BREED EFFECTS AND NON ADDITIVE GENETIC VARIATION IN INDIGENOUS AND COMMERCIAL SHEEP IN AN EXTENSIVE ENVIRONMENT

by

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DECLARATION

I hereby declare that the dissertation submitted for the Master's degree at the University of the Free State is my own work and has not been submitted at another university to obtain any qualification. I therefore cede copyright of the dissertation in favour of the University of Free State.

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ABSTRACT

The first part of the study compared a commercial, the Dorper as an arguably adapted commercial breed to the Namaqua Afrikaner as an unselected, indigenous, far-tail breed. The Dorper conclusively outperformed the Namaqua Afrikaner with reference to live weight and growth traits. On the other hand, Namaqua Afrikaner lambs were superior to Dorpers for an adaptive trait like total tick count. Lamb survival was unaffected by breed. When meat traits were considered, it was evident that Dorper lambs outperformed their Namaqua Afrikaner contemporaries for important attributes associated with size and meat yield, namely carcass weight and dressing percentage. Dorper carcasses also attained better grades and were more tender according to instrumental measurements (Warner Brazler equipment). Dorper lambs were fatter than Namaqua Afrikaner lambs, as derived from the backfat thickness at the 13th rib and the rump. While leaner meat would be preferred by health-conscious consumers, it is important to note that, under the conditions of the study, Dorper carcasses were more likely to be in the preferred grades.

In the second part of the study, Dorpers were evaluated against the SA Mutton Merino (SAMM; the most numerous dual-purpose breed in South Africa), as well as the reciprocal cross between the two breeds. No conclusive breed differences were found for weight traits, lamb survival, tick counts or meat traits. However, there was a suggestion that lamb survival of Dorpers was higher than that of their SAMM contemporaries (P = 0.08), but significance could not be demonstrated. Crossbred progeny outperformed the midparent value by 6.3% for weaning weight.

The corresponding study on meat traits was constrained by low numbers. However, it was evident that the observed heterosis for weaning weight was also present a later growth stage. Direct heterosis estimates amounted to 7.7% for slaughter weight and 7.1% for carcass weight. These estimates were consistent with the literature for the expected level of heterosis for early growth when assessed in fairly divergent sheep breeds. This outcome once again reiterated that crossbreeding may have a definite role to play at the commercial level in the

South African sheep industry. Further studies on the comparison of indigenous genetic resources with commercial breeds, as well as crossbreeding studies with the variety of available breeds were recommended.

CHAPTER 1

General introduction

Livestock production in South Africa is the largest agricultural sector with a total gross value of 47.5% (DAFF, 2018). The sheep industry in South Africa consists of commercial, emerging commercial and smallholder subsistence farmers. According to Molotsi *et al*. (2017a), commercial sheep farmers play a huge economic role in the industry by supplying meat products and wool to consumers both locally and abroad. Meissner *et al*. (2013) stated that 70% of Agricultural land in South Africa can only be utilized by livestock and game farming. Statistics in 2017 indicate 19.9 million commercial sheep, of which about 10.5 million are Merinos, 3.9 million dual-purpose breeds and 5.6 million meat sheep (DAFF, 2018). It is generally accepted that the SA Mutton Merino (SAMM) is one of the most important dual-purpose sheep breeds while the Dorper is the most important meat breed.

The main reasons for raising sheep are for their meat (lamb and mutton), milk and fibre production, manure and other religious and cultural roles. Fogarty *et al*. (2006) stated that, in sheep business, wool and meat are the main sources of profit and need to be included in breeding programmes. In addition to that, sheep farming plays an essential role in the economy of many nations in resource-poor regions, as it supports the livelihood of the people occupying arid and semi-arid regions of the world (Singh *et al*., 2006). This is especially true for smallholder and emerging farmers with limited or no agricultural land that are found in the diverse sections of society (Singh *et al.*, 2006). It serves as an additional income especially when crop production is low due to drought and other harsh climatic, soil or resource conditions.

Sheep production forms an integral part of the South African livestock industry and it is practiced throughout the country (DAFF, 2012). Small stock production, however, has a number of challenges such as predation, stock theft, variable rainfall patterns and increasing production cost. The livestock sector in South Africa has a range of indigenous and exotic and rare game species that are well adapted to the local environment and they play a major role in biodiversity conservation. Local sheep breeds could be sub divided as wool sheep, dual-purpose and mutton breeds. The main sheep breeds in South Africa are the woolled Merino and Dohne Merino breeds, the SAMM as a dual-purpose breed, as well as the Dormer and Dorper meat breeds (Cloete *et al*., 2014). Sheep breeds that are mostly reared by South African smallholder sheep farmers include the Dorper, Dorper crosses, as well as the fat tailed sheep breeds such as the Namaqua Afrikaner, Van Rooy, Damara, Nguni and Pedi (Molotsi *et al*., 2017a). Research has indicated that some hardy breeds such as Namaqua Afrikaner and Ronderib Afrikaner, which are the original indigenous breeds, are at risk of extinction in South Africa (Qwabe *et al*., 2010; Sandenbergh *et al*., 2018). Less than 1000 breeding animals are left for the Namaqua Afrikaner because the breed is neglected as a pure breed (Qwabe *et al*., 2010). Different sheep breeds are able to live, thrive and produce from the large range of ecosystems and are able to use the limited feed resources available (Cloete *et al*., 2013). Furthermore, indigenous and locally developed breeds are adapted to the local environment and have traits that enable them to be resistant to local pathogens (Cloete *et al*., 2013; 2016). They are considered to be important assets as compared to other breeds (Pranisha, 2004). However, indigenous breeds kept by smallholder farmers do not have proper production and reproduction performance records (Molotsi *et al*., 2017a).

In this study, the three breeds that were used were the Dorper, Namaqua Afrikaner (NA) and the SAMM. All animals were reared at the Nortier research farm on the west coast of South Africa. Dorper, NA and SAMM breeds originate from different places but they are all adapted to the range of South African environmental conditions. The Dorper and SAMM are good meat producers whereas the NA has a relatively low meat yield (Burger *et al*., 2013). However, the most important traits in all these breeds are growth traits, hence the increase in the demand for Dorper sheep to be used to improve the growth rate of lambs on a global basis (Ayichew, 2019). In comparison with other breeds, fat-tailed indigenous NA meat was comparable with commercial breeds.

However, it is traditionally considered to be inferior to other breeds (Burger, 2015). However, some breeds such as the South African Dorper and quasi-indigenous Damara sheep have developed adaptive traits while also having high quality mutton. Therefore, such breeds are in high demand in the market. Breed effects and heterosis accruing from crossbreeding systems have been reviewed by Fogarty *et al*. (1984) for lamb production and its components in pure breeds and in composite lines. The present study was investigating breed effects and non-additive genetic variation in three South African meat breeds in relation to growth, meat, lamb survival and tick counts traits.

Production and fitness traits have become the major challenge in animal breeding for the developing countries as farm animals are used as an important source of human nutrition (Oldenbroek & Van der Waaij, 2014). The economics of sheep production is greatly affected by growth performance, as heavier lambs with a high growth rate would fetch relatively more economic returns in a smaller time frame as compared to weaker lambs (Narula *et al*., 2009). To obtain improved production for growth traits, it is important to attain knowledge of genetic and cross-breeding parameters as well as breed effects to formulate breeding strategies (Gowane *et al*., 2014). Meat yield can be increased by exploiting breed and heterosis effects for growth performance in lamb production systems. Lupi *et al*. (2015) explained that change in volume, body size or shape in living organisms, especially in meat sheep throughout their lifetime, is a very essential contributor to efficient production.

With the fluctuating environmental conditions, producers and consumers in South Africa need to know which breed is most suitable for a certain production system. Information available on sheep breeds determines which breed should be chosen for the purpose of increasing product output under a specific set of conditions (Momoh *et al*., 2013). To have the biggest impact on decision-making in the meat industry, breed effects have to be researched thoroughly, while also considering the interactions of breed with factors such as chronological age, slaughter weight and sex as well as their effects on lamb/mutton quality (Hoffman *et al*., 2003).

Meat can be defined as an animal tissue that can be used as food for humans. It is considered as one of the most important food sources in the world and it is highly consumed in some countries where it is regarded as an essential product (Guerrero *et al*., 2013). Jacob & Pethick (2014) reported that sheep meat has a share of only 3% in the meat market, while it is considered as a suitable product for most people. About 183 000 tons of sheep meat (lamb and mutton) was consumed in South Africa in 2017-18 (DAFF, 2019). Meat is widely known to provide valuable amounts of protein, fatty acids, vitamins, minerals and other bioactive compounds to the human diet. People ranking in classes with a high economic status regularly consume high quality meat products. Therefore, there is a need for faster growing and heavier lambs due to recent increase in mutton prices in the market from R 51.42 per kilogram in 2014-15 to R 72.39 in 2017-18 (DAFF, 2019). According to Pethick *et al*. (2006), the number and the quality of carcasses produced are two important considerations in the lamb and mutton industry.

Guerrero *et al*. (2013) explained that meat quality and characteristics are different among the species of animals, even within more similar or homogenous groups such as small ruminants. Therefore, livestock industries have to know and understand the factors that cause these differences in meat quality and put into use management systems that will minimize quality variation to continuously provide the consumer with high quality meat (Warner *et al*., 2010). Ramírez-Retamel & Morales (2014) stated that consumers, producers and the meat industry along the agricultural food chain all have different perspectives on the quality of livestock products. The meat industry and farmers must reach global market standards by maintaining certain meat quality standards meeting the needs of consumers (Ramírez-Retamel & Morales, 2014). According to Souza *et al*. (2016), modernized people require more carcasses with good conformation, lean, but with sufficient intramuscular fat, as well as a desired level of tenderness and such high quality meat can be obtained from early maturing lambs. Therefore, a sheep industry that has the interests of its consumers at heart should prioritize the production of meat that is of a high and reliable standard, is safe and nutritious, as well as palatable (Shackelford *et al*., 2012).

Sheep production is highly affected by ticks (Rashid *et al*., 2018). Ticks are ectoparasites that live and survive temporarily through sucking blood on the vertebrates which include birds, mammals and reptiles. Some tick's species can spread toxins while others can cause paralysis of their host animals (Hurtado & Giraldo-Ríos, 2018). In all tropical and subtropical countries, including South Africa, Ixodid ticks are the most economically important ectoparasites of livestock. Ticks have both a direct and an indirect impact on their hosts, namely: the direct effect of a heavy infestation of ticks as "tick-worry" on animals as well as an indirect effect by acting as vectors of tick-borne diseases at both the economic and social levels (Spickett *et al*., 2011; Eskezia & Desta, 2016).

Heavy tick infestation causes anemia and a loss of weight in animals while also reducing the quality of hides and skins through their bites**.** Ticks increase mortality and morbidity rate of livestock while they also reduce production by impairing milk and meat production, causing damage to skins and hides as well as an increase in monetary losses associated with the cost of the control and prevention of tick borne diseases (Eskezia & Desta, 2016). According to Hurtado & Giraldo-Ríos (2018), sheep may suffer tick fever which is caused by the organism *Anaplasma phagocytophilum* and can show symptoms such as fever, neutropenia (predisposing to secondary bacterial and viral infections), cough, loss of appetite, fatigue and a reduction in milk weight and live weight. Tick load and distribution is interrelated with husbandry practices as keeping different animal species in the same pasture or housing allows an easy transmission of ticks and tick-borne diseases within a population (Sajid *et al*., 2017).

Against this background, the main objectives of the study were to investigate breed effects associated with three different South African breeds, namely the Dorper, Namaqua Afrikaner and South African Mutton Merino, as well as non-additive genetic effects in growth, tick resistance and meat traits when raised in a single flock under extensive conditions.

CHAPTER 2

Literature review

2.1 Introduction

Sheep are by far the dominant ungulate livestock species in South Africa. According to Cottle (2010), the ability of sheep to adapt to different and often adverse environmental conditions contributes to their status as a globally successful livestock species. This ability has also contributed to the ovine species being represented by the most distinct breeds of all livestock species (Cloete, 2012).

Fogarty *et al*. (2006) reported that, for better outcomes of selection, genetic evaluation of animals and implementation of proper breeding programmes, there is a need to know the genetic variation of traits of economic importance and the covariation among these traits. The design of effective sheep breeding programmes and their accurate predictions of genetic progress also requires an understanding of genetic variation and covariation among traits (Safari & Fogarty, 2003). A more detailed understanding of the potential role of meat quality in breeding objectives and as selection criterion for sheep breeding programmes for meat also requires estimates of the genetic and phenotypic correlations, of meat quality traits with growth and assessments of muscle and fat levels in live animals and carcasses.

Among many economically important traits in sheep, growth and meat production traits are the most important ones (Zhang, 2013). Direct additive and maternal genetic effects as well as environmental effects are known factors that influence body weight and growth traits in sheep (Kamjoo *et al*., 2014). An ideal ewe is described as the one with good mothering abilities, capable of giving birth with no difficulty, have a high twinning rate and should produce sufficient amount of milk of a good quality enabling adequate lamb growth (Csizmar *et al*., 2013). Meat yield is a polygenic trait impacted upon by non-genetic and genetic factors. Growth rate is the most important trait for selection across and within the breeds and as an economic trait, it stands as the reflection of the adaptability and economic viability of the lamb. Zaffer *et al.* (2015) demonstrated that, in meat industries, profitability is mainly determined by early growth traits. A rapid growth rate will ultimately determine the meat producing capability of offspring up to marketing age. Studying traits such as body weight is beneficial to breeders and producers because they opt for management practices that lead to the improvement of production to optimum levels (Singh *et al*., 2006; Lalit *et al.,* 2016b).

The meat industry and sheep producers must comply with certain quality standards in order to satisfy consumer demands and remain competitive in a global market (Ramírez-Retamal & Morales, 2014). The literature is dotted with conflicting and sporadic reports regarding genetic parameters of growth traits in sheep (Snyman *et al*., 1995). Lamb growth and carcass composition traits are important animal traits (Simm, 1998). Carcass value is usually a function of carcass weight, fatness and conformation, although breed, age and sex can also influence carcass price (Simm,1998). Sheep breeds reared specifically for mutton reach maturity fast, have high prolificacy, higher body weight gains, a high feed conversion efficiency, and high carcass yield with meat of a high quality. However, in South Africa, the total number of sheep is declining because of stock theft, climatic conditions and predation causing a scarcity of sheep meat being unable to meet the increasing demand by consumers.

Various sheep breeds are able to live, thrive and produce on the large range of South African ecosystems, being able to use the limited feed resources available (Cloete *et al*., 2013). The Dorper, Namaqua Afrikaner (NA) and South African Mutton Merino (SAMM) breeds originate from different geographical locations but they are all adapted to the variable South African environmental conditions. The Dorper and SAMM are good meat producers whereas the NA has a relatively low meat yield (Burger *et al*., 2013). Moreover, Cloete & Olivier (2010) noted that the Dorper is the most common meat breed and SAMM are the most common meat and wool production (dual-purpose) breed in South Africa. However, some breeds such as the Dorper, as well as indigenous breeds such as the unimproved NA are known to have developed adaptive traits to resist natural and environmental stressors in an arid environment (Cloete & Olivier, 2010).

Several topics are reviewed in this chapter, including: the general production of livestock in South Africa, sheep breeds for extensive farming, the potential roles of indigenous sheep, the description of indigenous breeds (Namaqua Afrikaner) as well as the commercial breeds (Dorper and SAMM). The review of different growth traits in sheep, breed effects on the quality of meat, different attributes of meat quality, lamb survival and tick infestation on sheep as they are all the factors that may potentially be useful in evaluating and comparing the genetic resources used in this study. Furthermore, genetic variation as well as the effects of non-genetic variation in sheep will be briefly discussed.

This study will therefore, investigate the effects of sheep breed and crossbreeding parameters on the growth performance, lamb survival, meat quality and tick count in three South African meat breeds raised in an extensive environment.

2.2 The South African extensive farming system

About 70% of South African agricultural land is only suitable for extensive livestock farming because of constraints involving soil, water and climate (Cloete & Olivier, 2010). This area comprises vast areas of rural South Africa and lacks infrastructure and development. Free-ranging small stock species are the only way to utilize this land productively, especially in the south western parts of the country. Sheep is a species that evolved to cope with the stressors typical of similar environments and are also able to thrive under marginal conditions commonly occurring in such ecosystems (Uğurlu *et al.*, 2017). Sheep therefore, contributes to the economic development and therefore, the livelihood of many rural communities in extensive areas. Moreover, extensive sheep are able to express a full range of their natural behaviour repertoires, making such systems highly desirable from an animal welfare perspective.

Extensive farming systems are often able to sustain animals under different climatic conditions without the need of high quantities of supplementary feeding. Since such pastures are a cheap resource to sustain adapted animals, farming enterprises on such resources could be quite economically viable. Sheep is known to be the most versatile and adapted livestock species being able to thrive under a wide range of conditions (Cottle, 2010). Therefore, the challenges associated with these extensive environments in terms of differences in topography, pasture quality, rainfall and temperature can easily be accommodated by adapted sheep breeds. The ability of sheep to cope with variable environmental conditions stems from the differentiation of the ovine species in a wide array of distinct breeds (Cloete, 2012).

Therefore, it is important to know what breeds would adapt to specific environments. A sound knowledge of specific stressors typical of each environment is also required to ensure that farming is practiced in a sustainable way. For instance, extensive production systems are due to be impacted upon by climate change in the foreseeable future (Rust & Rust, 2013). According to the latter authors, sheep are more capable to cope with excessive heat than most other livestock species. Specific pathogens such as external parasites with the ability to compromise productivity, animal welfare and the economic sustainability of the enterprise are quite commonly also present under extensive conditions (Molotsi *et al*., 2017a).

Extensive sheep farming systems, however, are prone to overutilization thereby impacting on plant biodiversity and sustainability (Molotsi *et al*., 2017a). The capacity of extensive pastures to sustain acceptable levels of production is then severely compromised by the impairment of the coping mechanisms sheep have to adapt to adverse conditions. This would result in the animals being more susceptible to stressors such as disease and parasitism. These conditions could be further aggravated by a reluctance to adopt improved management interventions as well as proper breeding practices (Kochewad *et al*., 2017). Failure to do so in semi-extensive and extensively reared animals will result in lower levels of production than could be achieved.

2.3 Sheep breeds for extensive farming

It has already been reported that sheep as a species have favourable characteristics enabling them to thrive in harsh agro-ecological regions subject to fluctuating climatic conditions, diets, management regimes and diseases (Rosali *et al*., 2005). They also have a high reproductive rate and a shorter gestation period allowing them to have three lambing opportunities in two years (Fogarty *et al*., 1984). Thutwa (2016) asserted that they have the ability to give birth to multiples. According to the latter author, sheep breeds adapting to extensive conditions include commercial breeds such as the Dorper and the SAMM and crosses of these breeds. There are very hardy indigenous breeds capable of coping with quite extreme conditions such as the NA, Van Rooy, Damara, Nguni and Pedi sheep. Such breeds are reputedly easily raised and utilized by small-scale sheep farmers (Molotsi *et al*., 2017b). On the con-side these unimproved breeds are known to be inferior for growth, carcass composition and meat output (Burger *et al*., 2013; Burger, 2015). Under small-scale farming systems, sheep also provide people with milk, manure and plays an important role in religious and cultural practices (Molotsi *et al*., 2017a). In addition, they also contribute to the production of meat globally (Bünger *et al*., 2005). As a result of their small body size, sheep are much easier to rear by small-scale farmers as they are a low cost investment which may yield appreciable returns while requiring limited inputs as far as land are concerned. Sheep can also be a reliable source of income and food security in some over-populated regions where there is limited space for crop production (Giorgis *et al*., 2017).

2.3.1 Constraints to sheep farming

Local sheep farming enterprises are susceptible to several factors such as climate, vegetation, topography and husbandry practices (Molotsi *et al*., 2017a).

2.3.1.1 Climate change

The phenomenon of climate change affects agriculture negatively by deteriorating natural water resources, ecosystem and agro-systems (Brahmi *et al*., 2012). Kumar *et al*., (2017) stated that reproductive performance of sheep decline as a result of continuous stress they may experience under extreme environmental conditions caused by climate change. Such stress indicators include heat stress and nutritional stress which are likely to occur because of extreme temperatures and more solar radiation. Adverse environmental conditions are expected to be aggravated by a reduced rainfall, adversely affecting pasture quantity and quality as well as crop yields. Breeding period may also be affected due to insufficient nutrients at the beginning of the reproduction cycle (Kumar *et al*., 2017). According to Rust & Rust (2013) the wool industry may potentially be impacted upon by climate change through its effect on the quality of forage, water resources, animal health as well as land sustainability. These impacts are expected to spread to other agricultural sectors such as cropping. However, climate change effects may be resisted by farming with adapted animals that are able to overcome harsh environmental condition by being more heat tolerant, resilient and more disease resistant (Rust & Rust, 2013). Burger *et al*. (2013) noted that, in the future, the contribution of commercial sheep such as Dorper and SAMM may decline as their growth and development maybe hindered because of insufficient food caused by climate change.

