DATABASE AND GUIDE FOR LESOTHO WOOL AND MOHAIR PRODUCTION AND QUALITY

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DATABASE AND GUIDE FOR LESOTHO WOOL AND MOHAIR PRODUCTION AND QUALITY

By

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DECLARATION

I, Papali Elizabeth Maqalika (student number: 211052086) hereby declare that the thesis for Philosophy Doctor (PhD) in Textile Science is my own work and that it has not been previously submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

Papali Elizabeth Maqalika

DEDICATIONS

I dedicate this piece of work to my family, my children (Thabelo, Ts'episo and Mpho) who endured a time without the physical and emotional presence of a mother as I pursued my studies, to my late father (Ntàte Lephoto Maqalika) whose dream has always been seeing his children advance academically. To my mother ('M'e 'Mamohapi Maqalika) who believed in me at all costs even when I lost faith in myself and for the unwavering trust in my abilities and unfailing support.

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ABSTRACT

Lesotho produces significant quantities of Merino apparel wool and mohair, both of a quality that allows them to compete on the global market and to make a significant contribution to the economy of the country. Nevertheless, very little production and quality data and trends of these fibres have been documented. This is a serious disadvantage in terms of international trading and benchmarking as well as attempts to improve the production and quality of Lesotho wool and mohair.

In the light of the aforementioned, the available production and quality data of the past 10 years have been captured and analysed for trends and also benchmarking, where considered applicable. The main focus is on fibre diameter (fineness), staple length, and yield since they largely determine fibre quality, application and price. Some quality related tests were undertaken to fill certain important gaps in the available data. In addition, prickle and medullation were evaluated on representative wool and mohair samples, respectively, because they represent important quality measures for apparel wool and mohair, respectively.

It was found that Lesotho wool and mohair are of a fairly good and internationally competitive quality, with the wool having an average fibre diameter (MFD) of ≈20μm, an average staple length of about 64mm, an average VM level of about 4%, an average yield of about 57%, and the annual production being about 4 million kilograms greasy. The average staple length of the mohair was about 140mm, average MFD about 29μm and the average medullation, which unless otherwise specified, refers to the objectionable medullated fibres (kemp type) including the flat medullated fibre, relatively high at about 5.7%. The latter is certainly an area of concern which needs attention and improvement.

It was found that the prickle level (Comfort Factor), of some of the wools tested was of such a level as to make the wool suitable for wearing against the skin. With respect to mohair, there is considerable scope to substantially reduce the level of objectionable medullated (kemp style) fibre level through the appropriate breeding interventions.

Production of both wool and mohair has increased slightly over the ten years covered by this study. It also became apparent that Lesotho wool and mohair quality and production are greatly influenced by the farming practices and climatic conditions. Greater adoption of the merino sheep breed, sheds/barns and sheep coats are suggested as ways to reduce mortality rate (due to extremely cold temperatures), improve quality and increase yield and production. Some farming practices such as the lack of barns, supplementary feeding and veterinary care present constraints in terms of production of both wool and mohair. The districts in the Highlands region had the highest production of mostly wool, this being ascribed to better pastures, climatic and other conditions conducive to wool and mohair production.

Both wool and mohair are considered to have potential for improved quality and production, which could be affected by appropriate interventions by the Small Agricultural and Development Project (SADP) and others through National Wool and Mohair Growers Association (NWMGA). Nevertheless, since the wool and mohair growers (farmers) do not form part of these and other interventions, they do not readily adopt the various strategies and decisions and do not receive the associated benefits immediately. It is therefore advised that local farmers, relevant educators and researchers be represented in policy and other decision making forums. In this way, educational campaigns will be demand driven with greater chance of adoption and success.

Key word: Lesotho, wool, mohair, prickle, medullation, wool quality, mohair quality, objectionable medullated fibres, wool production, mohair production.

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ACRONYM	MEANING
AGOA	African Growth and Opportunity Act
ASIA	American Sheep Industry Association
ASTM	American Society of Testing Materials
ATLAS	Automatic Tester for Length and Strength
AWTA	Australian Wool Testing Authority
AWI	Australian Wool Innovation
AWEX	Australian Wool Exchange Ltd.
BOS	Bureau of Statistics (Lesotho)
BKB	Boeremaklaars Koöperatief Beperk
CE	Coarse Edge
CF	Comfort Factor
CFW	Clean Fleece Weight
CRC	Cooperative Research Centre
CSIR	Council for Scientific and Industrial Research
CSIRO	Common Wealth Scientific and Industrial Research Orgarnisation
CV	Coefficient of Variation
CVD	Coefficient of Variation of Diameter
CWSA	Cape Wools South Africa
FD	Fibre Diameter
FFLwt	Fleece Free Live Weight (In kilograms)
FNF	Free, Nearly Free (Wool free from vegetable matter/fault)
IFAD	International Fund for Agricultural Development
IWTO	International Wool Textile Organization
KES	Kawabata Evaluation System
LDC	Least Developed Country
LED	Light Emitting Diode
LENA	Lesotho News Agency
LPMS	Livestock Product Marketing System
LNDC	Lesotho National Develoment Cooperation
MFD	Mean Fibre Diameter (μm)
NAMC	National Agricultural Marketing Council

NIR	Near Infrared
NIRA	Near Infrared Analysis
NIRS	Near Infrared Spectrophotometer
NUL	National University of Lesotho
NWMGA	National Wool and Mohair Growers Association of Lesotho
OFDA	Optical Fibre Diameter Analiser
RI	Refractive Index
RSPCA	Royal Society for the Prevention of Cruelty To Animals
SADP	Small Agricultural Development Project
SARDI	South Australian Research and Development Institute
SAWB	South African Wool Board
SAWTRI	South African Wool and Textile Research Institute
SD	Standard Deviation
SL	Staple Length
S/P	Secondary to Primary follicle ratio
SS	Staple Strength
TF	Tightness Factor
SGS	Société Générale de Surveillance *(French for General Society of Surveillance)*
VMB	Vegetable Matter Base
VOM	Visually Objectionable Medullated *(fibres)*
WB	Wool Base
WCM	Wool Comfort Meter
WRONZ	Wool Research Organization of New Zealand
WTAE	Wool Testing Authority of Europe

Contextual Definition of Terms

1. *Accuracy:* Refers to a measure of the closeness of a test result to the value. The difference between accuracy and precision should be noted.
2. *Beneficiation*: To add value by processing the raw materials into products that can serve a purpose or address a need/problem.

3. *Bias:* a constant or systematic difference between a true value and corresponding test results.
4. *Brightness*: Aspect of visual perception, whereby an area appears to emit more or less light.
5. *Coarse edge CE:* The percentage of fibres with diameter greater than 30µm.
6. *Coefficient of Variation of fibre diameter (CVD):* This is a measure of variation in diameter measurement along and between individual fibres, relative to the average (or mean) fibre diameter. CVD is calculated by dividing SD of the diameter by MFD then multiplying by 100 to express as a percentage. CVD allows comparison of the variability of samples that differ in fibre diameter.
7. *Confidence limits:* An expression of the precision of the mean of a set of values usually associated with the stated probability, most often 95%. It is the interval around the mean within which, with the stated probability, the true value is expected to lie.
8. *Consumer panel*: A panel of judges selected from the public according to the demographics necessary to a given product usage.
9. *Core sampling:* A process of sampling, where a representative sample of raw wool is drawn from each bale in the lot by a coring technique.
10. *Core test*: The series of measurements, typically of wool base, vegetable matter base and mean fibre diameter; carried out on core samples.
11. *Distribution:* Usually expressed in the form of a frequency table or histogram, with data grouped into classes of, for example 1µm size, and integer micro-metre values as midpoints of the class intervals.
12. *Fibre curvature:* The average amount of curvature measured over a 0.2mm length for fibre snippet presented to the OFDA for example. The units of measurement are degrees per millimetre (deg/mm). The Sirolan Laserscan uses a different measurement principle but provides average curvature measurements in the same units as the OFDA.
13. *Flat medullated fibres:* Fibres of opacity less than 80% which produce a wide light band (> 40 micrometers) under dark field illumination, and which have a diameter greater than 60 µm.
14. *Gare Fibres:* Coarse fibres deficient of crimp, found within the crotch area of an animal
15. *Grab sample:* A sample taken from within a bale of wool by a mechanically driven jaw sampling device.

