GENETIC PARAMETERS FOR SUBJECTIVE AND OBJECTIVE WOOL AND BODY TRAITS IN THE TYGERHOEK MERINO FLOCK

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GENETIC PARAMETERS FOR SUBJECTIVE AND OBJECTIVE WOOL AND BODY TRAITS IN THE TYGERHOEK MERINO FLOCK

by

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CHAPTER 1

GENERAL INTRODUCTION

1.1 History of the Merino breed in SA

Merino sheep is one of modern domesticated sheep breeds. According to McKee (1913) the country of origin and history of Merino sheep breed could not be found in the ancient literature. As a result it was decided to trace this breed back as far as Asia, where it had its origin according to more recent sources. Phoenician colonies were established in Spain hundreds of years B.C. and it is believed that traders and colonists from the Eastern countries introduced the ancestors of this breed to Spain (McKee, 1913). Subsequently, a distinction was made between non-migratory and migratory Spanish Merino sheep. The non-migratory Merino sheep were kept on their mountains or rangelands all year round. They were characterized by a small body size, narrow chest and very long legs. Their wool was of a higher quality than that of migratory sheep. On the other hand, the migratory Merino sheep were named after the annual migration management system. The local custom was that these sheep should graze on the lowlands of Southern Spain in the winter months while they utilised the mountains of the Northern Spain in summer.

The migratory Merino sheep found their way to other parts of the world. All Spanish migratory Merino sheep produced fine wool and were very similar, yet they belonged to different owners, and were of different strains (called cabanas). These cabanas were kept separate and each had some special characteristics of special quality which was carefully preserved. They were never crossbred because of the need to maintain the purity of these sheep with special characteristics pertaining to body weight and wool traits. Principal cabanas were the Negretti, the Paulars, the Infantados, the Guadeloupe and the Escurial (McKee, 1913).

The Negretti sheep, which, belonged to Negretti house were the largest and the strongest of the Spanish Merino Sheep. They produced large quantities of wool. It was from this flock that King George 111 obtained his Merino sheep through a direct application to the Spanish King (McKee, 1913). The Paulars Merino sheep belonged to the Paulars convent. They yielded very fine wool. They were not regarded as a good example of the Spanish Merino, and were remarkable for the throaty sound of their bleats (Mckee, 1913). The Escurial cabana belonged to the Escurial house. They yielded the finest wool of the highest quality compared to the other cabanas. The Guadeloupe belonged to the Guadeloupe house, while the Infantado belonged to the Prince Royal (Mckee, 1913).

Exportation of the Merino from Spain was strictly prohibited for ages. However, in early part of the 18th Century this absolute prohibition was relaxed, in special instances, in the case of royalty and for favourable applications. The first country to obtain breeding stock was Sweden in 1723. These Merinos adapted well in Sweden and produced large quantities of fine wool. Under the fostering government of Sweden they had increased in 1764 to 70 thousand purebred Merino sheep. The next countries after Sweden were Saxony in 1765 and France in 1776. The latter exports were used to develop the Rambouillet breed. Merinos were then exported freely, and the breed gradually spread to other parts of the world (Mckee, 1913).

There is conflicting evidence on the first introduction of the Merino breed in South Africa. According to McKee (1913) the Spanish Merino sheep were first introduced in South Africa in 1689 when the officials of the Dutch Government imported rams with the believe that valuable wool could be produced by a cross between these animals and the native sheep of South Africa. However, Ryder (1984), Mason (1996) and Anon. (2005) reported the first introduction of the Spanish Merino in to be during 1789 when two rams and four ewes were donated by the Dutch government to Col Jacob Gordon, the military commander at the Cape at that time on an experimental basis. This resulted in the government establishing a Merino Stud in 1806. By 1846, of the 3 million sheep in South Africa, half were Merinos. According to Mason (1996), American Vermont type Merinos were introduced in South Africa from 1891. Also, Australian Merinos were imported before 1929 (Ryder, 1984).

The South African Merino is considered a composite of Spanish, Saxony, Rambouillet, American and Australian Merinos (Mason, 1996). The Merino Breeder's Society was founded in 1921, but did not last long. The Society was then re-established in 1947. Following the establishment of the Breeder's society, different types of Merino sheep were developed for different regions based on the management regimes specific to those regions. Wool types ranged from strong wool of 25 microns to the finest wool of 16 microns. Plain bodied sheep were preferred for the more arid Karoo regions while a medium bodied sheep was developed for the Lucerne lands of the Western Cape, the northern Free State and the irrigation areas.

In 2005, the Breeder's Society had 714 members with 252 665 stud sheep (Anon., 2005). Out of 25 million sheep, 11 613 million were Merinos in 2005. The South African Merino is characterised by uni-coloured white coat and fine wool. They are relatively heavy animals with males and females achieving mature weights of respectively 100kg and 60kg (Anon., 2005). These animals adapted well to high potential cultivated pastures, and are also found in semi-arid to sub-humid climate zones, at medium to high altitude, and under ranching and agro-pastoral management systems (Anon., 2005). Among many Merino studs and experimental farms in South Africa, the Tygerhoek research farm in the Western Cape also maintains a flock of Merinos.

1.2 Genetic parameters

Improvement of live weight and objective wool traits have been an important breeding objective in sheep production systems worldwide. Olivier (1999) and Safari *et al.* (2005) however, indicated reproduction as being the most important aspect to be included into any sheep breeding enterprise. Knowledge of genetic parameters for economically important production traits to be included in the selection programme is essential to optimise breeding programmes and to predict the direction of genetic selection response. Accurate estimation of genetic parameters requires large data sets (Safari *et al.*, 2005) which have been collected in most Merino studs and experimental stations worldwide. The development of sophisticated computer software (Meyer, 1991; Gilmour *et al.*, 1999) and computing capacity also facilitated accurate estimation of genetic parameters. These advances in computing power enabled estimation of additional variance components and/or the partitioning of variance components into direct and maternal effects, animal and dam permanent environmental effects, litter effect as well as the correlation between direct and maternal effects. Partitioning of these (co)variances enables the estimation of a contribution of each individual effect to the overall performance of an animal. Previous researchers used animal models partitioning variance components to estimate genetic parameters for various livestock species (Meyer, 1997).

The Tygerhoek Merino flock has been studied earlier (Cloete, 1986; Duguma, 2002) and contributed genetic parameter estimates pertaining to reproduction and early live weight traits of Merino sheep to the scientific literature. However, few studies included staple strength (SS), coefficient of variation of fibre diameter (CVFD), and standard deviation of fibre diameter (SDFD) in the analyses.

The complexity of breeding objectives for sheep (Safari *et al*., 2005) forced previous researchers to include other traits such as disease and parasite resistance (Cloete *et al*., 2001a; Eady *et al*., 2003) and some wool quality traits (Morley, 1955, Brown & Turner, 1968; Gregory, 1982a & b; Lewer & McLeod, 1990; Mortimer & Atkins, 1993; Lewer *et al*., 1995; Brown *et al*., 2002; Brown *et al*., 2006) in their studies to assess their incorporation in the selection objectives for sheep. Following the development of a linear type scoring system for South African Merino sheep (Olivier *et al*., 1987), South African researchers also included some wool quality and conformation traits in their studies (Cloete *et al*., 1992; Groenewald *et al*., 1999; Snyman & Olivier, 2002a). Furthermore, Naidoo *et al*. (2004) and Olivier *et al*., (2006a) recently investigated the inclusion of other subjectively assessed wool traits into the Merino selection programmes using the Tygerhoek Merino flock and the Cradock fine wool Merino stud data sets respectively. Apart from the work of Snyman & Olivier (2002a) information is lacking on the genetic and phenotypic correlations between subjectively assessed wool and conformation traits with objective wool and live weight traits. Also, information regarding the environmental and maternal correlations for these traits could not be found in the literature

In the recent comprehensive review of genetic parameters in sheep, Safari *et al*. (2005) included wool, growth, meat and reproduction traits. The only subjectively assessed trait included in the review was crimp frequency which can also be measured objectively. Despite the findings from a bulk of literature on objective wool and live weight traits, the need to predict more accurate genetic parameters for Merino sheep continues. It also calls for the evaluation of breeding objectives including subjectively assessed wool and conformation traits that commercial Merino sheep producers frequently use for selection of their breeding stock. Such information is lacking from literature, while further investigations into their relationships with other traits of economic importance are also needed.

1.3 Study objectives

The main objectives of the present study were to:

i. Estimate variance components for objective wool and subjective wool and conformation traits as well as for live weight at 16 months of age,

ii. To estimate covariance components and correlations among objective wool traits, subjective wool traits and subjective conformation traits, and

iii. To estimate correlations of subjective wool traits and conformation traits with objective wool traits and live weight.

CHAPTER 2

A LITERATURE REVIEW

2.1 Introduction

In South Africa, Merino sheep constitute a large proportion of the woolled sheep numbers reared for commercial production of wool (Anon., 2005)**.** In the woolled sheep industry, selection objectives ranges from an objective to increase fleece weight at a constant fibre diameter to the reduction of fibre diameter while maintaining fleece weight as well as various combinations between these extremes (Cloete *et al*., 1998a). The development of effective genetic evaluation and improvement programmes for woolled sheep requires knowledge of genetic (co)variance components for economically important traits.

A comprehensive review of genetic parameter estimates and of economically important traits has recently been compiled by Safari *et al.* (2005). However, there is a need to update the review by presenting recently published genetic parameter estimates for woolled sheep.

2.2 Definition of traits

Wool traits can be classified as objective and subjective traits. As their names suggest, objective traits are measured according to defined measurements. Subjective traits, on the other hand, are measured with the use of scores.

Objective wool production traits include greasy fleece weight (GFW), clean fleece weight (CFW), clean yield (CY), fibre diameter (FD), staple length (SL), staple strength (SS), coefficient of variation for fibre diameter (CVFD) and standard deviation of fibre diameter (SDFD) (Table 2.1). Safari *et al.* (2005) indicated that staple length, clean fleece weight and fibre diameter are major wool production traits with fibre diameter being the most important of the three. Live weight traits include body weight measured at various stages of the life of an animal's (Table 2.1). Normally weight is measured at birth, weaning, yearling, hogget and adult stage in sheep.

Subjectively assessed wool traits include wool quality (QUAL), regularity of crimp (ROC), wool colour (COL), yolk (YOLK), fleece grade spinning count (FG), staple formation (STAPL), belly and points (BANDP), variation in crimps over the fleece (VAR), softness of fleece (SOFT), crimp definition (CRIM), crimp frequency (CRIMF), density of fleece (DENS), evenness of fleece (EVEN), softness of face (FACE), pigmentation (PIGM) and creeping belly (CBEL) (Table 2.2). Normally, wool traits are measured on yearling, hogget and mature sheep, which are ~360days, ~450days and >540 days of age respectively. Subjectively assessed conformation traits include total fold score (TOT) (also abbreviated as TFS or WS in other papers), head conformation (HEAD), front quarters (FQRT), topline (TOPL), hocks (HOCKS), pastern score (PAS), front pasterns (FPAS), hind pasterns (HPAS) and conformation (CON) (Table 2.2).

All the researchers cited in this literature review included a combination of two or more of the following fixed effects to estimate the genetic parameters: year of birth, sex of the animal, type of birth, age of the animal, age of the dam, group, flock, year of birth, season of birth and interactions between flock-year of birth, flock-year-season of birth, flock-year-season-sex as well as interactions between sex and year of birth. These fixed effects can be considered as noise in genetic evaluations, which needs to be accounted for. It will thus not be discussed in detail in this review.

2.3 Indicators of phenotypic variation

2.3.1 Objectively measured traits

Fogarty (1995) and Safari *et al.* (2005) did comprehensive reviews on wool and live weight traits using numerous literature reports (>165 studies) over the last two decades. Reports cited in this discussion will be limited to the two above mentioned reviews plus all reports since 2005.

Coefficients of variation (CV) for objectively measured traits on various sheep breeds are presented in Table 2.1. The CV of GFW (28.3%) reported by Safari *et al.* (2007a) was relatively higher than those reported from other literature sources (Table 2.1). The CV of 33.9% for CFW reported on South African Dohne Merino (Van Wyk *et al.*, 2006) was higher than most other literature estimates ranging from 12.2% to 29.0%.

The qualitative wool traits, FD and CY showed less variation than quantitative traits (GFW and CFW). Safari *et al.* (2007a) reported a higher CV of FD (12.0%) on Australian Merino sheep belonging to different resource flocks (including fine strains) than other literature values which were all lower than 10%. Australian Merino resource flocks studied by Safari *et al.* (2007a) had the highest CV for both CVFD (16.6%) and for SDFD (18.1%), compared to other literature values (Table 2.1). CV's for SL and SS ranged from 11.9% to 20.9% and 19.3% to 29.3% respectively. Literature estimates of CV for LW on various sheep breeds at different ages ranged from 6.0 % to 24.6% (Table 2.1).

Table 2.1 Literature values of descriptive statistics for objectively measured wool traits and live weight in sheep

Trait	Breed	Country	n	Age measured (months)	Mean ±SD	CV	Reference
Greasy fleece weight (GFW) (kg)	Wool and dual purpose breeds	-	-	-	-	16.50 & 16.20	Safari *et al*. (2005)
	Merino	Australia	17247	-	4.7±1.0	21.28	Brown *et al*. (2005)
	Polypay	-	8872	12	3.48±0.79	22.7	Hanford *et al*. (2006)
	Merino	Australia	117798	14-17	5.3±1.50	28.3	Safari *et al*. (2007a)
Clean fleece weight (CFW) (kg)	Wool and dual purpose breeds	-	-	-	-	16.20 & 20.80	Safari *et al*. (2005)
	Dohne Merino	South Africa	107389	12	3.12±1.8	33.97	Van Wyk *et al*. (2006)
	Merino	Australia	115244	14-17	3.83±1.11	28.98	Safari *et al*. (2007a)
Clean yield (CY) (%)	Wool and dual purpose breeds	-	-	-	-	7.00 & 6.00	Safari *et al*. (2005)
	Merino	Australia	116526	14-17	71.7±6.02	8.40	Safari *et al*. (2007a)
Fibre diameter (FD) (μm)	Merino	Australia	27672	-	18.6±1.1	5.91	Brown *et al*. (2005)
	Wool and dual purpose breeds	-	-	-	-	7.40 & 7.20	Safari *et al*. (2005)
	Dohne Merino	South Africa	107389	-	19.36±1.59	8.21	Van Wyk *et al*. (2006)
	Merino	Australia	116025	14-17	21.3±2.55	11.97	Safari *et al*. (2007a)
CV of fibre diameter (%) (CVFD)	Merino	South Africa	2801	14-16	20.2±3.1	15.30	Naidoo *et al.* (2004)
	Wool breeds	-	-	-	-	12.20	Safari *et al.* (2005)
	Targhee		847	-	17.5±2.2	12.60	Notter *et al.* (2007)

Table 2.1 (Continues)

	Merino	Australia	76603	14-17	20.8±3.45	16.59	Safari *et al*. (2007a)
SD of fibre diameter (µm) (SDFD)	Dual purpose breeds	-	-	-	-	14.70	Safari *et al*. (2005)
	Targhee	USA	847	-	3.81±0.50	13.12	Notter *et al*. (2007)
	Merino	Australia	55935	14-17	4.7±0.85	18.09	Safari *et al*. (2007a)
Staple length (SL) (mm)	Merino	South Africa	2796	14-16	83.2±14.5	17.40	Naidoo *et al*. (2004)
	Wool and dual purpose breeds	-	-	-	-	11.90 & 14.00	Safari *et al*. (2005)
	Targhee	USA	847	-	72.8±15.2	20.88	Notter *et al*. (2007)
Staple strength (SS) (N/ktex)	Wool breeds	-	-	-	-	29.20	Safari *et al*. (2005)
	Merino	South Africa	1517	-	-	19.30	Cloete *et al*. (2006)
Live-weight (kg)	Merino	Australia	25700	-	48.7±8.3	17.04	Brown *et al*. (2005)
	Wool, dual purpose and Meat breeds	-	-	-	-	12.4, 10.6 & 6.0	Safari *et al*. (2005)
	Merino	South Africa	107389	12	49.97±12.3	24.61	Van Wyk *et al*. (2006)
	Sangsari	Iran	931	-	28.49±5.44	19.15	Miraei-Ashtiani *et al*. (2007)
	Merino	Australia	52475	14-17	48.2±9.54	19.79	Safari *et al*. (2007a)

n = number of observations, CV = coefficient of variation, SD = standard deviation and USA = United State of America

2.3.2 Subjectively assessed wool and conformation traits

Apart from fleece grade (FG), moderate to high CV's were reported for subjectively assessed fleece traits recorded on various sheep breeds (James *et al.*, 1990; Cloete *et al.*, 1992; Groenewald *et al.*, 1999; Snyman & Olivier, 2002a; Naidoo *et al.*, 2004; Safari *et al.*, 2005). Only FG had a CV below 10% in all cases (Bromley *et al.*, 2002). However, COL also showed less than 10% variation in the Tygerhoek Merino resource flock (Cloete *et al.*, 1992) compared to the CV's for COL of 27.5 % and 27.2% (James *et al.,* 1990; Groenewald *et al.*, 1999) derived from other Merino resource flocks. On the other hand, Naidoo *et al*. (2004) reported a higher CV of 25.20% for the Tygerhoek Merino resource flock, using a larger data set than the one previously used by Cloete *et al.* (1992).

Among subjectively assessed conformation traits, the CV of pastern score was below 10% for Carnarvon Afrino sheep (Snyman & Olivier, 2002a). Higher CV's for other subjectively assessed conformation traits ranged from 11.3% to 41.7% (Cloete *et al.,* 1992; Groenewald *et al.*, 1999; Snyman & Olivier, 2002a; Olivier *et al*., 2006b). The highest CV among the subjectively assessed conformation traits was derived for wrinkle score (41.7% - Groenewald *et al.*, 1999) on South African Merino sheep participating in a national progeny test.

Table 2.2 Literature values of descriptive statistics for subjectively assessed wool traits in sheep

Trait	Breed	Country	n	Age measured (months)	Mean ± SD	CV	Reference
Subjective wool traits							
Fleece grade (FG)	Various	USA	4239-13544	-	57.4-61.5±2.6-3.1	4.53	Bromley *et al*. (2002)
	Rambouillet	USA	11155	-	63.2±2.1	3.32	Hanford *et al*. (2005)
	Polypay	USA	8872	12	58.2±2.70	4.64	Hanford *et al*. (2006)
Face cover score (FCS)	Merino	South Africa	267	17	26.7±5.5	20.6	Cloete *et al*. (1992)
Wool quality (QUAL)	Merino	Australia	803	18	3.51.5±0.64	18.3	James *et al*. (1990)
	Merino	South Africa	267	17	26.5±6.2	23.4	Cloete *et al*. (1992)
	Merino	South Africa	2700	14-16	30.3±8.7	28.70	Naidoo *et al*. (2004)
	Merino	South Africa	5242	15-18	29.44±7.28	24.73	Groenewald *et al*. (1999)
Regularity of crimp (ROC)	Merino	South Africa	2700	14-16	31.5±8.4	26.70	Naidoo *et al*. (2004)
Wool colour (COL)	Merino	Australia	803	18	2.95.5±0.81	27.5	James *et al*. (1990)
	Merino	South Africa	267	17	26.3±1.9	7.22	Cloete *et al*. (1992)
	Merino	South Africa	5242	15-18	35.03±9.51	27.15	Groenewald *et al*. (1999)
	Merino	South Africa	2700	14-16	31.4±7.9	25.20	Naidoo *et al*. (2004)
Wool oil (OIL)	Merino	South Africa	5242	-	24.58±2.56	10.41	Groenewald *et al*. (1999)
	Merino	South Africa	2700	14-16	27.2±4.5	16.50	Naidoo *et al*. (2004)
Staple formation (STAPL)	Merino	Australia	803	18	3.08.5±0.71	23.1	James *et al*. (1990)
	Merino	South Africa	267	17	23.8±5.1	21.43	Cloete *et al*. (1992)
	Merino	South Africa	5242	15-18	28.36±6.44	22.71	Groenewald *et al*. (1999)
	Merino	South Africa	2700	-	27.4±5.1	18.60	Naidoo *et al*. (2004)

Table 2.2 (Continues)

Belly and points (BANDP)	Merino	South Africa	267	17	24.7±5.7	23.08	Cloete *et al.* (1992)
	Merino	South Africa	5242	15-18	25.15±6.34	25.21	Groenewald *et al.* (1999)
	Merino	South Africa	2698	14-16	29.5±6.7	22.70	Naidoo *et al.* (2004)
Softness of fleece (SOFT)	Afrino	South Africa	3291	14-16	33.1	22.30	Snyman & Olivier (2002a)
Crimp definition (CRIM)	Afrino	South Africa	3291	14-16	27.1	33.70	Snyman & Olivier (2002a)
Density of fleece (DENS)	Afrino	South Africa	3291	14-16	34.8	16.10	Snyman & Olivier (2002a)
Evenness of fleece (EVEN)	Merino	South Africa	267	17	39.0±6.7	17.18	Cloete *et al.* (1992)
	Afrino	South Africa	3291	14-16	34.2	17.90	Snyman & Olivier (2002a)
Creeping belly (CBEL)	Afrino	South Africa	3291	14-16	38.7	28.90	Snyman & Olivier (2002a)
Crimp frequency (CF)	Wool breeds	-	-	-	-	16.10	Safari *et al.* (2005)
Variation (VAR)	Merino	South Africa	5242	15-18	32.35±7.95	24.57	Groenewald *et al.* (1999)
Subjective conformation traits							
Total fold score (TOT)	Merino	South Africa	3603	-	9.7±2.4	24.74	Cloete *et al.* (1998)
	Merino	South Africa	5242	15-18	4.7±1.96	41.70	Groenewald *et al.* (1999)
	Merino	South Africa	2683	-	-	30.30	Cloete *et al.* (2006)
	Merino	South Africa	5242	-	-	41.70	Groenewald *et al.* (1999)
General head conformation (GEN)	Merino	South Africa	267	17	20.1±7.8	38.81	Cloete *et al.* (1992)
	Merino	South Africa	5242	15-18	27.96±6.52	23.32	Groenewald *et al.* (1999)
	Afrino	South Africa	3291	14-16	35.8	16.40	Snyman & Olivier (2002a)
Front quarter (FQ)	Merino	South Africa	5242	15-18	26.29±5.66	21.53	Groenewald *et al.* (1999)
	Afrino	South Africa	3291	14-16	35.8	12.00	Snyman & Olivier (2002a)

Table 2.2 (Continues)

Topline (TOPL)	Afrino	South Africa	3291	14-16	35.4	11.30	Snyman & Olivier (2002a)
Hocks (HOCKS)	Merino	South Africa	267	17	23.4±9.7	41.45	Cloete *et al.* (1992)
	Merino	South Africa	5242	15-18	23.65±4.10	17.34	Groenewald *et al.* (1999)
	Afrino	South Africa	3291	14-16	35.2	16.60	Snyman & Olivier (2002a)
Pastern score (PS)	Merino	South Africa	267	17	32.7±8.0	24.46	Cloete *et al.* (1992)
	Merino	South Africa	5242	15-18	36.65±7.57	20.65	Groenewald *et al.* (1999)
Front pastern (FPAS)	Merino	South Africa	267	17	16.3±5.5	33.74	Cloete *et al.* (1992)
	Afrino	South Africa	3291	14-16	36.6	13.40	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	Afrino	South Africa	3291	14-16	38.9	9.90	Snyman & Olivier (2002a)
Conformation (CONF)	Merino	South Africa	5242	15-18	27.53±6.78	24.63	Groenewald *et al.* (1999)
Softness of face (FACE)	Afrino	South Africa	3291	14-16	35.5	15.10	Snyman & Olivier (2002a)
Pigmentation (PIGM)	Afrino	South Africa	3291	14-16	23.6	32.90	Snyman & Olivier (2002a)

See **Table 2.1** for abbreviations

2.4 Genetic parameters

2.4.1 Heritability estimates for objective traits

Heritability is a measure of the strength (reliability, consistency) of the relationship between the performance (phenotypic values) and breeding values for a trait within a population. When heritability of a trait is high, performance is on average a good indicator of the breeding value (Bourdon, 2000). Mean heritability estimates for objective wool, subjective wool and conformation as well as live-weight traits are presented in Tables 2.3 and 2.4.

2.4.1.1 Direct heritability estimates (h^2_a)

Weighted mean direct heritability estimates for GFW at different ages ranged from 0.17-0.68 with the highest estimates being recorded on the Polypay sheep breed at 12 months of age (Table 2.3). Direct heritability estimates for CFW (0.22±0.01 to 0.54±0.04) and FD (0.45±0.01 to 0.75±0.02) were moderate to high for various sheep breeds (Table 2.3). Literature estimates of h^2_a for CY ranged from 0.32 to 0.56. Estimates for SL ranged from 0.25 to 0.70. Cloete *et al.* (2003b) reported a very low h^2_a of 0.05±0.05 for SS, compared to the range of 0.12±0.04 to 0.39±0.11 reported in literature. It should be noted that the estimate of 0.05 was derived from repeated records on mature, reproducing ewes of 2-6 years of age. CVFD and SDFD are highly heritable traits, with h^2_a estimates ranging from 0.32 to 0.74 and from 0.49 to 0.60 respectively (Table 2.3).

Previous studies reported low to high h^2_a that ranged from 0.10 to 0.56 for various sheep breeds for LW at 12- to 18-months of age (Table 2.3). Gizaw *et al.* (2006) reported the highest h^2_a for Menz sheep at 12 months of age and the lowest estimate was derived at 12 months of age on the Sangsari sheep breed (Miraei-Ashtiani *et al.*, 2007). The range for LW on 14-18 months Merino sheep was 0.38 to 0.50 with the highest h^2_a reported for the South African Merino at 15 months of age (Olivier *et al.*, 2006b). The differences of estimates between studies on objectively measured wool traits could be attributed to the fitting of different random effects models, environmental effects, breed, data structure, selection history and a combination of these factors (Mortimer and Atkins, 1994; Olivier *et al.*, 1994; Snyman *et al.*, 1995; Safari *et al.*, 2007b).

2.4.1.2 Maternal heritability (h^2_m) estimates

Among the objectively measured wool traits, researchers reported GFW, CFW, FD, CY, CVFD and SDFD as being influenced by maternal genetic effects up to 18 months of age (Table 2.3). However, most studies reported nonsignificant h^2_m estimates for FD, apart from the estimate of 0.04 obtained by Safari *et al.* (2007b) from Australian Merino resource flocks. Also, h^2_m for SDFD was not significant in the Australian Merino resource flocks (Safari *et al.,* 2007b). Significant h^2_m estimates were reported for GFW and CFW ranging from 0.02 to 0.17 and from 0.06 to 0.15 respectively (Table 2.3). Higher h^2_m estimates for wool weights recorded on Australian fine-wool Merino sheep (Asadi Fozi *et al.*, 2005) may be because it was estimated at 10 months of age, when maternal influences are expected to be more pronounced. CY and CVFD were found to be maternally influenced only in Australian resource flocks although the magnitude of these variance ratios was small (Safari *et al.*, 2007a). Maternal effects for LW were reported up to 18 months of age for various sheep breeds (Table 2.3). Surprisingly, h^2_m were higher among South African Merinos when analysed at hogget age (Cloete *et al.*, 2005) compared to Ausrealian Merinos. Safari *et al.* (2005) reported h^2_m estimates that ranged from 0.04 to 0.06 for hoggets. However, the reported h^2_m estimates were all below 10%.

2.4.1.3 Maternal permanent environmental effects (c^2_{pe})

Apart from an extensive study by Safari *et al.* (2007b), previous studies denoted both dam permanent environmental effects as well as common environmental effects peculiar to (mostly mature) animals with repeated records with the abbreviation c^2 in the analysis of objective wool traits in sheep (Cloete *et al.*, 2003b & 2004b; Safari *et al.*, 2005; Naidoo & Cloete, 2006). For simplicity of the current literature review, the dam permanent environmental effect is denoted as c^2_{pe}, the common animal environmental effect as c^2 and the litter effect with l^2**.** Safari *et al.* (2007b) reported a c^2_{pe} of 0.00 for GFW, CFW, CY, FD, CVFD and SDFD for Australian Merino resource flocks.

Table 2.3 Summary of literature values on direct (h^2_a) and maternal (h^2_m) heritability estimates, covariance between animal effects (σ_{am}), dam (c^2_{pe}) and (c^2) common environmental effects as well as litter effect (l^2) for objectively measured traits in sheep

Trait	Breed	Country	Age measured (Months)	h^2_a ± SE	h^2_m ± SE	c^2_{pe}	c^2	l^2	σ_{am}	Reference
Greasy fleece weight (kg)										
	Fine-wool Merino	Australia	10	0.40±0.03	0.17±0.03	-	-	-	-0.48±0.10	Asadi Fozi *et al*. (2005)
	Merino	Australia	16-18	0.35±0.02	0.13±0.01	-	-	-	-	Brown *et al*. (2005)
	Rambouillet	USA	12	0.08±0.04	-	-	-	-	-	Hanford *et al*. (2005)
	Turkish Merino	Turkey	12	0.37±0.02	-	-	-	-	-	Ozcan *et al*. (2005)
	Wool breeds	-	-	0.38±0.03	0.08±0.01	0.15±0.09	-	-	-	Safari *et al*. (2005)
	Dual purpose	-	-	0.39±0.02	0.02±0.01	0.11±0.02	-	-	-	Safari *et al*. (2005)
	Menz sheep	Ethiopia	12	0.39±0.02	-	-	-	-	-	Gizaw *et al*. (2006)
	Polypay	USA	12	0.68±0.03	-	-	-	-	-	Hanford *et al*. (2006)
	Merino	Australia	14-17	0.46±0.01	0.08±0.01	0.00	0.03±0.01	0.08±0.01	-0.60±0.02	Safari *et al*. (2007b)
Clean fleece weight (kg)										
	Fine-wool Merino	Australia	10	0.36±0.03	0.15±0.03	-	-	-	-0.47±0.10	Asadi Fozi *et al*. (2005)
	Elsenburg Merino	South Africa	18	0.28±0.05	0.08±0.02	-	-	-	-	Cloete *et al*. (2005)
	Wool breeds	-	-	0.36±0.02	0.06±0.01	0.21±0.11	-	-	-	Safari *et al*. (2005)
	Dual purpose	-	-	0.51±0.07	-	-	-	-	-	Safari *et al*. (2005)
	Dohne Merino	South Africa	12-14	0.24±0.01	-	-	-	-	-	Swanepoel *et al*. (2005)
	Elsenburg Merino	South Africa	14-18	0.44±0.07	-	-	0.24±0.07	-	-	Naidoo & Cloete (2006)
	Fine-wool Merino	South Africa	15	0.54±0.04	-	-	-	-	-	Olivier *et al*. (2006)

Table 2.3 (Continues)

Dohne Merino	South Africa	-	0.22±0.01	-	-	-	-	-	Van Wyk *et al*. (2006)
Merino	Australia	14-17	0.42±0.01	0.07±0.01	0.00	0.04±0.01	0.06±0.01	-0.55±0.02	Safari *et al*. (2007b)
Clean yield (%)									
Wool breeds	-		0.56±0.03	-	-	-	-	-	Safari *et al.* (2005)
Dual purpose	-		0.48±0.03	-	-	-	-	-	Safari *et al.* (2005)
Elsenburg Merino	South Africa	14-18	0.32±0.08	-	-	0.35±0.07	-	-	Naidoo & Cloete (2006)
Merino	Australia	14-17	0.47±0.01	0.03±0.01	0.00	0.01±0.01	0.02±0.01	-0.29±0.05	Safari *et al*. (2007b)
Fibre diameter (µm)									
Australian Merino	Australia	16-18	0.60±0.02	0.00±0.00	-	-	-	-	Brown *et al*. (2005)
Wool breeds	-	-	0.59±0.02	-	-	-	-	-	Safari *et al.* (2005)
Dual purpose	-	-	0.57±0.05	-	-	-	-	-	Safari *et al.* (2005)
Elsenburg Merino	South Africa	18	0.53±0.04	-	-	-	-	-	Cloete *et al.* (2005)
Elsenburg Merino	South Africa	14-18	0.75±0.02	-	-	-	-	-	Naidoo & Cloete (2006)
Fine-wool Merino	South Africa	15	0.63±0.03	-	-	-	-	-	Olivier *et al.* (2006)
Dohne. Merino	South Africa	12-14	0.45±0.01	-	-	-	-	-	Swanepoel *et al.* (2006)
Dohne Merino	South Africa	12-14	0.48±0.01	-	-	-	-	-	Van Wyk *et al*. (2006)
Targhee	USA	12	0.62	-	-	-	-	-	Notter *et al.* (2007)
Merino	Australia	14-17	0.68±0.01	0.04±0.01	0.00	0.01±0.01	0.03±0.01	-0.42±0.03	Safari *et al*. (2007b)
CV of fibre diameter (%)									
Merino	South Africa	18	0.74±0.02	-	-	-	-	-	Cloete *et al.* (2003b)
Tygerhoek Merino	South Africa	14-16	0.50±0.04	-	-	-	-	-	Naidoo *et al.* (2004)
Wool breeds	-	-	0.52±0.04	-	-	-	-	-	Safari *et al.* (2005)

Table 2.3 (Continues)

Elsenburg Merino	South Africa	14-18	0.71±0.02	-	-	-	-	-	Naidoo & Cloete (2006)
Targhee	USA	12	0.32	-	-	-	-	-	Notter *et al*. (2007)
Merino	Australia	14-17	0.57±0.02	0.03±0.01	0.00	0.05±0.01	0.04±0.01	-0.32±0.05	Safari *et al*. (2007b)
SD of fibre diameter (%)									
Wool Breeds	-	-	0.52±0.05	-	-	-	-	-	Safari *et al*. (2005)
Targhee	USA	12	0.49	-	-	-	-	-	Notter *et al*. (2007)
Merino	Australia	14-17	0.60±0.02	0.01±0.01	0.00	0.07±0.01	0.02±0.01	-0.21±0.10	Safari *et al*. (2007b)
Staple length (mm)									
Merino	South Africa	-	0.25±0.04	-	-	-	-	-	Naidoo *et al*. (2004)
Rambouillet	USA	-	0.58±0.03	-	-	-	-	-	Hanford *et al*. (2005)
Wool breeds	Australia	-	0.46±0.02	-	-	-	-	-	Safari *et al*. (2005)
Dual purpose	Australia	-	0.48±0.03	-	-	-	-	-	Safari *et al*. (2005)
Menz	Ethopia	12	0.34±0.01	-	-	-	-	-	Gizaw *et al*. (2006)
Elsenburg Merino	South Africa	14-18	0.28±0.06	-	-	0.11±0.05	-	-	Naidoo & Cloete (2006)
Fine-wool Merino	South Africa	15	0.46±0.03	-	-	-	-	-	Olivier *et al*. (2006)
Targhee	USA	12	0.43	-	-	-	-	-	Notter *et al*. (2007)
Staple strength (N/ktex)									
Merino	South Africa	18	0.05±0.05	-	-	0.12±0.05	-	-	Cloete *et al*. (2003b)
Wool breeds	-	-	0.34±0.03	-	-	-	-	-	Safari *et al*. (2005)
Elsenburg Merino	South Africa	-	0.13±0.04	-	-	-	-	-	Cloete *et al*. (2005)
Merino	Australia	16	0.39±0.11	-	-	-	-	-	Greeff *et al*. (2006)

Table 2.3 (Continues)

Merino	South Africa	-	0.23-0.48	-	-	-	-	-	Herselman *et al.* (2006)
Afrino and Dohne Merino	South Africa	-	0.23-0.34	-	-	-	-	-	Herselman *et al.* (2006)
Merino	South Africa	14-18	0.12±0.04	-	-	0.06±0.08	-	-	Naidoo & Cloete (2006)
Live-weight (LW)									
Horro sheep	Ethiopia	18	0.33±0.07	-	-	-	-	-	Abegaz *et al.* (2005)
Merino	Australia	16-18	0.36±0.02	0.05±0.01	-	-	-	-	Brown *et al.* (2005)
Wool breeds	-	>12	0.42±0.03	0.04±0.01	-	0.10±0.04	-	0.74±0.15	Safari *et al.* (2005)
Dual purpose	-	>12	0.40±0.06	0.06±0.03	-	0.09±0.04	-	-0.16±0.29	Safari *et al.* (2005)
Merino	South Africa	18	0.37±0.05	0.09±0.02	-	-	-	-	Cloete *et al.* (2005)
Merino	South Africa	16	0.38±0.05	0.06±0.02	-	-	-	-	Cloete *et al.* (2006)
Merino	South Africa	>24	0.52±0.05	-	-	0.21±0.05	-	-	Cloete & Naidoo (2006)
Menz	Ethiopia	12	0.56±0.02	-	-	-	-	-	Gizaw *et al.* (2006)
Fine-wool Merino	South Africa	15	0.50±0.04	-	-	-	-	-	Olivier *et al*. (2006)
Sangsari	Iran	12	0.10±0.05	-	-	-	-	-	Miraei-Ashtiani *et al.* (2007)
Merino	Australia	14-17	0.38±0.01	0.3±0.01	0.00	-	0.06±0.01	0.25±0.08	Safari *et al*. (2007b)

h^2_a = direct heritability, h^2_m = maternal heritability, σ_{am} = covariance between animal effects, c^2_{pe} dam permanent environmental effect, c^2 common environmental effect, l^2 = litter effect, SE = standard error and USA = United State of America

Dual-purpose breeds had a moderate weighted mean dam permanent environmental effect (c^2_{pe}) of 0.11±0.02 for GFW (Safari *et al*., 2005). Analysis of Australian Merino resource flocks (Safari *et al*., 2007b) revealed a dam permanent environmental effect (c^2_{pe}) of 0.00 for LW. Safari *et al*. (2005) derived an animal effect (c^2_p) of 0.09 and 0.10 on wool and dual-purpose breeds respectively (for LW recorded beyond 12 months of age). Other studies cited did not derive c^2_{pe} estimates. Naidoo & Cloete (2006) reported a higher c^2 estimate of 0.21 on mature ewes of the Elsenburg Merino resource flock. Temporary environmental effect due to the dam (within-year or litter effect) (l^2) was found to have a significant effect on LW (0.06) for Australian Merino resource flocks (Safari *et al*., 2007b). Other studies cited did not partition dam environmental effects into the temporary and permanent components.

2.4.1.4 Genetic correlations between animal effects (r_{am})

Several negative genetic correlations between animal effects (r_{am}) were reported in the literature for GFW, CFW, CY, FD CVFD and SDFD (Table 2.3). Moderate to high r_{am} estimates for CFW and GFW were found in Australian fine-wool Merinos (Asadi Fozi *et al*., 2005). Furthermore, Safari *et al*. (2007b) reported moderate to high r_{am} for all abovementioned wool traits, ranging from -0.21 for SDFD to -0.60 for GFW. There is conflicting evidence with regard to the magnitude and sign of the correlation between animal (r_{am}) effects for LW on various sheep breeds. Safari *et al*. (2005) derived moderate and negative r_{am} for wool breeds (-0.16) and very high and positive values for dual purpose breeds (0.74). Safari *et al*. (2007b) reported a moderate and positive r_{am} for Australian Merino resource flocks.

Apart from existing genetic antagonism between animal effects, researchers attributed negative and variable genetic correlations between animal effects for growth traits on various species to one or a combination of sire by environmental interaction, flock-year-season, data structure, the number of dams with records, a small number of progeny per dam as well as limited data from the dam herself (Meyer, 1997; Hagger, 1998; Lee *et al*., 2000b; Maniatis & Pollot, 2002; Konstantinov & Brien, 2003; Maniatis & Pollot, 2003). The same reasoning may be applied to wool traits. However, Safari *et al*. (2007b) indicated that limited data and a low number of progeny per dam as well as limited information on the dam herself might not be reasons for a high negative genetic correlation between animal effects.

2.4.2 Heritability estimates for subjectively assessed wool and conformation traits

Published mean direct heritability (h^2_a) estimates for various subjectively assessed wool traits were generally moderate to high (Table 2.4) with estimates for hind pasterns (HPAS) (0.08±0.03) being the lowest and that for total fold score (TOT) (0.80) the highest.