2.3.1.2 Animal husbandry

Countries with arid, semi-arid and mountainous areas commonly depend on sheep husbandry to unlock the sustainable and economically viable utilization of resources. However, improper scientific knowledge of genetics of sheep reared under such conditions is a major setback (Gowane *et al*., 2014). Large human populations depend on sheep husbandry as food security in hot arid and semi-arid climates dependent on grazing (Kumar *et al*., 2017), while sheep often walk for long distances with insufficient feed under very extreme climatic conditions.

2.4 The potential roles of indigenous sheep

Among the available sheep breeds, there are several indigenous breeds which are highly adapted to the environmental conditions of the country (Jannoune *et al*., 2015). The indigenous South African sheep breeds are classified according to type, depending on their place of origin. In combination, indigenous breeds are a most significant group of livestock species (Nxumalo *et al*., 2018). Some of the known indigenous sheep breeds in South Africa are the Blinkhaar Ronderib Afrikaner, NA, Nguni and Pedi. Breeds such as the NA may play an important role in the flocks of small stock farmers of South Africa as a pure breed or in admixture with commercial breeds (Molotsi *et al*., 2017a; 2017b). It is contended that indigenous breeds can be sustained on little and cheap input, while still surviving and reproducing. The NA has a good survival and tick resistance (fitness traits) as compared to commercial breeds they were compared with (Molotsi *et al*., 2017a). Indigenous breeds are well adapted to harsh environmental, social and economic conditions in different ecological regions, therefore, they may play a major role in animal breeding (Abdelkader *et al*., 2017; Gebreyowhens *et al*., 2017).

Although indigenous breeds may be well adapted to the environment, they may sometimes yield insufficient economic returns because of their low genetic make-up to respond to strategic management (Getachew *et al*., 2016). In small scale farming operations, indigenous breeds are usually characterized by their low production performance (Gebreyowhens *et al*., 2017). Their poor appearance and inadequate growth and carcass performance may cause their real value to be underrated (Amare *et al*., 2018). Incomplete or absent records under uncontrolled breeding conditions used in small-holder farming systems may contribute to a general apathy towards indigenous breeds (Molotsi *et al*., 2017a). Nxumalo *et al*. (2018) reported that small-scale farmers keep the indigenous breeds with insufficient resources and practice a lot of crossbreeding due to lack of proper breeding management skills. Due to the effect of indiscriminate crossbreeding, indigenous breeds are facing the challenge of extinction (Nxumalo *et al*., 2018). The indigenous, fat-tailed Namaqua Afrikaner breed was therefore used in this study (Figure 2.1).

Figure 2.1 A typical example of an indigenous fat tailed Namaqua Afrikaner ram (Photo: Tino Herselman in Snyman, 2014b)

The NA (Figure 2.1) is a black- or red-headed fat-tailed sheep breed. It has long legs, allowing it to cover long distances searching for food and water. The NA is covered with a shiny smooth hair coat and its tail often has a distinct twist. As articulated by Sandenbergh *et al*. (2018); DAFF (2010) (as cited by Snyman, 2014), it is a hardy, indigenous fat tailed breed. It is lanky sheep with a relatively narrow body, long, lean legs and a fat tail in which up to 38% of its body reserves may be stored. As it stores the fat in the tail, it is a lean breed with its carcass fat being poorly distributed (Sandenbergh *et al*., 2018). Maleki *et al*. (2015) explained that fat-tail lambs are identified by their fat tail that is used for storing fat and make it more adapted to challenging environmental conditions.

Namaqua ewe's fat reserves might be mobilized during unfavorable drought conditions to assist them to rear heavy lambs under adverse conditions. According to Ramsay *et al*. (2001), the NA is known to be one of the oldest South African indigenous breeds. Since the NA and many other fat-tailed sheep are mostly kept in either conservation flocks or in smallholder sheep systems, they have low genetic variation. This has raised some concern about its extinction as a sustainable genetic resource (Molotsi *et al.*, 2017b). Averages of different growth traits and weights of NA ram and ewe lambs at Carnarvon (1982-1994) are summarized in Table 2.1 (Snyman, 2014b). Because of their good mothering ability, NA ewes are able to protect their lambs from any harm, either from the humans or predators. NA ewes reach maturity at an early stage and can be mated successfully at an early age.

Table 2.1 Averages of different growth traits and weights of Namaqua Afrikaner ram and ewe lambs (Snyman, 2014b)

Trait (kg)	Rams	Ewes
Birth weight (kg)	4.6	4.3
Weaning weight (kg)	26.1	24.7
8-month body weight (kg)	38.1	35.6
12-month body weight (kg)	51.9	44.0
18-month body weight (kg)	58.7	50.4
Mature ewe weight (kg)	N.A.	50.0

2.5 South African commercial sheep

The South African sheep industry is divided into different categories, namely: commercial, emerging commercial and smallholder subsistence farmers. Commercial sheep farmers are dominating in the country in terms of sheep numbers with more than two thirds of sheep supplying both meat and wool products locally and internationally (Molotsi *et al*., 2017a). Commercial sheep are classified into Merino, Karakul, other woolled sheep and non-wooled sheep (DAFF, 2018). The total number of commercial sheep is summarized in Table 2.2. Commercial sheep flocks benefitted from the implementation of various breeding techniques such as line breeding, crossbreeding and selection for traits of economic importance (Molotsi *et al*., 2017a). The Dorper, Dohne Merino, SAMM and Merino breeds are considered to be dominant in numbers (Cloete *et al*., 2014). However, only the Dorper as dominant meat breeds and the SAMM as dominant dual-purpose breed will be reviewed in this study.

Table 2.2 Commercial sheep numbers in South Africa (DAFF, 2018)

Category	Numbers (millions)
Merino	10 466
Karakul	23
Other white-woolled sheep (dual-purpose)	3 857
Non-woolled sheep (meat)	5 596
Total	19 942

2.5.1 Dorper

The Dorper is the largest meat breed in South Africa (Cloete & Olivier, 2010). It is a composite South African breed that was derived from a cross of Dorset Horn rams with Black-headed Persian ewes in 1930's (Csizmar *et al*., 2013). Cloete & De Villiers (1987) described the Dorper as a specialist meat breed.

The Dorper (Figure 2.2) was developed mainly to produce the breed that is capable of producing good quality carcasses under challenging South African conditions (Cloete *et al*., 2010). Selection is mainly based on growth and meat traits. It is a meat sheep with a long breeding season and good mothering ability, producing lambs with a top quality carcass for slaughter at a relatively early age. Dorper lambs have the ability to gain weight rapidly, thrive in the unfavorable weather conditions and their mild flavored meat has been met with consumer acceptance (Polachic, 2002). The objective of the South African Department of Agriculture and a group of farmers was to breed a composite that would do well in the free-range system and produce maximum litter size with a combination of good quality carcasses and the Dorper breed resulted.

Figure 2.2 Dorper ewes and lambs in the sheep-handling facility at Nortier Research Farm

The breed was demonstrated to be suited for lamb production in the arid and extensive areas of South Africa (Cloete & De Villiers, 1987). It adapted well in different environments and provided farmers with adequate levels of production under various conditions (Cloete *et al*., 2000), and adapts well under arid and hot conditions (Cloete *et al*., 2007). According to Budai *et al*. (2013), the Dorper has an excellent performance in dry areas with low rainfall and high temperatures. It can also perform well both on planted pastures as well as on low-potential pastures with sparse vegetation.

Csizmar *et al*. (2013) reported that Dorper lambs grow faster and can reach a weight of 28-30kg at weaning at 100 days of age. Ewe lambs have the potential to lamb for the first time at one year, implicating that Dorpers are early-maturing. In South Africa, majority of Dorpers (85%) are black headed. There are about 20 million commercial sheep in South Africa, of which roughly 5.5 million are Dorpers (DAFF, 2018). DAFF

(2011) reported that Dorper sheep breed is considered one of the best breeds because of its excellent carcass with well-distributed fat. Dorpers are also the most popular and improved commercial meat breed raised by commercial farmers in Zimbabwe (Assan & Makuza, 2005).

2.5.2 South African Mutton Merino

The SAMM (Figure 2.3) sheep is the biggest dual-purpose breed in South Africa. It is a well-muscled sheep with an excellent conformation and balance. It has a large body covered with a fleece of pure white wool, free of kemp and coloured fibers. Rams and ewes are both polled.

Figure 2.3 A typical example of South African Mutton Merino (Photo: SA Mutton Merino Breeders' Society in Snyman, 2014c)

The breed produces good quality wool with an average of 3.4kg greasy wool for ewes and 4.5kg greasy wool for rams (Snyman, 2014c). The South African Department of Agriculture imported the first sheep in 1932 from Germany for the Elsenburg breeding program. The breed was initially known as the German Merino. The breed is well adapted to South African weather conditions and became well distributed (Cloete & Olivier, 2010). The SAMM produces both wool and meat and has been selected for wool traits, as well as growth and meat production. It therefore, exhibits desirable production characteristics (Brand, 2017). It has been identified as a true dual-purpose mutton-wool sheep and is well known for its reproductive ability. Studies showed that multiple lambs at weaning were associated with increased weight of lamb weaned and result in improved ewe productivity per ewe per year (Cloete *et al*., 2002).

In the South African small stock industry, the SAMM breed played a major role in producing composite breeds. Among the breeds descended from the SAMM as a parental breed is the fine woolled Dohne Merino, the Dormer terminal sire breed, as well as the Afrino. The latter breed was developed as a terminal sire breed, but is at present mostly employed in a dam-line role. SAMM sheep are currently commonly exported to other countries as seed-stock (Schoeman *et al*., 2010).

2.6 Early growth traits in sheep

A high growth rate for animals kept in an extensive South African environment is an indication of their adaptability (Schoeman *et al*., 2010). Sheep production proficiency is highly determined by the growth characteristics (Issakowicz *et al*., 2018). Growth traits are an indicator of whether the animal is capable of adapting to available environmental conditions and they are related to production, reproduction and survivability (Lalit, 2016b). Besides being of economic importance, growth traits are easy to measure in meat animals.

Birth weight is the first available indicator of size. Lambs with higher birth weights also tend to record rapid growth rate under the influence of different genetic and non-genetic factors. Assan & Makuza (2005) emphasized that there is a positive genetic correlation between birth weight and other live weight traits. Birth weight is highly influenced by the maternal environment; however, Gardner *et al*. (2007) mentioned that litter size had the greatest influence on birth weight in their study. Lambs that are born with low birth weight are likely to die due to insufficient energy reserves, which impairs viability and result in stunted growth (Nowak & Poindron, 2006). Weaning weight is a second profit determining trait of great importance to sheep breeders (Assan & Makuza, 2005; Csizmar *et al*., 2013). Both birth and weaning weights are subject to maternal effects. In the case of birth weight, maternal effects could be related to the uterine environment provided by the dam. Weaning weight conveys information on the ewes' mothering ability as lambs suckle milk from the ewe. Weaning weight and the mothering ability are thus highly correlated as discussed by Lalit (2016b).

2.7 Meat traits

When considering the sheep meat market, it is important to consider both the quality and quantity of the meat. Sheep producers and meat processors are primarily interested in quantitative traits such as growth performance and meat yield but discerning consumers are becoming more and more concerned about the meat quality in the market (Payne *et al*., 2009). The quality of meat derived from breeding programmes is evaluated on either the live animal or on the carcass. It is usually expensive and challenging from a logistic perspective to measure meat quality (Duijvesteijn *et al*., 2018). Along the agricultural food chain, there are several participants having variable perceptions as pertaining to the quality of livestock products. Consumers, producers and the industry may have different and sometimes divergent expectations regarding meat and carcass quality. The meat industry and farmers should therefore reach consensus on some quality standards to meet consumer's demands thereby ensuring sustainability in the global sheep meat market. On the other hand, consumers' demand for meat quality can be met through specialized production systems which could depend on the type of feed used (Ramírez-Retamal & Morales, 2014).

2.7.1 Quantitative meat traits

According to Brand (2017), Dorpers reach maturity quickly and fat deposition takes place at an early chronological age and that would result in fattier carcasses as compared to SAMM and Merino lambs. Therefore, carcasses should be taken to the market at an early age to avoid being downgraded because of excessive fat cover (Cloete *et al*., 2000). Over-fat carcasses are penalized in the market, resulting in lower meat prices. The Dorper exhibits excellent carcass characteristics in terms of conformation and fat dispersion around the body, as well as adaptation to adverse environment (Webb & Casey, 1995; Brand, 2000). At an age of 12-14 weeks, Dorper lambs can already produce very muscular, lean carcasses which serves as proof that they have rapid growth traits. The subcutaneous fat cover of about 3.18 mm in Dorpers prevents carcasses from drying out during transportation even though its high intramuscular fat content of Dorper meat may not be preferred by those customers preferring lean meat (Brand, 2000). Dorper and SAMM carcasses did not differ significantly (P>0.05) for weight but NA carcasses had less meat (P≤0.05) when compared to Dorper and SAMM carcasses (Burger *et al*., 2013).

Burger (2015) reported that the dressing percentage of the NA was the lowest when compared to the Dorper and SAMM (36.4±0.75%; P<0.001). The Dorper breed presented carcasses that were square in conformation in comparison to the narrower carcasses presented by NA contemporaries. This might be the reason why end-users may not prefer fat-tailed carcasses, as the more expensive cuts are not as attractive in comparison to Dorper carcasses. Burger (2015) noted: “Since the NA is an unimproved, indigenous breed, it is noteworthy that its meat was mostly comparable with that of the commercial breeds, where traditionally it is presumed as inferior”. However, Sañudo *et al*. (1997) argued that due to the high amount of fat accumulated around the tail and nearby areas in the fat tailed sheep, the market value of their carcass is negatively affected. The Namaqua’s fat tail makes them to be easily recognized in abattoirs (Snyman *et al*., 1996). According to Cloete *et al*. (2013), the small size of cuts in the loin and leg from the NA could make the breed less preferable when compared to the commercial Dorper meat breed.

2.7.1.1 Slaughter and carcass weight

Slaughter age plays an important role in meat production of ruminants because it determines the price of the carcass. The marked difference is between grades A (lambs) and Grade B and C (adult sheep). Carcasses from older lambs would be heavier, thus realizing more money. An increase in slaughter age results in the value and quantity of commercial cuts and quality traits such as color, cooking loss, and shear force being compromised (Esteves *et al*., 2018). An increase in slaughter weight increases carcass weight in lambs (Uġurlu *et al*., 2017). Fogarty (2016) found that carcass traits differ genetically, including indicators of meat quality, with scope for selection to improve meat production and meat quality in the Merino. According to Bradford (1974), the most significant traits that can easily be measured as a proxy for meat production is slaughter weight. However, in some circumstances dressing percentage can indicate meat quality. Carcass cuts may have an equal distribution of fat while lamb carcasses that weigh 27kg are still categorized as A2 or A3. Sheep breeds mature in different places and may deposit fat in fat depots differently. Such breeds could therefore be slaughtered at different live weights to yield an A2 carcass (Brand *et al*., 2018). According to Snyman (1995), SAMM sheep deposits fat at a later age and can thus be slaughtered at a heavier live weight. Brand *et al*. (2018) observed that Merino and SAMM lambs should be slaughtered at a weight of ~42.7 kg while the Dorper lambs should be ~36.0 kg at slaughter time. Therefore, it is imperative to determine an accurate slaughter weight for each breed that will yield carcasses of the best commercial value. The following formula was used for this purpose:

Estimated carcass weight = live weight x dressing percentage

2.7.1.2 Dressing percentage

Dressing percentage is the ratio of hot or cold carcass weight in relation to pre-slaughter live weight, expressed as a percentage. Farmers should have a proper knowledge of dressing percentages between different breeds so that they are able to easily calculate carcass weight from live weight (Muir *et al*., 2008). Muir *et al*. (2008) explained that dressing percentage in animals is influenced by production factors like animal fatness, breed and stage of maturity. In sheep, dressing percentage can differ depending on factors such as nutrition, maturity type, wool growth and breed (Gardner *et al*., 2015). Dressing percentages could be based on hot or cold carcass weight and plays an important role in determining meat production as well as carcass quality. The most preferred in the market is the cold dressing percentage in which carcasses are delivered after the chilling process has been completed (Uġurlu *et al*., 2017).

2.7.2 Qualitative meat traits

Quality of meat refers to the combination of all sensoric, dietetic, hygienic, toxicological and processing-technological components (Becker, 2000). Meat quality traits are very important in formulating breeding goals for livestock (Oldenbroek & Van der Waaij, 2014), and is influenced by different factors. Lamb producers thus have to be knowledgeable on the different meat quality attributes so that they can easily describe the type of animal that meets the necessary standards (De Lima *et al*., 2016). Johnston *et al*. (2003) mentioned however that carcass and meat quality traits are difficult to measure, particularly on live animals. Hopkins & Geesink (2009) showed in their studies that palatability, water holding capacity, colour of the meat, nutritional value and safety all contributes to the quality of meat. Meat quality, even of animals of the same breed or species, for instance sheep, may be different (Guerrero *et al*., 2013). It could be affected by factors such as stress (Cloete *et al.,* 2005). In advanced countries, lean meat is preferred over fatty meat. Meat production is based on the growth process of the animal, which in turn depends on several environmental and managerial factors. Meat animal carcasses vary in composition through genetic, age, sex, nutritional and environmental effects (Irshad *et al*., 2012). A further complication of meat quality characteristics is that they also vary widely from muscle to muscle within the same carcass. Csizmar *et al*. (2013) mentioned that the quality of lamb meat preferred globally by consumers is determined by its colour, juiciness, tenderness and flavor.

Among other things, breed and the type of feed can impact on the carcass and meat quality (Ratamal & Morales, 2014). Among others, carcass weight, yields and conformation as well as pH and the fatty acid composition of the meat are highly dependent on breed. In a previous study by Shackelford *et al*. (2012), breed had a more pronounced effect on tenderness than on flavor. Breed also markedly affected growth and carcass traits. Significant genetic variation was reported for meat quality traits of different animal species. Genetic variation may also be reflected by between-breed variation for meat traits. Breed is a well-known factor that determines differences in both qualitative and quantitative carcass traits in sheep and contributes markedly to the amount of fat within a carcass (Maleki *et al*., 2015). However, the effect of breed is sometimes quite minimal on instrumental as well as on sensory meat quality traits (Ratamal & Morales, 2014). Meat quality of Merino lambs can deteriorate when animals are exposed to stress (Cloete *et al.,* 2005). According to Yalcintan *et al*. (2018), meat pH, drip loss, shear force, cooking loss and colour are all instrumental meat quality traits that should be considered when the aim is to improve meat quality.

2.7.2.1 Meat pH

The appropriate time to record meat pH is at least after 24 hours in the chiller (Hopkins *et al*., 2014). pH readings of 5.4 to -5.7 at this stage usually indicate good quality meat. The amount of glycogen found in the muscles before slaughtering determines the rate at which pH will decline post-slaughter. The environmental microbial balance is also determined by pH. Naudé *et al*. (2018) reported genetic correlations indicating that meat with a high pH is likely to be darker and with a low cooking loss. In contrast, meat with a low pH would be lighter with a higher cooking loss. Fogarty *et al*. (2003) reported that the ultimate pH and colour of muscle are important indicators of meat quality and selection may be an avenue to exploit genetic variation for these traits. pH impacts on other instrumental meat traits such as texture, meat colour and water holding capacity (Yalcintan *et al*., 2017). Intramuscular fat, muscle fibre composition as well as the amount of stromal tissue are mainly influenced by drip loss, shear force and pH values of meat (Hopkins *et al*., 2006).

2.7.2.2 Meat colour

Physical appearance of meat is normally reflected by the colour, chroma and hue angle (Sen *et al*., 2013). Meat colour changes in response to both the quantity of myoglobin it contains, as well as chemical changes in the myoglobin itself. A higher myoglobin concentration in meat is associated with a darker colour. The muscles of older sheep contain more myoglobin and hence have darker meat than in lambs. Colour is also greatly affected by muscle pH. At a high pH, the muscle has a closed structure and appears to be dark while the meat tends to be tough. Meat can also become discolored before reaching a retail outlet if it is allowed to dry. Hence, butchers prefer carcasses to have at least some subcutaneous fat cover evenly distributed over the carcass, since it aids in maintaining quality and an attractive appearance by preventing the meat from drying. However, meat colour is not likely to differ when there has been similarity in diet, however, intramuscular fat levels are adequate to give detectable improvements in juiciness and flavor in meat at a younger age. Colour traits are divided into three components; luminosity or lightness (*L**), redness (*a**) and yellowness (*b**) (Priolo *et al*., 2001), which can be measured among other things using the Minolta chroma meter (Mortimer *et al*., 2018). The differences in meat brightness, redness and yellowness mostly depend on age, weight, sex, pre- and post-slaughter handling, and the postmortem pH value. Breed has an influence on the enzymatic reducing system and an ability to determine oxidation change (Sañudo *et al*., 1997). Colour traits are likely to deteriorate as an animal ages. If sheep are slaughtered after 30 months of age, their meat may become darker, leading to a lower level of acceptance in the market (Esteves *et al*., 2018).