16. *Harris Tweed:* Is a hand-woven cloth processed by islanders at their homes in the Outer Hebrides of Scotland, finished in the Outer Hebrides, and made from pure virgin wool dyed and spun in the Outer Hebrides
17. *Hauteur (H, mm):* Is the mean length biased by cross-section (linear density) of the fibres. Combed wool (i.e. tops) is usually measured for mean fibre length in terms of Hauteur.
18. *Hedonic Scale:* A scale with which judges indicate the extent of their like or dislike for a particular sensory characteristics of a given product.
19. *Heterotypic hair/fibre*: Coarse crimp-less medullated fibres with a fragmented medulla.
20. *Haze*: In reflection, scattering of light at the glossy surface of the specimen responsible for the apparent reduction in contrast of objects viewed by reflection at the surface.
21. *Hogget*: Approximately 12-18 month old sheep. Regarded as the first fleece from young sheep/lambs commonly known as hogget wool in Australia.
22. *Intensity (of light):* The amplitude of the light vibration. The higher the amplitude of light vibration, the more intense the light is.
23. *Kemp*: An extreme case of medullation, where the medulla diameter is almost the same size as the fibre diameter, highly objectionable. Sometimes defined as when the medulla diameter to fibre diameter ratio equals 0.6 or more.
24. *Lanolin*: A common ingredient in most cosmetic applications, it is a secretion from a sebaceous gland of a sheep known as wool grease.
25. *Lock*: Short clump of wool that tends to stick together after shearing, it is sometimes referred to as a staple
26. *Lustre*: The smooth appearance characteristic of surface (usually flat) that reflects more in some directions than it does in other directions, but not of such high gloss as to form a clear mirror image. It is a preferred characteristic of fibres like mohair.
27. *Mean fibre diameter: (MFD)* Arithmetic mean of all fibre diameter readings in a sample.
28. *Medullation:* Medullated fibres which contain internal cells filled with air; these medullae may be continuous, interrupted or fragmented. These fibres are of a lower density than normal (i.e. solid) fibres; they tend to be coarser than non-medullated (solid) fibres, the medulla diameter tends to increase as the fibre diameter increases, there also being a tendency for the number of medullated fibres to increase as the coefficient of variation of diameter (CVD) increases. Medullated fibres are objectionable in clothing but desirable in carpets.

29. *Med Ratio (MD/FD)*: The ratio of the medulla diameter (MD) to the fibre diameter (FD) See Figure 2

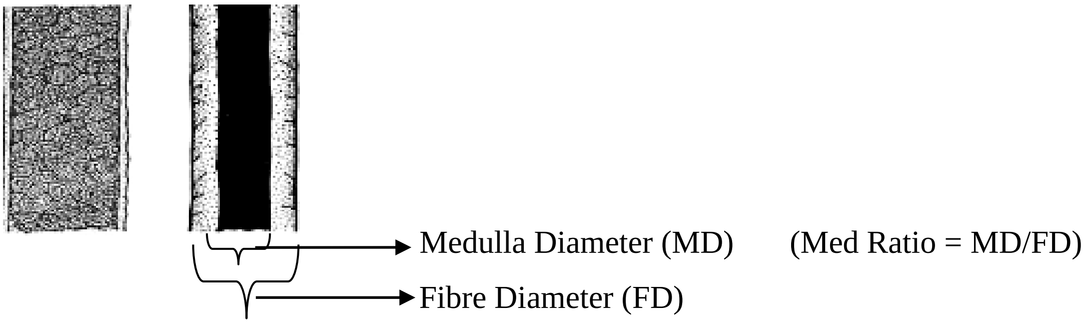


Figure 2: Illustration of Med Ratio (developed from Balasingam and Mahar, 2005)

30. *Mulesing*: A surgical process of removing strips of wool-bearing skin from around the breech of a sheep to prevent flystrike (myiasis). The wool around the buttocks can retain faeces and urine which attract flies (RSPCA Australia Knowledgebase, 2017)
31. *Neps:* One or more fibres occurring in a tangled and unorganized mass.
32. *Noil:* The short fibres removed in combing, applied particularly to wool and mohair but also to other fibres, such as cotton, silk and rayon.
33. *Objectionable Fibres:* Fibres that are not preferred in a given fleece or clip due to their characteristics that alter the behaviour of the clip negatively, e.g. medullated fibres.
34. *Objectionable Medullated Fibres:* Fibres having an opacity equal to, or greater than, 94% and a diameter greater than 25 micrometres.
35. *Opacity:* According to the IWTO definition, and as mounted on an OFDA. The ability of a specimen/fibre to transmit light, and is determined by the fibre's shape, internal structure, colour and surface quality. In white animal fibres, the main cause of opacity is medullation (hollow fibres).
36. *Oven-dry mass:* The mass of material obtained by scouring a sample and exposing it to air at 105^{o}C until equilibrium is reached, and corrected for the moisture content of the drying air.
37. *Overgrown:* Any wool shorn after 12months of uninterrupted growth.
38. *Position of break (POB)*: An indication of where a staple breaks during extension, determined by, for example, comparing the masses of the clean wool in the two broken portions of the staple. It does not imply that a break or tenderness exists in the staple.
39. *Polymodal nociceptors:* A group of skin receptors which respond to potentially skin-damaging mechanical, thermal and chemical external stimuli.

40. *Prickle:* An unpleasant sensation which evokes the desire to scratch similar to itch.
41. *Ranking Test:* A difference preference test in which more than two samples are presented for assessment and all of the samples are compared by ranking them from the lowest to the highest, this is done based on the intensity of a specific characteristic.
42. *Sensation:* A physical response or perception resulting from something that happens to, or comes into contact with the body.
43. *Sensory Evaluation:* A scientific measurement method of product quality based on sensory characteristics as perceived by the five senses.
44. *Singeing* : A process of burning protruding fibres from a textile structure. In this process the loose fibres that are not firmly bound into the yarn or fabric structure, the loose yarns that are not firmly bound into the fabric, and the protruding fibre ends sticking out of the textile yarns and/or fabric, are burned off (Hussain, 2008).
45. *Skirted fleece.* A fleece from which the belly, britches, and stained portions have been removed.
46. *Standard Deviation* (SD)*:* A statistical measure of dispersion of individual results.
47. *Stratum corneum:* This the outermost layer of the skin dermis, it is from this surface that sensation and pain are felt, since the receptors are situated just beneath this layer.
48. *Style:* Defined according to Australian AWEX-ID, refers to the wool quality. The lower the number the higher the quality, the numbers are defined as follows:
    1) *Choice*
    2) *Best Spinners*
    3) *Spinners*
    4) *Best*
    5) *Good*
    6) *Average*
    7) *Inferior*
49. *Suint:* A complex combination of natural grease found in raw sheep's wool, formed particularly from dried perspiration
50. *Vegetable matter base (VMB %):* Is the oven-dry mass of ash-free ethanol-extractive-free burrs (including hard heads), twigs, seeds, leaves and grasses present, expressed as a percentage of the dry mass of the sample.
51. *Velour:* A thick fabric with pile similar to velvet, often used for clothing and uphostry construction.

52. *Wool Base (WB %):* The oven-dry mass of wool fibre free from all impurities, i.e. ash free from ethanol extractives and all vegetable matter and other alkali-insoluble impurities, expressed as a percentage of the dry mass of the sample.
53. *Yarn Count:* A number indicating mass per unit length or length per unit mass of yarn.

CHAPTER 1

1. SCOPE AND MOTIVATION OF THE STUDY

1.1 THE SCOPE

The textile and clothing industries in Lesotho, play an important role in the employment and economy of the country, notably since the early to mid-2000s (Bennett, 2011 and Lesotho news Agency, 2014). In 2012-2013 this sector accounted for some 21% of the gross domestic product (GDP) of Lesotho, being Lesotho's biggest private employer, with the highest number of jobs being generated in 2006 (Clayton, 2013). Over the ten years; since 2006, the Lesotho textile industry and the clothing sector grew from being a marginal contributor to the economy to a globally integrated industry, assembling garments for some of the best-known brands in the world. The integration into the global economy was largely built on the preferential trade opportunities created by the US Growth & Opportunity Act (AGOA) and a partnership between the government and the private sector (Lesotho Textile Exporters Association, 2009). Currently the textile and clothing sub sector shows only a slight growth in employment.

