's from maxima initially during 1992 and towards the end of the recording period during 2017. In contrast, number of lambs scanned per ewe available declined from initially around 1.5 to 1.7 to 1.1 to 1.4 in the last years recorded in the SAMM flock (Figure 5.1b). The corresponding trend across birth years for number of lambs born per ewe present at lambing declined from around 1.7 to 1.9 initially to 1.4 to 1.6 in the later years. Number of embryos lost per ewe present at lambing were mostly in the 0.00 to 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 5.1a and 5.1b). Dohne Merino ewes also had a relatively poor year in 2003 with a figure of 0.074. Embryo losses in both breeds were again comparatively high in 2006, amounting to 0.073 in Dohne Merinos and 0.138 in SAMMs. Embryo losses in SAMM ewes also exceeded 0.1 in 2008, at 0.114. Apart from some years with relatively high embryo losses in both breeds, embryo losses appeared to be comparatively low in the initial years recorded prior to 1999 to 2000 in both breeds. It should also be noted that means for embryo losses in some years did not exceed zero, based on the standard errors provided in Figures 5.1a and 5.1b.

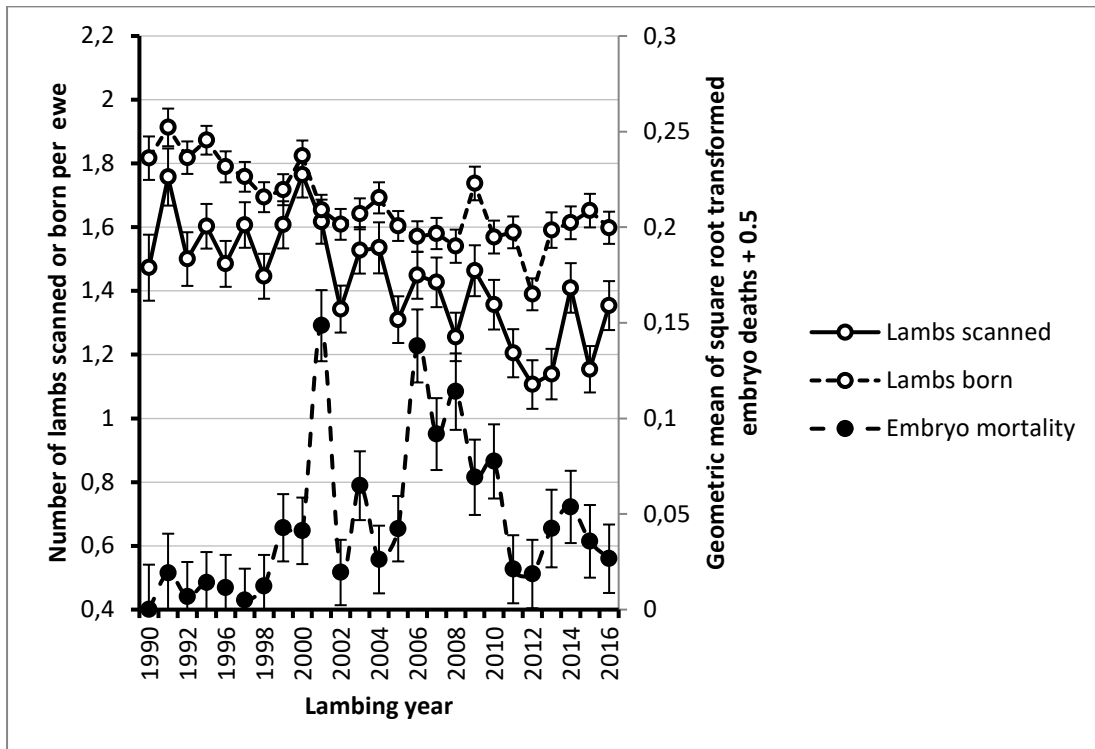
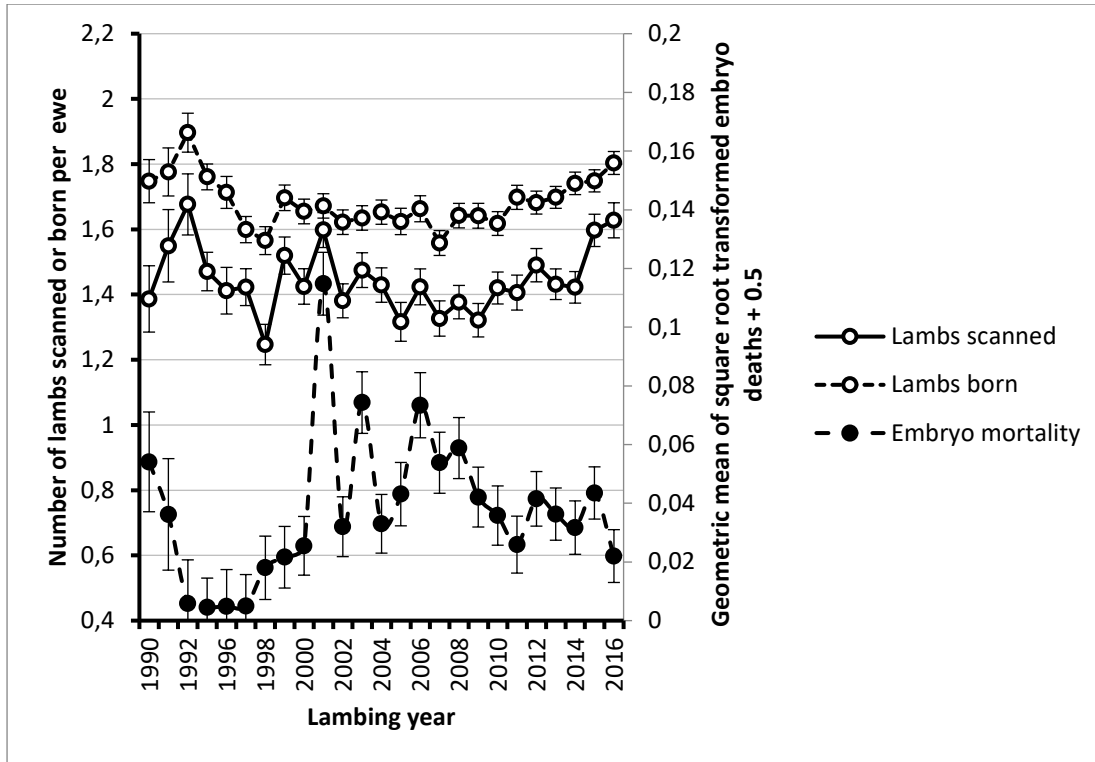