Researchers reported low to moderate h^2_a estimates (Table 2.4) for various subjectively assessed conformation traits in Merino sheep and in the Carnarvon Afrino flock, with the estimate for HEAD (0.32±0.04) being the highest and that for TOPL (0.06± 0.02) the lowest. Of the subjectively assessed wool and conformation traits, a maternal variance ratio (h^2_m**)** of 0.03 was only estimated for COL in Australia Merino sheep (Brown *et al*., 2006). None of the other literature sources cited found animal and dam permanent environmental effects as having a significant effect on subjectively assessed wool and conformation traits. Many of the earlier researchers probably lacked the software and computing power to allow for the partitioning of animal effects into the respective components.

Table 2.4 Summary of literature values on direct (h^2_a) and maternal (h^2_m) heritability estimates of subjectively assessed wool traits in sheep

Trait	Breed	Country	Age measured (Months)	h^2_a ± SE	h^2_m ± SE	Reference
Subjectively assessed wool						
Fleece grade (FG)	Various	USA	12-36	0.36 - 0.47	-	Okut *et al.* (1999)
	Various	USA	-	0.26 - 0.50	-	Bromley *et al.* (2000)
	Rambouillet	USA	-	0.16±0.01	-	Hanford *et al.* (2005)
	Polypay	USA	12	0.36±0.02	-	Hanford *et al.* (2006)
Wool quality (QUAL)	Merino	Australia	15-16	0.25±0.05	-	Gregory (1982a)
	Merino	Australia	14-16	0.23±0.04	-	Groenewald *et al.* (1999)
	Merino	Australia	-	0.27±0.04	-	Naidoo *et al.* (2004)
Regularity of crimp (ROC)	Afrino	South Africa	14-16	0.28±0.04	-	Snyman & Olivier (2002a)
	Merino	South Africa	14-16	0.19±0.03	-	Naidoo *et al.* (2004)
Wool colour (COL)	Merino	Australia	15-16	0.29±0.06	-	Mullaney *et al.* (1970)
	Various	Australia	15-16	0.27-0.34	-	Mullaney *et al.* (1970)
	Merino	Australia	15-16	0.25±0.13	-	Raadsma & Wilkinson (1970)
	Merino	Australia	15-16	0.61±0.11	-	McGuirk & Atkins (1980)
	Merino	Australia	15-16	0.42±0.13	-	James *et al.* (1990)
	Merino	Australia	14	0.18±0.06	-	Lewer *et al.* (1995)
	Merino	South Africa	-	0.17±0.03	-	Groenewald *et al.* (1999)
	Corriedale	Australia	-	0.27±0.13	-	Benavides & Maher (2003)
	Merino	South Africa	14-16	0.38±0.04	-	Naidoo *et al.* (2004)
	Merino	Australia	14-18	0.35±0.04	0.03±0.01	Brown *et al.* (2006)
Wool oil (OIL)	Merino	South Africa	-	0.24±0.04	-	Groenewald *et al.* (1999)

Table 2.4 (Continues)

	Merino	South Africa	14-16	0.25±0.04	-	Naidoo *et al.* (2004)
Staple formation (STAPL)	Merino	Australia	15-16	0.17±0.04	-	Gregory (1982a)
	Merino	Australia	15-16	0.20±0.10	-	James *et al.* (1990)
	Merino	South Africa	-	0.09±0.03	-	Groenewald *et al.* (1999)
	Merino	South Africa	14-16	0.13±0.03	-	Naidoo *et al.* (2004)
	Merino	South Africa	15	0.40	-	Olivier *et al.* (2006)
Belly and points (BANDP)	Merino	South Africa	-	0.17±0.03	-	Groenewald *et al.* (1999)
	Merino	South Africa	14-16	0.25±0.04	-	Naidoo *et al.* (2004)
Softness of fleece (SOFT)	Afrino	South Africa	14-16	0.51±0.04	-	Snyman & Olivier (2002a)
Crimp definition (CRIM)	Afrino	South Africa	14-16	0.47±0.04	-	Snyman & Olivier (2002a)
Fleece density (DENS)	Afrino	South Africa	14-16	0.26±0.04	-	Snyman & Olivier (2002a)
Creeping belly (CBEL)	Afrino	South Africa	14-16	0.37±0.04	-	Snyman & Olivier (2002a)
Crimp frequency (CRIMP)	Wool breeds	Australia	-	0.41±0.03	-	Safari *et al.* (2005)
Variation (VAR)	Merino	South Africa	-	0.23±0.04	-	Groenewald *et al.* (1999)
Face cover score (FCS)	Merino	Australia	-	0.38	-	Morley (1955)
	Merino	Australia	-	0.38	-	Brown & Turner (1968)
	Merino	Australia	-	0.76±0.17	-	Watson *et al.* (1977)
	Merino	Australia	15-16	0.31±0.05	-	Gregory (1982a)
	Merino	Australia	14	0.29±0.09	-	Lewer *et al.* (1995)
Softness of face (FACE)	Afrino	South Africa	14-16	0.23±0.04	-	Snyman & Olivier. (2002a)
Subjectively assessed conformation						
Total fold score (TOT)	Merino	Australia	-	0.50±0.07	-	Morley (1955)

Table 2.4 (Continues)

	Merino	Australia			0.28±0.21	-	Beattie (1962)
	Merino	Australia	-		0.38±0.04	-	Brown & Turner (1968)
	Merino	Australia	-		0.80±0.18	-	Jackson *et al*. (1975)
	Merino	Australia		15-16	0.29±0.05	-	Gregory (1982a)
	Merino	Australia		14	0.15-0.27	-	Lewer *et al*. (1995)
	Merino	South Africa		14-18	0.42±0.03	-	Cloete *et al.* (1998)
	Merino	South Africa	-		0.32±0.04	-	Groenewald *et al.* (1999)
	Merino	South Africa	-		0.54±0.04	-	Cloete *et al.* (2005)
General head conformation (GEN)	Merino	South Africa	-		0.23±0.04	-	Groenewald *et al.* (1999)
	Afrino	South Africa		14-16	0.32±0.04	-	Snyman & Olivier (2002a)
Front quarters (FQ)	Merino	South Africa		-	0.21±0.03	-	Groenewald *et al.* (1999)
	Afrino	South Africa		14-16	0.22±0.03	-	Snyman & Olivier (2002a)
	Merino	South Africa		15	0.51	-	Olivier *et al.* (2006)
Top line (TOPL)	Afrino	South Africa		14-16	0.06±0.02	-	Snyman & Olivier (2002a)
Hocks (HOCKS)	Merino	Australia		15-16	0.32±0.05	-	Gregory (1982a)
	Merino	Australia		14	0.27±0.08	-	Lewer *et al.* (1995)
	Merino	South Africa	-		0.12±0.02	-	Groenewald *et al.* (1999)
	Afrino	South Africa		14-16	0.36±0.04	-	Snyman & Olivier (2002a)
Pastern score (PS)	Merino	South Africa	-		0.23±0.04	-	Groenewald *et al.* (1999)
Front pasterns (FPAS)	Afrino	South Africa		14-16	0.21±0.04	-	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	Afrino	South Africa		14-16	0.08±0.03	-	Snyman & Olivier (2002a)
Conformation (CON)	Merino	South Africa	-		0.31±0.04	-	Groenewald *et al.* (1999)

Table 2.4 (Continues)

	Merino	South Africa	15	0.55	-	Olivier *et al.* (2006a)
Pigmentation (PIGM)	Afrino	South Africa	14-16	0.50±0.04	-	Snyman & Olivier (2002a)

See **Table 2.3** for abbreviations

2.4.3 Genetic, phenotypic and environmental correlations

Correlations are measures of the strength of the relationship between two variables. It is used to describe the relationship between two traits in a population or between two repeated values for the same trait in a population. The most common and useful correlations in animal breeding are genetic, phenotypic and environmental correlations. The genetic correlation is a measure of the strength of the relationship between breeding values for one trait and breeding values for another trait while phenotypic correlation is a measure of the strength of the relationship between performance in one trait and performance in another trait. Environmental correlations are a measure of the strength of the relationship between environmental effects on one trait and environmental effects on another trait (Bourdon, 2000).

2.4.3.1 Objectively measured traits

Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations among objectively measured traits are presented in Tables 2.5 to 2.10.

2.4.3.1.1 Live weight (LW) and other traits

Genetic, phenotypic and environmental correlations between objective wool traits and live-weight at hogget age are presented in Table 2.5. Fleece weights were positively related to live weight with the exception of a negative relationship of -0.21 estimated by Brash *et al.* (1994a). Researchers reported unfavourable and moderate r_g estimates between FD and live-weight (Table 2.5). Corresponding r_g estimates with CVFD was negative (Cloete *et al.*, 2002b; Safari *et al.*, 2005) and positive with CY at hogget age (Cloete *et al.*, 1998). At the genetic level, SL was favourably related to hogget weight (Cloete *et al.*, 1998; Olivier *et al.*, 2006b). The r_g between hogget weight and SS was unfavourable at -0.11 (Safari *et al.*, 2005).

Estimates of r_p were positive and ranged from 0.13 to 0.54 between live-weight and fleece weights. Corresponding correlations with FD were unfavourable, while LW was positively correlated to SL and SS. The r_e for live weight with FD and fleece weights estimated on mature Elsenburg Merinos was positive (Cloete *et al.*, 2006).

Environmental correlations for live-weight with SL, SS, CY and CVFD were not found in the literature.

Table 2.5 Literature values on the genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (±SE) between live weight and objective wool traits

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**Reference**
Hogget weight (HW) X				
Greasy fleece weight (GFW)	-0.21±0.30	0.54±0.02	-	Brash *et al.* (1994a)
	0.22	0.37	-	Safari *et al.* (2005)
Clean fleece weight (CFW)	0.37±0.03	0.49±0.01	-	Cloete *et al.* (1998)
	0.21	0.35	-	Safari *et al.* (2005)
	0.06±0.06	0.25±0.02	-	Olivier *et al.* (2006b)
	0.26±0.11	-	0.46±0.03	Cloete *et al.* (2006)
Fibre diameter (FD)	0.26±0.02	0.21±0.02	-	Cloete *et al.* (1998)
	0.15	0.13	-	Safari *et al.* (2005)
	0.26±0.08	-	0.18±0.05	Cloete *et al.* (2006)
	0.24±0.06	0.11±0.01	-	Olivier *et al.* (2006b)
Clean yield (CY)	0.16±0.02	0.02±0.02	-	Cloete *et al.* (1998)
	0.00	0.02	-	Safari *et al.* (2005)
Staple length (SL)	0.38±0.03	0.21±0.02	-	Cloete *et al.* (1998)
	0.01	0.10	-	Safari *et al.* (2005)
	0.20±0.06	0.13±0.02	-	Olivier *et al.* (2006b)
Staple strength (SS)	-0.11	0.04	-	Safari *et al.* (2005)
CV of fibre diameter (CVFD)	-0.17	-	-	Cloete *et al.* (2002b)

SE = standard error, CV of fibre diameter = coefficient of variation of fibre diameter, r_g =genetic correlation, r_e = environmental correlation, r_p = phenotypic correlation and r_m = maternal correlation

2.4.3.1.2 Greasy fleece weight (GFW) and other traits

Very high and positive genetic (0.86 to 0.98) and phenotypic (0.45 to 0.91) correlations were reported between GFW and CFW in the literature (Table 2.6). Corresponding r_e estimates (0.91 to 0.92) were also very high (Table 2.6). A maternal genetic correlation (r_m) of 0.98 was estimated between GFW and CFW on Australian fine-wool Merinos (Asadi Fozi *et al.*, 2005). GFW was negatively related to CY at both the genetic and phenotypic levels in all previous studies. An exception was a positive relationship reported by Swan *et al.* (1995) for Australian Merinos. None of literature cited reported significant corresponding r_e estimates. Unfavourable genetic and phenotypic correlations between GFW and FD were reported for various sheep breeds (Table 2.6).

Table 2.6 Literature values on the genetic (r_g), environmental (r_e), phenotypic (r_p) and maternal (r_m) correlations (±SE) between GFW and other objectively measured traits

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**(r_m)**	**Reference**
Greasy fleece weight (GFW) X					
Clean fleece weight (CFW)	0.87±0.03	0.90±0.01	0.92±0.01	-	Cloete *et al*. (2004b)
	0.91	0.91	-	0.98	Asadi Fozi *et al*. (2005)
	0.86	0.90	-	-	Safari *et al*. (2005)
	0.98±0.01	-	0.93±0.01	-	Cloete *et al*. (2006)
Clean yield (CY)	-0.07±0.10	-0.03±0.03	0.00±0.06	-	Cloete *et al*. (2004b)
	-0.14	-0.04	-	-	Safari *et al*. (2005)
	0.27 ± 0.12	0.21±0.04	-	-	Mortimer & Atkins (1989)
Fibre diameter (FD)	0.36	0.31	-	-	Safari *et al*. (2005)
	0.27±0.06	-	0.46±0.02	-	Cloete *et al*. (2006a)
Staple length (SL)	0.21±0.16	0.28±0.04	-	-	Mortimer & Atkins (1989)
	0.31	0.37	-	-	Swan *et al*. (1995)
	0.45	-	0.21	-	Hanford *et al*. (2005)
	0.44	0.32	-	-	Safari *et al*. (2005)
	0.65±0.03	0.50±0.02	-	-	Gizaw *et al*. (2006)
Staple strength (SS)	-0.06	0.09	-	-	Swan *et al*. (1995)
	0.16	0.19	-	-	Safari *et al*. (2005)
	0.18±0.12	-	0.29±0.03	-	Cloete *et al*. (2006)
CV of fibre diameter (CVFD)	-0.11	-0.04	-	-	Swan *et al*. (1995)
	0.09	0.36	-	-	Safari *et al*. (2005)
	0.12±0.08	-	-0.09±0.03	-	Cloete *et al*. (2006a)
SD of fibre diameter (SDFD)	0.11-0.25	0.09-0.15	-	-	Safari *et al*. (2005)

SD of fibre diameter = Standard deviation of fibre diameter, see other abbreviations in **Table 2.5**

Corresponding values of r_e were also unfavourable (Cloete *et al*., 2004b & 2006), indicating that an environment suitable for promoting wool weight would also lead to broader fibres. According to a literature survey, SL and SS were positively correlated to GFW at genetic, phenotypic and environmental levels. Only Swan *et al*. (1995) estimated a negative but very low r_g of -0.06 between GFW and SS. Furthermore, research showed that CVFD and SDFD were positively related to GFW with the exception of genetic and phenotypic correlations derived by Swan *et al.* (1995) on Australian Merino sheep, as well as a negative r_e derived from mature ewes at Elsenburg (Cloete *et al.*, 2006a).

2.4.3.1.3 Clean fleece weight (CFW) and other traits

Previous studies reported favourable and moderate genetic and phenotypic correlations between CFW and CY (Table 2.7). On the contrary, Naidoo & Cloete (2006) reported an unfavourable and moderate (-0.19) r_g between CFW and CY. Corresponding r_e were moderate and positive ranging from 0.24 to 0.36 (Table 2.7). Genetic relationships between CFW and FD were unfavourably for various sheep breeds (from 0.06 to 0.45), with the highest unfavourable r_g reported in Australian Merinos (Table 2.7). The r_p between CFW and FD were also unfavourable and ranged from 0.15 to 0.56. Information of r_e between CFW and FD was only found for South African Merino sheep. It ranged from 0.18 to 0.42 (Table 2.7).

Favourable r_g estimates for CFW with SL and SS were reported for various sheep breeds. Considering the r_g between CFW and SS, Swan *et al.* (1995) and Greeff *et al.* (1995) reported a very low r_g of 0.03 for Australian Merinos. Other studies reported r_g estimates that ranged from 0.23 to 0.70 between CFW and SL (Table 2.7). The range between CFW and SS was 0.20 to 0.42 in the literature cited (Table 2.7). The r_p for CFW with SL and SS were also moderate and positive.

Safari *et al.* (2005) derived an unfavourable and moderate r_g of 0.19 between CFW and CVFD from literature values. Similar estimates of 0.14 and 0.13 were reported for Elsenburg mature ewes (Cloete *et al.*, 2006a; Naidoo & Cloete, 2006). However, favourable and moderate r_g estimates were derived for some Australian Merino flocks (Greeff *et al.*, 1995; Swan *et al.*, 1995). The corresponding estimates for r_p were negative (Table 2.7). Environmental correlations of 0.01 and -0.13 between CFW and CVFD were estimated for mature ewes at Elsenburg (Cloete *et al.*, 2006; Naidoo & Cloete, 2006). According to a literature survey (Safari *et al.*, 2005), SDFD and CFW were positively related at both the genetic and phenotypic levels. Information on the sign and magnitude of r_e was lacking from literature for these traits.

Table 2.7 Literature values on the genetic (r_g) environmental (r_e) and phenotypic (r_p) correlations (±SE) estimates between CFW and other objectively measured traits

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**Reference**
Clean fleece weight X				
Clean yield	0.38	0.37	-	Safari *et al*. (2005)
	-0.19	-	0.30	Naidoo & Cloete (2006)
Fibre diameter	0.28	0.25	-	Safari *et al*. (2005)
	0.15	-	-	Swanepoel *et al*. (2005)
	0.36±0.07	-	0.27±0.03	Cloete *et al.* (2005)
	0.35	-	0.42	Cloete *et al.* (2006)
	0.35	-	0.42	Naidoo & Cloete (2006)
	0.17±0.06	0.17±0.02	-	Olivier *et al.* (2006b)
	0.14±0.02	0.18±0.00	-	Van Wyk *et al.* (2006)
	0.20	0.25	-	Olivier & Cloete (2007)
Staple length	0.23±0.15	0.36±0.04	-	Mortimer & Atkins (1989)
	0.46	-	-	Iman *et al*. (1992)
	0.24-0.51	0.28-0.39	-	Greeff *et al*. (1995)
	0.42	0.16	-	Swan *et al*. (1995)
	0.24±0.03	0.21±0.02	-	Cloete *et al*. (1998)
	0.50-0.70	-	-	Bromley *et al.* (2000)
	0.36	0.33	-	Safari *et al*. (2005)
	0.51±0.05	0.36±0.02	-	Olivier *et al.* (2006)
	0.23	0.29	-	Olivier & Cloete (2007)
Staple strength	0.03-0.42	0.03-0.22	-	Greeff *et al*. (1995)
	0.03	0.02	-	Swan *et al*. (1995)
	0.20	0.18	-	Safari *et al*. (2005)
	0.32±0.13	-	0.32±0.04	Cloete *et al.* (2006)
	0.34	-	0.31	Naidoo & Cloete (2006)
CV of fibre diameter	-0.21-0.38	-0.02- -0.16	-	Greeff *et al*. (1995)
	-0.18	-0.06	-	Swan *et al*. (1995)
	0.19	-0.04	-	Safari *et al*. (2005)
	0.14±0.09	-	0.01±0.03	Cloete *et al.* (2006)
	0.13	-	-0.13	Naidoo & Cloete (2006)
SD of fibre diameter	0.10-0.49	-0.01-0.19	-	Greeff *et al*. (1995)
	0.05	0.04	-	Swan *et al*. (1995)
	0.22	0.10	-	Safari *et al*. (2005)

See **Table 2.5** and **2.6** for abbreviations

2.4.3.1.4 Fibre diameter (FD) and other traits

According to a review of the literature, FD was unfavourably related to SL at both the genetic and phenotypic levels (Table 2.8), with exceptions of a very low favourable r_g reported for the Cradock fine-wool Merino flock (Olivier *et al.*, 2006b) and Australian mature ewes (Greeff *et al.*, 1995). The only estimate of r_e between FD and SL found from literature was moderate and positive (Naidoo & Cloete, 2006). The relationship between FD and SS was unfavourable at both the genetic and phenotypic levels (Table 2.8). The only exception was a low and favourable r_g (Greeff *et al.*, 1995) reported for Australian ram hoggets. Positive and moderate estimates of r_e of 0.26 and 0.28 were reported for the Elsenburg Merino resource flock using a mature ewe data set (Cloete *et al.*, 2006; Naidoo & Cloete, 2006).

Safari *et al.* (2005) derived an unfavourable but very low weighted mean r_g of 0.04 between FD and CY from literature values. Similar unfavourable albeit higher r_g estimates of 0.34 and 0.34 were reported for Australian Merino and South African Mutton Merinos (Mortimer & Atkins, 1989; Cloete *et al.*, 2004b). Other studies reported low and favourable r_g estimates that ranged from -0.01 to -0.08 (Table 2.8). While Safari *et al.* (2005) derived very low and positive r_p weighted mean estimates between FD and CY, Cloete *et al.* (2004b) reported a moderate and positive correlation of 0.13 for South African mutton Merino yearlings. An estimate of -0.12 was also reported for the Tygerhoek Merino resource flock (Cloete *et al.*, 1998a). Environmental correlations of -0.20 and 0.21 were reported between FD and CY for yearling South African Mutton Merinos and Elsenburg mature ewes respectively (Cloete *et al.* (2004b ; Naidoo & Cloete, 2006).

Of the genetic and phenotypic correlations reported between FD and CVFD from literature cited, Swan *et al.* (1995) reported an unfavourarable r_g of 0.05 on Merinos while Notter *et al.* (2007) reported an unfavourable r_p of 0.06 for the Targhee breed. Corresponding r_e estimates of -0.11 and -0.16 were also reported in the literature for mature Merino ewes (Cloete *et al.*, 2006; Naidoo & Cloete, 2006). FD was positively related to SDFD at the genetic and phenotypic levels (Table 2.8). No r_e estimates between FD and SS could be found in the literature.

Table 2.8 Literature values on the genetic (r_g) environmental (r_e) and phenotypic (r_p) correlations (±SE) between FD and other objectively measured traits

Trait	(r_g)	(r_p)	(r_e)	Reference
Fibre diameter X				
Staple length (SL)	0.16±0.14	0.09±0.05	-	Mortimer & Atkins (1989)
	-0.05-0.44	0.11-0.26	-	Greeff *et al*. (1995)
	0.16	0.16	-	Swan *et al*. (1995)
	0.34±0.03	0.13±0.02	-	Cloete *et al*. (1998)
	0.19	0.19	-	Safari *et al*. (2005)
	0.24	-	0.11	Naidoo & Cloete (2006)
	-0.02±0.06	0.02±0.02	-	Olivier *et al*. (2006)
	0.16	0.22	-	Olivier & Cloete (2007)
Staple strength (SS)	-0.07-0.46	0.17-0.32	-	Greeff *et al*. (1995)
	0.08	0.02	-	Swan *et al*. (1995)
	0.37	0.23	-	Safari *et al*. (2005)
	0.44±0.11	-	0.26±0.03	Cloete *et al*. (2006)
	0.46	-	0.28	Naidoo & Cloete (2006)
Clean yield (CY)	0.34±0.11	-0.02±0.04	-	Mortimer & Atkins (1989)
	-0.08±0.17	0.02±0.03	-	Lewer *et al*. (1994)
	-0.01±0.03	-0.12±0.02	-	Cloete *et al*. (1998)
	0.33 ± 0.07	0.13±0.03	-0.20±0.06	Cloete *et al*. (2004b)
	0.04	0.01	-	Safari *et al*. (2005)
	-0.06	-	0.21	Naidoo & Cloete (2006)
CV of fibre diameter (CVFD)	-0.03- -0.22	-0.11- -0.23	-	Greeff *et al*. (1995)
	0.05	-0.13	-	Swan *et al*. (1995)
	-0.10	-0.09	-	Safari *et al*. (2005)
	-0.12±0.07	-	-0.11±0.03	Cloete *et al*. (2006)
	-0.11	-	-0.16	Naidoo & Cloete (2006)
	-	0.06	-	Notter *et al*. (2007)
SD of fibre diameter (SDFD)	0.42-0.55	0.32-0.47	-	Greeff *et al*. (1995)
	0.14	0.14	-	Swan *et al*. (1995)
	0.43	0.40	-	Safari *et al*. (2005)
	-	0.60	-	Notter *et al*. (2007)

See **Table 2.5** and **2.6** for abbreviations

2.4.3.1.5 Clean yield (CY) and other traits

Favourable r_g estimates for CY with SS and SL were reported in the majority of previous studies (Table 2.9). The only exception was an unfavourable correlation (-0.18) between CY and SL as estimated from mature ewes maintained at the Elsenburg research farm (Naidoo & Cloete, 2006). At the phenotypic level, CY was favourably related to SL and SS. Environmental correlations of 0.03 and 0.15 were estimated for CY with SL and SS respectively. CVFD and SDFD were favourably related to CY at the genetic and phenotypic levels. The only corresponding r_e (-0.02) found was low and negative between CY and CVFD.

Table 2.9 Literature values on the genetic (r_g) environmental (r_e) and phenotypic (r_p) correlations (±SE) estimates between CY and other objectively measured traits

Trait	(r_g)	(r_p)	(r_e)	Reference
Clean yield X				
Staple length (SL)	0.14 ±0.15	0.21±0.05	-	Mortimer & Atkins (1989)
	0.30	0.25	-	Swan *et al*. (1995)
	0.34±0.02	0.16±0.02	-	Cloete *et al*. (1998)
	0.25	0.19	-	Safari *et al*. (2005)
	-0.18	-	0.03	Naidoo & Cloete (2006)
Staple strength (SS)	0.21	0.18	-	Swan *et al*. (1995)
	0.35	0.15	-	Safari *et al*. (2005)
	0.19	-	0.15	Naidoo & Cloete (2006)
CV of fibre diameter (CVFD)	-0.10	-0.08	-	Swan *et al*. (1995)
	-0.08	-0.13	-	Safari *et al*. (2005)
	-0.11	-	-0.02	Naidoo & Cloete (2006)
SD of fibre diameter (SDFD)	-0.08	-0.06	-	Swan *et al*. (1995)
	-	-0.13	-	Safari *et al*. (2005)

See **Table 2.5** and **2.6** for abbreviations

2.4.3.1.6 Correlations among staple length (SL), staple strength (SS), coefficient of variation (CVFD) and standard deviation of fibre diameter (SDFD)

Previous studies on Australian Merinos reported favourable genetic and phenotypic correlations that ranged from 0.08 to 0.80 between SL and SS (Greeff *et al.*, 1995).

However, Swan *et al.* (1995) reported an unfavourable estimate of -0.16 for a fine-wool Australian Merino resource flock. Safari *et al.* (2005) derived a weighted mean estimate of 0.05 from literature values in their comprehensive review. Naidoo & Cloete (2006) obtained an estimate of -0.42 for mature ewes at Elsenburg. Corresponding values for r_p were positive with few exceptions (Table 2.10).

Table 2.10 Literature values on the genetic (r_g) environmental (r_e) and phenotypic (r_p) correlations (± SE) estimates among staple length (SL), staple strength (SS), coefficient of variation of fibre diameter (CVFD) and standard deviation of fibre diameter (SDFD)

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**Reference**
Staple length X				
Staple strength (SS)	0.08-0.80	-0.12-0.21	-	Greeff *et al.* (1995)
	-0.16	-0.03	-	Swan *et al.* (1995)
	0.05	0.07	-	Safari *et al.* (2005)
	-0.42	-	-0.04	Naidoo & Cloete (2006)
CV of fibre diameter (CVFD)	-0.54-0.09	-0.21- -0.09	-	Greeff *et al.* (1995)
	-0.24	-0.08	-	Swan *et al.* (1995)
	0.37	-0.12	-	Safari *et al.* (2005)
	-0.38	-	-0.04	Naidoo & Cloete (2006)
	-	-0.06	-	Notter *et al.* (2007)
SD of fibre diameter (SDFD)	-0.34-0.02	-0.17-0.06	-	Greeff *et al.* (1995)
	-0.02	0.01	-	Swan *et al.* (1995)
Staple strength X				
CV of fibre diameter (CVFD)	-0.82- -0.46	-0.50- -0.36	-	Greeff *et al.* (1995)
	-0.78	-0.29	-	Swan *et al.* (1995)
	-0.52	-0.38	-	Safari *et al.* (2005)
	-0.37	-	-0.16	Naidoo & Cloete (2006)
SD of fibre diameter (SDFD)	-0.74- -0.13	-0.29- -0.11	-	Greeff *et al.* (1995)
	-0.37	-0.26	-	Swan *et al.* (1995)
CV of fibre diameter X				
SD of fibre diameter (SDFD)	0.70-0.87	0.76-0.84	-	Greeff *et al.* (1995)
	0.83	0.70	-	Swan *et al.* (1995)
	0.76	0.82	-	Safari *et al.* (2005)
	-	0.83	-	Notter *et al.* (2007)

See **Table 2.5** and **2.6** for abbreviations

Only one estimate of the r_e between SL and SS of -0.04 was reported by Naidoo & Cloete (2006). In general, favourable genetic and phenotypic correlations were mostly reported between SL and CVFD (Table 2.10). However, Safari *et al.* (2005) derived an unfavourable weighted mean r_g estimate of 0.37 between SL and CVFD. A corresponding r_e of -0.04 was derived from data recorded on mature ewes (Naidoo & Cloete, 2006).

Studies on Australian Merinos found moderate to very high genetic and phenotypic relationships between SS and CVFD (Table 2.10). The weighted means derived for wool sheep by Safari *et al.* (2005) were -0.52 and -0.38 respectively. Moreover, Naidoo & Cloete (2006) estimated a r_g value of -0.37 for mature South African Merinos. A comparable r_e of -0.16 was also reported in the literature (Naidoo & Cloete, 2006). SS was favourably related to SDFD at the genetic and phenotypic levels (Table 2.10). Safari *et al.* (2005) reported that the two measures of FD (SDFD and CVFD) were highly correlated. The genetic and phenotypic correlations between these traits were derived at 0.76 and 0.82 respectively. Notter *et al.* (2007) also reported a high and positive r_p of 0.83 between CVFD and SDFD.

2.4.3.2 Subjectively assessed wool traits

Correlations among subjective wool traits are presented in Table 2.11. PIGM was not related to any of the other subjective wool traits (Snyman & Olivier, 2002a) at all levels estimated, while FACE was significantly and favourably related to SOFT only. Snyman & Olivier (2002a) also reported generally moderate to high genetic and phenotypic correlations among subjectively assessed wool traits with the exception of the relationships between DENS and EVEN where the derived correlations were negligible and/or very low at respectively 0.02±0.12 and 0.05±0.02. Higher and favourable r_g estimates among SOFT, CRIM and EVEN (Snyman & Olivier, 2002a) suggested that these traits are largely influenced by a similar set of genes. Corresponding r_p estimates were moderate and favourable. However, SOFT was unfavourably related to DENS and CBEL at both the genetic and phenotypic levels in Afrino sheep. At -0.61 and -0.67, CRIM was highly unfavourably related to DENS and CBEL at the genetic level respectively. Corresponding r_p were also negative.

Table 2.11 Literature values on the genetic (r_g) and phenotypic (r_p) correlation (±SE) estimates among subjectively assessed wool traits

Trait	**(r_g)**	**(r_p)**	**Reference**
Pigmentation (PIGM) X			
Softness of face (FACE)	0.10±0.09	0.05±0.02	Snyman & Olivier (2002a)
Softness of fleece (SOFT)	-0.09±0.07	0.00±0.02	Snyman & Olivier (2002a)
Crimp definition (CRIM)	-0.05±0.07	0.03±0.02	Snyman & Olivier (2002a)
Density of fleece (DENS)	-0.03±0.09	-0.02±0.02	Snyman & Olivier (2002a)
Evenness of fleece (EVEN)	0.07±0.10	0.01±0.02	Snyman & Olivier (2002a)
Creeping belly (CBEL)	0.09±0.07	0.00±0.02	Snyman & Olivier (2002a)
Softness of face (FACE) X			
Softness of fleece (SOFT)	0.20±0.09	0.11±0.02	Snyman & Olivier (2002a)
Crimp definition CRIM)	0.05±0.10	0.04±0.02	Snyman & Olivier (2002a)
Density of fleece (DENS)	-0.05±0.11	-0.05±0.02	Snyman & Olivier (2002a)
Evenness of fleece (EVEN)	0.18±0.12	0.04±0.02	Snyman & Olivier (2002a)
Creeping belly (CBEL)	0.03±0.09	0.00±0.02	Snyman & Olivier (2002a)
Softness of fleece (SOFT) X			
Crimp definition (CRIM)	0.80±0.03	0.62±0.01	Snyman & Olivier (2002a)
Density of fleece (DENS)	-0.64±0.06	-0.40±0.02	Snyman & Olivier (2002a)
Evenness of fleece (EVEN)	0.81±0.05	0.32±0.02	Snyman & Olivier (2002a)
Creeping belly (CBEL)	-0.52±0.05	-0.35±0.02	Snyman & Olivier (2002a)
Crimp definition (CRIM) X			
Density of fleece (DENS)	-0.61±0.07	-0.36±0.02	Snyman & Olivier (2002a)
Evenness of fleece (EVEN)	0.62±0.07	0.40±0.02	Snyman & Olivier (2002a)
Creeping belly (CBEL)	-0.67±0.05	-0.45±0.02	Snyman & Olivier (2002a)
Density of fleece (DENS) X			
Evenness of fleece (EVEN)	0.02±0.12	0.05±0.02	Snyman & Olivier (2002a)
Creeping belly (CBEL)	0.51±0.07	0.31±0.02	Snyman & Olivier (2002a)
Evenness of fleece (EVEN) X			
Creeping belly (CBEL)	-0.27±0.10	-0.15	Snyman & Olivier (2002a)
Wool quality (QUAL) X			
Variation over fleece (VAR)	0.43±0.06	0.34±0.02	Oliver *et al*. (2006b)
Staple formation (STAPL)	-0.46±0.06	-0.26±0.07	Oliver *et al*. (2006b)
Variation over fleece X			
Staple formation (STAPL)	-0.51±0.07	0.20±0.02	Oliver *et al*. (2006b)

See **Table 2.5** for parameter symbols

The relationships between CBEL and DENS were positive, while CBEL was negatively related to EVEN. According to Olivier *et al.* (2006b), QUAL was positively related to VAR and unfavourably related to STAPL at all levels. The relationship between VAR and STAPL was negative at the genetic level and positive at the phenotypic level. Information on environmental correlations is lacking.

2.4.3.3 Subjectively assessed conformation traits

A number of correlations among subjective conformation traits are reported by Snyman & Olivier (2002a) for Afrino sheep and by Olivier *et al*. (2006b) for Cradock fine-wool Merinos. Most of these correlations were associated with high standard errors, and therefore not significant (>twice the corresponding standard error).

Table 2.12 Literature values of the genetic (r_g) and phenotypic (r_p) correlation (±SE) estimates among subjectively assessed conformation traits

Trait	(r_g)	(r_p)	Reference
General head formation (GEN) X			
Front quarters (FQ)	0.80±0.06	0.45±0.02	Snyman & Olivier (2002a)
Top line (TOPL)	0.33±0.18	0.11±0.02	Snyman & Olivier (2002a)
Hocks (HOCKS)	0.42±0.09	0.15±0.02	Snyman & Olivier (2002a)
Front pasterns (FPAS)	0.15±0.12	0.04±0.02	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	0.14±0.16	0.05±0.02	Snyman & Olivier (2002a)
Front quarters X			
Top line (TOPL)	0.53±0.19	0.11±0.02	Snyman & Olivier (2002a)
Hocks (HOCKS)	0.65±0.09	0.14±0.02	Snyman & Olivier (2002a)
Front pasterns (FPAS)	-0.04±0.13	0.04±0.02	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	-0.18±0.16	0.01±0.02	Snyman & Olivier (2002a)
General body conformation (CON)	0.89±0.02	0.72±0.02	Olivier *et al.* (2006a)
Top line X			
Hocks (HOCKS)	0.64±0.16	0.19±0.02	Snyman & Olivier (2002a)
Front pasterns (FPAS)	0.18±0.20	0.04±0.02	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	0.10±0.25	0.00±0.02	Snyman & Olivier (2002a)
Hocks X			
Front pasterns (FPAS)	0.02±0.10	0.01±0.02	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	0.00±0.14	0.03±0.02	Snyman & Olivier (2002a)

See **Table 2.5** for parameter symbols

It was evident from the study by Snyman & Olivier (2002a) that GEN and FQ are largely affected by pleotropic set of genes, as suggested by a very high r_g of 0.80 between these traits. GEN was also favourably related to TOPL and HOCKS and not significantly related to pastern score (Snyman & Olivier, 2002a). Corresponding estimates of r_p were positive and ranged from 0.04 to 0.45. FQ was favourably and highly related to TOPL and HOCKS (Snyman & Olivier, 2002a). The corresponding estimate of r_g with CON was favourable and very high at 0.89 (Olivier *et al*., 2006a). The r_p between FQ and CON was also very high at 0.72 (Olivier *et al*., 2006a) and moderate with TOPL and HOCKS (Snyman & Olivier, 2002a). At 0.64, TOPL was positive and highly related to HOCKS at the genetic level. The r_p between TOPL and HOCKS was 0.19 (Snyman & Olivier, 2002a). No r_e and r_m correlation estimates among subjective conformation traits could be found in the literature.

2.4.3.4 Objective traits and subjective wool traits

Correlations among objective and subjective wool traits are presented in Tables 2.13 to 2.16.

2.4.3.4.1 Greasy fleece weight (GFW), clean fleece weight (CFW) and clean yield (CY) with subjective wool traits

Correlations for fleece weights and CY with subjective wool traits are presented in Table 2.13. Positive correlations between COL and GFW were estimated for Australian Merinos (Brown *et al.,* 2006). However, Lewer *et al.* (1995) reported a negative relationship between COL and GFW for another Australian Merino resource flock, although with a higher standard error. Among the subjective wool traits, QUAL, STAPL and BANDP were favourably related to CFW at all levels in South African Merinos (Naidoo *et al.,* 2004; Olivier *et al*., 2006b) while DENS was favourably related to CFW in Carnarvon Afrino sheep (Snyman & Olivier, 2002a).

The only noteworthy unfavourably relationship between CFW and subjective wool traits was with CBEL at the genetic (0.53) and the phenotypic (0.29) levels in Afrino sheep (Snyman & Olivier, 2002a). Naidoo *et al.* (2004) reported favourable r_g estimates for CY with QUAL, COL, STAPL and BANDP and a negative r_g with yolk.

Table 2.13 Genetic (r_g) environmental (r_e) and phenotypic (r_p) correlations (±SE) for greasy (GFW) and clean (CFW) fleece weights with subjective wool traits

Trait	r_g	r_p	r_e	Reference
Greasy fleece weight (GFW) X				
FCS	-0.11±0.19	-0.01±0.03	-	Lewer *et al.* (1995)
COL	-0.16±0.23	-0.02±0.02	-	Lewer *et al.* (1995)
COL	0.29-0.34±0.07	0.11-0.12±0.02	-	Brown *et al.* (2006)
Clean fleece weight (CFW) X				
QUAL	0.13±0.09	0.08±0.02	0.05±0.04	Naidoo *et al.* (2004)
	0.40±0.06	0.22±0.02	-	Olivier *et al.* (2006b)
EVEN	-0.02±0.09	0.00±0.02	-	Snyman & Olivier (2002a)
ROC	-0.05±0.11	-0.05±0.02	-0.06±0.03	Naidoo *et al.* (2004)
COL	-0.44	-	-	James *et al.* (1990)
	0.11±0.20	0.06±0.02	-	Lewer *et al.* (1995)
	-0.22	-0.17	-	Swan *et al.* (1997)
	-0.03±0.09	-0.04±0.02	-0.04±0.04	Naidoo *et al.*, (2004)
YOLK	0.21±0.10	0.17±0.02	0.16±0.04	Naidoo *et al.* (2004)
STAPL	0.52±0.10	0.27±0.02	0.21±0.03	Naidoo *et al.* (2004)
BANDP	0.51±0.08	0.40±0.02	0.34±0.03	Naidoo *et al.* (2004)
	0.57±0.06	0.37±0.02	-	Olivier *et al.* (2006b)
SOFT	0.02±0.07	0.00±0.02	-	Snyman & Olivier (2002a)
DENS	0.22±0.08	0.13±0.02	-	Snyman & Olivier (2002a)
CBEL	0.53±0.05	0.29±0.02	-	Snyman & Olivier (2002a)
FCS	-0.12±0.20	-0.04±0.03	-	Lewer *et al.* (1995)
PIGM	0.08±0.06	0.01±0.02	-	Snyman & Olivier (2002a)
Clean yield (CY) X				
QUAL	0.30±0.07	0.18±0.02	0.10±0.05	Naidoo *et al.* (2004)
EVEN	-0.22±0.09	-0.06±0.02	-	Snyman & Olivier (2002a)
ROC	0.13±0.09	0.07±0.02	0.05±0.04	Naidoo *et al.* (2004)
COL	0.46±0.18	-0.07±0.02	-	Lewer *et al.* (1995)
	0.53±0.06	0.33±0.02	0.14±0.04	Naidoo *et al.* (2004)
YOLK	-0.45±0.07	-0.26±0.02	-0.15±0.05	Naidoo *et al.* (2004)
STAPL	0.32±0.11	0.09±0.02	-0.01±0.04	Naidoo *et al.* (2004)
BANDP	0.24±0.08	0.12±0.02	0.06±0.05	Naidoo *et al.*(2004)
FCS	0.00±0.17	-0.05±0.03	-	Lewer *et al.* (1995)
SOFT	0.14±0.07	0.09±0.02	-	Snyman & Olivier (2002a)
DENS	-0.04±0.09	-0.09±0.02	-	Snyman & Olivier (2002a)
CBEL	0.41±0.06	0.19±0.02	-	Snyman & Olivier (2002a)
PIGM	-0.05±0.06	0.01±0.02	-	Snyman & Olivier (2002a)

See **Table 2.2** and **2.5** for abbreviations

Furthermore, Snyman & Olivier (2002a) reported generally negative r_g estimates between CY and subjective wool traits, with the exception of the r_g for CY with SOFT and CBEL. Moreover, Lewer *et al.* (1995) reported nonsignificant correlations between CY and the subjective wool traits with the only significant r_g of 0.46 between CY and COL. Environmental correlation estimates for CY with QUAL and COL were positive, while CY was negatively related to YOLK on the environmental level (Naidoo *et al*., 2004).