2.7.2.3 Meat tenderness

The most essential characteristic of meat quality is tenderness, and tough meat is met with high levels of consumer resistance (Wood *et al*., 1999). Tenderness in meat can be assessed by objectively measuring shear force (Hopkins *et al*., 2011). It can also be tested and judged by the use of some special mechanical devises as well as the sense of taste (sensory attributes). Therefore, the different results in testing the tenderness of meat need to be considered to ensure the production of tender meat in future. Myofibrilar degradation caused by the enzymatic functions as the animal grows older increases meat tenderness (Guerrero *et al*., 2013).

2.7.2.4 Cooking loss

Cooking loss depends on the amount of connective tissue as well as the fat concentration, as the fat will melt and drip out during cooking (Hopkins *et al*., 2006).

2.8 Fitness and robustness traits in sheep

It is important to benchmark more productive commercial genotypes against adapted and robust indigenous breeds for fitness traits such as lamb survival and resistance to tick infestation. Some fitness traits, however, involve challenge by a potential pathogenic organism by either a natural or artificial infestation. The role of largely neglected genetic resources such as the NA in promoting ovine robustness and fitness may be determined by such studies (Cloete *et al*., 2016).

2.8.1 Lamb survival

Lamb survival is defined as the number of lambs weaned per 100 lambs born (dead and alive) (Dalton *et al*., 1980). It is an important breeding goal for improving lamb production, economic viability and welfare of sheep farming enterprises (Tomaszyk *et al*., 2014), and is highly influenced by genetic, maternal genetic or permanent environmental and environmental effects (Hincks *et al*., 2014). The interrelationship between genetics, physiology and management within an appropriate environment lead to successful production of lambs from birth to weaning and selection can be used as a tool for improving the chances of survival in a population even although lamb survival was identified as a lowly heritable trait (Ipsen, 2013). According to Nowak & Poindron (2006), the ewe has an ability to take care of the newborn lamb during its early stages of development as well as their survival. Lamb vigour at birth, birth coat score, latency to bleat, rectal temperature and crown-rump length are marked as indicator traits that could potentially improve lamb survival (Ipsen, 2013). Johns *et al*. (2016) concluded that lamb survival and lamb live weight can be improved by ensuring that ewes reach the targeted body condition score (BCS). Different literature reports showed from their analysis that survival is affected by factors such as birth weight, age of dam, breed of lamb, sire and birth rank (Morris *et al*., 2000). In a study conducted by Dalton *et al*. (1980), however, the peri-parturient period up to 3 days after the birth of the lamb was the most critical period for lamb survival and flock or breed differences were highly significant. Various effects and their interactions with one another that affect lamb survival result in different proportions of lambs that will survive from birth to weaning. Dalton *et al*. (1980) explained that different weather conditions can be experienced both within and between seasons and can be significant for both within and between flocks. Lamb mortality not only causes major losses to the quantity of lambs weaned as well as to income generation, but it also impacts on the welfare on animals (Cloete *et al*., 2014).

Sustained genetic progress in lamb survival is feasible if directed selection is applied to correlated trait such as ability of ewes to rear multiples, as discussed by Cloete *et al*. (2009). Cloete *et al*. (2001a), however, mentioned that there are only a few literature reports about the survivability of lambs. Increasing the survival rate of lambs to weaning increases the cash flow of sheep enterprises (Olivier *et al*., 2010). Lamb losses not only affects the profitability of the flock for farmers but it also causes the animal welfare to be compromised (Cloete *et al*., 2009; Zishiri *et al*., 2013). A major setback in efficient sheep production is caused by the reduced and variable lamb survival on the flock level (Haughey, 1991).

The ability of a lamb to survive as well as the maternal ability of the ewe have a major influence on the survival of a lamb as a trait (Vatankhah & Talebi, 2009). The first week of the lambs' life is very important. The provision of a lambing environment conducive to maternal care and the formation of a strong ewe-lamb bond increases the probability of lambs to survive. Ewe-lamb interactions and lamb survival is maximized if ewes remain on or near their birth sites for at least six hours (Ipsen, 2013). The managerial intervention of housing pregnant ewes before lambing has been proven to increase the chances of lamb survival in many countries (Ipsen, 2013). Dystocia and starvation caused by poor mothering ability are the main causes of lamb deaths in an extensive environment (Nowak & Poindron, 2006). Lamb deaths with symptoms indicative of starvation-mismothering-exposure are aggravated by bad weather conditions, insufficient offspring energy reserves, an inadequate amount of colostrum, multiple births as well as udder problems. Insufficient maternal body reserves leading to a lower availability of colostrum for the newborn lamb has a negative impact on survival as colostrum serves as a crucial source of food and immunity for the newborn (Nowak & Poindron, 2006). It is very important to develop the genetic and managerial procedures, as based on identified genetic and non-genetic factors that affect survival, in order to improve lamb output (Ferreira *et al*., 2015).

Breeding sires for the purpose of improving lamb survival is possible as the sires play a pivotal role in genetic selection. Proper selection of a sire breed or of individual rams to sire the next generation may benefit lamb survival (Nowak & Poindron, 2006). Zishiri *et al*. (2013) mentioned that there is limited genetic information on lamb survival of the Dorper breed despite its popularity.

2.8.2 Resistance to ticks

Ticks are the external parasites of a wide range of livestock species. They are major transmitting agents of protozoan, rickettsian and viral diseases in livestock and result in major losses globally (Rajput *et al*., 2006). Tick infestation is a major threat to animal health in tropical and subtropical countries as it causes great economic losses (Rehman *et al*., 2017). Ticks and tick-borne diseases are dependent on climate, species, genotype as well as socioeconomic and technological advances in control measures (Rashid *et al*., 2018). When ticks affect animals directly, for example, by compromising growth or milk yield, the impact is referred to as primary. When tick infestation results in secondary effects such as impairing reproduction of dams and progeny weaning weight because of tick-derived udder damage in dams, the impact is referred to as secondary. There are 97 tick species classified under the 10 genera which are known to infest sheep globally (Liebisch, 1997; Spickett, 1992). Even though there are various types of external parasites that attack the sheep, most of them do not result in major production losses (Horak & Fourie, 1992). Although ticks and the diseases they cause may have a limited impact, they still cause considerable economic and social losses to sheep businesses and farmers. Rehman *et al*. (2017) reported that the intensity of tick infestation was determined by the animal species, sex, age, and preferred host breed. Genomic selection may in future allow selection for an increased resistance to pathogens in the absence of industry-wide natural or artificial challenge, if phenotypic data could be obtained from a genetically linked reference population (Cloete *et al*., 2014).

Budeli *et al*. (2009) suggested that tick counts should be recorded when the tick population is abundant when natural tick infestation is used to differentiate between animals. Very dry weather conditions as well as extreme temperatures are two main factors inducing ticks to actively locate and attach to suitable host species. Climate is therefore of paramount importance to tick survival (Floyd *et al*., 1986). On the other hand, tick activity, stocking density, pick up efficiency and evasive behavior of hosts at high tick densities are major factors influencing the transmission of ticks from one host to another (Floyd *et al*., 1986). Ticks become infested with the causative organisms of diseases while they are feeding on infected host animals. According to Cloete *et al*. (2014) resistance to external and internal parasites in sheep is heritable and can be improved through a proper selection strategy.

2.8.2.1 Effects of ticks on livestock

Ticks may cause a major loss in production of animal products and may, in severe cases, directly result in the mortality of affected animals (Hurtado & Giraldo-Ríos, 2018). Extensive, free range sheep are most likely to be infested by ticks (Figure 2.4) (Cloete *et al*., 2016). Ticks affect animals directly by feeding on the blood of the host, while indirect losses are incurred due to tick-borne diseases as well as costs for treatment and control of the infestation or infection in the case of tick-borne diseases (Hurtado & Giraldo-Ríos, 2018). High tick loads of animals may interfere with proper feeding and result in weight and production losses (Bedada *et al*., 2017). Losses in body weight due to anemia are minimized in cattle by dipping to lower tick numbers, as well as the spread of tick-borne diseases. As ticks differ in size according to species and life-stage, it may be difficult to determine the actual infestation based on the average number of ticks. Debilitation, anaemia, weight loss and (in severe cases) death are the immediate results of heavy tick infestation on cattle. In a study conducted by Scholtz *et al*. (1991), the production of Nguni cows was less affected by tick infestation, presumably because the Nguni is highly resistant to ticks.

South African farmers are subject to major production costs due to diseases that are caused by ticks in many areas (Kok & Fourie, 1995). Other ticks may not cause a major harm (Kok & Fourie, 1995); however, that does not mean they should not be considered in the small-livestock industry. Cattle are proportionally more affected by ticks and tick-borne diseases than sheep and goats in South Africa (Masika *et al*., 1997). Desalegn *et al*. (2015) found a higher prevalence of tick infestation in cattle than in sheep and goats, 25.23% vs. 10.1% and 10.0%, respectively. Horak & Fourie (1992) conducted a special survey of ticks in South Africa and concluded that ticks were common ecto-parasites in many regions of South Africa where the Dorper sheep is also found.

Figure 2.4 Ticks infesting the udder region of a sheep at Nortier (see Cloete *et al*., 2016)

Their research indicated that there are 17 species or subspecies of ticks under the six genera that infest Dorpers. The negative impact of ticks is not only important for production animals, but also in equines and companion animals. Tick borne diseases can reduce the international business market for these species and ticks may be found in abundance at sports activity events involving these non-livestock species (Hurtado & Giraldo-Río, 2018).

Ticks therefore are a major cause of economic loss on sheep farmers, processors and a country as a whole (Bedada *et al*., 2017). Areas that are much softer and more hidden from the direct sun light are the target places on the body of an animal for ticks, while ticks also prefer areas with less friction as the animal moves to avoid detachment

(Bubeli, 2010). Rashid *et al*. (2018) found that the ears are the most infested body part and reported that 91.3% of sheep had ticks, compared to 62.0% for goats. The lamb skin is the most vulnerable part and suffers major damage from tick bites (Hurtado & Giraldo-Ríos, 2018). The extent to which bovine hides are damaged depends on the quantity of ticks and the cattle breed (Jonsson, 2006).

2.9 Crossbreeding

Genetic options to improve productivity hinges on the exploitation of additive gene action by selecting animals for a variable and heritable trait of economic importance or the exploitation of non-additive gene action in a structured crossbreeding programme. The crossbreeding option generally involves the crossing of exotic breeds with traditional indigenous breeds (Momani *et al*., 2010). According to Amare *et al*. (2018) farmers in developing countries often cross exotic breeds with the local indigenous breeds to increase production while trying to maintain the adaptive traits of the indigenous breed. This process often takes place without a proper investigation of the production ability of indigenous breeds. This results in indigenous animals being underused in conservative breeding programmes in Africa because of improper classification and an inability to identify breeds with traits of economic importance (Wilson, 2018). Crossbreeding is mainly done to verify that the average performance of crossbred animals with genes from different parental breeds will outperform the midparent performance of the parental breeds. The difference in performance between crossbred progeny relative to the average performance of the two parent breeds for a particular trait is defined as heterosis or hybrid vigour (Yadav *et al*., 2018). Heterosis can either be positive or negative, large or small, and depending on the economic value of the difference can be said to be favorable or unfavorable (Cassell & McAllister, 2009). Structured crossbreeding can, however, generate hybrid vigour and may benefit from breed complementarity. The following formula can be used to calculate percentage heterosis:

$$\% \text{ Heterosis} = [(\text{crossbred average} - \text{straight bred average}) / \text{Straight bred average}] \times 100$$

Crossbreeding increases heterozygosity and reduces the number of homozygous gene pairs i.e. the resultant cross is outbred (as an opposite of inbred). A proper knowledge of a breed (possession of useful traits, weaknesses and available resources) makes it easier to know what breeds to use in crossbreeding. It is easier to start a crossbreeding program than it is to return to a purebred line in a crossbred population (Cassell & McAllister, 2009).

2.9.1 Effects of crossbreeding on livestock

Crossbreeding in Africa was successful in areas where environmental conditions are most suitable to exotic breeds (Wilson, 2018), and it should be treated as a long term plan. Most traits that determine productivity, adaptability to environmental conditions and resistance to diseases can be selected for, using well-described genetic variation. Crossbreeding has been practiced for a long period and it introduces favorable alleles for specific production functions into the genetic make-up of animals and increases heterosis, predominantly in lowly heritable fitness traits. In some cases, purebred cows that have high milk production cannot adapt to some challenging agro-ecological zones. However, their genes for excellence in milk production can be transferred trough crossbreeding with a local indigenous breed to better the production of their F1 progeny. Crossbred progeny also inherit traits associated with adaptation to the local conditions from their indigenous parents while hybrid vigour in the F1 progeny benefits lowly heritable fitness traits such as reproduction, age at first calving and calving interval in cattle (Yadav *et al*., 2018). Also, local sheep can be back-crossed with F1 male crossbreds to improve adaptability to the local environment in the F2 generation (Gebreyowhens *et al*., 2017).

Getachew *et al*. (2016) revealed that the reproductive performance of crossbred progeny differs depending on factors such as management, location, dam breed as well as breed composition. However, indiscriminate crossbreeding of indigenous breeds dilutes the adaptability of the available local genetic resources and may result in the indigenous livestock breed being severely compromised, if not becoming extinct. An example of this happening is the case of the indigenous fat-tailed NA breed, which is faced with extinction in South Africa and is only found in numbers in conservation flocks (Sandenbergh *et al*., 2018). Indigenous Zulu sheep is also under threat of extinction as a result of crossbreeding with Dorper sheep and it requires a major intervention to avoid this (Kunene *et al*., 2014).

2.10 Objectives

Against this background, the following objectives were identified for research on extensively managed sheep under challenging environmental conditions on the Strandveld region on the Western Seaboard of the Western Cape Province in South Africa:

(i) To study growth traits (birth weight and weaning weight) as well as fitness traits (lamb survival and tick count under natural challenge) in an adapted commercial meat breed with local influence (the Dorper) and an adapted, unimproved, indigenous breed (the NA)

(ii) To study qualitative and quantitative meat traits in an adapted commercial breed with local influence (the Dorper) and an adapted, unimproved, indigenous breed (the NA)

(iii) To study growth traits (birth weight and weaning weight) as well as fitness traits (lamb survival and tick count under natural challenge) in pure breeds as well as the reciprocal cross of an adapted commercial meat breed with local influence (the Dorper) and a dual-purpose breed (the SAMM)

(iv) To study qualitative and quantitative meat traits in pure breeds as well as the reciprocal cross of an adapted commercial meat breed with local influence (the Dorper) and a dual-purpose breed (the SAMM)

These objectives will be studied to gain knowledge about breed and crossbreeding effects under challenging conditions. The intention of the study is to provide both the commercial and emerging sheep sectors with information to base decisions regarding breed choice and breeding strategy upon.

CHAPTER 3

Effect of breed on growth traits, lamb survival and tick count in Dorper and Namaqua Afrikaner sheep reared in an extensive environment

3.1 Introduction

Small stock production is practiced under different production systems ranging from extensive systems in the arid areas to semi-intensive systems found in the higher rainfall areas (Cloete & Olivier, 2010). Extensive small stock farming plays a crucial role in some countries which lack the resources and infrastructure for intensive farming. In South Africa approximately 80% of the agricultural land is not suitable for crop production, while the largest part thereof is not even suitable for other production enterprises such as beef production (Cloete & Olivier, 2010). Small stock production is thus the only viable farming enterprise in such extensive arid areas (Schoeman *et al*., 2010). According to Cloete & Olivier (2010) extensive small stock production is the dominant livestock industry in the drier western and northwestern parts of the country, with a grazing capacity well below 12 ha per large stock unit.

The first measurable trait that is used to evaluate growth performance is birth weight (Ptáček *et al*., 2017), which plays an important role in increasing sheep output (Petrović *et al*., 2015). Birth weight is favorably correlated with some live weight traits and lamb survival, therefore it is considered as a trait of interest (Assan & Makuza, 2005). Ptáček *et al*. (2017) reported that litter size impacts on birth weight and further explained that lambs with a low birth weight are more likely to succumb prior to weaning, while they may also grow slower. Weaning weight, on the other hand, is also a trait of economic importance as it directly contributes to the profitability of the sheep enterprise (Csizmar *et al*., 2013).

According to Knuth *et al*. (2018), breeders should have a breeding plan to improve lamb production traits. Dorper sheep adapt well under diverse climatic conditions (Belete *et al*., 2015), and can be used to produce lambs with faster growth rates (Csizmar *et al*., 2013). Burger *et al*. (2013) explained that climate change negatively impacts food resources and exotic sheep breeds suffer in growth and development and their contribution to profit is constrained as a result of harsh conditions. On the other hand, poor appearance as well as relatively low production in indigenous breeds results in an underestimation of their value (Amare *et al*., 2018). However, despite all the environmental limitations, production and reproduction of the Namaqua Afrikaner breed (NA) is still within acceptable levels (Schoeman *et al*., 2010).

Survival rate is undoubtedly an important trait in all systems of sheep production and in all environments. The inability of the ewe to raise her lamb(s) have a negative impact on the flock; leading to a reduction in the number of surplus sheep for sale, reduced options for selection and also a reduction in flexibility to change flock structures (Hinch & Brien, 2014). Lamb survival can be defined qualitatively on the binomial scale as either the proportion of lambs survived or those that succumbed (then defined as lamb mortality; Brien *et al*., 2014). Akhtar *et al*. (2012) explained that extreme climate and seasonal conditions like droughts and floods in different years may compromise flock production as a whole and result in a need for managerial interventions. Lamb survival is affected by several factors such as weather and flock management from birth to weaning (Hincks *et al*., 2014). The performance of individual animals is also likely to be affected by environmental factors such as sex (male/female), birth type, dam age, lamb age and weight of the dam. During prolonged dry periods and in arid regions, high fecundity levels cannot be sustained due to the unfavorable environment. In times like that, lamb quality should be improved rather than quantity (Zishiri *et al*., 2013) as productivity is determined by lamb survival among other things (Morris *et al*., 2000).

Tick infestation impairs the general wellbeing of livestock and result in economic losses because they attach themselves on the skin surface, excrete toxins and transmit diseases. They damage hides and skins and interfere with meat and milk production (Desalegn *et al*., 2015), and reduces body weight gain (Kok & Fourie, 1995; Rinaldi *et al*., 2014). If an animal loses a lot of blood as a result of ticks, nutrients are eventually lost and ‘tick worry’ can irritate animals causing a drop in production (Cloete *et al*., 2013). Ticks and tick borne diseases may result in high input costs (Kok & Fourie, 1995). Rinaldi *et al*. (2004) explained that it is very important to keep accurate records of ticks' distribution to reduce and avoid losses incurred by them. Effective tick control programmes should be formulated at the national or regional level.

Indigenous breeds are more resistant to tick infestation and have a stronger immunity against tick-borne diseases compared to commercial genotypes that may be less well adapted to local conditions (Spickett & Fivaz, 1992). Although such genotypes have advantages in terms of fitness traits, they may be inferior to commercial livestock in other traits of economic importance (Burger *et al*., 2013). According to Cloete *et al*. (2014), the ability of sheep to resist internal parasites is heritable and can be improved through selection. Therefore, the authors suggested that some efforts should be made to include disease resistance traits in the national small stock analysis. South Africa has the indigenous fat-tailed NA which is a very hardy breed (Sandenbergh *et al*., 2018). The breed has fewer ticks on sensitive parts such as the udder and hind legs than the South African Mutton Merino and Dorper (Cloete *et al*., 2013). The NA breed is facing extinction and is only found in conservation flocks. Therefore, Sandenbergh *et al*. (2018) recommended that sustainable conservation methods should be applied to this breed. Part of the strategy will be to prevent unplanned crossbreeding and unintentional introduction of hybrids to help preserve the limited number of NA genetic resource flocks which are left.

The aim of this study was to evaluate birth weight, weaning weight, lamb survival and tick count of two sheep breeds (Dorper and NA) in an extensive environment in an effort to understand the adaptability and robustness of these breeds in a limiting production environment.

