QUALITATIVE AND QUANTITATIVE CHARACTERISTICS OF CASHMERE PRODUCED BY SOUTH AFRICAN INDIGENOUS GOATS

BY

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DECLARATION

I, Sandiswa Keva hereby declare that this thesis, submitted by me to the University of Pretoria for the degree MSc. (Agric) (Animal Production) has not been previously submitted for a degree at any other University.

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SANDISWA KEVA
PRETORIA, 2004

QUALITATIVE AND QUANTITATIVE CHARACTERISTICS OF CASHMERE FIBRE PRODUCED BY SOUTH AFRICAN INDIGENOUS GOATS

By

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ABSTRACT

The objectives of this study were to evaluate the quantity and quality of cashmere produced by South African indigenous goats under different environmental conditions and to compare two techniques (Video Image Analyser-VIA and Optical Fibre Diameter Analysis-OFDA) which were used for fibre diameter analysis.

The study was conducted in Irene, University of Pretoria, Mara, Delftzyl, Roodeplaat and Centurion. In this study three breeds namely Indigenous, Boer and Savanna goats were used and a total of 217 animals were combed during the moulting season (July to September) in 1997.

Location and colour of the animals had significant effects on fibre yield and diameter ($P<0.05$). The Boer goats produced significantly ($P<0.05$) more fibre, which was coarser, compared to the indigenous goats, irrespective of age of the animal. The savanna goats

produced good quality cashmere which was comparable to that produced by Boer goats and indigenous goats. Males produced significantly more and coarser fibre than females ($P < 0.05$). Reproductive status did not show any significant effects ($P > 0.05$) on yield but the lactating animals produced very little cashmere per annum. Age had no significant effects ($P > 0.05$) on total yield and diameter although both yield and diameter increased with age.

According to the results of this experiment, the VIA technique resulted in more accurate fibre diameter values compared to the OFDA technique. The cashmere fibre diameters measured by the VIA were 5 µm finer than with the OFDA, while guard hair diameters by the OFDA were 27 µm thicker than diameters by the VIA. The correlation between these two techniques was very low, with r^2 of 27.1 for cashmere and 16.0 for guard hair respectively.

The South African indigenous goats produced good quality (fine) fibre, with fibre diameter ranging between 9 and 14 µm, although the quantity was very small. This fibre diameter range meets the requirements for cashmere diameter as recommended by the cashmere industry.

KWALITATIEWE - EN KWANTITATIEWE - EIENSKAPPE VAN KASJMIERVESEL GEPRODUSEER DEUR SUID-AFRIKAANSE INHEEMSE BOKKE

DEUR

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UITTREKSEL

Die doelwit van hierdie studie was om die kwantiteit en kwaliteit van kasjmier, wat geproduseer word deur Suid-Afrikaanse inheemse bokke, onder verskillende omgewingsomstandighede te evalueer. Die twee tegnieke ("Video Image Analyzer-VIA" en "Optical Fibre Diameter Analysis-OFDA") wat gebruik word om die veseldeurnee te bepaal, is vergelyk ten opsigte van akkuraatheid.

Die studie is uitgevoer te Irene, Universiteit van Pretoria, Mara, Delftzyl, Roodeplaat en Centurion. In hierdie studie is drie rasse naamlik inheemse, Boer en savannabokke gebruik en ŉ totaal van 217 diere is gekam gedurende die verharingseisoen (Julie tot September) in 1997.

Lokaliteit en kleur van die dier het betekenisvolle effekte op veselproduksie en deursnee ($P<0.05$) gehad. Die Boerbokke het betekenisvol ($P<0.05$) meer vesel, met ŉ growwer tekstuur geproduseer, as die Inheemse bokke (ongeag ouderdom van die dier). Die Savanna bokke het ook ŉ goeie kwaliteit kasjmier geproduseer. Manlike diere het betekenisvol meer en growwer vesel geproduseer as vroulike diere ($P<0.05$). Reproduksiestatus het geen betekenisvolle effek ($P>0.05$) op opbrengs en deursnee gehad nie, alhoewel beide oprengs en deursnee toegeneem het met ouderdom.

Na gelang van die resultate van hierdie eksperiment, het die VIA-tegniek meer akkurate veseldeursnee waardes tot gevolg gehad indien dit gelyk is met die OFDA-tegniek se waardes. Die deursneewaardes van die kasjmier, soos gemeet deur die “VIA”- tegniek, was vyf µm laer as die waardes afkomstig van die “OFDA” tegniek, terwyl die buitehaar se deursneewaardes, 27 µm hoër was as die waardes bepaal deur die “VIA” tegniek. Die korrelasie tussen die twee tegnieke is baie laag, onderskeidelik r^2 = 27.1 vir kasjmier en r^2 = 16.0 vir buitehaardeursnee.

Die Suid-Afrikaanse inheemse bokke het goeie kwaliteit (fyn) vesel geproduseer, met veselwaardes tussen 9 en 14 µm, alhoewel die kwantiteit baie laag was. Hierdie grense van deursneewaardes voldoen aan die vereistes soos voorgestel deur die kasjmier industrie.

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LIST OF ABREVIATIONS

OFDA	-	Optical Fibre Diameter Analysis
VIA	-	Video Image Analyzer
FDA	-	Fibre Diameter Analyser
SD	-	Standard Deviation
MFD	-	Mean Fibre Diameter
Ca	-	cashmere
gh	-	guard hair

CHAPTER 1

Introduction

1.1 Background

During the past two decades, consumers have exploited the unique properties of cashmere to their limit, which make the fibre unique in processing and wear performance, notably comfort and softness (Poolman, 1992; Braun, 1998). This caused the world textile industry to go through a revolutionary change, moving towards the more comfortable, lighter, casual and easy care type of garments. Manufacturers have had no alternative but to go for lighter and finer fibres with a soft appealing handle and added comfort. For this reason cashmere, being the second finest animal fibre, became one of the worlds sought after animal fibres today (Braun, 1998). According to Braun (1998) the world demand for cashmere was 12 000 tons, while only 8 000 tons were being produced, thus resulting in a deficit of 4 000 tons. The scarcity of fibres like cashmere was due to the fact that they were difficult to produce on a large scale, because of climatic conditions and genetic factors (Braun, 1998; Cashmere Working Group, 1998).

1.2 Motivation for the study

There are world wide several goat breeds, rather than a distinct breed, which possess the ability to produce cashmere. This has led to numerous studies in various countries in search of goats that possess the ability to produce this highly wanted durable fibre, and South Africa is no exception. The Cashmere Working Group (1998) reported that despite the presence of South Africa's medium sized commercial goat industry and much larger informal industry, most South Africans do not currently harvest cashmere. The reasons being that many goat owners were not aware of the cashmere producing potential of their goats and its only now they are beginning to learn. A second reason is that the quality of cashmere needs some improvement, more especially, the average yield per goat is economically unattractive (20 g compared to the 150 g in normal cashmere goats per year). Goats were generally kept for their meat, milk, and skins and for controlling bush encroachment and for ceremonial purposes (De Villiers, Letty & Madiba, 2000). The potential of earning an income from these animals without sacrificing meat and milk production of the goat, is an interesting possibility and the farmer will benefit from cashmere production. A further advantage is that cashmere has maintained its market grip and price, despite massive price fluctuations in both wool and mohair internationally over the last decade (Cashmere Working Group, 1998). Cashmere Working Group (1998) reported five breeds of goats, which were proven producers of cashmere fibre in South Africa. These were the Boer goat which produced approximately 50 g of white cashmere, Savanna which produced the same as the Boer goat, Gorno Altai which produced approximately 600 g, Australian feral goat which produced approximately 200 g of super white cashmere and indigenous goats which produced approximately 20 g of multi-coloured cashmere. However recognizing South Africa's rich resource of approximately six million goats, it was felt that the highly priced cashmere fibre yield could be increased per animal and exploited. This could lead to the possibility of creating a viable cashmere industry in South Africa, thereby adding value to the existing animals (Braun, 1998; Cashmere Working Group, 1998). The vast number of indigenous goats, which possess the ability to produce a double-coated fleece, provides a way of diversification of existing agricultural resources without the large capital outlay. The Indigenous goat, the Boer goat, the Savanna and the Gorno Altai are at present, an enormous untapped financial resource for both the developing and commercial farmers (Cashmere Working Group, 1998). This means that South Africa has a potential market for its unexploited cashmere hair. Of course, extra income can be generated if the smallholder farmer or the entrepreneur processes the cashmere fibre into products by carding, combing, spinning and weaving, knitting and felting the fibres. It is therefore imperative for South Africa to utilize its existing potential of the indigenous goats to the fullest. The utilization of the fibres as an additional source of income (by harvesting and processing the cashmere) would make the goat flocks more profitable. Furthermore, the establishment of small agro-industries that convert the fibre into the final products, with specific emphasis on tourist textiles, provides a golden opportunity for creating employment in rural areas (Braun, 1998).

1.3 Objectives of the study

- To evaluate the quality and quantity of cashmere produced by South African indigenous goats.
- To compare the Optical Fibre Diameter Analysis (OFDA) and the Video Image Analyzer (VIA) which are the techniques used to measure fibre diameter.

CHAPTER 2

Literature Review

2.1 Introduction

2.1.1 What is cashmere?

Cashmere or Pashmina, as it is called in India, is the superfine down fibre produced by the secondary follicles of goats that do not produce mohair (Cashmere Working Group, 1998). The cashmere fibre grows as an undercoat to the coarse guard hair (Harris, 1994) to protect the animals during the cooler (winter) months of the year (Couchman & McGregor, 1983). After serving its purpose, it moults in spring when it can be collected by combing or shearing. Cashmere grows in response to shorter day lengths. It starts growing after the longest day (mid summer), and starts shedding after the shortest day (mid winter).

The cashmere-producing goat is not a breed, since any goat can produce cashmere down. This characteristic originated from the Middle Eastern and Asian countries and more recently, in Australia and New Zealand (Mowlem, 1988; Taylor & Taylor, 2000). Cashmere is soft, lightweight, durable, and very warm and makes wonderful feeling garments. It has long been one of the most exotic and the rarest fibres to be found (Taylor & Taylor, 2000). The price of cashmere on the world market is mainly determined by its colour, fibre diameter and clean yield (ratio of fine to course fibres). Cashmere fibres range in colour from white to brown, should be 18.5 microns in diameter or finer and must be at least 3 cm long for processing purposes. White is the most desirable colour giving the widest range of alternatives at the dyeing stage and it fetches the highest price (Johnson, 1991).

2.1.2 Differences between wool, cashmere and mohair.

Wool is the fibre produced by sheep, cashmere and mohair are fibres produced by goats. Mohair grows from both the primary and secondary follicles, thus both the follicles produce the same fibre. Cashmere fibres grow only from the secondary hair follicles of goats, while primary follicles in the goats produce coarse guard hair. Wool is produced from both the primary and secondary fibre follicles, the finest wool being produced from the secondary follicles. The season of cashmere fibre growth differs from that of mohair growth in Angora goats, because cashmere grows during the decreasing daylight, whereas mohair growth is a continuous process. Table 2.1 shows the typical composition and characteristics of the three animal fibres (Smuts, 1999).

Table 2.1 Typical composition and characteristics of fibre: Goats compared to sheep (Smuts, 1999)

	Sheep	Goats	
	Wool	Mohair	Cashmere
Yield, unscoured fibre (kg)	4	4	0.2-1.5
Clean fibre %	70	80	60
Kemp, % of total fleece	Negligible	<10	negligible
Length (mm)	100	140	40
Fineness (µm)	20	36	16

Skin follicle development in cashmere goats is different to those of sheep. In general the primary follicles are initiated 60 days post-conception and are mature at birth. Secondary follicles are initiated at birth and kids have mature profiles of fibre bearing secondary follicles by 12 weeks of age (Henderson & Sabine, 1991). Henderson & Sabine (1991) reported that secondary follicle maturation continues until the age of 6 months, with the greatest increase in the secondary to primary follicle ratio (S: P ratio) occurring within the first three months after birth. In sheep all primary follicles are mature at birth, and almost all secondary follicles are initiated before birth, although many do not mature until after birth (Henderson & Sabine, 1991). Microscopically, cashmere fibres have similar appearance to Merino wool of comparable dimensions. The epidermal scales (epicuticle) are more distinct in cashmere fibres than in mohair, but they are less distinct than in wool. In cashmere 5-7 scales per 100 µm cover the cortex (Lupton, 1992).

Chemically, cashmere fibres are indistinguishable from wool and mohair. All fibres are complex mixtures of proteins of the α-keratin family. These proteins are rich in the sulphur containing amino acids cystine and cysteine, which, in the goat and in other ruminants are derived from methionine. However lipids found on raw cashmere are different in composition from those produced by Angora goats and sheep (Lupton, 1992). Johnson (1991) and Smuts (1999) reported cashmere to be more sensitive to the effects of chemicals largely because of its fineness. It is also generally weaker than wool and mohair (Shelton, 1981). Cashmere is shorter than mohair, seldom more than 6 cm in length (Johnson, 1991) although it can be longer than 7 cm.

2.1.3 The history of cashmere production

A number of goat breeds originated in and around the mountains of Tibet. The cashmere producing goat originated in Asia Minor during the Mogul empire in the 15th century, in particular at Kashmir in the Northern Indian countries, hence the name (Johnson, 1991). Ever since Victorian England discovered the loft, warmth and the feel of the fabric from cashmere, it has been in demand for those who are in high society and demand for these items has remained steady. This is because of the wonderful feel and handle of the fibre combined with the low bulk and high loft. These factors combine to make the warmest, softest and the most comfortable garments (Petri, 1995).

Cashmere producing areas remained in the Himalayan region throughout the first part of the previous century, extending east to China and west to Iran. Actually cashmere producing goats are adapted to cold rather than heat, and are farmed with in the high mountainous areas of Asia including Tibet, Inner Mongolia, Kashmir, Iran, Turkey, Kurdistan and the neighbouring localities in the U.S.S.R. The parent breed is the Kel of Kashmir and the geographic closely related Chegu, Gaddi and the Kiaghani breeds (Devendra & Burns, 1976). Historically China, Mongolia, Afghanistan and Iran have been the major suppliers of raw cashmere to the textile manufacturing countries. In the late 1980's and the early 1990's, the cashmere producing countries started to process their own cashmere and there were a number of reasons for this. Firstly, the manufacturers acquired most of the value of the cashmere garment and growers only received approximately 2-5 % of the final retail price. Secondly, because the international recession mostly affected the cashmere consuming countries, manufacturers reduced their purchases to the suppliers of the raw material. Countries like China realized that they have immense manufacturing potential and China and Mongolia started to process the cashmere themselves and this lead to the dearth (scarcity) of the raw material on the world market. However Braun (1998) reported the demand of 12 000 tons per year is greater than the supply of 8 000, tons so other countries such as the USA, Australia, New Zealand, Great Britain and South Africa, are busy establishing cashmere industries.

Commercial production of cashmere fibre began in Australia in the late 1970's, using the feral goats as foundation animals (Johnson, 1991). Most of the fibre has found its way onto the world market via Kashmir and India (Devendra & Burns, 1976). The fibre and its great qualities became renowned in the 19^{th} century and were traded via India to England, Scotland and Italy. In Europe it was the Scottish spinners and knitters who produced most cashmere products and these were also the ones with the longest experience, many indeed dating back well over 100 years. There were also several Scottish-Asian joint productions, which produced cashmere products of very high quality. Among them being the Dawson, known for the Pringle of Scotland and Ballantyre brands and also the McNish Company, which has set itself the target of supplying the world's best cashmere (Johnson, 1991).

2.2. Biology of fibre growth

Fibres are produced in follicles. Sheep and goats have two distinct types of fibre-producing follicles within the skin, distinguished by their associated accessory structures. The types of fleeces grown by sheep and goats vary from a double coat, comprising a coarse outer-coat and a fine inner-coat, to a single coat in which all fibres are essentially similar in their physical characteristics. In double-coated breeds of sheep and goats, the primary follicles produce the long coarse outer coat and the inner-coat produced by secondary follicles (Summer & Bigham, 1993). Primary follicles are characterized by an associated sudoriferous or sweat gland, an often bilobed sebaceous gland and erector pili muscle, whereas secondary follicles are only associated with a monolobed sebaceous gland. The sweat glands secrete sweat, various salts and the sebaceous glands secrete fatty acids and lanolin which are thought to provide a protective coating for the fibre to prevent the weakening or deterioration effects of the sun rays. Other suggested benefits from these secretions are prevention of matting or felting of fibres and provision of water repellency in the coat of the animals

(Shelton, 1981). Table 2.2 shows coat composition and structure in different animals (Allain, 1993).