2.4.3.4.2 Staple length (SL) and subjective wool traits

Staple length is one of the factors that affect wool quality (Olivier & Roux, 2007). Reis & Sahlu (1994) indicated SL as one of the functions of wool quality. Relationships between SL and the subjective wool traits are presented in Table 2.14.

Table 2.14 Genetic (r_g) environmental (r_e) and phenotypic (r_p) correlation (±SE) estimates between staple length (SL) and subjectively assessed wool traits

Trait	r_g	r_p	r_e	Reference
Staple length (SL) X				
QUAL	0.15±0.30	0.21±0.02	0.01±0.03	Naidoo *et al*., (2004)
	0.31±0.06	0.20±0.02	-	Olivier *et al.* (2006b)
ROC	-0.19±0.10	-0.09±0.02	-	Snyman & Olivier (2002a)
	0.24±0.36	0.01±0.02	-0.01±0.03	Naidoo *et al*., (2004)
COL	0.05±0.30	0.03±0.02	0.04±0.03	Naidoo *et al*., (2004)
YOLK	-0.34±0.37	-0.04±0.02	-0.02±0.03	Naidoo *et al*., (2004)
STAPL	-0.13±0.41	0.04±0.02	0.05±0.03	Naidoo *et al*., (2004)
	0.02±0.07	0.02±0.02	-	Olivier *et al.* (2006b)
BANDP	0.40±0.32	0.09±0.02	0.07±0.03	Naidoo *et al*., (2004)
SOFT	0.00±0.09	0.05±0.02	-	Snyman & Olivier (2002a)
CRIM	-0.09±0.09	0.00±0.02	-	Snyman & Olivier (2002a)
DENS	-0.38±0.09	-0.16±0.02	-	Snyman & Olivier (2002a)
CBEL	0.27±0.08	0.19±0.02	-	Snyman & Olivier (2002a)
PIGM	0.04±0.08	0.00±0.02	-	Snyman & Olivier (2002a)

See **Table 2.2** and **2.5** for abbreviations

Naidoo *et al.* (2004) reported nonsignificant correlations between SL and subjective wool traits. However, Olivier *et al.* (2006b) reported favourable and moderate estimates of r_g between SL and QUAL. On the other hand, an unfavourable relationship was estimated between SL and CBEL in Afrino sheep (Snyman & Olivier, 2002a). The corresponding correlation between SL and CRIMP was negative (Snyman & Olivier, 2002a) in Carnarvon Afrino sheep. Environmental (Naidoo *et al.,* 2004) and phenotypic correlations between subjective and objective wool traits were mostly low/or negligible (Table 2.14).

2.4.3.4.3 Fibre diameter (FD) and coefficient of variation of fibre diameter (CVFD) with subjective wool traits

Moderate to high r_g estimates for FD and CVFD with subjective wool traits are summarized in Table 2.15. Of the subjective traits, STAPL (Naidoo *et al.* 2004; Olivier *et al.*, 2006b) and BANDP (Naidoo *et al.* 2004) were unfavourably related to FD in South African Merino sheep. Snyman & Olivier (2002a) also reported an unfavourable r_g between FD and DENS.

The corresponding r_p estimates for FD with STAPL and BANDP in South African Merinos and between FD and DENS in South African Afrino sheep were also unfavourable. Naidoo *et al.* (2004) reported moderate and positive r_e estimates for FD with BANDP and STAPL. CVFD was favourably related to QUAL and ROC at both the phenotypic and genetic levels. The relationship between CVFD and STAPL was unfavourable (Naidoo *et al.*, 2004). Environmental correlations of CVFD were negative with QUAL, ROC and COL, and positive with YOLK (Naidoo *et al.*, 2004).

Table 2.15 Genetic (r_g), environmental (r_e) and phenotypic (r_p) correlations (±SE) for fibre diameter (FD) and coefficient of variation of fibre diameter (CVFD) with subjective wool traits

Trait	r_g	r_p	r_e	Reference
Fibre diameter (FD) X				
QUAL	-0.42±0.07	-0.23±0.02	-0.08±0.05	Naidoo *et al.* (2004)
	-0.47±0.05	-0.33±0.02	-	Olivier *et al.* (2006b)
ROC	-0.57±0.07	-0.26±0.02	-	Snyman & Olivier (2002a)
	-0.38±0.09	-0.21±0.02	-0.13±0.04	Naidoo *et al.* (2004)
COL	-0.49±0.18	0.18±0.02	-	Lewer *et al.* (1995)
	-0.10±0.07	-0.07±0.02	-0.06±0.05	Naidoo *et al.* (2004)
YOLK	-0.08±0.09	-0.02±0.02	0.03±0.04	Naidoo *et al.* (2004)
STAPL	0.60±0.08	0.31±0.02	0.23±0.04	Naidoo *et al.* (2004)
	0.63±0.05	0.38±0.02	-	Olivier *et al.* (2006a)
BANDP	0.31±0.08	0.23±0.02	0.20±0.04	Naidoo *et al.* (2004)
FCS	-0.24±0.15	-0.12±0.03	-	Lewer *et al.* (1995)
SOFT	-0.80±0.03	-0.50±0.02	-	Snyman & Olivier (2002a)
CRIM	-0.42±0.05	-0.31±0.02	-	Snyman & Olivier (2002a)
DENS	0.48±0.06	0.29±0.02	-	Snyman & Olivier (2002a)
CBEL	0.41±0.05	0.31±0.02	-	Snyman & Olivier (2002a)
PIGM	0.08±0.06	0.02±0.02	-	Snyman & Olivier (2002a)
Coefficient of variation of fibre diameter (CV) X				
QUAL	-0.50±0.06	-0.27±0.02	-0.12±0.04	Naidoo *et al.* (2004)
ROC	-0.58±0.08	-0.27±0.02	-0.14±0.04	Naidoo *et al.* (2004)
COL	-0.08±0.08	-0.10±0.02	-0.12±0.04	Naidoo *et al.* (2004)
YOLK	-0.07±0.09	0.03±0.02	0.10±0.04	Naidoo *et al.* (2004)
STAPL	0.45±0.10	0.16±0.02	0.06±0.04	Naidoo *et al.* (2004)
BANDP	0.02±0.09	-0.00±0.02	-0.01±0.04	Naidoo *et al.* (2004)

See **Table 2.2** and **2.5** for abbreviations

2.4.3.5 Objective wool and subjective conformation traits

Genetic, environmental and phenotypic correlations between objective and subjective conformation traits are presented in Tables 2.16 to 2.18. These correlations obtained from literature were estimated on South African and Australian Merino sheep. Snyman & Olivier (2002a) estimated genetic and phenotypic correlations on South African Afrino sheep.

2.4.3.5.1 Greasy fleece weight (GFW), clean fleece weight (CFW) and clean yield (CY) with subjective conformation traits

The genetic relationship between WS and fleece weights were negative and favourable for Western Australian sheep (Lewer *et al.*, 1995) although with high standard error (Table 2.16).

Table 2.16 Literature values on the genetic (r_g) environmental (r_e) and phenotypic (r_p) correlation (±SE) estimates for GFW, CFW and CY with subjective conformation traits

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**Reference**
Greasy fleece weight X				
Wrinkle score (WS)	-0.16- -0.35	-	-	Lewer *et al.* (1995)
Clean fleece weight X				
Wrinkle score (WS)	-0.18- -0.24	-0.14 – 0.17	-	Lewer *et al.* (1995)
Total fold score (TOT)	0.19±0.02	0.10±0.02	-	Cloete *et al.* (1998)
	0.27±0.09	-	0.19±0.04	Cloete *et al.* (2005)
	0.30±0.09	-	0.18±0.04	Cloete *et al.*(2006)
General head formation (GEN)	-0.18±0.08	0.07±0.02	-	Snyman & Olivier (2002a)
Front quarters (FQ)	-0.02±0.09	0.14±0.02	-	Snyman & Olivier (2002a)
	-0.11±0.06	0.05±0.02	-	Olivier *et al.* (2006b)
Top line (TOPL)	-0.25±0.17	0.03±0.02	-	Snyman & Olivier (2002a)
Hocks (HOCKS)	-0.45±0.07	-0.15±0.02	-	Snyman & Olivier (2002a)
Front pasterns (FPAS)	-0.11±0.09	-0.01±0.02	-	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	-0.09±0.13	0.00±0.02	-	Snyman & Olivier (2002a)
Clean yield X				
Wrinkle score (WS)	0.01- 0.28	0.12- 0.17	-	Lewer *et al.* (1995)
Total fold score (TOT)	-0.10±0.02	0.36±0.04	-	Cloete *et al.* (1998)
General head formation (GEN)	-0.07±0.08	-0.01±0.02	-	Snyman & Olivier (2002a)
Front quarters (FQ)	0.21±0.09	0.03±0.02	-	Snyman & Olivier (2002a)
Top line (TOPL)	-0.02±0.16	0.04±0.02	-	Snyman & Olivier (2002a)
Hocks (HOCKS)	-0.23±0.08	-0.09±0.02	-	Snyman & Olivier (2002a)
Front pasterns (FPAS)	0.09±0.09	0.01±0.02	-	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	0.09±0.13	0.03±0.02	-	Snyman & Olivier (2002a)

See **Table 2.5** for abbreviations

However, positive and moderate r_g estimates were reported for the Tygerhoek (Cloete *et al*., 1998a) and Elsenburg (Cloete *et al*., 2005 & 2006) Merino resource flocks. The positive correlations are unfavourable in this case, because the desired direction of change is downwards for total fold score. CFW was also unfavourably related to other subjectively assessed conformation traits in Merinos (Olivier *et al*., 2006b) and Afrino sheep (Snyman & Olivier, 2002a). The highest unfavourable relationship was estimated between CFW and HOCKS. Phenotypic correlations were positive for CFW with TOT, GEN and FQ, while negative correlations were estimated for CFW with WS and HOCKS. Among the subjectively assessed conformation traits, the only r_e estimate in the literature was for CFW with TOT at 0.18 and 0.19 for two studies on the Elsenburg Merino resource flock (Cloete *et al*., 2005; 2006). While Lewer *et al*. (1995) estimated an unfavourable r_g between CY and WS, Cloete *et al*. (1998) reported a favourable relationship at -0.10 between these traits (Table 2.16). The corresponding correlation of CY with HOCKS was also unfavourable and favourable with FQ. No estimates of r_e for CY with subjective conformation traits were found in the literature.

2.4.3.5.2 Fibre diameter (FD) and subjective conformation traits

Unfavourable r_g estimates were derived for FD with TOPL and with HOCKS on Afrino sheep (Snyman & Olivier, 2002a). Olivier *et al*. (2006b) also reported an unfavourable r_g between FD and FQ in the Cradock fine-wool Merino stud. Correlations with other subjective conformation traits were favourable although with high standard errors (Table 2.17). Environmental correlations between FD and subjectively assessed conformation traits are lacking in the literature.

Table 2.17 Literature values on the genetic (r_g), environmental (r_e) and phenotypic (r_p) correlation (±SE) estimates for fibre diameter (FD) with subjective conformation traits

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**Reference**
Fibre diameter X				
Wrinkle score (WS)	-0.22- -0.26	-0.21 - -0.25	-	Lewer *et al.* (1995)
Total fold score (TOT)	0.05±0.03	-0.02±0.04	-	Cloete *et al.* (1998)
	-0.07±0.07	-	-0.02±0.05	Cloete *et al.* (2005)
	-0.08±0.07	-	-0.02±0.05	Cloete *et al.* (2006)
General head formation (GEN)	-0.05±0.07	0.03±0.02	-	Snyman & Olivier (2002a)
Front quarters (FQ)	0.09±0.08	0.08±0.02	-	Snyman & Olivier (2002a)
	0.17±0.06	0.12±0.02	-	Olivier *et al.* (2006a)
Top line (TOPL)	0.33±0.16	0.06±0.02	-	Snyman & Olivier (2002a)
Hocks (HOCKS)	0.13±0.07	0.08±0.02	-	Snyman & Olivier (2002a)
Front pasterns (FPAS)	-0.14±0.09	-0.01±0.02	-	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	-0.23±0.12	-0.04±0.02	-	Snyman & Olivier (2002a)

See **Table 2.5** for abbreviations

2.4.3.5.3 Staple length (SL) and subjective conformation traits

Correlations between SL and subjectively assessed conformation traits are presented in Table 2.18. SL was favourably related to FQ (Olivier *et al*., 2006b) and TOPL (Snyman & Olivier, 2002a).

Table 2.18 Literature values on the genetic (r_g), environmental (r_e) and phenotypic (r_p) correlation (±SE) estimates between staple length (SL) and subjective conformation traits

Trait	**(r_g)**	**(r_p)**	**Reference**
Staple length X			
Total fold score (TOT)	-0.50±0.03	-0.08±0.02	Cloete *et al.* (1998a)
General head formation (GEN)	-0.05±0.10	0.07±0.02	Snyman & Olivier (2002a)
Front quarters (FQ)	-0.07±0.11	0.07±0.02	Snyman & Olivier (2002a)
	0.24±0.09	0.15±0.02	Olivier *et al.* (2006a)
Top line (TOPL)	0.34±0.17	0.02±0.02	Snyman & Olivier (2002a)
Hocks (HOCKS)	-0.20±0.09	-0.05±0.02	Snyman & Olivier (2002a)
Front pasterns (FPAS)	-0.29±0.11	0.00±0.02	Snyman & Olivier (2002a)
Hind pasterns (HPAS)	-0.26±0.14	0.00±0.02	Snyman & Olivier (2002a)

See **Table 2.5** for abbreviations

Corresponding r_g estimates with HOCKS, FPAS and HPAS were unfavourable. At the phenotypic level, SL was negatively related to TOT and HOCKS and positively related to FQ and GEN (Table 2.18). Information on r_e estimates between SL and subjective conformation traits was lacking in the literature.

2.4.3.5.4 Live weight and subjective traits

Estimates of genetic, phenotypic and environmental correlations between live weight and subjective conformation traits are presented in Table 2.19. Relationship of LW with GEN and FQ indicated these traits being largely depend on a similar set of genes, as suggested by a high r_g reported for Cradock fine-wool Merino sheep (Olivier *et al.*, 2006b). The r_g with TOT was favourable (Cloete *et al.*, 1998; Cloete *et al.*, 2005). The r_p for LW with subjective conformation traits were generally positive. The only r_e estimate found between LW and TOT in the literature was positive (Cloete *et al.*, 2005)

Table 2.19 Literature values on the genetic (r_g) environmental (r_e) and phenotypic (r_p) correlations (±SE) for live-weight with subjective wool and conformation traits

Trait	(r_g)	(r_p)	(r_e)	Reference
Live weight (LW)				
Wool quality (QUAL)	0.07±0.07	0.02±0.04	-	Olivier *et al.* (2006b)
Staple formation (STAPL)	0.00±0.07	0.11±0.02	-	Olivier *et al.* (2006b)
General body conformation (GEN)	0.81±0.03	0.46±0.02	-	Olivier *et al.* (2006b)
Front quarters (FQ)	0.67±0.04	0.60±0.01	-	Olivier *et al.* (2006b)
Total fold score TOT)	-0.24±0.04	0.19±0.02	-	Cloete *et al.* (1998)
	-0.26±0.08	-	0.12±0.05	Cloete *et al.* (2005)

See **Table 2.5** for abbreviations

2.4.3.6 Subjectively assessed wool and conformation traits

Published correlations between subjective wool and conformation traits are presented in Table 2.20. Many of the r_g estimates among these traits were low or negligible and therefore of no economic importance in Merino or Afrino sheep. The only r_g of significance between subjective wool and conformation traits in Australian Merino sheep were those between STAPL and TOT (-0.61) and between SOFT and HOCKS (0.46) (Gregory, 1982b). On the contrary, Snyman & Olivier (2002a) reported an unfavourable r_g between FACE and HOCKS in South African Afrino sheep. Moreover, SOFT and EVEN were also unfavourably related to FQ and HOCKS in Afrino sheep. The relationships between CBEL and subjective conformation traits were also unfavourable. Most of the r_p estimates between subjective wool and conformation traits were also not significant. The significant correlations ranged from -0.29 to 0.19. The r_e of significance estimated on Australian Merino sheep (Gregory, 1982b) were those between STAPL and TOT (-0.22) as well as for FACE with TOT (0.10) and HOCKS (0.08).

Table 2.20 Literature values on the genetic (r_g), environmental (r_e) and phenotypic (r_p) correlation (±SE) estimates between subjective wool and conformation traits

Trait	**(r_g)**	**(r_p)**	**(r_e)**	**Reference**
Wool quality (QUAL) X				
TOT	-0.20±0.13	-0.08±0.03	-0.04±0.07	Gregory (1982b)
HOCKS	-0.09±0.13	0.03±0.03	0.06±0.04	Gregory (1982b)
FQ	-0.04±0.06	0.01±0.02	-	Olivier *et al*. (2006b)
GEN	0.07±0.06	0.08±0.01	-	Olivier *et al*. (2006b)
Staple formation (STAPL)X				
TOT	-0.61±0.12	-0.29±0.03	-0.22±0.05	Gregory (1982b)
HOCKS	-0.24±0.15	0.00±0.03	0.01±0.03	Gregory (1982b)
FQ	0.02±0.07	0.10±0.02	-	Olivier *et al*. (2006b)
GEN	0.11±0.07	0.19±0.02	-	Olivier *et al*. (2006b)
Softness of face (FACE) X				
GEN	0.04±0.11	0.17±0.02	-	Snyman & Olivier (2002a)
FQ	-0.03±0.12	0.08±0.02	-	Snyman & Olivier (2002a)
TOPL	-0.14±0.21	0.01±0.02	-	Snyman & Olivier (2002a)
HOCKS	0.46±0.11	-0.04±0.02	0.08±0.03	Gregory (1982b)
	-0.43±0.09	-0.06±0.02	-	Snyman & Olivier (2002a)
FQ	0.06±0.12	0.02±0.02	-	Snyman & Olivier (2002a)
TOT	0.05±0.13	0.11±0.05	0.10±0.03	Gregory (1982b)
HPAS	-0.29±0.15	0.00±0.02	-	Snyman & Olivier (2002a)
Softness of fleece (SOFT) X				
GEN	-0.03±0.09	-0.01±0.02	-	Snyman & Olivier (2002a)
FQ	-0.24±0.09	-0.07±0.02	-	Snyman & Olivier (2002a)
TOPL	-0.35±0.19	-0.04±0.02	-	Snyman & Olivier (2002a)

Table 2.20 (continues)

HOCKS	-0.29±0.08	-0.09±0.02	-	Snyman & Olivier (2002a)
FPAS	-0.02±0.11	-0.01±0.02	-	Snyman & Olivier (2002a)
HPAS	0.14±0.14	-0.01±0.02	-	Snyman & Olivier (2002a)
Evenness of fleece (EVEN) X				
GEN	-0.15±0.12	-0.08±0.03	-	Snyman & Olivier (2002a)
FQ	-0.27±0.12	-0.11±0.02	-	Snyman & Olivier (2002a)
TOPL	-0.17±0.21	-0.05±0.02	-	Snyman & Olivier (2002a)
HOCKS	-0.23±0.10	-0.10±0.02	-	Snyman & Olivier (2002a)
FPAS	0.10±0.13	0.04±0.02	-	Snyman & Olivier (2002a)
HPAS	0.00±0.17	-0.03±0.02	-	Snyman & Olivier (2002a)
Creeping belly (CBEL) X				
GEN	-0.25±0.09	-0.06±0.02	-	Snyman & Olivier (2002a)
FQ	-0.23±0.09	0.00±0.02	-	Snyman & Olivier (2002a)
TOPL	-0.32±0.17	0.03±0.02	-	Snyman & Olivier (2002a)
HOCKS	-0.23±0.08	0.01±0.02	-	Snyman & Olivier (2002a)
FPAS	-0.25±0.10	-0.01±0.02	-	Snyman & Olivier (2002a)
HPAS	-0.26±0.13	-0.01±0.02	-	Snyman & Olivier (2002a)
Density of fleece (DENS) X				
GEN	0.00±0.11	0.05±0.02	-	Snyman & Olivier (2002a)
FQ	0.14±0.11	0.11±0.02	-	Snyman & Olivier (2002a)
TOPL	-0.18±0.22	0.01±0.02	-	Snyman & Olivier (2002a)
HOCKS	0.05±0.10	0.09±0.02	-	Snyman & Olivier (2002a)
FPAS	-0.08±0.13	0.02±0.02	-	Snyman & Olivier (2002a)
HPAS	-0.35±0.16	-0.03±0.02	-	Snyman & Olivier (2002a)
Pigmentation (PIGM) X				
GEN	0.12±0.08	0.09±0.02	-	Snyman & Olivier (2002a)
FQ	0.12±0.09	0.05±0.02	-	Snyman & Olivier (2002a)
TOPL	-0.02±0.17	0.03±0.02	-	Snyman & Olivier (2002a)
HOCKS	-0.04±0.08	-0.02±0.02	-	Snyman & Olivier (2002a)
FPAS	0.05±0.10	0.01±0.02	-	Snyman & Olivier (2002a)
HPAS	0.06±0.13	0.02±0.02	-	Snyman & Olivier (2002a)

See **Table 2.2** and **2.5** for abbreviations

2.5 Conclusions

A lot of research has been done on the estimation of genetic parameters in sheep. Most of these reports are included in the extensive and recent review of Safari *et al.* (2005). Apart from the work of Lewer *et al.* (1995), Brown *et al.* (2002a & b), Snyman *et al.* (2002a), Naidoo *et al.* (2004) and Olivier *et al.* (2006a & b) little has been done on the heritability estimates and correlations between objectively measured wool with subjectively assessed wool and conformation and live weight traits in sheep. These genetic parameters and correlations will be investigated in the present study on the Tygerhoek Merino resource flock.

CHAPTER 3

DATA AND ANALYSES

3.1 Experimental site

The experimental flock is maintained on the Tygerhoek experimental farm, near Riviersonderend in the Western Cape Province of South Africa. The experimental site is situated at latitude 33º 30' south and longitude 21º 11' east. The climate at the site is Mediterranean, with 60% of the average total precipitation of 426 mm being recorded between April and September. The climate at the site is mild with cool winters (average maximum temperatures of 17.8-18.7 ºC and average minimum temperatures of 5.0-6.0 ºC recorded between June and August) and mild summers (average maximum temperatures of 27.7-28.8 ºC and average minimum temperatures of 14.3-15.8 ºC recorded between December and January).

3.2 History of the Tygerhoek Merino flock

The origin and initial selection in the flock were first described by Heydenrych (1975) and Heydenrych *et al.* (1984). Subsequent analyses on animals from the flock involved studies on reproduction (Cloete, 1986) and early live weight as well as testicular size and reproduction (Duguma, 2002).

Selection of the Merino flock in the Tygerhoek experimental farm originally started with 800 ewes, ranging from 1.5 years to five years and 5.5 years (Heydenrych *et al.*, 1984). These ewes were divided into five equal groups, thus, from 1 to 5 by stratified sampling within age groups according to their wool production at 18 months of age. Breeding rams for group 1 and group 3 were selected on clean fleece weight. In addition to these, the rams had to have fibre diameter lower than the average of their contemporary group in the same selection group and not less than 9 crimps per 25mm. Group 2 and 4 rams were selected for a wider skin follicle ratio (S/F ratio) at three months of age, with no restriction on wool quality traits. Ewe replacements for groups

3 and 4 were selected on corrected 42-day body weight as an early selection criterion (Heydenrych *et al*., 1984). Therefore, the first experimental mating was done in November 1970 based on previously discussed criteria, where five breeding rams and three reserves were selected for each selection group. From 1971 onward, the best two 2.5-year-old rams were retained based on the original selection while three newly selected 1.5-year-old rams were added and three extra young rams were kept as reserves. Also, 33 replacement ewes were selected annually for each selection group to maintain flock size and a balanced age structure (Heydenrych *et al*., 1984).

The genetic control group (group 5) consisted of 160 ewes and 16 rams from 1969 to 1971. Rams for group 5 were selected at random. Each ram was therefore replaced by a son and used for one season only. Ewes in group 5 were replaced by a second daughter reaching a joining age. This was done to retain the same age structure as in the selection groups. During 1976, groups 1 & 3 and 2 & 4 were respectively pooled (combined to form one group), reduced to 150 ewes and each named group 1 and 2, based on preliminary results by Heydenrych (1975). Also in 1976, the control group was increased to 200 ewes and 20 rams.

In 1992, group 4 was re-introduced in Tygerhoek experimental farm. This selection line was introduced after having bred from control group rams at Elsenburg, using a wet and dry technique described by Fourie & Cloete (1993). In this group, male replacement animals were selected by using maternal ranking values on lamb weaned/ewe joined (Cloete & Scholtz, 1998). Ewes in this line have been culled on failure to lamb or rear at least one lamb per lambing opportunity since 1993.

The Tygerhoek Fine-wool line (group 6) was established in 1997. Cloete *et al.* (2001a) reported this line as being descended from a similar line maintained at the Cradock experimental farm (The Cradock Fine wool Merino stud, as described by Olivier *et al*., 1999). The foundation ewes for this stud were ewes with the finest clips and an above average live weight that were bought from Merino breeders throughout South Africa. The rams used for the initial matings were imported from Australia. Replacements of both sexes were subsequently selected on fibre diameter, live weight and conformation from within the flock (Olivier *et al*., 1999). Initially selection pressure was directed towards increased LW and CFW. It was from 1996 when the selection objectives were changed to an increased LW and reduced fibre diameter (Cloete *et al.*, 2007).

At Tygerhoek experimental farm, all selection lines were managed as one flock and ewes in all selection lines were mated during October-November to lamb during March-April of the following year (Cloete *et al.*, 2001a). Records of growth, reproduction, objective wool and subjective wool and conformation traits have been recorded in an attempt to evaluate the breeding objectives for the improvement of traits of economic importance in Merino sheep.

3.3 Data

Data utilized in this study were collected on the Tygerhoek Merino flock from 1989 and 2004 and consisted of records of 4 495 animals, the progeny of 449 sires and 1 831 dams. The pedigree records that were used have been collected between 1969 and 2004. In this data, four lines were represented, namely Group 1, Group 4, Group 5 and Group 6, as detailed above.

3.4 Traits analysed

Traits included in the analyses were classified as (i) live weight, (ii) objective wool traits, (iii) subjective wool traits and (iv) subjective conformation traits.

Live-weight was defined as the weight measured at 16months of age after shearing, without fasting (hogget weight).

Objective wool traits included were greasy fleece weight (GFW), clean fleece weight (CFW), clean yield (CY), fibre diameter (FD), staple length (SL) and staple strength (SS). Two measurements of the variability of FD were also included in the analysis namely standard deviation of FD (SDFD) and coefficient of variation of FD (CVFD). Greasy fleece weight was recorded at shearing in August-September each year, while the measures of quality were determined on a midrib wool sample taken from each animal at 14-16months of age. Information on GFW was combined with CY data to derive CFW.

Table 3.1 Linear scale for assessment of subjectively assessed fleece and conformation traits in Tygerhoek Merino sheep (Olivier *et al*., 1987)

Trait	**Scale of assessment**		
	1	**25**	**50**
Subjective wool			
Face cover score	Hard	Average	Soft
Pigmentation	Excessive	Average	None
Woolly face score	Woolly faced	Ideal	Open faced
Quality	Poor	Average	Ideal
Regularity of crimp	Poor	Average	Ideal
Colour	Yellow	Average	White
Oil	None	Ideal	Excessive
Staple formation	Ropy	Average	Thick, blocky
Belly and points	Watery, yellow	Average	Thick, white
Subjective conformation			
Head general	Weak	Average	Strong
Hocks	Narrow	Average	Wide
Front quarters	Narrow	Average	Wide
Pastern score	Weak	Average	Strong
Top line	Poor	Average	Ideal
Total fold score	Plain (score=1)	-	Most wrinkly (score=18)

For most traits the following partitioning applied: 1-10 = poor; 11-20 = below average; 21-30 = average; 31-40 = above average and 41-50 = excellent. The exceptions were woolly face score and oil, which had an intermediate optimum.

A total of 15 subjectively assessed wool and conformation traits were included in the analyses. These traits were assessed according to a linear scale (Table 3.1) ranging from 1-50 (Olivier *et al*., 1987) at 14-16 months of age. At least three experienced judges were used for the allocation of the scores for individual animals. The scores given by each of the judges were averaged to provide a final score for the trait concerned in each animal.

Subjectively assessed wool traits included were face cover score (FCS), pigmentation (PIGM), woolly face score (WFS), quality (QUAL), regularity of crimp (ROC), colour (COL), oil (OIL), staple formation (STAPL) and belly and points (BANDP).

Subjectively assessed conformation traits included were: total fold score scored (TOT) according to photographic standards (Cloete *et al*., 1998), head general (GEN), hocks (HOCKS), front quarters (FQ), topline (TOPL) and pastern score (PS).

Editing constituted checks on biologically feasible records, pedigree identification records, sex, birth status of the animals, missing records and typing errors. All animals without a sire or dam, birth status and sex were excluded from the analysis. Only animals with biologically feasible records were retained and all animals without records were excluded from the analysis. Animals with a missing record for a particular trait were excluded from the analysis of that particular trait. Preliminary analyses were performed, using the ASREML programme (Gilmour *et al*., 2002). These analyses were used to determine the fixed effects to be included in the subsequent runs.

3.5 Statistical analyses

The statistical analysis was divided into three consecutive steps. Firstly, the significance of fixed effects was tested using the ASREML programme (Gilmour *et al*., 2002) leaving only significant effects in the model.

The following fixed-effect model was fitted for all traits:

$$Y_{ijklmnp} = \mu + s_j + bt_k + ad_l + y_m + g_n + sy_p + e_{ijklmnp}$$

where $Y_{ijklmnp}$ = an observation of a trait on the i^th^ animal of the j^th^ sex of the k^th^ birth status from the l^th^ age of the dam, m^th^ year, n^th^ line and p^th^ sex and year interaction.

μ = the overall mean

s_j = the fixed effect of the j^th^ sex (j = ram, ewe)

bt_k = the fixed effect of the k^th^ birth status (k = singles, multiples)

ad_l = the fixed effect of the l^th^ age of dam class (l = 2, 3, 4, 5, 6^+ years)

y_m= the fixed effect of the m^{th} birth year class (m = 89, 90, 91, …, 104)

g_n= the fixed effect of the n^{th} line (n = 1, 2, 3, 4)

sy_p= the fixed effect of the p^{th} sex and year interaction (n = 1, 2, 3, …, 32)

$e_{ijklmnp}$= randomly distributed residual variance used as error term to test the other effects for significance

Fixed effects from the analyses were consistent with those reported in the literature, and were thus not presented and discussed further.

The second step was the estimation of (co)variance components for each trait. This was obtained using the ASREML program (Gilmour *et al.*, 2002) fitting single trait animal models initially. These models include a combination of direct additive, maternal additive and maternal permanent environmental effects as well as the covariation between direct additive and maternal additive effects. Six different forms of single trait mixed animal models (in matrix notation) that were fitted for all traits were as follows:

Model 1 $Y = X\beta + Z_1a + e$

Model 2 $Y = X\beta + Z_1a + Z_2m + e$ {with cov (a, m) = 0}

Model 3 $Y = X\beta + Z_1a + Z_2m + e$ {with cov (a, m) = $A\sigma_{am}$}

Model 4 $Y = X\beta + Z_1a + Z_2m + Z_3c + e$ {with cov (a, m) = 0}

Model 5 $Y = X\beta + Z_1a + Z_2m + Z_3c + e$ {with cov (a, m) = $A\sigma_{am}$}

Model 6 $Y = X\beta + Z_1a + Z_3c + e$

Where Y= vector of observations,

β = vector of fixed effects influencing traits,

a = vector of direct additive effects,

m = vector of random maternal additive (dam) effects,

c = vector of random permanent maternal environmental effects,

e = randomly distributed vector of residuals;

where X, Z_1, Z_2 and Z_3 are considered as the corresponding incidence matrices relating observations to their respective fixed and random effects as well as the vector of residuals. The variance-covariance structure of the effects was:-

$$\operatorname{var}\begin{pmatrix} a \\ m \\ c \\ e \end{pmatrix} = \begin{pmatrix} A\sigma^2_a & A\sigma_{am} & 0 & 0 \\ A\sigma_{am} & A\sigma^2_m & 0 & 0 \\ 0 & 0 & INd\sigma^2_c & 0 \\ 0 & 0 & 0 & INd\sigma^2_e \end{pmatrix}$$

Where **A** is the numerator relationship matrix among animals in the pedigree file, **I** is an identity matrix and **Nd** represents the number of dams. The (co) variances σ^2_a, σ^2_m, σ_{am}, σ^2_c, σ^2_e, were defined as the direct genetic variance, the maternal genetic variance, the covariance between the direct and maternal genetic effects, the permanent environmental variance due to the dam and the residual (error) variance, respectively. The phenotypic variance (σ^2_p) was defined as the sum of all variance components estimated in the model of analysis, and could be derived from all the above mentioned variances, as appropriate for the specific analysis. Heritability estimates were computed as the direct heritability ($h^2_a = \sigma^2_a/\sigma^2_p$) and the maternal heritability ($h^2_m = \sigma^2_m/\sigma^2_p$). According to Willham (1972) total heritability can be estimated as $\{(h^2_t = \sigma^2_a + 0.5\ \sigma^2_m + 1.5\ \sigma_{am})/\ \sigma^2_p\}$.

The significance of the random effects was tested using the log likelihood ratio tests after inclusion of one random effect in the model. A random effect was considered significant when its inclusion in the model caused a significant improvement in the log likelihood ratio. A chi-square distribution of $\alpha = 0.05$ at one degree of freedom was used as a test statistic (3.841). When -2 times the difference between the log likelihoods was greater than this critical value, the inclusion of the particular random effect was considered to significantly improve the fit of the model (Swalve, 1993). The objective of testing the significance of different models is to identify the best and simplest models that could be used for subsequent runs. Therefore the model with the least possible number of random effects was used when the inclusion of an additional random effect was not significant.

The third and final step was to estimate genetic, environmental, phenotypic and maternal correlations between most of the traits by fitting two-trait models using ASREML (Gilmour *et al*., 2002). Starting values for the (co)variance components of two-trait models were obtained from the single trait models fitted in step two.

CHAPTER 4

(CO) VARIANCE COMPONENTS AND GENETIC PARAMETERS FOR LIVE WEIGHT AND OBJECTIVELY MEASURED WOOL TRAITS

4.1 Introduction

Objectively assessed wool traits and body weight remain the most economically important traits in a wool enterprise, apart from reproduction (Olivier, 1999). The genetic improvement of these traits is important for increased productivity and profitability. Knowledge of variance components and the accurate estimation of the genetic parameters are required to design breeding programmes for the genetic improvement of these traits.

Sophisticated computer software has been developed to derive accurate estimates of genetic parameters (Meyer, 1991; Gilmour *et al.*, 1999). Such software enables the partitioning of genetic variances into direct additive and maternal additive effects, the covariance between animal effects, animal permanent environmental effect as well as the maternal permanent environmental effects (Lewis & Beatson, 1998). The advent of these software packages enabled researchers to conduct studies partitioning the respective random effects for various livestock species (Meyer, 1992, 1994; Olivier *et al.*, 1994; Purvis, 1995; Swan *et al.*, 1995; Snyman *et al.*, 1996; Meyer, 1997). In addition, Van Wyk *et al.* (2003) and Safari *et al.* (2007b) partitioned the dam permanent environmental variance into a temporary litter effect and a permanent environmental effect (the correspondence of records of the same dam across breeding seasons) to accurately reflect the contribution of the respective components. Furthermore, Asadi Fozi *et al.* (2005) recently stated the importance of including maternal genetic effects for fleece traits in Merino breeding programs. A successful genetic improvement plan for economically important performance traits in woolled sheep depends on selection for a specific trait and understanding the correlated responses in other traits because of selection for that specific trait. Genetic parameters for ovine production traits have been studied widely in the past and were reviewed by Fogarty (1995), Snyman *et al.* (1995) and Safari *et al.* (2005) for a wide range of traits recorded on woolled sheep, dual-purpose sheep and meat sheep. Moreover, the genetic and phenotypic correlations among objective wool traits and body weight have been estimated for many South African Merino populations (Cloete *et al.*, 1998a; Cloete *et al.*, 2005; Cloete *et al.*, 2006; Naidoo & Cloete, 2006; Van Wyk *et al.*, 2006). However, few studies included staple strength (SS), coefficient of variation of fibre diameter (CVFD), and the standard deviation of fibre diameter (SDFD) in the analyses. Apart from the extensive work on Tygerhoek and Elsenburg Merino flocks (Cloete *et al.*, 1998a; Cloete *et al.*, 2004b; Cloete *et al.*, 2005; Cloete *et al.*, 2006; Naidoo & Cloete, 2006; Olivier & Cloete, 2007), there is little information about genetic and environmental correlations among objective wool and body weight traits of economic importance. Maternal correlations among objective wool and body weight traits were absent in the literature cited.

The objectives of the present study were thus to estimate the (co)variance components and ratios as well as the genetic, phenotypic, environmental and maternal correlations for 16- months live weight and objectively measured wool traits involving South African Merino sheep.

4.2 Materials and methods

4.2.1 Data

Data utilised in this study consisted of 4 495 animals, the progeny of 449 sires and 1 831 dams, born between 1989 and 2004 in the Tygerhoek Merino flock. Pedigree records were collected between 1969 and 2004. A detailed description of the management, animals used, selection lines represented and traits included as well as data editing is given in Chapter 3. A description of data used to analyse live weight and objective wool traits is presented in Table 4.1. The fixed effects were tested for significance using the ASREML programme (Gilmour *et al.*, 2002) to determine the fixed effects to be included in subsequent runs. Details of the model fitted for fixed effects are described in Chapter 3.