Lesotho wool, produced solely from merino sheep and mohair produced from Angora goats as a national recommendation are key players within the textile and clothing sector of the manufacturing industry into which they are grouped. Alone, these two fibres accounted for some 26% of the income and employment in this sector for 2017. According to the Lesotho Review (2018), wool and mohair are major income earners for Lesotho, and have considerable potential for expansion.

Despite the contribution made by wool and mohair to the Lesotho economy, little, and generally only very superficial, technical and scientific data and information are available in terms of their production and quality, and associated trends. Although some research has been directed towards production improvement, little attention has been given to fibre quality, consumption and marketing. Information and knowledge dealing with the quality of Lesotho wool and mohair are virtually non-existent, incomplete or outdated, and do not represent a clear and up-to-date picture of these two main agricultural export products. For this reason, the quality and quality trends, as well as possible areas of improvement are not easy to establish for Lesotho wool and mohair. An appropriate database is one of the tools required for accurate production and quality forecasting and improvement. In this respect, Lesotho lags far behind other leading wool and mohair producing countries, notably its immediate neighbour South Africa, which places it at a serious disadvantage in both the domestic and international markets. The present study aims to address the gap existing in technical data, information and knowledge about Lesotho wool and mohair, and is the very first of its kind.

In essence, this study aims to capture and analyse Lesotho wool and mohair production and quality related data and information available for the period 2007-2017 and to integrate it in the form of a database, which is readily updatable, and which can be used to identify potential areas of improvement in production and quality as well as further research. It is also intended for use in Lesotho as a general guide on wool and mohair quality and production related issues, with a particular focus on Lesotho. Although the focus is on fibre fineness, and closely related properties (i.e. mean fibre diameter (MFD), coefficient of variation of fibre diameter (CV %) and medullation), other quality and price determining characteristics, such as yield, vegetable matter, staple length and production, are also covered to a limited extent.

The fineness (diameter) of wool and mohair fibres represents their most important quality and price determining characteristic, accounting, for example, for almost 50% of the wool fibre price at the auction (McGregor, 2007, Botha and Hunter 2010). Fibre diameter, or fineness, is very important for the comfort of wool clothing, particularly when worn next to the skin. In this respect, the next to the skin comfort; prickliness or scratchiness, is closely related to the level of relatively coarse fibres (coarse edge) which is an important quality parameter (Naylor et al., 1992 and Liu et al., 2004a). Certain other fibre properties (particularly fibre length and average fibre diameter), play a role in determining the fibre buckling load and in flexural rigidity and consequent ability to evoke prickle (Asad et al., 2015 and Vetharaniam et al., 2018). In the case of mohair, on the other hand, medullation, particularly in terms of the objectionable medullated fibres (also referred to as kemp), is a key quality and price-determining characteristics. In the light of the above, it was decided that, in addition to fibre fineness, to also focus on “coarse edge and objectionable medullated fibres”, in assessing Lesotho wool and mohair quality and quality related trends, respectively, with a view to establishing a database and benchmark values against which future quality related data and quality improvements can be assessed.

1.2 MOTIVATION AND OUTCOMES

The main motivation for this study is the serious lack of reliable data on Lesotho wool and mohair production and quality. Most importantly, the impact such a lack has on the proper planning for wool and mohair production and quality improvement and benchmarking, as well as competitiveness in general.

At present, it is very difficult to plan or implement any project that could contribute to the improvement of wool and mohair in Lesotho. To do so, it is often necessary for extensive baseline information to be collected before any such project could commence. The presence of an up-to-date database could eliminate this and ensure that the allocated funds go directly into the intended project activities. The available data is currently neither captured nor managed centrally or by a designated body or authority, but by various, resulting in different sets of data with different values and quality of information. This therefore, does not give an accurate picture of the Lesotho wool and mohair pipeline and industry to researchers, learners, buyers and potential investors interested in the wool and mohair trade. As a result, benchmarking for quality and production improvement is not enabled.

One of the outcomes of this study will be the first technical and production database, covering the wool and mohair production and the main fibre quality parameters The study is expected to be facilitated by the Livestock department in the Ministry of Agriculture and Food Security Lesotho, compiled and managed by the Textile Science department of the National University of Lesotho (NUL) in collaboration with the office of the NWMGA and LPMS in the Ministry of Trade and Industries. This updatable database will inform readers on the quality and production related properties and trends of Lesotho wool and mohair, and will form an important basis for their improvement and further research. It should also prove valuable for practicing and aspiring textile scientists, technologists, professionals, relevant government Ministries and investors interested in the quality and production of Lesotho wool and mohair. The Ministry of Trade and Industry, in particular the Lesotho National Development Cooperation (LNDC), can use the findings of this study as a benchmark and guide to deal with issues of value addition, processing, marketing, and also possibly facilitate the introduction of a local wool and mohair research and testing department or facility. The establishment of such a facility can assist Lesotho farmers, traders, processors and users of Lesotho wool and mohair to assess and monitor the fibre quality, as well as for future research and new product development. Another outcome relates to those areas of Lesotho wool and mohair needing improvement in terms of production and/or quality, as well as possible strategies for Lesotho wool and mohair industry development.

This thesis will also be suitable to use as a guide and educational document for creating a wider awareness of the basic, but pertinent, aspects of wool and mohair production and quality and related aspects in Lesotho. For this reason, considerable general or background information has been included as part of the literature review. The following objectives guided the research:

1. To develop a unique updatable database on Lesotho wool and mohair production and textile quality.
2. To describe the trends in the production and quality profile of Lesotho wool and mohair in the decade studied *(2007-2017 for wool and 2005-2015 for mohair).*
3. To assess selected key characteristics of Lesotho wool and mohair.
4. Provide a Lesotho wool and mohair basic guide for stakeholders and interested parties, both within and outside the fibre and textile sector.

1.3 LIMITATIONS

There are some engrossments that occurred during the research that limited the study. Although the study covered Lesotho wool and mohair data for a 10 year period, the same starting dates could not be followed for the two fibres due to the unavailability of data in certain years. Ideally the same starting dates should have been used, although it should have little or no impact on the overall results and findings. In addition, the preparation of the wool samples should have been done in more controlled and standardised conditions. These involved manual scouring and spinning which made it virtually impossible to produce uniform yarns of the same linear density (tex), which impacted on the knitted sleeves and consequently the prickle evaluation.

In the case of samples, sample selection was limited to the wool and mohair auctioned in Port Elizabeth, South Africa. Ideally, the entire Lesotho wool and mohair clips should have been sampled to ensure a proper representation of all the wool and mohair produced in Lesotho. The majority of the Lesotho wool and mohair is exported, through a broker (BKB) in Port Elizabeth, South Africa; and this was the source of the samples drawn. Nevertheless, there are still some wool and mohair produced in Lesotho which are not auctioned by this broker.

Some of such wool and mohair is used locally in the craft industry in Lesotho. Be it as it may, the quantities of wool and mohair not handled by BKB, and therefore, not covered in the study is considered so small (about ≤10%), that it would not significantly affect the findings of the study.

It is worth noting that the study has an intentional bias towards textile use of wool and mohair since the ultimate goal is to ascertain suitability and competitiveness of Lesotho wool and mohair in apparel and other textile products. A number of unknown factors affecting quality and production of the two, are inevitable in a study dealing with wool and mohair quality and production.

1.4 THE STRUCTURE/OUTLINE OF THE STUDY

The study plan is illustrated in Figure 1, which gives an idea of the approach followed.