Table 2.2 Coat composition and structure in the Angora rabbit, goat and sheep (Allain, 1993)

	Rabbit	Goat		Sheep	
	Angora	Cashmere	Angora	Primitive	Merino
Medullated Fibres					
Primaries	Bristle	Guard hair	(Kemp)	Kemp	-
	30–80 μ	30-100 μ	-	-	-
	10 cm	6-20 cm			
Secondaries	Down				
	15 μ	-	-	-	-
	6 cm				
Non-medullated					
Primaries	-	-	Mohair	-	Wool
Secondaries	-	Cashmere	Mohair	(wool)	Wool
4-8 cm		12-18 μ	22-45 μ	12-20 μ	18-25 μ

Both types of follicles are formed prenatally by a downward growth of the epidermis into the underlying dermis. Primary follicles are fully formed and actively producing fibre at birth. However the secondary follicles will continue to form after birth and up to one month of age. Approximately half of the secondary follicles in down producing goats are immature at birth but all are producing fibre by five months of age. The follicles in adult animals are arranged within groups consisting typically of three primary follicles and a variable number of secondary follicles (Summer & Bigham, 1993). The ratio of the number of the secondary to primary follicles – the S: P ratio can vary from less than 4:1 to more than 9:1. Those animals with the higher ratio generally have higher levels of production of fibre of commercial value (Smuts, 1999). The S: P ratio and follicle density influence the potential production of the animal (Johnson, 1991). In adult cashmere goats, there are normally between 5-7 secondary follicles for each primary follicle (Litherland, undated). Primary follicles are the larger of the two types (Smuts, 1999) and therefore fibres produced from the primary follicles tend to be larger in diameter. In cashmere producing goats the guard hair (produced from the primary follicles) has a fibre diameter of around 80 μm or more and has little commercial value (Lupton, 1992).

Cashmere goats exhibit a seasonal pattern of fibre growth and the seasonality of production may be viewed from a number of perspectives. One of these is that it permits the animal to respond to seasonal climatic changes, and that the period of down production does not conflict in a very direct way with the high nutrient demands of parturition and lactation. Also seasonal shedding permits harvesting by combing in the traditional centers of production (Shelton, 1992). In general the secondary fibre follicles are reputed to be active from the summer solstice to the winter solstice and to be in the resting phase during the remaining six months (Russel, 1992). Summer & Bigham (1993) reported that the S: P fibre ratio in these animals was thus low in early summer and high in winter. Cashmere was coarsest during spring and early autumn when follicles were producing cashmere at their fastest rate. As the cashmere growth season proceeds, finer follicles make a greater contribution to the fleece and some coarser fibres may be shed from the fleece. Overall fibre diameter declines during the winter season. The fibre diameter of the fleece has an average of two microns finer in early spring compared to early autumn (Litherland, undated). Except during the inactive or resting period, follicle growth from the bulb at the base of the follicle is continuous.

2.3 Quality characteristics of cashmere

Introduction

The physical characteristics of the textile fibre, determines its suitability for different end uses, and hence its commercial value. Quality objectives set for the producer by the industry and supported by price are fibre diameter, colour, fibre length and ease of dehairing the product from the guard hair. The yield of cashmere in relation to the total fleece must be greater than 28% as well as a minimum contamination that includes stain, vegetable matter and other animal fibres (Holst, 1990). The relative importance of these characteristics varies between processing systems because they affect processing and end-use performance of the fibre (Johnson, 1991; Petri, 1995). These values and the level of fleece production from individual animals influence returns to the goat farmer from fibre sale (Summer & Bigham, 1992). Quality of fibre improves with the distance from the usually coarse neck. Midside fibre is usually the best, with rump fibre being finer, crimpier and unfortunately shorter, although some goats had coarser crimps (Cornwell, 1990).

2.3.1 Fibre character or style

Fibre character or style refers to the natural crimp of each individual fibre and results from the microscopic structure of each fibre. Style and crimp frequency on cashmere forms an important part of purchasing strategy. The more frequent the crimps, the finer the spun yarn can be and therefore the softer the furnished product (Petri, 1995). Finer fibre generally has better crimp. Without cashmere character, fibres have the appearance of mohair (loaded with kemp) or cashgora down (Lupton, 1992).

Handle refers to the feel or 'hand' of the finished product. It is very easy for the human eye to be deceived by a well crimped, but coarser fibre. For this reason, estimating fibre diameter is best left for the fibre testing experts. Very fine fibre that lacks good crimp should not be categorized as quality cashmere. It is the crimp of quality cashmere fibre that allows fibre to interlock during processing. This loft retains heat and it makes cashmere different from wool, mohair and especially man made fibres. Warmth without weight and incredible softness is what cashmere is all about (Petri, 1995; Cornwell, 1990). Australian cashmere growth (but not that been shorn) is of superior length, softer handle, of higher tensile strength compared with that harvested in most parts of the world (Davies & Murray, 1998).

2.3.2 Cashmere yield

Cashmere yield is the proportion of down in the total fleece after the removal of guard hair expressed as a percentage. Cashmere yield is determined using a dehairing machine that separates down from guard hair (medullated). This feature is very important to the producer because it shows the amount of down grown by each animal (Ryder, 1987). The average yield from feral goats was 20%, but superior bred animals had yields of up to 45% cashmere. Individual production in China was shown to be as low as 80 g, average of 125 g and the maximum of 250 g per year (Ryder, 1987). Through breeding and selection cashmere goats produced nearly 500 g (Ryder, 1987) and production of up 1 kg was also observed (Johnson, 1991). De Villiers *et al.* (2000) reported cashmere yields as varying from 0.04 to 70.65 g / goat per year in KwaZulu-Natal from Boer and indigenous goats.

Since the major growth of down takes place in late summer and autumn, autumn is the best time to assess the amount of down produced by individual animals (Ryder, 1987). As the rule, the finer the fibre the lower the production, and the thicker the fibre the higher the production. The down is typically non-medullated, low in lustre and has good crimp (Litherland, undated). The presence of intermediate fibres is undesirable because it makes it difficult to separate the fibres during the dehairing process. Consequently the value of such fleeces is adversely affected. For this reason, industrial dehairing of raw cashmere requires a strong distinction between the two fibre populations (fine and coarse) to enable easy and effective dehairing. It is generally desirable that the ratio of the diameter of the guard hair to that of the down fibre be 4:1 and that the guard hair has a fibre diameter greater than 60 μm (Braun, 1998). Clearly large goats with long down are required, but an increase in fibre diameter of the down will reduce the quality. Animals with a high density of follicles in the skin had greater down production coupled with fine down fibres (Ryder, 1987).

2.3.3 Fibre diameter

Fibre diameter is the single most important characteristic of cashmere, because the finer the fibre the higher the price (Petri, 1995). The extreme fineness of cashmere makes it more difficult to assess diameter by eye than with wool from sheep. Objective testing must be used to measure fibre diameter compared to subjective testing (Petri, 1995). Cashmere fibre is described as the fibre that has a down diameter of up to 18 μm (Couchman & McGregor, 1983). Cashmere has a fibre diameter between 11 and 18 microns with no down above 18 microns. Processors prefer the finer, 15 -16 μm cashmere and this range attracts a premium price. A diameter of 15.5 μm is considered as the standard for cashmere. Fibre, which averages above 18.5, is technically not cashmere, although some processors have shown interest in it. These physical properties combine to produce an extremely fine sleek yarn, which produces garments with very desirable wearing qualities (Johnson, 1991).

Chinese cashmere has the finest fibre diameter, with means ranging from 13-16 μm. Fibre with a mean diameter of 16.5 μm is used in knitwear. A mean of 15.5 μm is a much quoted desirable figure for qualities to be used into cloth for such garments as overcoats, and for this purpose the cashmere is frequently blended (mixed) with wool (Ryder, 1987).

2.3.4 Fibre length

Commercially, mean fibre length determines the system on which the fibre will be spun (worsted or woolen) and the type of product into which the fibre will be manufactured. Fibre length is important to producers as a component of weight of down produced, since longer fibres obviously weigh more. It is also important to the processor, so fibre length contributes directly to the price. The cashmere fibre is shorter than mohair, seldom more than 60 mm (Johnson, 1991) although it can be longer than 70 mm. Cashmere fibres shorter than 40 mm in length cannot be processed on the worsted system, and so this reduces its value (Ryder, 1987). The longer the fibre the better the quality. Processors can handle fibres ranging from 10-55 mm for the woolen system (knitwear) and about 70 mm for the worsted system. The down length is affected by ultra-violet rays, which damage the exposed tips, causing brittleness. This reduces the length during combing. The Chinese Commodity Inspection Bureau specified that the hair should be longer than 32 mm. A fibre length of 46 mm is considered long (Petri, 1995). Any length over 30 mm after shearing is acceptable. Combing is recommended to shearing since shearing reduces fibre length especially if the second cuts occur.

After processing, the longer fibres (over 70 mm) go to the spinner for manufacture into fine, soft yarns and the shorter fibres (50- 55 mm) to the weaving trade to be blended with cotton, silk or wool to produce a superior quality woven fabric. A single fleece may contain some long fibres, usually grown on the neck and midside, as well as some shorter fibres, present on the rump and the belly. The short down fibre length (less than 40 mm) would be problematic in terms of fibre loss and waste during dehairing.

2.3.5 Fibre colour

Down is produced in a range of colours, from white, to light grey through to dark grey and brown. White is most desirable giving the widest range of alternatives at the dyeing stage resulting in the purest colours. Because of this, white cashmere fetches a higher price on the world market (Smuts, 1999). This led to the development of the bleaching processes to produce white cashmere from less valuable coloured down (Lupton, 1992). Cashmere colour often contrasts with colour of guard hair (Johnson, 1991). Most processors prefer white down from goats with white guard hair. It usually attracts a price premium over grey and brown cashmere. White down from coloured goats generally receives the price for grey. Goats with coloured hair can grow white down. In view of the price premium for white fibre, breeding objectives usually aim to produce white animals and tend to ignore some of the other important characteristics (Pattie & Restall, 1992). However, natural colours are at times used in the finished product (Gall, 1981). Although colour is important in influencing the price of the fibre, high priority need not be given to the breeding of white goats only because other dark colours are desirable as well. First even in all black animals, the down is paler, secondly many feral animals are not only grey but piebald (having patches of white hair), thirdly white is dominant to coloured in cross-breeding. This means that the increase of individual production, while maintaining fibre fineness, can be put first, since at a later stage the use of superior white males will soon eliminate fibre pigmentation. Some Toggenburgs have grey down, while in others it appears to be completely white. In some Portuguese goats in which all the hairs were black, the proportion of coloured down fibres ranges from 1-67%. A common shade for cashmere sweaters is fawn and after thousands of years of breeding sheep lacking natural pigmentation, a premium is now paid for coloured wools which are more desirable than white wool in handicraft outlets. The same might apply to locally- produced cashmere, which would provide a new speciality fibre for handicraft use (Ryder, 1987). This is particularly important for cashmere knitwear where soft pastel shades are perennial favourites. Crossbreeding can result in undesirable coloured fibre (Petri, 1995). Table 2.3 shows the differences in fibre prices according to fibre colour and length.

Table 2.3 World cashmere prices (US $) (2003) (www.lookchina.com)

Premium cashmere grades	Length (30-32 mm)	Length (32-34 mm)
White	$97.00	$128.00
Grey	$35.00	$88.00
Brown	$142 .00	$31.00

Coloured animals have been observed to produce more down than white animals (Smuts, 1999).

2.3.6 Staple strength and lustre

Staple strength is rarely a limiting factor in the production of mohair and cashmere yarns, but weak staples can seriously affect the efficiency and quality of yarn production (Lupton, 1992). Cashmere is also generally weaker than wool and mohair.

The best Chinese cashmere has no lustre. Some of the cashmere produced in the USA and in Australia exhibit low to medium lustre. Although this type can be very fine and aesthetically pleasing, lustre in cashmere is usually interpreted as being indicative of Angora influence and therefore coarse fibres (Lupton, 1992).

2.4 Factors influencing cashmere fibre characteristics

Introduction

Variations in the fleece are the result of variations in either the environment or the inherent characteristics of the animal (Ryder & Stephenson, 1968). Genetics and environment influence both the quantity and quality of the fibre and this then affects the commercial value of the fibre (Summer & Bigham, 1993). The environment results from all the external conditions that an animal experiences. Some cannot be measured or controlled but might influence animal health and performance. Environmental elements change with time at a given place, because weather and facility occupancy vary with time. The rate of environmental change is critical. Abrupt environmental changes tend to be more critical than those occurring over a long period (Curtis, 1983). Variation due to environment includes such factors as photoperiod, reproductive status of the female (pregnancy and lactation), birth type, live weight, age, gender, animal health as well as nutrition (Restall & Pattie, 1989; Summer & Bigham, 1993). Some environmental factors cause varying degrees of damage to the fibres and thus affect the efficiency of fibre production. The effects of the environment range from complete shedding of the fibre to reduction in fibre quality (Donald, 1979). Damaged wool fibres have dry brittle tips which lead to faulty dyeing and such fibres are regarded as inferior, and are therefore low-priced (Visser, 1964). Many factors in turn influence staple strength, fineness, fleece weight and the fleece value (Johnson, 1991).

2.4.1 Photoperiod and season

Many mammalian species exhibit seasonal changes in their pelage. The usual pattern being the production of a dense, fine coat, which traps warm air for winter warmth, and a less dense coat in the spring and summer months allowing air circulation and evaporative cooling (Henderson & Sabine, 1992). The variation in day length between seasons affects the growth of wool, mohair and cashmere with fibre growth being lowest in mid winter and highest in mid summer (McGregor, 1998). Some animals have a visible moult once a year, with the shedding of the heavy winter coat in spring and the gradual growth of a new coat throughout the summer, while others such as the vole, moult twice a year (Henderson & Sabine, 1992). Unlike the Merino sheep and Angora goats, which have continuous growing commercial fibres, most of the cashmere-bearing goats grow their fleece in only half a year (McGregor, 1998).

McGregor (1998) stated that during the cashmere-growing period the secondary fibre follicles are active until late autumn or early winter when follicle activity ceases. Cashmere growth rates decline linearly from summer to mid-winter. The cashmere goat thus appears to be similar to the Soay sheep in its pattern of seasonal fibre growth, whereas the Angora is more like the Merino (Henderson & Sabine, 1992). Decreasing day length in autumn provides the stimulus which suppresses fibre follicle activity to the point at which follicles may even enter the winter rest period. The increasing day length in spring is the stimulus that reactivates them. This shows that the annual cycle of follicle activity is in summer and inactivity in winter (Henderson & Sabine, 1992). McDonald & Hoey (1987) concluded that alternative exposure to continuous light and natural light for various cycles has the potential to increase cashmere production. This may provide five fleece growths in three years.

Early in the season (spring), as the new season's fibre begins to be produced, there is a gradual increase in both the percentage and the diameter of the fibre. Henderson & Sabine (1992) reported that a maximum of about 84 % of fibre growth is reached by January (mid-summer), and it is maintained until July / August (late winter) when cashmere fibres begin to be lost from the coat (Henderson & Sabine, 1992). Fibre diameter increases early in the growing season and is maintained throughout the season until winter, when it decreases. Cashmere fibre diameter decreases in winter. It also decreases in both young and old animals over the same period (Klören, Norton & Waters, 1993b). Henderson & Sabine (1992) suggested that the narrowing of the fibre in winter be probably due to a decrease in follicle activity in preparation for shedding.

Climatic conditions play a large role in determining cashmere yield. Johnson (1991) reported that goats from warmer areas tend to produce less fibre than goats from cooler areas. Cashmere goats thrive in harsh dry mountainous climates and they produce the highest quality fibre. In moderate climates, goats lose their ability to grow the downy coats that produce quality cashmere (Harris, 1994). According to De Villiers *et al* (2000), cashmere yields decreased as environmental conditions became moderate as presented in Table 2.4. However, weather conditions can indirectly influence wool growth by altering feed intake (Reis, 1982), because animals in cold environments tend to eat more to keep warm and those in warm environments eat less to prevent hyperthermia.