Figure 5.1. Line graphs representing the effects of lambing year on the number of lambs scanned per ewe available, number of lambs born per ewe present at lambing and number of embryos lost per ewe present at lambing in Dohne Merino (a) and SAMM (b) ewes (SE's are around means)

5.4.4 Effects of ewe age on reproduction

The frequency of 2-year-old ewes that scanned barren was higher than in their mature contemporaries in the flock in both breeds. In the Dohne Merino breed, a proportion of $283/1889=0.150$ 2-year-old ewes scanned barren compared to $478/5763=0.083$ in mature ewes (Chi-square=70.3, degrees of freedom=1; $P<0.01$). Corresponding figures for the SAMM breeds were respectively $196/991=0.198$ vs. $201/2373=0.085$ in mature ewes (Chi-square=84.8, degrees of freedom=1; $P<0.01$).

Number of lambs scanned per ewe available and number of lambs born per ewe present at lambing increased significantly from 2-year-old to 4-year-old ewes in both breeds ($P<0.05$; Figure 5.2a and 5.2b). Subsequent differences between age groups were generally not significant, but there was an indication that reproduction will start declining again in the 6+-year-old ewes for both traits in SAMM ewes and for number of lambs scanned in Dohne Merino ewes. The graph for number of lambs born per ewe present at lambing trended above that of number of lambs scanned per ewe available for both breeds. Square root transformed embryo mortality per ewe lambled was independent of ewe age in both breeds ($P>0.20$; Figure 5.2) with no clearly discernible age trend.