Table 4.1 Description of data used for analyses in terms of numbers

Description	LW	GFW	CFW	CY	FD	SL	SS	CVFD	SDFD
Number of records before editing	5261	5172	5114	5209	5236	4667	1929	4047	4047
Number of records after editing	4993	4824	4816	4890	4890	4618	1914	3751	3751
Number of sires after editing	449	437	436	446	445	424	144	323	323
Number of dams after editing	1831	1783	1778	1804	1805	1656	650	1370	1370
Number of years	16	16	16	16	16	15	7	11	11
Number of sex*year of birth	32	32	32	32	32	30	14	22	22
Period	89-04	89-04	89-04	89-04	89-04	89-03	96-99 & 01-03	94-04	94-04

LW = live weight, GFW = greasy fleece weight, CFW = clean fleece weight, CY = clean yield, FD = fibre diameter, SL = staple length, SS = staple strength, CVFD = coefficient of variation of fibre diameter and SDFD = standard deviation of fibre diameter

4.2.2 Statistical analyses

Heritability estimates and variance components were computed using ASREML software (Gilmour *et al.*, 2002) fitting single trait animal models initially. According to Goddard (2001) the most commonly used model to analyse quantitative traits is the animal model with only the direct additive genetic variance as a random source of variation. However, Van Wyk *et al.* (2003) emphasized the need to use appropriate models when estimating genetic parameters. Therefore, the models used in this study included a combination of direct additive, maternal additive and maternal permanent environmental effects as well as the covariance between animal effects. A more detailed description of the models used, definition of the effects and log likelihood ratio tests can be found in Chapter 3.

4.3 Results and Discussion

The following reports in the literature have been used for comparison and will mostly not be referred to again in this Chapter, unless it is generally cited as literature or mentioned specifically as one or two references in special situations (Erasmus *et al.*, 1990; Howe *et al.*, 1991; Brash *et al.*, 1994a & b; Mortimer & Atkins, 1994; Olivier *et al.*, 1994; Fogarty *et al.*, 1995 (review); Greeff *et al.*, 1995; Ponzoni *et al.*, 1995; Purvis, 1995; Snyman *et al.*, 1995; Swan *et al.*, 1995; Snyman *et al.,* 1996; Vaez Torshizi *et al.*, 1996; Brash *et al.*, 1997; Greeff *et al.*, 1997; Meyer *et al.*, 1997; Swan *et al.*, 1997; Swan & Purvis, 1997; Cloete *et al.*, 1998a & b; Lewis & Beatson, 1998; Snyman *et al.*, 1998a & b; Groenewald *et al.*, 1999; Hygate & Scrivener, 1999; Hill & Ponzoni, 1999; Purvis & Swan, 1999; Lee *et al.*, 2000; Cloete *et al.*, 2001b; Cloete *et al.*, 2002b; Duguma *et al.*, 2002; Maniatis & Pollott, 2002; Snyman & Olivier, 2002a; Cloete *et al.*, 2003a & b; Maniatis & Pollott, 2003; Cloete *et al.*, 2004b; Lupton *et al.*, 2004; Naidoo *et al.*, 2004; Asadi Fozi *et al.*, 2005; Brown *et al.*, 2005; Cloete *et al.*, 2005; Ozcan *et al.*, 2005; Safari *et al.*, 2005 (weighted means for important wool traits based on estimates of 165 studies); Gizaw *et al.*, 2006; Hanford *et al.*, 2006; Herselman *et al.*, 2006; Naidoo & Cloete, 2006; Olivier *et al*. 2006b; Van Wyk *et al.*, 2006; Notter *et al.*, 2007; Safari *et al.*, 2007a & b).

4.3.1 Non genetic effects and descriptive statistics

Preliminary analysis of non genetic effects indicated that birth status (single/multiple), sex (male/female), age of the dam in years (2-6$^+$years), year of birth (1989-2004) selection line (1-4) and the sex*birth year interaction had a significant ($P<0.05$) effect on all objective wool traits and live weight and were included in the models for subsequent analyses. These results are consistent with those reported by Cloete *et al.* (1998a) and Naidoo *et al.* (2004) pertaining to the same South African Merino flock. The fixed effect solutions corresponded with those reported in the literature for wool and dual-purpose sheep. These effects are therefore not reported in detail, because it would duplicate results that are well described in the literature.

Table 4.2 Data description of objective traits

Trait	Mean	SD	CV (%)	Minimum	Maximum
Live weight (kg)	49.5	9.8	19.79	18.5	93.5
Greasy fleece weight (kg)	5.1	1.29	25.29	1.0	9.4
Clean fleece weight (kg)	3.6	0.95	26.24	0.7	7.0
Clean yield (%)	71.8	5.70	7.94	49.9	84.1
Staple length (mm)	89.7	16.60	18.51	33.0	144.1
Staple strength (N/ktex)	34.9	12.70	36.39	2.0	74.0
Fibre diameter (µm)	19.9	1.70	8.54	14.4	27.6
CV of fibre diameter (%)	20.2	2.70	13.37	13.7	39.0
SD of fibre diameter (µm)	4.0	0.60	15.00	2.1	6.8

SD = standard deviation, CV = coefficient of variation, CV of fibre diameter = coefficient of variation of fibre diameter, SD of fibre diameter = standard deviation of fibre diameter.

Means, standard deviations (SD) and coefficients of variation (CV) for objective wool traits and LW are summarised in Table 4.2. Means for CFW, CY, FD, CVFD and SL obtained from this study were similar to those reported by Naidoo *et al.* (2004) using a smaller data set recorded on the same Merino resource flock. Duguma *et al.* (2002) reported a slightly higher mean of 53.8 kg for LW from the same flock. Coefficients of variation (CV) among the objectively measured traits ranged from 7.94% to 36.39% with SS being the most variable trait (Table 2.1). The qualitative wool traits, CY and FD showed less variation than the other objective traits (<10%). This is in agreement with results obtained by Naidoo *et al.* (2004) where CY and FD showed the lowest variation among the objective wool traits.

Literature CV values for GFW and CFW ranged from 13.0% to 29.1% and from 13.6% to 42.0% respectively. The CV of 25.3% for GFW in this study is lower than that reported by Cloete *et al.* (2004b) and Olivier & Cloete (2007) and higher than most other literature values. Previous studies by Olivier *et al.* (1994) and Groenewald *et al.* (1999) and Olivier & Cloete (2007) reported higher CV's of 34.0%, 28.6% and 0.42% for CFW in South African Merino sheep. Naidoo *et al.* (2004) also reported a higher CV of 28.6% for CFW in the same flock on a smaller data set compared to the value of 26.2% obtained in the current study. The CV of 26.2% for CFW in this study is higher than the weighted means derived by Safari *et al.* (2005) for wool and dual-purpose sheep breeds.

The ranges of CV derived for qualitative wool traits, CY and FD ranged from 4.9% to 11.0% and 5.1 % to 11.8 % respectively. The CV for FD (8.6 %) in this study is within the range of these literature values. However, previous studies by Olivier *et al.* (1994) and Snyman *et al.* (1996) reported somewhat higher values for South African Merino sheep. A recent study on Australian Merino sheep also resulted in a higher CV value of 12.0% (Safari *et al.*, 2007a). The results of CV for FD in the present study, as well as from the literature cited, suggested that FD was more variable in the latter study. This result may stem from the fact that various resource flocks from throughout Australia were used.

Coefficient of variation (CV) for CY (7.9%) in this study is higher than that reported by Naidoo *et al.* (2004) on the same flock using smaller data. Safari *et al.* (2005) also derived lower CV's from literature values for both wool and dual-purpose sheep breeds. In contrast, Snyman & Olivier (2002a) and Cloete *et al.* (2004b) reported higher values of 11.0% and 8.9% for Afrino and South African Mutton Merino sheep respectively. Safari *et al.* (2007a) reported slightly higher CV of 8.4% for CY in Australian Merino resource flocks. Staple strength (SS) is the most variable among the objective traits in this study. The CV of 36.4 % for SS in this study is slightly higher than those reported for Merino sheep and wool breeds (29.2 % to 32.4 %) from the literature cited. Literature values for CV of SL ranged from 11.9% to 23.0%. The

CV of SL (18.5%) derived in this study is thus lower than the value of 23.0% reported for Targhee sheep (Notter *et al*., 2007) and somewhat higher than most other CV values reported from the literature cited. However, Cloete *et al.* (1998b) reported a higher CV for SL on the same resource flock.

Previous studies on the Australian Merino suggested a CV of less than 15% for CVFD (Greeff *et al*., 1995). Safari *et al*. (2005) derived a CV of 12.2% for CVFD on wool breeds. However, Safari *et al.* (2007a) reported a CV of CVFD being 16.6% among various Australian Merino resource flocks, which is higher than the value of 13.4% in the current study. Furthermore, Naidoo *et al.* (2004) reported slightly higher CV of 15.3% for CVFD from the same flock using a smaller data set. Safari *et al.* (2007a) reported a higher CV for SDFD (18.1 %) for Australian Merino resource flocks. All other values for the CV of SDFD from the literature cited were less than 15 %, which are lower than the CV of SDFD of 15.0 % derived from the present study. The ranges for the CV of CVFD and SDFD obtained from the literature were from 12.1 to 15.3% and from 10.7 to18.1 % respectively. At 14-18months of age, the CV of LW ranged from 10.4 to 32.4%. The 19.8 % calculated for 16-months LW in the present study is within the range of literature values and consistent with values reported for the Afrino breed (Snyman *et al*., 1998a) (19.0%) and for South African Merino sheep (Groenewald *et al*., 1999) (19.6%). Furthermore, Safari *et al.* (2007a) reported a similar CV of 19.8% for LW at 14-17-months in Australian Merino resource flocks.

4.3.2 (Co)variance components and ratios for objective traits

The (co)variance components and genetic parameter estimates using single-trait animal models are presented in Tables 4.3 – 4.11. The most appropriate model for GFW and CFW was Model 5 while Model 3 was most appropriate for FD and LW. Several studies reported significant maternal effects on these traits for various sheep breeds. In contrast, Vaez Torshizi *et al.* (1996) reported no significant maternal effects for any of the corresponding wool traits beyond 12 months of age. Some studies also reported the dam permanent environmental effect having a significant effect on FD. The model with only the additive effect (Model 1) fitted the data best for CY, SL, SS, CVFD and SDFD in the present study. However, Safari *et al.* (2007b) found a significant maternal additive effect, the covariance between animal effects, animal permanent environmental effect as well as litter effect on 14-17-months of age for LW, GFW, CFW, FD, CY, SD and CV. The results from the current study and literature strongly indicate that more random effects should be considered during the estimation of models for 16-months LW and some objective wool traits. A detailed discussion of the (co)variance components for the objectively measured wool traits and LW are presented below.

4.3.2.1 Greasy fleece weight (GFW)

The (co)variance components and genetic parameters for GFW from the single-trait analysis are presented in Table 4.3. According to the log likelihood ratio tests (LRT) the most appropriate model for GFW was Model 5 which included the direct additive and maternal additive effects, the covariance between animal effects as well as the dam permanent environmental effect. Several researchers used different random models for GFW analysis

The h^2_a estimate of 0.36 for GFW (Table 4.3) is within the range (0.08-0.68) of literature values estimated from various breeds of sheep in different countries. The derived h^2_a estimate is consistent with a figure of 0.38±0.05 reported by Cloete *et al.* (2004b) for yearling South African Mutton Merino sheep, but higher than the value of 0.17±0.05 reported by Brash *et al.* (1994a) for 14-month-old dual-purpose breeds in Australia. Ozcan *et al.* (2005) also reported a very low estimate (0.08) for Turkish Merino sheep compared to the h^2_a estimate in the current study. The latter estimate is in agreement with the weighted mean value derived by Safari *et al.* (2005) for wool sheep breeds (0.37±0.02) but lower than that 0.46±0.01 reported by Safari *et al.* (2007b) for Australian Merino resource flocks. The difference in h^2_a estimates from literature is possibly due to the models used and data structure from which the estimates were derived. However, the agreement with the weighted mean estimates derived from numerous literature sources by Fogarty (1995) and Safari *et al.* (2005) was good, indicating that the present h^2_a estimate was consistent with the bulk of corresponding values in the literature.

Table 4.3 (Co)variance components and ratios for greasy fleece weight in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	**Model 5**	Model 6
(Co)variance components						
σ^2_a	0.20	0.17	0.25	0.17	**0.25**	0.18
σ^2_m	-	0.04	0.09	0.01	**0.06**	-
σ^2_{pe}	-	-	-	0.03	**0.04**	0.05
σ^2_e	0.49	0.48	0.43	0.47	**0.42**	0.47
σ^2_p	0.69	0.69	0.69	0.69	**0.69**	0.69
σ_{am}	-	-	-0.09		**-0.09**	-
Variance ratios						
h^2_a	0.29	0.25	0.36	0.25	**0.36**	0.26
SE	0.03	0.03	0.05	0.03	**0.05**	0.03
h^2_m	-	0.06	0.14	0.02	**0.09**	-
SE	-	0.02	0.03	0.02	**0.03**	-
r_{am}	-	-	-0.56	-	**-0.65**	-
SE	-	-	0.08	-	**0.10**	-
c^2_{pe}	-	-	-	0.06	**0.05**	0.07
SE	-	-	-	0.02	**0.02**	0.02
h^2_t	0.29	0.28	0.23	0.25	**0.21**	0.26
Log L	-1455.15	-1447.08	-1437.18	-1443.10	**-1433.78**	-1443.43

σ^2_a = direct additive variance, σ^2_m = maternal additive variance, σ^2_{pe} = permanent environmental variance, σ^2_e = residual variance, σ^2_p = total phenotypic variance, σ_{am} = covariance between direct and maternal additive effects, h^2_a= direct heritability, h^2_m= maternal heritability, r_{am} = genetic correlation between direct and maternal additive effects, h^2_t = total heritability $\{(\sigma^2_a + 0.5\ \sigma^2_m + 1.5\ \sigma_{am})/\ \sigma^2_p\}$, Log L = Log likelihood

The h^2_m estimate for GFW (0.09±0.01) accords well with weighted means of 0.08 and 0.07 for wool breeds and Australian resource flocks respectively (Safari *et al.*, 2005; Safari *et al.*, 2007b). However, it was lower than the h^2_m estimates of 0.13 and 0.17 reported by Brown *et al.* (2005) and Asadi Fozi *et al.* (2005) for Australian Merinos.

At -0.65, the genetic correlation between animal effects was negative in sign and large in magnitude in the present study. Safari *et al.* (2007b) reported a slightly lower estimate of -0.60±0.02 in Australian Merino resource flocks. Researchers in various animal species reported a high negative correlation between direct and maternal effects on growth traits. This result is often ascribed to a poor pedigree structure, a small number of progeny per dam, limited information from the dam herself and genotype by environmental interaction (Meyer, 1997; Lee *et al*., 2000; Maniatis & Pollott 2002; 2003). The only published estimate (Safari *et al*., 2007b) of the correlation between direct and maternal genetic effect for GFW was in agreement with the current estimate. In their studies Safari *et al*. (2007b) indicated that their estimate is fairly precise due to the quality of data used and the size of the combined data set. Therefore, this emphasises the good quality of data used in this study and the reliability of the current estimate of correlation between direct and maternal genetic effects for GFW in South African Merinos.

The permanent environmental effect (c^2_{pe}) of 0.05±0.02 in the present study, the value of 0.00 in the Australian Merino resource flocks (Safari *et al*., 2007b) and the results, of an extensive review (Safari *et al.,* 2005) indicated that c^2_{pe} of GFW are not as important as the additive maternal variance. A total heritability of 0.21 was estimated from the data used in the present study.

4.3.2.2 Clean fleece weight (CFW)

(Co)variance components and genetic parameter estimates were computed for CFW (Table 4.4) using six different single-trait models. Similar to the GFW analysis, the log likelihood ratio tests indicated Model 5 to be the best model for analysing CFW. Similar models have been used for analysis of CFW in previous studies. However, Safari *et al*. (2007b) used a model that included direct and maternal additive variances, the covariance between animal effects, animal permanent environmental effects as well as a litter effect as random variables for analysing CFW in Australia Merino resource flocks.

CFW was highly heritable at 0.40±0.05 in the present study. This value is within the range of the literature values of 0.22 - 0.55 but much lower than estimates of 0.62 and 0.68 reported by Snyman *et al.* (1995) and Cloete *et al.* (2001b) for Afrino and South African Mutton Merino sheep respectively. Olivier *et al.* (2006) also reported a higher estimate of 0.54±04 for the Cradock fine wool Merino flock. The estimate in the present study is, however, somewhat higher than a corresponding weighted mean estimate of 0.28±0.01 derived by Safari *et al.* (2005) from literature values for wool sheep breeds, and 0.22±0.01 for the South African Dohne Merino breed (Van Wyk *et al.*, 2006). Olivier & Cloete (2007) reported a lower estimate of 0.29 for South African Merino sheep participating in the Merino plan. On the other hand, Safari *et al.* (2007b) reported a similar estimate of 0.42±0.01 for CFW in Australian Merino resource flocks, which is in close agreement with the present estimate.

Table 4.4 (Co)variance components and ratios for clean fleece weight in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	**Model 5**	Model 6
(Co)variance components						
σ^2_a	0.12	0.18	0.17	0.11	**0.17**	0.11
σ^2_m	-	0.02	0.06	0.01	**0.04**	-
σ^2_{pe}	-	-	-	0.02	**0.02**	0.03
σ^2_e	0.29	0.28	0.25	0.27	**0.24**	0.27
σ^2_p	0.41	0.41	0.41	0.41	**0.41**	0.41
σ_{am}	-	-	-0.06	-	**-0.06**	-
Variance ratios						
h^2_a	0.30	0.26	0.40	0.26	**0.40**	0.27
SE	0.03	0.03	0.05	0.03	**0.05**	0.03
h^2_m	-	0.06	0.15	0.02	**0.10**	-
SE	-	0.02	0.03	0.02	**0.03**	-
r_{am}	-	-	-0.61	-	**-0.70**	-
SE	-	-	0.07	-	**0.09**	-
c^2_{pe}	-	-	-	0.05	**0.05**	0.06
SE	-	-	-	0.02	**0.02**	0.02
h^2_t	0.30	0.46	0.27	0.28	**0.24**	0.27
Log L	-189.557	-181.649	-168.824	-178.737	**-165.905**	-179.234

See **Table 4.3** for abbreviations

In general, the h^2_m estimate from this study (0.10±0.03) is slightly higher than the bulk of literature estimates, ranging from 0.01 to 0.08. The exceptions are slightly higher h^2_m estimates of 0.12 reported by Olivier *et al.* (1994) for 14-16-month animals from the Grootfontein Merino stud and an estimate of 0.15 reported by Asadi Fozi *et al.* (2005) for Australian fine-wool Merinos.

The present correlation estimate between animal effects of -0.70±0.09 estimate is higher than literature estimates of -0.35 (Olivier *et al.*, 1994) and -0.55 (Safari *et al.*, 2007b). The maternal permanent environmental variance ratio accounted for 5% of the overall phenotypic variance in the present study, which is slightly lower than the 6% reported for yearling South African Mutton Merinos (Cloete *et al.*, 2004b). In contrast Safari *et al.* (2007b) reported a c^2_{pe} effect of 0.00 for Australian resource flocks. The results from the present study, as well as those of Safari *et al.* (2007b) suggested that h^2_m is generally more important than c^2_{pe} when wool traits of 16-months Merino sheep are considered. The total heritability estimated in the present study (0.24) is slightly lower than the estimates of 0.27 and 0.33 reported by Snyman *et al.* (1996) and by Cloete *et al.* (1998a) for South African Merino sheep, and much lower than an estimate of 0.62 reported for Afrino sheep (Snyman *et al.*, 1995). Researchers attributed the large differences between studies in genetic parameters to the managerial environment and the usage of different models for analysis.

4.3.2.3 Clean yield (CY)

Unlike GFW and CFW, Model 1 (including only the direct additive effect) fitted the data best for CY. In previous studies, a similar model has been used to estimate the variance components and ratios for CY in South African Merino sheep. However, Safari *et al.* (2007b) found significant maternal additive, animal permanent environmental and litter effects as well as the covariance between animal effects for CY involving Australian Merino resource flocks. (Co)variance components and genetic parameters from single-trait models are presented in Table 4.5.

The h^2_a of 0.65±0.03 for CY from the present study is within the range (0.32 to 0.69) of literature values reported on various sheep breeds and similar to the estimate of 0.64±0.04 reported by Naidoo *et al.* (2004), using a smaller data set of the same flock. In contrast, Safari *et al.* (2007b) reported a lower value of 0.47±0.01 when the covariance between animal effects was included as an additional random effect in the model and 0.42±0.01 when the covariance between animal effects was excluded.

The total heritability estimated presently (0.65) is slightly lower than an earlier estimate of 0.69±0.01 reported by Cloete *et al*. (1998a) on the same Merino flock. It is believed that the partitioning of h^2_a and c^2_{pe} in the models used in other studies could have contributed to the differences in the magnitude of the h^2_a estimates for CY.

Table 4.5 (Co)variance components and ratios for clean yield in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**10.61**	10.57	11.01	10.83	11.01	10.60
σ^2_m	**-**	0.01	0.16	0.06	0.16	-
σ^2_{pe}	**-**	-	-	0.251E-05	0.552E-07	0.34E-07
σ^2_e	**5.75**	5.73	5.52	5.91	5.52	5.76
σ^2_p	**16.36**	16.37	16.41	16.80	16.41	16.36
σ_{am}	**-**	-	-0.29	-	-0.29	-
Variance ratios						
h^2_a	**0.65**	0.65	0.67	0.64	0.67	0.65
SE	**0.03**	0.03	0.04	0.03	0.04	0.03
h^2_m	**-**	0.004	0.01	0.004	0.01	-
SE	**-**	0.01	0.01	0.01	0.01	-
r_{am}	**-**	-	-0.22	-	-0.22	-
SE	**-**	-	0.23	-	0.23	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.00
SE	**-**	-	-	0.00	0.00	0.00
h^2_t	**0.65**	0.65	0.65	0.65	0.65	0.65
Log L	**-8738.90**	-8737.84	-8737.53	-8738.06	-8737.53	-8738.08

See **Table 4.3** for abbreviations

4.3.2.4 Fibre diameter (FD)

FD has been regarded as one of the primary determinants of wool price (Purvis, 1995; Purvis & Swan, 1999). In Table 4.6, the estimates of (co)variance components and genetic parameters under six different models are presented for FD with the best model in bold. The best model (Model 3) included both direct and maternal additive effects as well as the covariance between animal effects. Among comparable sources in the literature only Olivier *et al.* (1994) and Safari *et al.* (2007b) reported FD as being significantly influenced by direct and maternal additive components and the covariance between the animal effects. Most previous studies on various sheep breeds reported FD as being significantly influenced by only the direct additive effect (Model 1). This is also the general trend evident from previous studies on Merino sheep.

Fibre diameter had the highest heritability among objective wool traits, with a h^2_a estimate of 0.68±0.05 in the present study. This value is within the range of literature values (0.18 to 0.86) for FD estimated on various sheep breeds. It also accords with an estimate of 0.63±0.03 reported for Cradock fine wool Merino sheep (Olivier *et al.*, 2006a) and an estimate of 0.68±0.01 reported for Australian Merino resource flocks (Safari *et al.*, 2007b). The estimate in the current study is somewhat higher than a corresponding mean h^2_a estimate of 0.59±0.02 derived from literature values by Safari *et al.* (2005). Recent studies on South African Merino also reported lower h^2_a estimates of 0.52 (Cloete *et al.*, 2006) and 0.48 (Van Wyk *et al.*, 2006) and of 0.55 (Olivier & Cloete, 2007) for FD, compared to the estimate obtained in the present study. In contrast, Lupton *et al.* (2004) reported a higher h^2_a estimate of 0.86±0.16 for crossbred sheep. The differences between estimates stemming from different studies may be attributed to the inclusion of the maternal additive genetic effect, litter effect and the covariance between the animal effects as random variables in the models of analysis in some instances. This emphasises the need to include all possible random effects to accurately estimate the heritability of economic important wool traits in Merino sheep.

The h^2_m estimate in the present study of 0.05±0.02 is slightly higher than the corresponding estimates reported on Merino sheep in the literature cited. The correlation between animal effects was estimated at -0.43±0.11 in the present study. Safari *et al.* (2007b) reported a very similar negative and moderate estimate of -0.42±0.03 for Australian Merino resource flocks. The total heritability estimated from the present study is 0.58 which is slightly lower than the estimates of 0.62-0.63 in the literature cited.

Table 4.6 (Co)variance components and ratios for fibre diameter in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	**Model 3**	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	1.05	1.03	**1.20**	1.03	1.21	1.05
σ^2_m	-	0.03	**0.09**	0.03	0.08	-
σ^2_{pe}	-	-	**-**	0.03	0.01	0.02
σ^2_e	0.72	0.71	**0.63**	0.71	0.62	0.71
σ^2_p	1.77	1.78	**1.78**	1.77	1.78	1.77
σ_{am}	-	-	**-0.14**	-	-0.14	-
Variance ratios						
h^2_a	0.59	0.58	**0.68**	0.58	0.68	0.59
SE	0.03	0.03	**0.05**	0.03	0.05	0.03
h^2_m	-	0.02	**0.05**	0.02	0.04	-
SE	-	0.01	**0.02**	0.02	0.02	-
r_{am}	-	-	**-0.43**	-	-0.45	-
SE	-	-	**0.11**	-	0.13	-
c^2_{pe}	-	-	**-**	0.00	0.01	0.01
SE	-	-	**-**	0.02	0.02	0.01
h^2_t	0.59	0.59	**0.58**	0.59	0.59	0.59
Log L	-3424.76	-3423.62	**-3419.97**	-3423.62	-3419.88	-3424.17

See **Table 4.3** for abbreviations

4.3.2.5 Staple length (SL)

The (co)variance components and genetic parameters for SL are presented in Table 4.7. Model 1 (only direct additive effect) fitted the data best for the SL analysis. According to the literature survey similar models with only an additive effect were used for analysis of SL in Merinos.

The h^2_a estimate of 0.37±0.03 for SL in the present study accords with an estimate of 0.34±0.01 reported for Menz sheep (Gizaw *et al.*, 2006). It is however somewhat below the weighted mean estimates derived by Safari *et al.* (2005) for woolled sheep (0.46±0.02) and for dual-purpose (0.48±0.03) sheep. It is also below the estimates of

0.46 and 0.43 reported in South African Merino and Targhee sheep by Olivier *et al.* (2006a) and Notter *et al.* (2007) respectively. A very high h^2_a estimate of 0.70±0.06 was reported for SL in South African Merino sheep participating in the national progeny test (Groenewald *et al.*, 1999). However, Olivier & Cloete (2007) reported a lower h^2_a estimate of 0.26 in South African Merino sheep participating in the Merino plan compared to the present estimate of 0.37. Breed differences and genotype by environmental interaction could have contributed to different estimates. Total heritability was estimated at 0.37 for SL. This estimate accords with a corresponding estimate of 0.36±0.02 previously reported by Cloete *et al.* (1998a) in the same Merino resource flock.

Table 4.7 (Co)variance components and ratios for staple length in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**31.90**	31.91	28.10	32.18	35.76	31.89
σ^2_m	**-**	0.07	0.07	0.18E-04	0.07	-
σ^2_{pe}	**-**	-	-	0.14E-04	0.55E-05	0.3E-04
σ^2_e	**54.35**	54.40	57.68	54.20	52.55	54.39
σ^2_p	**86.24**	86.31	84.41	86.38	86.84	86.28
σ_{am}	**-**	-	-1.44	-	-1.55	-
Variance ratios						
h^2_a	**0.37**	0.37	0.33	0.37	0.41	0.36
SE	**0.03**	0.03	0.00	0.03	0.00	0.03
h^2_m	**-**	0.00	0.00	0.00	0.00	-
SE	**-**	0.00	0.00	0.00	0.00	-
r_{am}	**-**	-	-0.99	-	-0.99	-
SE	**-**	-	0.00	-	0.00	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.00
SE	**-**	-	-	0.00	0.00	0.00
h^2_t	**0.37**	0.37	0.42	0.37	0.39	0.37
Log L	**-12381.6**	-12381.7	-12382.6	-12381.7	-12383.4	-12381.7

See **Table 4.3** for abbreviations

4.3.2.6 Staple strength (SS)

Previous studies indicated SS to be an important determinant of wool price (Howe *et al.*, 1991; Greeff *et al.*, 1995; Swan & Purvis, 1997). Researchers in Australia reported that wool with a SS lower or equal to 30N/ktex was consistently penalized. As a result, a number of studies have been widely conducted to estimate genetic parameters for SS and correlations between SS and other traits of economic importance in Merino sheep, with the aim of including SS in the breeding objective for Merino sheep.

Table 4.8 (Co)variance components and ratios for staple strength in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**24.69**	19.10	16.67	18.41	16.68	22.63
σ^2_m	**-**	4.63	1.64	7.45	1.64	-
σ^2_{pe}	**-**	-	-	0.11E-04	0.4E-08	2.41
σ^2_e	**100.49**	100.86	102.40	99.48	102.45	99.96
σ^2_p	**125.2**	124.9	124.9	125.3	124.9	125.0
σ_{am}	**-**	-	-4.09	-	-4.09	-
Variance ratios						
h^2_a	**0.20**	0.15	0.13	0.15	0.13	0.18
SE	**0.05**	0.05	0.06	0.05	0.06	0.05
h^2_m	**-**	0.04	0.01	0.06	0.01	-
SE	**-**	0.03	0.04	0.03	0.04	-
r_{am}	**-**	-	0.08	-	0.08	-
SE	**-**	-	2.20	-	2.20	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.02
SE	**-**	-	-	0.00	0.00	0.030
h^2_t	**0.20**	0.21	0.09	0.18	0.09	0.18
Log L	**-5542.02**	-5544.05	-5543.75	-5544.31	-5543.75	-5544.81

See **Table 4.3** for abbreviations

(Co)variance components and ratios for SS in the Tygerhoek Merino flock are presented in Table 4.8. The model of choice included only the direct additive effect as random. Similar models have been widely used by researchers where the direct additive effect was included as the only random variable for the analysis of SS data. The h^2_a estimate of 0.20±0.05 in the present study is generally lower than most comparable estimates in the literature with the exception of an estimate of 0.05±0.05 reported by Cloete *et al.* (2003b). The latter estimate was derived from repeated records on mature, reproducing ewes of 2-6 years of age. The total h^2_t estimated from the present study amounted to 0.20. None of the literature studies cited reported a total heritability for SS.

4.3.2.7 Coefficient of variation of fibre diameter (CVFD)

It has been shown in previous studies that CVFD could be a valuable and relatively inexpensive indirect selection criterion for SS in Merino sheep, as it is expensive to measure SS directly (Greeff *et al.*, 1995; Greeff *et al.*, 1997; Swan *et al*, 1997; Hygate & Scrivener, 1999). Therefore, researchers widely estimated genetic parameters for CVFD and examined the possibility of its inclusion in Merino sheep breeding programmes as an indirect selection criterion for SS.

(Co)variance components and ratios for CVFD under six different models are shown in Table 4.9, with the best model in bold (Model 1). It is an animal model where only the direct additive effect was included as a random effect. This result is complimented by papers from other researchers where this model fitted the data best for CVFD. In contrast, Safari *et al.* (2007b) fitted the models with direct and maternal additive effects, their covariance as well as dam and animal permanent environmental effects and litter as random effects.

CVFD was highly heritable at 0.61, and free from complications arising from maternal variance components. The h^2_a estimate in the present study (0.61±0.04) is in good agreement with estimates reported for South Australian and Western Australian Merino resource flocks (Ponzoni *et al.*, 1995; Cloete *et al.,* 2002b). It is somewhat higher than the weighed mean of 0.52±0.04 derived from the literature values by Safari *et al.* (2005) on wool sheep breeds. However, Greeff *et al.* (1995) reported a higher h^2_a estimate of 0.74±0.02 for Western Australian Merino sheep. Accordingly, higher h^2_a estimates of 0.74±0.02 and 0.71±0.02 on mature ewes were reported for the Elsenburg Merino resource flock, though these estimates derived from studies on mature ewes are not directly comparable (Cloete *et al.*, 2003b; Naidoo & Cloete, 2006). The estimated value in the present study is within the range (0.32 to 0.74) of literature values indicating that CVFD is moderately to highly heritable and should respond to selection.

Table 4.9 (Co)variance components and ratios for coefficient of variation of fibre diameter in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**3.83**	3.77	4.04	3.77	4.03	3.88
σ^2_m	**-**	0.06	0.10	0.06	0.10	-
σ^2_{pe}	**-**	-	-	0.72E-06	0.23E-06	0.01
σ^2_e	**2.42**	2.42	2.29	2.14	2.28	2.31
σ^2_p	**6.25**	6.25	6.28	6.25	6.26	6.19
σ_{am}	**-**	-	-0.15	-	-0.15	-
Variance ratios						
h^2_a	**0.61**	0.60	0.64	0.60	0.64	0.63
SE	**0.04**	0.04	0.06	0.04	0.06	0.04
h^2_m	**-**	0.01	0.02	0.01	0.02	-
SE	**-**	0.02	0.02	0.02	0.02	-
r_{am}	**-**	-	-0.24	-	-0.24	-
SE	**-**	-	0.25	-	0.25	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.002
SE	**-**	-	-	0.00	0.00	0.02
h^2_t	**0.61**	0.61	0.62	0.60	0.62	0.63
Log L	**-4446.36**	-4446.07	-4445.65	-4446.07	-4445.66	-4446.36

See **Table 4.3** for abbreviations

4.3.2.8 Standard deviation of fibre diameter (SDFD)

(Co)variance components and ratios for SDFD are presented in Table 4.10. The log likelihood ratio tests indicated Model 1 as the model of choice for SDFD. It includes only the direct additive effect as a random variable. Safari *et al.* (2007b) fitted direct and maternal additive effects, their covariance as well as dam and animal permanent environmental effects and litter as random effects.

Table 4.10 (Co)variance components and ratios for standard deviation of fibre diameter in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**0.18**	0.18	0.12	0.17	0.12	0.18
σ^2_m	**-**	0.99E-08	0.26E-03	0.48E-07	0.76E-04	-
σ^2_{pe}	**-**	-	-	0.61E-07	0.68E-07	0.38E-02
σ^2_e	**0.11**	0.11	0.14	0.11	0.14	0.11
σ^2_p	**0.29**	0.29	0.27	0.29	0.27	0.29
σ_{am}	**-**	-	0.01	-	0.00	-
Variance ratios						
h^2_a	**0.61**	0.61	0.45	0.61	0.46	0.61
SE	**0.03**	0.03	0.00	0.03	0.00	0.03
h^2_m	**-**	0	0.00	0.00	0.00	-
SE	**-**	0	0.00	0.00	0.00	-
r_{am}	**-**	-	-	0.99	0.99	-
SE	**-**	-	-	0.00	0.00	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.00
SE	**-**	-	-	0.00	0.00	0.00
h^2_t	**0.62**	0.62	0.45	0.57	0.46	0.62
Log L	**750.372**	750.369	N/C	750.371	N/C	750.371

See **Table 4.3** for abbreviations and N/C = not converged

Like CVFD, SDFD was highly heritable at 0.61, and free from the complications arising from maternal variance components. This estimate is higher than the weighted mean of 0.52±0.05 derived by Safari *et al.* (2005) from literature values. Notter *et al.* (2007) also reported a lower estimate of 0.49 for United States Targhee sheep. Safari *et al.* (2007b) reported a similar h^2_a estimate of 0.60±0.02 for Australian Merino resource flocks. Total heritability was estimated at 0.62 in the present study. No corresponding estimates were found in the literature.

4.3.2.9 Live weight (LW)

In Table 4.11, the estimates of variance components and ratios under six different models are presented for LW with the best model in bold. The best model (Model 3) included direct and maternal additive effects as well as their covariance. Similar models have been used for the analysis of LW. However, Safari *et al.* (2007b) used a model that included the direct and maternal additive effects, animal and dam permanent environmental effects, as well as a litter effect as additional random effects.

The h^2_a estimates for the present study (0.38±0.05) is within the range of the literature values (0.18 to 0.86) for LW estimated on various sheep breeds. This estimate accords with a recent estimate of 0.38±0.05 reported for LW in two-tooth Elsenburg Merinos (Cloete *et al*., 2006) and a more recent estimate of 0.38±0.01 reported for Australian Merino resource flocks (Safari *et al*., 2007b). The present estimate is slightly lower than the weighted mean value of 0.42±0.03 derived from the literature values by Safari *et al.* (2005) for wool breeds. A recent study on South African fine wool Merinos also reported a somewhat higher h^2_a estimate of 0.50±0.04 (Olivier *et al*., 2006b). Furthermore Gizaw *et al*. (2006) also reported a higher h^2_a estimate of 0.56±0.02 for Menz sheep. Olivier & Cloete (2007) reported a lower h^2_a estimate of 0.35 for South African Merino sheep participating in the Merino plan

The h^2_m estimate in the present study of 0.05±0.02 is slightly higher than comparable estimates reported in the literature. The correlation between animal effects estimated in the present study was moderate in magnitude and negative in sign (-0.28±0.12). This is in agreement with the estimate of -0.27 reported by Olivier *et al.* (1994). In Contrast, Safari *et al.* (2007b) reported a moderate and positive correlation of 0.25±0.08 between animal effects. Safari *et al*. (2007b) also reported a litter effect amounting to 0.06±0.01. The total heritability estimated in the present study is 0.35, which is in agreement with an estimate of 0.33 reported for Horro sheep (Abegaz *et al.*, 2005). This estimate is lower than other estimates (0.60 for Afrino and 0.57 – 0.63 for Merino) reported in the literature. The differences between these estimates may be attributed to one or a combination of the use of different random models, data structure and environmental factors.

Table 4.11 (Co)variance components and ratios for live-weight in Tygerhoek flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	**Model 3**	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	16.47	11.08	**16.18**	14.11	16.28	15.23
σ^2_m	-	2.48	**3.66**	2.19	3.26	-
σ^2_{pe}	-	-	**-**	0.36	0.48	1.82
σ^2_e	26.12	25.93	**24.79**	25.81	24.61	25.37
σ^2_p	42.60	42.49	**42.47**	42.47	42.46	42.41
σ_{am}	-	-	**-2.16**	-	-2.18	-
Variance ratios						
h^2_a	0.37	0.33	**0.38**	0.33	0.38	0.36
SE	0.03	0.03	**0.05**	0.03	0.05	0.03
h^2_m	-	0.03	**0.05**	0.03	0.05	-
SE	-	0.02	**0.02**	0.02	0.03	-
r_{am}	-	-	**-0.28**	-	-0.30	-
SE	-	-	**0.12**	-	0.13	-
c^2_{pe}	-	-	**-**	0.01	0.01	0.04
SE	-	-	**-**	0.02	0.02	0.01
h^2_t	0.39	0.29	**0.35**	0.36	0.35	0.36
Log L	-11069.0	-11060.9	**-11059.0**	-11060.7	-11058.9	-11064.3

See **Table 4.3** for abbreviations

4.3.3 Correlations among objective traits

Estimates of the genetic, phenotypic, environmental and maternal correlations (where appropriate) from the two-trait analyses among objective traits are presented in Tables

4.12-4.16. Maternal correlations were only estimated for analyses involving LW, GFW, CFW and FD. Maternal genetic effects were not significant for the other traits. Some of the genetic, phenotypic and environmental correlations among objective wool traits were not significant. The significant genetic, phenotypic and environmental correlations ranged from low to high, with the highest correlations reported for GFW with CFW and for CVFD with SDFD. The significant maternal correlations were moderate to high.

4.3.3.1 Live weight (LW) and the objective wool traits

Estimates of genetic, phenotypic, environmental and maternal correlations from the two-trait analysis between live weight and the objective wool traits are presented in Table 4.12. The maternal correlations were computed only for maternally influenced traits namely LW with GFW, CFW and FD. Most of the correlations between live weight and other objective traits were not significant. The significant correlations ranged from low to moderate with the highest correlations reported for LW with GFW and CFW.

Table 4.12 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations between (± SE) 16 months live weight and objective wool traits

Trait	r_g	r_p	r_e	r_m
Live-weight (LW) X				
Greasy fleece weight	0.13±0.07	0.37±0.01	0.48±0.02	0.84±0.12
Clean fleece weight	0.14±0.07	0.36±0.02	0.48±0.03	0.46±0.12
Fibre diameter	-0.01±0.06	0.14±0.02	0.31±0.04	0.16±0.17
Clean yield	0.08±0.06	0.06±0.02	0.06±0.04	-
CV of fibre diameter	-0.15±0.07	-0.16±0.02	-0.18±0.05	-
SD of fibre diameter	-0.13±0.06	-0.06±0.02	-0.01±0.04	-
Staple length	0.05±0.12	0.10±0.02	0.12±0.04	-
Staple strength	0.09±0.07	0.16±0.02	0.22±0.03	-

r_g = genetic correlation, r_p= phenotypic correlation, r_e environmental correlation, r_m maternal correlation, CV of fibre diameter = coefficient of fibre diameter, SD of fibre diameter = standard deviation of fibre diameter and SE = standards error.