Table 2.4 Production rates of cashmere in different environmental conditions in KwaZulu-Natal (De Villiers *et al.*, 2000)

Area	Mean temperatures (^{0}C) December	June	Mean sunshine (Hours)	Mean Rainfall (mm)	Average Diameter (Micron)	% Clean yield
Pongola	25.4	17.1	7.6	588	15.2 ± 0.846	76.3 ± 7.32
Bartlow	23.7	16.1	7.1	661	14.7 ± 0.23	69.9 ± 12.56
Wasbank	20.8	11.2	7.2	836	15.5 ±1.39	69.9 ± 12.56
Colenso	20.7	11.1	7.4	708	15.3 ± 1.35	81.9±10.93
Kranskop	19.5	11.8	6.6	836	15.8 ± 1.4	69.7±14.64
Estcourt	19.5	10.5	7.2	714	15.3 ± 1.54	68.9 ± 19.9
Mpophomeni	19.1	11.4	6.9	838	15.2 ± 1.22	81.7 ± 8.6
Bergville	20.2	9.7	6.5	971	15.9 ± 0.63	68.3 ± 8.23
Impendle	18.8	11	6.7	967	16.1 ± 1.39	74.9 ± 9.88
Kokstad	18.1	10.4	7.1	751	16.1 ± 10.26	74.2 ± 9.73

2.4.2 Gender

The gender of the animal does not affect cashmere growth to a certain extent, but some differences are present between the different genders. Generally, male goats grow more fibre than castrates and females. Males tend to have a small live weight advantage and down weight advantage over females, but diameter and length of down are similar (Restall & Pattie, 1989). This could be because male goats generally receive better treatment than female goats, they are farmed separately for management reasons and often preferentially fed (Summer & Bigham, 1993). Corbett (1979) suggested that the increased cashmere production in males is associated with sex hormones. The steroid sex hormones promote an increase in protein synthesis and androgens stimulate body growth and also the gross efficiency of feed conversion to fibre. The effects of age, gender and breeding on fleece characteristics are presented in Table 2.5.

Initiation of cashmere growth was found to be earlier in female goats and the periods of growth tending to be longer than that of males (Klören *et al*., 1993). No significant changes in cashmere growth rate were measured between males, females and castrated animals, although females generally initiated growth earlier and had longer periods of growth than males and castrates. Similarly, gender difference in the coat growth of mice has been shown to be small. However rams have been shown to grow cashmere at a faster rate than wethers and ewes, which has been attributed to testosterone (Klören *et al.*, 1993b).

Table 2.5 Fleece characteristics, down production of different ages, genders and breeding (Couchman & McGregor, 1983)

Group	No. of animals	Total fibre (g)	Down yield	Greasy down (g)	Weight of grease	Fibre diameter (μm)
Adult male	12	701	46.6	330	1.97	19.0
Yearling F1 male	17	352	47.2	170	2.19	16.3
Yearling F2 male	10	336	43.6	148	1.77	16.4
Adult female	12	399	40.4	157	2.86	16.9
Adult F1 female	16	375	45.5	171	2.53	17.3
Yearling F1 female	7	331	57.6	192	4.02	15.9
Yearling F1 female	13	320	38.9	124	_	15.3
Yearling F2 females	6	329	35.7	117	_	16.3

Restall & Pattie (1989) reported that male kids were heavier than female kids and grew more fleece although both genders grew similar amounts of cashmere. Primary and secondary follicle densities were greater in females and diameter of cashmere did not differ between males and females at any age (Restall & Pattie, 1989). Male kids had a higher S: P ratio than the females at birth but became similar afterwards. Henderson & Sabine (1992) reported that the S: P ratio for females at 2 weeks of age was found to be higher than that of males but this disappeared by six weeks. The absence of the differences in fibre diameter between genders is in contrast to the held belief amongst breeders that male cashmere was consistently 1-2 μm coarser than contemporary females (Henderson & Sabine, 1992).

2.4.3 Reproductive status

Smuts (1999) reported that pregnancy and milk production together reduce cashmere production. Pregnancy and lactation severely restrict fleece growth, according to a report by Restall & Pattie (1989) pregnancy reduced down production by 30% and lactation by 48%, together resulted in a reduction of 65%. Female kids have been reported to have superior production compared to their dams. This may be due to the absence of the previous pregnancies and lactations in the female kids. Both pregnancy and lactation reduced fleece weight, down weight and down length, but have no effect on down diameter (Restall & Pattie, 1989). Summer & Bigham (1993) reported that cashmere production was not affected by pregnancy and lactation following an autumn mating, as fibre growth has all but ceased by mid-pregnancy and does not recommence until about the time of weaning. There have been no reports as to whether the hormonal status of cashmere producing goats during lactation affects fibre shedding in any way. In sheep, wool growth rate decreases during pregnancy and lactation relative to non-pregnant ewes, indicating a higher relative demand for nutrients associated with reproduction compared to wool growth (Restall & Pattie, 1989).

It is a general industry practice to avoid kidding in the cashmere-growing period. It is common experience that does with kids prior to shearing in mid winter will either prematurely moult their fleece or grow a lighter fleece. Producers have been advised to kid after shearing in August- September. The reason for this was that kidding in December and March could delay the initiation of cashmere follicles and kidding in July can prematurely end follicle growth (McGregor, 1998). In Australia, goats are not normally mated at a time that would result in pregnancy or lactation during the cashmere growing season, but some problems could arise in animals mated before February. In addition there may be some reduction in fleece growth if artificial breeding techniques are used for out of season breeding, or to avoid unfavourable environment for management purposes (Restall & Pattie, 1989).

Individual effects of pregnancy and lactation are closely interrelated due to hormone status and natural biological sequence (Summer & Bigham, 1993). The physiological changes that occur during pregnancy and lactation include a change in partitioning of the nutrients as well as changes in prolactin and other elements (Restall & Pattie, 1989). In addition, time of birth affected productivity at nine months with kids born earlier in the season having greater down weights than those born later. Consequently in cases where there is an extended kidding period, adjustments for age or selection within age groups may be necessary if selection is to be based on productivity at first shearing (Newman & Paterson, 1992). The initiation of cashmere growth is significantly delayed for does kidding in summer and cessation of cashmere growth is significantly advanced in the winter kidding groups. These results suggest that both initiation and cessation of cashmere growth may be altered through physiological changes associated with pregnancy and lactation. Kidding in autumn has the greatest effect on cashmere growth, with an apparent depression in the average rate of cashmere elongation. The effects of pregnancy and lactation on cashmere growth may be attributed to the last 1-2 months of pregnancy and the first month of lactation (McDonald & Hoey, 1987).

2.4.4 Birth type and dam

According to Newman & Paterson (1992) single born progeny had a significant weight advantage compared to the twin born kids and they also produced more cashmere at the first shearing than twins. Newman & Paterson (1992) reported that twin–reared hoggets (unshorn animals from 12 months of age) had low weights and produced fleece with a higher diameter. They also had greater fibre diameter variability than single reared hoggets. Single born animals averaged 6.3% heavier than twins and grew 6.6% more down, which was longer and coarser as reported by Restall & Pattie (1989). Diameter, secondary follicle density and the S: P ratio were significantly larger for singles overall (Restall & Pattie, 1989).

Age of the dam had a significant effect on live weight and the hogget total fleece weight. Progeny from hogget dams had a lighter total fleece weight than progeny from three year old and older dams. Progeny from hoggets and two and three year old dams were lighter at hogget shearing than progeny from older dams. Live weight, total fleece weight, down weight and fibre diameter was significantly lower in hoggets than in older does. Dry does had lighter live weight and total fleece weight than does weaning one or two kids, but there were no differences in yield, down weight or fibre diameter (Newman & Paterson, 1992).

2.4.5 Age

Fibre production and fleece characteristics are influenced by age. There were significant differences between ages, with down yield and fibre diameter increasing with increasing age. Fibre growth rate increased from birth to a maximum at three to four years of age, after which it declined, also attained maximum production at this age (Corbett, 1979; Summer & Bigham, 1993). Henderson & Sabine (1992) reported that kids had approximately 40% of cashmere in their coat. This percentage increased to about 80% at about 16-20 weeks of age. The effect is similar for many sheep breeds, cashmere producing goats and Angora goats. Fibre diameter also increases with age. Cashmere diameter of older goats was reported to be higher than that of younger goats. It is generally accepted that the first fleece is finer than that grown by the adult animals. There is a gradual coarsening of the fibres, as the animal grows older (up to three and four years of age), although aged animals usually have finer fibre (Ryder & Stephenson, 1968). Restall & Pattie (1989) reported cashmere diameter as increasing by 1.1 μm from the first to second fleece, 0.7 μm from the second to the third fleece with an additional 0.4 μm increase to the fourth fleece thus fibre decreasing over years (Restall & Pattie, 1989). Henderson & Sabine (1992) also reported that diameter as 12.0 μm at six weeks and was up to 13.5 μm at 64 weeks of age, 13 months later it increased by 1.5 μm.

There are several reports of age effects on fleece characteristics in Merinos. Although fibre diameter increases, there is a relatively greater reduction in staple length, colour, handle and washing yield. Crimp frequency falls and crimp abnormalities increase (Summer & Bigham, 1993).

Klören *et al*. (1993b) reported that there was a difference in cashmere length between younger and older animals. Older animals had longer additive cashmere lengths compared to kids. Older goats had a greater cashmere volume growth rate when compared to younger goats. The young animals grew less fibre per unit of feed intake, presumably due to competition for nutrients between follicles and other tissues (Klören *et al*., 1993b).Older goats had more actively growing cashmere fibre follicles than young goats in autumn, but there was a decline in number of actively growing cashmere and hair fibres in May to July (Klören *et al*., 1993a)

2.4.6 Live weight

Differences between age groups, genders and birth types in primary and secondary follicle densities, reflect differences in body size as indicated by live weight, as animals grow and skin expands (Restall & Pattie, 1989). Cashmere growth is highly correlated to mean live weight. McGregor (1992) indicated that for each kilogram increase in live weight, cashmere growth increased by 4.69 g and fibre diameter increased by 0.0076 μm. For each kilogram loss, cashmere growth is reduced by 11 g. McGregor (1992) suggested that in order to achieve maximal cashmere production, goats being kept during summer should have small live weight gains (1-2 kg) and maintain body condition during winter.

2.4.7 Animal health

Introduction

Diseases which directly affect fibre growth in sheep and goats are rare. Animal diseases are an important factor inhibiting world trade and hampering the free movement of both live animals and animal products (Musson, 1983). Those that do affect fibre-producing goats are of concern to managers and are caused by bacteria, viruses, protozoa and physiologic dysfunction, pinkeye, sore mouth, pregnancy toxaemia and internal and external parasites (Johnson, 1991). Some disease conditions such as skin infections, fly strike and some disease toxins are temporary and only affect a section of a flock or flock. While these diseases affect the survival of individual animals, their effects on total production of the flock are slight. Short-term conditions associated with extreme stress tend to induce shedding, or a loss of tensile strength, due to sudden thinning of the fibre. The most serious condition which affects fibre production is where the whole flock is continually exposed to re-infection, such as with gastro-intestine parasitism. In this situation the infection results in anaemia or intake depression, particularly where poly-parasitic infections are involved. This depresses fibre growth with an equivalent reduction in both, fibre length, and fibre diameter. The potential gains to wool production through the eradication of internal parasites have been shown to be up to 45% in young animals and 10% in adult animals (Summer & Bigham, 1993).

2.4.7.1 Effects of parasites and diseases

Effects of microbial and parasitic infections on fibre growth range from complete shedding of fibres in acute, severe disease conditions, to reduction in fibre diameter and length growth rate of varying severity and duration in more chronic conditions. Arthropod parasites on the skin surface damage the fleece due to rubbing, which is induced by irritations. Large, severe blowfly strikes are sometimes followed by a break in the fleece, but strikes usually produce only modest reductions in fleece weights.

Various microbial infections and external parasites can reduce fibre production. Infestations with internal parasites can considerably reduce fibre growth (Reis, 1982). Infection with internal parasites reduce feed intake and hence fibre growth, but there are also specific effects on protein metabolism associated with loss of blood proteins at sites of infection. Goats do not normally have a resistance to parasitic infections. Generally, goats infected with internal parasites will have a rough coat and pale mucous membranes (such as gums). However when goats are allowed to utilize their natural browsing habit, worm burdens may be substantially lower (Reis, 1982). Open pasture conditions will minimize parasitic infection among the flock members, but parasites can lead to death (Johnson, 1991).

2.4.7.1.1 Microbial infections

Some of the microbial infections cause reduction in fibre production or cause a break or shedding of the fleece. These include contagious footrot, footabscess, contagious ecthyma (scabby mouth) and contagious opthalmia (pink eye). These conditions are likely to induce inappetite and to interfere with grazing behaviour, resulting in lowered intake. Break and shedding of the fleece might also result from temporary adrenal hyperactivity, brought about by the stress of the disease. Mycotic dermatitis and fleece rot (in sheep) primarily affect fleece itself but may have local effects on fibre follicles resulting in reduced fibre production (Donald, 1979). Goats are less susceptible to this condition because of their grazing and browsing behaviour.

2.4.7.1.2 External parasites

Insect pests cause annual losses in wool, meat and milk totalling to a loss of millions of rands (Drummond, 1983).

Lice

Lice are relatively common parasites of goats when regular control is not practiced, or where newly purchased goats are introduced to the flock without prior treatment. There are two types of lice namely, the biting and sucking lice. The biting lice feed on debris close to the skin, while sucking lice feed on blood. Both types can cause severe irritation, resulting in the animals rubbing on trees and fences, damaging the fleeces and reducing its value. Massive infestations can cause anaemia, loss of condition, decreased efficiency of feed conversion, a scurfy appearance and loss of wool and hair. Louse infestations can then lead to the death of the animal (Drummond, 1983).

Flies

Sheep and goats are attacked by bloodsucking insects such as keds, horn flies, biting gnats and mosquitos, non biting flies such as fleece worms, blow flies and screw worm flies, and non-feeding insects such as sheep bot flies. Larvae of several blowflies attack sheep and goats. These flies lay eggs on dead and decaying flesh and the maggots (called fleece worms) do not destroy living flesh as does the maggots of the screw worm fly (Drummond, 1983).

Mites

Sheep and goats are infected with several species of itch, mange or scab mites. These very tiny species live on or in the skin and can cause intense irritation, itching, loss of wool or hair, thickening of skin and considerably discomfort to infested animals (Drummond, 1983).

2.4.7.1.3 Internal parasites

Internal parasites of small ruminants are a primary limiting factor to the successful production of these animals. Internal parasites are a problem to sheep and goat producers all around the world. Death and production losses run into a million of rands annually (Thedford, 1983). Such losses include decreases in gain and feed conversion as well as unreached potential of fleece and hair weight. Internal parasites lead to emaciation due to loss of nutrients from the host's digestive tract or from chronic loss of blood. Anaemia, diarrhoea and jaundice will lead to poor performance and death can follow in chronic conditions (Thedford, 1983).

2.4.8 The effects of nutrition on cashmere production

Environmental changes in the photoperiod, together with qualitative and quantitative changes in nutrition, partly cause seasonal changes in fibre growth. However, these changes in fibre growth are partly also caused by changes in the physiological state of the animal, which may be associated with the season (Russel, 1992). McGregor (1998) reported that between all the non-genetic and technological influences on commercial cashmere production, nutritional manipulation appeared to have the largest capacity to influence cashmere production in Australia. In most countries, goat production occurs on either natural or cultivated pastures, which exhibit seasonal patterns of pasture growth (McGregor, 1998). The period of cashmere growth coincides however with the period in which the greatest nutrient restriction occurs (summer-autumn). Because of this, cashmere growth may be reduced (McGregor, 1998). Russel (1992) reported that the effects of nutrition in one season might affect wool production in sheep in the next season. In addition, fibre quality is also adversely affected by poor nutrition.

2.4.8.1 Effects of nutrition on follicle development

Variations in the supply of nutrients to the follicles can exert a considerable influence on the rate of fibre production and the characteristics of the fleece (McGregor, 1992). Henderson & Sabine (1991) reported that the total number of follicles per sheep determine the amount of wool grown. Under nutrition of the ewe (during the latter part of pregnancy) and of the lamb (during the first few months of life) can prevent or retard development of some follicles. As a result, the wool production of adult animals may be impaired or characteristics may be altered. The major effect of poor nutrition during pregnancy is on the initiation and maturation of secondary follicles during the latter third of pregnancy, when the nutrient demands for growth are greatest (Corbett, 1979). Severe nutritional restrictions at this time permanently reduce adult wool production due to reduced follicle numbers, and are associated with reduced body size and skin area. Thus the expression of the genotype may therefore be modified by early environmental influences (Reis, 1982). As all follicles are initiated at birth, postnatal restrictions of nutrient supply do not reduce follicle numbers, but may permanently impair the capacity of some follicles to produce fibre (Reis, 1982).