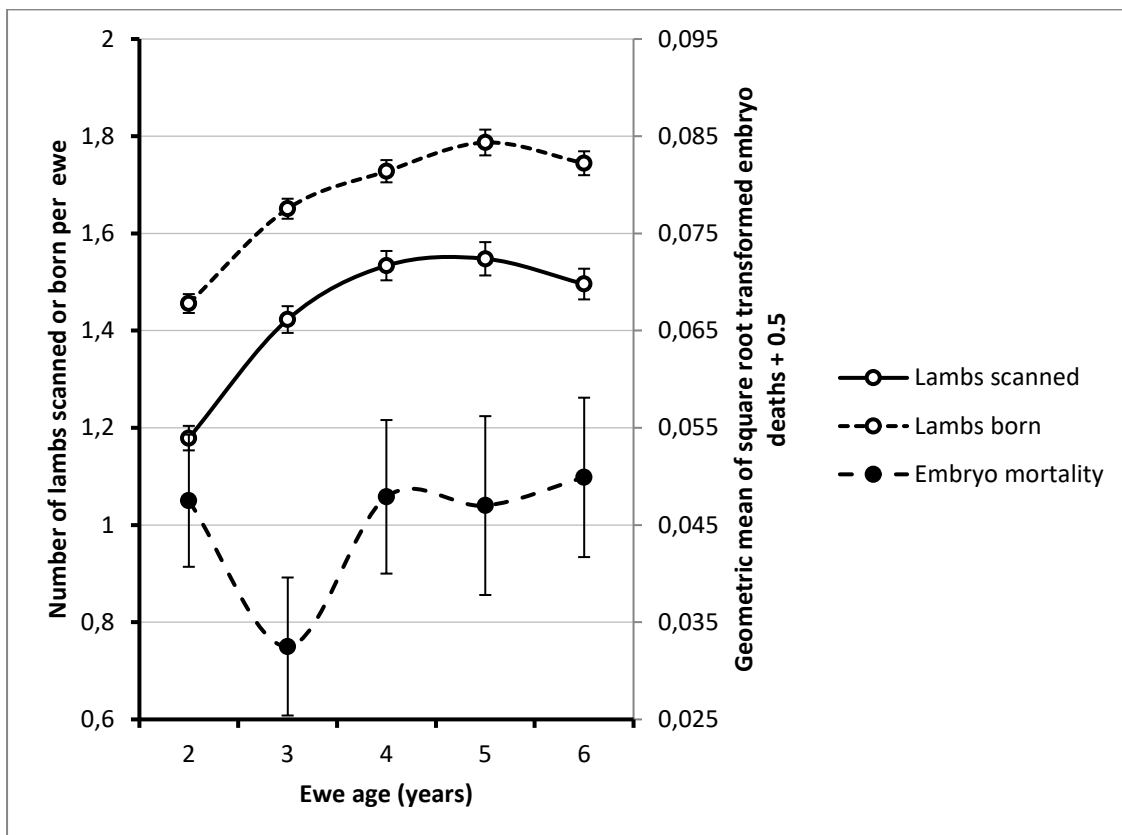
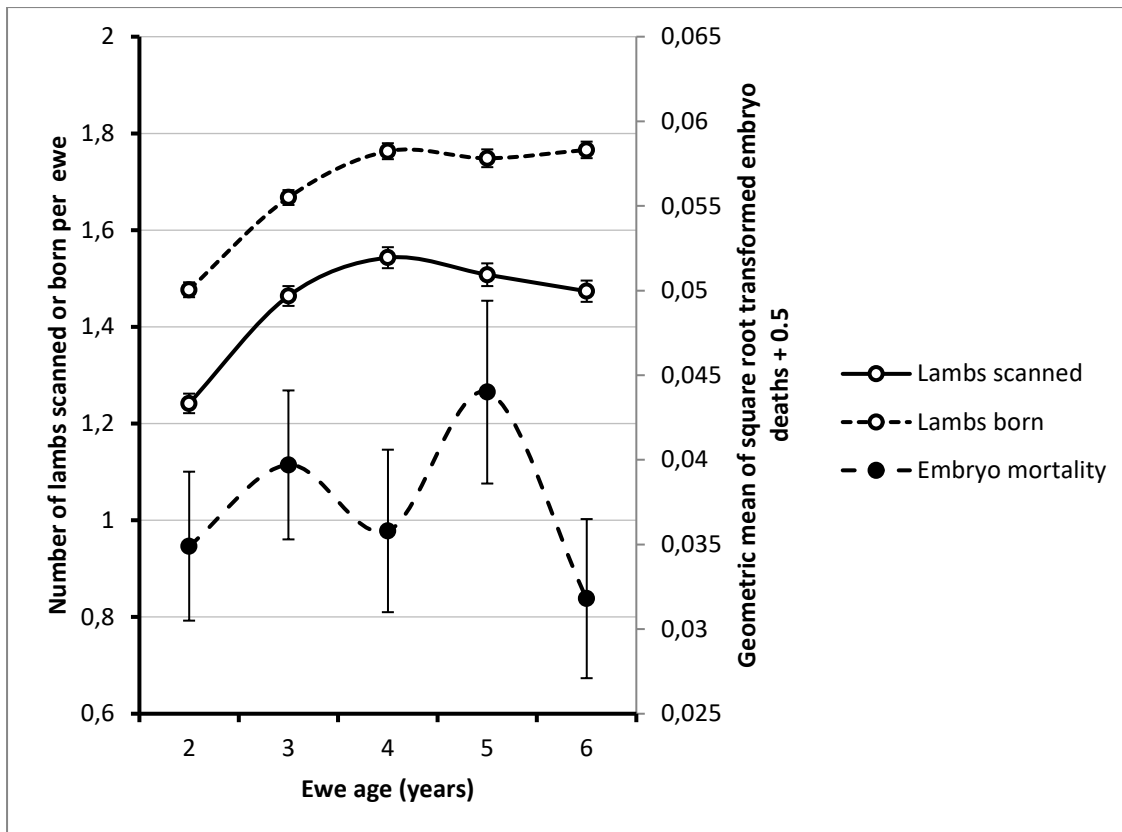