The genetic and phenotypic correlations between LW and the objective wool traits were generally positive with the exception of negative and favourable genetic correlations for LW with CVFD and SDFD and phenotypic correlations of LW with CVFD and SDFD. The genetic correlation between LW and FD was negligible. Genetic correlations of LW with GFW (0.13), FD (-0.01), CY (0.08), SL (0.05) and SS (0.09) were generally low, and not significant (Table 4.12). The ranges of correlations with LW in the literature were -0.21 to 0.39 for GFW, -0.01 to 0.58 for CFW, 0.06 to 0.31 for FD and 0.01 to 0.38 for SL (Cloete *et al*., 1998; Safari & Fogarty, 2003; Safari *et al*., 2005; Olivier *et al*., 2006a). The present correlations for LW with GFW, CFW and SL are within these ranges. The present estimate of r_g for LW with CY and CVFD are lower than previous estimates of 0.16 between LW and CY (Cloete *et al*. 1998a) and -0.17 between LW and CVFD (Cloete *et al*., 2002a) reported for South African and Australian Merino sheep. Safari *et al*. (2005) suggested that CY is not correlated with live weight at 16 months but that LW is negatively correlated with SS (-0.11) and CVFD (-0.08). It is notable that the latter correlation is favourable.

Positive phenotypic correlations were estimated for LW with GFW (0.37±0.01), CFW (0.36±0.02), CY (0.06±0.02), FD (0.14±0.02), SL (0.10±0.02) and SS (0.16±0.02). Negative phenotypic correlations were found for LW with CVFD (-0.16±0.02) and SDFD (-0.06±0.01) from the present study. Generally similar correlations were derived by Safari *et al*. (2005) from the literature. Recently, Olivier *et al*. (2006b) also reported similar correlations for the Cradock fine wool Merino flock. Cloete *et al*. (2006) reported a comparable environmental correlation between LW and CFW (0.46±0.03) and a slightly lower correlation with between LW and FD (0.18±0.05) although mature ewes were used. Moderate to high maternal correlations of 0.84±0.12, 0.46±0.12 and 0.16±0.17 were also estimated for LW with GFW, CFW and FD respectively. Corresponding maternal genetic correlations could not be found in the literature.

4.3.3.2 Greasy fleece weight (GFW) and other objective traits

The genetic and phenotypic correlations between GFW and other objective wool traits were generally positive (Table 4.13) with the exception of negative genetic correlations with CY and SS. Both correlations were below -0.10 and not significant. As expected, correlations between GFW and CFW were very high, at 0.87±0.02 and 0.89±0.00 for the genetic and phenotypic correlations respectively. This suggests that GFW and CFW are dependent on a largely similar set of genes. A previous study by Mortimer & Atkins (1989) reported similar genetic (0.87±0.03) and phenotypic (0.87±0.01) correlations between GFW and CFW. Accordingly, Safari *et al.* (2005) derived similar weighted mean genetic correlation of 0.86 and a similar phenotypic correlation of 0.90 from literature values. Very high environmental and maternal genetic correlations of respectively 0.91±0.01 and 0.86±0.05 were also estimated between GFW and CFW in the current study. A similarly high environmental correlation of 0.92±0.01 was reported for the South African Mutton Merinos (Cloete *et al.*, 2004b). The agreement of the genetic, phenotypic and environmental correlations of the present study with the estimates derived from numerous sources by Safari *et al.* (2005) indicate that the present correlations were quite robust. No maternal genetic correlations were found in the literature.

Table 4.13 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations (± SE) between greasy fleece weight and other objective wool traits

Trait	$\mathbf{r_g}$	$\mathbf{r_p}$	$\mathbf{r_e}$	$\mathbf{r_m}$
Greasy fleece weight X				
Clean fleece weight	0.87±0.02	0.89±0.00	0.91±0.01	0.86±0.05
Fibre diameter	0.08±0.06	0.21±0.02	0.39±0.04	0.08±0.02
Clean yield	-0.09±0.05	-0.06±0.02	-0.06±0.04	-
Staple length	0.18±0.06	0.26±0.02	0.33±0.03	-
Staple strength	-0.07±0.11	0.10±0.02	0.18±0.04	-
CV of fibre diameter	0.04±0.06	0.02±0.02	0.01±0.04	-
SD of fibre diameter	0.11±0.06	0.15±0.02	0.21±0.04	-

See **Table 4.12** for abbreviations

The genetic and phenotypic correlations between GFW and FD were positive and very low to moderate, the genetic correlation being 0.08±0.06 and the phenotypic correlation being 0.21±0.02. These estimates are lower than those derived by Safari *et al.* (2005) (respectively 0.36 and 0.31). The inclusion of the maternal genetic correlations in the two-trait analysis of GFW and FD in the present study could have contributed to these lower estimates. The environmental and maternal genetic correlations were estimated at 0.39±0.04 and 0.08±0.02 respectively. Cloete *et al.* (2004b) estimated a slightly lower environmental correlation of 0.31±0.05. Comparable maternal genetic correlation estimates could not be found in the literature. The genetic correlation between CY and GFW was negative and not significant. Cloete *et al.* (2004b) reported corresponding negative and nonsignificant genetic and phenotypic correlations between CY and GFW on South African Mutton Merinos. Other researchers reported comparable results in terms of the sign of the estimate, although the magnitude was somewhat smaller.

The estimates of genetic (0.18±0.06) and phenotypic (0.26±0.02) correlations between GFW and SL were moderate. These estimates were lower than the corresponding mean estimates derived by Safari *et al.* (2005), being respectively 0.44 and 0.32. Gizaw *et al.* (2006) also reported higher genetic (0.65±0.03) and phenotypic (0.50±0.02) correlation for Menz sheep. An environmental correlation of 0.33±0.03 was estimated from the present study. Hanford *et al.* (2005) reported a lower environmental correlation of 0.21 for Rambouillet sheep.

The genetic correlation between SS and GFW was negative and not significant at -0.07, with the phenotypic (0.10±0.02) and environmental (0.18±0.04) correlations being positive but low. In contrast, Safari *et al.* (2005) reported an averaged positive and low genetic correlation of 0.16 between GFW and SS. A similar phenotypic correlation of 0.19 was derived from the literature values (Safari *et al.*, 2005). This difference may be attributed to differences in management and modeling.

SDFD was the only measure of FD that was significantly correlated with GFW in the present study. All correlations were low to moderate between GFW and SDFD, the genetic correlation being 0.11±0.05 and the phenotypic correlation being 0.15±0.02.

In comparison, Safari *et al.* (2005) reported low to moderate correlations for GFW with CVFD and SDFD. The genetic and phenotypic correlations between GFW and CVFD were estimated at 0.09 and 0.36 respectively. Higher genetic and similar phenotypic correlations between GFW and SDFD were derived from literature values by Safari *et al.* (2005). The environmental correlation between GFW and SDFD was estimated at 0.21±0.04 in the present study. No literature sources reporting environmental correlations of GFW and SDFD could be found.

4.3.3.3 Clean fleece weight (CFW) and other objective traits

Generally, CFW is positively correlated with other objective wool traits with the exceptions of the negative but nonsignificant genetic correlation between CFW and SS, as well as negative phenotypic and environmental correlations of CFW with CVFD. The most striking aspect of the present results is a nonsignificant genetic correlation of 0.04±0.06 between CFW and FD. A previous study by Erasmus *et al.* (1990) reported a similar nonsignificant genetic correlation of 0.06±0.16 between CFW and FD. On the contrary, Safari *et al.* (2005) derived a higher mean genetic correlation of 0.28 from the literature values. Recent South African studies reported higher genetic correlations that ranged from 0.14 to 0.17 for the genetic correlation between CFW and FD.

Table 4.14 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations (± SE) between clean fleece weight and other objective wool traits

Trait	**r_g**	**r_p**	**r_e**	**r_m**
Clean fleece weight X				
Fibre diameter	0.04±0.06	0.18±0.02	0.36±0.04	0.19±0.02
Clean yield	0.33±0.05	0.23±0.02	0.18±0.04	-
Staple length	0.29±0.06	0.30±0.02	0.34±0.03	-
Staple strength	-0.12±0.11	0.10±0.02	0.21±0.04	-
CV of fibre diameter	0.02±0.06	-0.01±0.02	-0.05±0.04	-
SD of fibre diameter	0.08±0.06	0.10±0.02	0.13±0.04	-

See **Table 4.12** for abbreviations

These differences may be attributed to the inclusion of the maternal genetic correlation in the two-trait analysis between CFW and FD in the current study. A greater portion of the genetic correlation between CFW and FD may have been partitioned in this direction, as indicated by the somewhat higher maternal correlation of 0.19. Although the genetic correlation between CFW and FD was not significant, the relationship between fleece weights and FD were positive in the bulk of supporting literature.

Other correlations between CFW and FD were low to moderate being respectively 0.18±0.02, 0.36±0.04 and 0.19±0.01 for the phenotypic, environmental and maternal correlations. The phenotypic correlation estimated in the present study is within the range of literature values and slightly lower than the corresponding weighted mean estimate of 0.25 derived by Safari *et al.* (2005) from literature values. The present r_p estimate is in agreement with the estimates of respectively 0.17±0.02 and 0.18±0.02 reported for South African sheep breeds (Olivier *et al*., 2006b; Van Wyk *et al*., 2006). The environmental correlation estimated in the present study (0.36±0.05) is higher than the estimates of 0.27 reported by Cloete *et al.* (2005) but lower than that of 0.42 reported for Elsenburg mature ewes (Cloete *et al*., 2006; Naidoo & Cloete 2006).

The genetic and phenotypic correlations of 0.33±0.05 and 0.23±0.02 reported between CFW and CY in the present study were generally lower than corresponding estimates in the literature, but similar in sign. The environmental correlation reported in the present study (0.18±0.04) is also lower than most literature estimates. In general, CFW is positively and moderately related to SL. The genetic and phenotypic correlations between CFW and SL in Table 4.14 were slightly lower than corresponding values of 0.36 and 0.33 derived from the literature (Safari *et al*., 2005). The environmental correlation of 0.34±0.03 in the present study is higher than estimates of 0.21 (Cloete *et al*., 1998a) and 0.36±0.02 (Olivier *et al.,* 2006a) reported for South African Merino flocks.

Unlike other objective wool traits, SS was negatively related to CFW but the correlation was not significant (Table 4.14). In contrast, Safari *et al.* (2005) derived a positive and moderate genetic correlation of 0.20 between CFW and SS from the literature. Research in South African Merinos (though in mature ewes) also suggested moderate and positive genetic correlations of 0.34 and 0.32 as reported by Cloete *et al*. (2006) and Naidoo & Cloete (2006). The corresponding phenotypic correlation in the present study (0.10±0.02) was slightly lower than the derived value of 0.18 (Safari *et al*., 2005). CVFD and SDFD were not significantly related to CFW (Table 4.14). The literature reports positive and low to moderate genetic correlations of CFW with CVFD and SDFD. The phenotypic correlation (0.10) between CFW and SDFD was low and positive.

4.3.3.4 Clean yield (CY) with other objective traits

Results of the present study showed nonsignificant genetic correlations (Table 4.15) between CY and most of the traits. The exception was the positive and moderate genetic correlation estimated between CY and SL. Researchers have reported conflicting evidence on the direction of the genetic correlation between CY and FD in various sheep breeds. Nonsignificant and negative genetic correlations were reported for Australian and South African Merino sheep (Lewer *et al.,* 1994; Cloete *et al*., 1998a). A moderate and positive genetic correlation of 0.33 ± 0.07 between CY and FD was reported for South African Mutton Merino sheep (Cloete *et al*., 2004b). At 0.04, Safari *et al.* (2005) also derived a positive but very low genetic correlation between CY and FD from literature values.

Table 4.15 Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (± SE) between clean yield and other objective wool traits

Trait	**r_g**	**r_p**	**r_e**
Clean yield X			
Fibre diameter	-0.09±0.04	-0.05±0.02	0.02±0.05
Staple length	0.33±0.05	0.22±0.02	0.12±0.04
Staple strength	0.01±0.10	0.08±0.03	0.14±0.05
CV of fibre diameter	-0.04±0.05	-0.12±0.02	-0.25±0.05
SD of fibre diameter	-0.10±0.05	-0.13±0.02	-0.19±0.05

See **Table 4.12** for abbreviations

The phenotypic correlation between CY and FD was negative and accorded with the estimate reported by Cloete *et al.* (1998a) in direction. In contrast, a positive correlation of 0.13±0.03 was reported for these traits in South African Mutton Merino sheep (Cloete *et al.*, 2004b). While nonsignificant environmental correlation was estimated between CY and FD, Cloete *et al.* (2004b) reported a negative environmental correlation of -0.20±0.06 between CY and FD for South African Mutton Merino sheep.

The genetic correlation between CY and SL in the present study is similar to the estimate reported by Cloete *et al.* (1998a) and somewhat higher than the weighted mean estimate of 0.25 derived from literature values by Safari *et al*. (2005). The corresponding phenotypic correlation estimate of 0.22±0.02 in the present study was consistent with a weighted mean estimate of 0.19 derived from the literature. Positive and nonsignificant correlations between CY and SS were estimated in the present study. This is similar in direction with the estimates derived from the literature values. CVFD and SDFD were negatively correlated to CY. Comparable negative genetic correlations were reported in the literature. The corresponding phenotypic and environmental correlations were low to moderate and generally higher than comparable estimates in the literature.

4.3.3.5 Fibre diameter (FD) and other objective traits

The correlations for FD with SL, SS and SDFD were positive and moderate while CVFD was low and negatively correlated to FD (Table 4.16). The genetic correlation (0.15±0.05) between FD and SL reported in the present study was in line with the weighted mean estimate of 0.19 derived from the literature (Safari *et al*., 2005). Cloete *et al.* (1998a) estimated a somewhat higher estimate on the same flock utilised in this study. The phenotypic correlation between FD and SL was in agreement with the weighted mean value derived from the literature, but somewhat higher than the corresponding estimate reported by Cloete *et al*. (1998a). The corresponding environmental correlation between FD and SL reported in the present study was moderate at 0.25.

Table 4.16 Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (± SE) between fibre diameter and other objective wool traits

Trait	$\mathbf{r_g}$	$\mathbf{r_p}$	$\mathbf{r_e}$
Fibre diameter X			
Staple length	0.15±0.05	0.19±0.02	0.25±0.04
Staple strength	0.40±0.09	0.29±0.02	0.28±0.05
CV of fibre diameter	-0.08±0.05	-0.10±0.02	-0.15±0.06
SD of fibre diameter	0.38±0.05	0.38±0.02	0.42±0.05

See **Table 4.12** for abbreviations

The genetic and phenotypic correlations for FD with SS (0.40±0.09 and 0.29±0.02) were in agreement with derived estimates from the literature (0.37 and 0.23) respectively (Safari *et al*., 2005). Due to insufficient data the present genetic estimate was compared to estimates reported by Cloete *et al.* (2006) and Naidoo & Cloete (2006) who estimated comparable genetic correlations between FD and SS on mature ewes of the Elsenburg Merino flock. The unfavourable genetic correlation between FD and SS generally suggested that, animals with a higher tensile strength would also have broader fibres particularly when breeding objectives are based only on CFW and FD, even when CVFD is included in the selection index (Purvis & Swan, 1999). The corresponding environmental correlation in this study was consistent with estimates of 0.26±0.03 and 0.28 reported for mature ewes of the Elsenburg Merino flock.

The genetic and environmental correlations between CVFD and FD estimated on the Elsenburg Merino flock accorded with the estimates from the present study (Table 4.16). Positive and moderate correlations between SDFD and FD were estimated in the present study being 0.38±0.04, 0.38±0.02 and 0.42±0.05 for the genetic, phenotypic and environmental correlations respectively. These estimates were consistent with correlation estimates of 0.43 (genetic) and 0.40 (phenotypic) derived from the literature by Safari *et al.* (2005).

4.3.3.6 Relationships among staple length (SL), staple strength (SS), coefficient of variation of fibre diameter (CVFD) and standard deviation of fibre diameter (SDFD)

The genetic and phenotypic correlations between SL and SS were positive at 0.19±0.12 and 0.14±0.03 respectively (Table 4.17). These estimates were in agreement pertaining to direction with those derived from the literature but larger in magnitude (Safari *et al*., 2005). This implies that, animals with longer staples are likely to yield wool with stronger staples. Due to lack of information on the correlations between these traits results of a study on mature ewes will be used for comparison of current study, where Naidoo & Cloete (2006) reported a negative and moderate genetic correlation (-0.42) between these two traits. The corresponding environmental correlation of 0.12±0.04 obtained in the present study was different in direction and larger in magnitude with the estimate of -0.04 reported for the Elsenburg Merino flock though not directly comparable. These differences may be due to the fact that mature reproducing ewes were used in the study of Naidoo & Cloete (2006).

CVFD and SDFD were negatively correlated with SL. Most of these correlations were not significant. The only significant correlations were the phenotypic (-0.14±0.02) and environmental (-0.18±0.05) correlations between SL and CVFD. Naidoo & Cloete (2006) reported a similar genetic correlation (-0.42) in direction, but slightly larger in magnitude, possibly because mature, reproducing ewes were used in their study. In contrast, Safari *et al.* (2005) derived a positive and moderate genetic correlation between SL and CVFD. The phenotypic correlations for SL with CVFD (-0.14±0.02) and SDFD (-0.02±0.02) were in line with those reported by Notter *et al.* (2007). The corresponding environmental correlation between SL and CV reported in the present study is similar in direction but larger in magnitude than the estimate of -0.04 reported for the Elsenburg Merino flock. Similarly, these differences may be due to the fact that mature reproducing ewes were used in the study of Naidoo & Cloete (2006).

Table 4.17 Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (± SE) among staple length, staple strength, coefficient of variation of fibre diameter and standard deviation of fibre diameter

Trait	r_g	r_p	r_e
Staple length X			
Staple strength	0.19±0.12	0.14±0.03	0.12±0.04
CV of fibre diameter	-0.11±0.07	-0.14±0.02	-0.18±0.05
SD of fibre diameter	-0.03±0.07	-0.02±0.02	-0.02±0.04
Staple strength X			
CV of fibre diameter	-0.57±0.09	-0.39±0.02	-0.35±0.05
SD of fibre diameter	-0.28±0.10	-0.21±0.02	-0.19±0.05
CV of fibre diameter X			
SD of fibre diameter	0.87±0.01	0.86±0.01	0.85±0.02

See **Table 4.12** for abbreviations

Staple strength is one of the most important determinants of the wool price (Howe *et al.,* 1991; Greeff *et al.,* 1995; Purvis, 1995). The relationships between SS and other wool traits of economic importance were previously studied, in an attempt to incorporate SS into the breeding objective of Merino sheep. This was done because SS is an expensive trait to measure (Greeff *et al.*, 1995), and researchers considered cheaper alternatives to incorporate SS into the breeding objectives for Merino sheep. It was found that CVFD could be a relatively cheap alternative, as suggested by consistently strong and favourable negative genetic relationship between SS and CVFD. Furthermore, in an attempt to address the wool tenderness problem (Howe *et al.*, 1991; Greeff *et al.,* 1997) prevailed in Australia, Purvis & Swan (1999) investigated the inclusion of SS into the breeding objectives for Australian Merino sheep. It was found that, near optimal gains were achieved cheaply for the objective which included CVFD in a selection criterion as an indicator trait for SS.

Accordingly, the present study estimated sizable negative correlations for SS with CVFD and SDFD at all levels (Table 4.17). The genetic (-0.57) and phenotypic (-0.39) correlations between SS and CVFD in the present study were also consistent with those reported from the literature, albeit slightly higher in magnitude. This suggests that the genetic correlations for SS with CVFD and SDFD in South African Merino sheep are quite robust. The corresponding environmental correlation between SS and CVFD estimated in the present study accorded with the estimate reported for Elsenburg Merino flock in mature ewes. It is evident that animals with staples of a higher tensile strength would have a more uniform fibre diameter, as suggested by a significant genetic correlation of -0.28 between SS and SDFD. A moderate and negative phenotypic correlation was also estimated in the present study. Comparable estimates between SS and SDFD were previously reported for Australian Merino resource flocks (Greeff *et al.*, 1995; Swan *et al.,* 1995). The present environmental correlation was also negative and moderate at -0.19. No environmental correlations between SS and SDFD could be found from the literature.

The two measures of FD were highly related at genetic level (0.87±0.01). Other correlations were also positive and high, with the phenotypic correlation being 0.86±0.01 and the environmental correlation being 0.85±0.02. Corresponding genetic and phenotypic correlations derived from the literature by Safari *et al.* (2005) amounted to 0.76 and 0.82 respectively. Notter *et al.* (2007) reported a similar phenotypic correlation of 0.83. These results imply that selection for CVFD as an indicator trait for animals with stronger staples would not result in animals with excessive variation of FD along their fleeces/staples. No comparable environmental correlations of CVFD with SDFD could be found from the literature.

4.4 Conclusions

The results presented in the present study generally correspond with the most recent literature parameter estimates for objective wool traits. This underlines the reliability of the current estimation procedures as well as the quality of data utilised in analyses. These results also emphasises the importance of the model of choice to be used in the analysis of LW and objective wool traits in South African Merino sheep. Moderate to high heritability estimates suggest responses to selection, and the feasibility of genetic change in live weight, wool weight and wool quality. It is also evident that antagonistic relationships between animal effects are unlikely to compromise responses to selection for LW, GFW, CFW as well as FD. This contention is supported by substantial genetic progress reported for South African Merino sheep when directed selection was applied to these traits of economic importance.

The genetic correlation between the two most important determinants of wool price (SS and FD) was moderate and unfavourable. These results have implications for selection programmes for a decreased FD, if SS needs to be maintained. SS and CVFD were favourably correlated while favourable but low correlations were also estimated between FD and CVFD. These results suggested a favourable correlated response to selection for decreased FD when direct selection is practiced on CVFD as an indicator trait for SS (Greeff *et al*., 1995). The generally unfavourable correlations between quantitative wool traits (GFW and CFW) with some qualitative wool traits (SS, FD and CVFD) need to be considered carefully during selection for an increased profit. Fortunately the size of these correlations is generally small and they are not expected to cause a major problem. The genetic correlations of LW with the objective wool traits were mostly not significant, thus the correlated response to selection for these traits will either be not important or alternatively favourable, as for CVFD and SDFD.

CHAPTER 5

(CO) VARIANCE COMPONENTS AND GENETIC PARAMETERS FOR SUBJECTIVELY ASSESSED WOOL AND CONFORMATION TRAITS

5.1 Introduction

Subjectively assessed wool and conformation traits form part of the selection objective for breeding stock in the wool sheep industry. Commercial Merino breeders frequently used these subjectively assessed wool and conformation traits during the selection of sires and dams (Morley, 1955, Brown & Turner, 1968; Gregory, 1982a & b; Lewer *et al*., 1990; Lewer *et al*., 1995; Groenewald *et al*., 1999; Snyman & Olivier, 2002a; Naidoo *et al*., 2004; Olivier *et al*., 2006a). Olivier *et al*. (2006a) emphasised that, in some instances, the subjective scores for specific fleece and conformation traits are the only selection criteria used by both meat and wool producers, as some traits such as wool quality and body conformation are seen as important for the economic viability of farms. Furthermore, Snyman & Olivier (2002a) stated that animals are culled on the basis of these traits in some instances. Knowledge of variance components and genetic parameters for subjective traits are required to design breeding programmes incorporating such traits in the breeding objectives.

Linear type scoring was developed for South African Merino sheep (Olivier *et al*., 1987) to obtain data for determining the variance components and ratios for subjective wool and conformation traits. Therefore, researchers previously used such data to estimate variance components and genetic parameters for some subjectively assessed wool and conformation traits in South African Merino and Afrino sheep (Cloete *et al*., 1992; Groenewald *et al*., 1999; Snyman & Olivier, 2002a; Naidoo *et al*., 2004; Cloete *et al*., 2005; Olivier *et al*., 2006a & b; Cloete *et al*., 2006). Phenotypic (Cloete *et al*., 1992 and genetic (Snyman & Olivier, 2002a; Olivier *et al*., 2006b) correlations among some subjectively assessed wool and conformation traits have also been reported in South African Merino and Afrino sheep. Information regarding environmental and maternal correlations for these traits could not be found in the literature.

Data for Merino sheep have been accumulated for more than a decade to accurately estimate variance components and genetic parameters for subjectively assessed wool and conformation traits. Therefore, the objective of the current study was to estimate genetic parameters for subjectively assessed wool and conformation traits. The genetic, phenotypic, environmental and maternal correlations between nine subjectively assessed wool and six subjectively assessed conformation traits were also estimated.

5.2 Materials and methods

5.2.1 Data

The Merino flock maintained on the Tygerhoek experimental farm was used as experimental animals in the current study. It consisted of four lines as described in Chapter 3. The traits were assessed according to a linear scale (Table 3.1) ranging from 1-50 (Olivier *et al*., 1987) at 14-16 months of age. The subjectively assessed wool traits were wool quality (QUAL), regularity of crimp (ROC), wool colour (COL), face cover score (FCS), pigmentation (PIGM), woolly face score (WFS), staple formation (STAPL), belly and points (BANDP) and wool oil (OIL). The subjectively assessed conformation traits included in the analysis were pastern score (PS), general head conformation (GEN), front quarters (FQ), top line (TOPL), total fold score (TOT) and hocks (HOCKS). A description of the data used for analyses is presented in Table 5.1. The data used for the analysis of subjective wool and conformation traits were edited as described in Chapter 3. Fixed effects to be included in the operational model for each trait were tested using the ASREML programme (Gilmour *et al*., 2002). Details of the models fitted for fixed effects are described in Chapter 3.

Table 5.1 Description of data used for analysis of subjective wool and conformation traits

	Trait														
Description	QUAL	ROC	COL	OIL	STAPL	BANDP	WFS	FCS	PIGM	GEN	HOCKS	FQ	PS	TOPL	TOT
No of animals before editing	5093	5093	5093	5093	5093	5091	4368	5093	5090	4274	4275	4276	4275	4310	4579
No of animals after editing	4512	4785	4784	4811	4811	4809	4351	4811	4809	4625	4266	4267	4235	4268	4549
No of sires after editing	416	433	433	433	434	434	382	434	434	396	396	396	393	395	413
No of dams after editing	1621	1745	1745	1759	1759	1758	1545	1740	1759	1500	1500	1500	1492	1504	1630
Number of years	16	16	16	16	16	16	15	16	16	14	14	14	14	14	15
No of sex*year classes	32	32	32	32	32	32	30	32	32	28	28	28	28	28	30
Period	1989 - 2004	1989 - 2004	1989 - 2004	1989 - 2004	1989 - 2004	1989 - 2004	1991 - 2004	1989 - 2004	1989 - 2004	1989 - 2002	1989 - 2004	1989 - 2002	1989 - 2002	1989 - 2002	1989 - 2002

TOT = total fold score, FCS = face cover score, PIGM = pigmentation, WFS = woolly face score, QUAL = quality, ROC regularity of crimp, COL = colour, STAPL = staple formation, BANDP = belly and points, GEN = head general, FQ = front quarters, PS = pastern score and TOPL = top line

5.2.2 Statistical analysis

Similar procedures as described in Chapter 3 were adopted to estimate variance components and ratios for subjective wool and conformation traits. The correlations (genetic, phenotypic, environmental and maternal) among the subjectively assessed wool and conformation traits were subsequently computed by fitting two-trait animal models using ASREML (Gilmour *et al.*, 2002). Model 1 was used to estimate the (co)variance structure and correlations for most of the subjective wool and conformation traits. The exceptions were for QUAL, ROC, OIL and PS where Model 3 was used and for GEN where Model 6 was used. The two-trait animal models that were fitted subsequently to derive correlations between traits included all the components found to be significant in the single-trait analyses as appropriate.

5.3 Results and Discussion

5.3.1 Non-genetic effects and descriptive statistics

Analysis of non genetic effects indicated that birth status (single/multiple), sex (male/female), age of the dam in years (2-6), year of birth (1989-2004) selection line (1-4) and the sex*birth year interaction had a significant ($P<0.05$) effect on all subjective wool and conformation traits. This is in accordance with the results reported by Cloete *et al.* (1998) and Naidoo *et al.* (2004) in South African Merinos where all these fixed effects had a significant effect on the corresponding subjective wool traits. Snyman & Olivier (2002a) also included similar fixed effects in models for corresponding subjective conformation traits in Afrino sheep. As a result, all these fixed effects were retained in the models for subsequent analyses.

Means, standard deviations (SD) and coefficients of variation (CV) for subjective wool and conformation traits are summarised in Table 5.2. Of all the subjective traits TOT had the lowest mean while PIGM had the highest mean, as related to the scale of measurement. Standard deviations (SD) ranged from 4.0 to 9.0 for subjectively assessed wool traits and from 2.0 to 9.0 for subjectively assessed conformation traits. TOT had the smallest SD compared to the other subjective traits. PIGM, QUAL, ROC, WFS, FQ and HOCKS were the most variable traits, as denoted by CV's exceeding 25%. OIL showed less variation than the other subjective traits. This is in agreement with the corresponding results obtained from the literature.

Table 5.2 Descriptive statistics of data used for the analysis of subjective wool and conformation traits after editing

Trait	Mean	SD	CV (%)	Minimum	Maximum
Subjective wool traits					
Quality (QUAL)	31.0	9.0	29.0	1	50
Regularity of crimp (ROC)	33.0	9.0	27.3	1	50
Colour (COL)	30.0	7.0	23.3	1	50
Oil or yolk (OIL)	26.0	4.0	15.4	3	45
Staple formation (STAPL)	28.0	5.0	17.9	2	48
Belly and points (BANDP)	30.0	6.0	20.0	1	50
Woolly face score (WFS)	28.0	8.0	28.6	1	50
Face cover score (FCS)	29.0	6.0	20.7	1	50
Pigmentation (PIGM)	34.0	9.0	26.5	1	50
Subjective conformation traits					
Head general (GEN)	28.0	7.0	25.0	1	50
Hocks (HOCKS)	26.0	9.0	34.6	1	48
Front quarters (FQ)	24.0	7.0	29.2	1	50
Pastern score (PS)	33.0	7.0	21.2	2	50
Topline (TOPL)	29.0	7.0	24.1	1	50
Total fold score (TOT)	9.0	2.0	22.2	3	17

SD = standard deviation and CV = coefficient of variation

5.3.2 (Co)variance components and ratios of subjective traits

The (co)variance components and genetic parameter estimates for subjectively assessed traits using single-trait animal models are presented in Tables 5.3 to 5.17. The most appropriate model for QUAL, COL, ROC and PS was Model 3 while Model 6 was the most appropriate for GEN. Model 1 fitted the majority of traits, namely FCS, PIGM, WFS, OIL, STAPL, BANDP, HOCKS, FQ, TOPL and TOT best. Significant maternal effects on these traits were not expected, because scoring took place at a stage of an animal's life where the maternal effects were believed not to have an effect. Also previous studies on these traits did not report significant maternal variation. Direct heritability estimates in the present study for subjectively assessed wool (Table 5.3 to 5.11) and conformation (Tables 5.12 to 5.17) traits were moderate to high and ranged from 0.13±0.03 for TOPL to 0.50±0.03 for WFS. Low maternal heritability estimates for some of these traits were also estimated. The correlation between animal effects estimated for some of these traits in the present study were moderate to high and negative in sign. Detailed discussions of individual subjective traits and the relationships between traits follow below.

5.3.2.1 Wool quality (QUAL)

Wool quality is one of the most important subjective wool traits. It is believed to be of importance for the economic viability of sheep farms (Olivier *et al.,* 2006a). The (co)variance components and genetic parameters for QUAL from single-trait analysis are presented in Table 5.3. According to the log likelihood ratio test the most appropriate model for QUAL (Model 3) included the direct and maternal additive effects as well as the covariance between animal effects. Groenewald *et al.* (1999) and Naidoo *et al.* (2004) used the Model with direct additive effect as the only random variable.

QUAL is highly heritable at 0.49±0.05 in the present study and should respond to selection if desired. The present h^2_a estimate is higher than estimates of 0.23±0.04 (Groenewald *et al.*, 1999) and 0.27±0.04 (Naidoo *et al.*, 2004) reported for South African

Merino sheep. Gregory (1982a) also reported a lower h^2_a estimate of 0.25±0.05 for Australian Merinos.

Table 5.3 (Co)variance components and ratios for wool quality in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	**Model 3**	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	20.59	20.57	**27.73**	20.56	27.87	20.42
σ^2_m	-	0.03	**3.18**	0.11E-04	2.33	-
σ^2_{pe}	-	-	**-**	0.59	1.15	0.60
σ^2_e	35.87	35.87	**31.86**	34.97	31.33	35.48
σ^2_p	56.46	56.48	**56.95**	56.11	56.94	56.50
σ_{am}	-	-	**-5.82**	-	-5.82	-
Variance ratios						
h^2_a	0.36	0.36	**0.49**	0.37	0.49	0.36
SE	0.03	0.03	**0.05**	0.03	0.05	0.03
h^2_m	-	0.00	**0.06**	0.00	0.04	-
SE	-	0.01	**0.02**	0.00	0.03	-
r_{am}	-	-	**-0.62**	-	-0.71	-
SE	-	-	**0.09**	-	0.15	-
c^2_{pe}	-	-	**-**	0.01	0.02	0.01
SE	-	-	**-**	0.01	0.02	0.01
h^2_t	0.36	0.36	**0.36**	0.37	0.36	0.36
Log L	-11153.4	-11153.4	**-11145.8**	-11153.1	-11145.2	-11153.1

σ^2_a = direct additive genetic variance, σ^2_m = maternal additive genetic variance, σ^2_{cpe} = permanent environmental variance, σ^2_e = residual variance, σ^2_p = total phenotypic variance, σ^2_{am} = covariance between direct and maternal additive genetic effects, h^2_a= direct heritability, h^2_m= maternal heritability, r_{am} = genetic correlation between direct and maternal additive genetic effects, heritability, h^2_t = total heritability $\{(\sigma^2_a + 0.5\,\sigma^2_m + 1.5\,\sigma_{am})/\,\sigma^2_p\}$, Log L = Log likelihood

However, if the corresponding model used in their analyses (Model 1) was considered, the present estimate of 0.36 was comparable with those estimated earlier. These differences in h^2_a may be attributed to different random effects fitted in the analyses.

Safari *et al.* (2007b) concluded that the inclusion of the covariance between direct additive and maternal additive variances resulted in higher heritability estimates for objective wool traits. This is likely to be also applicable to the present study for analysis of QUAL compared to estimates in the literature that were cited. An h^2_m estimate of 0.06±0.02 was obtained from the current study. The correlation between direct additive and maternal additive effects was high and amounted to -0.62±0.09, while h^2_t was estimated at 0.36. No maternal and total heritability estimates and the direct-maternal correlation pertaining to QUAL could be found in literature.

5.3.2.2 Regularity of crimp (ROC)

In practice, less emphasis is placed on regularity of crimp than on QUAL in Afrino sheep (Snyman & Olivier, 2002a). However, ROC is one of the subjectively assessed wool traits that Merino sheep breeders consider during selection (Olivier *et al.*, 1987; Cloete *et al.*, 1992; Naidoo *et al.*, 2004). Its heritability and relationship with other economically important traits thus need to be investigated. Current estimates of (co)variance components and genetic parameters for ROC using six different models are presented in Table 5.4. Model 3 proved to be the best model for ROC as for QUAL. In contrast, Naidoo *et al.* (2004) and Snyman & Olivier (2002a) used the model with the direct additive effect as the only random variable.

The direct h^2_a estimated in the present study was 0.28±0.04, which is in agreement with an estimate of 0.28±0.04 for Afrino sheep (Snyman & Olivier, 2002a). However, Naidoo *et al.* (2004) estimated a relatively lower heritability of 0.19±0.03 on the same flock using a smaller data set. The differences between studies may be the result of accumulated data for the present study as well as the use of different random effects models. Estimates for h^2_m and h^2_t amounted to 0.03±0.00 and 0.20 respectively. A very high correlation between animal effects was estimated at -0.70±0.14. This suggests that the inclusion of a number of random effects in models of analysis for ROC to be considered. Literature estimates for the corresponding effects could not be obtained.

Table 5.4 (Co)variance components and ratios for regularity of crimp in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	**Model 3**	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	9.89	10.11	**14.39**	9.96	14.39	10.24
σ^2_m	-	0.54E-05	**1.61**	0.35	1.61	-
σ^2_{pe}	-	-	**-**	0.51E-05	0.22E-04	0.85E05
σ^2_e	40.56	40.38	**38.12**	40.22	38.12	40.29
σ^2_p	50.43	50.50	**50.76**	50.55	50.16	50.50
σ_{am}	-	-	**-3.35**	-	-3.35	-
Variance ratios						
h^2_a	0.20	0.20	**0.28**	0.20	0.28	0.20
SE	0.03	0.03	**0.04**	0.03	0.04	0.03
h^2_m	-	0.00	**0.03**	0.01	0.03	-
SE	-	0.00	**0.00**	0.01	0.02	-
r_{am}	-	-	**-0.70**	-	-0.70	-
SE	-	-	**0.14**	-	0.14	-
c^2_{pe}	-	-	**-**	0.00	0.00	0.00
SE	-	-	**-**	0.00	0.00	0.00
h^2_t	0.20	0.20	**0.20**	0.20	0.20	0.20
Log L	-11692.3	-11692.3	**-11687.6**	-11692.8	-11687.6	-11692.3

See **Table 5.3** for abbreviations

5.3.2.3 Wool colour (COL)

Wool colour is an important determinant of wool price in Merinos (James *et al.*, 1990; Brown *et al.,* 2006). Researchers reported wool colour being a trait of interest from the wool processing perspective. Wool was graded based on colour in Australian markets where a discount was provided for clean wool (James *et al.*, 1990; Brown *et al.*, 2006). Wool colour is also associated with economically important wool problems like fleece rot and body strike, where increased greasy wool colour may also increase the risk of fleece rot and flystrike (McGuirk & Atkins, 1984; Raadsma *et al.,* 1989; James *et al.,* 1990; Raadsma & Wilkinson, 1990; Cloete *et al*., 2001a). Previous studies suggested wool colour as being moderately to highly heritable and also suggested greasy wool colour as an indirect selection criteria for selection against fleece rot and body strike that damage the fleece and reduce its value (James *et al.,* 1990; Raadsma & Wilkinson, 1990; Brown *et al*., 2006). In the present study, (co)variance components and genetic parameter estimates for COL are presented in Table 5.5.

Like for QUAL and ROC, Model 3 fitted the data best for analysis of COL in the present study. Brown *et al*. (2006) used the model with direct and maternal additive effects as random variables for analysis of COL in Australian Merino sheep. Also, other researchers used different random models in the analysis of COL for various sheep breeds where only the additive effect was mostly the only random variable (Lewer *et al*., 1995; Groenewald *et al*., 1999; Benavides & Maher, 2003; Naidoo *et al*., 2004).

Direct heritability estimates of COL for Merinos ranged from 0.17±0.03 to 0.61±0.11 (Mullaney *et al*., 1970; Raadsma & Wilkinson, 1990; McGuirk & Atkins, 1980; James *et al*., 1990; Lewer *et al*., 1995; Groenewald *et al*., 1999; Naidoo *et al*., 2004) and from 0.27 to 0.34 for dual purpose breeds (Mullaney *et al*., 1970; Benavides & Maher, 2003). The h^2_a estimate of 0.33±0.05 obtained from the present study falls within the range of these literature values. A slightly higher value (0.38±0.04) was reported for the same flock, using a smaller data set (Naidoo *et al*., 2004). McGuirk & Atkins (1980) and James *et al*. (1990) reported higher h^2_a estimates of respectively 0.42 and 0.61 for Australian Merino sheep. In contrast, lower h^2_a estimates were reported for Western Australian Merinos (0.18±0.06) (Lewer *et al.,* 1995), South African Merino (0.17±0.03) (Groenewald *et al.,* 1999) and Corriedales (0.27±0.13) (Benavides & Maher, 2003). The h^2_m estimate for COL amounted to 0.07±0.03. Brown *et al*. (2006) reported a lower h^2_m of 0.03 in Australian Merino. The conflicting result may be attributed to the differences in scoring methods, models used for analyses and different environments where sheep were managed.