3.2 Materials and methods

3.2.1 Study area, data and animals (recording)

The records used were collected between 2009 and 2017 on Nortier Research Farm in the Strandveld region on the West Coast of South Africa (32˚02' S and 18˚20' E). The Nortier

Research Farm is situated near Lamberts Bay and serves the North West region (from Bitterfontein in the north to Elands Bay and Citrusdal in the south) of the Western Cape. Previous studies described the site in detail (Cloete & De Villiers, 1987; Van Niekerk *et al*., 1990; Cloete *et al*., 2016). The animals used were the Dorper and NA resource flocks onsite (Cloete *et al*., 2016; 2017). These breeds were maintained as a single flock from 2009 to 2017, except during mating. The ewes of the respective breeds were mated annually within breeds to 3-4 rams in single-sire groups during January-February.

Lambing took place during June-July, when the natural pasture on the farm is expected to be actively growing after the expected autumn and winter rains. Ewes were side-branded with stock-marker spray to facilitate the identification of lambs with their dams from a distance. During lambing in a single group on natural pasture with shrub cover, lambs were tagged, weighed and identified with their dams within 24 hours of birth. They were also sprayed with the same number as the dam to facilitate the reunification of lambs with their dams. The lambs were grazed with their dams until weaning weight was recorded at an average (±SD) age of 116±16 days. Overall lamb survival from birth to weaning could be deducted from the birth and weaning records. Total full-body tick counts were also recorded for lambs within 14 days of weaning for the period from 2010-2017. Only total tick count was available for 2010, but body-site specific counts were recorded as described by Cloete *et al*. (2016) for subsequent years. Tick counts on the head, brisket, axillia and front legs (denoted as the front half) as well as the belly from the navel, udder, groin and hind legs but excluding the perineum and tail in NA (denoted as the back half) were genetically very similar to total tick counts (Cloete *et al*., 2016; 2017), as could be expected from traits in a part-whole relationship. Therefore, only total tick counts were analysed in this study.

Rainfall data from the farm weather station collected from 2008 to 2017 were used to describe the environmental conditions of where the sheep were kept. In this study, a minimum rainfall of 105.9 mm per year to a maximum of 281.7 mm per year was recorded. According to Botai *et al*. (2017), the amount of rainfall received in the Western Cape differs across the province and it is usually defined in three dominant rainfall zones namely, the winter, late summer and constant rainfall regimes.

3.2.2 Data analysis

All data were analysed using the ASREML software (Gilmour *et al*., 2016). The software allows for the analysis of fixed effects (including linear covariates), interactions among fixed effects, as well as random variables in animal breeding experiments. Fixed effects included in this study were birth year (2010-2017 for total tick counts and 2009-2017 for the other traits), sex (male or female), age of dam (2-7+ years) and birth type (single or multiple). Weaning age was fitted as a linear covariate to weaning weight and total tick count. Binomial survival data were initially analysed using the logit transformation to link the binomial distribution to the normal distribution. However, after it was ascertained that the outcome was similar, an analysis using a normal linear model was preferred for ease of interpretation. Total tick count data were skewed and leptokurtic. To normalize these data, individual tick counts were transformed to natural logarithms after 3 was added to account for zero counts. The size of the data set did not warrant the fitting of a full set of random effects. However, the random effect of animal was fitted within and across breeds to verify the consistency of the derived between-animal variance components across the two breeds considered.

Total monthly rainfall was combined into four seasons: November, December and January (Summer), February, March and April (Autumn), May, June and July (Winter) and August, September and October (Spring). The total rainfall data in the four seasons of different years were used to prepare an area chart depicting the seasonal and overall rainfall.

3.3 Results and Discussion

3.3.1 Average seasonal rainfall

The total seasonal rainfall at Nortier from 2008-2017 is depicted in Figure 3.1. Total annual precipitation varied markedly among years and there was a distinct reduction in the rainfall received in recent years. Heavy rainfall occurred in 2008 and 2013 was the year that received the second highest rainfall. Total rainfall varied among the seasons in different years. The winter season was evidently characterized by higher precipitation in earlier years, but there was only a limited amount of winter rainfall received in this season during 2014-2017. Botai *et al*. (2017) mentioned that the Western Cape Province experienced the worst water shortage in 2014-2017 compared to the past 113 years. The seasons with the highest precipitation exceeded the long-term average of 221 mm but less than 150 mm of rainfall was received in 2014-2017 in winter. In 2013 and 2008, above 300 mm annual precipitation was received. However, some years (2011, 2015, 2016 and 2017) experienced an annual rainfall of below 150 mm. It is known that the Western Cape has a Mediterranean climate and it receives most of its rainfall in winter. The long-term average precipitation of Nortier amounts to 221 mm per annum. According to Botai *et al*. (2017), the annual precipitation in the Western Cape Province varies from ~300 mm to more than 900 mm. However, the province has repeatedly encountered great drought incidences over the past three decades.

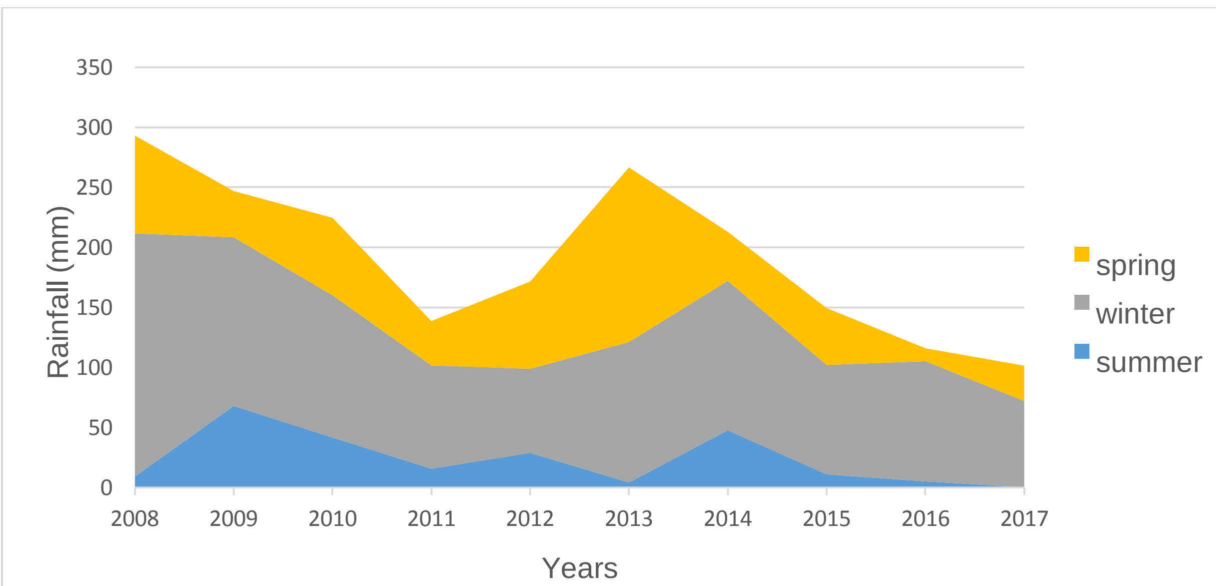

Figure 3.1 An area chart depicting the seasonal and overall rainfall for Nortier Research farm for the period 2008-2017

3.3.2 Descriptive statistics

Descriptive statistics, i.e. the numbers of records, means and standard deviations, coefficients of variation (CV), ranges, skewness and kurtosis for the respective traits are depicted in Table 3.1. Average birth weight of lambs was 3.79 kg in this study. A similar mean was reported for a

Merino flock by Cloete *et al*. (2009). These reports are consistent with the literature that an ideal birth weight should be in the range of 3.5 to 6.0 kg for lambs (Oldham *et al*., 2011). The CV of 24% for WW is in accordance with that of Thutwa (2016) for the same breeds. However, numerous reports showed slightly lower CVs for WW, in Dormers (21.9%) (Van Wyk *et al*., 2003), SAMM (21.1%) (Cloete *et al*., 2001b) and Dorpers (14.6%) (Zishiri *et al*., 2013). One should consider that the current analysis was on a two-breed genetic resource while the studies cited were for a single breed. CVs for production traits are usually expected to exceed 10% (Van Wyk *et al*., 2008). Lamb survival had a CV of 56.4% which was higher than the figure of 46.3% reported by Van Wyk *et al*. (2003) on Dormer sheep. The CV of untransformed tick count exceeded 100% but the log transformation resulted in the trait being normally distributed with a CV of 54%.

Table 3.1 Descriptive statistics for birth weight (BW), weaning weight (WW), lamb survival (Surv) and tick count (Ticks) of Dorper and Namaqua Afrikaner (NA) sheep raised extensively

Trait	n	Mean±SD	CV%	Range	Skewness	Kurtosis
BW (kg)	1527	3.79±0.93	24.5	1.0-7.0	-0.073	-0.158
WW (kg)	1160	28.6±6.9	24.1	7.5-53.0	0.248	-0.097
Surv	1530	0.77±0.43	56.4	0-1	-1.207	-0.544
Ticks (n)						
Raw	914	9.37±10.38	110.8	0-116	3.12	19.09
Transformed	914	1.89 ± 1.02	53.9	0-4.76	-0.304	-0.646

n=number of records; SD=standard deviation; CV= coefficient of variation

3.3.3 Significance of fixed effects included

There were significant differences in birth and weaning weight and tick count due to breed (P<0.05; Table 3.2). Differences in birth and weaning weight due to breed were also reported by Fasae *et al*. (2012). In contrast, lamb survival was independent of breed. Interaction effects were not significant between breed X birth year on birth weight and lamb survival, breed X age of dam on all traits and breed X birth type on all the traits except weaning weight. Birth year affected all traits analyzed (P<0.01) and also interacted with breed for WW and tick count (P<0.05).

Year of birth was the main significant (P<0.05) source of variation in this study. The significant effect of birth year on BW and WW of sheep was also reported by Lalit *et al*. (2016a). This could be because some lambs were born in dry years while some were born in rainy years. Therefore, lambs that were born and weaned in rainy years consumed high quality and quantity forage. Thutwa (2016) explained that differences on extensive pastures throughout the years is as a result of seasonal variation of climate, quality and quantity of pasture and the susceptibility of animals to diseases and parasites. The availability of pastures in different years is mainly affected by variation in climatic conditions and has an effect on the wellbeing of pregnant ewes, ewes themselves as well as their lambs (Lalit *et al*., 2016b). The main reasons for birth year to affect growth ability is that this factor are above all different nutrition and climatic conditions (Kuchtík & Dobeš, 2006). The significant interaction between breed X birth year for WW suggested that the breeds did not respond in the same way to the respective birth years. A possible explanation for this result is that the breeding values of the rams used could have differed between birth years. This could be especially true for the NA, where sires had to be sourced from other conservation flocks with limited or no records.

Sex of the lamb had a significant influence on BW, WW and tick count (P<0.01) but did not influence lamb survival (P>0.05). Single lambs were 20% and 19% heavier than the multiples both at birth and weaning respectively (4.16±0.07 kg vs. 3.47±0.06 kg and 31.6±0.4 kg vs. 26.6±0.4 kg; Table 3.3). Birth type was highly significant (P<0.05) for BW, WW and lamb survival. The significant effect of birth type on BW and WW is in agreement with the findings of Giorgis *et al*. (2017) on Dorper sheep and its F1. The regression of WW on weaning age as a linear covariate was also significant (P<0.01). Age of dam was a significant source of variation for both BW and WW (P<0.01, Table 3.2). The significant effect of age of dam was reported by Mellado *et al*. (2016) on BW and WW, Karakuş *et al*. (2008) on BW and Cloete *et al*. (2001b) on WW of lambs. In this study BW of lambs increased with age from 2-year-old ewes and peaked at 4 years after which it decreased with age of dam. According to Mellado *et al*. (2016), the uterus of older ewes is larger than that of young ewes, therefore it is capable of holding more nutrients for the lamb during its growth in the uterus. However, age of dam had a non-significant effect on the pre weaning traits of Buchi sheep (Akhtar *et al*., 2012).

Table 3.2 Significance of the effect of breed, year, sex, age of dam, birth type, weaning age and two factor interactions on birth weight (BW), weaning weight (WW), lamb survival (Surv) and tick count (Ticks)

	Traits			
Fixed effects	BW (kg)	WW (kg)	Surv	Ticks
Breed	**	**	0.458	**
Birth year	**	**	**	**
Breed* birth year	0.161	*	0.756	**
Sex	**	**	0.983	**
AOD	**	**	0.895	*
Breed*AOD	0.330	0.289	0.710	0.066
Birth type	**	**	**	0.392
Breed*Bt	0.151	*	0.903	0.642
Regression on weaning age	-	**	-	0.297

AOD=age of dam; Bt=birth type; Wage=weaning age;* - P<0.05; ** - P<0.01; - not fitted

Tick count was unaffected by weaning age (b=0.297 ticks per day of age) but was affected by age of dam. This result is similar to that reported by Thutwa (2016). However, total tick count was affected by breed type, an interaction between breed and birth year as well as an interaction between breed and AOD. Mapholi *et al*. (2017) revealed that the level of tick infestation can be indicated by total tick count.

3.3.4 Solutions for fixed effects

Although main effects were involved in significant interactions, overall means will be considered initially, followed by a discussion of significant interactions. The effects of breed, sex, birth type and weaning age on the respective traits are presented in Table 3.3. Dorper lambs were 0.39 (11%) and 5.6 kg (21%) heavier at birth and weaning than NA lambs.

Table 3.3 Least squares means (±SE) for the effects of breed, sex, birth type (Bt) and weaning age (WAGE) on birth weight (BW), weaning weight (WW), lamb survival (Surv) and total tick count (Ticks)

	Traits			
Effect and breed	BW (kg)	WW (kg)	Surv	Ticks (n)
Breed				
Namaqua Afrikaner	3.62±0.06	26.3±0.5	0.787±0.040	1.57±0.06 (3.82)
Dorper	4.01±0.10	31.9±0.7	0.742±0.037	2.20±0.07 (8.01)
Sex				
Male	3.93±0.06	30.6±0.4	0.765±0.030	1.99±0.05 (6.31)
Female	3.71±0.06	27.6±0.4	0.764±0.030	1.78±0.05 (4.94)
Birth type				
Single	4.16±0.07	31.6±0.4	0.827±0.032	1.91±0.06 (5.76)
Multiple	3.47±0.06	26.6±0.4	0.703±0.028	1.86±0.05 (5.43)
Regression on weaning age	-	0.166±0.017	-	0.0019±0.0018

Csizmar *et al*. (2013) reported a lower birth weight (3.8 kg) in Dorper lambs. Birth and weaning weights for female lambs were 5.9% and 11% lower than those of males, respectively. These results are consistent with the reports of Lupi *et al*. (2015) and Knuth *et al*. (2018). Chitner *et al*. (2009) added that lambs which were heavier at birth are usually single males, produced by older ewes with larger body sizes and good feeding conditions. The regression of weaning weight on age amounted to 0.166±0.017kg/day indicating that lamb weaning weight increase by 166 g per day.

Singles were 0.69 kg heavier at birth and 5 kg heavier at weaning than multiples. These results are comparable to those obtained by Cloete *et al*. (2007) in the same breeds, Baneh *et al*. (2010) in Ghezel sheep, Akhtar *et al*. (2012) in Buchi sheep and Knuth *et al*. (2018) in the SAMM breed. Akhtar *et al*. (2012) mentioned that singles are usually heavier than twins as they get more nutrients for foetal growth as well as an increased uterine space (Momoh *et al*., 2013). They do not have to compete for milk after birth, resulting in a higher weaning weight (Thutwa, 2016). Therefore, twin bearing ewes should be provided with additional attention in terms of feed and managerial care (Assan & Makuza, 2005; Csizmar *et al*., 2013). Dalton *et al*.

(1980) and Oldham *et al*. (2011) stressed that the probability of survival is low when the respective ranges for birth weight of lambs are either below 3.0 kg or in excess of 6.5 kg.

Therefore, very small or very big sizes compromise lamb survival (Oldham *et al*., 2011). The breed effect on lamb survival was non-significant in this study. However, these results are different from the report of Cloete *et al*. (2013) where the indigenous NA lambs achieved higher survival rates from birth to weaning than Dorpers. Chadwick & Pearce (2013) outlined that Red Massai lambs had higher survival than Dorper lambs in the sub-humid tropics of Kenya. According to Hight & Jury (1970), the variability in lamb survival rate between flocks indicate that it is associated with genetic factors depending either on the dams' maternal ability and/or the inherent ability of the lamb to survive. Lamb survival was independent of sex in this study. The insignificant effect of sex on lamb survival was not consistent with results reported by Cloete & Villiers (1987).

Total tick count was unaffected by age (b±SE=0.0019±0.0018 ticks per day). The effect of breed on total tick count was highly significant. NA were more tick resistant than Dorper lambs, Dorpers had a 40% higher tick load than NA. Fourie & Horak (2000) stated that Dorpers resistance to ticks and diseases can be improved through proper selection. Higher total tick count on exotic vs indigenous breeds was also reported by Rehman *et al*. (2017) in cattle. Sex of the lambs also had a significant effect ($P<0.05$) on the total tick count. Male lambs had a 12% higher tick burden than female lambs. Bedada *et al*. (2017) reported that males had a higher tick infestation than females; however, Rehman *et al*. (2017) reported that tick count was higher in females than males. Birth type did not affect total tick count ($P>0.05$). Similar results were reported by Thutwa (2016) on the same breeds.

Log transformed tick count mean was highest for the progeny of 7+year-old ewes (2.14±0.12) as graphically illustrated in Figure 3.2. Ewes between the ages of 2 and 5 years had a transformed mean tick count ranging from 1.83±0.07 to 1.91±0.0.07 ($P>0.05$), while the progeny of 6-year-old ewes had the lowest transformed mean of 1.68±0.09. The mean for log-transformed tick count of the progeny of 7+-year-old exceeded that of 6-year-old dams by

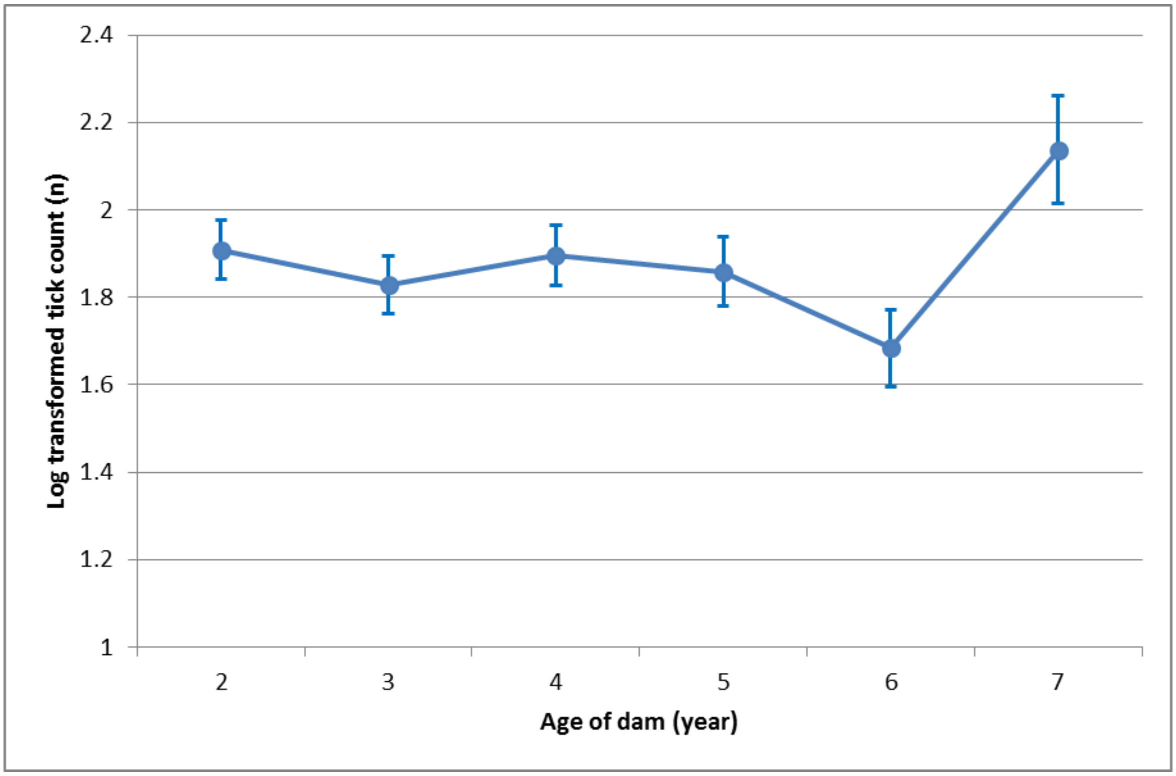

Figure 3.2 Effect of age of dam on the log transformed tick count

29%. The effect of age of dam on back transformed total tick count is presented in Figure 3.3. The progeny of 6-year-old ewes had the smallest transformed mean of 4.39±0.47 while 7+ years old ewes had the highest value of 7.47±1.05 for the back transformed tick count. Transformed means for the progeny of ewes between the ages of 2 and 5 years did not have marked variation.