Cashmere fibre is developed from the secondary fibre follicles. Follicle development occurs in two stages, namely initiation (physical development of the follicles) and maturation (production of fibre from follicles) (Henderson & Sabine, 1991). The same author reported that, in sheep, nutrition has an important influence on the development and maturation of the secondary follicle population. A sheep stunted of malnutrition cannot express its full hereditary ability of wool production (Ryder & Stephenson, 1968). Secondary follicles are initiated before birth and mature in two waves. One wave reaches a peak just before birth, while the second wave reaches its peak two to four weeks afterwards (Corbett, 1982). It is possible that poor nutrition during foetal and early post-natal life imposes a permanent limitation on fibre production ability of the animal. Poor nutrition reduces the number of follicles developed (Ryder & Stephenson, 1968; Hogan, Elliot & Hughes, 1979 & Henderson & Sabine, 1991). Corbett (1979) reported that while under nutrition in early life caused a reduction in the capacity of the follicles to produce fibre, it did not cause a permanent reduction in wool growth (except in most extreme situations) after a good diet was restored.

Manipulation of the level of nutrition could have a marked effect upon adult fibre production. It is therefore important to determine precisely when the development takes place. Ryder & Stephenson (1968) stated that lambs whose dams were being poorly fed, progeny of young ewes, and twin lambs could develop fewer follicles. This could subsequently reduce the wool producing capacity in the adult. Under such circumstances, secondary follicle development is slowed down and this results in less secondary fibres in the fleece at birth (Summer & Bigham, 1993). A reduction in the secondary follicle population in the newborn lamb (whether due to under nutrition or maternal handicaps in the pregnant ewe) will not necessarily result in lower wool production in the adult. This is in view of the fact that the second wave of secondary follicle maturation in early post-natal life may be enhanced by a high nutrition at this time (Corbett, 1979). Corbett (1979) suggested that the influence of the level of nutrition on secondary follicle formation during the late foetal period was established by the close relationship between birth weight and a mature S: P ratio. However, S: P ratios at birth and at weaning were correlated with body weight at birth, which illustrated the importance of foetal growth for secondary follicle formation and the final S: P ratio.

A restriction in terms of body size and the total number of follicles highly affected wool growth potential. This was caused by low levels of nutrient supply during pre-natal life. A restriction of nutrient intake during early post-natal life, also permanently reduced the capacity of the individual follicles to produce fibre material. The implication of these results is that for maximum wool production in the Merino it is essential for breeding ewes to have plenty to eat during the latter part of pregnancy and the first few weeks after lambing (Ryder & Stephenson, 1968).

2.4.8.2 The effects of energy on cashmere production

Cashmere growth may be reduced by relatively severe under nutrition but is unaffected by any nutrients beyond those required for maintenance (McGregor, 1988). Reports have shown that variations in energy intake have varying effects in cashmere production. McGregor

(1988) reported a 51% increase in production when the energy supply increased from below maintenance to above maintenance. In addition, significant differences in cashmere diameter appeared between goats that were fed to gain live weight (McGregor, 1998). McGregor (1998) also reported that when goats were energy deprived, nutrients were diverted and less total cashmere was grown. On the other hand, when goats were fed to gain live weight, more total cashmere was grown. It is clear that once a cashmere goat reaches its maximum potential for cashmere growth, nutrients for fibre growth can only be utilized for additional guard hair growth (McGregor, 1998; De Villiers *et al*., 2000).

Variations in live weight of cashmere goats and in seasonal conditions significantly affected cashmere growth and fibre diameter. Early studies with feral goats indicated that very low levels of nutrition could reduce the diameter of the produced cashmere from 14 to 13.5 μm (Russel, 1992). The quantity of nutrients used by cashmere goats to produce the two types of fibre (guard hair and cashmere down), and the secretions of grease and suint, is small when compared to the total and relative values calculated for sheep and Angora goats. Smuts (1999) reported that a goat that produced 250 g cashmere per year, stored approximately 0.3% of the energy and 1% of the protein consumed during the year in the fibre or associated secretions. The corresponding values for wool and mohair production were 3-5 times greater.

McGregor (1998) reported that supplementary feeding of grazing cashmere goats increased cashmere growth by 10-15%. In years when seasonal conditions enabled live weight gain during summer and autumn, the feeding of supplementary energy did not increase live weight or produce a significant increase in cashmere growth (McGregor, 1998). Compared to goats that grazed pasture only, goats that received supplementary feeding during winter showed a significant increase in live weight at the end of winter and spring (McGregor, 1998). McGregor (1992) reported that energy supply affects cashmere production. It also affected the partitioning of nutrients between cashmere and hair growth. *Ad libitum* feeding of the goats altered the partitioning of nutrients towards the hair. In addition, there was no corresponding increase in cashmere growth. The provision of supplementary energy during the first four months of the cashmere-growing season, can significantly increase cashmere growth (McGregor, 1992). In order to maximize cashmere growth, McGregor (1992) stated that supplementary energy should be supplied to obtain 1-2 kg live weight gains and to maintain body condition during the summer and early autumn period. Supplementary feeding increased total fleece production.

Cashmere growth is reported to be highly and positively correlated to mean live-weight and other live-weight measurements. Regression coefficients indicated that for each kilogram increase in live weight, cashmere growth increased with 4.69 g and fibre diameter with 0.076 μm. While sufficient green pasture is available to enable live-weight gain, live-weight loss would occur on dry pastures (McGregor, 1992). In years when cashmere goats lose live-weight during autumn, energy supplementation (to maintain or increase live-weight) will increase cashmere growth (McGregor, 1992). McGregor & Umar (2000) reported that during the entire cashmere growing season (in Australia from November to July) cashmere production gains (up to 67%) were obtained in adult goats when energy intake was increased. McGregor (1988) reported that goats that were fed above maintenance grew more total cashmere of coarser diameter than goats that were fed at 80% maintenance as well as those fed only to maintain body weight. The results are presented in Table 2.6. These observations support the hypothesis that energy restrictions reduce cashmere production during the period of cashmere growth. McGregor (1988) concluded that supplementary energy should be supplied to avoid normal seasonal live-weight loss from December until April during the summer rainfall areas of Australia, with a similar condition as Southern Africa.

Table 2.6 Total cashmere growth, cashmere fibre diameter and yield, and hair growth of whether goats fed at three levels of energy intake (McGregor, 1988)

Feeding levels	0.8 Maintenance	Maintenance	More than maintenance
No of goats	5	15	15
Cashmere growth (g)	146	192	221
Cashmere fibre diameter (μm)	16.67	16.93	17.69
Cashmere yield (% w/w)	47.0	45.1	43.1
Hair (g)	193	217	284

It has been reported that luxury levels of feeding cause thickening of the fibre. According to Johnson, Gheradi & Dhaliwal (1994) goats with the Angora influence in their genetic background are the only ones that are affected by nutrition whereas McGregor (1988) reported an increase in fibre diameter as energy levels increase to above maintenance level. A nutritional reduction in clean fleece weight is associated with a reduction in the length and diameter of cashmere and guard hair. Moderate changes in nutrition have no effect on total fibre number. It is clear that nutritional changes in weight are brought about by changes in the length and diameter of individual fibres (Ryder & Stephenson, 1968). Fibre diameter is more susceptible to nutritional influences than fibre length. Changes in length precede changes in diameter. Poor nutrition has a lesser influence on diameter than on length. The breaking stress of staples and of individual fibres decreases, as fibres become finer. This suggests that a poor diet reduces the breaking stress per unit cross sectional area. It also leads to the thinning of fibres. Ryder and Stephenson (1968) reported that weak wool has reduced cystine content. The thinning of the fibre leads to tender fibre and a break in staple. The disadvantage of tender fibre and a break in staple is the increased fibre breakage during processing, particularly in combing (Ryder & Stephenson, 1968).

Increasing the level of nutrition increased the relative length growth rate of cashmere but at the cost of increased cashmere fibre diameter (McGregor & Umar, 2000). The effect of nutrition on crimp frequency is very slight, if at all. Character seems to become worse only after prolonged, under nutrition occurs, but it is nevertheless severely affected by copper deficiency.

2.4.8.3 Effects of protein on cashmere production

Wool and mohair growth is affected by protein nutrition, especially by the sulphur-containing amino acids in the protein, cystine and methionine. Wool growth in sheep increases with the level of feeding and responds mainly to the increased supply of amino acids rather than to the energy to the wool follicle (Klören *et. al.*, 1993). Fleece growth in Angora goats has also been reported to increase with increased nitrogen availability and methionine supplementation. Galbraith (2000) found that growth of mohair might be limited by an inadequate supply of protein in the diet. With regard to this, protein supplementation stimulated yield but produced commercially undesirable increases in fibre diameter. When goats are fed on diets that are deficient in protein, protein supplementation leads to large increases in both cashmere growth and fibre diameter.

Galbraith (2000) reported responses of cashmere yield in goats that were supplemented with rumen protected intestinally available methionine. These responses of increasing yield without affecting diameter, indicate greater growth due to an enhanced rate of elongation in the cashmere fibre. Guard hair was not affected by supplementation. This positive response for cashmere production contrasts with the report by Ash & Norton (1987a), McGregor (1988) & McGregor and Umar (2000) who observed that dietary supplementation of methionine in three to four year old Australian cashmere rams, resulted in no response in cashmere production. Several workers reported that despite reports of significant increases in fibre production in response to increased levels of nutrient input, and the inclusion of high levels of dietary protein (including proteins of low rumen degradability), these increases were wholly attributable to effects on the guard hair. No significant effects of nutrition on the weight of cashmere fibre were however reported.

According to Ash & Norton (1987a) total fleece growth (hair and cashmere) was increased when methionine was supplemented. The increased fleece growth can be largely attributed to improved hair yields, as there was little difference in cashmere growth. McGregor (1992) found that when minimal degradation of protein was avoided, substantial increases in wool growth rate were obtained with protein. Only small responses were associated with energy. Ash & Norton (1987a) also reported no improvement in cashmere yield where feral goats were offered diets containing increased amounts of fishmeal (a protein source of low degradation in the rumen). The reason for this may be that cashmere growth was determined by the genetic make up of the animal. Subsequently, supplementation was of little value, especially if one considers the very low rates of protein accretion in fleece (0.3 g/goat/day). It was furthermore reported that, unlike in sheep, methionine was not a major limiting amino acid affecting cashmere growth in goats (Ash & Norton, 1987b). Unlike wool growth in sheep, the feeding of large quantities of protected protein to the goats failed to stimulate cashmere growth (AFRC, 1998). This suggests that improved nutrition is not necessary to achieve maximum cashmere production in animals of limited genetic potential (Ash & Norton, 1987b). Ryder (1987) reported that the slight increase in down weight was associated with an unacceptable increase in mean fibre diameter. These findings show that the growth of the coat in double-coated goats is firstly strongly influenced by genetic factors. Secondly, coat-growth is more closely related to seasonal changes than to nutritional variation (Ryder, 1987). It is probable that the maximum protein requirements for cashmere production are met in all but the severest nutritional crisis (AFRC, 1998).

2.4.8.4 Other dietary factors

For goats, the 23 major and trace elements are essential. A deficiency of these elements causes metabolism disorders, which can only be prevented or cured when the lacking elements are supplied (Kessler, 1991). Deficiencies in trace mineral nutrition cause a loss of production and health in fibre producing animals (Reis, 1982). The effects of mineral deficiencies on fibre producing goats are known to be large in practice. However, many of the effects of minerals appear to be due to changes in the supply of major nutrients caused by changes in feed intake, or in the balance of nutrients flowing from the rumen. Definite effects on fibre growth have only been demonstrated for Zinc and Copper. Yet, some of these changes may be related to changes in feed intake (Reis, 1982). Zinc deficiency in sheep causes cessation of fibre growth and fleece shedding. In certain types or breeds of goats, Zinc deficiency has been reported to cause a reduced length growth of hair. Copper deficiency is also very significant because of its direct effect on wool (Reis, 1982). It causes loss of pigment and produces fibre which lacks crimp. Such fibre is weak and difficult to process and furthermore has abnormal dyeing properties. Iron deficiency has been found to cause hair loss in rats and goats. An excess of iron was reported to be the cause of follicle degeneration in sheep. Cobalt deficiency had a noticeable effect on ruminants in reducing appetite, but it had no direct effect on fibre growth (Reis, 1982). Phosphorus and calcium deficiency is a major problem in many parts of the world. It causes a loss of appetite but has no specific effects on fibre growth. Goitre is caused by iodine deficiency and its common symptom is hair loss. There is no evidence that higher than adequate levels of zinc influence wool growth (Reis, 1982). Qi *et al.,* (1992) reported responses to sulphate for mohair growth, staple strength and staple length, but no responses to other mohair quality traits. AFRC (1998) proposed that mineral requirements for fibre growth in goats should at present be based on the composition of the fleece of sheep. As for sheep, Ca, P and Mg requirements for fibre production are likely to be very low compared to those for maintenance, growth and milk production.

Vitamins of the vitamin B complex do not affect fibre production, because a supply of these is assured from micro flora of the rumen. Deficiency of vitamin B (biotin) retards hair growth in mice. In addition, deficiency of riboflavin has been found to cause hair loss in rats (Ryder & Stephenson, 1968). Deficiency of pantothenic acid causes depigmentation of hair and poor hair growth. In many possible cases this is the result of decreased mitosis. It was reported that a deficiency of Vitamin A had caused keratinization (Kessler, 1991). Vitamin A deficiency in some animals leads to excessive keratinization of follicular epithelium and subsequently blocks the opening of the follicle. Ryder & Stephenson (1968) reported that although a deficiency in vitamin A caused night blindness in sheep, it did not cause any abnormalities in the fleece. Ryder & Stephenson (1968) ascertained that trace element supplements could only be useful in cases where there were deficiencies of those elements. Therefore, no element can be of use to livestock in cases where the pastures already provide the sufficient quantity.

2.5 Techniques to measure fibre diameter

2.5.1 The older techniques which were used for fibre diameter analysis

Before 1920, evaluation of mean fibre diameter was based on experience and expertise in visual and manual appraisal. Subjective techniques are still used as preliminary means of evaluation. Such methods are inaccurate due to human perceptual bias. Trained technicians can measure only 200 fibres in approximately 15 minutes (Qi *et al.*, 1994).

2.5.1.1 Projection Microscope (PM)

The Projection Microscope (PM) was regarded as the primary method for measuring fibre diameter (Wood, 2000). Before 1920, the projection microscope has been widely used for measuring Mean fibre diameter (MFD) and fibre distribution (SD) and is still considered the standard method. The measurements are performed manually, so the PM method is subject to human error. The PM defines mean fibre fineness in terms of the mean width of the projected image of fibre (Sommerville, 2000). An image of the fibre is magnified and projected onto a screen, from which the apparent diameter is measured. Because of the large variation in the diameter of wool fibres, it is necessary to measure a lot of fibres (at least 500) to get a reasonably precise result (Wood, 2000). Projection Microscopy was widely used in the United States and was also considered the standard method. The PM is a very slow and labour intensive technique and it was very imprecise when the measurements are conducted within one laboratory (Sommerville, 2000). Although it is tedious time-consuming, it is used as a benchmark for other methods, for example the airflow method

2.5.1.2 The Airflow method

Determination of fibre diameter by airflow method is relatively quick, convenient and fairly accurate and is consequently widely accepted and used for obtaining fineness estimates of both mohair and wool (Hunter, Smuts & Gee, 1986; Qi *et al*, 1994). This simple and inexpensive method had been used for many years in most wool producing and processing countries. The airflow instrument defines fibre fineness in terms of the surface area of the fibres (Sommerville, 2000). The airflow method of measuring fibre diameter utilizes the principle that, for a given pressure difference, the air flowing through a certain fibre weight is an indirect measure of the fibre diameter of the sample (Doak & Maher, 1999). Before using the instrument it must be calibrated using the range of wool of known fibre diameter from the PM (a benchmark for other methods). A thoroughly cleaned and blended sample of a known weight (2.5 g) is compressed in a cylinder to a known volume and subjected to an air current at a known pressure. The rate of airflow through the porous plug of fibre is measured, the flow meter often being calibrated in terms of fineness instead of volumes per unit time e.g. microns for wool fibres. For fibres of circular cross-section, specific surface is inversely proportional to the fibre diameter. Therefore by measuring the rate of airflow under controlled conditions, the specific surface of the fibre can be determined and consequently the fibre diameter. When a constant difference in air pressure is maintained across the plug, the rate at which air flows through it depends on a number of factors, including the fibre diameter of the wool. The rate of flow of air through and the pressure drop across a compressed plug of fibres, is related to the diameter of these fibres. The wool will span the fibre diameter range 20-40 microns (Wood, 2000). The airflow test works remarkably well for measuring the fibre diameter of wool, hence its wide spread use. However it has several limitations, especially its inability to provide any detail on the spread of fibre diameters in a wool sample (Wood, 2000). Hunter (1987) reported that the error in airflow results due to experimental method tended to decrease as the degree of fibre randomization increased. To demonstrate this statement two cylinders of similar dimensions were filled with a few circular rods of large diameter or many rods of small diameter. The numbers and dimensions being chosen so that the total cross-sectional area is equal. If the air were blown through the two cylinders at the same pressure, it would be found that the rate of airflow through the small rods was less than through the large rods, even though the space through which air passes is the same for both cylinders. The reason is that the air flowing through the small rods has more rod surface to flow past. This surface acts as a drag on the air in a manner similar to the drag of the water by the riverbanks. A difference in the rate of airflow is a measure of the difference in the surface area of the large diameter and small diameter rods. Speaking of fibres instead of rods, we might now consider that for equal weights of fibre sample the rate of airflow will be less for the fine fibres than for coarse fibres (Booth, 1968). The disadvantages of the PM and the airflow methods are the number of fibres that can be investigated, the manual or semi-automatic nature of the methods, the fact that the measurements can be subjective and there is no differentiation between very similar fibre samples (Phan, 2000).