Table 5.5 (Co)variance components and ratios for wool colour in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	**Model 3**	Model 4	Model 5	Model 6
(Co) variance components						
σ^2_a	10.07	9.30	**12.03**	9.31	12.00	9.75
σ^2_m	-	1.00	**2.60**	0.95	2.59	-
σ^2_{pe}	-	-	**-**	0.077	0.14E-04	0.75
σ^2_e	26.02	25.80	**24.17**	25.77	24.10	25.56
σ^2_p	36.09	36.10	**36.29**	36.10	36.19	36.06
σ_{am}	-	-	**-2.51**	-	-2.49	-
Variance ratios						
h^2_a	0.28	0.26	**0.33**	0.26	0.33	0.27
SE	0.03	0.03	**0.05**	0.03	0.05	0.03
h^2_m	-	0.03	**0.07**	0.03	0.07	-
SE	-	0.02	**0.03**	0.02	0.02	-
r_{am}	-	-	**-0.45**	-	-0.45	-
SE	-	-	**0.12**	-	0.12	-
c^2_{pe}	-	-	**-**	0.002	0.00	0.02
SE	-	-	**-**	0.02	0.00	0.01
h^2_t	0.28	0.27	**0.26**	0.27	0.26	0.27
Log L	-10834.8	-10834.7	**-10829.4**	-10832.7	-10829.6	-10833.5

See **Table 5.3** for abbreviations

The h^2_t estimate for COL amounted to 0.26 in the present study. The derived correlation between animal effects obtained from the present study was -0.45±0.12. No comparable results were found in the literature.

5.3.2.4 Wool oil (yolk) (OIL)

Unlike previously discussed subjective wool traits, the LRT test suggested Model 1 as the "best" model to be fitted for the analysis of OIL. It is a model with only the direct additive animal effect as a random variable. Groenewald *et al.* (1999) and Naidoo *et al.* (2004) used similar random models in analyses involving South African Merinos. Table 5.6 presents (co)variance components and ratios for OIL in the Tygerhoek Merino flock.

Table 5.6 (Co)variance components and ratios for wool oil in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**3.28**	3.40	3.83	3.18	-	3.19
σ^2_m	**-**	0.33E-05	0.05	0.105E-05	-	-
$\sigma^2_{c/pe}$	**-**	-	-	0.17	-	0.17
σ^2_e	**10.67**	10.58	10.46	10.60	-	10.58
σ^2_p	**13.95**	13.98	13.97	13.94	-	13.94
σ_{am}	**-**	-	-0.37	-	-	-
Variance ratios						
h^2_a	**0.23**	0.24	0.28	0.23	-	0.23
SE	**0.03**	0.03	0.04	0.03	-	0.03
h^2_m	**-**	0.00	0.003	0.00	-	-
SE	**-**	0.00	0.02	0.00	-	-
r_{am}	**-**	-	-0.88	-	-	-
SE	**-**	-	2.10	-	-	-
c^2_{pe}	**-**	-	-	0.01	-	0.01
SE	**-**	-	-	0.01	-	0.01
h^2_t	**0.23**	0.24	0.24	0.23	-	0.22
Log L	**-8661.89**	-8661.93	-8660.92	-8661.52	-	-8661.52

See **Table 5.3** for abbreviations

The estimated h^2_a from the present study was 0.23±0.03, as was the h^2_t. These estimates are in agreement with the value of 0.25±0.04 for the same flock, on less data (Naidoo *et al.,* 2004) and 0.24±0.04 for data obtained from the National Merino progeny test (Groenewald *et al.*, 1999).

5.3.2.5 Staple formation (STAPL)

(Co)variance components and genetic parameters for STAPL from single-trait analysis are presented in Table 5.7. Like for OIL, a model with only the direct additive effect fitted the data best for STAPL. This is consistent with models used in previous studies (Groenewald *et al.*, 1999; Naidoo *et al.*, 2004). The h^2_a estimate obtained in the present study was 0.21±0.03 with a similar h^2_t.

Table 5.7 (Co)variance components and ratios for staple formation in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**4.45**	3.94	4.29	3.94	4.31	4.09
σ^2_m	**-**	0.49	0.68	0.30	0.49	-
σ^2_{pe}	**-**	-	-	0.27	0.29	0.49
σ^2_e	**17.08**	17.07	16.88	16.97	16.76	16.91
σ^2_p	**21.53**	21.50	21.51	21.48	21.49	21.50
σ_{am}	**-**	-	-0.34	-	-0.35	-
Variance ratios						
h^2_a	**0.21**	0.18	0.20	0.18	0.20	0.19
SE	**0.03**	0.03	0.04	0.03	0.04	0.03
h^2_m	**-**	0.02	0.03	0.01	0.02	-
SE	**-**	0.01	0.02	0.02	0.02	-
r_{am}	**-**	-	-0.20	-	-0.24	-
SE	**-**	-	0.24	-	0.27	-
c^2_{pe}	**-**	-	-	0.01	0.01	0.02
SE	**-**	-	-	0.02	0.02	0.01
h^2_t	**0.21**	0.19	0.19	0.19	0.19	0.19
Log L	**-9720.90**	-9719.32	-9719.12	-9719.15	-9719.93	-9719.54

See **Table 5.3** for abbreviations

Lower estimates of h^2_a were reported on a smaller data set for the same flock (0.12±0.03; Naidoo *et al*., 2004) and for the Animals in the National Merino progeny test (0.09±0.03; Groenewald *et al*., 1999). In contrast, Olivier *et al.* (2006) estimated a higher h^2_a of 0.40 for STAPL in the Cradock fine wool Merino flock compared to the present study. There thus appears to be genetic variation for STAPL, although the magnitude of h^2 estimates differs between studies.

5.3.2.6 Belly and points (BANDP)

BANDP refers to the quality and the quantity of wool growing on the belly and points. A previous study on Afrino sheep by Snyman & Olivier (2002a) reported that, in practice animals are culled mostly on the basis of the belly wool creeping into the sides of the sheep. Research in the South African Merino investigated the quality of such wool and its heritability that would aid in selection decisions (Groenewald *et al*., 1999; Naidoo *et al*., 2004). Current estimates of (co)variance components and genetic parameters for BANDP using six different random effect models are presented in Table 5.8. Model 1 which includes only the direct additive effect fitted the data best for BANDP. Similar random effects models have been used in previous genetic analyses on South African Merino sheep (Groenewald *et al*., 1999; Naidoo *et al*., 2004).

It was evident from the literature cited that BANDP is a moderately heritable trait and h^2_a estimates ranged from 0.17±0.03 to 0.25±0.04 for South African Merino sheep (Groenewald *et al*., 1999; Naidoo *et al*., 2004). The h^2_a estimated in the present study (0.22±0.03) is within this range of literature values. Naidoo *et al.* (2004) estimated a slightly higher h^2_a, using a smaller data set obtained from the same flock used in the present study. In contrast, Groenewald *et al.* (1999) reported a slightly lower h^2_a than the value derived from the present study.

Table 5.8 (Co)variance components and ratios for belly and points in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**7.95**	7.85	8.80	7.83	8.67	8.03
σ^2_m	**-**	0.12	0.66	0.10	0.25	-
$\sigma^2_{c/pe}$	**-**	-	-	0.53E-05	0.12E04	0.11E-04
σ^2_e	**27.55**	27.53	26.98	27.39	26.86	27.51
σ^2_p	**35.50**	35.50	35.53	35.33	35.35	35.55
σ_{am}	**-**	-	-0.91	-	-0.42	-
Variance ratios						
h^2_a	**0.22**	0.22	0.25	0.22	0.25	0.23
SE	**0.03**	0.03	0.04	0.03	0.04	0.03
h^2_m	**-**	0.003	0.02	0.003	0.007	-
SE	**-**	0.01	0.02	0.01	0.02	-
r_{am}	**-**	-	-0.38	-	-0.29	-
SE	**-**	-	0.22	-	0.38	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.00
SE	**-**	-	-	0.00	0.00	0.00
h^2_t	**0.22**	0.22	0.22	0.22	0.23	0.23
Log L	**-10896.4**	-10896.4	-10895.7	-10896.4	-10895.7	-10896.4

See **Table 5.3** for abbreviations

5.3.2.7 Woolly face score (WFS)

WFS measures the quantity of wool around non wool areas of the face where woolly faced, with the wool growing into the bare areas around the nose, cheek folds and eyes is undesirable. An excessive tuft, cheek folds and wool surrounding eyes is mostly undesirable because it could cause wool blindness (Morley, 1955). WFS analysed in the present study refers to a trait face cover score (FCS) that were previously analysed in Australian Merinos. In Australian research, FCS was evaluated as a potential indicator trait for fertility in Merino sheep (Young *et al.,* 1963), where it was suggested that animals with heavily covered faces were likely to have fewer lambs born. Therefore, WFS will be compared to Australian FCS in the current discussion. The present (co)variance components and genetic parameters for WFS from single trait models are presented in Table 5.9. Model 1 including only the direct additive effect as a sole random variable was the model of choice for the analysis of WFS.

Table 5.9 (Co)variance components and ratios for woolly face score in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**26.71**	26.74	27.38	26.55	20.96	26.47
σ^2_m	**-**	0.43E-05	0.09	0.42E-05	0.96E-03	-
$\sigma^2_{c/pe}$	**-**	-	-	0.29	0.34	0.30
σ^2_e	**27.08**	27.05	26.79	26.90	30.38	26.96
σ^2_p	**53.79**	53.79	53.81	53.74	51.82	53.74
σ_{am}	**-**	-	-0.45	-	-0.14	-
Variance ratios						
h^2_a	**0.50**	0.50	0.51	0.49	0.40	0.49
SE	**0.03**	0.03	0.05	0.03	0.01	0.03
h^2_m	**-**	0.00	0.002	0.00	0.00	-
SE	**-**	0.00	0.02	0.00	0.00	-
r_{am}	**-**	-	-0.28	-	0.99	-
SE	**-**	-	1.14	-	0.00	-
c^2_{pe}	**-**	-	-	0.01	0.01	0.01
SE	**-**	-	-	0.01	0.01	0.01
h^2_t	**0.50**	0.50	0.51	0.49	0.40	0.49
Log L	**-10528.6**	-10528.6	-10528.6	-10528.5	-10529.5	-10528.5

See **Table 5.3** for abbreviations

WFS is a highly heritable trait, as suggested by a direct h^2_a as well as h^2_t estimated at 0.50±0.03. Previous researchers indicated WFS being moderately to highly heritable at 0.29 to 0.76, and should respond to selection if desired (Morley, 1955; Brown & Turner, 1968; Watson *et al.*, 1977; Gregory, 1982a; Lewer *et al.*, 1995). The highest heritability of 0.76 was estimated by Watson *et al.* (1977) for one of the Australian Merino resource flocks while other estimates (0.29-0.38) were lower than the present estimate.

5.3.2.8 Face cover score (FCS)

FCS measures the softness of wool covering the face. In Afrino research, Snyman & Olivier (2002a) referred to it as FACE and identified is as one of the subjectively assessed traits on which much emphasis is placed during selection of Afrino breeding animals. The (co)variance components and genetic parameters for FCS are presented in Table 5.10. Model 1, with only the direct additive effect as a random source of variation fitted the data best for FCS. Snyman & Olivier (2002a) also used a similar model to analyse FCS. Information of this trait for Merinos was lacking from literature.

The present h^2_a of 0.15±0.03 was slightly lower than that of 0.23 reported for Afrino sheep (Snyman & Olivier, 2002a). Similarly, h^2_t was estimated at 0.15 for FCS in the present study. No comparable estimates were found from the literature cited.

Table 5.10 (Co)variance components and ratios for face cover score in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**3.67**	3.77	4.34	3.67	4.33	3.66
σ^2_m	**-**	0.26E-05	0.25	0.44	0.24	-
σ^2_{pe}	**-**	-	-	0.21E-05	0.21E-05	0.29E-09
σ^2_e	**21.07**	21.00	20.75	20.75	20.76	20.90
σ^2_p	**24.75**	24.78	24.78	24.86	24.79	24.60
σ_{am}	**-**	-	-0.56	-	-0.54	-
Variance ratios						
h^2_a	**0.15**	0.15	0.18	0.15	0.17	0.15
SE	**0.03**	0.03	0.04	0.03	0.04	0.03
h^2_m	**-**	0.00	0.01	0.02	0.01	-
SE	**-**	0.00	0.02	0.01	0.02	-
r_{am}	**-**	-	-0.54	-	-0.53	-
SE	**-**	-	0.33	-	0.34	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.00
SE	**-**	-	-	0.00	0.00	0.00
h^2_t	**0.15**	0.15	0.15	0.16	0.15	0.15
Log L	**-10085.8**	-10085.2	-10085.2	-10087.4	-10085.3	-10085.4

See **Table 5.3** for abbreviations

5.3.2.9 Pigmentation (PIGM)

Dark fibres in white wool are a serious defect that is heavily penalised in the market when identified (Fleet *et al.,* 2002). In an attempt to attend to wool quality and price problems caused by pigmented fibre, Australian Wool Innovation initiated a research program to develop technology for presale measurements of wool bales for dark and highly medullated fibres (Fleet *et al.*, 2002). It was from extensive work by Fleet (1996) that the inheritance and importance of pigmented fibres were highlighted. Recently

Snyman & Olivier (2002a) investigated the heritability of PIGM and its relationship with other traits of economic importance in Afrino sheep, owing to the fact that the extent of pigmentation on the face and ears was one of the subjectively assessed traits on which much emphasis was placed during selection.

Table 5.11 (Co)variance components and ratios for pigmentation in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**28.44**	27.78	24.55	28.50	-	28.50
σ^2_m	**-**	0.12E-0.4	0.74E-03	0.13E-04	-	-
$\sigma^2_{c/pe}$	**-**	-	-	-	-	0.19
σ^2_e	**34.58**	33.69	37.01	34.54	-	34.70
σ^2_p	**63.02**	61.47	69.69	63.04	-	63.22
σ_{am}	**-**	-	-0.13	-	-	-
Variance ratios						
h^2_a	**0.45**	0.45	0.40	0.45	-	0.45
SE	**0.03**	0.03	0.00	0.03	-	0.03
h^2_m	**-**	0.00	0.00	0.00	-	-
SE	**-**	0.00	0.00	0.00	-	-
r_{am}	**-**	-	0.99	-	-	-
SE	**-**	-	0.00	-	-	-
c^2_{pe}	**-**	-	-	0.00	-	0.00
SE	**-**	-	-	0.00	-	0.00
h^2_t	**0.45**	0.45	0.35	0.45	-	0.45
Log L	**-12059.6**	12059.6	-12061.1	-12059.6	-	12059.6

See **Table 5.3** for abbreviations

In the present study on South African Merino sheep, the estimates of (co)variance components and genetic parameters for PIGM are presented in Table 5.11. Model 1, with the direct additive effect as the only random source of variation fitted the data best for PIGM. Snyman & Olivier (2002a) used a similar model to analyse PIGM.

At 0.45±0.03 PIGM was highly heritable in Merino sheep. This estimate corresponded fairly well, but was slightly lower than the corresponding estimate of 0.50±0.04 reported in Carnarvon Afrino sheep (Snyman & Olivier 2002a). A similar h^2_t (0.45) was estimated for PIGM in the present study.

5.3.2.10 Total fold score (TOT)

TOT is one of the subjectively assessed conformation traits on which much emphasis is placed during selection in Merino sheep. Plainer sheep are more desirable at present. Previous research investigated the heritability and relationship of TOT with other traits of economic importance in Merinos (Morley, 1955; Beattie, 1962; Brown & Turner, 1968; Jackson *et al.*, 1975; Gregory, 1982a; Lewer *et al.*, 1995; Cloete *et al.*, 1998b; Groenewald *et al.*, 1999; Cloete *et al.*, 2005). It was found that TOT is a moderately to highly heritable trait. Current study estimates of (co)variance components and genetic parameters for TOT are presented in Table 5.12. Similar to the majority of other conformation traits, a model including only the direct additive effect as random effect, proofed to be the best model for the analysis of TOT. Authors previously used similar models to analyse TOT for South African Merino sheep (Cloete *et al.*, 1998; Groenewald *et al.*, 1999; Cloete *et al.*, 2005).

The estimated h^2_a of TOT ranged from 0.32±0.04 to 0.54±0.04 for South African Merino sheep and from 0.15 to 0.80 for Australian Merino sheep. The h^2_a of 0.39±0.03 in the present study is within the range of literature estimates. The present estimate is somewhat lower than the h^2_a estimate of 0.54 reported for the Elsenburg Merino flock (Cloete *et al.*, 2005) but higher than that reported by Groenewald *et al.* (1999). The estimate of h^2_a in the present study accords with a corresponding estimate (0.42±0.04) reported by Cloete *et al.* (1998a) for the same flock. An estimated h^2_t of 0.39 was derived from the current study.

Table 5.12 (Co)variance components and ratios for total fold score in the Tygerhoek Merino flock under six different random effect models with the “best” model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**1.77**	1.78	-	1.78	-	1.76
σ^2_m	**-**	0.163E-05	-	0.34E-06	-	-
$\sigma^2_{c/pe}$	**-**	-	-	0.577E-02	-	0.01
σ^2_e	**2.81**	2.80	-	2.80	-	2.80
σ^2_p	**4.58**	4.58	-	4.57	-	4.57
σ_{am}	**-**	-	-	-	-	-
Variance ratios						
h^2_a	**0.39**	0.39	-	0.39	-	0.38
SE	**0.03**	0.03	-	0.03	-	0.03
h^2_m	**-**	0.00	-	0.00	-	-
SE	**-**	0.00	-	0.00	-	-
r_{am}	**-**	-	-	-	-	-
SE	**-**	-	-	-	-	-
c^2_{pe}	**-**	-	-	0.00	-	0.00
SE	**-**	-	-	0.01	-	0.03
h^2_t	**0.39**	0.39	-	0.39	-	0.39
Log L	**-5558.14**	-5558.14	-	-5558.13	-	-5558.13

See **Table 5.3** for abbreviations

5.3.2.11 General head conformation (GEN)

GEN was the only subjective assessed conformation trait that was affected by the dam permanent environmental effect in the present study. As a result Model 6 fitted the data best. It incorporated direct additive and dam permanent environmental effects as random sources of variation.

Table 5.13 (Co)variance components and ratios for general head conformation in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	**Model 6**
(Co)variance components						
σ^2_a	13.10	12.00	12.94	12.02	13.52	**12.07**
σ^2_m	-	1.15	1.49	0.11	0.45	**-**
σ^2_{pe}	-	-	-	1.52	1.67	**1.59**
σ^2_e	19.31	19.21	18.73	18.61	17.83	**18.60**
σ^2_p	32.41	32.36	32.39	32.27	32.36	**32.26**
σ_{am}	-	-	-0.76	-	-1.11	**-**
Variance ratios						
h^2_a	0.40	0.37	0.40	0.37	0.42	**0.37**
SE	0.03	0.04	0.05	0.04	0.05	**0.04**
h^2_m	-	0.04	0.05	0.00	0.01	**-**
SE	-	0.017	0.02	0.02	0.02	**-**
r_{am}	-	-	-0.17	-	-0.45	**-**
SE	-	-	0.02	-	0.35	**-**
c^2_{pe}	-	-	-	0.05	0.05	**0.05**
SE	-	-	-	0.02	0.02	**0.02**
h^2_t	0.40	0.42	0.39	0.37	0.39	**0.37**
Log L	-9335.33	-9332.49	-9332.17	-9329.84	-9329.16	**-9329.87**

See **Table 5.3** for abbreviations

In Afrino sheep, Snyman & Olivier (2002a) used a model with only the direct additive effect as a random effect. It was further reported that the dam permanent environmental effect did not contribute to the phenotypic variation for GEN (Snyman & Olivier, 2002a). Estimates of (co)variance components and genetic parameters for GEN are presented in Table 5.13.

Both h^2_a and h^2_t estimates amounted to 0.37±0.04 in the present study. The estimated h^2_a was somewhat higher, but in general agreement, with a corresponding estimate of 0.32±0.04 reported for Carnarvon Afrino sheep (Snyman & Olivier, 2002a). However, it was markedly higher than an estimate of 0.23±0.04 reported for South African Merino sheep participating in the national progeny test (Groenewald *et al.*, 1999). The c^2_{pe} effect contributed 5 % of the phenotypic variation in the current study. No corresponding effects were found in the literature.

5.3.2.12 Pastern score (PS)

Unlike in the analysis of GEN, Model 3 proofed to be the most suitable model for PS. It is an animal model that included the direct additive and maternal additive effects as well as the covariance between these animal effects. In the past, researchers reported PS being influenced by only the direct additive effect (Groenewald *et al.*, 1999; Naidoo *et al.*, 2004). The (co)variance components and genetic parameter estimates for PS are presented in Table 5.14.

The direct h^2_a estimates for Afrino and Merino sheep ranged from 0.08±0.03 to 0.23±0.04 (Groenewald *et al.*, 1999; Snyman & Olivier, 2002a). The present estimate for the Tygerhoek Merino flock (0.15±0.04) is within the range of these literature values. An h^2_m estimate of 0.05±0.03 was derived in the present study, while h^2_t amounted to 0.09. The correlation between animal effects was estimated at -0.71±0.13. The latter effect for PS could not be substantiated from the literature and further research is indicated.

Table 5.14 (Co)variance components and ratios for pastern score in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	**Model 3**	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	3.94	3.84	**6.01**	3.64	5.96	3.64
σ^2_m	-	0.13	**1.81**	0.3E-05	1.79	-
σ^2_{pe}	-	-	**-**	0.76	1.02	0.71
σ^2_e	33.45	33.42	**32.03**	32.98	31.56	32.93
σ^2_p	37.39	37.39	**37.49**	37.38	37.47	37.28
σ_{am}	-	-	**-2.35**	-	-2.20	-
Variance ratios						
h^2_a	0.11	0.10	**0.16**	0.10	0.16	0.10
SE	0.02	0.03	**0.04**	0.02	0.04	0.02
h^2_m	-	0.00	**0.05**	0.00	0.03	-
SE	-	0.01	**0.03**	0.00	0.03	-
r_{am}	-	-	**-0.71**	-	-0.85	-
SE	-	-	**0.13**	-	0.22	-
c^2_{pe}	-	-	**-**	0.02	0.03	0.02
SE	-	-	**-**	0.02	0.02	0.02
h^2_t	0.11	0.12	**0.09**	0.10	0.10	0.10
Log L	-9762.62	-9762.61	**-9759.26**	-9761.78	-9758.21	-9761.78

See **Table 5.3** for abbreviations

5.3.2.13 Front quarters (FQ)

(Co) variance components and genetic parameters for FQ are presented in Table 5.15. A model with only direct additive effect as a random variable proofed to be the best model for FQ. Similar models have been previously used for the analysis of FQ (Groenewald *et al.*, 1999; Snyman & Olivier, 2002a; Olivier *et al.*, 2006a). The present h^2_a estimate for FQ of 0.15±0.03 is somewhat lower than the estimate of 0.21±0.03 reported by Snyman & Olivier (2002a) for Afrino sheep. This estimate is also lower than previous estimates for South African Merino sheep (0.21±0.03 – Groenewald *et al.*, 1999; 0.51 – Olivier *et al.*, 2006). Total heritability was estimated at 0.15 in the present study. No comparable results were found.

Table 5.15 (Co)variance components and ratios for front quarters in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**5.70**	6.29	10.06	5.62	-	5.54
σ^2_m	**-**	0.37E-05	1.18	0.3E-05	-	-
σ^2_{pe}	**-**	-	-	0.22	-	0.22
σ^2_e	**31.74**	31.29	29.66	31.59	-	31.66
σ^2_p	**37.43**	37.58	37.75	37.43	-	37.42
σ_{am}	**-**	-	-3.14	-	-	-
Variance ratios						
h^2_a	**0.15**	0.17	0.27	0.15	-	0.15
SE	**0.03**	0.03	0.05	0.03	-	0.03
h^2_m	**-**	0.00	0.03	0.00	-	-
SE	**-**	0.00	0.02	0.00	-	-
r_{am}	**-**	-	-0.91	-	-	-
SE	**-**	-	0.18	-	-	-
c^2_{pe}	**-**	-	-	0.01	-	0.01
SE	**-**	-	-	0.02	-	0.02
h^2_t	**0.15**	0.17	0.16	0.15	-	0.15
Log L	**-9822.17**	-9822.71	-9816.03	-9822.10	-	-9822.51

See **Table 5.3** for abbreviations

5.3.2.14 Hocks (HOCKS)

Estimates of (co)variance components and genetic parameters for HOCKS are presented in Table 5.16. A model with the direct additive effect as a sole random variable was found to be the best model for HOCKS. Snyman & Olivier (2002a) used a similar model for the analysis of HOCKS in Afrino sheep.

Table 5.16 (Co)variance components and ratios for hocks in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**19.79**	19.21	22.49	19.19	22.45	19.68
σ^2_m	**-**	0.59	2.42	0.60	2.38	-
σ^2_{pe}	**-**	-	-	0.14E-04	0.18E-04	0.19
σ^2_e	**42.98**	42.97	41.14	42.92	40.99	42.88
σ^2_p	**62.77**	62.77	62.83	62.72	62.65	62.75
σ_{am}	**-**	-	-3.22	-	-3.17	-
Variance ratios						
h^2_a	**0.32**	0.31	0.36	0.31	0.36	0.31
SE	**0.03**	0.04	0.05	0.04	0.05	0.03
h^2_m	**-**	0.01	0.04	0.01	0.04	-
SE	**-**	0.02	0.02	0.02	0.02	-
r_{am}	**-**	-	-0.44	-	-0.43	-
SE	**-**	-	0.15	-	0.16	-
c^2_{pe}	**-**	-	-	0.00	0.00	0.03
SE	**-**	-	-	0.00	0.00	0.01
h^2_t	**0.32**	0.32	0.30	0.31	0.30	0.31
Log L	**-10808.9**	-10808.7	-10807.1	-10808.7	-10807.2	-10808.9

See **Table 5.3** for abbreviations

The direct h^2_a in the present study was 0.32±0.03, which is higher than a previous estimate (0.12±0.02) reported for the South African Merino (Groenewald *et al.*, 1999). It is also somewhat higher than an estimate of 0.27±0.08 reported for Western Australian Merino sheep (Lewer *et al.*, 1995). The present h^2_a estimate accorded with an estimate of 0.36±0.04 reported for Afrino sheep by Snyman & Olivier (2002a). The estimate of h^2_t in the present study was 0.32. No comparable results were found in literature reviewed.

5.3.2.15 Topline (TOPL)

(Co)variance components and ratios for TOPL are presented in Table 5.17. Model 1, with only the direct additive effect fitted the data best for the analysis of TOPL. A similar model has been previously used for the analysis of TOPL in Afrino sheep (Snyman & Olivier, 2002a). The h^2_a and h^2_t was estimated as 0.13±0.03 in the present study. This estimate is higher than the estimate of 0.06±0.02 reported for Afrino sheep (Snyman & Olivier, 2002a). Information on the analysis of TOPL is lacking from the literature.

Table 5.17 (Co)variance components and ratios for top line in the Tygerhoek Merino flock under six different random effect models with the "best" model in bold

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Co)variance components						
σ^2_a	**5.36**	5.59	6.81	5.00	-	4.99
σ^2_m	**-**	0.611E-05	0.60	0.35E-05	-	-
σ^2_{pe}	**-**	-	-	0.70	-	0.68
σ^2_e	**35.37**	35.20	34.64	35.01	-	35.05
σ^2_p	**40.74**	40.79	40.81	40.71	-	40.72
σ_{am}	**-**	-	-1.29	-	-	-
Variance ratios						
h^2_a	**0.13**	0.14	0.17	0.12	-	0.12
SE	**0.03**	0.03	0.04	0.03	-	0.03
h^2_m	**-**	0.00	0.01	0.00	-	-
SE	**-**	0.00	0.02	0.00	-	-

Table 5.17 (Continues)

r_{am}	**-**	-	-0.61	-	-	-
SE	**-**	-	0.27	-	-	-
c^2_{pe}	**-**	-	-	0.02	-	0.02
SE	**-**	-	-	0.02	-	0.02
h^2_t	**0.13**	0.14	0.13	0.12	-	0.12
Log L	**-10013.9**	-10013.9	-10013.1	-10013.3	-	-10013.3

See **Table 5.3** for abbreviations

5.3.3 Correlations among traits

Genetic, phenotypic, environmental and maternal correlations (where appropriate) among subjectively assessed wool and conformation traits are presented in Tables 5.18 to 5.24. Most of the correlations were not significant. The correlations that reached significance (i.e. a level double the corresponding standard error) were low to moderate and variable in sign.

5.3.3.1 Subjective wool traits

5.3.3.1.1 Wool quality (QUAL) and other traits

It was evident that sheep with higher scores for QUAL would also generally have better scores for ROC and COL, as suggested by significant genetic correlations of 0.49 and 0.26 between the respective traits. The genetic correlations for QUAL with STAPL (-0.45±0.07) and BANDP (-0.20±0.07) were unfavourable. The implications are that, sheep with higher scores for QUAL would likely have ropier staples and more yellow/watery wool on their bellies. The genetic correlations with other subjective wool traits were not significant A comparable unfavourable genetic correlation of -0.46±0.06 was estimated between QUAL and STAPL for the Cradock fine wool Merino flock (Olivier *et al.*, 2006b). Phenotypic correlations between QUAL and other subjective wool traits were generally not significant. The exceptions were moderate and positive correlations for QUAL with ROC (0.43±0.01) and with COL (0.27±0.02), as well as a negative correlation (-0.23±0.02) with STAPL. A recent study on the Cradock fine wool Merino stud yielded a similar phenotypic correlation (-0.26±0.07) between QUAL and STAPL (Olivier *et al.*, 2006b).

Table 5.18 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations (± SE) between wool quality and other subjective wool traits

Trait	r_g	r_e	r_p	r_m
Wool quality (QUAL) X				
Regularity of crimp (ROC)	0.49±0.06	0.45±0.02	0.43±0.01	0.13±0.28
Wool colour (COL)	0.26±0.06	0.27±0.03	0.27±0.02	0.39±0.18
Face cover score (FCS)	0.07±0.08	0.11±0.03	0.09±0.02	-
Pigmentation (PIGM)	-0.11±0.05	0.08±0.03	-0.01±0.02	-
Woolly face score (WFS)	0.10±0.06	0.01±0.04	0.05±0.02	-
Staple formation (STAPL)	-0.45±0.07	-0.16±0.03	-0.23±0.02	-
Belly and points (BANDP)	-0.20±0.07	0.03±0.03	-0.05±0.02	-
Wool oil (OIL)	0.08±0.07	0.08±0.03	0.07±0.02	-

r_g = genetic correlation, r_p = phenotypic correlation, r_e environmental correlation, r_m maternal correlation, CV of fibre diameter = coefficient of fibre diameter, SD of fibre diameter = standard deviation of fibre diameter and SE = standards error.

Corresponding r_e were also mostly not significant. The exceptions were the moderate correlations for QUAL with ROC, COL and STAPL. The maternal correlations of QUAL with ROC and COL were positive, but only the latter correlation reached significance (0.39±0.18). No comparable literature results were found to confirm or refute the environmental and maternal correlations of QUAL with the other subjective wool traits.

5.3.3.1.2 Regularity of crimp (ROC) and other traits

Genetic correlations between ROC and other subjective wool traits were generally not significant. The exceptions were the moderate and positive (0.31±0.08) genetic correlation with COL which suggests that animals with higher scores for ROC would generally have whiter wool, and an unfavourable correlation (-0.49±0.08) of ROC with STAPL, suggesting that animals with more regular crimps or even fleeces would generally have thinner/ropier staples.

Table 5.19 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations between (± SE) regularity of crimp and other subjective wool traits

Trait	$\mathbf{r_g}$	$\mathbf{r_e}$	$\mathbf{r_p}$	$\mathbf{r_m}$
ROC X				
Wool colour (COL)	0.31±0.08	0.26±0.02	0.27±0.02	0.18±0.27
Face cover score (FCS)	0.08±0.09	0.11±0.02	0.10±0.02	-
Pigmentation (PIGM)	-0.04±0.07	0.04±0.03	0.01±0.02	-
Woolly face score (WFS)	-0.01±0.07	0.01±0.03	-0.02±0.02	-
Staple formation (STAPL)	-0.49±0.08	-0.10±0.02	-0.19±0.02	-
Belly and points (BANDP)	-0.10±0.08	-0.04±0.02	-0.06±0.02	-
Wool oil (OIL)	-0.01±0.08	0.02±0.02	0.02±0.02	-

See **Table 5.18** for abbreviations

Most of the phenotypic correlations between ROC and other subjective wool traits were also not significant with the exception of the positive phenotypic and environmental correlations between COL and FCS and corresponding negative correlations of ROC with STAPL. Snyman & Olivier (2002a) reported similar positive and nonsignificant genetic and phenotypic correlations between ROC and FCS in Afrino sheep.

5.3.3.1.3 Staple formation (STAPL) and other traits and correlations among BANDP, FSC, PIGM, WFS, COL and OIL

The result of the present study suggested that sheep with higher scores for STAPL would also generally have better scores for BANDP, as suggested by a high genetic correlation of 0.58 between these traits. The genetic correlations between STAPL and other subjective wool traits were generally not significant. A significant phenotypic correlation between STAPL and BANDP was accordingly estimated at 0.38 in the present study.

Table 5.20 Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (± SE) between wool colour and other subjective wool traits and correlation among other traits

Trait	r_g	r_e	r_p
Wool colour (COL) X			
Face cover score (FCS)	0.13±0.09	0.02±0.02	0.04±0.02
Pigmentation (PIGM)	0.05±0.06	0.01±0.03	0.03±0.02
Woolly face score (WFS)	0.06±0.06	0.03±0.03	0.04±0.02
Staple formation (STAPL)	0.09±0.08	0.00±0.03	0.02±0.02
Belly and points (BANDP)	0.12±0.08	0.08±0.03	0.09±0.02
Wool oil (OIL)	-0.05±0.08	-0.06±0.03	-0.05±0.02
Face cover score (FCS) X			
Pigmentation (PIGM)	0.11±0.09	0.11±0.03	0.10±0.02
Woolly face score (WFS)	-0.25±0.09	0.03±0.03	-0.05±0.02
Staple formation (STAPL)	0.26±0.11	-0.00±0.02	-0.05±0.02
Belly and points (BANDP)	-0.09±0.11	0.06±0.02	0.03±0.02
Wool oil (OIL)	-0.09±0.02	0.01±0.02	-0.01±0.02
Pigmentation (PIGM) X			
Woolly face score (WFS)	0.07±0.06	0.05±0.04	0.06±0.02
Staple formation (STAPL)	0.08±0.08	0.00±0.03	0.03±0.02
Belly and points (BANDP)	0.10±0.07	-0.01±0.03	0.03±0.02
Wool oil (OIL)	-0.10±0.07	-0.01±0.03	-0.04±0.02
Woolly face score (WFS) X			
Staple formation (STAPL)	0.09±0.08	-0.02±0.03	0.02±0.02
Belly and points (BANDP)	-0.12±0.07	0.02±0.03	-0.03±0.02
Wool oil (OIL)	-0.03±0.08	-0.01±0.03	-0.01±0.02
Staple formation (STAPL) X			
Belly and points (BANDP)	0.58±0.07	0.32±0.02	0.38±0.01
Wool oil (OIL)	0.09±0.09	0.10±0.02	0.10±0.02
Belly and points (BANDP) X			
Wool oil (OIL)	-0.18±0.09	0.06±0.02	0.00±0.02

See **Table 5.18** for abbreviations

The corresponding environmental correlation was also moderate and positive at 0.32±0.02. Other correlations between STAPL and objective wool traits were not significant but variable in sign. Correlations among BANDP, FSC, PIGM, WFS, COL and OIL were not significant but variable in sign. Snyman & Olivier (2002a) reported similar nonsignificant correlations of FCS and PIGM with other subjective wool traits for Afrino sheep.

5.3.3.2 Subjective conformation traits

5.3.3.2.1 General head conformation (GEN) and the other traits

Most of the genetic correlations estimated in the present study for GEN with the other subjective conformation traits were positive but nonsignificant. The only significant correlation was a moderate and favourable genetic correlation between GEN and TOT (-0.31). The economic implication is that animals with stronger heads are also generally plainer. Corresponding significant phenotypic correlations were positive and ranged from 0.10±0.02 between GEN and TOPL to 0.24±0.02 between GEN and FQ. Of the environmental correlations only the correlation between GEN and PS was not significant.

Table 5.21 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations between (± SE) general head conformation and other subjective conformation traits

Trait	r_g	r_e	r_p	r_m
General head conformation (GEN) X				
Pastern score (PS)	0.14±0.10	0.001±0.03	0.04±0.02	0.21±0.02
Hocks (HOCKS)	0.10±0.08	0.28±0.03	0.21±0.02	-
Front quarters (FQ)	0.24±0.10	0.26±0.03	0.24±0.02	-
Top line (TOPL)	0.11±0.11	0.11±0.03	0.10±0.02	-
Total fold score (TOT)	-0.31±0.07	0.11±0.03	-0.05±0.02	-

See **Table 5.18** for abbreviations

All the other environmental correlations between GEN and the other subjective conformation traits were positive and ranged from 0.11±0.03 to 0.28±0.03, with the highest environmental correlation being estimated between GEN and HOCKS.

5.3.3.2.2 Hocks (HOCKS) and other traits

Scores for HOCKS and FQ appeared to be dependent on a fairly similar set of genes, as suggested by a high genetic correlation of 0.71 between these traits. Other genetic correlations between HOCKS and subjective conformation traits were not significant. Snyman & Olivier (2002a) reported a comparable positive and nonsignificant genetic correlation between HOCKS and PS.

Table 5.22 Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (± SE) between hocks and other subjective conformation traits

Trait	$\mathbf{r_g}$	$\mathbf{r_e}$	$\mathbf{r_p}$
Hocks (HOCKS) X			
Front quarters (FQ)	0.71±0.06	0.41±0.02	0.47±0.01
Pastern score (PS)	0.05±0.10	0.18±0.03	0.15±0.02
Top line (TOPL)	0.07±0.11	0.14±0.03	0.12±0.02
Total fold score (TOT)	-0.05±0.07	0.02±0.03	-0.01±0.02

See **Table 5.18** for abbreviations

Corresponding significant phenotypic correlations were positive and ranged from 0.12±0.02 to 0.47±0.01, with the highest phenotypic correlation estimated between HOCKS and FQ. The environmental correlation estimates were mostly positive and moderate. The environmental correlation between HOCKS and TOT did not reach significance (P>0.05).

5.3.3.2.3 Front quarters (FQ) and topline (TOPL) with other traits

The genetic correlations estimated in the present study for FQ with PS (0.14±0.11) and with TOPL (0.20±0.13) were positive but not significant. A negative but nonsignificant genetic (-0.06±0.09) correlation between FQ and TOT was also found. A higher positive genetic correlation was estimated between FQ and TOPL (0.53±0.19) in the Afrino breed (Snyman & Olivier, 2002a). Significant correlations estimated in the present study were positive and generally low between FQ and PS (0.12±0.02) and between FQ and TOPL (0.11±0.02). The negative phenotypic correlation between FQ and TOT was not significant. A similar phenotypic correlation of 0.11±0.02 between FQ and TOPL were estimated in Afrino sheep (Snyman & Olivier, 2002a). Corresponding environmental correlations of FQ with PS and TOPL were low and positive (P>0.05). The environmental correlation between FQ and TOT was negligible.