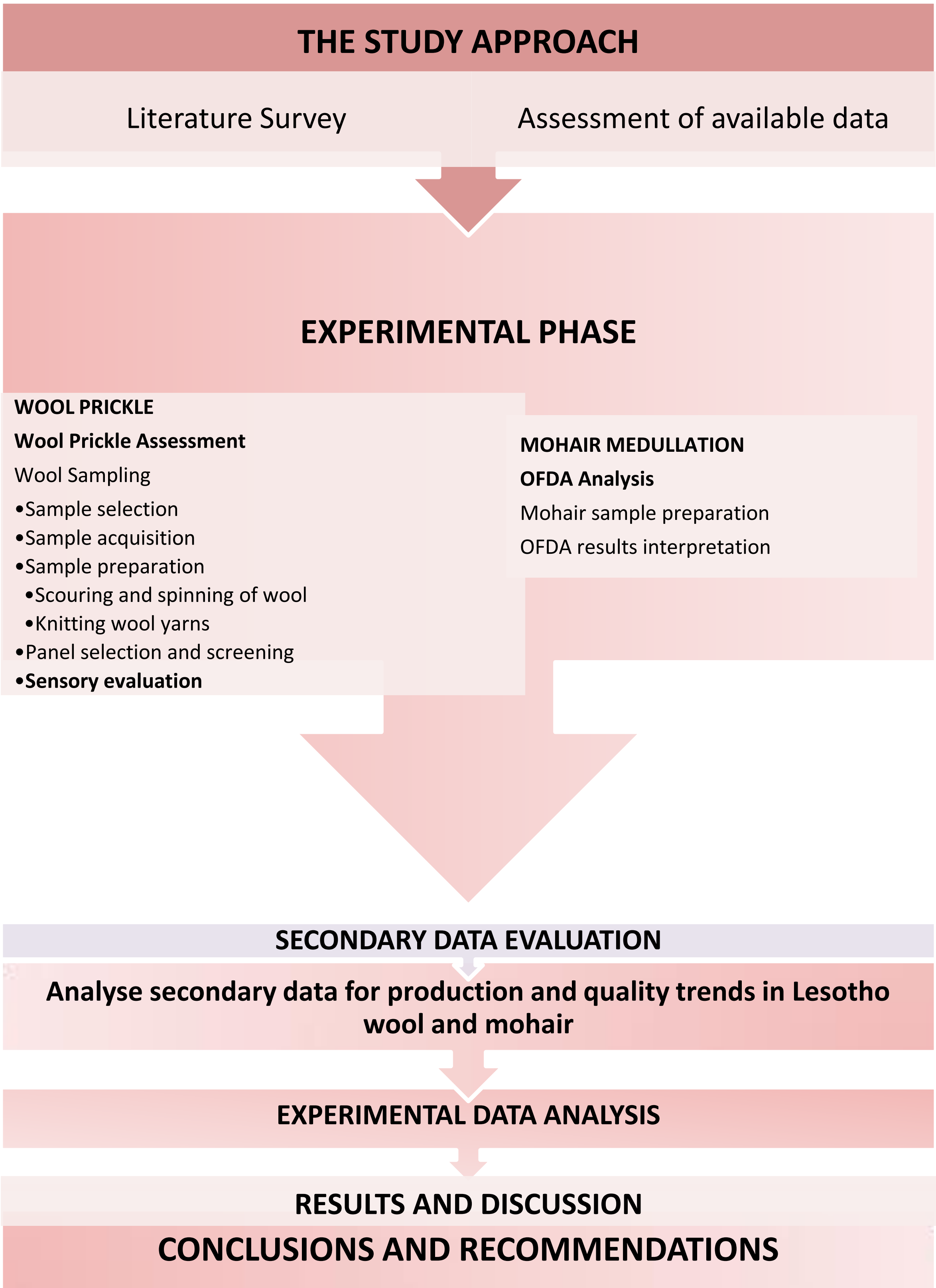


Figure 1: The Study plan/approach

The structure of the thesis follows a logical pattern that gradually builds up to the contribution of the study to the pool of knowledge pertaining to Lesotho's two main fibres, namely wool and mohair. The thesis consists of the following eight chapters.

Chapter 1: Scope and motivation

This opening chapter gives the rationale behind the study and describes the setting, within which the study was conducted, stating and justifying the selection of the attributes of Lesotho wool and mohair investigated, as well as the scope and main purpose of the study. This study encountered certain limitation, however, such as insufficiently documented data on Lesotho wool and mohair, which is also reflected in the inconsistent starting dates of the analysis. The manual, as opposed to mechanical, processing of the wool impacted on the variation in the prickle results. Furthermore, sampling was limited to the auctioned wool and mohair due to the difficulty in tracing all the wool and mohair producing farmers, no records being available for those not registered with the National Wool and Mohair Growers Association (NWMGA).

Chapter 2: Introduction and background

This chapter provides a background and historical information about Lesotho wool and mohair; from which the problem under investigation arose, as well as brief insights into the Lesotho textile industry. The agricultural and economic background is described within the context of the study.

Chapter 3: Characterisation of wool and mohair

This chapter explores the general quality related properties and standards of both wool and mohair, and evaluates the status of Lesotho wool and mohair in this respect. In this chapter, the potential means of assessing and improving the quality attributes of Lesotho wool and mohair are discussed, including physical quality characteristics, the production status as well as the monetary value of these fibres.

Chapter 4: Review of mohair medullation

This chapter covers a literature review on medullation, with specific reference to mohair. Medullation is defined; and classified, as well as the possible origin or cause of medullation. The chapter also discusses the effect of medullation on mohair quality and value, as well as the methods and instruments available for use in the measurement and assessment of medullation.

Chapter 5 Review of wool prickle

This chapter provides a limited review of the subject of wool prickle, and its role in against skin comfort.

Chapter 6: Experimental / Methodology

This chapter deals with the sampling, measurements (tests) and methodology employed and is essentially divided into two sections, namely Lesotho wool prickle assessment and Lesotho mohair medullation measurement. In both sections, the sampling procedures, instrumentation and analysis of data are discussed.

Chapter 7: Results and discussion

This chapter contains the results and discussion, covering Lesotho wool and mohair production, quality and value trends, as well as the database.

Chapter 8: Conclusions and recommendations

This final chapter contains the main conclusions arising from this study and also deals with the limitations of the study, as well as recommendations for further research. Also included in this chapter are the implications of the findings, and suggested projects for the improvement of Lesotho wool and mohair.

CHAPTER 2

INTRODUCTION AND BACKGROUND

2.1 BACKGROUND AND SETTING

Lesotho is one of the smallest countries in Africa, both geographically and population wise, with a unique geographical location, situated within the Southern African plateau, at an elevation of between 1500 m and 3482 m above sea level. Lesotho is divided into four agro-ecological regions and 10 districts (see Figure 2.1) based on climate and elevation. The four regions are the Lowlands (17 %), Senqu River Valley (9 %), Foot-hills (15 %) and Highlands (59 %), the latter being found in the mountains (Mekbib et al., 2011 and Cauley, 1986). Each of the districts stretches over a maximum of four regions, Mohale's Hoek being an example of one which stretches across all four regions. Depending upon their geographical position; the regions can experience different climatic conditions, which, in turn, can have a significant impact on agriculture within the region and districts, including stock farming. Approximately 9 % of Lesotho land area is arable, the remainder being dominated by rangeland, which is suitable for extensive livestock production (Bureau of Statistics and Planning, 2007).