Figure 5.2. Line graphs representing the effects of ewe age on the number of lambs scanned per ewe available, number of lambs born per ewe present at lambing and number of embryos lost per ewe present at lambing in Dohne Merino (a) and SAMM (b) ewes (SE's are around means)

5.4.5 Ewe and service sire effects as well as repeatability of performance

The single-trait variance components and ratios for number of lambs scanned per ewe available at scanning, lambs born per ewe present at lambing as well as square root transformed number of embryos lost per ewe present at scanning are provided in Table 5.3 for Dohne Merino and SAMM ewes. Based on repeated ewe records for 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 below 0.05, all estimates were significant at more than double the corresponding standard error. Repeatability estimates for number of lambs born per ewe present at lambing were 0.17 for Dohne Merino ewes and 0.16 for SAMM ewes (Table 5.3). 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 to the other reproduction traits, neither between-ewe nor between-service sire variance ratios were significant for number of embryos lost per ewe present at lambing.

According to the results in Table 5.3, the occurrence of embryo losses was random and not conclusively related to ewes or to service sires. These analyses were therefore followed up with breed specific two-trait analyses involving number of lambs scanned per ewe present at scanning and number of lambs born per ewe present at lambing (Table 5.4). Repeatability components from the two-trait analyses were very similar to corresponding single-trait results in Table 5.3 for Dohne Merinos and number of lambs scanned per ewe available at scanning in SAMMs. In contrast, the repeatability of number of lambs born per ewe present at lambing in SAMM ewes was 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. It is notable that service sire variance ratios were similar to single-trait estimates for the number of lambs scanned per ewe available at scanning in both breeds (Tables 5.3 and 5.4). However, service sire effects for the number of lambs born per ewe present at lambing were increased from 0.01 to 0.03 in Dohne Merinos and from 0.00 to 0.02 in SAMMs. These results imply that scanning and lambing performance were practically the same trait on 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 of 0.78 ± 0.01 in Dohne Merinos and 0.77 ± 0.01 in SAMMs between these traits. The between-service sire correlation between the two traits

exceeded 0.96 in both breeds. The phenotypic correlations between the two traits were also high at around 0.80.

Table 5.3. Single-trait variance components and ratios for 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 SAMM ewes

Breed, variance components and ratios	Trait		
	Number of lambs scanned	Number of lambs born	Number of embryos lost
Dohne Merino			
<u>Variance components:</u>			
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
<u>Variance ratios:</u>			
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
SAMM			
<u>Variance components:</u>			
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
<u>Variance ratios:</u>			
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

Table 5.4. Two-trait variance components and (co)variance ratios for number of embryos scanned per ewe present at scanning and number of lambs born per ewe present at lambing for Dohne Merino and SAMM ewes

Breed, (co)variance components and ratios	Trait	
	Number of lambs scanned	Number of lambs born
Dohne Merino		
<u>Repeatability in bold on the diagonal and the between-ewe correlation below the diagonal:</u>		
Number of lambs scanned	0.111±0.012	
Number of lambs born	0.950±0.016	0.167±0.013
<u>Between-service sire variance ratios in bold on the diagonal and the service sire correlation below the diagonal:</u>		
Number of lambs scanned	0.044±0.008	
Number of lambs born	0.979±0.016	0.035±0.007
<u>Phenotypic variance components (σ^2_p) in bold on the diagonal and the phenotypic correlation below the diagonal:</u>		
Number of lambs scanned	0.4333	
Number of lambs born	0.808±0.005	0.4290
SAMM		
<u>Repeatability in bold on the diagonal and the between-ewe correlation below the diagonal:</u>		
Number of lambs scanned	0.126±0.020	
Number of lambs born	0.963±0.023	0.190±0.021
<u>Between-service sire variance ratios in bold on the diagonal and the service sire correlation below the diagonal:</u>		
Number of lambs scanned	0.034±0.010	
Number of lambs born	0.968±0.050	0.020±0.008
<u>Phenotypic variance components (σ^2_p) in bold on the diagonal and the phenotypic correlation below the diagonal:</u>		
Number of lambs scanned	0.4433	
Number of lambs born	0.799±0.007	0.4079