Table 5.23 Genetic (r_g), phenotypic (r_p) and environmental (r_e) correlations (± SE) for front quarters and top line with other subjective conformation traits

Trait	r_g	r_e	r_p
Front quarter (FQ) X			
Pastern score (PS)	0.14±0.11	0.12±0.02	0.12±0.02
Top line (TOPL)	0.20±0.13	0.11±0.02	0.12±0.02
Total fold score (TOT)	-0.06±0.09	0.01±0.03	-0.01±0.02
Top line (TOPL) X			
Total fold score (TOT)	-0.47±0.09	-0.05±0.03	-0.15±0.02
Pastern score	-0.05±0.13	0.09±0.02	0.07±0.02
Pastern score (PS) X			
Total fold score (TOT)	0.03±0.08	-0.03±0.03	-0.01±0.02

See **Table 5.18** for abbreviations

A favourable genetic correlation of -0.47±0.09 between TOPL and TOT suggested that animals with higher scores for TOPL would also be plainer. The genetic correlation between TOPL and PS was negligible. The corresponding phenotypic correlation between TOPL and TOT was negative and low while the positive phenotypic correlation between TOPL and PS was below 0.10. Environmental correlations estimated in the present study were not significant and negative between TOPL and TOT and positive between TOPL and PS. The genetic, phenotypic and environmental correlations between TOT and PS were not significant.

5.3.3.3 Subjective wool and subjective conformation traits

Genetic, phenotypic, environmental and maternal correlations (where appropriate) from the present study for subjective wool and conformation traits are presented in Table 5.24. The genetic correlations were generally not significant with few exceptions. Genetic correlations of GEN with WFS (0.35±0.06) and OIL (-0.22±0.08) suggested that, animals with stronger heads would generally be more open faced but their wool are likely to contain more oil. It is also evident from the present results that plainer animals would generally have wool with less oil and poorer scores for BANDP, as suggested by significant correlations of TOT with BANDP (0.20±0.07) and TOT with OIL (0.46±0.07). Genetically, animals with wider hocks had whiter fleeces and more even wool across the fleece, as suggested by positive and moderate genetic correlations of HOCKS with ROC (0.21±0.09) and with COL (0.21±0.08). The genetic correlation between FQ and FCS (0.36±0.12) also suggested that sheep with a softer face cover are likely to have wider front quarters. Comparable correlations were estimated in Afrino sheep for the corresponding traits (Snyman & Olivier, 2002a).

The phenotypic correlations were not significant for most of the subjective wool traits with the subjective conformation traits. The significant phenotypic correlations were generally low to moderate. They ranged from -0.09±0.02 to 0.28±0.02 with the highest phenotypic correlation being estimated between GEN and WFS. Corresponding significant environmental correlations were positive and moderate in magnitude with the highest environmental correlation between GEN and WFS. The maternal correlations between subjective wool and subjective conformation traits estimated in the present study were positive, associated with high standard errors and not significant (Table 5.24).

Table 5.24 Genetic (r_g), phenotypic (r_p), environmental (r_e) and maternal (r_m) correlations (± SE) between subjective wool and conformation traits

Trait	$\mathbf{r_g}$	$\mathbf{r_e}$	$\mathbf{r_p}$	$\mathbf{r_m}$
General head conformation (GEN) X				
Wool quality (QUAL)	-0.05±0.07	0.06±0.03	0.02±0.03	-
Regularity of crimp (ROC)	0.06±0.08	0.01±0.03	0.04±0.03	-
Wool colour (COL)	-0.01±0.08	0.07±0.03	0.05±0.03	-
Face cover score (FCS)	0.19±0.10	0.14±0.03	0.15±0.02	-
Pigmentation (PIGM)	0.07±0.07	0.11±0.03	0.09±0.02	-
Woolly face score (WFS)	0.35±0.06	0.23±0.04	0.28±0.02	-
Staple formation (STAPL)	0.06±0.09	0.13±0.03	0.11±0.02	-
Belly and point (BANDP)	0.13±0.08	0.19±0.03	0.16±0.02	-
Wool oil (OIL)	-0.22±0.08	0.03±0.03	-0.04±0.02	-
Pastern score (PS) X				
Wool quality (QUAL)	0.06±0.09	-0.01±0.03	0.01±0.02	0.03±0.20
Regularity of crimp (ROC)	-0.03±0.10	0.05±0.02	0.05±0.02	0.40±0.31
Wool colour (COL)	-0.12±0.10	-0.01±0.03	-0.01±0.02	0.40±0.22
Face cover score (FCS)	-0.03±0.11	0.07±0.02	0.05±0.02	-
Pigmentation (PIGM)	0.07±0.08	0.03±0.03	0.04±0.02	-
Woolly face score (WFS)	-0.01±0.08	-0.01±0.03	-0.01±0.02	-
Staple formation (STAPL)	-0.08±0.10	0.02±0.02	-0.00±0.016	-
Belly and point (BANDP)	-0.09±0.10	0.05±0.02	0.02±0.015	-
Wool oil (OIL)	-0.07±0.10	0.04±0.02	0.02±0.016	-
Top line (TOPL) X				
Wool quality (QUAL)	0.02±0.09	0.05±0.03	0.04±0.03	-
Regularity of crimp (ROC)	0.17±0.10	0.02±0.02	0.05±0.02	-
Wool colour (COL)	0.12±0.10	0.04±0.03	0.05±0.02	-
Face cover score (FCS)	0.17±0.13	0.02±0.02	0.04±0.02	-
Pigmentation (PIGM)	-0.06±0.10	0.05±0.03	0.02±0.02	-
Woolly face score (WFS)	0.07±0.10	0.07±0.03	0.06±0.02	-
Staple formation (STAPL)	-0.21±0.12	0.02±0.02	-0.02±0.02	-

Table 5.24 (Continues)

Belly and point (BANDP)	-0.22±0.11	0.06±0.02	0.01±0.02	-
Wool oil (OIL)	-0.31±0.11	0.01±0.02	-0.05±0.02	-
Front quarters (FQ) X				
Wool quality (QUAL)	0.14±0.07	0.02±0.03	0.06±0.02	-
Regularity of crimp (ROC)	0.10±0.08	-0.00±0.02	0.02±0.02	-
Wool colour (COL)	0.18±0.08	0.02±0.03	0.06±0.02	-
Face cover score (FCS)	0.36±0.12	0.01±0.02	0.06±0.02	-
Pigmentation (PIGM)	-0.14±0.09	0.05±0.03	-0.00±0.02	-
Woolly face score (WFS)	0.03±0.09	0.12±0.03	0.09±0.08	-
Staple formation (STAPL)	-0.11±0.11	0.09±0.02	0.05±0.02	-
Belly and point (BANDP)	0.05±0.11	0.13±0.02	0.12±0.02	-
Wool oil (OIL)	-0.15±0.11	0.02±0.02	-0.01±0.02	-
Hocks (HOCKS) X				
Wool quality (QUAL)	0.08±0.07	0.02±0.03	0.04±0.02	-
Regularity of crimp (ROC)	0.21±0.09	0.04±0.03	0.08±0.02	-
Wool colour (COL)	0.21±0.08	0.01±0.03	0.07±0.02	-
Face cover score (FCS)	0.18±0.10	-0.01±0.03	0.03±0.02	-
Pigmentation (PIGM)	0.01±0.07	0.01±0.03	0.01±0.02	-
Woolly face score (WFS)	0.04±0.07	0.12±0.03	0.09±0.02	-
Staple formation (STAPL)	-0.11±0.09	0.09±0.03	0.04±0.02	-
Belly and point (BANDP)	0.03±0.09	0.15±0.03	0.11±0.02	-
Wool oil (OIL)	-0.10±0.09	0.02±0.03	-0.01±0.02	-
Total fold score (TOT) X				
Wool quality (QUAL)	-0.03±0.06	-0.02±0.03	-0.03±0.02	-
Regularity of crimp (ROC)	-0.01±0.08	-0.07±0.03	-0.05±0.02	-
Wool colour (COL)	-0.01±0.07	-0.06±0.03	-0.04±0.02	-
Face cover score (FCS)	-0.01±0.09	0.02±0.03	0.01±0.02	-
Pigmentation (PIGM)	0.03±0.06	0.01±0.03	0.01±0.02	-
Woolly face score (WFS)	-0.12±0.06	-0.06±0.03	-0.09±0.02	-
Staple formation (STAPL)	0.03±0.08	0.09±0.03	0.14±0.02	-
Belly and point (BANDP)	0.20±0.07	0.10±0.03	0.13±0.02	-
Wool oil (OIL)	0.46±0.07	0.15±0.03	0.24±0.02	-

See **Table 5.18** for abbreviations

5.4 Conclusions

The results obtained in this study generally accorded with results of previous studies, although higher heritabilities were estimated for some traits. Fairly low to surprisingly high heritability estimates were found for subjectively assessed wool and conformation traits in this study. High heritability estimates indicated the possibility to achieve sustained genetic improvement by selection for subjectively assessed wool and conformation traits in South African Merino sheep. There is therefore little doubt that, genetic change in these traits can be achieved through selection, should it be desired.

Most estimates of genetic, phenotypic, environmental and maternal correlations between subjective wool and conformation traits were not significant. The significant correlations were variable in sign and magnitude, but generally favourable. Unfavourable correlations were mostly between measures of wool style (QUAL and ROC) and measures of wool yield (STAPL and BANDP). Plainer sheep, which are preferred at present, were also shown to be inclined to lower scores for BANDP. The magnitude of these unfavourable correlations was such that they would not be expected to cause serious problems in a selection programme. It is also noteworthy that a trait like PIGM, which could be related to contamination of wool with dark and pigmented fibres was not related to any of the other subjectively assessed traits. It is therefore unlikely that genetic change towards more desired genotypes pertaining to conformation would lead to an unwanted increase in PIGM.

CHAPTER 6

RELATIONSHIPS BETWEEN SUBJECTIVELY ASSESSED WOOL AND OBJECTIVELY MEASURED WOOL TRAITS AND LIVE WEIGHT

6.1 Introduction

Construction of an appropriate breeding plan for a wool sheep enterprise requires knowledge of genetic parameters and correlations between traits of economic importance. Researchers estimated genetic parameters for production traits in the past decades, and these were reviewed by Fogarty (1995) and Snyman *et al*. (1995). More recent genetic parameters for sheep were reviewed by Safari *et al*. (2005). Traditionally, however, Merino sheep have been selected using a classing system that relied on visual differences, with a believe that subjective traits are either an important part of production or are related to qualitative or quantitative traits of economic importance (Morley *et al*., 1955; Young *et al*., 1963; Cloete *et al*., 1992; Lewer *et al*., 1995).

Previous studies in South African Merino and Afrino sheep indicated that, emphasis is placed on subjectively assessed wool traits in selecting breeding sires and dams. Animals are thus culled on the basis of these traits at the expenses of the economically important traits, such as fibre diameter, fleece weight, staple strength, live-weight and reproduction (Snyman & Olivier, 2002a; Olivier *et al*., 2006a).

Phenotypic (Cloete *et al*., 1992; Crook *et al*., 1994) and genetic (Lewer *et al*., 1995; Snyman & Olivier, 2002a; Naidoo *et al*., 2004; Brown *et al*., 2006; Olivier *et al*., 2006a; Olivier *et al.,* 2006b) correlations among some subjective wool and objective traits of economic importance such as fibre diameter, clean fleece weight, and live-weight were estimated. Apart from these references, there is little information about the genetic, phenotypic and the environmental relationships of these subjectively assessed traits with live-weight and objective wool traits of economic importance. Moreover, information on maternal correlations for subjectively assessed wool with objective wool traits and live-weight was lacking in the literature. The objectives of the present study were thus to estimate genetic, maternal, phenotypic and environmental correlations for subjectively assessed wool traits with objectively measured wool traits and live-weight.

6.2 Materials and methods

6.2.1 Data

The data are described in Chapter 3, and were collected on the Tygerhoek Merino flock from 1989 to 2004. Objectively measured traits included in the analysis were 16-months live weight (LW), greasy fleece weight (GFW), clean fleece weight (CFW), clean yield (CY), fibre diameter (FD), staple length (SL), staple strength (SS), coefficient of variation of fibre diameter (CVFD) and standard deviation of fibre diameter (SDFD) respectively. Subjective wool traits included in the analysis were assessed according to a linear scale ranging from 1-50 (Olivier *et al*., 1987) at 14-16 months of age. The subjectively assessed wool traits included in the analysis were wool quality (QUAL), regularity of crimp (ROC), wool colour (COL), wool oil (OIL), staple formation (STAPL), belly and points (BANDP), woolly face score (WFS), face cover score (FCS), and pigmentation (PIGM). A description of data used to analyse live weight and the objective wool traits is presented in Table 4.1 in Chapter 4. Table 5.1 in Chapter 5 presents a description of data used to analyse subjectively assessed wool traits. The data were edited according to descriptions in Chapter 3 prior to analysis.

6.2.2 Statistical analysis

The ASREML programme of Gilmour *et al*. (2002) was used to estimate the correlations between subjective wool traits and the objective wool traits as well as live weight, by fitting two-trait animal models. Therefore, Models 5 and 3 were used to estimate the correlations for GFW and CFW with QUAL, ROC, and COL, while Models 5 and 1 were used to estimate the correlations of GFW and CFW with OIL, STAPL, BANDP, WFS, FCS and PIGM. Furthermore, Models 3 and 1 were used for FD and LW with OIL, STAPL, BANDP, WFS, FCS and PIGM. Model 3 was used for both traits to estimate the correlations of FD and LW with QUAL, ROC and COL while Model 1 was used for both traits to estimate correlations of CY, SL, SS, CVFD and SDFD with OIL, STAPL, BANDP, WFS, FSC and PIGM. The two-trait animal models included all the random components shown to be significant in the single-trait analyses as appropriate.

6.3 Results and discussion

6.3.1 Live weight (LW) and subjectively assessed wool traits

At genetic level, LW was positively (Table 6.1) correlated with ROC (0.20±0.08) and with WFS (0.20±0.08). These correlations were favourable and suggested that, heavier sheep are likely to have more even fleeces and higher scores for WFS. However, all the other genetic correlations were nonsignificant (P>0.05). Therefore, they should be reviewed to ascertain the direction of the genetic correlations for LW with these subjective wool traits. Comparable nonsignificant genetic correlations for LW with QUAL (0.07±0.07) and with STAPL (0.00±0.07) were reported for the Cradock fine wool Merino stud (Olivier *et al.*, 2006a).

Phenotypic correlations of LW with subjective wool traits were generally positive and low to moderate with the exception of the negative phenotypic correlation for LW with OIL. Olivier *et al.* (2006a) reported comparable phenotypic correlations for LW with QUAL (0.02±0.04) and STAPL (0.11±0.02). Corresponding environmental correlations were positive, mostly below 0.10, and either not significant or marginally significant. The significant environmental correlations were estimated for LW with STAPL (0.16±0.03), BANDP (0.20±0.03) and WFS (0.08±0.03) respectively. Maternal correlations for LW with QUAL (0.17±0.17), ROC (0.14±0.23) and COL (0.02±0.15) were positive in sign, variable in magnitude, and not significant. Comparable results on the environmental and maternal correlations for LW with subjective wool traits were not found in the literature sourced.

Table 6.1 Correlations (±SE) between live weight (LW) and subjectively assessed wool traits

Trait	$\mathbf{r_g}$	$\mathbf{r_p}$	$\mathbf{r_e}$	$\mathbf{r_m}$
Live weight X				
Wool quality	-0.01±0.07	0.04±0.02	0.06±0.03	0.17±0.17
Regularity of crimp	0.20±0.08	0.08±0.02	0.02±0.03	0.14±0.23
Wool colour	-0.03±0.07	0.03±0.02	0.06±0.03	0.02±0.15
Oil	-0.15±0.08	-0.01±0.02	0.05±0.03	-
Staple formation	-0.01±0.09	0.11±0.02	0.16±0.03	-
Belly and points	0.01±0.08	0.14±0.02	0.20±0.03	-
Woolly face score	0.21±0.07	0.13±0.02	0.08±0.03	-
Face cover score	0.01±0.10	0.02±0.02	0.03±0.03	-
Pigmentation	-0.00±0.07	0.04±0.02	0.06±0.03	-

r_g = genetic correlations, r_p = phenotypic correlation, r_e = environmental correlation and r_m = maternal correlation and SE = standards error.

6.3.2 Greasy fleece weight (GFW) and subjectively assessed wool traits

GFW was unfavourably correlated to COL (-0.19±0.07) in the present study, suggesting that sheep with higher GFW had yellow wool (Table 6.2) Brown *et al.* (2006) also reported unfavourable correlations between GFW and COL that ranged from 0.17 to 0.34 for the Australian Merino (their lowest number represented white wool colour while the current study reports the lowest number being yellow wool). However, these results disagree with that of Lewer *et al.* (1995) who reported a favourable genetic correlation of -0.16 for Western Australian Merinos. Research attributed this conflicting results to environment in which the sheep were managed which had an effect on the source of increased wool colour (Brown *et al.,* 2006). Corresponding correlations with STAPL and

BANDP were favourable. As a result, selection for STAPL and BANDP would likely result in an increased GFW. GFW was positively related to OIL and not significantly correlated to QUAL, ROC, WFS and PIGM. Information on the genetic correlations for corresponding traits was lacking from literature. The genetic correlation of GFW with FCS was positive but not significant. Lewer *et al.* (1995) reported a nonsignificant but negative correlation between GFW and FCS for Australian Merino.

Table 6.2 Correlations (±SE) between greasy fleece weight (GFW) and subjectively assessed wool traits

Trait	r_g	r_p	r_e	r_m
Greasy fleece weight X				
Wool quality	0.10±0.06	0.05±0.02	0.01±0.03	0.06±0.13
Regularity of crimp	0.02±0.08	-0.04±0.01	-0.08±0.03	0.03±0.16
Wool colour	-0.19±0.07	-0.09±0.01	-0.07±0.03	0.07±0.12
Oil	0.48±0.08	0.24±0.02	0.18±0.02	-
Staple formation	0.35±0.08	0.24±0.02	0.21±0.02	-
Belly and points	0.42±0.08	0.33±0.01	0.31±0.02	-
Woolly face score	-0.00±0.07	-0.01±0.02	-0.01±0.03	-
Face cover score	0.04±0.11	0.07±0.02	0.08±0.02	-
Pigmentation	0.09±0.07	0.03±0.02	0.01±0.03	-

See **Table 6.1** for abbreviations

Previous studies on Australian Merino sheep reported positive phenotypic correlations of GFW with COL that ranged from 0.11 to 0.12. The present estimate on the South African Merino is lower than that range in magnitude and negative in sign. Current phenotypic correlations for GFW with QUAL (0.05±0.02), STAPL (0.24±0.02), BANDP (0.33±0.01) and FCS (0.07±0.02) were favourable. In contrast, Lewer *et al.* (1995) reported an unfavourable correlation between GFW and FCS. Furthermore, GFW was not significantly correlated with WFS and PIGM at the phenotypic level.

Environmental correlations of GFW were positive for QUAL, OIL, STAPL, BANDP and FCS and negative with ROC and COL. GFW was not significantly related to WFS and PIGM on the environmental level. Information on maternal correlations for GFW with QUAL, ROC and COL was lacking from the literature. The present positive but nonsignificant maternal correlations of GFW with QUAL, ROC and COL could thus not be supported from the literature.

6.3.3 Clean fleece weight (CFW) and subjectively assessed wool traits

There were favourable genetic correlations of CFW with QUAL, STAPL and BANDP (Table 6.3), as suggested by moderate and positive genetic correlations of CFW with the respective traits. Selection for CFW would generally result in sheep with wool of good quality and higher scores for STAPL and BANDP. However, selection for CFW should be done with caution as might lead to breeding stock with excessive wool oil, as suggested by the significant and positive genetic correlation of 0.28 between CFW and OIL. Similar positive genetic correlations for corresponding traits were reported by Naidoo *et al.* (2004) on a smaller data set. However, Olivier *et al.* (2006a) reported higher genetic correlations for CFW with QUAL at 0.40±0.06 and for CFW with STAPL at 0.57±0.06. The genetic correlations of CFW with ROC, COL, WFS, FCS and PIGM were not significant in the latter study. Similar nonsignificant correlations were reported between CFW and ROC (Naidoo *et al.*, 2004) and between CFW and COL (Lewer *et al.*, 1995; Naidoo *et al.*, 2004).

On the phenotypic level, CFW was positively related to QUAL, OIL, BANDP and FSC and not significantly correlated with ROC, COL, STAPL, WFS and PIGM. Comparable phenotypic correlations were estimated for the corresponding traits on the same Merino flock using a smaller data set (Naidoo *et al.,* 2004) and for the Cradock fine wool Merino stud (Olivier *et al.,* 2006b). Corresponding environmental correlations that reached significance ($P<0.05$) were for CFW with OIL, STAPL, BANDP and FCS. Naidoo *et al.* (2004) reported similar environmental correlations for corresponding traits on the same flock. No maternal correlations were found in the literature for comparison with the nonsignificant correlations reported in Table 6.3.

Table 6.3 Correlations (±SE) between clean fleece weight (CFW) and subjectively assessed wool traits

Trait	r_g	r_p	r_e	r_m
Clean fleece weight X				
Wool quality	0.18±0.06	0.09±0.02	0.02±0.03	0.09±0.13
Regularity of crimp	0.01±0.07	-0.03±0.02	-0.06±0.03	0.04±0.15
Wool colour	-0.02±0.07	-0.02±0.02	-0.04±0.03	0.15±0.12
Oil	0.28±0.08	0.16±0.02	0.12±0.03	-
Staple formation	0.39±0.08	0.25±0.01	0.21±0.02	-
Belly and points	0.48±0.07	0.34±0.01	0.31±0.02	-
Woolly face score	0.00±0.07	-0.01±0.02	-0.01±0.03	-
Face cover score	0.12±0.10	0.08±0.02	0.08±0.02	-
Pigmentation	0.06±0.07	0.03±0.02	0.02±0.03	-

See **Table 6.1** for abbreviations

6.3.4 Clean yield (CY) and subjectively assessed wool traits

On genetic level CY was favourably related to QUAL, COL, STAPL, BANDP and FCS. These correlations suggested that sheep with higher percentage of clean wool are likely to have whiter wool of good quality, their faces will have a softer handle and they will have higher scores for STAPL and BANDP. These results corresponded fairly well with corresponding correlations reported from the literature (Lewer *et al.*, 1995; Naidoo *et al.*, 2004).

The genetic correlation for CY with OIL was moderate and negative (-0.44±0.06). Naidoo *et al.* (2004) reported a similar genetic correlation between CY and OIL (-0.45±0.07) for the same Merino flock. Genetic correlations of CY with ROC, WFS and

PIGM were not significant. Comparable nonsignificant genetic correlations were reported for CY with PIGM (Snyman & Olivier, 2002a) on Afrino sheep and for CY with ROC (Naidoo *et al.*, 2004) on the same Merino flock. On the contrary, Snyman & Olivier (2002a) reported negative and moderate genetic correlation of -0.22±0.09 between CY and ROC.

Table 6.4 Correlations (±SE) between clean yield (CY) and subjectively assessed wool traits

Trait	r_g	r_p	r_e
Clean yield X			
Wool quality	0.30±0.05	0.04±0.04	0.17±0.02
Regularity of crimp	0.06±0.07	0.06±0.03	0.05±0.02
Wool colour	0.45±0.05	0.10±0.03	0.25±0.02
Oil	-0.44±0.06	-0.13±0.03	-0.24±0.02
Staple formation	0.21±0.07	0.03±0.03	0.09±0.02
Belly and points	0.24±0.06	0.07±0.03	0.13±0.02
Woolly face score	0.03±0.05	-0.01±0.04	0.01±0.02
Face cover score	0.18±0.08	0.01±0.03	0.06±0.02
Pigmentation	-0.00±0.05	-0.02±0.04	-0.01±0.02

See **Table 6.1** for abbreviations

The phenotypic correlation of CY with COL (0.10±0.03) was positive, while CY was negatively related to OIL (-0.13±0.03). Naidoo *et al.* (2004) reported somewhat higher phenotypic correlations of 0.33±0.02 and -0.26±0.02 for the corresponding traits. In contrast, Lewer *et al.* (1995) reported negative phenotypic correlation of -0.07±0.02 between CY and COL. Other phenotypic correlations between CY and the subjective wool traits were not significant. Corresponding environmental correlation were positive for CY with QUAL, COL, STAPL and BANDP. The environmental correlation of CY with OIL was moderate and negative (-0.24±0.02). CY was not significantly related to

ROC, WFS and PIGM. Similar environmental correlations were reported for the corresponding traits on a smaller data set of the same Merino flock (Naidoo *et al.*, 2004).

6.3.5 Fibre diameter (FD) and subjectively assessed wool traits

Maintaining or decreasing FD is a major component of the overall breeding objective in the Merino breed. Selection for sheep with a good quality wool that have more even fleeces and softer wool covering of the face (if desired) would likely result in a reduced FD in breeding stock, as suggested by favourable genetic correlations of FD with QUAL (-0.32±0.05), with ROC (-0.27±0.06) and with FCS (-0.30±0.08). Similar genetic correlations were obtained (Snyman & Olivier, 2002a; Naidoo *et al*. 2004; Olivier *et al.*, 2006b) from the literature, though the correlations were somewhat higher for Afrino sheep (Snyman & Olivier, 2002a).

Table 6.5 Correlations (±SE) between fibre diameter (FD) and subjectively assessed wool traits

Trait	r_g	r_p	r_e	r_m
Fibre diameter X				
Wool quality	-0.32±0.05	-0.20±0.02	-0.11±0.04	0.21±0.22
Regularity of crimp	-0.27±0.06	-0.17±0.02	-0.14±0.03	0.23±0.28
Wool colour	-0.09±0.06	-0.06±0.02	-0.05±0.04	0.12±0.17
Oil	-0.02±0.07	-0.01±0.02	-0.00±0.03	-
Staple formation	0.59±0.06	0.32±0.02	0.19±0.03	-
Belly and points	0.37±0.06	0.25±0.02	0.20±0.03	-
Woolly face score	0.03±0.06	0.07±0.02	0.11±0.04	-
Face cover score	-0.30±0.08	-0.09±0.02	-0.01±0.03	-
Pigmentation	0.09±0.05	0.04±0.02	-0.02±0.04	-

See **Table 6.1** for abbreviations

Corresponding correlations of FD with STAPL and BANDP were unfavourable and moderate to high, suggesting that selection for sheep with higher scores for BANDP and

STAPL will probably result in sheep with a broader fibre diameter. Similar genetic correlations were obtained for South African Merino sheep (Naidoo *et al*. 2004; Olivier *et al*., 2006b). Genetic correlations of FD with COL, OIL, WFS and PIGM were not significant. Similar nonsignificant estimates for FD with COL and OIL were reported for the same Merino flock on a smaller data set (Naidoo *et al*., 2004). Also, a similar estimate for FD with COL (-0.49±0.18) was reported for Australian Merinos with respect to sign but the value was higher in magnitude and significant (Lewer *et al*., 1995). Snyman & Olivier (2002a) also reported a nonsignificant genetic correlation between FD and PIGM. Information regarding correlations between WFS and FD is lacking from the literature reviewed.

Phenotypic correlations were favourable for FD with QUAL (-0.20±0.02), and with ROC (-0.17±0.03) in the present study. Naidoo *et al*. (2004) reported slightly higher estimates of -0.23±0.03 and -0.21±0.03 for the corresponding traits on a smaller data set of the same Merino flock. Moreover, Olivier *et al*. (2006b) reported a higher phenotypic correlation of -0.33±0.02 between FD and QUAL for Cradock fine wool Merino sheep, while Snyman & Olivier (2002a) reported a slightly higher phenotypic correlation of -0.26±0.02 for Afrino sheep. FSC was also favourably correlated with FD (-0.09±0.02) in the present study. This is similar to the results (-0.12±0.03) obtained by Lewer *et al*. (1995) in Australian Merinos, while Snyman & Olivier (2002a) reported a higher phenotypic correlation of -0.50±0.02 between FD and FSC in Afrino sheep. Corresponding correlations with STAPL (0.32±0.02), BANDP (0.25±0.02) and with WFS (0.07±0.02) were unfavourable. Similar unfavourable phenotypic correlations for FD with STAPL (0.31±0.02 and 0.38±0.02) were reported for South African Merinos, but both estimates were slightly higher in magnitude (Naidoo *et al*., 2004; Olivier *et al*., 2006b). COL was negatively correlated with FD (-0.06±0.02) in the present study, as in the study of Naidoo *et al*. (2004) on the same Merino flock. In contrast, Lewer *et al*. (1995) reported a moderate and positive phenotypic correlation between FD and COL (0.18±0.02) for Western Australian Merinos. Of the subjectively assessed wool traits, OIL and PIGM were not significantly related to FD at the phenotypic level. Nonsignificant phenotypic correlations for the corresponding traits were accordingly reported for South African Merino and Afrino sheep (Snyman & Olivier, 2002a; Naidoo *et al*., 2004).

A previous study on the same Merino flock suggested favourable environmental correlations of FD with QUAL and ROC as well as unfavourable correlations with STAPL and BANDP (Naidoo *et al*., 2004). These results corresponded fairly well with current results, using a larger data set. The environmental correlations for FD with other subjectively assessed wool traits (COL, OIL, FSC and PIGM) were not significant in the present study. Similar nonsignificant estimates for the environmental correlation of FD with COL and OIL were reported on the same Merino flock (Naidoo *et al.,* 2004). FD was not maternally related to QUAL, ROC and COL, as suggested by nonsignificant maternal correlations. Information regarding maternal correlations for these traits was not found from literature.

6.3.6 Coefficient of variation (CVFD) and standard deviation of fibre diameter (SDFD) with subjectively assessed wool traits

It was shown in Chapter 4 that CVFD and SDFD are largely controlled by a similar set of genes, as suggested by a high genetic correlation of 0.87±0.01 between these two traits. Therefore, it is not surprising that correlations for CVFD and SDFD with subjectively assessed wool traits followed similar patterns. Genetic correlations of CVFD and SDFD with QUAL and ROC were favourable and moderate to high (Table 6.6).

Corresponding correlations with STAPL were unfavourable and high. These results suggested that sheep with higher scores for QUAL and ROC had lower scores for STAPL and their fibre diameter had less variation. A previous study on the same Merino flock reported similar results for the correlations of CVFD with QUAL, ROC and STAPL (Naidoo *et al*., 2004). SDFD was also unfavourably correlated with BANDP. No comparable results were found from literature pertaining to the relationship of SDFD with subjectively assessed wool traits. The genetic correlations for CVFD and SDFD with other subjectively assessed wool traits did not reach significance ($P<0.05$).

Table 6.6 Correlations (±SE) of coefficient of variation of fibre diameter (CVFD) and standard deviation of fibre diameter (SDFD) with subjectively assessed wool traits

Trait	r_g	r_p	r_e
CV of fibre diameter X			
Wool quality	-0.50±0.06	-0.34±0.02	-0.20±0.04
Regularity of crimp	-0.73±0.06	-0.34±0.02	-0.14±0.04
Wool colour	-0.08±0.07	-0.11±0.02	-0.14±0.04
Oil	0.05±0.08	0.07±0.02	0.09±0.04
Staple formation	0.49±0.07	0.20±0.02	0.04±0.04
Belly and points	0.04±0.08	-0.04±0.02	-0.03±0.04
Woolly face score	-0.05±0.06	-0.10±0.02	-0.10±0.05
Face cover score	-0.05±0.09	-0.04±0.02	-0.04±0.04
Pigmentation	-0.06±0.06	0.00±0.02	0.07±0.05
SD of fibre diameter X			
Wool quality	-0.62±0.05	-0.40±0.02	-0.22±0.04
Regularity of crimp	-0.81±0.05	-0.40±0.02	-0.20±0.03
Wool colour	-0.14±0.07	-0.13±0.02	-0.15±0.04
Oil	0.03±0.07	0.06±0.02	0.09±0.04
Staple formation	0.71±0.05	0.34±0.02	0.15±0.03
Belly and points	0.20±0.07	0.12±0.02	0.09±0.04
Woolly face score	-0.02±0.06	-0.03±0.02	-0.04±0.04
Face cover score	-0.18±0.09	-0.06±0.02	-0.01±0.04
Pigmentation	-0.01±0.06	0.01±0.02	0.04±0.04

CV of fibre diameter = coefficient of variation of fibre diameter and SD of fibre diameter = standard deviation of fibre diameter. See **Table 6.1** for other abbreviations.

A previous study on South African Merino sheep reported favourable phenotypic correlations of CVFD with QUAL and ROC (Naidoo *et al.*, 2004). These results are similar in sign to the present estimates, but the present results are albeit higher in magnitude. The corresponding correlation with STAPL was unfavourable, which was similar to that previously reported for the same Merino flock on a smaller data set (Naidoo *et al*., 2004). The present study also reported favourable genetic correlations of CVFD with COL and WFS. No comparable estimates were found in the literature. CVFD was positively related to OIL and not significantly related to BANDP, FCS and PIGM. Naidoo *et al*. (2004) also reported a nonsignificant genetic correlation of CVFD with BANDP.

Phenotypic correlations for SDFD with subjectively assessed wool traits generally followed a similar pattern as the corresponding correlations of CVFD with subjective wool traits (Table 6.6). The exception was the phenotypic correlation of SDFD with BANDP which was moderate and positive. There were negative and significant environmental correlations for CVFD and SDFD with QUAL, ROC, and COL. The corresponding correlation with OIL was positive. SDFD was also positively correlated with STAPL and BANDP. A previous study on the same Merino flock reported similar results for environmental correlations of CV with QUAL, ROC, COL, BANDP and STAPL (Naidoo *et al*., 2004). Comparable information on the correlations of SD with subjectively assessed wool traits was lacking from the literature.

6.3.7 Staple length (SL) and staple strength (SS) with subjectively assessed wool traits

On a genetic basis, SL was moderately and favourably related to COL, BANDP and WFS and negatively related to OIL (Table 6.7). These results indicated that sheep with longer staples had better scores for COL, BANDP and WFS as well as lower scores for OIL. The economic implications for Merino sheep breeding programs are that, sheep with longer staples are likely to have whiter wool, with better scores for BANDP and more open faces. Corresponding correlations with QUAL, ROC, STAPL, FCS and PIGM were not significant. While Naidoo *et al*. (2004) found no significant genetic correlations between SL and the respective subjective wool traits, Snyman & Olivier (2002a) reported a negative correlation of -0.19 for SL with ROC in Afrinos. Furthermore, Olivier *et al*. (2006b) reported a significant correlation of SL with QUAL (0.31±0.06) and a nonsignificant correlation with STAPL (0.02±0.07). Of all the subjectively assessed wool traits, only ROC was related with SS, as suggested by a significant genetic correlation of 0.33. This result suggested that sheep with wool with a very regular crimp were less likely to produce tender wool. No genetic correlations of SS with subjectively assessed wool traits were found in the literature sourced.

Table 6.7 Correlations (±SE) of staple length (SL) and staple strength (SS) with subjectively assessed wool traits and live weight

Trait	r_g	r_p	r_e
Staple length X			
Wool quality	-0.01±0.08	0.01±0.03	0.01±0.03
Regularity of crimp	0.09±0.08	-0.01±0.02	-0.04±0.03
Wool colour	0.16±0.07	0.06±0.02	0.02±0.03
Oil	-0.33±0.08	-0.10±0.02	-0.02±0.03
Staple formation	0.12±0.08	0.11±0.02	0.10±0.03
Belly and points	0.40±0.07	0.23±0.02	0.16±0.03
Woolly face score	0.16±0.06	0.13±0.02	0.10±0.04
Face cover score	-0.02±0.10	0.02±0.02	0.04±0.03
Pigmentation	0.00±0.06	0.02±0.02	0.04±0.03
Staple strength X			
Wool quality	0.17±0.12	0.07±0.03	0.04±0.04
Regularity of crimp	0.33±0.14	0.09±0.02	0.03±0.04
Wool colour	0.17±0.12	0.06±0.02	0.03±0.04
Oil	0.10±0.13	-0.01±0.02	-0.03±0.04
Staple formation	-0.05±0.14	0.02±0.03	0.04±0.04
Belly and points	0.08±0.13	0.13±0.03	0.14±0.04
Woolly face score	-0.10±0.11	-0.01±0.02	0.04±0.04
Face cover score	0.06±0.16	-0.03±0.02	-0.05±0.04
Pigmentation	0.08±0.11	0.01±0.03	-0.01±0.04

See **Table 6.1** for abbreviations

Phenotypic correlations of SL with COL, STAPL, BANDP and WFS were positive, while SL was negatively correlated with OIL. Naidoo *et al.* (2004) reported no significant phenotypic correlations of SL with COL or STAPL and a positive correlation with BANDP on a smaller date set from the same Merino flock. Correlations of SL with QUAL, ROC, FCS and PIGM did not reach significance (P>0.05). In contrast to the present study, previous studies on South African Merino sheep reported positive and moderate phenotypic correlations of 0.21 and 0.20 respectively between SL and QUAL (Naidoo *et al.*, 2004; Olivier *et al.*, 2006b). Phenotypic correlations for SS with QUAL, ROC, COL and BANDP were positive in the present study, but generally low at <0.15. Environmental correlations of SL with STAPL, BANDP and WFS were moderate and positive. SL was not significantly related to QUAL, ROC, COL, OIL, FCS and PIGM on the environmental level. Similar results were reported for corresponding traits, using a smaller data set on the same Merino Flock (Naidoo *et al.*, 2004). Apart from the positive environmental correlation between SS and BANDP, there were no noteworthy environmental correlations between SS and the subjectively assessed wool traits. No comparable results for SS were found in the literature.

6.4 Conclusions

Genetic parameters obtained in this study accorded with results of previous studies, in cases where comparable results were available. Most correlation estimates between LW as well as the objective wool traits with the subjective wool traits were favourable or not significant. Selection for LW and objective wool traits will thus not seriously compromise the subjective wool traits. The exception is FD, CVFD and SDFD where unfavourable genetic correlations with STAPL and BANDP were found. Like with other subjectively assessed traits, PIGM was also not related to any of the objective wool traits or live-weight in the present study. Therefore, selection for LW and objective wool traits would not increase the risk of a higher proportion of dark fibres in the wool of breeding stock.

CHAPTER 7

RELATIONSHIPS AMONG SUBJECTIVELY ASSESSED CONFORMATION AND OBJECTIVELY MEASURED WOOL TRAITS AND LIVE WEIGHT

7.1 Introduction

Body conformation is very important for an animal's production and reproduction. In sheep breeding enterprises, body conformation traits played an important role in selection systems for several commercial Merino studs (Olivier *et al.,* 1987; James *et al*., 1990; Lewer *et al*., 1995). These traits are therefore seen as important for the economic viability of farms (Olivier *et al*., 2006a), and were in some instances used exclusively for the selection and culling of breeding stock (Lewer *et al*., 1995; Snyman & Olivier, 2002a). However, Gregory (1982b) emphasised that, knowledge of genetic relationships for these traits with economically important wool and body traits is essential to enable prediction of how selection on these traits will affect traits of economic importance.

Previous research estimated mostly phenotypic correlations for some subjectively assessed conformation traits in Merino sheep (Cloete *et al*., 1992; Lewer *et al.,* 1995; Olivier *et al.,* 1997). A few studies in Merino sheep reported genetic correlations for some subjectively assessed conformation traits with production traits (Cloete *et al*., 1998a; Cloete *et al*., 2005; Cloete *et al*., 2006), while only Snyman & Olivier (2002a) reported corresponding correlations with reproduction traits for Carnarvon Afrino sheep. Therefore, six body conformation traits of Tygerhoek Merino resource flock were assessed on a linear scale (Olivier *et al*., 1987) for South African Merino sheep. Correlations (genetic, phenotypic, environmental and maternal) were then estimated. This was done to enable prediction of the direction and magnitude of genetic progress of economically important traits in Merino sheep, when selection of breeding sires and dams depends largely on subjectively assessed conformation traits.

7.2 Materials and methods

7.2.1 Data

Data utilised in the present study for objective wool traits were similar to that described in Chapter 3. Subjective conformation traits included in current analysis were also similar to those analysed in Chapter 5 and they included pastern score (PS), general head conformation (GEN), front quarters (FQ), topline (TOPL), total fold score (TOT) and hocks (HOCKS). A description of data used to analyse live-weight and objective wool traits is presented in Table 4.1 in Chapter 4. Table 5.1 in Chapter 5 presents a description of data used to analyse subjectively assessed conformation traits. A similar procedure of editing described in Chapter 3 was applied to the data utilized in this part of the study.