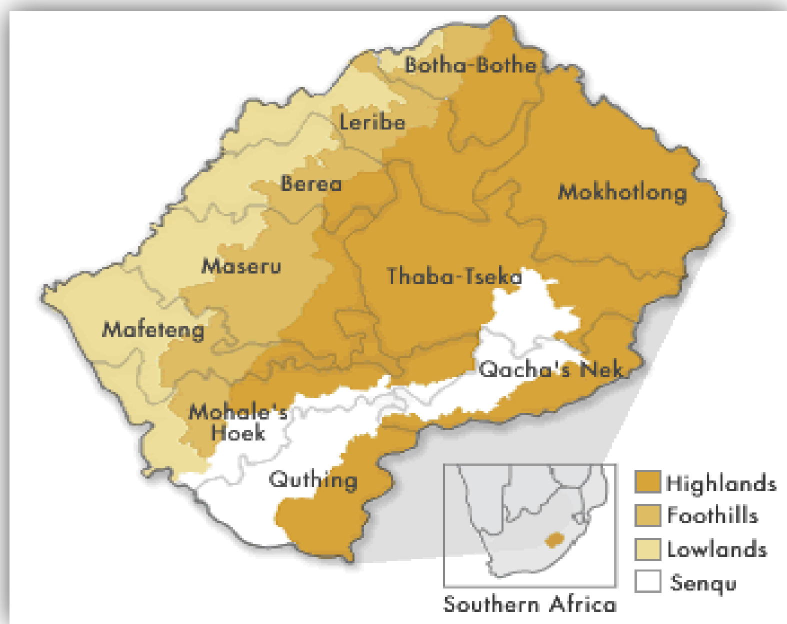


Figure 2.1: Lesotho geographical map showing the various regions (Mekbib et al., 2011)

The Orange-Senqu River has its source in the Lesotho kingdom highlands, which are about 3,300 m above sea level. As a result; the river has a steep topography into South Africa (see Figure 2.2), and it continues to flow through Namibia and Botswana (ORASECOM, 2011). The Orange-River basin is situated on porous rock, associated with the rock ground that easily breaks off (UNEP, 2009 and Cobbing et al., 2008). The climate of the river channel surrounding drainage area varies significantly along the route/path of the river. The profile shown in Figure 2.2 clarifies the array of topographic altitudes within a specific area. The Orange River (Senqu) climate varies from Lesotho snow in winter to scorching Namib dessert in Namibia (Hattingh et al., 2014). Much of the basin is in a state of imbalance between water availability and demand, degradation of ground and surface water quality, intersectional competition, interregional and international conflict all contributing towards water scarcity (Lange et al., 2007). Out of the four countries along the Orange-Senqu basin, only South Africa has the capacity to manage drought with its sophisticated dams and water transfer systems, Lesotho is vulnerable to drought due to poor water distribution, Botswana and Namibia also being prone to drought, because of the shortage of water sources and their downstream location (Ionescu et al., 2005). The agricultural conditions of areas/regions around the Senqu valley are greatly affected by the river profile.

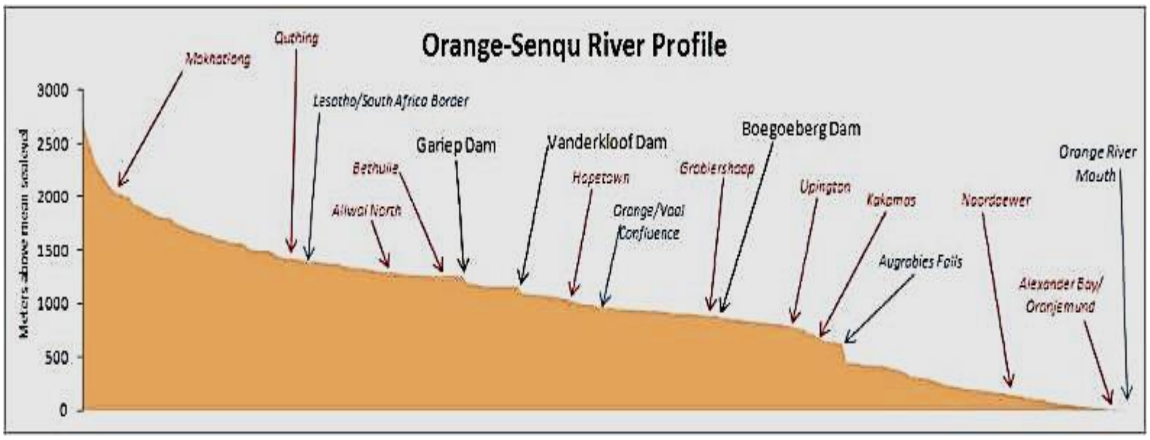


Figure 2.2: Representation of the Orange-Senqu River path

Mafisa (1993), Motselebane (2010) and Mokhethi et al. (2015), agree that Lesotho farmers produce wool and mohair in significant quantities, wool and mohair together accounting for 58.3 % of agricultural exports. In 2016/2017 Lesotho produced slightly above 6 million kilograms of merino type greasy wool and about 680 thousand kilograms of Angora type greasy mohair, representing 0.2 % and 14 % of 2016 world production, respectively. As such, Lesotho is not a major wool producing country but is the second largest mohair producer in the world after South Africa. In 2016/2017, Lesotho wool reached a high average price of 138.50 South African Rands (ZAR) per kilogram (greasy) for the first time (Capewool, 2017 and BKB, 2017). Wool is Lesotho's leading agriculture export commodity, while mohair ranks 5th (IFAD, 2014). Although these two fibres make a notable contribution to Lesotho's gross domestic product (GDP), the two fibres do not receive sufficient local attention in terms of application and economic impact, despite their good quality and international competitiveness. This is evident from the lack of data and research on Lesotho wool and mohair.

Despite the contribution of wool and mohair to the Lesotho economy, very little, and mostly superficial, technical and scientific data are available on their quality. Literature dealing with the quality of Lesotho grown wool and mohair is either incomplete or out of date, and certainly does not give a clear indication of the quality and production related prospects of these two main agricultural export products. For this reason, the quality of these two fibres, factors contributing to their status, as well as possible means of improvement are not easy to determine. In essence, the present and future potential contribution of wool and mohair to the Lesotho GDP is neither known nor documented.

2.2 LESOTHO AGRICULTURAL CONDITIONS

The climate of Lesotho is primarily influenced by its location in the Karoo Basin, spanning altitudes ranging from about 1400 m to 3480 m above sea level. The altitude and latitudinal largely determine the climate of Lesotho. The altitude and geographical position also have an effect in terms of the sub-tropical high pressure zone; the basic air mass circulation being anti-cyclonic, with a westerly current superimposed at heights of 3,000 m above sea level (Lesotho Meteorological Services, 2013).

The climatic conditions in Lesotho are considered very suitable for wool and mohair production (IFAD, 2007). Motselebane (2010) stated that the most favourable conditions for wool and mohair farming are in the highlands comprising of foothills and mountains, since only 10 % is arable, while about 50 % is suitable for graze lands, this being reflected in the distribution of the sheep and goat population by district. The highland region is best suited for extensive small stock production, about 82 % and 76 % of sheep and goats, respectively, being found in this region, only about 18 % and 24 %, respectively, being found in the Lowland region.

The temperature in Lesotho often drops to as low as -6 ºC and -5 ºC in the Highland and Lowland regions, respectively, while in extreme winters it can even drop to -11 ºC in the Lowlands and -21 ºC in the Highlands (Lesotho Meteorological Services, 2013). The winter mornings are generally frosty, and the first and last days of the frost occur around 18 May and 06 September, respectively, in the Lowlands and 16 February and 19 November respectively in the Highlands/mountains (see climate graph in appendix 6). This confirms the low temperatures prevailing in Lesotho almost throughout the year, especially in the Highlands.

The climatic conditions of each district are largely determined by the region within which it is located. The Senqu River valley region, commonly known as Sephula, or simply Senqu; meanders along the Senqu River, and this gives the region its outstandingly unique climatic characteristics. It is not surprising, therefore, to find different climatic conditions in different regions and within districts.

2.3 LESOTHO CLOTHING AND TEXTILE INDUSTRY AND THE ECONOMY

Lesotho's economic growth was adversely affected by the poor performance of the agricultural and manufacturing sectors during 2009-2011 when Lesotho experienced severe floods causing a setback in agricultural production, while the global economic crisis resulted in a low demand for Lesotho textile exports to the USA. This lowered the contribution of Lesotho textiles to the economy, which in turn contributed to the dropping of GDP growth rate from 4.8% in 2006-2008 to 4.2% during 2009-2011. The preferential imports into the USA were less than $1 billion for over half of the 40 AGOA beneficiary countries in 2014 (Williams, 2015). Lesotho is one of the countries that benefitted from preferential treatment and has to remain one of the top clothing producers and exporters, into the USA, to continue receiving preferential treatment. The formal textile and clothing industry in Lesotho is its second largest employer, providing well over 40,000 jobs (Irin News, 2008). The formal industry, however, presently imports all the fibre and fabric it uses for manufacturing, using no locally produced fibre in the process, the exception being denim, which is manufactured locally using imported cotton fibre.