2.5.1.3 Fibre Diameter Analyzer (FDA)

The fibre diameter analyzer (FDA) is the instrument used to measure the distribution of wool fibre diameter within a sample of fibre snippets. The FDA is capable of accurately measuring fibre diameters in the typical range of 5-240 μm and is now in widespread use in the wool industry in the form of the FDA-200 and more recently the Sirolan- Laserscan (Glass, Dabbs & Chudley, 1995). The FDA 200 was introduced in the 1970's based on image analysis and laser technology. This instrument was capable of measuring MFD and SD of animal fibres in a relatively short time compared to the PM. The FDA 200 was more automated and faster than the Particle Measurement Computer (PiMc) System but suffered from three shortcomings. Firstly it was incapable of measuring animal fibre coarser than 80 μm. Secondly fibre blockages at measuring cell frequently interrupted measuring. Thirdly, the FDA 200 produced measures of SD that were substantially greater than the values produced by PM (a benchmark for other methods). The latest version of the FDA 200, the Sirolan Laserscan was introduced and seems not to contain the above-mentioned problems. However, the instrument is quite expensive considering that it is capable of measuring only two fibre parameters, mean fibre diameter and standard deviation (Qi *et al.*, 1994). Laserscan provides a similar set of results to Optical Fibre Diameter Analyzer (OFDA) but it operates according to a different principle. The fibre snippets are transported in alcohol to pass through a laser beam. The shadow that a snippet makes on a light sensor provides an electrical signal that is related to the diameter of the snippet. The signal is analyzed by a computer to provide the fibre distribution and other data. (Wood, 2000).

2.5.2 New techniques which are used for fibre diameter analysis

2.5.2.1 Optical Fibre Diameter Analyzer (OFDA)

2.5.2.1.1 Description and performance of the OFDA

The Optical Fibre Diameter Analyzer (OFDA) instrument is based on automatic image analysis technology and was recently introduced to provide a rapid, accurate measurement of mean fibre diameter (MFD) and diameter distribution (SD) of textile fibres (Qi *et al.*, 1994; Phan, 2000). The OFDA is internationally accepted for the determination of fibre diameter distribution as well as medullation (Lupton & Pfeiffer, 1998). The OFDA is used at all stages of the wool-processing pipeline, from fleece to yarn and fabric. Each measurement on a prepared slide, which represents one sample, take less than a minute to complete, so that, with appropriate sampling, slide-handling, and preparation techniques, several hundred samples may be measured in an eight hour shift (Baxter *et al.*, 1992). Using distribution, the fibre characteristics of the fine as well as the coarse hair content, i.e. the fibre quality (mean fibre diameters, standard deviation of the fibre diameter, number of fibre pieces) can be determined and used for calculation of down yield (Herrmann & Wortmann, 1997). The OFDA is the first automatic instrument to measure fibre opacity and fibre curvature. Recently the OFDA has acquired the new feature of measuring the diameter variability along the short length of fibre. The wool measurement provided in real time by the OFDA, includes fibre diameter (including a distribution histogram), standard deviation and coefficient of variation of diameter. It also includes percentage of fibres less than 30 micron (comfort factor, curvature and standard deviation curvature, staple length-diameter profile, staple length, position of the finest and broadest sections and the average diameter of fibre ends.

The components of the OFDA are as follows: An IBM-AT computer with a processor, a microscope, custom-built stage and the light source. An IBM-AT performs the task of the user interface, microscope-stage stepper-monitor control, measuring the fibres, and further data processing. The instrument comprises a slide to hold the prepared staple, a slide holder assembly, which is moved incrementally so that a new section of the staple is scanned at each step along its length, and a low-powered microscope, and illuminant assembly, which traverse the staple at each step (Baxter, 2001a). The light source is an ultra-bright light emitting diode (LED) that is strobed under computer control to produce a beam of light that passes through the slide and the optical system to perform the image on the camera sensor (Baxter *et al.*, 1992). The stage is driven under computer control by two stepper motors allowing an X-Y scan of part of the slide. The microscope is shipped with two objectives which give a normal magnification on the video screen of approximately 200X and the option to use approximately 500X to examine or measure individual fibre images (Baxter *et al.*, 1992). A Charge Coupled Device (CCD) camera, which is a completely solid-state camera, that precisely converts the light image to a standard video signal. The custom-designed frame-grabber board captures the video image from the camera in real time and stores the image in the memory as an array of pixels. The OFDA software is the part of it, which is critical for the success of it. By multitasking, it synchronizes the camera, LED strobing, and slide positioning at the same time as it performs the measurement task. An industry standard printer provides a hard copy of the measured data in various formats, including the histograms and tabular results (Baxter *et al*., 1992). The video monitor allows the display of the output of the frame-grabber card. Whereas it is normally used for checking focus, or verifying the results of pattern recognition, as above, it can be used in combination with the computer mouse to perform manual dimensional measurements on individual fibres. A separate VGA graphics display, together with a standard keyboard and mouse provides the user interface. The instrument is shipped with a snippet spreader, to distribute prepared snippets uniformly over the surface of the microscope slide (Baxter *et al.*, 1992). The OFDA is less expensive and potentially a more versatile instrument (Qi *et al.*, 1994).

2.5.2.1.2 Method

The OFDA magnifies and captures images of the individual fibres using the video camera and identifies and measures each fibre. If the opacity and the curve options are enabled, the OFDA measures these at the same time as it measures the diameter, so there is no extra measurement process involved. The OFDA is essentially an automatic microscope set above a moving sample of fibres. The snippets (2 mm) of the conditioned sample are obtained using a minicore. The snippets are spread onto hinged glass slides of 6.5 X 6.5 m^2 with automatic spreader and mounted to the motor driven sample holder. About 10 000 fibres are measured in about two minutes. The OFDA is sensitive to snippet length, for both fibre diameter and coefficient of variation in diameter, but these effects diminished as the snippet length approached 2 mm (Herrmann & Wortmann, 1997). The OFDA determines the distribution of fibre diameter by measuring the diameter of a number of individual fibre snippets constituting a specimen. Each fibre measurement is then assigned to a diameter bin of 1 μm width, and after a predetermined number of fibres have been successfully measured, the contents of the bins are analyzed to calculate the mean fibre distribution of diameter. This fibre diameter distribution has to be separated onto a down and guard hair fibre distribution (Herrmann & Wortmann, 1997). The OFDA measurement provides a rapid and accurate evaluation of the fibre diameter of both kinds of fibres present in a cashmere fleece, and the respective fibre diameter (IWTO, 2001). Herrmann & Wortmann (1997) reported that the fibre diameter classes range from 4-30 μm for down fibres and from more than 30 μm to 150 μm for guard hair fibres as presented in Figure 1. The same authors also reported that the OFDA measurement provides an accurate estimation of the fibre quality without the necessity to dehair the fleece samples.

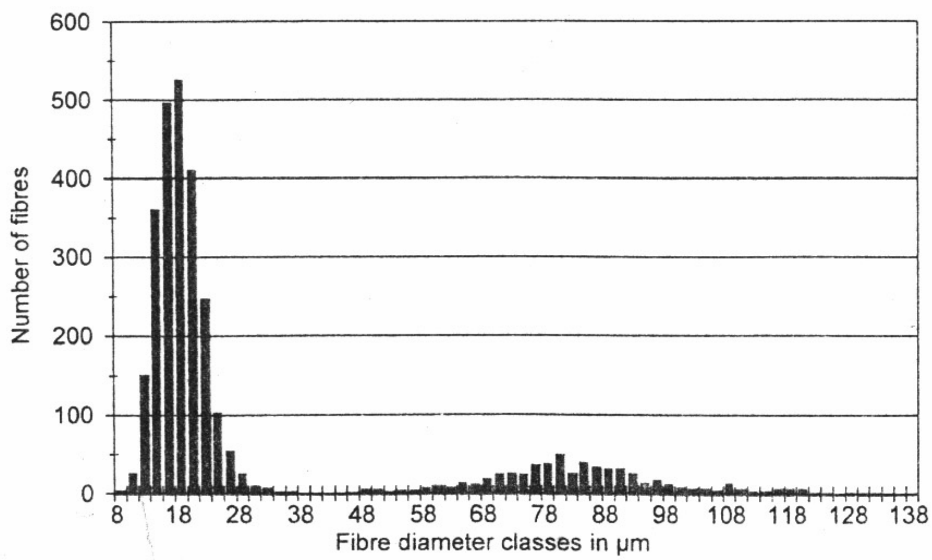


Fig 1 Fibre diameter distribution of a typical cashmere fleece (Hermann & Wortmann, 1997)

2.5.2.1.3 Advantages and benefits of the OFDA

The OFDA has many advantages over the competing instruments. Amongst the International Wool Testing Organisation (IWTO) recognized instruments which automatically provide mean diameter CV and Prickle Factor (PF) measurements, only the OFDA improves efficiency because it measures 3000 fibres in the time that others measure 1000. It is the fastest technique, so it allows more tests to be done each day. It can routinely measure fibre curve (which is a component of crimp) that is measurable at all stages of wool processing and also medullation (the hollowness of fibres that causes dyeing and breakage problems). The OFDA does not utilize flammable chemicals that require storage, mixing and continuous monitoring and it saves time. The machine measures fibre diameters of up to 300 microns and can keep slides of different fibre samples such as wool, mohair and alpaca for remeasuring. The OFDA is a portable machine, thus making it useful for measuring exotic fibres at different sites (Brims, 2000; Paterson & Gheradi, 2001).

2.5.2.2. Video Image Analysis (VIA)

The Video Image Analysis (VIA) is an electronic technique whereby pictorial information from a video input source is numerically represented (digitized) to enable subsequent computer analysis (Higgerson & Whitely, 1983; Gerten & Wiese, 1987). These digits are manipulated via algorithms, so that the most important features can be identified (Winston, 1989). The computer is connected to the camera, microscope or to the scanner (Snyman H., personal communication, 2002, Animal Nutrition and Products Institute (ANPI)-ARC, Irene). The microscope set-up is similar to that of the OFDA. Two different devices can be chosen as image-input devices. One is a JVC TK1070U CCD video camera. The camera should be equipped with a HZ-H1713 zoom lens to gain a magnification of up to 13X or with a microscope for higher magnification. This device is mainly used for fibre-cross-sectional analysis. A HP Scanjet IIC serves as the second option of input device. Both input devices are linked to the circuit boards plugged in a computer. The scanner can offer a spatial resolution of up to 10^{24} or 10.8 million colours (24 bits/ pixels). The scanner can easily maintain an identical environment of image capturing in terms of illumination conditions and background for spatial tests. The scanner is the main input device for fibre longitudinal measurement and colour evaluation (Xu & Ting, 1996a). The VIA resulted in accurate measurements and is capable of applying to various shapes of area (Irie, Izuma & Mohri, 1996). The digitizing process sequentially isolates specific picture elements (pixels) within the video image using a rectangular grid-scanning pattern. A data quantization level (grey-level) is assigned to each pixel. The VIA system utilize more powerful computers which have greater memory capacities (Gerten & Wiese, 1987). Fibre samples can be imaged through the scanner for low magnification. The scanner can measure longitudinal measurements, diameter and length and cross-sectional measurement (Xu & Ting, 1996a).

2.5.2.2.1 Method

Samples are prepared from all over the whole body. The hair is washed two times with ether. Fibres are cut into short segments and dispersed on a microscope slide and mounted with DPX (glue). With the aid of the microscope, the Charge Coupled Device (CCD) camera can obtain a 500X magnification under which fibre images can be easily resolved. Since fibre segments are allowed to cross over each other, tedious work needed in other methods to ensure that fibres are well dispersed is eased, and more fibre segments can be viewed in one image frame. From the longitudinal view, fibre diameter equals the distance between two edges of fibre. Scanning and shrinking are two different approaches for measuring fibre diameters. Both of the algorithms can avoid measuring diameters at fibre intersection points, thus reducing the care required to disperse segments manually in the sample preparation. Cross-sectional measurements (area, parameter, equivalent diameter, roundness, ellipticity, modification ratio and aspect ratio) can provide more size and shape information which is a valuable supplement to longitudinal measurements (Xu & Ting, 1996b). In the present system a video camera is coupled to a lens with a wide range of magnification which obviates the need to use a microscope and special lightning (Alagha, Oxenham & Iype, 1994). Make sure that the sample is in focus when doing the measurements, because if it is not in focus it can be measured incorrectly. Measure one fibre only once and after measuring one field go to another field to avoid repetition. The VIA can also be used for counting objects on the screen (Snyman H., personal communication, 2002, ANPI- ARC, Irene).

The VIA can also measure the primary to secondary ratio population (S: P ratio) of goats. It can also measure horizontal, vertical, arbitrary distances, polygon length (follow branches), areas and circumference. The results of the VIA can be presented as histograms and scale bar on picture. Filters are used to make the picture better, can also change the colour of the pictures, remove shadows, can determine pixel values on a picture. The operator can also copy pictures from the program to any compatible program i.e. slides. According to Snyman (2002) the VIA is more accurate manually than automatically and is better to use for research than the OFDA but this statement will be evaluated later in this study.

2.5.2.2.2 Scanning

The focus of scanning is on preventing mis-identification of the fibre. The image is scanned horizontally from left to right. Each scanning locates all pixels where intensity gradient show abrupt changes (edge pixels). When an edge pixel is found, the computer pauses the scanning in the horizontal direction and searches for more edge pixels on both sides of this pixel. If the pixels are roughly on the same straight line (a high correlation coefficient), this fitting line can be used to indicate the left edge of the fibre. The computer scans the image in a direction perpendicular to the fitting line until another abrupt change in intensity gradient occurs. A number of neighbouring edge pixels are also located to calculate the best fitting line for the right edge of the fibre. If both fitting lines are approximately parallel to each other, the distance between these two lines is the fibre diameter at this point (Xu & Ting, 1996b). The computer then continues to scan the image to find the next edge pixel on the same scanning line. The computer will skip the edge pixel if the left edge at this pixel or the right edge corresponding to this pixel is not straight (a low correlation of the fitting line) or the two edges are divergent. This is how the computer avoids taking measurement at crossover or any irregular positions. To reduce redundant measurements, the scanning lines are equally spaced to accommodate differences in image size when running the program. Since a fibre is scanned at different positions, the diameter measurements contain variations between fibres as well as within a fibre (Xu & Ting, 1996a).

CHAPTER 3

Materials and Methods

3.1 Animals

Five indigenous goat flocks with a total of 217 animals (155 indigenous and 24 Boer goats) were identified for combing in 1997. 38 Savannah goats from the Centurion flock were later identified and combed only once in September the same year. These flocks were from ARC-ANPI, Irene (18 indigenous goats); University of Pretoria (35 indigenous goats); ARC-RFI, Roodeplaat (36 Indigenous goats), Department of Agriculture Northern Province, Delftzyl (38 Indigenous goats) and the Department of Agriculture Northern Province, Mara (28 Indigenous and 24 Boer goats).

Age

The animals were of different ages. The age of the goats ranges from as young as less than one year to eleven years of age. The ages were grouped into three categories: age 1 = less than one to one year of age, 3 = two to three years of age and 5 = four years and above.

Colour

The colour of the animals varied. Some were black, white and others brown. Most of the indigenous goats were multi-coloured, from black with brown spots, other brown with white and black spots, etc. Savanna goats were white and the Boer goats white with red/brown heads. The colours of the animals were grouped in to 1 = Black, 2 = White, 3 = Brown and 4 = Multi coloured.

Gender

198 females, 15 males and 4 wethers were used in this study.