3.3.4.1 Least squares means (±SE) depicting interaction between year and breed for weaning weight (WW)

Unlike in the study of Thutwa (2016), where WW was not affected by the breed x birth year interaction, an interaction was observed in this study (Figure 3.4). Dorper lambs were heavier than their NA contemporaries throughout, although the magnitude of the breed differences varied between years. Thutwa (2016) also found that NA lambs were the lightest at weaning compared to the improved commercial breeds (Dorper and SAMM).

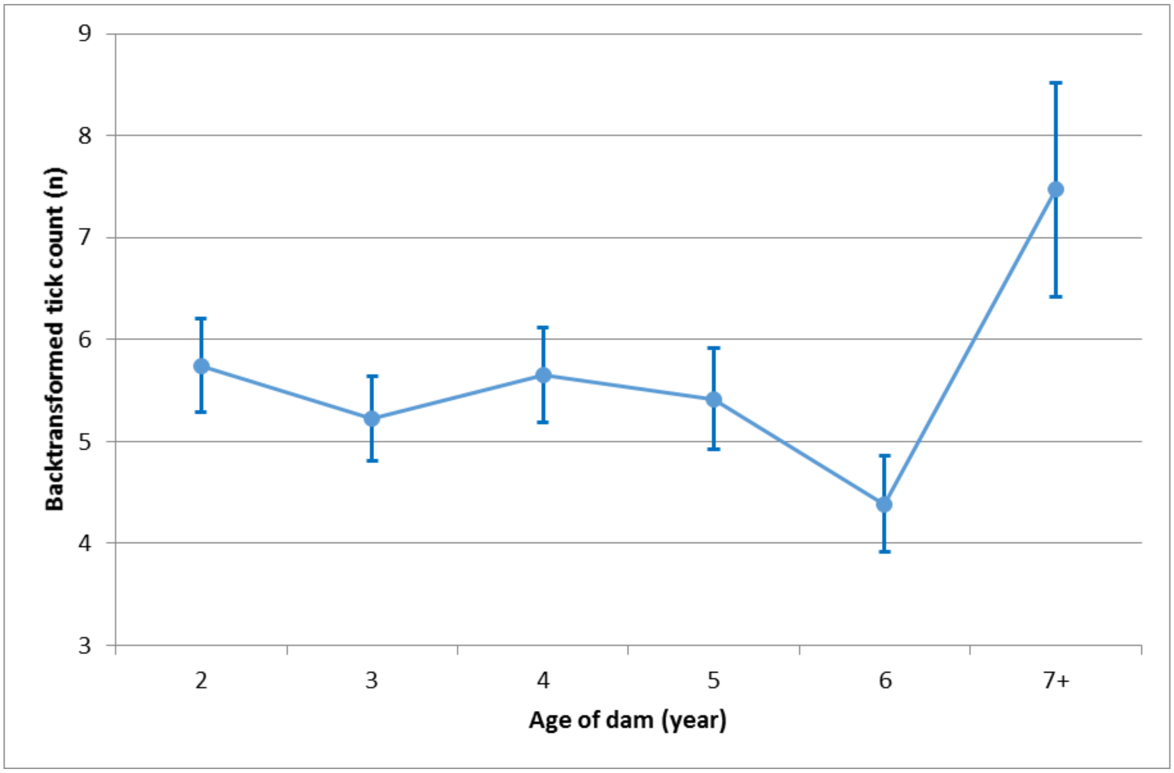

Figure 3.3 Effect of age of dam on the back transformed tick count

When expressed relative to means for the NA, the advantage in WW for Dorper lambs ranged from 14% in 2011 and 2013 to 29% in 2012. It can thus be concluded that, although some year-to-year variation in the magnitude may occur, Dorper lambs were consistently heavier than their unimproved NA contemporaries. Lambs that were weaned in rainy years had higher weights because of the good pasture. Favorable environmental conditions during the rainy season also provided more quantity and better quality of pasture for cows that translated into a higher BW of calves (Segura-Correa *et al*., 2017).

3.3.4.2 Least squares means (±SE) depicting interaction between year of birth and breed for total tick count

Total tick count was also affected by an interaction between breed and birth year (P<0.01). Transformed total tick counts of Dorper lambs were consistently higher than those of the NA breed for the early years of the study (2010-2014, Figure 3.5). In contrast, no clear breed differences could be established in the period from 2015-2017. In 2013, the tick count of Dorper lambs was almost twice as much as that of NA.

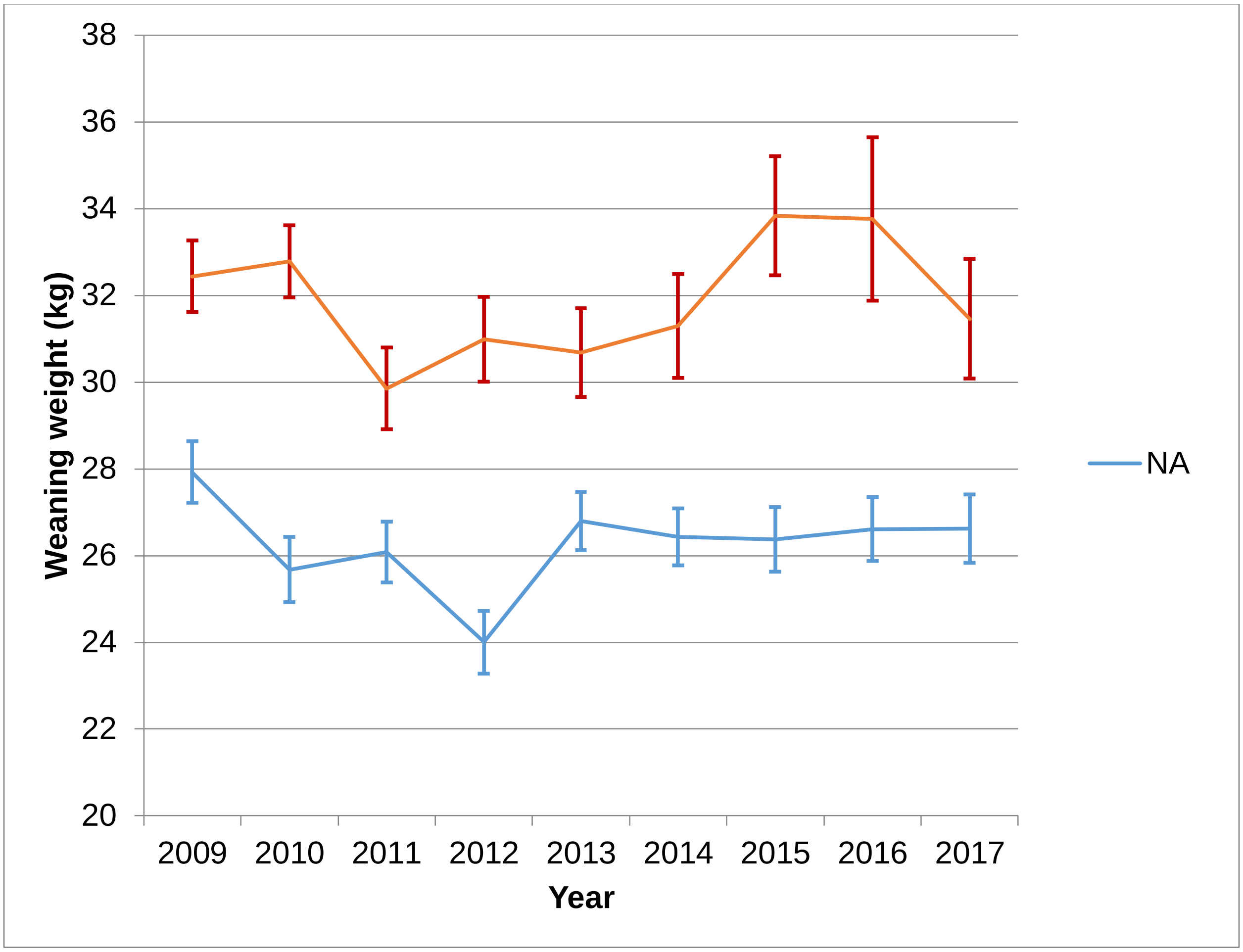

Figure 3.4 Least squares means (±SE) depicting interaction between years X breed for weaning Weight (WW) in Namaqua Afrikaner (NA) and Dorper (D) lambs

Corresponding means for back transformed total tick count confirmed markedly lower tick loads for NA lambs compared to Dorpers for most of the study period. Transformed mean for total tick count increased from 2013 to 2015 for both the Dorper and NA lambs by 80.3% and 91.4%, respectively. Thutwa (2016) similarly found a higher tick challenge from 2013-2015 in Dorper, NA and NA x Dorper lambs. In 2017, the back transformed mean for total tick count of Dorper lambs exceeded that of the NA breed by 39%. Mean tick count was highest in 2015 while lambs born in 2013 had the lowest tick count in both Figure 3.5 and 3.6. Comparable results were previously reported by Thutwa (2016).

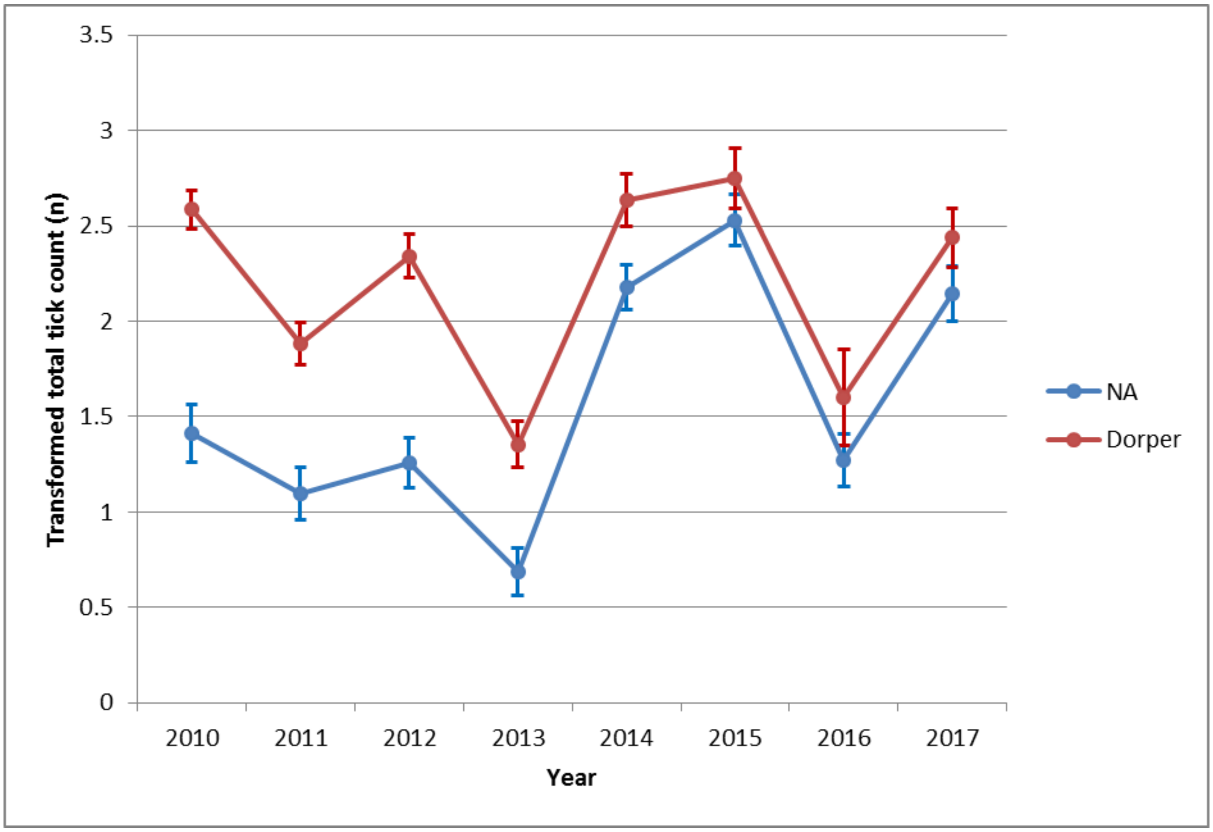

Figure 3.5 Least squares means (±SE) depicting the breed x year for transformed total tick count for the Namaqua Afrikaner and Dorper breeds

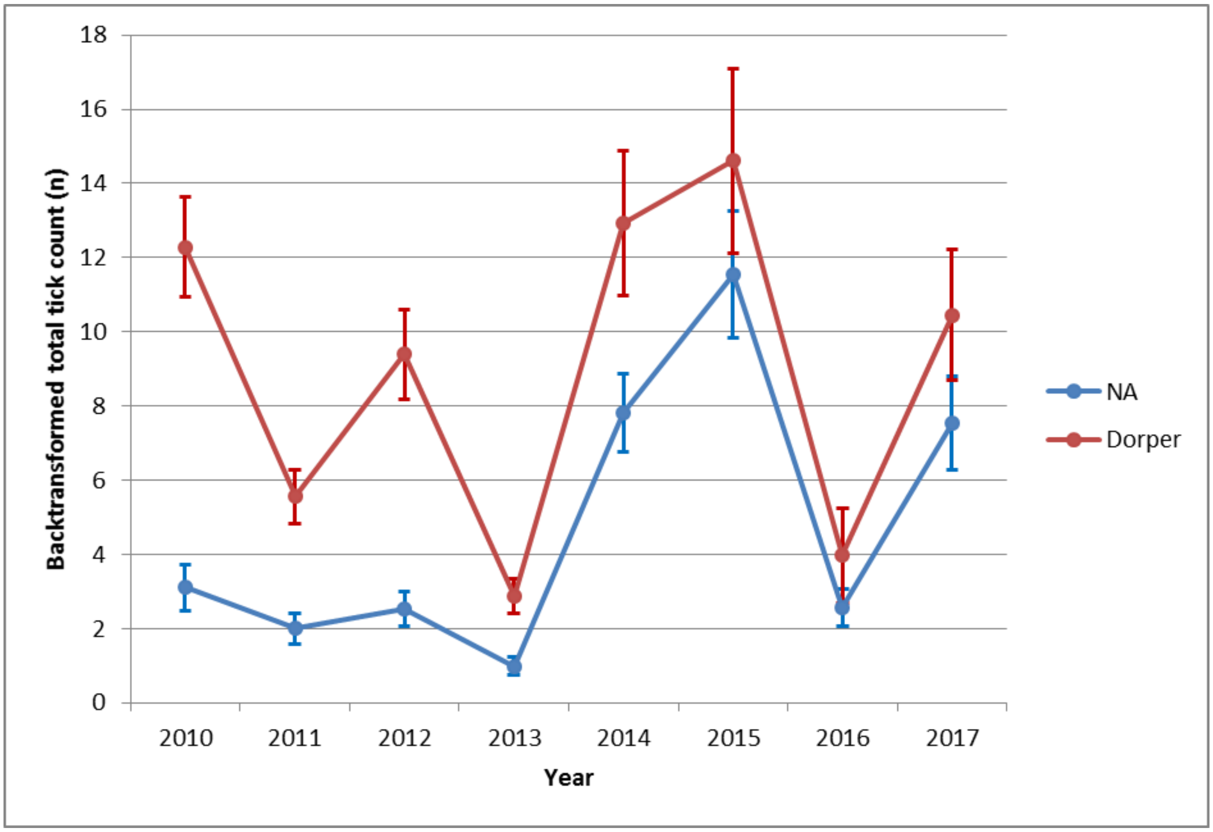

Figure 3.6 Least squares means (±SE) depicting an interaction between the breed x back transformed total tick count of the Namaqua Afrikaner and Dorper breeds

3.4 Conclusion

This study has demonstrated that breed clearly had a marked influence on the growth traits, although a measure of year-to-year variation was also observed. The higher birth and weaning weights of male and single lambs were consistent with the findings of many studies. Ticks burdens on lambs varied according to breed and birth year. Indigenous NA lambs appeared to be more resistant to tick infestation, although the magnitude of the breed effect varied between years. Further research on the effect of breed on tick count on small ruminants should thus be conducted, as there is only a limited amount of literature on it.

CHAPTER 4

Breed effects on the meat quality of the South African Dorper and Namaqua Afrikaner breeds reared extensively

4.1 Introduction

South Africa's cuisine consists mainly of a meat component which can be derived from different domesticated and wild animal species (Erasmus & Hoffman, 2017). Although there are a large variety of domesticated ruminants in South Africa, sheep and cattle meat are, however, the preferred types of red meat (Sheridan *et al*., 2003). During 2016/17, the total consumption of meat (lamb & mutton) in South Africa was estimated to be 186 000 tonnes (DAFF, 2018). Sheep meat is a niche product that accounts for only 3% of the meat market worldwide (Jacob & Pethick, 2014). In years of crop failure, due to drought or disease, and during periods of unstable grain prices, farmers depend on sheep farming as their only means of providing a livelihood for their family and employees (Cloete & Olivier, 2010). Lorentzen & Vangen (2012) reported that the main focus in sheep breeding has been placed on increasing fecundity and growth, as well as increasing the carcass output.

Different participants along the agricultural food chain have developed different views on the quality of livestock products (Ramírez-Retamal & Morales, 2014). The increasing economic value of meat quality traits as well as their characteristics makes them more important for sheep breeding systems (Brito *et al*., 2017a). The carcass and meat quality traits of the lamb together with ovine productive traits should be combined and improved simultaneously to acceptable levels in order for the lamb industry to remain sustainable or viable for a longer period (Brito *et al*., 2017a). Sena *et al*. (2016) explained that through genetic evaluation of growth traits and proper selection of high performing animals, meat breeds can be improved genetically. Artificial selection can be used as a tool for improving the slaughter traits of South African sheep (Naudé *et al*., 2018). An interaction between breed, chronological age, slaughter weight and sex with the use of genetics and nutritional practices need to be considered by the producers and processors for the production of a high quality lamb for the consumers (Hoffman *et al*., 2003). Ramírez-Retamal & Morales (2014) reviewed the quality of breed and feed on the quality of carcass and meat and concluded that breed can have an influence on weight, yield and carcass conformation among other things.

Consumers are most likely to be biased by the meat colour when choosing fresh meat (Cho *et al*., 2015). Meat colour is evaluated in different levels where (L*) is lightness, (a*) is the red color level and (b*) the yellow color level (Esteves *et al*., 2018; Mortimer *et al*., 2018). The physical appearance of meat is also described by the chroma, hue angle and the colour differences in meat (Sen *et al*., 2013). More research is required to develop a simple and practical method to predict meat colour stability. Yalcintan *et al*. (2018) did not find any statistically significant differences between breeds in terms of instrumental meat quality traits, except for meat colour. Breed, as well as the differences in slaughter weight, were however assumed to be the cause of paler, pink and light colour of meat samples in a study conducted by Yalcintan *et al*. (2018) when comparing the meat quality between Gokceada and hair goat kids. Greeff *et al*. (2008) reported high positive genetic correlations among the meat colour traits studying Merino hoggets. Meat quality traits such as several measures of meat quality (fresh meat redness, retail meat redness, retail oxy/meat value and iron content) appears to have potential for inclusion in meat breeding objectives (Mortimer *et al*., 2014). Meat colour, cooking loss and shear force were compromised as the slaughter age of an animal increases (Esteves *et al*., 2018). However, according to Naudé *et al*. (2018) fatter carcasses result in lower cooking loss values.

Shear force is an indicator of meat tenderness and it plays an essential important role in the mouth when masticating meat. The differences in meat tenderness are caused by the fluctuating myofibrillar protein structure of the muscle within the period of slaughtering and consumption (Wood *et al*., 1999). Tenderness is a very crucial meat quality attribute and the tough meat is discriminated against (Wood *et al*., 1999). Meat tenderness in a diet is highly influenced by the fat composition and percentage of intramuscular fat (IMF) in the muscle (Cho *et al*., 2015). In addition to that, differences in meat tenderness between breeds are not only caused by the genetic factors but also by the type of muscles under study (Baldassini *et al*., 2016). The modelling of pH decline post slaughter represents an enhanced method of predicting the temperature of the lamb loin at pH 6. Merino sheep meat is likely to have a high pH (Hopkins *et al*., 2011). According to Naude *et al*. (2018) meat with a high pH will be dark in colour and will result in low cooking loss, whereas a higher cooking loss will result from the lighter meat. Meat with high pH may be less preferred with reference to meat odour and flavor (Young *et al*., 1993).

The meat quality of the Namaqua Afrikaner (NA), Dorper and SA Mutton Merinos (SAMM) breeds has been studied previously (Burger, 2015). The combination of the Dorset Horn sheep with its good qualities for growth and carcass traits with the black headed Persian for its hardiness, resulted in a composite breed called the Dorper which became the most popular meat breed in South (Cloete & Olivier, 2010). Dorper sheep have tender and juicy meat that is well covered with lean to medium fat on its carcasses (Snyman, 2014).