Lesotho is heavily dependent on South Africa for most of its imports, and on USA for its textile exports. It is still eligible in terms of the African Growth and Opportunity Act (AGOA), qualifying it for the textile and clothing benefits of the agreement, being one of the sub-Sahara African countries which benefits tremendously from AGOA. According to Naumann (2008), Lesotho commercial clothing firms, mostly Asian owned, in 2007 moved from providing 15,000 jobs to providing 55,000 jobs, largely as a result of AGOA. According to the Lesotho Government (2017), these numbers have fluctuated greatly, eventually dropping to around 46,604 in 2017 (see Table 2.1). Lesotho is one of the largest garment/clothing exporters to the United States of America (USA). Lesotho, like other countries, was negatively impacted by the global economic crisis of 2008, causing the rate of economic growth to decrease substantially, thereby exposing Lesotho's vulnerabilities in this respect. It became evident that infrastructure and other measures had to be put into place as a matter of urgency in order to improve the country's economic competitiveness and export diversification and to promote rapid broad based economic growth, and thereby also reduce poverty. The best way to attempt to address the most urgent areas for sustainable growth, would be to utilise what resources the country already has, as opposed to seeking assistance from outside.

Traditionally, agriculture has been the main contributor to the gross domestic product (GDP) of Lesotho, but its contribution to GDP declined greatly from 1983 to 2011, from being 20% in 1983 to being only about 14% in 1999, only about 7% in 2011, becoming almost insignificant in 2017, when it was grouped with other negligible contributors together referred to as "other". This performance did not only affect the GDP but compounded Lesotho's already serious food security situation (SARC Department, 2013). In contrast to this, the contribution of the manufacturing sector to the GDP remained substantial as illustrated in Figure 2.3, this sector being mainly driven by the textile and clothing sector, which has been the engine of national economic growth and job creation in this century. Its contribution to GDP rising from 10.4 %, in 1999 to nearly 16 % in 2011 and to 18.5 % in 2017. Rapid growth in this sector was boosted by the inclusion in 2000, of Lesotho as a beneficiary of the AGOA. Nevertheless, this sector has experienced challenges in recent years in the US market, due to increased competition, following the cessation of quotas under the Multi-Fibre Arrangement (MFA). In addition, investors are still concerned about Lesotho's continued duty free access to the USA market under AGOA, despite the extension of its expiration in 2015, when the Trade Preference Extension Act of 2015, passed by USA Senate 14th May 2015 extended AGOA, with its generalized system of preferences, by another ten years to 2025 (US Government, 2015). This brings hope for improved trade in textiles and clothing for Lesotho.

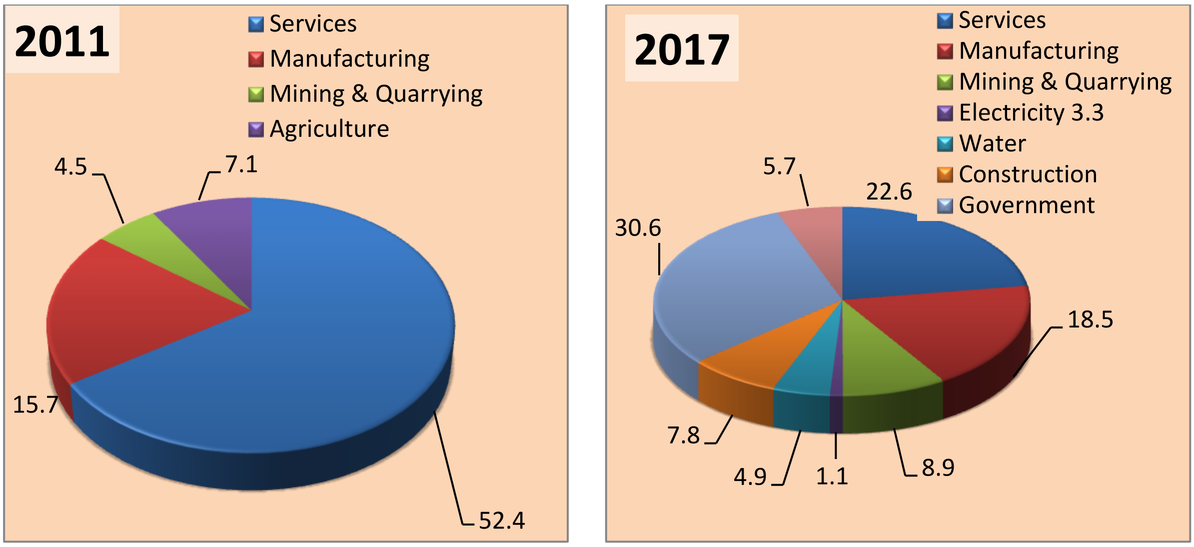


Figure 2.3: Sectorial Contribution to GDP (%) (Central Bank of Lesotho, 2017)

Even though the formal textile industry in Lesotho does not process any of the locally produced wool and mohair, it is widely believed that to do so would be beneficial to them as well as to the country as a whole. The Lesotho textile industry specialises in the production of woven denims, using mainly imported cotton fibre, as well as in garments made from cotton knit fabrics (Bennett, 2011). The profile of the textile industry is shown in Table 2.1.

Table 2.1: Profile of the Lesotho Clothing and Textile Industry (Lesotho Government, 2016-2017)

Industrial Sector	*No of firms*	*No of Employees*	*Approximate units of garments produced*
Textile	1	1,220	Yarn – 18 00 tons Fabric – 15.6 million metres
Denim woven bottoms	9	13,124	23,304,000
Non-Denim woven fashion	4	1,580	6,360,000
Industrial Work wear	6	4,690	11,003,800
Knit garments	33	24,513	115,143,600
Footwear	2	1,253	7,200,000
Supporting Industry	11	218	-
TOTAL	**66**	**46,604**	**155,811,400 (typical clothing units)** **7,200,000(pairs of typical shoes)**

The textile industry in Lesotho is presently performing well and contributing significantly to the economic growth of the country. Lesotho Government (2017a) reported that the contribution of Lesotho's exports to economic growth is about $34-billion against about $321million in 2013; largely as a result of AGOA being extended until 2025. Growth in this industry was stimulated in the 1990s by investments, mainly from Taiwanese companies, which moved to Lesotho to take advantage of duty-free access to the EU, under the ACP-EU agreement, of clothing originating in Africa, Caribbean and Pacific (ACP) countries; It was further boosted following the designation of Lesotho, by the USA, as one of AGOA eligible countries. Taking advantage of this opportunity, Lesotho's textile and clothing industry achieved very rapid growth, and the country became the largest single exporter in sub-Saharan Africa of textiles and clothing to the USA. However, following the elimination of quotas, with the phasing out of the Multi-Fibre Agreement (MFA), Lesotho began to face fierce competition from low cost and more efficient producers from China and the Far East. Even though the MFA expired in 2005, the impact only started to be felt in 2008. The drop in Lesotho's textile and clothing exports to the USA was exacerbated by the onset of the global economic crisis in 2008 and investor concern regarding Lesotho's continued duty free access to the USA under AGOA beyond 2012, with exports reaching a seven-year low in 2010. Table 2.2 shows the dollar value of Lesotho clothing exports to the USA.

Table 2.2: Lesotho Clothing and Apparel Exports

	Export value (Million $)
Year of export	**USA**
2007	443.1
2008	374.1
2009	364.2
2010	294.9
2011	384.4
2012	310.6
2013	351.4
2014	361
2015	332
2016	310
2017	308.6

SARC Department (2017).

2.4 MARKETING OF LESOTHO WOOL AND MOHAIR

Very little of the wool and mohair produced in Lesotho is processed or ultimately consumed locally. The trading of mohair in Lesotho saw a major change from 2015/2016 season. This change involved giving one Chinese agent the monopoly of trading Lesotho wool and mohair in 2018. Accessing production and quality related data became difficult after the change in the way trading of wool and mohair was done. Typically, the majority of the wool and mohair produced is baled at the shearing sheds and transported to the Livestock Products Marketing Systems (LPMS) for storage and shipping to the agent (BKB) in Port Elizabeth, South Africa, and some smaller amounts to another agent (CMW) where the fibres are auctioned on behalf of Lesotho farmers in their greasy, unprocessed state. This makes it even more difficult to trace the end users or the final destination of the Lesotho clip *per sé*.