7.2.2 Statistical analysis

The ASREML programme of Gilmour *et al*. (2002) described in Chapter 3 was used to estimate correlations between subjective conformation and objective wool traits as well as live-weight by fitting two-trait animal models. Models 5 and 6 were used to estimate the correlations for GFW and CFW with PS, while Models 5 and 1 were used to estimate the correlations of GFW and CFW with FQ, TOPL, TOT and HOCKS. Furthermore, Models 3 and 1 were used for the analysis of FD and LW with FQ, TOPL, TOT and HOCKS. Models 3 and 6 were used to analyse LW and FD together with PS. Moreover, Models 1 and 6 were used for CY, SL, SS, CV and SD with PS. Model 3 was used for both traits to estimate the correlations of FD and LW with GEN while Model 1 was used for both traits to estimate correlations of CY, SL, SS, CV and SD with FQ, TOPL, TOT and HOCKS.

7.3 Results and discussion

7.3.1 Live weight (LW) and subjectively assessed conformation traits

It is evident from the present results that heavier Merino sheep reared at the Tygerhoek experimental farm were generally plainer and had better scores for GEN, HOCKS, and FQ as well as for TOPL, as suggested by significant genetic correlations between these traits. In Table 7.1, correlations between live weight (LW) and subjectively assessed wool traits are summarized. The genetic correlation between live weight and PS was also favourable but not significant. Previous studies on South African Merino sheep reported comparable genetic correlations of -0.24±0.04 and -0.26±0.08 between LW and TOT (Cloete *et al*., 1998a; Cloete *et al*., 2005). These correlations are regarded as favourable in view of the plainer genotypes preferred at present in South Africa. A corresponding favourable correlation (0.67±0.04) of LW with FQ was also reported for Cradock fine wool Merino sheep (Olivier *et al*., 2006b). No estimates of genetic correlations of LW with HOCKS, TOPL, PS and GEN could be found in literature.

Table 7.1 Correlations (±SE) between live weight (LW) and subjectively assessed wool traits

Trait	r_g	r_p	r_e	r_m
Live weight (LW) X				
PS	0.18±0.10	0.04±0.02	-0.01±0.03	0.16±0.19
GEN	0.67±0.05	0.55±0.01	0.45±0.03	0.74±0.01
HOCKS	0.36±0.07	0.28±0.02	0.25±0.03	-
FQ	0.42±0.09	0.29±0.02	0.28±0.03	-
TOPL	0.25±0.10	0.21±0.02	0.21±0.03	-
TOT	-0.23±0.07	-0.00±0.02	0.14±0.03	-

LW = live-weight, GEN = general head conformation, HOCKS = hocks, FQ = front quarters, TOPL = topline, TOT = total fold score, r_g = genetic correlation, r_p = phenotypic correlation, r_e = environmental correlation, r_m = maternal correlation and SE = standard error

At the phenotypic level, LW was positively related to GEN, HOCKS, FQ and TOPL. Olivier *et al*. (2006b) reported a similar phenotypic correlation in sign (0.60±0.01), albeit higher in magnitude. Corresponding correlations with PS and TOT were not significant. Previously, Cloete *et al*. (1998a) reported a moderate and positive phenotypic correlation of 0.19±0.02 between LW and TOT, for the same Merino flock, in contrast to the extremely low and nonsignificant (-0.00±0.02) phenotypic correlation in the present study. The environmental correlation between LW and TOT was moderate and positive. A similar environmental correlation of 0.12±0.05 was reported on two-tooth replacements of the Elsenburg Merino flock (Cloete *et al*., 2005). Maternal correlations of LW were high with GEN at 0.71, but not significant with PS. Information on the maternal correlations between LW and subjective conformation traits was lacking from literature.

7.3.2 Greasy (GFW) and clean fleece weights (CFW) with subjectively assessed conformation traits

Correlations of greasy (GFW) and clean fleece weight (CFW) with subjectively assessed conformation traits are summarized in Table 7.2. Unfavourable genetic correlations that occurred between TOT and fleece weights (GFW 0.48±0.06 and CFW 0.28±0.07) suggested that, plainer sheep had generally lower fleece weights. Comparable genetic correlations between CFW and TOT of respectively 0.19±0.02, 0.27±0.09 and 0.30±0.09 have been reported for South African Merino sheep (Cloete *et al*., 1998a; Cloete *et al*., 2005; Olivier *et al*., 2006b). On contrary, previous research on Western Australian Merino sheep estimated favourable genetic correlations that ranged from -0.16 to -0.35 between wool weight and TOT, but with very high standard errors (Lewer *et al*., 1995).

Furthermore, it was found that sheep with heavier fleeces generally had lower scores for TOPL, as suggested by unfavourable r_g between TOPL and fleece weights (-0.34 for GFW and -0.29 for CFW). Snyman & Olivier (2002a) reported a similar unfavourable relationship of -0.25 between TOPL and CFW in Afrino sheep. Sheep with stronger heads had higher weights for clean wool in Tygerhoek Merino flock, as suggested by significant genetic correlation between CFW and GEN (0.23). On the contrary, Snyman & Olivier (2002a) reported a negative genetic correlation of -0.18 between GEN and CFW in Afrinos. This discrepancy may be due to breed differences. While no significant genetic correlations were found between HOCKS and wool weights, Snyman & Olivier (2002a) estimated an unfavourable genetic correlation of -0.45 for CFW with HOCKS. Other genetic correlations between wool weights and subjective conformation traits did not reach significance (P>0.05). Snyman & Olivier (2002a) also reported nonsignificant genetic correlations of CFW with PS and FQ.

Table 7.2 Correlations (±SE) between greasy (GFW) and clean fleece weight (CFW) with subjectively assessed conformation traits

Trait	**r_g**	**r_p**	**r_e**	**r_m**
Greasy fleece weight (GFW) X				
PS	-0.13±0.10	0.03±0.02	0.07±0.03	0.15±0.14
GEN	0.11±0.08	0.28±0.02	0.35±0.03	-
HOCKS	-0.01±0.09	0.10±0.02	0.16±0.03	-
FQ	0.07±0.11	0.12±0.02	0.14±0.03	-
TOPL	-0.34±0.11	-0.01±0.02	0.06±0.03	-
TOT	0.48±0.06	0.34±0.02	0.28±0.03	-
Clean fleece weight (CFW) X				
PS	0.09±0.09	0.04±0.02	0.07±0.03	0.18±0.14
GEN	0.23±0.07	0.30±0.02	0.32±0.03	-
HOCKS	0.03±0.08	0.11±0.02	0.15±0.03	-
FQ	0.16±0.11	0.14±0.02	0.15±0.03	-
TOPL	-0.29±0.11	-0.00±0.02	0.07±0.03	-
TOT	0.28±0.07	0.25±0.02	0.24±0.03	-

See **Table 7.1** for abbreviations

Of the subjective conformation traits, PS and TOPL were not significantly related to wool weights at the phenotypic level in Tygerhoek Merino sheep. This is in agreement with results obtained for Afrino sheep (Snyman & Olivier, 2002a). However, positive phenotypic correlations were estimated for wool weights with GEN, HOCKS, FQ and TOT in the present study. Cloete *et al.* (1998a) reported a phenotypic correlation of 0.10 for CFW with TOT for the same Merino flock. Snyman & Olivier (2002a) also reported comparable positive phenotypic correlations for CFW with GEN and FQ for Afrino sheep. However, the corresponding correlation with HOCKS was negative for Afrinos (Snyman & Olivier, 2002a), in contrast with a current positive correlation between these traits.

Information on environmental correlations between wool weights and subjective conformation traits was lacking from literature. Only two correlations of 0.19 ± 0.04 and 0.18 ± 0.04 between TOT and CFW were found for Elsenburg Merino flock for two-tooth replacements (Cloete *et al*., 2005; Cloete *et al*., 2006), which were in accordance with the current estimate of 0.24 ± 0.03 for the Tygerhoek Merino flock. Other correlations between wool weights and subjective conformation traits were positive in sign and moderate in magnitude. Maternal correlations for wool weights with PS were positive, but did not reach significance ($P>0.05$).

7.3.3 Clean yield (CY) and subjectively assessed conformation traits

Estimates of r_g were favourable for CY with GEN (0.25), HOCKS (0.19) and FQ (0.18) (Table 7.3), suggesting that sheep with higher percentage of CY had stronger heads and higher scores for HOCKS and FQ. In contrast, Snyman & Olivier (2002a) reported an unfavourable correlation of CY with HOCKS (-0.23) and a nonsignificant correlation of CY with GEN in Afrino sheep. However, the present r_g between CY and FQ was consistent with that reported for Afrino sheep (Snyman *et al*., 2002a).

Research reported conflicting evidence on the direction and magnitude of the r_g between CY and TOT for Merino sheep. Lewer *et al.* (1995) reported unfavourable correlations of CY with TOT that ranged from 0.01 to 0.28 for Western Australian Merino sheep, but with high standard errors. However, Cloete *et al.* (1998a) reported a favourable correlation of -0.36, which is somewhat higher than the present estimate of -0.26 on the same flock. The economic implication of the current results is that plainer sheep had a higher CY. Furthermore, PS and TOPL were not significantly related to CY in the current study. This accorded with results obtained for Afrino sheep (Snyman & Olivier, 2002a).

Table 7.3 Correlations (±SE) between clean yield (CY) and subjectively assessed conformation traits

Trait	r_g	r_p	r_e
Clean yield (CY) X			
Pastern Score	0.12±0.09	0.03±0.02	-0.01±0.03
GEN	0.25±0.05	0.12±0.02	-0.01±0.04
HOCKS	0.19±0.06	0.07±0.02	-0.04±0.04
FQ	0.18±0.08	0.07±0.02	0.03±0.03
TOPL	0.03±0.09	0.04±0.02	0.05±0.03
TOT	-0.26±0.05	-0.17±0.02	-0.09±0.04

See **Table 7.1** for other abbreviations

At the phenotypic level, CY was positively related to GEN (0.12), HOCKS (0.07) and FQ (0.07) in the present study. On the contrary, Snyman & Olivier (2002a) reported nonsignificant correlations for CY with GEN and FQ, as well as a negative correlation with HOCKS (-0.09). Previous research on the same Merino flock reported a moderate and positive phenotypic correlation of -0.10 for TOT with CY, which was lower than the current estimate of -0.17. However, Lewer *et al.* (1995) reported moderate and positive phenotypic correlations for CY with TOT that ranged from 0.12 to 0.17 for Western Australian Merino sheep. No noteworthy environmental correlations for CY with subjective conformation traits were detected. The exception was a low and negative environmental correlation of -0.09 between CY and TOT. No estimates of environmental correlations were found from the literature for comparison.

7.3.4 Fibre diameter (FD) and subjectively assessed conformation traits

A reduced FD would result in lower scores for HOCKS and TOT in Tygerhoek Merino flock, as suggested by the significant and unfavourable r_g of 0.13 in both cases (Table 7.4). Thus, plainer sheep would generally have broader fibres and narrower hocks. Other studies on South African Merino sheep reported nonsignificant genetic correlation between FD and TOT (Cloete *et al*., 1998a; Cloete *et al*., 2005; Cloete *et al*., 2006). In contrast, Lewer *et al*. (1995) reported favourable genetic correlations for FD with TOT, but with high standard errors. On the other hand, Snyman & Olivier (2002a) reported a nonsignificant genetic correlation between FD and HOCKS in Afrino sheep. While FD was not significantly related to PS, TOPL and FQ in this study, Snyman & Olivier (2002a) reported a favourable correlation between FD and PS, and an unfavourable corresponding correlation of FD with TOPL. Also, Olivier *et al.* (2006b) reported an unfavourable genetic relationship between FD and FQ. FD was also not related to GEN and FQ in Carnarvon Afrino sheep (Snyman & Olivier 2002a), which is in good agreement with current results for Tygerhoek Merino resource flock.

Positive phenotypic correlations were estimated for FD with GEN, HOCKS, FQ and TOT, while TOPL and PS were not significantly related to FD. Similar positive and low correlations were reported for FD with FQ (Snyman & Olivier, 2002a; Olivier *et al*., 2006b) and HOCKS (Snyman & Olivier, 2002a). Like in the present study, FD and PS were not significantly related in Afrino sheep (Snyman & Olivier, 2002a). A nonsignificant environmental correlation was previously reported between TOT and FD for mature ewes of Elsenburg Merinos (Cloete *et al.,* 2006), which was similar to the current estimate for the Tygerhoek Merino resource flock. PS was not significantly related to FD at the environmental level in the present study. Other environmental correlations estimated between FD and subjective conformation traits were moderate and positive. No comparable estimates were found from the literature.

Table 7.4 Correlations (±SE) between fibre diameter (FD) and subjectively assessed conformation traits

Trait	r_g	r_p	r_e
Fibre diameter (FD) X			
PS	-0.16±0.08	-0.03±0.02	0.05±0.03
GEN	-0.06±0.06	0.11±0.02	0.27±0.04
HOCKS	0.13±0.06	0.12±0.02	0.12±0.04
FQ	0.08±0.08	0.10±0.02	0.13±0.03
TOPL	-0.18±0.09	0.03±0.02	0.14±0.03
TOT	0.13±0.06	0.05±0.02	-0.01±0.04

See **Table 7.1** for abbreviations

7.3.5 Coefficient of variation (CVFD) and standard deviation of fibre diameter (SDFD) with subjectively assessed conformation traits

Estimates of r_g were favourable for CVFD with HOCKS (-0.17), FQ (-0.33) and with TOPL (-0.25) (Table 7.5) and nonsignificant with the other subjectively assessed conformation traits. SDFD was significantly related to FQ (-0.20±0.09) and TOPL (-0.27±0.09) among the subjectively assessed conformation traits. Information on the relationship of SDFD and CVFD with subjective conformation traits was lacking from the literature.

At the phenotypic level CVFD was favourably related to GEN, HOCKS and FQ. An unfavourable correlation occurred between CVFD and TOT. Low and favourable correlations were found between SDFD and HOCKS, FQ and TOPL. The corresponding correlation with TOT was unfavourable while nonsignificant correlations occurred for SDFD with PS and GEN. Environmental correlations for CVFD and SDFD with subjective conformation traits were generally not significant, the exceptions being correlations of CVFD with GEN, HOCKS and TOT, and the correlation of SDFD with TOT.

Table 7.5 Correlations (±SE) of coefficient of variation of fibre diameter (CVFD) and standard deviation of fibre diameter (SDFD) with subjectively assessed conformation traits

Trait	r_g	r_p	r_e
Coefficient of variation of fibre diameter (CVFD) X			
PS	-0.01±0.11	-0.02±0.02	-0.03±0.04
GEN	-0.06±0.07	-0.10±0.02	-0.16±0.05
HOCKS	-0.17±0.07	-0.14±0.02	-0.12±0.04
FQ	-0.33±0.09	-0.13±0.02	-0.06±0.04
TOPL	-0.25±0.10	-0.10±0.02	-0.05±0.04
TOT	0.03±0.07	0.11±0.02	0.21±0.04
Standard deviation of fibre diameter (SDFD) X			
PS	-0.12±0.11	-0.01±0.02	0.03±0.04
GEN	-0.06±0.06	-0.04±0.02	-0.01±0.04
HOCKS	-0.07±0.07	-0.05±0.02	-0.04±0.04
FQ	-0.20±0.09	-0.06±0.02	0.00±0.04
TOPL	-0.27±0.09	-0.06±0.02	0.03±0.04
TOT	0.06±0.06	0.12±0.02	0.19±0.04

See **Table 7.1** for abbreviations

7.3.6 Staple length (SL) and staple strength (SS) with subjectively assessed conformation traits

At genetic level, SL was favourably related to GEN (0.31) and TOT (-0.43), suggesting that, selection for an increased SL would result in plainer sheep with stronger heads (Table 7.6). Previously, a nonsignificant correlation was reported between SL and GEN in Afrino sheep (Snyman & Olivier, 2002a), as well as for SL and TOT in the same Merino resource flock (Cloete *et al*., 1998a). The genetic correlations of SL with other subjective conformation traits were nonsignificant in the present study. On the contrary, a significant correlation between SL and FQ was previously reported for Cradock fine-wool Merinos (Olivier *et al*., 2006a). Moreover, Snyman & Olivier (2002a) reported nonsignificant correlations between SL and TOPL, as well as between FQ and PS in Afrino sheep. An unfavourable r_g of 0.25 occurred between SS and TOT, thus plainer sheep would produce wool with weaker staples. The genetic correlation between SS and FQ was favourable and nonsignificant correlations were found between SS and other subjective conformation traits. None of literature sources cited estimated genetic correlations of SS with the respective subjective conformation traits.

Table 7.6 Correlations (±SE) of staple length (SL) and staple strength (SS) with subjectively assessed conformation traits

Trait	r_g	r_p	r_e
Staple length (SL) X			
PS	-0.20±0.11	-0.03±0.02	0.02±0.03
GEN	0.31±0.06	0.24±0.02	0.20±0.03
HOCKS	0.09±0.08	0.09±0.02	0.08±0.03
FQ	0.07±0.10	0.10±0.02	0.10±0.03
TOPL	0.14±0.10	0.08±0.02	0.07±0.03
TOT	-0.43±0.06	-0.19±0.02	-0.04±0.03
Staple strength (SS) X			
PS	0.13±0.19	0.05±0.03	0.09±0.04
GEN	0.05±0.13	0.07±0.03	0.12±0.05
HOCKS	0.20±0.13	0.07±0.03	0.03±0.04
FQ	0.39±0.17	0.11±0.03	0.06±0.04
TOPL	0.04±0.18	0.03±0.03	0.03±0.04
TOT	0.25±0.12	-0.02±0.03	-0.12±0.04

See **Table 7.1** for abbreviations

Phenotypic correlations between SL and subjective conformation traits were favourable and nonsignificant with PS. Cloete *et al*. (1998a) also found a favourable phenotypic correlation between SL and TOT, while Olivier *et al*. (2006a) reported a favourable correlation between SL and FQ for the Cradock fine-wool Merino flock. Moreover, Snyman & Olivier (2002a) reported favourable correlations for SL with GEN and FQ, as well as a nonsignificant corresponding correlation between TOPL and PS in Afrino sheep. In the current study, favourable phenotypic correlations were also found for SS with GEN, HOCKS and FQ. Corresponding correlations of SS with PS and TOT were not significant. While none of the literature sources cited reported environmental correlations between SL and subjective conformation traits, significant relationships were found for SL with GEN, HOCKS, FQ and TOPL, as well as for environmental correlations of SS with PS and GEN in the present study.

7.4 Conclusions

The present results were consistent with the present selection objectives in the South African Merino industry, favouring heavier and plainer breeding stock, supported by a favourable and moderate genetic correlation between LW and TOT. However, from these results, it was clear that unrestrained discrimination against wrinkles in Merino sheep would adversely affect economically important objectively assessed wool traits such as SS, FD and wool weight. Selection against wrinkles should be carefully monitored to minimise the risk of animals producing reduced fleece weights with broader fibres. It is therefore, proposed that animals with excessive wrinkles be culled from the breeding stock. In addition a favourable relationship was found between TOT and CVFD. This relationship could be used to indirectly select against wool tenderness, based on the favourable genetic correlation of -0.57 between CVFD and SS (see Chapter 4). This contention is supported by the results of near optimal gains being achieved (Purvis & Swan, 1999) when CVFD was included in the selection criterion as an indicator trait for SS.

CHAPTER 8

GENERAL CONCLUSIONS

The primary objective of animal breeding is to obtain genetic improvement in traits of economic importance through selection. Selection objectives in the Merino industry ranges from an objective to reduce fibre diameter while maintaining fleece weight to the increase of fleece weight at a constant fibre diameter, and any combinations between these extremes. Staple strength as an additional trait of economic importance was later investigated to be included in a selection objective to address the problem of wool tenderness. Fluctuations in the ratio between wool and meat prices have also resulted in the emphasis on the two products changing markedly over the past decade. This resulted in distinct changes in the South African Merino industry involving the adaptation of the breeding strategy for Merino sheep to also enable an improved meat production capability (Olivier, 1999). Some selection pressure is therefore also directed towards the improvement of net reproduction rate and growth in Merinos. In practise, Merino breeders also include subjectively assessed wool and conformation traits in their selection objectives. A combination of all these factors resulted in breeding objectives of Merino sheep becoming more complex. Against this background, there is an urgent need to provide accurate estimates of genetic parameters and relationships between objective traits of high economic value with subjectively assessed wool and conformation traits. These parameters are needed for accurate genetic evaluation of animals and for the development of optimum breeding objectives.

Moderate to high heritability estimates among objective traits suggested worthwhile response to selection and the feasibility of genetic change in live weight, wool quantity and wool quality. The results from single trait analysis showed that, among the objective traits, live weight, fleece weights and fibre diameter were subject to significant maternal effects. Clean fleece weight had the highest maternal variance ratio of 10%. The contribution of dam permanent environmental effects was less than 10% for the fleece weights. Thus, maternal genetic and environmental effects need to be considered when carrying out genetic evaluations of live weights and fleece weights. Also, a maternal effect needs to be included in the analysis of fibre diameter as an additional random variable. Other objective wool traits studied on Tygerhoek Merino flock were only under direct genetic control. An antagonistic relationship between animal effects for fleece weights as well as fibre diameter calls for the inclusion of a correlation between animal effects as an additional random variable in analyses for the genetic evaluation of these traits.

Low to high heritability estimates indicated mentionable responses to selection for subjectively assessed wool and conformation traits in South African Merino sheep. Of the subjective traits, maternal genetic effects had a significant influence on wool quality, regularity of crimp, wool colour and pastern score. However, in all cases the contribution of maternal genetic effects was below 10%. Apart from gene action, general head conformation was also influenced by a dam permanent environmental effect amounting to 5% of the total phenotypic variance. This emphasises the importance of implementing the correct model regarding random effects for the estimation of genetic parameters for subjectively assessed wool and conformation traits.

The most noteworthy genetic correlations among objective wool traits were a moderate and unfavourable genetic correlation between the most important qualitative determinants of wool price (staple strength and fibre diameter), and favourable genetic correlations for the coefficient of variation of fibre diameter with staple strength and fibre diameter. The unfavourable results have implications for selection programmes for a decreased fibre diameter, if staple strength needs to be maintained. However, the relationship of coefficient of variation of fibre diameter with staple strength and fibre diameter suggested a favourable correlated response to selection for a decreased fibre diameter. This is when direct selection is practised on the coefficient of variation of fibre diameter, as an indicator trait for staple strength. Quantitative wool traits (greasy and clean fleece weight) and some qualitative wool traits (staple strength, fibre diameter and coefficient of variation of fibre diameter) were also unfavourably related, and thus need careful consideration during selection. However, the size of these correlations was generally small and they are not expected to cause a major problem. Generally nonsignificant correlations of live weight with those objective wool traits related to wool quality suggested either non important or favourable correlated responses to selection for these traits.

The genetic relationships among subjective wool and conformation traits were mostly not significant. The noteworthy relationships between subjective wool traits and objective wool traits were unfavourable correlations between measures of wool style (quality and regularity of crimp) and measures of wool yield (staple formation and belly and pieces). Plainer sheep were also likely to have lower scores for belly and points. However, the magnitude of these unfavourable correlations was relatively low and they were not expected to cause serious problems in selection programmes. It was also noted that, selection for live weight and objectively assessed wool traits without compromising subjectively assessed wool and conformation traits appeared to be feasible. This contention was supported by the present results of either nonsignificant or favourable relationships among those traits. Of the objective wool traits, fibre diameter, coefficient of variation of fibre diameter and the standard deviation of fibre diameter were unfavourably related to staple formation and belly and points.

The present breeding objectives for Merino industry favours plainer and heavier breeding stock. A favourable and moderate genetic correlation between live weight and total fold score were in accordance with this breeding objective. However unrestrained discrimination against wrinkles in Merino sheep could adversely affect economically important objectively measured wool traits such as staple strength, fibre diameter, and wool weights. The presence of a favourable genetic correlation between total fold score and coefficient of variation of fibre diameter could however, be used to indirectly select against wool tenderness based on the favourable genetic correlation between coefficient of variation of fibre diameter and staple strength.

It was also noteworthy that pigmentation on the face, which is associated with contamination of wool with dark and pigmented fibres, was not related to any of the traits studied. Therefore the genetic change towards more desired genotypes pertaining to live weight, wool quantity and wool quality as well as conformation would not likely lead to unwanted increases in pigmentation.

As a bottom line, it is important to note that all subjective traits that were assessed in this study were heritable. There is thus little doubt that selection for these traits will result in genetic gains, should it be desired. On the other hand, the present selection pressure for heavier, plainer and finer Merinos should not compromise subjective wool and conformation traits too severely. The only subjective wool traits likely to be deleteriously affected were staple formation as well as belly and points. Some attention to these traits could thus be warranted, should they be identified as sufficiently important in the overall selection objective.

Abstract

Genetic evaluation systems require accurate estimates of genetic parameters. The genetic, phenotypic and environmental parameters for objectively measured wool, subjectively assessed wool and conformation traits as well as 16-month live weight were estimated for South African Merino sheep. Records of the Tygerhoek Merino resource flock were used to estimate these parameters. The database consisted of records of 4 495 animals, the progeny of 449 sires and 1 831 dams born in the period 1989 to 2004. The pedigree records used have been collected between 1969 and 2004. In this data, four lines were represented, namely a line selected on clean fleece weight, a line selected against rearing failure, a fine wool line, as well as an unselected control line. Single trait linear mixed models were used. Fixed effects that were assessed included birth status (single/multiple), sex (male/female), age of the dam in years (2-6^+years), year of birth (1989-2004) selection line (1-4) and the sex*birth year interaction. Preliminary analysis showed that all the fixed effects had significant ($P<0.05$) effects on all the traits studied. The random effects included a combination of direct additive, maternal additive and maternal permanent environmental effects as well as the covariance between direct and maternal additive effects.

The direct heritability estimates (h^2_a) for objectively measured traits were 0.38 for 16-month live weight (LW), 0.36 for greasy fleece weight (GFW), 0.40 for clean fleece weight (CFW), 0.65 for clean yield (CY), 0.37 for staple length (SL), 0.20 for staple strength (SS), 0.68 for fibre diameter (FD), 0.61 for coefficient of variation of fibre diameter (CVFD) and 0.61 for standard deviation of fibre diameter (SDFD). The maternal heritability estimates were 0.05 for LW, 0.09 for GFW, 0.10 for CFW and 0.05 for FD. The proportion of the total phenotypic variance due to the maternal permanent environment (c^2_{pe}) amounted to 5% for fleece weights. The correlation between direct and maternal genetic effects for LW, GFW and CFW were -0.28, -0.65 and -0.70 respectively. These results suggested that worthwhile responses to selection for objectively measured traits would result from directed selection.

Estimates of h^2_a for subjectively assessed wool traits were 0.49 for wool quality (QUAL), 0.28 for regularity of crimp (ROC), 0.33 for wool colour (COL), 0.23 for wool oil (OIL), 0.21 staple formation (STAPL), 0.22 belly and points (BANDP), 0.50 for woolly face score (WFS), 0.15 for face cover score (FCS), and 0.45 for pigmentation (PIGM). Maternal genetic effects were significant for QUAL, ROC and COL amounting to 0.06, 0.03 and 0.07 respectively. The correlation between direct and maternal genetic effects for QUAL, ROC and COL were -0.62, -0.70 and -0.45 respectively. The h^2_a estimates for subjectively assessed conformation traits were 0.13 for topline (TOPL), 0.39 for total fold score (TOT), 0.15 for front quarters (FQ), 0.16 for pastern score (PS), 0.32 for hocks (HOCKS) and 0.37 for the general conformation score of the head (GEN). Among the subjectively assessed conformation traits the maternal genetic effects were significant only for PS at 0.05 while GEN was affected by c^2_{pe} at 5%. The correlation between direct and maternal genetic effects was -0.71 for PS. The improvement of subjectively assessed wool and conformation traits by selection seems possible from the results of present study.

Genetic correlations (r_g) among objectively assessed traits general agreed with literature values. Among the subjectively assessed traits favourable r_g estimates were estimated between ROC and COL (0.31), for QUAL with ROC (0.49) and COL (0.26) and between STAPL and BANDP (0.58). The relationships between ROC and STAPL (-0.49) and for QUAL with STAPL (-0.45) and BANDP (-0.20) were unfavourable. Estimates of r_g among subjective conformation traits were generally low, variable in sign and not significant. The only exceptions were r_g's between HOCKS and FQ (0.71) and of GEN and TOPL with TOT (-0.31 and -0.47 respectively). Phenotypic and environmental correlations among objective, subjective wool and conformation traits were low to moderate. Maternal relationships of respectively 0.86 and 0.19 were found between GFW and CFW and between CFW and FD.

The r_g of LW with subjective wool traits were not significant, with the exception of moderate and favourable r_g for LW with ROC (0.20) and for LW with WFS (0.20). These results suggested that heavier sheep are likely to have more even fleeces and higher scores for WFS. The r_g were favourable with COL (-0.19), STAPL (0.35) and BANDP (0.42). CFW and CY were also favourably related to COL, STAPL, BANDP and QUAL where sheep with higher fleece weights and yield had wool with higher quality and better scores for COL, STAPL as well as BANDP. SL was favourably related to COL, BANDP and WFS and negatively related to OIL. These results indicated that sheep with longer staples had better scores for COL, BANDP and WFS as well as lower scores for OIL. Among the subjective wool traits only ROC was significantly related to SS at 0.33. Moderate and unfavourable genetic correlations were estimated for FD with QUAL, ROC and FCS, where sheep with a good quality wool that have more even fleeces and softer wool covering the face had reduced FD. The corresponding relationship with STAPL and BAND were unfavourable. Genetic correlations of CVFD and SDFD with QUAL and ROC were favourable and while these traits were unfavourably related to a number with STAPL. Phenotypic and environmental relationships between objectively measured traits and subjectively assessed wool traits were low to high and variable in sign.

On the genetic level LW was favourably related to all the subjectively assessed conformation traits studied. Heavier sheep were generally plainer, had better scores for GEN, HOCKS, and FQ as well as for TOPL. Estimates of r_g were favourable for CY with GEN (0.25), HOCKS (0.19), TOT (-0.26) and FQ (0.18), for FD with PS (-0.16) and TOPL (-0.18), for CVFD with HOCKS (-0.17), FQ (-0.33) and TOPL (-0.25), between CFW and GEN (0.23), and between SS and FQ (0.39). The relationships of SDFD with FQ and TOPL were negative. Unfavourable correlations occurred between SS and TOT (0.25), between FD and HOCKS and FD and TOT at 0.13, for fleece weights with TOT (GFW 0.48 and CFW 0.28) and TOPL (GFW 0.34 and CFW 0.29) and between CY and TOT at -0.26. Phenotypic and environmental relationships between objectively measured traits and subjectively assessed wool traits were low to high in magnitude and variable in sign.

The results showed that selection for LW and objective wool traits will thus not seriously compromise subjective wool and conformation traits. The exception is FD, CVFD and

SDFD, where unfavourable genetic relationships with STAPL and BANDP were found. Furthermore, from these results, it was clear that unrestrained discrimination against wrinkles in Merino sheep would adversely affect economically important objectively measured wool traits such as SS, FD and wool weight. Selection against wrinkles should be carefully monitored to minimise the risk of animals producing reduced fleece weights with broader fibres. It is therefore, proposed that animals with excessive wrinkles be culled from the breeding stock.

Keywords: Merino, live weight, objective wool traits, subjective wool and conformation traits, genetic parameters, phenotypic and environmental parameters

Opsomming

Genetiese evaluasie-stelsels het die akkurate beraming van genetiese parameters nodig. Genetiese, fenotipiese en omgewingsparameters vir objektiewe wol, subjektiewe wol, subjektiewe bouvorm, sowel as vir 16-maande gewig is vir Suid-Afrikaanse Merinoskape beraam. Rekords van die Tygerhoek Merino navorsingskudde, insluitende waarnemings op 4 495 diere, die nageslag van 449 vaars en 1 831 moers en gebore in die periode 1989 tot 2004, is gebruik om hierdie parameters te beraam. Die rekords wat gebruik is, is tussen 1969 en 2004 versamel. Vier lyne is in die data verteenwoordig, naamlik: 'n lyn geselekteer op skoonvaggewig, 'n lyn geselekteer teen grootmaakverliese, 'n fynwollyn, sowel as 'n ongeselekteerde kontrolelyn. Enkel-eienskap gemengede modelle is gebruik. Vaste effekte sluit die effek van geboortestatus (enkel/meerling), geslag (manlik/vroulik), ouderdom van ooi (2-6 jaar), jaar van geboorte (1989-2004), seleksielyn (1-4), en die geslag*geboortejaar interaksie in. Voorlopige ontledings het aangedui dat al die vaste invloede 'n betekenisvolle ($P<0.05$) effek op al die kenmerke wat bestudeer is, gehad het. Die toevallige effekte het kombinasies van direkte additiewe, maternale additiewe en maternale permanente omgewingsinvloede sowel as die korrelasie tussen direkte en matrenale additiewe invloede ingesluit.

Die direkte oorerflikheid beramings (h^2_a) vir objektiewe eienskappe was 0.38 vir 16-maande gewig (LW), 0.36 vir rouwol gewig (GFW), 0.40 vir skoonwolgewig (CFW), 0.65 vir skoonopbrengs (CY), 0.37 stapellengte (SL), 0.20 vir stapelsterkte (SS), 0.68 vir veseldeursnit (FD), 0.61 vir die koeffisient van variasie van veseldeursnit (CVFD) en 0.61 vir standaardafwyking van veseldeursnit (SDFD). Die maternale oorerflikheidsberamings was 0.05 vir LW, 0.09 vir GFW, 0.10 vir CFW en 0.05 vir FD. Die proporsie van die totale fenotipiese variansie as gevolg van die maternale permanente omgewing (c^2_{pe}) het 5% tot die vaggewigte bygedra. Die korrelasie tuseen die direkte en maternale genetiese effekte vir LW, GFW en CFW was -0.28, -0.65 en -0.70

onderskeidelik. Hierdie resultate wys dat ‘n response op seleksie vir objektief gemete eienskappe hoogs waarskynlik is.

Skattings vir h^2_a vir subjektiewe woleienskappe was 0.49 vir wolkwaliteit (QUAL), 0.28 vir eweredigheid van karteling (ROC), 0.33 vir wolkleur (COL), 0.23 vir wololie (OIL), 0.21 vir stapelformasie (STAPL), 0.22 pens en punte (BANDP), 0.50 vir wolgesigpunt (WFS), 0.15 vir gesigbedekking (FCS), en 0.45 vir pigmentasie (PIGM). Maternale genetiese effekte was betekensivol vir QUAL, ROC en COL, en was 0.06, 0.03 en 0.07 onderskeidelik. Die korrelasie tussen direkte en matrenale genetiese effekte vir QUAL, ROC and COL was -0.62, -0.70 en -0.45 onderskeidelik. Die h^2_a beraming vir subjektiewe bouvorm-eienskappe was 0.13 vir toplyn (TOPL), 0.39 vir totale plooitelling (TOT), 0.15 vir voorkwart (FQ), 0.16 kote (PS), 0.32 vir hakke (HOCKS) en 0.37 vir die algemene punt vir kop (GEN). Tussen die subjektief beoordeelde bouvormeienskappe was die maternale genetiese effekte slegs betekenisvol vir PS (0.05) terwyl GEN deur c^2_{pe} (5%) beïnvloed is. Die korrelasie tussen direkte additiewe en direkte matrenale effekte vir PS was -0.71. Die verbetering van subjektiewe wol- en bouvorm eienskappe deur seleksie lyk waarskynlik op grond van die resultate van die huidige studie.

Genetiese korrelasiee (r_g) tussen objektiewe eienskappe stem met literatuurwaardes ooreen. Tussen die subjektiewe eienskappe was daar gunstige genetiese korrelasies (r_g) tussen ROC en COL (0.31), QUAL met ROC (0.49), QUAL met COL (0.26) en tussen STAPL en BANDP (0.58). Die r_g tussen ROC en STAPL (-0.49), QUAL en STAPL (-0.45) en QUAL en BANDP (-0.20) was ongunstig. Ramings van r_g tussend subjektiewe bouvormeienskappe was in die algemeen laag, wisselend en nie betekenisvol nie. Die enigste uitsonderings was r_g’s tussen HOCKS en FQ (0.71), GEN en TOPL (-0.31) en GEN en TOT (-0.47). Fenotipiese- en omgewingskorrelasies tussen objektiewe en subjektiewe wol- en bouvorm eienskappe was laag tot matig. Maternale korrelasie van onderskeidelik 0.86 en 0.19 is tussen GFW en CFW en tussen CFW en FD gevind.

Die r_g van LW met subjektiewe woleienskappe was nie betekenisvol nie, met die uitsondering van ‘n matige en gunstige r_g van LW met ROC (0.20) en LW met WFS

(0.20) wat daarop dui dat swaarder skape waarskynlik meer eweredige wol en hoër punte vir WFS sal hê. Die r_g was gunstig met COL (-0.19), STAPL (0.35) en BANDP (0.42). CFW en CY was gunstig verwant met COL, STAPL, BANDP en QUAL wat daarop dui dat skape met hoër vaggewigte en skoonopbrengs wol gehad met ‘n beter kwaliteit en beter punte vir COL, STAPL sowel as vir BANDP gehad het. SL was gunstig verwant aan COL, BANDP en WFS, en negatief verwant aan OIL. Hierdie resultate is ‘n aanduiding dat skape met langer stapels beter punte vir COL, BANDP en WFS sowel as laer tellings vir OIL behoort te hê. Onder die subjektiewe woleienskappe was slegs ROC betekenisvol verwant aan SS (0.33). Matige en gunstige genetiese korrelasies van FD met QUAL, ROC en FCS is beraam, wat daarop dui dat skape met goeie kwaliteit wol ‘n gelykmatige vag en sagter wol op die gesig, sowel and ‘n laer FD behoort te hê. Die ooreenstemmende verhouding van FD met STAPL en BAND was ongunstig. Genetiese korrelasies van CVFD en SDFD met QUAL en ROC was gunstig, maar die eienskappe was ongunstig verwant aan STAPL. Fenotipiese en omgewingskorrelasies tussen objektiewe eienskappe en subjektiewe eienskappe was laag tot hoog en veranderlik in rigting.

Op die genetiese vlak was LW gunstig verwant tot al die subjektief beoordeelde bouvormeienskappe wat bestudeer is. Swaarder skape was oor die algemeen minder geplooid, en het beter tellings vir GEN, HOCKS, en FQ sowel as vir TOPL gehad. Berамings van r_g was gunstig vir CY met GEN (0.25), HOCKS (0.19), TOT (-0.26) en FQ (0.18), vir FD met PS (-0.16) en TOPL (-0.18), vir CVFD met HOCKS (-0.17), FQ (-0.33) en TOPL (-0.25), tussen CFW en GEN (0.23), en tussen SS en FQ (0.39). Die korrelasies van SDFD met FQ en TOPL was gunstig. Ongunstige korrelasies is beraam tussen SS en TOT (0.25), FD en HOCKS, FD en TOT, tussen vaggewig en TOT sowel as TOPL asook tussen CY en TOT. Fenotipiese- en omgewingskorrelasies tussen objektiewe en subjektiewe woleienskappe was laag tot hoog en veranderlik in rigting.

Die resultate dui daarop dat die seleksie vir LW en objektiewe woleienskappe nie die subjektiewe wol- en bouvormeienskappe sal benadeel nie. Die uitsondering is FD, CVFD en SDFD, waar ongunstige genetiese korrelsies met STAPL en BANDP gevind is.

Verder, uit hierdie resultate is dit duidelik dat die diskriminsie teen plooie in Merinoskape ekonomies belangrike objektiewe woleienskappe soos SS, FD en vaggewig negatief kan beïnvloed. Seleksie teen plooie moet versigtig gemoniteer word om die risiko van diere met laer vaggewigte en met sterker vesels te verminder. Dit word aanbeveel dat diere met uitermate plooie uit die teeltrop verwyder word.

Sleutelwoorde: Merino, lewende gewig, objektiewe woleienskappe, subjektiewe woleieinskappe, bouvormeienskappe, genetiese parameters, fenotiepiese en omgewings-parameters

CHAPTER 9

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