The indigenous NA is an endangered sheep breed in South Africa which is mainly reared and used in small-scale farming systems (Qwabe *et al*., 2010). Namaqua Afrikaner rams are well known to perform well as teaser rams (Cloete & Olivier, 2010). Burger (2015) reported an average shear force of 49.3±0.85 N for NA lambs. This result indicated that, even if the intramuscular fat content (IMF) (%) of NA were low, their tenderness had no significant ($P>0.05$) difference from that of the Dorper and SAMM. However, the nutritional profile of NA lambs carcasses had the lowest amount of fat which could be preferred by health-conscious consumers and may increase the market-share of the breed (Burger, 2015). There is a paucity of information on the NA meat quality traits as well as their carcass yield. Maleki *et al*. (2015) studied the effects of breed on muscle fatty acid composition in fat-tailed sheep.

The main objective of this study was to determine and compare the effects of two different South African sheep breeds (the Dorper and the indigenous, fat-tailed NA) for different quantitative and qualitative meat traits.

4.2 Materials and methods

4.2.1 Experimental site and animals

The NA and Dorper lambs used in this study were kept and raised at Nortier Research Farm of the Western Cape Department of Agriculture. The farm is situated to the north of Lamberts Bay on the Western Seaboard of South Africa. The study area and the sheep management were discussed in detail in Chapter 3 (see Subheading 3.2.1).

4.2.2 Slaughter and sampling procedures

The NA and Dorper lambs destined for slaughter were weighed and selected based on visual appraisal as slaughter ready after weaning in October each year. These weights were recorded less than 24 hours ante mortem and were therefore used as slaughter weights for downstream analyses. The lambs were transported for approximately 250 km by road to either of two EU-approved commercial abattoirs, namely Roelcor in Malmesbury or Tomi's abattoir near to Hermon. Upon arrival at the abattoir, lambs were housed in overnight lairage where they had access to ad libitum potable water, but no access to feed. The slaughter procedures commenced the next morning at 7 am and were executed according to standard South African procedures (Hoffman et al., 2003). Lambs were rendered unconscious by electrical stunning (4 s; 200 V) before being suspended by the Achilles tendon and the jugular veins and carotid arteries severed with a single knife stroke, allowing exsanguination (Cloete *et al*., 2004). Carcasses were not electrically stimulated.

Immediately following exsanguination, the carcasses were dressed and tagged with numbered tags to simplify identification upon sample collection. Forty-five minutes after exsanguination and dressing the pH and temperature of each carcass was measured and the carcasses were moved into cold storage (4° C). The pH and temperature of the *longissimus lumborum* (LL) was measured on the left side of each carcass, between the 11th and 13th rib. A CRISON PH 25 portable handheld pH-meter (507) (Lasec (Pty) Ltd, South Africa) was used to record both pH and temperature measurements. The pH-meter was fitted with a glass CRISON electrode

(Cat. 52-32) and equipped with an automatic thermometer, allowing for simultaneous measurements of pH and temperature. The pH meter was calibrated with the standard buffers, provided by the manufacturer, at pH 4.0 and pH 7.0. After being cooled and kept in cold storage for 48 h (4° C) at the abattoir, the dressed carcasses were weighed to obtain cold carcass weight. Temperature and the ultimate pH were once again recorded as described above. The *longissimus lumborum* (LL) muscle was excised from the first to the sixth lumbar vertebrae on the right side of each carcass, placed in coded bags and transported to the Meat Science Laboratory at Stellenbosch University.

The LL muscles were used for the analysis of the physical properties of the meat. Physical measurement involved the recording of subcutaneous fat depth, the percentage cooking loss, the percentage drip loss, instrumental colour as well as the Warner-Bratzler shear force immediately upon arrival at the Meat Science laboratory. Starting from the posterior side, two sub-samples (1.5-2.5 cm thick steaks) were cut from the LL and weighed to the nearest gram (initial weight, W1) (Honikel, 1998). Each sample were then suspended from a thin piece of wire (threaded through a small hole in the sample), inside an inflated, sealed polyethylene bag. These bags were left hanging at refrigeration temperatures (4°C) for 24 hours. At the end of this period, the samples were removed from the bags, blotted dry with absorbent paper and weighed (final weight, W2). These weights were used to calculate drip loss as a percentage of the initial weight of the sample. The following formula (Honikel, 1998) was used:

$$\text{Drip loss (\%)} = ((W1 - W2) / W1) \times 100\%$$

A second sub-sample (1.5-2.5 cm thick) were cut and also weighed to the nearest gram (initial weight, W1), before being inserted into a coded polyethylene bag (Honikel, 1998). These bagged samples were subsequently cooked in a water bath for 60 min at 80°C. After cooking, all water was drained and the samples were cooled down by submersion in cold water overnight at refrigeration temperatures (4°C). After the cooling-down period, all samples were removed from the bags. They were then gently blotted dry with absorbent paper as when determining drip loss and weighed (final weight, W2). Cooking loss was afterwards calculated and expressed as a percentage of initial sample weight. The following formula (Honikel, 1998) was used for this purpose:

$$\text{Cooking loss (\%)} = ((W1 - W2) / W1) \times 100\%$$

Prior to determining meat surface colour freshly cut sub-samples (prior to usage for cooking loss) were exposed to the atmosphere for 30 min. This period allowed time for the meat sample to bloom (oxygenate) (Honikel, 1998). A calibrated handheld Color-guide 45°/0° colorimeter (BYK-Gardner GmbH, Gerestried, Germany) was used to record three measurements at random locations on the bloomed surface to determine the CIEL* (lightness), a* (green-red range) and b* (blue-yellow range) values. Green, black (L* = 0) and white (L* = 100) standards (as provided by the manufacturer) was used to calibrate the colorimeter.

The cooked samples used to determine cooking loss were used to evaluate tenderness by using the Warner-Bratzler shear force method (Honikel, 1998). Cylindrical cores (1.27 cm diameter) were cut at random from the center of each of the cooled (4°C) LL samples, parallel to the muscle fibre direction. The cores were cut perpendicular to the longitudinal axis of the muscle by utilizing a Warner-Bratzler shear attachment. The maximum shear force (N) necessary for shearing a cylindrical core of 1.27 cm diameter at a crosshead speed of 200.0 mm/min was recorded. Three cores were processed per slaughter lamb and used to calculate means that were used during the statistical analysis of the data.

4.2.3 Statistical Analysis

All traits were statistically analysed by using the ASREML software (Gilmour *et al*., 2015). Fixed effects that were fitted included breed (Dorper or NA), birth year (2009 to 2017), sex (male or female), dam age (2 to 7+ years) and birth type (single or pooled multiples). The breed X year interaction as well as slaughter age as a linear covariate was also fitted in the fixed part of the model. Animal was fitted as a single random effect to control for between-family variation. Appropriate least-squares means were estimated and presented as tables or graphs.

4.3 Results and discussion

4.3.1 The effects of year and breed

Year effects were significant for most traits (P<0.05). However, these results were not reported as year effects are unlikely to be repeated in subsequent years. Year effects were included in the final analyses for the variance it controlled.

The effect of breed was significant (P<0.01) for several meat traits (Table 4.1). Dorper lambs were 15.2% heavier at slaughter than the NA lambs (P<0.01). This difference was enhanced by a 13% greater (P<0.01) dressing percentage resulting in an eventual breed difference in carcass weight amounting to 26.8% in favour of Dorpers (P<0.01).

Table 4.1 Least squares means (±SE) for the effect of breed on the quantitative and qualitative meat attributes

Trait	NA	Dorper	Significance
Slaughter weight (kg)	32.3±0.6	37.2±0.5	**
Carcass weight (kg)	12.7±0.4	16.1±0.4	**
Dressing percentage (%)	38.5±0.7	43.5±0.7	**
Grading (n)	1.12±0.08	1.40±0.046	**
pH after 45 minutes	6.86±0.04	6.82±0.03	0.20
Temp after 45 minutes (^{o}C)	30.8±0.3	32.0±0.2	**
pH after 48 hours	5.70±0.02	5.65±0.01	0.49
Temp after 48 hours (^{o}C)	4.56±0.09	4.31±0.08	0.06
Fat depth at the 13th rib (mm)	1.18±0.18	1.84±0.13	**
Fat depth at the rump (mm)	3.81±0.35	4.53±0.25	**
Drip loss (%)	1.89±0.07	1.75±0.06	0.89
Cooking loss (%)	29.1±0.4	29.9±0.3	0.07
Lightness (L*)	37.6±0.2	37.0±0.2	0.06
Redness (a*)	12.7±0.2	12.7±0.1	0.26
Yellowness (b*)	10.1±0.2	10.1±0.1	0.55
Shear force (N)	54.2±1.6	47.5±1.1	*

*P<0.05; **P<0.01; NA – Namaqua Afrikaner

This breed difference is relatively small to that previously reported by Burger *et al*. (2013) in a smaller study involving 14 lambs of each breed. Brand *et al*. (2018) also reported a slightly higher Dorper dressing percentage (47.9 ± 0.86%) as compared to the findings of this study. However, a higher dressing percentage of Dorpers was also reported by Tshabalala *et al*. (2003) when comparing them with fat-tailed Damaras. The latter authors reported mean carcass weight of 10.5 kg for Damaras compared to 17.4 kg for Dorpers, i.e. a difference of 65.7%. The initial carcass temperature (45 minutes post slaughter) of Dorpers was 1.2^{o}C higher than those recorded in NA slaughter lambs.

Dorpers were fatter than NA lambs, as indicated by a greater subcutaneous fat cover (P<0.01) amounting to 55.9% at the 13th rib and 18.9% at the rump. These results are comparable to those reported by Burger (2015) for Dorper and NA hoggets at an average age of 502 days. Brand *et al*. (2018) reported that the Dorpers reached subcutaneous fat depth of 20.4 mm fat after 105 days at the 13th rib. However, it should be stressed that the present study reported breed differences ranging from 19 to 56% in lambs. In contrast, Burger (2015) reported a 2.5- to 3.4-fold increase in fat-depth at the more mature life stage. It could be believed that the increased fat cover combined with the smaller carcasses of the NA may also have contributed to the faster temperature loss in this breed.

NA slaughter lambs had 14% tougher meat relative to Dorpers (P<0.05). This result is consistent with the sensory analysis conducted by Burger (2015) indicating a lower value (i.e. less tender) for tenderness (first bite) when compared to purebred Dorpers as well as the Dorper X NA cross. An increased fat cover protects the carcass from cooling and reduces the amount of drip loss. However, none of the qualitative traits (pH, carcass temperature, drip loss, cooking loss or colour) were affected by breed (P>0.05) in this study. Similarly, no differences in cooking loss were reported by Burger (2015) when comparing the same breeds. The tendency (P=0.07) of a higher cooking loss in the Dorper was not supported by the genetic correlations between fatness and cooking loss reported by Naudé *et al*. (2018), indicating that fatter carcasses would have lower cooking loss values.

4.3.2 The effect of sex

The effect of sex was significant only for slaughter and carcass weight (P<0.01) (Table 4.2). Male lambs were 3.5% heavier at slaughter than the ewes in this study. Cloete *et al*. (2012) also reported that castrated Dorper ram lambs were heavier than ewes. None of the other traits were affected by the sex of the lamb. Various authors reported a lack of significance for the effect of sex on drip and cooking loss of lamb meat (Hoffman *et al*., 2003; Cloete *et al*., 2008; Cloete *et al*., 2012). Hopkins & Mortimer (2014) also found a non-significant effect of sex on pH and shear force in light-weight animals. By contrast, Claffey *et al*. (2018) found a significant effect of sex on the dressing percentage of Scottish Blackface and Texel x Scottish Blackface lambs. The subcutaneous fat depth of castrated ram lambs was also similar to that of ewes in the study of Cloete *et al*. (2012).

Table 4.2 Least squares means (± SE) depicting the for effect of sex on the meat traits

Trait	Male	Female	Significance
Slaughter weight (kg)	35.4±0.4	34.2±0.5	**
Carcass weight (kg)	14.9±0.3	13.9±0.4	**
Dressing percentage (%)	41.7±0.5	40.3±0.7	0.10
Grade (n)	1.29±0.05	1.24±0.07	0.59
pH 45 minutes post slaughter	6.83±0.03	6.85±0.03	0.59
Temp 45 minutes post slaughter (^{o}C)	31.6±0.2	31.2±0.3	0.09
pH 48 hours post slaughter	5.86±0.01	5.66±0.02	0.38
Temp 48 hours post slaughter (^{o}C)	4.46±0.06	4.41±0.09	0.63
Fat depth at the 13th rib (mm)	1.51±0.11	1.50±0.18	0.94
Fat depth at the rump (mm)	4.16±0.22	4.19±0.34	0.98
Drip loss (%)	1.79±0.05	1.84±0.07	0.82
Cooking loss (%)	29.6±0.3	29.4±0.4	0.62
Lightness (L*)	37.5±0.2	37.1±0.3	0.12
Redness (a*)	12.8±0.1	12.6±0.2	0.37
Yellowness (b*)	10.2±0.1	10.1±0.2	0.39
Shear force (N)	51.4±1.0	50.3±1.5	0.40

**P<0.01

4.3.3 The effect of birth type

Multiples were lighter with a lower dressing percentage, lower carcass grading and fat depth compared to singles ($P<0.01$; Table 4.3). The carcasses of multiples were 0.8^{o} C colder than those of singles at 45 min after slaughter with a higher cooking loss ($P<0.01$). The lower initial temperature of carcasses from multiples could be attributed to a generally small size as well as less fat cover. It is interesting to note that multiples had a higher ultimate temperature which is a phenomenon that is difficult to explain. The statistically significant ($P<0.05$) effect of birth type in this study was in agreement with literature reports that singles were fatter than the multiples (Greeff *et al*., 2003; Cloete *et al*., 2008). Single carcasses were slightly yellower than multiples but the small magnitude of this difference would make it difficult for consumer to differentiate between the two birth type classes.

Table 4.3 Least squares means (± SE) depicting the effect of birth type on the slaughter traits

Trait	Singles	Multiples	Significance
Slaughter weight (kg)	36.0±0.4	33.5±0.4	**
Carcass weight (kg)	15.4±0.3	13.4±0.3	**
Dressing percentage (%)	42.1±0.6	39.9±0.6	**
Grade (n)	1.45±0.06	1.07±0.06	**
pH 45 minutes post slaughter	6.83±0.03	6.85±0.03	0.55
Temp 45 minutes post slaughter (^{o}C)	31.8±0.2	31.0±0.2	**
pH 45 hours post slaughter	5.68±0.01	5.67±0.01	0.51
Temp 48 hours post slaughter (^{o}C)	4.36±0.07	4.52±0.07	*
Fat depth at the 13th rib (mm)	1.78±0.14	1.23±0.13	**
Fat depth at the rump (mm)	5.12±0.27	3.22±0.26	**
Drip loss (%)	1.82±0.05	1.82±0.05	0.98
Cooking loss (%)	28.9±0.3	30.1±0.3	**
Lightness (L*)	37.4±0.2	37.2±0.2	0.66
Redness (a*)	12.8±0.1	12.6±0.1	0.19
Yellowness (b*)	10.3±0.2	10.0±0.1	*
Shear force (N)	51.6±1.2	50.1±1.1	0.26

*$P<0.05$, **$P<0.01$

The marked variation between carcass weights of the two breeds across birth years is evident in Figure 4.1. The only years where no significant (P>0.05) breed differences were observed during 2009 and 2014. In the other years, Dorpers clearly outperformed NA, breed differences ranging from 16.1% in 2016 to 60.8% in 2010. It is therefore, quite evident that Dorpers were heavier than NA as was also pointed out for weaning weight in Chapter 3. The lack of a breed difference in the year 2009 probably stems from very few NA lambs being born as they were recently introduced to Nortier from Carnarvon experimental station. The large standard error around the mean for NA confirms this observation. It may thus be coincidental that the low number of NA was similar in weight to the Dorpers in this year. In 2014, carcass weight data were not recorded in those lambs that were slaughtered early in the season (November 2014). These lambs therefore did not contribute to the mean reported in Figure 4.1.

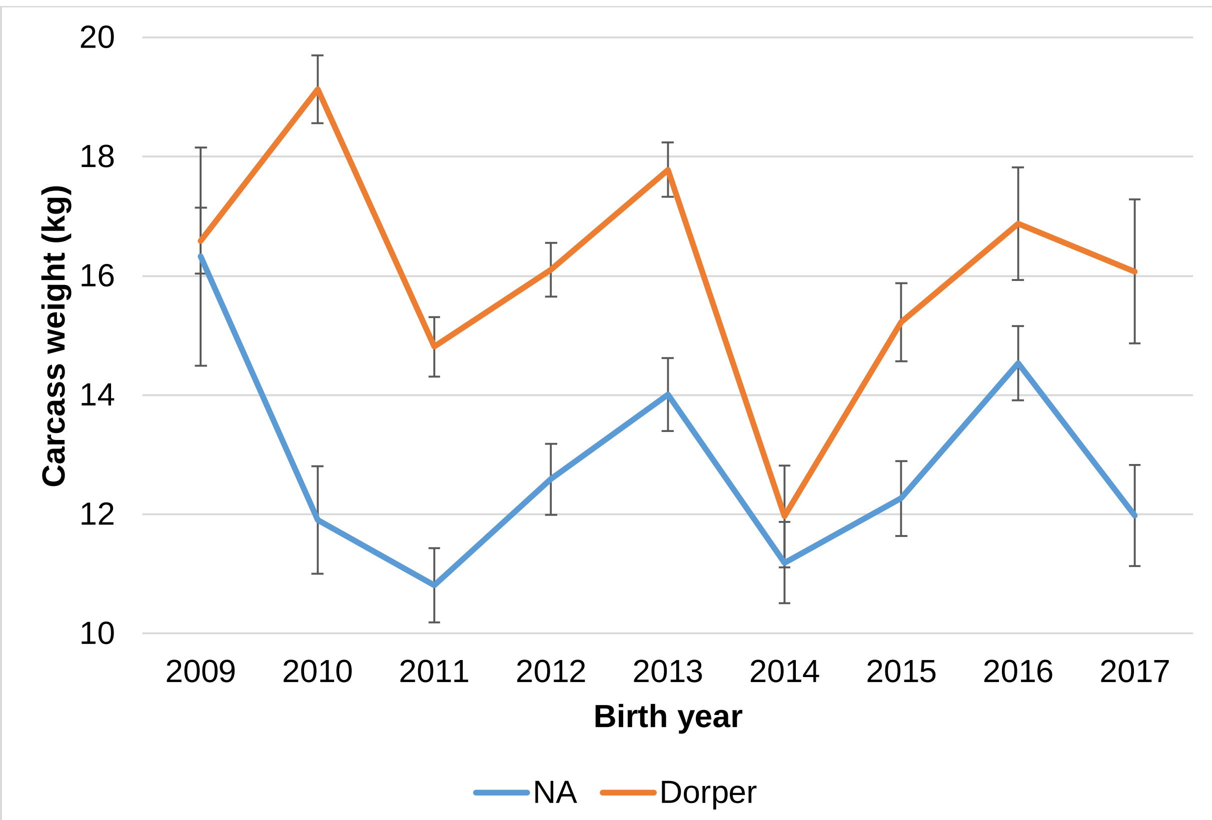

Figure 4.1 Least squares means (±SE) depicting the interaction between breed and birth year for carcass weight for Dorper and Namaqua Afrikaner (NA) lambs.

The data contained in Figure 4.1 therefore only include lambs slaughtered in February 2015 when they were already at a different stage of maturity. It is possible that this change in management could have resulted in the observed trend.

4.5 Conclusion

The study confirms that a commercial breed, namely the Dorper outperformed an unimproved indigenous fat-tailed breed, the NA in terms of weight and carcass yield. Dorper lambs also had more tender meat which is an advantage in terms of consumer acceptability. On the other hand, NA lambs had leaner carcasses which may be an advantage for consumers wanting to pursue a healthy, low-fat diet. It needs to be stressed though that intramuscular fat contributes to the eating experience of red meat. It is therefore evident that further research is required on the acceptability of meat from these breeds to the general consumer.

CHAPTER 5

Breed and crossbreeding effects for the Dorper and South African Mutton Merino breed and their reciprocal cross on birth and weaning weight, lamb survival and tick count

5.1 Introduction

Sheep form an integral part of agriculture in the developing countries as they have the ability to thrive and adapt well to harsh, arid and hot environments where resources do not support cropping and larger livestock species fail to adapt (Rosali *et al*., 2005; Rust & Rust, 2013). In so many countries, the availability of exotic breeds with a higher performance, especially in reproduction, compared to indigenous breeds prompted an interest in breed evaluation and crossbreeding (Fogarty, 2006). According to Leymaster (2002), variation among sheep breeds is a very important asset of the sheep industry. Divergent sheep breeds differ in their ability to adapt to different environmental conditions as well as in performance pertaining to the quantity and quality of their products. Genetic change resulting from within-breed selection is generally slow compared to potential benefits resulting from crossbreeding at the level of commercial production (Cloete & Durand, 2000).