There are currently 158 recorded shearing sheds in the country, 123 of which are government owned, one built by the National Wool and Mohair Growers Association (NWMGA), and the other thirty five (35) being private (Alotsi, 2017). They are generally distributed geographically, based on the number of animals in the district, Table 2.3 shows the geographical distribution of the shearing sheds in Lesotho. To ensure proper running, NWMGA in collaboration with the government, occasionally holds workshops for the farmers at the sheds on skills required for various farming activities relevant to wool and mohair production. For some of these workshops the relevant qualified facilitators have to be outsourced. There is a Small Agricultural Development Project (SADP), which started running in 2012 and was initially intended to end in 2018, but resumed in June 2019 assisted by different donors from within the World Bank (LENA, 2019). Part of the project's mandate (SADP-I) is to develop the wool and mohair industry in the form of marketing support, genetic improvement of communal flocks through the introduction of quality rams as well as training and mentorship. The second phase of the project (SADP-II) is focused on minimising the potential impact of climate change on wool and mohair production and to improve productivity.

The Ministry of Trade and Industry is responsible for the general marketing of all Lesotho products; wool and mohair being no exception, the only difference being that the NWMGA is highly involved and knowledgeable regarding the marketing of their products. The NWMGA is responsible for the daily running of the sheds as it serves them directly. The activities at the sheds include shearing, classing, recording and packaging of the fibre.

Table 2.3: Distribution of shearing sheds per district

District	Number of Shearing Sheds
Maseru	21
Mohale's Hoek	16
Mokhotlong	25
Leribe	16
Mafeteng	12
Thaba-Tseka	18
Quthing	14
Qhacha's Nek	15
Berea	11
Butha-Buthe	10
TOTAL	**158**

SOURCE: Lesotho Livestock Services (2017)

2.5 LESOTHO WOOL AND MOHAIR PRODUCTION

The history of the merino sheep and Angora goats in Lesotho is scanty. It is, however, believed that the non-merino sheep Basotho farmers keep today are the descendants of a fat-tailed non-wool producing type sheep, similar to those originally kept by the Hottentot (Khoisan) in the Cape. Merino sheep mostly found their way into Lesotho from raids on flocks kept by the white settlers in the Orange Free State around the 1850s. Some sheep were brought into Lesotho by Basotho who worked on the white settlers' farms, who paid them with sheep in lieu of wages. Angora goats, which originated mostly from the Eastern Cape, probably found their way into the mountain kingdom in a similar manner (Uys, 1970). These breeds increased in numbers as owners sold their progeny to their neighbours and/or allowed them to be used for breeding (Mafisa, 1993).

Uys (1970) noted that the first goats that arrived in Lesotho in the early 1880s were tough and lean by description, they were also multi-coloured and had straight and hard hair, similar to the ones described earlier by Roberts (1926). According to Uys (1970), in 1899-1900 the primitive goats and Angora goats were together referred to as mixed goats, and after the census in 1904 they were then listed separately, in 1906 reference being made to Boer goats. It is believed that Angora goats crossed into Lesotho before 1888, because 881 Angora goats were recorded in the census in 1904, with some further 744 being listed as other types of goats. The indigenous short hair goat strain has been diluted through generations of crossing with Angora goats and the original characteristics have essentially disappeared. There has, however, not been a systematic importation of improved Angora bucks (Mafisa, 1993).

The Lesotho small stock owners were later encouraged by the government to rear only the merino and Angora breeds of sheep and goats, respectively, this being the policy since 1927, when the importation of crossbred rams and bucks were prohibited in the country (Hunter, 1987). It is, however, easier to monitor the breeds reared by association member farmers, than those who are not members. In 1965, the Lesotho government, assisted by the South African Wool Board (SAWB), established a Merino Sheep Stud in Quthing - Lesotho to reduce its dependency on South Africa for the rams and ewes required at the time for breeding the newly introduced merino sheep, these initially having been imported from South Africa.

Traditionally, sheep and goats have been farmed in Lesotho for both fibre and meat, the former largely for export, and the latter largely for local consumption, the farmers in Lesotho keeping large flocks of sheep and goats for their wool and mohair. Motselebane (2010) reported that wool and mohair represent Lesotho's main Agricultural export and that in Lesotho, livestock farming has historically been the most traditional of all Basotho occupations, it being so highly regarded that a man's wealth was measured by the number of sheep he has. Being classified as a Least Developed Country (LDC), Lesotho struggles to grow her economy independently, often having to survive on "hand-outs" and donations. Lesotho wool and mohair producers/farmers, have organised themselves in an association registered as the Lesotho Wool and Mohair Growers Association (LWMGA). There are roughly 40,000 farmers producing wool and mohair in Lesotho, 15,000 of these being registered members of the Lesotho Wool and Mohair Growers Association. The farmers, who are not members of LWMGA, are the ones more likely to sell their fibre to private buyers as individual transportation to the auction is more costly. Figure 2.4 compares the wool and mohair production in Lesotho since 2007/2008.

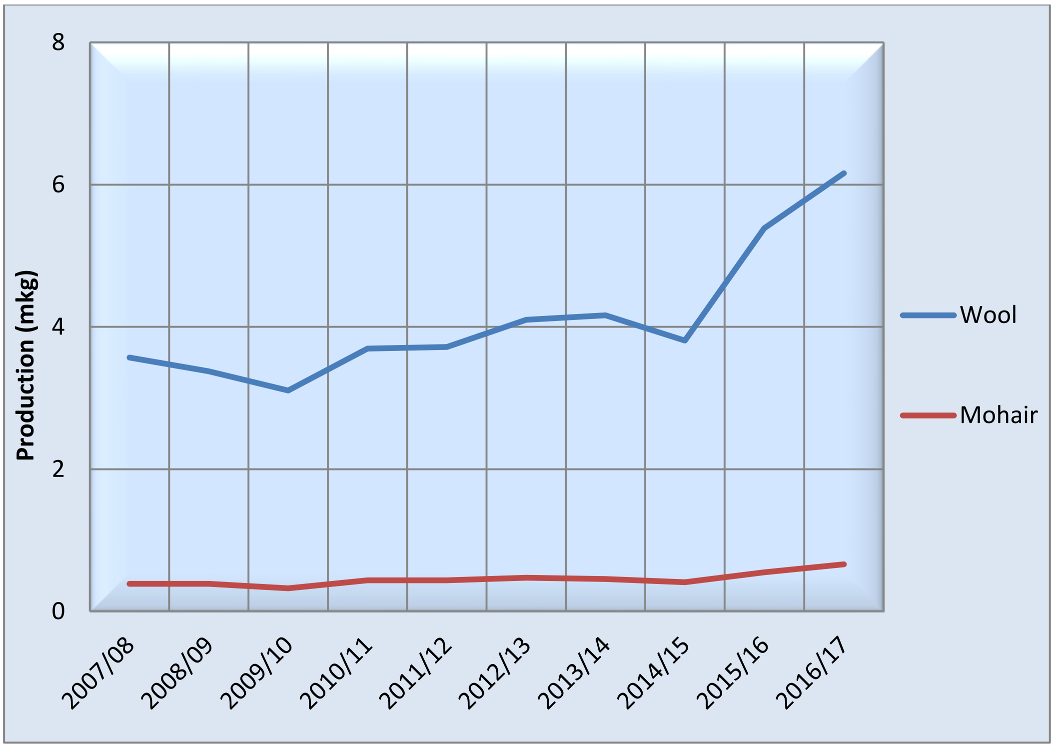


Figure 2.4: Annual Lesotho greasy wool and mohair production (BKB, 2017)

The Lesotho sheep population fluctuated between 1 million and 1.7 million during the 10 year period from 1979/80 to 1988/89, while the goat population fluctuated between 0.8 and 1 million during the same period (Bureau of Statistics, 1990). Periodic droughts are believed to be mainly responsible for the fluctuations in the sheep and goat populations in Lesotho; these contribute to the high rate of lamb and kid mortalities in a sector that already has low productivity. Rearing of small ruminants differs in the four agro-ecological regions of the country. The Merino sheep and Angora goat population distributions are given in Table 2.4. for 2014, Lesotho's merino sheep population, prior to winter, is usually about 2.7 million, of which about a million is lost every winter mostly the lambs and kids die during the harsh winters, due to lack of supplementary feed and water, coupled with the extremely low temperatures of below zero in the country (Rust and Rust, 2013 and Matla, 2014).