5.5 Discussion

5.5.1 Scanning figures and outcomes

According to Table 5.1, ultrasonic methods accurately predicted multiple (89 to 95%) and single (82 to 96%) births in all three breeds studied. The accuracy of barrenness diagnostics could not be confirmed as the bulk of barren ewes (99 to 100%) were not followed to lambing. However, Plant (1980) used a rectal probe to accurately diagnose barrenness in 96.9% of ewes in the flock. With recent advances in ultrasonography, there is no reason to believe that the accuracy in the flocks studied would be worse. Trapp & Slyter (1983) determined that pregnancy diagnosis using ultrasonic devices are better for the animal welfare and are still very accurate. They reported a correct diagnosis of multiples with an accuracy of 89.1% to 98.8%, which closely corresponded with the figures reported in Table 5.1. As reported in the current study, the number of lambs scanned per ewe available at scanning

ranged from 1.41 in SAMM ewes to 1.45 in Dohne Merino ewes, with a coefficient of variation (CV %) of just below 50%. White *et al.* (1984) reported a higher range of 1.50 to 1.80 lambs scanned per ewe present in English sheep breeds at an accuracy rate of 95% - 99%.

5.5.2 Descriptive statistics

In the present study means for number of lambs scanned per ewe available amounted to 1.45 in Dohnes and 1.41 in SAMMs with CV % exceeding 45% (Table 5.2). No CV % were available for number of lambs scanned. Safari *et al.* (2005) did report CV % for lambs born per ewe joined (52.7 ± 2.6) and embryo survival (26.8 ± 0.4). The corresponding means for number of lambs born per ewe available at lambing amounted to 1.64 in SAMM ewes to 1.67 in Dohne Merino ewes with CV % just exceeding 33%. This is in agreement with Safari *et al.* (2005) who reported a CV % for number of lambs born per ewe at lambing to be 34.1 ± 0.6 in Australian Merinos. The study done on Sabi sheep reported CV % values of 36.5% for fertility and 30.4% for prolificacy (Matika *et al.*, 2001). The generally higher values for number of lambs born compared to number of lambs scanned in this study stem from two causes, namely: 1. Although there were occasional instances when triplets were identified in the scanning records, the primary intention was only to discern between singles and multiples when scanning took place as reflected by a substantial number of triplets and a quadruplet in ewes scanned as multiples; 2. Scanning figures includes the ewes scanned barren, the vast majority of which were not maintained until lambing and thus not included in the lambing records. The number of lambs born per ewe available at lambing was much higher than in previous studies. Fourie & Cloete (1993) and Kleemann & Walker (2005) reported lower fecundity percentages ranging from 122 to 140% for the above mentioned breeds. An older paper by Knight *et al.* (1975) reported even lower performance levels in their flocks compared to the figures reported by Fourie & Cloete (1993). From the literature sources cited above, a clear trend can be seen, with the fecundity increasing with time. This may be due to genetic gain as time progressed, but the impact improved managerial practices and intensification cannot be ruled out. The two breeds in question are also known for high fertility (Campher *et al.*, 1998; SA Dohne Merino Breeders society, 2019). These two breeds are exceptionally well adapted to the climate according to Van der Merwe *et al.* (2019), because they are developed within the same region by the South African Department of Agriculture. Most of the barren ewes were not maintained until lambing, which made the selection process very strict in terms of reproduction.

From Table 5.1, it was 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. The study done by Turner & Dolling (1965) yielded similar results, with proportion of ewes failing to lamb ranging from 8 to 18%, with Kleemann & Walker (2005) reporting 13.2%. Both of these studies used Merino sheep. Knight *et al.* (1975a) reported a much higher loss of 20.1 to 26.4% owing to barrenness in Merino and Corriedale ewes. The low levels of embryonic losses of 5 to 6% in this study (Table 5.1) are in general agreement with literature (Dolling & Nicholson, 1967; Alostia *et al.*, 1998; Kleemann & Walker, 2005).

5.5.3 Effects of lambing year on ewe reproduction

Marked year-to-year variation in the reproduction of sheep, as shown in Figure 5.1, is not surprising. Mullaney & Hyland (1967) reported in their study that there was marked seasonal variation in reproductive performance of Australian sheep flocks. These changes were not in the same direction year after year. Mullaney & Hyland (1967) related these results to variable weather conditions. A study done on Horro sheep showed that year had a significant effect on reproduction (Abegaz *et al.*, 2002). Thus 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, 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 a situation such as in the Dohne Merino flock, where the year-to-year variation did not follow a clear trend (Figure 5.1a). However, changes in management of the flocks could potentially also affect reproductive potential of ewes. This could be a plausible explanation for the decline in the number of lambs scanned per ewe available from around initially 1.5 to 1.7 to reach 1.1 to 1.4 in the last years recorded for the SAMM flock. The corresponding trend across birth years for number of lambs born per ewe present at lambing declined from around 1.7 to 1.9 initially to 1.4 to 1.6 in the 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 to 6% (Table 5.2). However, embryonic losses exceeded 10% in quite a number of lambing years in both breeds (Figure 5.1). The reason of the higher levels of embryonic losses in some years is not apparent. In the late 1990 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 ranged from 0.034 to 0.053 in Australian Merinos. Alosta *et al.* (1998) also reported embryonic losses to be 0.172 in four sheep breeds (Suffolk cross, Cheviot, Grey-face and Mountain). Both of these studies sacrificed animals to do an abattoir survey on the ewes' reproductive tract. 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 source of these losses. In the current study it is indicated that the year of lambing did had an obvious effect on embryonic losses, while the source of these losses is not clear. Further studies are therefore needed to better understand the cause of such losses.