Crossbreeding systems utilize the variation across the flocks to increase production of crossbred as compared to purebred flocks (Leymaster, 2002). Increased heterosis is expected in crossbred progeny (Cloete *et al*., 2008). According to Fogarty (2006), crossbreeding uses the breed and the land resources wisely to exploit hybrid vigour for increased productivity. Structured crossbreeding combines the qualities of different breeds and utilizes heterosis and sexual dimorphism to increase profitability at the commercial level (Khusro *et al*., 2005; Cloete & Cloete, 2016). Crossbred systems were also demonstrated to emit less greenhouse gases compared to commercial wool production using purebred Merinos (Kopke *et al*., 2008).

Crossbreeding has been used as an important and economical method of improving production in commercial meat sheep production systems (Puppel *et al*., 2018). Heterosis increases the lifespan as well as the health and fertility of animals (Puppel *et al*., 2018). The utilization of different attributes in combinations of two or more divergent breeds is referred to as breed complementarity (Rosali *et al*., 2005). Lóbo *et al*. (2009) indicated that the less productive local breeds in Brazil are usually crossed with the exotic breeds. South African Mutton Merino (SAMM) rams are occasionally used in the Western Cape Province to mate with Merino ewes to produce F1 cross-ewes for the purpose of commercial lamb and wool production (Cloete & Durand, 2000; Cloete *et al*., 2003a).

Cloete *et al*. (2007) demonstrated that meat from crossbred progeny of SAMM rams on Dorper ewes had superior tenderness and were leaner compared to purebred Dorpers. According to Gebreyowhens *et al*. (2017), Ethiopian smallholder farmers consider crossbred Dorper sheep appropriate for improving meat production. In Kenya, farmers utilize crosses of Red Maasai sheep with Dorpers (Kȍnig *et al*., 2017b). However, there is a concern that crossbreeding with Dorpers may compromise the indigenous genetic resource. The latter authors therefore suggested that both breeds need to be improved on their own for continued usage in commercial crossbreeding. The Dorper was exported from South Africa to Kenya in the 1970's for the purpose of research and increasing the weight gain of local breeds (Kȍnig *et al*., 2017b). Crossbreeding with Dorpers can only be successful when the environment is conducive for it (Kȍnig *et al*., 2017b). According to Kȍnig *et al*. (2017a) crossbred lambs have high levels of meat production; therefore, they can be mated with Red Maasai ewes as a terminal sire breed. Of local concern, however, is the fact that Selepe *et al*. (2018) reported that the integrity of the highly adapted Zulu breed was severely compromised by crossbreeding with Dorpers. The purebred Zulu sheep population flock declined by 7.4% between the years of 2007-2010. A compromise between productivity and conservation of adapted genetic resources is clearly needed.

The purpose of the study was to compare the performance of purebred Dorper and SAMM sheep with their reciprocal cross in an extensive environment. This was done by assessing the effect of breed and estimating crossbreeding parameters on birth weight, weaning weight, lamb survival and total tick count.

5.2 Materials and methods

5.2.1 Animals and experimental site

The animals used in this study (2009-2017) were commercial Dorper and SAMM sheep present at the Nortier research farm in the extensive grazing regions of the Western coast Strandveld Proper (Acocks, 1988). The resource flock was represented by the pure breeds and the reciprocal cross between them. The research farm is situated near Lamberts Bay on the west coast of South Africa (32˚02' S and 18˚20' E) and was described by Cloete *et al*. (2016). Ewes were mated from January to February (summer). Lambing occurred from June to July (winter) to coincide with the expected winter rainfall typical of the Mediterranean climate of the region (Chapter 3). Prior to lambing, all the pregnant ewes were marked on their sides with spray-paint to easily identify their lambs in the extensive conditions while avoiding distraction of ewes from their lambs and *vice versa* (Thutwa, 2016). At birth, lambs were weighed, ear marked and spray-painted to relate the lamb to its mother. Lambs were weaned from September to October (spring) at an average (±SD) age of 117±16 days.

5.2.2 Statistical analysis

The data used in this study was unbalanced and required least-squares analyses. Moreover, tick counts were skewed and leptokurtic. Transformation of tick counts to square roots after 0.5 were added to reduce the difference between 0 and 1 on the transformed scale, however, rendered the data suitable for analysis (Table 5.1). The ASREML software (Gilmour *et al*., 2015) is suitable for fitting a wide range of linear models to animal breeding data, and was used to estimate fixed and random effects in this study. Fixed effects included genetic group (Dorper and SAMM, as well as their reciprocal cross), birth year (2009 to 2017), sex (male or female), age of dam (2 to 6+ years of age) and birth type (singles and pooled multiples). Weaning age was included as a linear covariate for analyses on weaning weight and tick count. Random animal effects were fitted to account for between-family variation within breeds. Given the small size of the data set used, it was not attempted to use these variance components to derive heritability estimates.

The degrees of freedom for genetic group were used to construct three linear contrasts to allow testing for the additive effect of pure breed (Dorper vs. SAMM), direct heterosis (crossbred performance related to the midparent value of the two pure breeds) and maternal heterosis (the comparison of Dorper and SAMM dams acting as dam or maternal lines).

5.3 Results and discussion

5.3.1 Descriptive statistics

Descriptive statistics for all the traits included in this study are presented in Table 5.1. The CV's of birth and weaning weight were appreciably higher than values ranging from 14.2-19.2% for birth weight and 15.8-18.0% for weaning weight reviewed from ovine literature by Safari *et al*. (2005).

Table 5.1 Descriptive statistics for birth weight, survival, weaning weight and total tick count of Dorper and South African Mutton Merino lambs (SAMM) and their reciprocal crosses

Trait	n	Mean	SD	CV(%)	Skewness	Kurtosis
Birth weight (kg)	1147	4.02	0.91	33.7	-0.17	0.09
Survival	1150	0.73	0.44	60.2	-1.02	-0.97
Weaning weight (kg)	835	31.5	6.9	21.9	0.09	-0.08
Total tick count (n)						
Raw	700	11.8	10.9	92.6	3.03	17.89
Transformed	700	2.21	0.89	40.4	-0.70	0.51

n – number of records; SD – Standard deviation; CV(%) – Coefficient of variation percent

The difference relative to the latter study can potentially be ascribed to the multibreed nature and possible heterosis effects forming part of the present data. As expected, the mean and CV of weaning weight was in close correspondence with those of Thutwa (2016), who used a subset of the present data. Untransformed total tick count had a large CV approaching 93% and was also skewed and leptokurtic. However, this CV is relatively low compared to those of Sae-Lim *et al*. (2017), exceeding 100%. It should be stated that the latter study included an excess of zero counts. This extremely skewed distribution necessitated that the latter authors had to resort to a number of non-parametric approaches in order to obtain unbiased heritability estimates. The present distribution was adequately normalized by the square root transformation which substantially reduced the observed CV to approximately 40%. The CV of lamb survival was 60% in this study in contrast to a value of 46% reported by Safari *et al*. (2005).

5.3.2 Breed and crossbreeding effects

Birth weight was affected by genotype ($P<0.05$). Dorper X SAMM lambs were between 6.7 and 8.5% heavier ($P<0.05$) at birth compared to the other three genetic groups, which did not differ ($P>0.05$; Table 5.2). In contrast, Atashi & Izadifar (2012) reported that fat-tailed crossbred lambs did not outperform their purebred contemporaries under the same environmental conditions. Crossbred progeny sired by Ile de France and Merino Landsheep rams were respectively 12 and 7% heavier than purebred Dorper lambs in a previous study on the same experimental site (Cloete *et al*., 2007). With reference to weaning weight, there was a clear advantage of crossbred progeny relative to purebred performance ($P<0.05$). This is in accordance with the review of Gebreyowhens *et al*. (2017) demonstrating that crossbreeding of Dorper rams with the highland sheep in the tropics improved the growth rate of the local breeds. Cloete *et al*. (2007) reported that Ile de France and Merino Landsheep sired lambs were heavier at weaning than purebred Dorper contemporaries. In contrast to the present study, the latter authors found no advantage in favour of SAMM crossbred lambs in comparison to purebred Dorpers ($P>0.05$).

Table 5.2 Least-squares means depicting the effect of breed (Dorper and SAMM and their reciprocal cross) on birth weight (BW), lamb survival (Surv), weaning weight (WW) and total tick count (Ticks), together with contrasts (expressed as percentages) depicting additive breed effects, heterosis effects and the effect of dam breed

Breed combination	Trait			
	BW (kg)	Surv (n)	WW (kg)	Ticks (n)[#]
Dorper	4.16 ± 0.10	0.78 ± 0.03	32.1 ± 0.6	2.17 ± 0.08 (7.78)
SAMM	4.12 ± 0.16	0.62 ± 0.06	32.2 ± 1.0	2.19 ± 0.13 (7.90)
Dorper x SAMM	4.44 ± 0.12	0.71 ± 0.06	33.5 ± 0.8	2.23 ± 0.14 (8.26)
SAMM x Dorper	4.09 ± 0.14	0.69 ± 0.06	34.8 ± 0.9	2.35 ± 0.14 (9.50)
Contrasts (%)				
Breed	$-0.9^{0.17}$	$-20.6^{0.08}$	$0.2^{0.44}$	$0.6^{0.16}$
Heterosis	$2.9^{0.08}$	$-0.4^{0.80}$	6.3**	$5.0^{0.41}$
Dam breed	3.8*	$-9.9^{0.38}$	$-1.9^{0.22}$	$-2.5^{0.44}$

* - P < 0.05; ** - P< 0.01; Superscript - Actual significance for P > 0.05; SAMM- South African Mutton Merino; [#] - Transformed mean±SE with geometric means on the observed scale in brackets

It is notable that the contrast comparing the pure breeds were not significant for any of the traits (P>0.05; Table 5.2). In contrast, sizeable additive breed effects were reported by Khusro *et al*. (2005) on their study in Australian meat breeds, with Coopworth progeny being lighter compared to other breeds. This result could be attributed to the fact that the Coopworth is actually a designated maternal breed and not a specialist meat breed (Khusro *et al*., 2005). There was a tendency (P=0.08) of favouring Dorper lambs relative to SAMM lambs for survival. No results were found in the literature to confirm or refute this trend and it should possibly be targeted in future studies. In the majority of cases neither direct nor maternal (dam line) heterosis effects were significant (P>0.05). The lack of maternal heterosis effects is consistent with a report of Khusro *et al*. (2005), but the latter authors did report substantial direct heterosis effects for birth weight (5-22%). The direct heterosis estimate for weaning weight in the present study indicated that crossbred performance exceeded the mid parent value by 6.3%. This value is consistent with expected heterosis values amounting to 3-10% for weaning weight in sheep (Fogarty, 2006), as well as estimates ranging from 3-6% in Australian meat breeds (Khusro *et al*., 2005). In absolute terms, the present estimate is slightly above the previous value of 4.1% reported by Thutwa (2016). It is well-known that the genetic distance between the parental breeds determines heterosis (Atashi & Izadifar, 2012). It should be remembered that lamb heterosis represents the performance of crossbred lambs raised by purebred ewes relative to purebred lambs raised by purebred ewes (Leymaster, 2002).

In contrast to the present study, significant heterosis commonly occur for a fitness trait like lamb survival (Mortimer & Atkins, 1997). In this respect, Ferreira *at al*. (2015) indicated that the large effect of individual heterosis on lamb survival indicates that breed comparisons should only be done among groups of animals that have the same expected amount of retained F1 heterosis or the amount of retained heterosis should be included in the model to avoid the confounding of breed effects and heterosis effects. Ferreira *et al*. (2015) and Fogarty (2006) claimed that lambs born from indigenous ewes often have greater survival than lambs born from prolific-cross ewes with large litter sizes.

5.3.3 Sex and birth type effects

Weaning weight increased by 0.156±0.012 kg per day of age. Male and single lambs were respectively 4 and 19% heavier than females and multiples at birth (P<0.01; Table 5.3). The corresponding differences in weaning weight amounted to respectively 10 and 19% (P<0.01). The significant effects of sex and birth type on birth and weaning weight commonly occur in literature (Cloete *et al*., 2003a; Chniter *et al*., 2009; Rahimi *et al*., 2014). The effect of sex on tick count was highly significant (P<0.01). Male lambs were 16% more affected by the ticks than the female lambs on the square root transformed scale. This difference was inflated to 45% on the observed scale. Bayisa *et al*. (2013) similarly reported higher infestations of ecoparasites on male lambs (64%) than on their female contemporaries. Lamb survival was independent of sex (P=0.59). This is in contrast to the bulk of results available in the literature suggesting that survival is compromised in male lambs relative to females (Morris *et al*., 2000; Riggio *et al*., 2008; Ferreira *et al*., 2015). The percentage of single lambs surviving was 19% higher (P<0.01) than the lambs born as multiples as was also reported in numerous literature sources (Hatcher *et al*., 2009; Everett-Hincks *et al*., 2014; Pettigrew *et al*., 2018).

Table 5.3 Least-squares means depicting the effects of sex (male or female) and birth type (single or multiple) on birth weight (BW), lamb survival (Surv), weaning weight WW) and total tick count (Ticks)

Effect	Trait			
	BW (kg)	Survl	WW (kg)	Ticks (n)[#]
Sex	**	0.59	**	**
Male	4.29 ± 0.10	0.71 ± 0.03	34.4 ± 0.6	2.40 ± 0.09 (10.0)
Female	4.11 ± 0.10	0.70 ± 0.04	31.4 ± 0.6	2.07 ± 0.08 (6.89)
Birth type	**	**	**	0.95
Single	4.57 ± 0.10	0.76 ± 0.03	35.7 ± 0.6	2.24 ± 0.09 (8.35)
Multiple	3.83 ± 0.09	0.64 ± 0.03	30.1 ± 0.6	2.23 ± 0.08 (8.32)

[#] - Transformed mean±SE with geometric means on the observed scale in brackets

5.3.4 Dam age effects

Birth and weaning weight of lambs inclined ($P<0.01$) with dam age to maxima at respectively 4 and 4-5 years followed by a trend to subsequently decline.

Table 5.4 Least-squares means depicting the effect of dam age (2-6 years) on birth weight (BW), lamb survival (Surv), weaning weight (WW) and total tick count (Ticks)

Effect	Trait			
	BW (kg)	Surv	WW (kg)	Ticks (n)
Dam age (years)	**	0.24	**	*
2	3.98 ± 0.11	0.67 ± 0.05	31.4 ± 0.7	2.29 ± 0.10 (8.92)
3	4.17 ± 0.10	0.73 ± 0.04	32.4 ± 0.7	2.14 ± 0.10 (7.52)
4	4.36 ± 0.10	0.75 ± 0.04	34.0 ± 0.7	2.29 ± 0.09 (8.88)
5	4.27 ± 0.11	0.69 ± 0.05	34.0 ± 0.7	2.36 ± 0.10 (9.58)
6	4.23 ± 0.10	0.66 ± 0.05	32.9 ± 0.7	2.02 ± 0.11 (6.51)

* - $P < 0.05$; ** - $P < 0.01$; Actual significance for $P > 0.05$

[#] - Transformed mean±SE with geometric means on the observed scale in brackets

Numerous literature sources confirm this trend (Cloete *et al*., 2003b; Rauw *et al*., 2007; Aktaş *et al*., 2015). Lamb survival was independent of dam age in this study (P=0.24) but numerous other studies suggest that lamb survival is compromised in the progeny of 2- and 5-year-old dams (Morris *et al*., 2005; Ferreira *et al*., 2015; Pettigrew *et al*., 2018). Tick counts in progeny of 2-, 4- and 5-year-old dams were higher than in progeny of 6- year-old dams. No literature sources to compare dam age effects on tick count were found to compare present results.

5.4 Conclusion

No conclusive advantage for either pure breed was seen for any of the traits considered. Significant non-additive genetic variation was, however, demonstrated for weaning weight. These results indicate that commercial operations may benefit from crossbreeding using a combination of a meat and dual-purpose breed. However, the consequences of such strategy, such as the potential contamination of wool in the SAMM with dark fibres need to be considered. Further studies involving the structured crossing of local ovine genetic resources should be conducted.

CHAPTER 6

Breed and crossbreeding effects of the Dorper and South African Mutton Merino breed and their reciprocal cross on slaughter traits

6.1 Introduction

The importance of sheep in the local agricultural landscape has been emphasized in the previous chapters. This chapter studies crossbreeding parameters for the reciprocal cross between the Dorper and SA Mutton Merino breeds for meat traits that were recorded after slaughter. It has been mentioned previously that the Dorper represents the most numerous meat sheep in South Africa, while the SAMM is the dominant dual-purpose breed (Cloete & Olivier, 2010).

The potential benefits of crossbreeding systems have been noted in Chapter 5. This chapter focuses on the estimation of heterosis for quantitative and qualitative meat traits in the two breeds mentioned in the previously as well as their reciprocal cross. Previous studies found that there were notable heterosis effects in weight traits close to slaughter in meat breeds (Bouix *et al*., 2002; Fogarty, 2006). Maternal heterosis are more likely closer to birth and tend to diminish as the animals age to slaughter stage (Bouix *et al*., 2002). So far, no structured studies on crossbreeding, where it was possible to estimate direct and maternal heterosis from pure breeds as well as their reciprocal cross, were found in the South African literature.

Against this background, this chapter studied the slaughter performance of purebred Dorper and SAMM sheep with their reciprocal cross in an extensive environment. The experimental outlay allowed for the estimation of additive breed effects, direct heterosis as well as dam-line heterosis for quantitative and qualitative meat traits.

6.2 Materials and methods

6.2.1 Animals and experimental site

The study was carried out on the Nortier research farm of the Western Cape Department of Agriculture using animal data that accrued from 2009 to 2017. The locality was described by Cloete & De Villiers (1987) as well as in previous chapters. The animals that were used were commercial Dorper and SAMM sheep present at farm and they grazed shrub pasture typical of the Western Coast Strandveld ecotype (Acocks, 1988). The study involved the pure breeds and the reciprocal cross between them. Numbers of slaughter animals considered in this study were 252 purebred Dorpers, 47 SAMM lambs, 18 Dorper x SAMM lambs and 32 SAMM x Dorper lambs. The SAMM breed was represented by fewer ewes in the flock. Therefore, to make provision for purebred replacements, a limited number of Dorper x SAMM matings were allowed. This resulted in the low number of Dorper x SAMM carcasses available for this study. As this cross was not represented in all years, the birth year x breed combination could not be fitted.

6.2.2 Slaughter procedure and traits recorded

After weaning (see Chapter 5), lambs were weighed and selected on visual appraisal as slaughter ready at an average (±SD) age of 152 ± 24 days. As these weights were recorded within 24 hours *ante mortem*, the same weights were used as slaughter weight. The lambs were transported approximately 250 km by truck to one of two EU approved abattoirs in the Western Cape, namely Roelcor in Malmesbury or Tomi's abattoir near to Hermon. There the lambs were housed in overnight lairage, with *ad libitum* access to water, but no access to food. Immediately following exsanguination, the carcasses were dressed and tagged with numbered tags to simplify identification upon sample collection. Forty-five minutes after exsanguination and dressing the pH and temperature of each carcass was measured and the carcasses were moved into cold storage (4°C). pH and carcass temperature was also measured after being cooled and kept in cold storage for 48 h (4°C) at the abattoir. The pH and temperature of the *longissimus lumborum* (LL) was measured on the left side of the carcass, between the 11th and

13th rib. Both pH and temperature measurements were taken with a CRISON PH 25 portable handheld pH meter (507) (Lasec (Pty) Ltd, South Africa), fitted with a glass CRISON electrode (Cat. 52-32) and equipped with an automatic thermometer, allowing for simultaneous measurements of pH and temperature. The pH meter was calibrated with the standard buffers, provided by the manufacturer, at pH 4.0 and pH 7.0.

When carcass pH and temperature were measured 48 hours *post mortem*, the *longissimus lumborum* (LL) muscle was also excised from the first to the sixth lumbar vertebrae on the right side of each carcass, placed in coded bags and transported to the Meat Science Laboratory at Stellenbosch University. These samples were used for the analysis of the physical properties of the meat, including subcutaneous fat depth at two sites namely the 13th rib and the rump, percentage cooking loss, percentage drip loss, instrumental colour and Warner Bratzler shear force (see Chapter 4 for detail as to how these records were collected).