Reproductive status

106 females were open, 55 pregnant and 36 lactating during the study period.

3.2 Description of the study areas

Irene, University of Pretoria, Mara, Delftzyl, Roodeplaat and Centurion were chosen as study areas. These areas were chosen because they were within a close distance from Pretoria. Most of these flocks were mainly situated at the experimental stations where record keeping was good.

Climatic conditions of the study areas

Table 3.1 Weather conditions for the study for 1997 (South African Weather Bureau, 1997)

AREA	Latitude (South)	Longitude (East)	Altitude (m above sea level)	Min Temp (^{0}C)	Max Temp (^{0}C)	Av. Annual Rain (mm)
Irene	25^{0}55”	28^{0}21”	1524	4.6	28.0	717
Delftzyl	24^{0}35”	29^{0}14”	1850	4.0	35.0	450
Roodeplaat	25^{0}35”	28^{0}21”	1164	2.3	31.5	660
University of Pretoria	25^{0}45”	28^{0}16”	1372	3.5	28.9	686
Mara	23^{0}09”	29^{0}34”	894	2.6	32.2	449

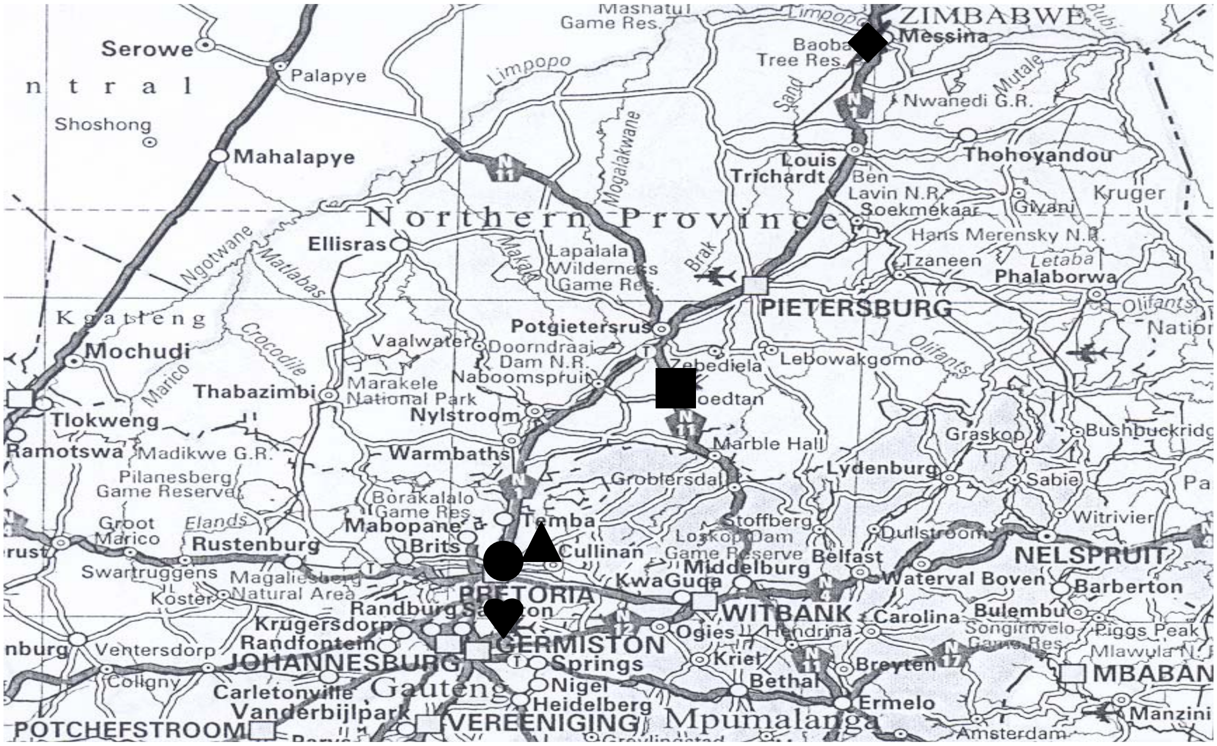
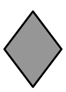
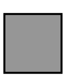
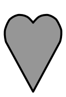


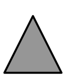
Figure 2 Map showing the location of the study areas.

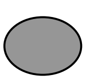
The following shapes show the location of the different areas in the map

 = Mara

 = Delftzyl

 = Irene and Centurion

 = Roodeplaat

 = University of Pretoria

Management

The animals were dewormed regularly, vaccinated against endemic diseases and kept clean from external parasites.

The stocking rate at the different locations was more or less the same.

The animals at Roodeplaat were kept on natural grazing throughout summer known as sourish mixed veld (Acocks, 1988). Early and mid winter grazing was from the same source however, late winter grazing was supplemented with grazing on various planted pastures (standing hay / foggage) and hay (Mixture of *Digeteria eriantha* & Rhode *grass (Chloris gayana* and lurcene hay) fed at night. The combed goats were part of a mixed flock of indigenous sheep and goats numbering around 1000. They grazed as one flock on an area of about 500 ha natural veld (Mappledoram B., personal communication, 2003, ARC-RFI, Roodeplaat).

The goats in Mara were kept on natural veld, mainly *Acacia tortilis,* known as sweet veld. In summer they mainly selected *Commiphora africana*, forbes and a little bit of grass. In winter the animals were kept on *Boscia albitrunca* and grass. There were approximately 150 goats and 100 sheep on approximately 1 500 ha. This area was also utilised by cattle. The animals at Mara were not fed anything else than the natural veld. Not even a salt lick was supplied (Du Plessis I., personal communication, 2003, Mara Research Station, Limpopo).

At Delftzyl the animals were kept on natural pastures and the veld type is known as mixed veld (Acocks, 1988).

At Irene the animals were kept on *Eragrostis curvula* veld. During winter the animals were being supplemented with lucerne, lamb pellets as well as chocolate maize. Chocolate maize (as known in the industry) is the maize treated with nitrogen, molasses, calcium and a buffer. The females were always given chocolate maize in order to prepare them for breeding. The total number of animals was 60 (Langa T., personal communication, 2003, ANPI-Irene)

At the University of Pretoria the animals were mostly kept on mixed veld / planted pastures dry land or given *Eragrostis curvula* hay.

3.3 Combing

The animals were combed using a metal or plastic comb. Combing took place from July until September (the shedding season). The animals were being combed three times with two weeks intervals. The total yield of each animal was collected separately in small plastic bags, marked and weighed.

3.4 Fibre diameter analysis by Video Image Analyzer (VIA)

The total yield of all three combings was combined. The yield was spread out on a black velvet-working surface (diameter 28 cm). Using a pair of tweezers a representative sample was taken and placed into a glass tube (diameter 2.4 cm, height 7.5 cm with plastic cap). The sample was washed two times with ether and dried using filter paper. The sample was cut into small pieces and stored in the glass slide (surface 7.5 x 2.5 cm) with DPX Mountant and covered with a small plastic top slide of 2.0 x 2.0 cm. The slides were left to dry for a few days. These slides were viewed with a Video Image Analyzer at 40X to measure the fibre diameter of the fibres. The hairs were viewed through the microscope on a video screen. Using a computer mouse pointer, the sides of the hairs were selected and then the computer calculated the distance between the sides selected, taking the magnification into consideration. The computer calculated the minimum and maximum fibre diameters, mean value, sum of all measurements, the variance and the standard deviation (SD).

3.5 Optical Fibre Diameter Analysis (OFDA)

The remaining part of the total yield were marked with pieces of paper and stapled on each plastic bag and sent to the CSIR, Division of Textile Technology, in Port Elizabeth. The samples were analyzed for clean cashmere yield on the Shirley Analyzer, and fibre diameter analysis by means of the completely automated OFDA-method. The samples were mixed thoroughly by hand and a 50 g sub-sample was taken from each sample. The sample was minicored using the pneumatic minicore sampler. Immediately, the fibre snippets were spread over a slide and 3 000 measurements per sample were made automatically by the computer. In this method cashmere and guard hair diameters were measured simultaneously. The computer separated the measured data into the guard hair and cashmere according to the criteria, namely fibre diameter and fibre diameter distribution, which were previously programmed into the computer (Hermann & Wortmann, 1996).

3.6 Clean cashmere yield analysis

To determine the clean cashmere yield, the combed cashmere / guard hair samples were first scoured in hot soapy water, followed by oven drying until a moisture content of 12%. The samples were then separated using the Shirley Analyzer. After separation each fraction was weighed and clean cashmere yield was expressed as a percentage of the total weight.

3.7 Statistical analysis

The data was first arranged in a spreadsheet of MS Excel. The Proc GLM (General Linear Model) procedure by Statistical Analysis Systems (1994) was used to analyze the data. All possible main effects (breed, location, age, gender, reproductive status and colour) and all possible first-order interactions were included in the initial models. The relationship between the OFDA and VIA was evaluated using the GLM procedure of SAS. These models were then fitted according to a step-down procedure in which the main effects and the first-order interactions not making a significant ($P<0.05$) contribution to the variance, were omitted in subsequent analyses. Higher-order interactions were, owing to complexity and the highly unbalanced nature of the data set, not included. Significance of difference between least square means was determined by the Fischer test (Samuels, 1989).

CHAPTER 4

Results and Discussion

4.1 The influence of environmental factors on fibre yield

Reports have shown that various environmental and physiological factors influence fibre quality and quantity (Corbett, 1979). Environmental factors include nutrition, seasonal changes in light and temperature, and immediate surroundings of the animal such as soil and climate (Ryder, 1969).

Based on data found in the literature the following environmental influences on fibre yield and diameter were investigated: location, age, colour, reproductive status, breed, and gender. Because the animals were situated in different locations and were of different breeds, the effects of age and the reproductive status on yield and fibre diameters are presented in three tables. The savanna goats were for example only kept in Centurion, the Boer goats in Mara and the indigenous goats in all the areas except Centurion.

4.1.1 Location

Location clearly influenced fibre production of indigenous goats. The results are presented in Table 4.1 and diagrammatically in Figure 2. The Irene flock had a significantly ($P<0.05$) higher fibre production per goat, compared to the other areas. There were no significant differences ($P>0.05$) in production per goat between the flocks from the University of Pretoria, Roodeplaat and Mara. The flock from Delftzyl however produced significantly less fibre per goat, compared to the rest of the flocks. This low fibre yield may be due to the different combing times, because the animals were not combed at the same time in the different areas. Braker (1997) showed that animals which were combed in July (at the beginning of the combing season), yielded more cashmere, compared to those animals combed later in the season. It is possible that animals that were combed later in the season may have already lost some fibre before combing. This could have an influence on fibre yield due to fibre loss.

Table 4.1 The influence of location on total production of fibre, cashmere, and guard hair yields of indigenous goats

Location	Total Fibre (g)	Cashmere (g)	Guard Hair (g)
Irene	67[a] (±6.7)	47[a] (±4.5)	18[a] (± 4.6)
University of Pretoria	42[b] (±5.0)	22[b] (±3.6)	21[c] (± 3.6)
Roodeplaat	34[b] (±5.4)	21[b] (± 3.8)	13[a] (± 3.8)
Delftzyl	20[c] (±5.3)	13[b] (± 4.5)	2[b] (± 4.6)
Mara	34[b] (± 5.8)	20[b] (± 4.1)	14[a] (±14.1)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

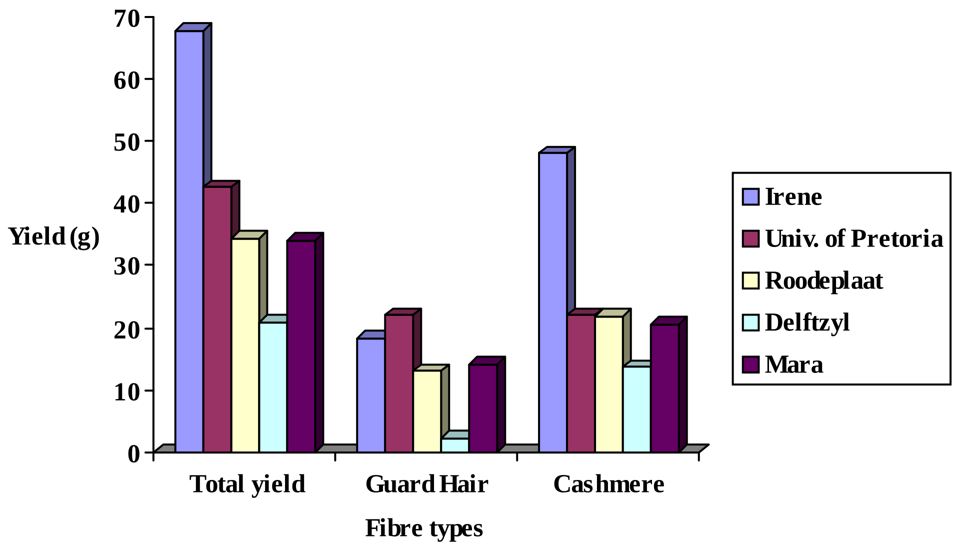


Figure 3 The influence of location on total production of guard hair and cashmere of indigenous goats (g)

Other possible causes for differences in production in various locations include dissimilar climatic conditions (as presented in Table 3.1) and management (type of pastures at which the animals were kept and also the number of animals in a farm) in the different locations as explained in Chapter 3. Corbett (1979) reported that weather conditions could either have a direct effect on wool production by affecting the metabolism on the wool follicle, or an indirect effect by affecting feed consumption. Chang-An (1992) & De Villiers *et. al.*, (2000) reported that goats in dry and cold places had a low cashmere production. Their fibre production was however very fine and of a high quality, compared to animals from moist and warm areas. Compared to cashmere producing areas with minimum temperatures of as low as -40^{0}C, South African environments are nonetheless not very cold.

According to Robards (1979) & McGregor (1988), stocking rate, pasture type and management influenced the amount and quality of fibre produced. The animals from Irene were few (16) compared to the other areas and had the highest fibre production. The high production of the Irene flock could be a possible reflection of stocking rate on fibre production. Mara had the highest number (54) of animals combed. The numbers in the other areas under investigation were between 36 and 38. There were no significant ($P<0.05$) differences between the University of Pretoria and Roodeplaat, but the animals from Delftzyl had the lowest production of fibre.

Ryder (1969) reported increased fibre yields with improved pastures. The goats from Irene and University of Pretoria were kept on cultivated pastures or natural pastures and supplemented when required. The goats from Roodeplaat received supplements around the winter season (as explained in the previous chapter). In Mara (sweet veld) and Delftzyl (mixed veld), the animals were kept under natural grazing conditions with no supplementary feeding. Animals from Delftzyl had the lowest production of fibre. These animals were kept on mixed veld which normally has a lower quality compared to sweet veld such as in Mara.

Summer & Bigham (1993) reported that fibre production was directly proportional to the herbage consumed. McGregor (1998) reported that cashmere production was insensitive to nutrition under grazing conditions, despite the fact that guard hair production was responsive.

Under severe nutritional deficiencies, animals preferentially used the available nutrition for cashmere production.

In this study, there is a possibility that nutrition due to different environments could have played a role in terms of fibre production. At Delftzyl the animals were kept on mixed veld where they were not supplemented. Their fibre production was very low, whereas supplemented animals produced more fibre. The results of this study agree with the findings of McGregor (1998). McGregor (1998) revealed that animals that were kept under natural grazing conditions had much lower fibre production than animals kept on cultivated pastures or supplemented animals. McGregor (1998) reported that energy deprived goats grew less total cashmere but diverted nutrients preferentially to cashmere growth. In contrast, goats fed to gain live weight, grew more total cashmere. The goats at Irene had the highest production of both cashmere and guard hair. These results revealed nutrients have been diverted to guard hair production where the animals have reached their maximum cashmere production (McGregor, 1998). Supplementary feeding of energy was reported not to have any significant differences in cashmere fibre yield (McGregor, 1998) however when required, supplementary feeding had significant effects. However, in cases where abundant feeding occurred, there was no need to supplement the animals. McGregor (1992) reported that there was no need to supplement the animals in areas where rainfall enabled significant pasture germination. The reason for this is that cashmere production would reach its maximum potential because the presence of green pasture enabled all goats to maintain or gain live weight.

According to Braker (1997), more fibre harvested meant more guard hair production and lesser cashmere. In this study, cashmere production yielded more than 50% of the total fibre produced, while guard hair production increased with the increase in fibre yield. Braker (1997) suggested that the longer the combing lasts, the greater the chance would be of gaining guard hair. Subsequently, the total hair yield would be greater. Also, for the reason that guard hair is heavier, the total yield would also be greater. This was found especially at the end of the combing process, where only a little cashmere combed and consistently more guard hair.