5.5.4 Effects of ewe age on reproduction

Two-year-old ewes were proportionally more likely to be barren than their mature contemporaries. This result 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 that for number of lambs scanned per ewe available for both breeds (Figure 5.3). This result indicates that there was a net gain in embryos which is not biologically feasible. This result can be traced back to the reasons already stated under the Descriptive statistics section. Kleemann & Walker (2005) reported a 9.3% decline in lambs born compared to records obtained from ultrasonography, thus reflecting a net loss.

The proportion of barren ewes was higher in 2-year-old ewes compared to mature ewes aged 3+ years. Cloete & Heydenrych (1986) accordingly reported that conception rate improved from 2-year-old ewes to mature ewes. In contrast to the bulk of the literature, including the present results, Kleemann & Walker (2005) reported that neither age of the ewe nor year affected fertility significantly. Other contradictory results were reported by Mullaney & Brown (1969a) in Merino sheep, where a steady decrease in lambing rate were reported with an increased ewe age. Results from the other breeds reported in the study by Mullaney & Brown (1969a), however, agree with the findings of the present study.

Ewe reproduction improved from 2 to 4 years and plateaued as ewes got older, before there was a suggestion of declining again in ewes aged 6+ years (Figure 5.2). 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 lambled) with the age of the ewe, with

six year old ewes having the highest fecundity. Other literature also strongly 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). Optimal flock age structure is thus of great importance to ensure optimal economical returns from self-replacing ewe flocks. It is well documented in literature that ewe body weight has an effect on reproductive performance (McLaughlin, 1970; Molina *et al.*, 1994; Gordon, 1997; Snyman *et al.*, 1998a; Vatankhah & Salehi, 2010; Zishiri *et al.*, 2013; Aktaş *et al.*, 2015). Aktaş *et al.* (2015) reported that younger ewes had lower body weights compared to 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) (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 not be studied.

With reference to the suggestion that reproduction will start declining again in the 6+-year-old ewes for both traits in SAMM ewes and for number of lambs scanned in Dohne Merino ewes, it is notable that most previous studies investigated more ewe age groups than the current study. However, it was clear that a decline as 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 6 years, this result may be of a greater academical than practical value.

The square root transformed embryo mortality per ewe lambled was independent of ewe age in both breeds ($P > 0.20$; Figure 5.2). Kleemann & Walker (2005) similarly reported that total reproductive loss did not vary significantly with either age of the ewe or season of mating.

5.5.5 Ewe and service sire effects as well as repeatability of performance

Repeatability estimates of 0.15 to 0.19 for number of lambs born per ewe lambled (Tables 5.3 and 5.4) would be able to support moderately-low current flock gains in the sheep flocks used in this study. 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 Merino sheep. Other

literature sources reported lower repeatability estimates for the number of lambs born per ewe lambled. Using crossbred sheep, Dzakuma *et al.* (1982) reported a repeatability estimate of 0.14. 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). Bunter *et al.* (2020) reported a repeatability estimate of 0.10 for litter size in Merinos. In a study on Dormers, Van Wyk *et al.* (2003) reported a repeatability estimate of 0.133 for number of lambs born per ewe exposed. Parental half-sib repeatability estimates for ewe prolificacy (defined as number of lambs born per ewe at lambing) and fecundity (defined as number of lambs born per 100 ewes exposed) respectively ranged from 0.11 to 0.19 and 0.12 to 0.13 (Hansen & Shrestha, 1997) in three different sheep breeds (Canadian, Outaouais and Rideau).

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 fetuses per ewe joined. A more recent, and with half a million of records the most comprehensive to date, study done by Bunter *et al.* (2020) 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.

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 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 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) 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 that is in better agreement with the current study, of 0.001 for litter size.

In contrast to the other reproduction traits neither between-ewe nor between-service sire variance ratios were significant for number of embryos lost per ewe present at lambing

(Table 5.2). The occurrence of embryo losses was thus random and not conclusively related to either ewes or to service sires.