6.2.3 Statistical analysis

The number of records for the respective traits ranged from 270 for the colour traits to 349 for slaughter weight and initial pH 45 minutes post slaughter. Colour traits were not recorded in 2009. Given that the data were unbalanced, least-squares single-trait analyses were conducted in ASREML on all traits (Gilmour *et al*., 2016). The software allows for the fitting of a range of fixed, regression and random effects in animal breeding and genetics studies. Fixed effects included in this study included the animal breed combination (Dorper, SAMM, Dorper x SAMM and SAMM x Dorper), birth year (2009 to 2017), sex (male or female), age of dam (2 to 7^{+} years) and birth type (single and pooled multiples). Slaughter age was included as a linear covariate, while animal was fitted as a single random effect. Although animal was included, the derived between-animal variance components were not used to compute heritability estimates. Larger and more informative data sets would be more suitable for this purpose.

The degrees of freedom for breed combinations were used to compute three linear contrasts, namely a breed additive effect (Dorper vs. SAMM), direct heterosis (crossbred performance vs. the purebred midparent value) and maternal or dam line heterosis by contrasting Dorper dams with SAMM dams. These contrasts were tested for significance, tabulated and expressed as percentages.

6.3 Results and discussion

6.3.1 Year and slaughter age effects

Year effects were significant (P<0.01) for all traits with the exception of pH recorded 45 minutes after slaughter (P=0.14) and lightness (a*; P=0.41). It is generally known that year effects are a function of the ambient climate and managerial interventions slaughter animals were subjected to. As year effects are transient and not repeatable, these effects are not tabulated or discussed in detail. It was retained in the analyses to prevent that the between-year variation inflated the residual variation in the analyses.

Significant (P<0.05) regressions on slaughter age were observed for slaughter weight, dressing percentage, grading, carcass temperature recorded 45 minutes after slaughter and fat depth at both sites (P<0.05). These regressions were all negative, indicating that older animals were generally lighter, with a lower dressing percentage, a poorer grading, a lower carcass temperature and lower fat depths. These results probably reflect the poorer performance of older animals that were slaughtered prior to the upcoming summer when lambs were slaughtered even if they were marketed ready. This choice was made against the background of a certain dry summer under Mediterranean conditions that would prevent growth of the slaughter animals once the pasture dried off in late spring-early summer.

6.3.2 Breed and crossbreeding effects

Least-squares means for the four breed combinations on quantitative and qualitative meat traits are provided in Table 6.1 together with linear contrasts denoting the effect of additive breed, direct heterosis and the effect of the dam line of the slaughter animal. Relatively few contrast were significant (P<0.05) possibly because the number of records was relatively low, while the data were also not optimally distributed. Contrasts approaching significance (P<0.10) will thus also be noted. Slaughter weight and carcass weight were subject to direct heterosis (P<0.05), amounting to respectively 7.7 and 7.1% of the midparent average respectively. These results followed on from the significant heterosis estimate for weaning weight that was reported in Chapter 5. Comparable estimates that were found in the literature amounted to 4.8% for weaning weight (Sidwell & Miller, 1971), -9.1 to 7.3% (Rastogi *et al*., 1982), 11% for 105-day weight (Mavrogenis, 1996), 3% for 90-day weight (Analla et al, 1998), as well as 2.7% for yearling weight and 3.4% for postweaning weight in Australian meat sheep (Brown *et al*., 2016). Ch'ang & Evans (1985) accordingly reported a heterosis estimate of 9.3% and Farid (1989) 2.6% for hot carcass weight. The lack of dam line effects for weight traits in this study should perhaps be viewed against this finding. In accordance with the present study, fat depth was not subject to mentionable heterosis in an Australian study as well (Brown *et al*., 2016).

Slaughter lambs born to Dorper dams tended to display an 86% thicker rump fat cover when contrasted with the progeny of SAMM dams (Table 6.1). This result was possibly causative to a dam line effect amounting to 8% for cooking loss in favour of the progeny of Dorper dams. It is not surprising that carcasses that were expected to be fatter would display a lower cooking loss, as such an outcome would be consistent with the genetic correlation between fatness and cooking loss, as reported by Naudé *et al*. (2018). The lack of significance for dam line effects for most of the traits assessed was in line with most references (Analla *et al*., 1998; Bouix *et al*., 2002; Brown *et al*., 2016). The exception to this rule is the study of Mavrogenis (1996), where a maternal heterosis estimate of 6.6% was reported for 105-day weight. This discrepancy could possibly be attributed to the older age of the lambs in the present study (152 days vs. 105 days in the study by Mavrogenis, 1996). This result should be viewed against the trend for maternal heterosis to decline with lamb age in the study of Bouix *et al*. (2002).

Table 6.1 Least-squares means (±SE) depicting the effects of breed combination on quantitative and qualitative meat traits considered

Trait	Pure breed		Cross		Contrast#		
	Dorper	SAMM	D x SAMM	SAMM x D	B	H	D
Slaughter weight (kg)	37.3±0.6	37.2±0.9	39.9±1.3	40.3±1.2	0.91	**	0.79
Carcass weight (kg)	16.1±0.2	14.8±0.4	16.1±0.7	17.0±0.5	0.70	*	0.28
Dressing %	44.1±0.5	40.0±0.8	40.3±1.4	41.6±1.2	0.16	0.28	0.46
Grading	1.49±0.07	1.02±0.13	1.19±0.19	1.22±0.16	0.15	0.71	0.91
pH 45 min	6.83±0.10	6.75±0.19	6.84±0.29	6.72±0.23	0.65	0.94	0.76
Temp 45 min	32.1±0.2	31.2±0.5	32.2±0.8	32.5±0.6	0.57	0.22	0.77
pH 48 h	5.65±0.02	5.69±0.03	5.65±0.04	5.66±0.04	0.51	0.46	0.90
Temp 48 h	4.33±0.06	4.19±0.11	4.19±0.18	4.05±0.16	0.27	0.26	0.55
Fat rib (mm)	1.92±0.13	1.08±0.24	1.35±0.39	1.67±0.31	0.34	0.97	0.52
Fat rump (mm)	4.81±0.26	2.59±0.48	2.33±0.74	4.11±0.61	0.69	0.36	0.06
Cooking loss (%)	29.5±0.4	31.8±0.8	31.1±1.0	29.6±0.9	0.34	0.90	*
Drip loss (%)	1.73±0.08	1.91±0.13	2.04±0.17	1.57±0.16	0.67	0.65	0.25
Lightness (l*)	36.9±0.2	39.4±0.3	38.2±0.6	37.3±0.5	0.06	0.34	0.24
Redness (a*)	12.5±0.1	11.9±0.2	12.4±0.4	12.8±0.3	0.56	0.25	0.45
Yellowness (b*)	10.1±0.2	10.7±0.3	10.4±0.4	10.0±0.4	0.70	0.58	0.51
Shear force (N)	47.3±1.1	51.8±2.0	47.2±3.2	45.1±2.6	0.61	0.13	0.61

#Linear contrasts: B – Breed; H – Direct heterosis; D – Dam line heterosis

* P<0.05; ** P<0.01; Actual significance for P>0.05

Pure breed effects were limited to a tendency in the case of lightness (l*), while no other traits were affected differences between pure breeds (P>0.15; Table 6.2). The latter tendency suggested that meat of purebred SAMM slaughter lambs tended to be 6.8% lighter than that of their purebred Dorper contemporaries (P=0.06). The author could not find any results in the literature that supported or refuted this tendency. Cloete *et al*. (2007) previously compared purebred Dorper lambs with SAMM x Dorper lambs and similarly found no differences in weaning weight, slaughter age and dressing percentage. The lack of conclusive breed differences for backfat thickness is a bit perplexing though, as Cloete *et al*. (2007) found that SAMM x Dorper carcasses were leaner that Dorpers in the previous study. Although the direction of the absolute differences in this study would support this reasoning, it was not significant.

6.3.3 Sex and birth type effects

Significant sex effects were limited to slaughter weight and carcass weight, where male lambs were respectively 5.0 and 6.5% heavier than their female contemporaries (Table 6.2). Additionally, there were tendencies for female lambs to have a lower muscle temperature 45 minutes after slaughter (P=0.06), to have a slightly lower drip loss (P=0.09) and to be somewhat more tender (P=0.08). If substantiated in further research, the higher cooling rate of female carcasses could be related to their smaller size.

Single slaughter lambs were heavier than multiples (Table 6.2), with a higher dressing percentage, better grading, a higher muscle temperature 45 minutes after slaughter, a thicker fat cover at both sites as well as a lower cooking loss. All these differences were consistent with those reported in Chapter 4 for the effect of birth type on Dorper and Namaqua Afrikaner lambs. Since sex and birth type effects on meat traits were exhaustively discussed in the latter chapter, this discussion will not be repeated here.

6.3.4 Dam age effects

The only traits that were affected by dam age in the present study were slaughter weight, carcass weight and fat depth at the rump. Age of dam trends are provided for the weight traits in Figure 6.1.

Table 6.2 Least-squares means (±SE) depicting the effects of sex (male or female) or birth type (single or multiple) on slaughter traits in the present study

Trait	Sex		Significance	Birth type		Significance
	Male	Female		Single	Multiple	
Slaughter weight (kg)	39.6±0.6	37.7±0.7	**	40.1±0.7	37.3±0.6	**
Carcass weight (kg)	16.5±0.3	15.5±0.4	*	17.3±0.3	14.7±0.3	**
Dressing %	41.6±0.6	41.5±0.8	0.90	42.8±0.7	40.3±0.6	**
Grading	1.20±0.09	1.26±0.10	0.55	1.46±0.10	1.00±0.09	**
pH 45 min	6.82±0.13	6.75±0.15	0.66	6.71±0.15	6.86±0.13	0.54
Temp 45 min	32.4±0.3	31.7±0.4	0.06	32.7±0.4	31.3±0.3	**
pH 48 h	5.67±0.02	5.66±0.03	0.49	5.68±0.02	5.66±0.02	0.46
Temp 48 h	4.15±0.08	4.24±0.10	0.36	4.14±0.09	4.25±0.08	0.38
Fat rib (mm)	1.50±0.16	1.51±0.21	0.94	1.90±0.19	1.11±0.17	**
Fat rump (mm)	3.34±0.32	3.57±0.41	0.59	4.55±0.37	2.37±0.33	**
Cooking loss (%)	30.9±0.5	30.1±0.6	0.15	29.6±0.5	31.4±0.5	**
Drip loss (%)	1.90±0.09	1.73±0.11	0.09	1.82±0.10	1.82±0.09	0.81
Lightness (l*)	38.1±0.2	37.7±0.2	0.23	37.9±0.2	38.0±0.2	0.94
Redness (a*)	12.4±0.2	12.5±0.2	0.72	12.5±0.2	12.4±0.2	0.26
Yellowness (b*)	10.4±0.2	10.2±0.2	0.59	10.5±0.2	10.1±0.2	0.14
Shear force (N)	49.4±1.3	46.3±1.7	0.08	47.2±1.5	48.5±1.4	0.70

* P<0.05; ** P<0.01; Actual significance for P>0.05

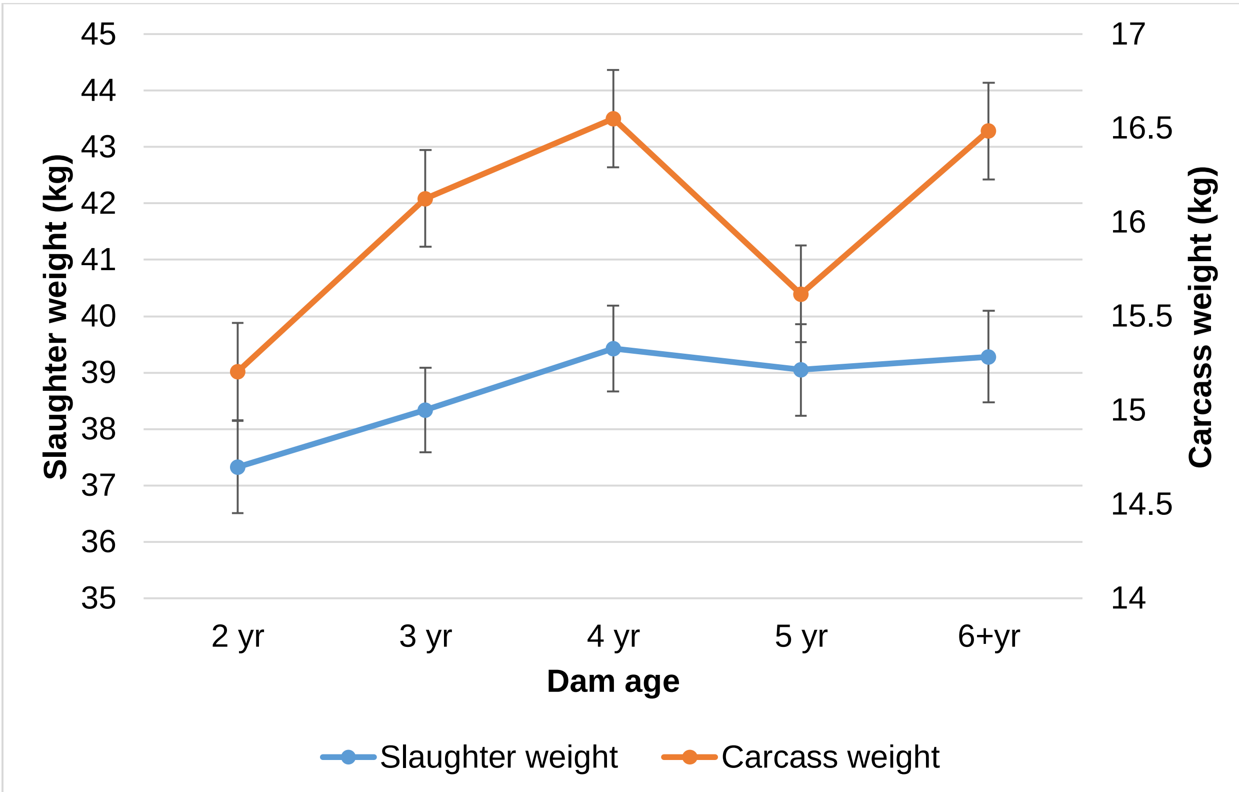

Figure 6.1 Least-squares means (±SE) depicting the effects of dam age on slaughter weight and carcass weight

It is clear that slaughter weight inclined as the dams of the slaughter lambs became older before stabilizing at a dam age of 4 years. This result is consistent with the dam age trend for weaning weight in Chapter 5, and is not unexpected. Carcass weight largely followed the same trend, although an unexpected drop occurred at 5 years. This result cannot be explained readily and is probably associated with the low number of records forming the basis of this study.

6.4 Conclusion

As was reported in Chapter 5, it was evident that no conclusive advantage for either pure breed was seen for any of the traits considered, with the possible exception of lightness. As this result only tended to be significant, it should perhaps also be subjected to reappraisal once more data are available. Significant non-additive genetic variation, in the form of direct heterosis, was recorded for slaughter and carcass weight. Commercial operations may therefore benefit from a higher meat output when a meat- and a dual-purpose breed are combined in a structured crossbreeding system. If black-headed Dorpers are used, such a system could lead to the contamination of wool in SAMM dams with dark as well as medulated fibres. As this would compromise wool income in the dual-purpose breed, it is definitely a factor that should be factored into the decision-making process. Considering that there is a dearth of similar studies in the local literature, it is recommended that further studies should be conducted on the structured crossing in the local ovine genetic resource.

CHAPTER 7

General Conclusions and Recommendations

7.1 Background

The point of departure for this study is the fact that large areas in South Africa are only suitable for extensive small stock production because of environmental constraints. Additionally, it is expected that at least some sheep producing parts will become hotter and drier in the foreseeable future. Research on the adaptability of sheep breeds to challenging environments is motivated against this backdrop. The resource population used (Figure 7.1) was appropriate for obtaining specific answers in this respect as all animals were maintained in a single flock, as is evident in the picture below of the breeding rams. Unfortunately, only a limited number of animals could be maintained on the property, resulting in some analyses ending up with a limited capacity to test the genetic group x birth year interaction.

Figure 7.1 Breeding rams of the three breeds used in this study at Nortier Research Farm (note the natural shrub vegetation available for the animals to graze)

7.2 Conclusions

The first part of the study was devoted to the comparison of a commercial, arguably adapted breed (the Dorper, the most numerous meat breed in South Africa) to an unselected, indigenous, far-tail breed adapted to local conditions over millennia (the Namaqua Afrikaner (NA), which is only maintained in a few conservation flocks). It was evident that the Dorper conclusively outperformed the NA with reference to live weight and growth traits. On the other hand, Namaqua Afrikaner lambs were superior to Dorpers for an adaptive trait like total tick count. Lamb survival was unaffected by breed. There was some evidence that the magnitude of the breed superiority of the Dorper for growth and the Namaqua Afrikaner for live weight and tick counts differed between birth years.

When meat traits were considered, it was evident that Dorper lambs outperformed their Namaqua Afrikaner contemporaries for important attributes associated with size and meat yield, namely carcass weight and dressing percentage. Dorper carcasses also attained better grades and were more tender according to instrumental measurements (Warner Brazler equipment). Dorper lambs were also fatter than Namaqua Afrikaner lambs, as derived from the back fat thickness at the 13th rib and the rump. While leaner meat would be preferred by health-conscious consumers, it is important to note that, under the conditions of the study, Dorper carcasses were more likely to be in the preferred grades. Namaqua Afrikaner carcasses were more likely to grade A0, which would imply a price penalty for these carcasses.

In the second part of the study, Dorpers were evaluated against the SA Mutton Merino (SAMM; one of the biggest dual-purpose breeds in South Africa), as well as the reciprocal cross between the two breeds. Crossbred performance allowed inferences to be made regarding non-additive genetic variation in crosses between these breeds. No evident breed differences were found for weight traits, lamb survival or tick counts. There was a suggestion that lamb survival of Dorpers was higher than that of their SAMM contemporaries (P = 0.08), but significance could not be demonstrated. Crossbred progeny outperformed the midparent value by 6.3% for weaning weight. This estimate is consistent with the literature for the expected level of heterosis for fairly divergent breeds.

Although the results on quantitative and qualitative meat traits reported in Chapter 6 were constrained by low numbers, it was evident that the observed heterosis for weaning weight was also present a later growth stage. Direct heterosis estimates amounted to 7.7% for slaughter weight and 7.1% for carcass weight. This result once again demonstrated that crossbreeding may have a definite role to play at the commercial level in the South African sheep industry.

7.3 Recommendations

It is recommended that further studies should seek a better understanding of the differences in magnitude of breed effects between years. If this could be properly understood, it would possibly lead to a better understanding of the genetic material underlying adaptiveness in the ovine species.

The superiority of Namaqua Afrikaners with regard to tick infestation also warrants further study. The history of the breed suggests that it was exposed to pathogens inherent to the study area for a much longer period than Dorpers. It could be argued that this breed evolved with pathogens typical of the area over millennia, allowing a balance to develop at the host-pathogen interface. Studies involving a genome-wide association scan for tick counts on genotyped animals from the resource flocks could potentially shed more light on the underlying genetics as far as resistance to this common pathogen is concerned. This information could be developed further on the premises that marker-assisted selection and/or the estimation of genomic breeding values may play a role in the combating of ticks on sheep in the national ovine genetic resource. However, for this to happen, substantial additional research and development inputs will be needed.

There is little doubt that other indigenous genetic resources than the Namaqua Afrikaner will potentially display similar adaptive advantages relative to commercial genotypes. Unfortunately, these resources are relatively poorly described and in danger of being diluted by indiscriminate crossbreeding with higher-yielding commercial types. Studies on these indigenous genetic resources, involving breed comparisons as well as crossbreeding studies are therefore strongly recommended. Such studies may well be limited by relatively low animal numbers (a constraint also evident in the present study), but should nevertheless be allowed to play a pivotal role in the optimum utilization of the local ovine genetic resource.

Furthermore, the study once again reiterated the utility of crossbreeding in commercial ovine production. Given the diversity of sheep breeds in South Africa, further research on this topic is warranted. This is important when seen against the background that crossbreeding is considered as a managerial intervention with potential to curb the emission of greenhouse gases of the commercial sheep production sector. It should, however, be cautioned that injudicious crossbreeding should not be contemplated, as it may have a deleterious effect on the local genetic resource. Examples of such negative effects could be the dilution of important indigenous resources, as well as injudicious crossing of wool breeds with rams of breeds that would advance the contamination of the clip with undesired dark and medulated fibres.

The study only scratched the surface as far as crossbreeding and the further development of local sheep breeds are concerned. The widely divergent ovine genetic resource, as well as specialization in wool, dual-purpose, meat, terminal and indigenous breeds creates endless opportunities for studies to exploit these sources of variation in pure- and crossbreeding situations as well as for further breed development. The author hopes that this study will stimulate other studies involving the comparison of indigenous genetic resources with commercial types, as well as in crossbreeding studies using other breeds present in the South African genetic resource.

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