4.1.2 Reproductive status

The influences of reproductive status on fibre yield are presented in Tables 4.2, 4.3 & 4.4. The reproductive statuses of the animals are presented in three tables as explained earlier.

Table 4.2 The influence of reproductive status on total fibre, cashmere and guard hair yields of indigenous goats at Irene, University of Pretoria, Roodeplaat, Mara and Delftzyl

Reproductive Status	**Total Fibre (g)**	**Guard Hair (g)**	**Cashmere (g)**
Open (71)	31[a] (± 4.6)	7[a] (± 3.5)	20[a] (±3.4)
Pregnant (28)	30[a] (± 6.1)	4[a] (± 4.3)	23[a] (± 4.2)
Lactating (33)	31[a] (± 5.1)	8[a] (± 4.0)	20[a] (± 3.9)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.3 The influence of reproductive status on total fibre, cashmere and guard hair yields of Boer goats at Mara

Reproductive Status	**Total Fibre (g)**	**Cashmere (g)**	**Guard Hair (g)**
Open (14)	27[a] (±4.5)	23[a] (±4.1)	3[a] (0.7)
Pregnant (10)	21[a] (±4.8)	15[a] (4.4)	4[a] (0.8)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.4 The influence of reproductive status on total fibre, cashmere, and guard hair yields of savanna goats at Centurion

Reproductive Status	**Total Fibre (g)**	**Guard Hair (g)**	**Cashmere (g)**
Open (21)	16[a] (± 3.3)	7[a] (± 1.5)	13[a] (±2.5)
Pregnant (13)	17[a] (± 3.6)	7[a] (± 1.5)	11[a] (±2.5)
Lactating (3)	2[a] (± 7.9)	2[a] (± 5.3)	0[a] (± 8. 8)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

The differences in cashmere, guard hair and total fibre production were not significant between the open, pregnant and lactating goats. This is in contrast to the reports by Restall & Pattie (1989) and Zhou *et al.* (2003) of the effects of pregnancy and lactation on fibre production. Pregnancy and lactation had variable effects on fibre. Oddy and Annison (1979) & Summer and Bigham (1993) reported that the greatest fibre reduction in ewes occurred during late pregnancy and early lactation. Corbett (1979) reported that up to 10% and 12% of wool reductions were due to pregnancy and lactation respectively. Corbett (1979) also found small differences in wool production of non-pregnant ewes. Summer & Bigham (1993) suggested that the reduction in production might be due to the higher demand of nutrients for reproduction compared to wool growth. Brown, Turner, Young & Dolling, (1966) as cited by Mullaney, Brown, Young & Hyland, (1969) found a greater effect for lactation than for pregnancy. In the case of indigenous goats as presented in Table 4.2 there were 71 open females compared to 28 pregnant and 33 lactating females. The number of animals used per treatment could be having effects on the non-significant differences. The results presented in Table 4.4 show similar effects. The lactating savanna females produced very little total fibre and all of it was guard hair (see Table 4.4). Despite reports that lactation and pregnancy reduce fibre production, Table 4.3 shows no significant differences between the pregnant and lactating females. According to a report by Newman & Paterson (1992), dry females had a lower live weight and fleece weight than does weaning one or two kids. Kidding before shearing or moulting can prematurely moult the fleece or grow a lighter fleece. Kidding during the cashmere-growing season can delay the initiation of the cashmere follicles. For this reason and to prevent fibre losses, kidding should be avoided before moulting or shearing. Brown *et al.*, (1966) reported that pregnancy reduced fibre population density and length but not fibre diameter, while lactation reduced body weight and fibre diameter.

4.1.3 Gender

Tables 4.5 and 4.6 show significant differences in total fibre, guard hair, and cashmere fibre production between females and males. The males had higher fibre production compared to females. Corbett (1979) supported this and reported that, rams produce more wool than ewes. Corbett (1979), Summer & Bigham (1993) and Zhou *et al*., (2003) suggested that the high fibre yield of males may be due to the following reasons: The male's larger body size, their preferential feeding for management purposes and the direct effects of their hormonal status. Corbett (1979) also reported that the greater wool production of rams was attributable to a larger follicle population and greater staple length.

Table 4.5 The influence of gender on total fibre, cashmere and guard hair yields of indigenous goats at Irene, University of Pretoria, Roodeplaat, Mara and Delftzyl

Gender	Total Fibre (g)	Guard Hair (g)	Cashmere (g)
Females (137)	31^{b} (± 4.6)	7^{b} (± 3.5)	20^{b} (±3.4)
Males (18)	65^{a} (± 6.6)	35^{a} (±4.9)	36^{a} (± 4.9)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.6 The influence of gender on total fibre, cashmere, and guard hair yields of savanna goats at Centurion

Gender	Total Fibre (g)	Guard Hair (g)	Cashmere (g)
Females (37)	16^{b} (± 3.3)	7^{b} (± 1.5)	13^{b} (±2.5)
Males (1)	53^{a} (± 13.6)	17^{a} (± 5.2)	35^{a} (±8.6)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

According to Corbett (1979) the steroid sex hormones promote an increase in protein synthesis and androgens stimulate body growth and the gross efficiency of feed conversion to fibre while increased doses of testosterone increased wool growth rate (Summer & Bigham. 1993).

4.1.4 Age

The influence of age on fibre yield is presented in Table 4.5, 4.6 & 4.7.

Table 4.7 The influence of age on total fibre, cashmere and guard hair yields of indigenous goats from Irene, Roodeplaat, University of Pretoria and Mara

Age	**Total Fibre (g)**	**Cashmere (g)**	**Guard Hair (g)**
<1yr – 1yr (7)	37^{a} (± 7.8)	22^{a} (±6.3)	13^{a} (± 6.4)
2yr - 3yr (47)	49^{a} (± 4.5)	25^{a} (±3.2)	15^{a} (±3.2)
4yrs $^{+}$ (95)	42^{a} (±3.8)	28^{a} (±2.5)	12^{a} (± 2.6)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.8 The influence of age on total fibre, cashmere and guard hair yields of Boer goats at Mara

Age	**Total Fibre (g)**	**Cashmere (g)**	**Guard Hair (g)**
2 - 3 yrs (13)	18^{a} (±4.5)	14^{a} (±4.1)	3^{a} (±0.7)
4yrs $^{+}$ (11)	30^{a} (±4.8)	24^{a} (±4.4)	4^{a} (±0.8)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.9 The influence of age on total fibre, cashmere and guard hair yields of savanna goats at Centurion

Age	**Total Fibre (g)**	**Cashmere (g)**	**Guard Hair (g)**
<1yr – 1 yrs (19)	19[a] (± 4.7)	12[a] (± 3.6)	7[a] (± 2.2)
2yr – 3 yrs (11)	23[a] (± 5.4)	14[a] (± 4.2)	8[a] (± 2.5)
4yrs + (8)	23[a] (± 5.8)	18[a] (± 4.3)	10[a] (± 2.6)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Restall & Pattie (1989) reported significant differences in all parameters with increasing age (increasing down weight and diameter with increasing age of the animal). Tables 4.7, 4.8 & 4.9 show that age had no significant effect on goat's production of total fibre yield, cashmere and guard hair. Differences were not significant, but total fibre, guard hair, and cashmere production increased from younger to older animals. This may be due to the high nutrient requirements for growth by young animals or the variance between the body tissues and wool growth (Corbett, 1979). According to Braker (1997), cashmere production reduced but guard hair production increased with age. In the case of the indigenous goats (see Table 4.7), the oldest animals (four years and above) had the lowest guard hair production compared to the animals in the other age groups. The differences in production were however not significant. Corbett (1979), Litherland (Unpublished) and Summer & Bigham (1993) reported that fleece weights showed a tendency to increase to a maximum at the age of three to four years, but to decline thereafter. Reductions in wool growth with age could be related to changing patterns of feed intake and diet selection (Reis, 1979).

4.1.5 Colour

Table 4.10 presents the influence of colour on total fibre, cashmere and guard hair. White animals produced significantly high total fibre and cashmere compared to other animal colours. The total yield of the white indigenous goats ranged between 4.914 - 185 g / annum while the production range of other colours was between 0 - 60g / annum. The multi-coloured goats produced very little or nothing at all as presented in Table 4.10. The difference in guard hair yield between all the animals was not significant.

Table 4.10 The influence of colour on total fibre, cashmere and guard hair yields of indigenous goats

Colour	**Total Fibre (g)**	**Cashmere (g)**	**Guard Hair (g)**
Black (16)	23^{b} (± 5.4)	16^{b} (± 4.2)	10^{a} (± 4.2)
White (2)	88^{a} (± 13.1)	54^{a} (± 8.5)	24^{a} (± 8.6)
Brown (13)	24^{b} (± 5.7)	16^{b} (± 4.4)	11^{a} (± 4.5)
Multi-coloured (124)	22^{b} (± 2.8)	13^{b} (±2.2)	9^{a} (± 2.3)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

These results contradict the findings of Devendra and Burns (1976) & Couchman & McGregor (1983), who reported insignificant differences in fibre production between white goats and black goats from the same flock, with coloured goats producing more fibre compared to the white goats. The results of this study cannot be warranted, because the high yield of the white goats was the result of only four male goats with the highest fibre yield. The high yield of the white animals can be advantageous since white fibre is the most desirable colour, as it provides good and variable colours at dyeing.

4.1.6 Breed

Differences in production potential may occur in animal breeds, even though they are kept under the same environmental conditions as shown in Table 4.11 below.

Table 4.11 The influence of breed on total fibre, cashmere and guard hair yields of indigenous and Boer goats at Mara

Breed	**Total Fibre (g)**	**Cashmere (g)**	**Guard Hair (g)**
Indigenous (28)	19^{b} (±2.5)	8^{b} (±2.5)	1^{b} (± 0.4)
Boer (24)	24^{a} (±2.6)	18^{a} (±2.4)	3^{a} (± 0.4)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

The Boer goats produced significantly more total fibre, cashmere and guard hair compared to the indigenous goats. This may be due to their larger body size compared to the smaller size of the indigenous goats. The results of De Villiers *et al.*, (2000) contradicts the findings of this study where it was reported that indigenous goats in small-scale communal systems had the highest yield of cashmere, while the Boer goats in commercial systems had the lowest yield. The possible cause of the low yields of the Boer goats in the commercial systems could be that, according to the Boer Goat Society the hair of the goats should be fairly short and smooth with a good gloss. In winter a little down is acceptable. This selection against woolliness could be the cause of the decrease in the natural cashmere producing ability of the Boer goats (Cashmere Working Group, 1998).

Table 4.12 shows that the effects of interaction between age and breed also influenced fibre production. The Boer goats aged four years and above, produced significantly (P<0.05) more fibre than those aged two to three years as well as all the indigenous goats (two to three years or four years and above). The differences between old and young indigenous goats were however not significant (P>0.05). Boer goats of the age group two to three years produced more fibre compared to indigenous goats at any age. This shows that Boer goats generally have higher fibre production than indigenous goats, irrespective of their age group.

Table 4.12 The effects of interaction between age and breed on total fibre, cashmere and guard hair yields of indigenous and Boer goats

Breed	**Age**	**Total (g)**
Indigenous (15)	**2 - 3 yrs**	10^{b} (± 3.4)
Indigenous (13)	**4yrs** $^{+}$	8^{b} (± 3.8)
Boer goats (13)	**2 - 3 yrs**	18^{b} (± 3.5)
Boer Goats (11)	**4yrs** $^{+}$	29^{a} (± 3.8)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

4.2 The influence of environmental factors on fibre quality and the comparison between the VIA and OFDA techniques

4.2.1 Environmental factors influencing fibre quality

4.2.1.1 Location

The influences of location on fibre quality are presented in Table 4.13.

Table 4.13 The influence of location on cashmere and guard hair diameter of indigenous goat using the VIA technique

Location	**Cashmere diameter (µm) by VIA**	**Guard Hair diameter (µm) by VIA**
Irene (18)	11^{a} (±0.3)	69^{a} (±3.6)
University of Pretoria (35)	10^{b} (±0.2)	57^{b} (±2.6)
Roodeplaat (36)	9^{c} (±0.2)	61^{b} (±2.9)
Delftzyl (38)	9^{c} (±0.2)	59^{b} (±2.8)
Mara (28)	10^{b} (±0.2)	60^{b} (±3.1)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

There were significant differences in cashmere diameter due to location. These differences were not significant on guard hair diameter (excluding the animals from the Irene flock). There were no differences in cashmere fibre diameter between the animals from the University of Pretoria and Mara and between those from Roodeplaat and Delftzyl. There were no significant differences in guard hair diameter from the other areas. The differences in fibre diameter can be associated with nutrition and general management, as fibre diameter increased with improved nutrition (McGregor & Umar, 2000). According to Russel (1992), low levels of nutrition reduced fibre diameter. The conditions, under which the animals were kept, differed. In addition, the type of management that they were kept under (e.g. feeding) also differed. The coarser cashmere and guard hair fibre diameters of the animals from Irene illustrated the effects of a higher level of nutrition on fibre diameter.

4.2.1.2 Reproductive status

The influences of reproductive status on fibre diameter are presented on Tables 4.14 to 4.16.

Table 4.14 The influence of reproductive status on cashmere and guard hair diameter of indigenous goats using the VIA technique

Reproductive Status	**Cashmere diameter (μm) by VIA**	**Guard hair diameter (μm) by VIA**
Open (71)	9[a] (±0.2)	62 [a] (±2.4)
Pregnant (28)	10[a] (±0.2)	65[a] (±3.2)
Lactating (33)	9[a] (±0.2)	57[b] (±2.7)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.15 The influence of reproductive status on cashmere and guard hair diameter of savanna goats using the VIA technique

Reproductive Status	**Cashmere diameter (μm) by VIA**	**Guard hair diameter (μm) by VIA**
Open (21)	11^{a} (± 0.2)	62^{a} (±1.9)
Pregnant (13)	11^{a} (± 0.3)	70^{bc} (±2.1)
Lactating (3)	12^{a} (± 0.6)	71^{ac} (±4.6)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.16 The influence of reproductive status on cashmere and guard hair diameter of Boer goats using the VIA technique

Reproductive Status	**Cashmere diameter (μm) by VIA**	**Guard hair diameter (μm) by VIA**
Open (14)	12^{a} (± 0.1)	71^{a} (±2.3)
Pregnant (10)	11^{a} (± 0.2)	68^{a} (±2.4)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.14 shows non-significant differences in cashmere diameters between all the indigenous goat females (open, pregnant and lactating). This is in view of the fact that the pregnant females tend to gain weight during pregnancy while the lactating females need more nutrients for milk production and most probably losing weight. According to the results of Restall & Pattie (1989), the reproductive status of the female did not have any effects on cashmere fibre diameter. The guard hair diameter of the lactating goats differed significantly (P<0.05) from that of the open and pregnant females. The difference may be due to the high nutrient requirements for milk production.

Table 4.15 shows non-significant (P>0.05) differences in cashmere fibre diameter of savanna females irrespective of reproductive status. The guard hair diameter of the open females differed significantly from that of the pregnant females but did not differ from that of the lactating females. The reduced wool growth indicated a higher demand for nutrients associated with reproduction compared with wool growth (Summer & Bigham. 1993).

Table 4.16 shows non-significant differences due to reproductive status (P>0.05) in cashmere and guard hair diameters of the Boer goats in Mara.

The above three tables generally show non-significant differences in cashmere diameter of open and pregnant females. The reason for this may be that the pregnant females tend to gain a lot of weight during pregnancy. Table 4.14 and Table 4.15 show significant differences in guard hair diameter between lactating and pregnant and open females. The reason for this could be that the pregnant females are gaining a lot of weight and the open females do not have a lot of nutrient requirements, whereas the lactating females have got a lot of nutrient requirements for lactation.

4.2.1.3 Gender

The influences of gender on fibre diameter are presented on Tables 4.17 and 4.18.