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 number of lambs scanned and 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 5.4), 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 the number of lambs scanned were highly correlated. Genetic correlations ranged from 0.88 ± 0.03 to 1.0 ± 0.01 and phenotypic correlations were between 0.80 ± 0.00 and 0.92 ± 0.00 (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. 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 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 number of lambs scanned possibly captured some between-ewe variance in barrenness, on which information in number of lambs born was very scant as the large majority of barren ewes were not recorded post scanning.

It was similarly clear from the environmental correlation in Table 5.4 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 the lambing data is not complete with regards to lambs born or the number of lambs born dead as mentioned in the last paragraph. In instances like this if there is scanning data available it can be used to compensate for this loss; although it cannot replace the lambing data it can help with predictions. With this high correlation between the two traits it enables the farmer to predict with a good accuracy the number of lambs he expects to be born. This will aid him in the management aspects of the flock with nutrition (fodder flow) as well as financial planning.

5.6 Conclusion

Reproduction was influenced by fluctuating environmental factors, this varied annually. Making management one of the most important strategies to ensure an excellent lamb crop. Age effects confirmed that an optimal flock structure would contribute to a desirable reproductive output. Younger ewes require better management to ensure a better lambing season, as they have a reduced reproduction potential when compared to older ewes. Young ewes will always be part of a well-balanced flock structure, thus giving them the best opportunity during their first reproductive cycle is of outmost importance. Results indicated that the occurrence of embryo losses was random and not meaningfully related to either year of lambing or the age of the ewe, or random effects. The scan data that was used to calculate the embryonic losses were not 100 percent accurate, due to ewes being culled before lambing based on scanning/pregnancy status with their outcome of mating/fertilization not being known. With regards to scanning there will always be a human error involve, as the scanning is done by a person. Making scan errors a real possibility, even though they are few and far between this also might have had an effect on the outcome of the data. Moderate repeatability estimates for reproduction traits would support low-moderate current-flock gains for scanning and lambing rate. The high genetic and phenotypic correlation between the number of lambs born and the number of lambs scanned, confirms that scanning - and lambing data would supply the same information. Ultrasound scanning may thus be used as a valuable management aid to optimize reproduction on an on farm level when detailed reproduction records are not kept. This data is more helpful if record keeping is done properly up until weaning of the lambs. Only taking scanning and lambing records into account when culling animals will lead to problems in one's selection program. Incorporating records up until weaning would maximize the accuracy of genetic evaluation for reproductive traits of ewes. Taking all of the reproduction records of an ewe into account will lead to culling the correct animals and having a better selection program.

5.7 References

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Chapter 6:

Conclusions and recommendations

6.1 Relevance

The South African sheep industry needs information on potential tools for managerial decision-making to ensure that production remains efficient, but also be aligned with consumer expectations with reference to sustainable and ethical production practices. This study was designed to investigate the utility of two managerial tools, namely ewe body condition scoring and ultra-sound diagnosis of reproductive status in ewes. Information needed for the study is not routinely recorded on South African sheep flocks, and the data had to be sourced from resource flocks under constitutional control to make inferences as to how such information may contribute to effective sheep farming in South Africa.

First of all, all the findings of this study are relevant and pertinent to current best practices, as many sheep farmers already consider body weight measurements in their management and selection regimes. Many farmers participating in performance recording also already record aspects of reproduction in the flocks they manage (Schoeman *et al.*, 2010). It would thus be feasible to additionally develop a framework to allow the recording of scanning figures and condition scores as a part of data supporting ewe reproductive management.

6.2 Environmental effects

All of the studies showed that mating weights, condition scores and scanned reproductive performance were markedly affected by fluctuating environmental factors, such as differences between years, stemming from a combination of climatic and seasonal effects as well as management decisions (Chapters 3, 4 and 5). Although it is difficult to plan for unpredictable and transient year effects, it is important to model it statistically for the environmental variation accounted for. Ewe age effects on scanned reproductive performance (Chapter 5) confirmed that an optimal flock structure would contribute to an improved reproductive output. This study, with support from previous local and international studies, suggests that no more than five ewe age groups should normally be maintained. This structure allows for adequate flock reproduction, while not extending the generation interval on the ewe side appreciably. There is scope for studies involving only four age groups, specifically when

dealing with fairly productive resource flocks, such as those studied. It was implied that young ewes (two-year-old) require better management to allow for their needs to still grow, while also maintaining pregnancy and lactation. Young ewes will always be part of a well-balanced flock structure (this is unavoidable), thus giving them the best opportunity by using managerial aids such as ultrasound scanning and body condition scoring during their first reproductive cycle is advisable.