Table 4.17 The influence of gender on cashmere and guard hair diameter of indigenous goats using the VIA technique

Gender	**Cashmere diameter (μm) by VIA**	**Guard hair diameter (μm) by VIA**
Females (137)	10^a (±0.2)	62^a (±2.4)
Males (18)	11^b (±0.3)	62^a (±3.5)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.18 The influence of gender on cashmere and guard hair diameter of savanna goats in Centurion using the VIA technique

Gender	**Cashmere diameter (μm) by VIA**	**Guard hair diameter (μm) by VIA**
Females (37)	11[a] (± 0.2)	63[a] (±1.9)
Males (1)	13[a] (± 1.1)	88[b] (±7.9)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

At Mara there were no males, therefore there was no comparison between males and females. Table 4.17 shows that there were no significant (P>0.05) differences in guard hair diameters of the males and females. There were however significant differences (P<0.05) in the cashmere diameter of males and females from Irene, University of Pretoria, Roodeplaat and Delftzyl. Table 4.18 shows that the cashmere diameters of savanna females did not differ significantly from that of males, whereas guard hair diameters differed significantly (P<0.05). A possible reason for this was that the savanna goats had sufficient nutrients for fibre production. These differences may however also be due to general management factors (as explained in Chapter 3). The other possible reasons for these differences may be that there were only a few male animals compared to the number of females in this study. No really significant conclusions can be made due to only one male being used for this analysis in Table 4.18.

Braker (1997) found that female guard hair was coarser than that of the males and that there is a large variation between cashmere and guard hair of females compared to that of males. There is not much variation in guard hair and cashmere diameter of males and females in this study. The large differences between guard hair and cashmere diameters could ease the separation using the Shirley Analyzer method. This may benefit the goat farmers, whose flock most probably largely exists of female indigenous goats. In research done by Corbett (1979), no significant differences were found in fibre diameter between rams and ewes, although the fibre diameter of rams was slightly higher.

4.2.1.4 Age

The following tables 4.19, 4.20 and 4.21 present the effects of age on fibre diameter.

Table 4.19 The influence of age on cashmere and guard hair diameter of indigenous goat using the VIA technique

Age	Cashmere diameter (μm) by VIA	Guard hair diameter (μm) by VIA
<1yr – 1yr (7)	9[b] (± 0.3)	57[a] (±4.2)
2yrs - 3yrs (47)	10[a] (± 0.2)	64[a] (±2.4)
4yrs + (94)	10[a] (±0.1)	64[a] (±2.0)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.20 The influence of age on cashmere and guard hair diameter in savanna goats using the VIA technique

Age	Cashmere diameter (μm) by VIA	Guard hair diameter (μm) by VIA
<1yr – 1yr (19)	11[a] (± 0.4)	70[a] (±2.7)
2yrs - 3yrs (11)	12[a] (± 0.4)	76[a] (±3.1)
4yrs + (8)	12[a] (± 0.5)	72[a] (±3.4)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.21 The influence of age on cashmere and guard hair diameter of Boer goats using the VIA technique

Age	Cashmere diameter (μm) by VIA	Guard hair diameter (μm) by VIA
2yrs - 3yrs (13)	12[a] (± 0.1)	69[a] (±2.3)
4yrs + (11)	11[a] (± 0.2)	70[a] (±2.4)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Ryder & Stephenson (1968) reported that fibre diameter increased with age. The results in Table 4.19, 4.20 & 4.21 show that age had no significant difference on guard hair and cashmere diameter in the different age groups. Table 4.20 shows that the guard hair diameter of the age group four years and above was the finest, although the diameters did not differ significantly in this experiment. The cashmere diameters did not differ significantly between age groups, except in indigenous goats of one year old and younger. These animals produced the finest cashmere compared to the other age groups. In younger animals, guard hair was finer (analyzed by VIA). In young animals, this may indicate that their guard hair and guard hair follicles have not completely matured, which means that the medulla had not thickened yet (Reis, 1979).

4.2.1.5 Colour

The influence of colour on fibre diameter is presented on Table 4.22.

Table 4.22 The influence of colour on cashmere and guard hair diameters of indigenous goats using the VIA technique

Colour	Cashmere diameter (μm) by VIA	Guard hair diameter (μm) by VIA
Black (16)	10[a] (±0.2)	52[b] (± 2.9)
White (2)	10[a] (±0.6)	72[a] (± 7.0)
Brown (13)	9[a] (±0.2)	62[ac] (±3.1)
Multi-coloured (124)	10[a] (±0.1)	58[bc] (±1.5)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.22 shows that colour did not have any significant effects on cashmere fibre diameter. There were also no significant differences in guard hair diameter between the white, brown and multi coloured goats, whereas black goats produced significantly the finest guard hair. These findings are inline with those of Braker, 1997. The reason for this may be due to the fact that black animals are adapted to extremely cold environments as they are producing the finest fibre, compared to those from hotter environments (Summer & Bigham, 1992).

4.2.1.6 Breed

The influence of breed on fibre diameter is presented in Table 4.23.

Table 4.23 The influence of breed on cashmere and guard hair diameter using the VIA technique

Breed	Cashmere diameter (μm) by VIA	Guard hair diameter (μm) by VIA
Indigenous (28)	10 [b] (± 0.1)	63[b] (±1.6)
Boer goat (24)	12[a] (± 0.1)	69[a] (±1.1.7)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.23 shows significant differences in cashmere and guard hair diameter between the indigenous and the Boer goats. The cashmere and guard hair diameter of the Boer goats was thicker than those of indigenous goats. Braker (1997) revealed that the indigenous goats produced finer cashmere and coarser guard hair than the Boer goats. The finer diameter of the cashmere fibre of the indigenous goats would benefit goat farmers, as their flocks are mostly comprised of such animals.

4.2.2 Comparison between the OFDA and the VIA techniques

The OFDA and the VIA techniques were used to evaluate fibre diameters of cashmere and guard hair. The diameters presented on Tables 4.13 – 4.23 are the results of the VIA technique. This technique was chosen because it resulted in more precise results. Tables 4.24 and 4.25 below show the differences in fibre diameters of cashmere and guard hair fibres while utilizing the two techniques. From these tables it is clear that the diameters measured by the VIA technique were always finer than the diameters measured by the OFDA technique.

Table 4.24 The influence of location on guard hair of indigenous goats using the VIA and OFDA techniques

Location	**Guard hair diameter (um) by VIA**	**Guard hair diameter (um) by OFDA**
Irene (18)	69[a] (3.6)	89[a] (5.7)
University of Pretoria (35)	58[b] (2.6)	89[a] (4.5)
Roodeplaat (36)	62[b] (2.9)	95[a] (4.7)
Delftzyl (38)	60[b] (2.8)	89[a] (5.7)
Mara (28)	60[b] (3.1)	85[a] (5.3)

[abc] Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Table 4.25 The influence of location on cashmere diameter of indigenous goats using the VIA and OFDA techniques

Location	**Cashmere diameter (um) by VIA**	**Cashmere diameter (um) by OFDA**
Irene (18)	12^{a} (0.3)	17^{a} (0.9)
University of Pretoria (35)	10^{b} (0.2)	14^{bc} (0.7)
Roodeplaat (36)	9^{c} (0.2)	14^{bc} (0.7)
Delftzyl (38)	9^{c} (0.2)	15^{bc} (0.9)
Mara (28)	10^{b} (0.2)	15^{ac} (0.8)

^{abc} Column means with common superscripts do not differ significantly (P>0.05)

(±) = Standard error

Figures 4 & 5 show the relationship between cashmere and guard hair diameters using the VIA and the OFDA techniques. The regression coefficient between the OFDA and VIA techniques was very low (for cashmere fibre r^2 = 27.1 and for guard hair r^2 = 16.0). The regression coefficient values show that there was a poor correlation between the two techniques. The slope in Figure 4 shows that for every µm increase in the cashmere diameter by the VIA, the cashmere diameter by the OFDA increased by 0.949. This value approaches 1 and thus shows that there is almost a 1:1 relationship between these techniques for cashmere fibre. The guard hair diameter and cashmere diameters measured by the OFDA were on average 27 µm and 5 µm coarser than those measured by the VIA technique.

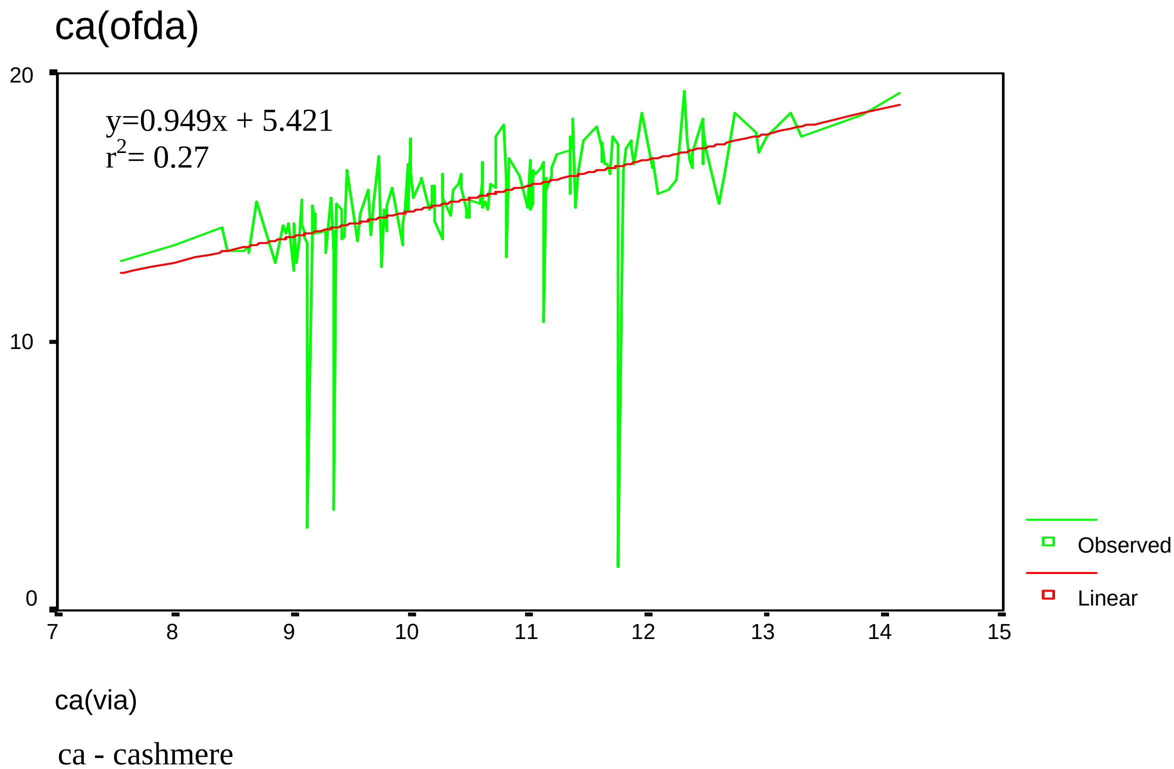
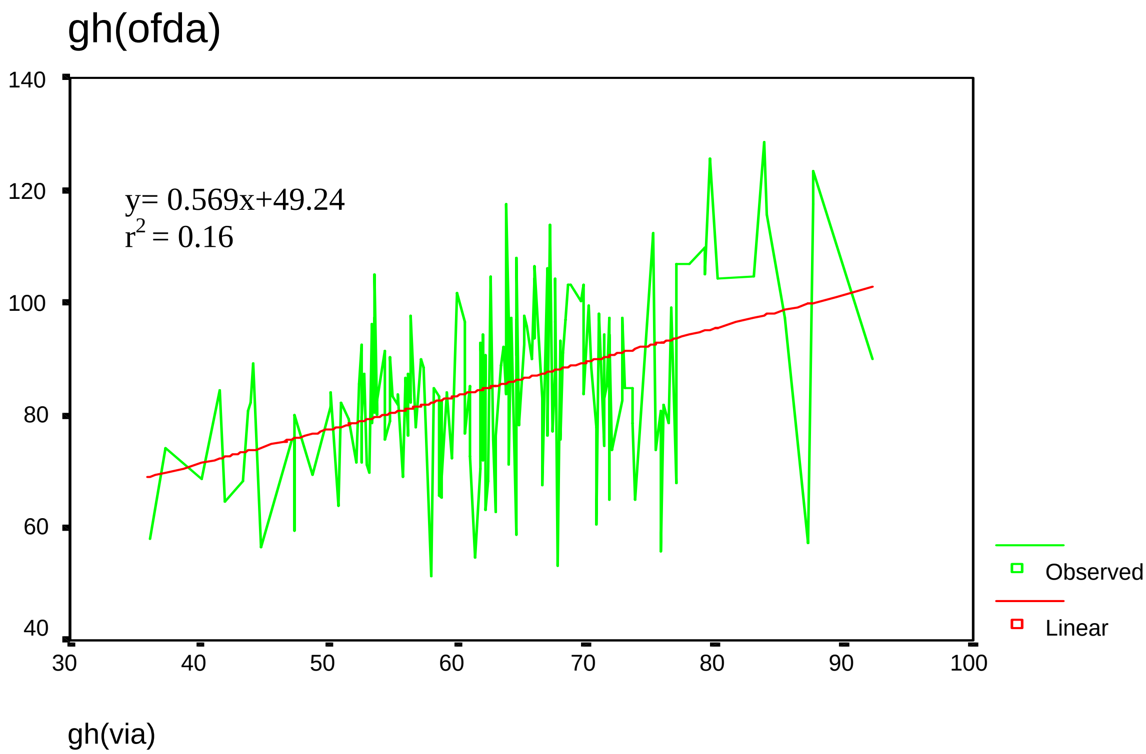


Figure 4 Comparison of the cashmere diameters measured by the VIA and OFDA techniques

Figure 5 shows a large variation between the guard hair values by the OFDA and the VIA techniques, hence the low r^2 value. The OFDA method may however produce several inaccuracies, since by this method, the computer does the measurements (a total of 3000) and determines according to the predetermined criteria (for fibre diameter and fibre diameter distribution) which fibres should be taken as cashmere and which as guard hair. When predetermined criteria are used, no leeway is allowed. The result is that there will be hairs that the computer cannot differentiate between and these will probably be ignored. It is therefore possible that the pre-determined parameters set on the OFDA may have considered finer guard hair as cashmere. There is also the possibility that the finer guard hair was not measured because of this lack of differentiation, thus resulting in incorrect data.



gh - guard hair

Figure 5 Comparison of the guard hair diameters using the VIA and OFDA techniques.

With the OFDA technique it is not necessary to dehair the fibre. A minimum sample size of 3 g was necessary for analysis of clean cashmere yield and fibre analysis by the OFDA method. Unfortunately some animals did not produce enough hair for this analysis. On the other hand, with the VIA, sample size is not critical, a sample of any size was analyzed. However with the VIA method, 20 measurements of each hair type are made manually. According to this method, one may determine to which category the hair belongs, by viewing the features of the hair. This will determine the difference between cashmere and guard hair.

Since it is a portable machine, the OFDA may be used in the field in cases where a researcher would require immediate results. The VIA may be used in the laboratory where accurate and precise results are required. According to Stanford *et al*., (1998) the VIA shows potential as an objective, accurate, yet cost-effective method.

CHAPTER 5

Summary, recommendations and conclusion

5.1 Summary

The different environmental and physiological conditions showed varying effects on the quality and quantity of cashmere fibre. Location showed significant (P<0.05) effects on cashmere fibre yield and diameter of the goats. Breed has also shown significant (P<0.05) effects on cashmere production whereby the Boer goats produced more fibre that was coarser than the fine fibre produced by the indigenous goats. The savanna goats also produced fine fibre. Age did not show any significant (P>0.05) effects on cashmere production. Fibre production differed between genders: The males produced significantly (P<0.05) more and coarser fibre than the females. This may be advantageous since most of the flocks are generally made up of females. Reproductive status did not show any significant (P>0.05) effects on cashmere production. The lactating animals yielded less cashmere than the pregnant animals. Colour had a significant (P<0.05) effect on fibre quantity and quality. White goats produced more cashmere fibre that was coarser than coloured animals. There were differences in guard hair fibre diameter between the animal colours. A comparison between the VIA and the OFDA techniques revealed that fibre diameters measured by the OFDA were coarser than those measured by the VIA technique.

5.2 Recommendations

If further research is to be carried out, the following recommendations should receive greater attention:

- Harvesting the cashmere at the beginning of and within the shedding season (July to September) will reduce fibre loss.
- All animals should preferably be combed at the same time throughout the combing season.
- Selection from big flocks should be considered to ensure a wider variety of animals.

- More attention should be given on the influence of gender, reproductive status and the age of the animals.
- Interactions such as breed and gender, colour and gender, age and reproductive status, and other possible interactions, should be researched to compare the different effects.
- The relationship between guard hair and cashmere diameters should be investigated (using both the VIA and OFDA techniques) to determine the relationship between the different fibres.
- The low cashmere yields of the indigenous goats should be improved through breeding and selection.

5.3 Conclusions

The indigenous goats of South Africa produced cashmere fibre of good quality and South African environmental conditions are suitable for cashmere production. The indigenous goats produced low quantities of fibre. According to the finding of this study the VIA technique seems to have resulted to more precise results. This study shows that goats can be an alternative financial investment for farmers.

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