Results on ultrasound scanning indicated that the occurrence of embryonic losses was quite random and not conclusively related to either year of lambing or the age of the ewe, as well as to random ewe effects. The scan data that was used to calculate the embryonic losses were not optimal for an exhaustive scientific assessment on the benefit of scanning, as the vast majority of ewes scanned barren was culled before lambing with the outcome of mating/fertilization not being explicitly known. Ultrasound scanning is well adapted to such a management regime and is extensively used in this capacity (see Bunter *et al.*, 2016), as was also proposed by Fourie & Cloete, (1993). The derivation of genetic parameters from a resource flock where scanned performance could be related to actually lambing records would arguably have been better from a scientific perspective.

6.3 Repeated ewe effects and genetic parameters

In general, it was clear that random ewe effects were present for all traits studied, namely scanned reproduction traits (Chapter 5) as well as ewe mating weight and condition scores (Chapters 3 and 4). Scanned reproductive traits were low-moderately repeatable in Dohne Merino and South African Mutton Merino (SAMM) ewes (Chapter 5), as was also suggested by the literature. Ewe mating weight and condition scores at mating as well as at lambing were heritable and variable in Merino, SAMM and Dormer ewes (Chapters 3 and 4). These traits will thus respond to genetic selection, should it be required. Ewe permanent environmental effects were occasionally present, for BCS at lambing in Merinos and for mating weight in SAMMs and Dormers. Genetic correlations among mating weight and condition scores were moderately-high, suggesting that correlated responses in the other traits are likely if one of these traits is targeted during selection.

When studying genetic correlations with reproduction, it was found that ewe body weight and condition scores were not good indicators of the reproductive potential of individuals on a genetic basis. A fair portion of these correlations were negative, occasionally significantly so, indicating unfavourable genetic correlations of mating weight and condition scores with the reproductive traits modelled both in Merinos (Chapter 3) as well as in SAMMs

and Dormers (Chapter 4). These correlations likely stem from complex relations between ewe age and past (as well as present in the case of BCS at lambing) reproductive status of the ewes studied. A further complication is a nonlinear relationship of ewe BCS with reproduction on a flock basis, with ewes with intermediate scores generally performing best (Chapter 3 and literature cited). Extensive further analyses are thus needed, involving larger databases. For instance, the relation of BCS with reproduction in two-year-old H Line Merino ewes appears to differ from older ages groups. However, the derivation of age-specific genetic correlations, as indicated by this result, requires substantially larger data sets than available at present. Apart from the continuation of recording in the flocks with BCS records at present, it is also recommended that scores should also be recorded in other resource flocks with extensive phenotypic records.

However, it is clear that body weight at mating and condition scores should not be used as indicator traits to base indirect selection for an improved reproductive performance on. It should also be considered that bigger ewes also have a higher maintenance requirement than smaller ewes. There is considerable scope for further studies to partition the effects of ewe mating weight and condition scores when modelling reproductive output in pure- and crossbreeding enterprises with specific attention to ewe efficiency and product output per hectare. The papers by Walkom & Brown (2017) and Walkom *et al.* (2019) could serve as a guideline in this respect.

Moderate repeatability estimates for scanned reproduction traits, barring embryo mortality, support low-moderate current-flock gains for scanning and lambing rate (Chapter 5). Adding pedigree information to the analyses conducted should be prioritised, to allow for the partitioning of genetic and ewe permanent environmental effects. The high between-animal (ewe) and phenotypic correlations between the number lambs scanned and number of lambs born recorded at birth, confirms that scanning results could indeed be used as proxy for lambing records in flocks not recording reproduction explicitly. Ultrasound scanning thus has the potential be used as a valuable management aid to optimize reproduction on an on-farm level when detailed reproduction records are not kept (Fourie & Cloete, 1993). National recording of reproduction records could also be facilitated by adding scanning records on individual ewes to the national sheep database. This will account for some of the deficiencies in the current recording scheme, such as the inconsistent recording of barren ewes as well as of lamb survival. Ideally, ultrasound scanning data would be more helpful if record keeping is maintained until the weaning of the lambs.

It is evident from the afore-mentioned that some urgent issues for South African sheep were addressed in this study. However, it is also clear that there is ample scope for further refining both BCS records and ultrasound scanning results to be of greater benefit to South African sheep farmers. Further studies suggested above are thus needed for these technologies to play a greater part in the local sheep industry. Once a clear understanding of the advantages and limitations of these technologies emerge it can be put to general use. The information of this and future studies has the potential to inform local sheep producers to implement such management aids in their own flocks. Both technologies are expected to have a role to play as sustainable aids to ensure the welfare of animals while also promoting sustainable and economically sound production practices.

6.4 References

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