Table 2.4: The 2014 distribution of sheep and goat numbers by districts

District	Merino Sheep	Angora Goats
Butha-Buthe	100, 625	47,160
Berea	117, 974	43,488
Leribe	63, 457	23,792
Maseru	229, 946	98,952
Mafeteng	89, 294	22,353
Mohale's Hoek	116, 097	55,673
Quthing	153, 086	39,427
Qacha's Nek	90, 382	32,467
Mokhotlong	238, 064	91,017
Thaba-Tseka	226, 483	76,216
Total	**1, 425, 408**	**530,545**

Source: Bureau of statistics of Lesotho (2014)

2.6 BENEFICIATION OF LESOTHO WOOL AND MOHAIR

Currently, the large textile firms in Lesotho, making up the formal part of the textile industry, hardly process any locally produced wool and mohair, even though they represent the bulk of fibres produced in Lesotho. Only a few small local cottage industries convert any locally produced wool and mohair into consumer products. The majority of these groups scour and spin the fibres manually and use them to manufacture tapestries, some knitwear and other crafts, aimed mostly at the tourists. The amount of fibre used by these producers is relatively small (Lesotho Review, 2015). Most of the wool and mohair processing cottages, commonly referred to as weaving centres, are small in scale and traditional, most being located in the Maseru and Berea districts, which are easily accessible to tourists, their target market. These centres manually carry out all the processes required to convert the shorn fibre into a marketable product, including washing, combing, spinning, weaving etc., to produce products, such as tapestry wall hangings, rugs, bags and occasionally scarves. Examples of some of the woven products they produce are shown in Figure 2.5.

As already mentioned the quality and price of wool and mohair used for tapestry tend to be low, most farmers preferring to export their produce (fibre) and thereby obtain a much higher price for their fibre. This means, however, that virtually no local value addition takes place for these high value and highly sought after fibres before they get exported. Therefore, in terms of beneficiation, the country and Basotho people neither benefit nor take advantage of the excellent properties of locally produced wool and mohair, imported wool and mohair garments being expensive and luxurious. The local beneficiation, or value addition, of wool and mohair, to the benefit of the country's economy and that of its citizens and create much needed employment represents a major challenge facing Lesotho.

i)

ii)

a) Commissioned and customised wall hangings and floor rugs

b) Figurative wall hangings

Figure 2.5: Examples of hand-woven wall hangings and floor rugs produced in Lesotho a) customised and b) figurative wall hangings. **(***Elelloang Basali weaving centre, 2008 and Setsoto design weaving centre 2010***)**

CHAPTER 3

CHARACTERISATION OF WOOL AND MOHAIR QUALITY

3.1 OVERVIEW

This chapter deals with the characterisation of wool and mohair quality in general, and that prevailing in Lesotho within the context of the study. Secondary data, containing statistical and quality information, were used for content analysis. Wool and mohair production rates, sales and some selected fibre properties that have a direct impact on the fibre quality and price are covered, with the focus being on fibre diameter (fineness), as it largely determines the application and price of the fibre (Holman and Malau-Aduli, 2012, and Khan et al., 2012). This detailed general information is considered important since it is envisaged and planned that this thesis also be used as a general guide by non-textile and less knowledgeable stakeholders, as well as by other interested parties in Lesotho, such as present and future buyers of Lesotho wool and mohair.

Information about developments in Lesotho wool and mohair, leading to their present quality and production, as well as their contribution to the Lesotho national economy in the past ten years (2007 – 2017), can assist in identifying areas that require improvement in the value chain. The current value chain (see Figure 3.1) for Lesotho wool and mohair is stable, though very basic, with very few major players, such as the government, the NWMGA, licenced traders and a few individuals trading privately. Figure 3.1 shows that Lesotho wool and mohair are either exported, via auctions, or processed locally, although local processing is minimal, as already mentioned. A few individual wool and mohair producers are not registered members of the NWMGA, as they use their own means for production and marketing of the fibres, their wool and mohair not going to the auction platforms.

There is no record of the domestic market and value of Lesotho wool and mohair, since the majority of these fibres form part of the country's exports through a South African broker, with only a small amount of wool and mohair being consumed locally; details of the wool and mohair traded on the domestic platform not being recorded, except for the personal use of the producer. Often the growers accept any price the buyer is willing to pay for their fibre. The value-chain for the production and marketing of wool and mohair (see Figure 3.1) is expected to improve and to be documented through the introduction of the wool and mohair promotion project by the government funded through IFAD.

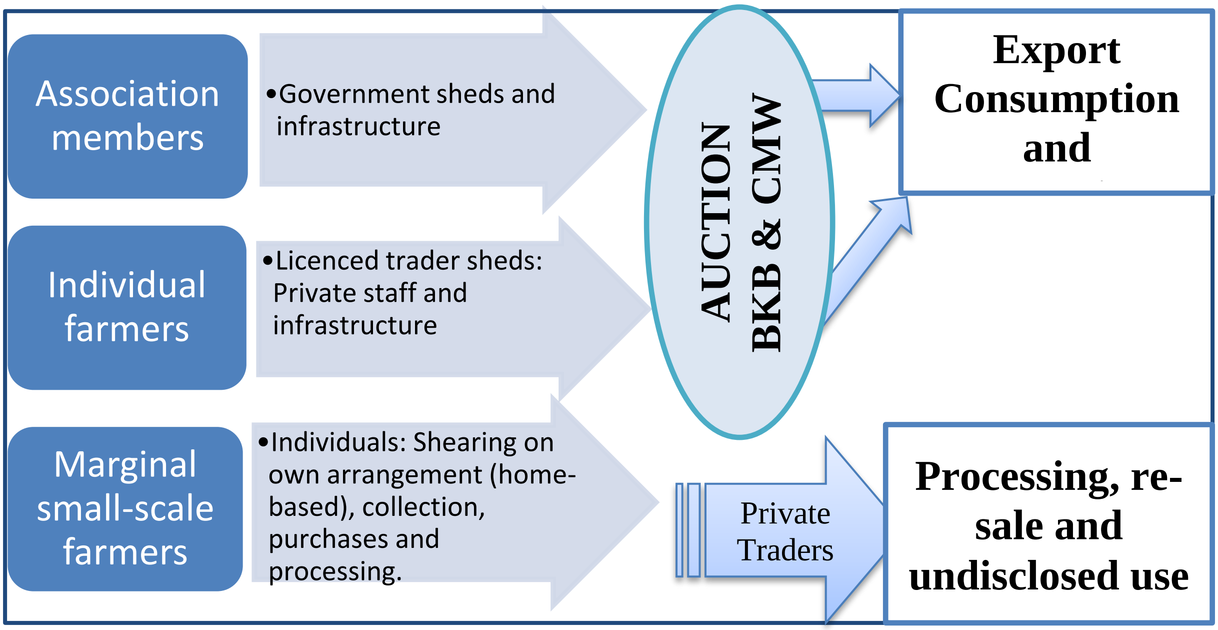


Figure 3.1: The Lesotho wool and mohair value chain (Mokhethi et al., 2015).

3.2 CHARACTERISATION OF LESOTHO WOOL

3.2.1 Wool Quality

Wool fibre quality does not have a simple definition, although there are various essential characteristics and defects in the fleece, either inherited or acquired, which influence the quality and end use of wool, most of these characteristics having some biological base. Wool quality is characterised by various properties, such as mean fibre diameter, coefficient of variation of diameter, staple length and strength, fibre curvature and clean fleece yield, vegetable and foreign matter content, crimp and colour (Schoenian, 2015). The association between these characteristics and wool quality (and price) stems from their correlation with wool processing performance, durability, ultimate use and consumer satisfaction. An evaluation of these characteristics allows wool quality to be objectively quantified prior to purchase and processing. For instance, wool fibre diameter has a great influence on post-processing wool value and quality (Botha and Hunter, 2007; Botha and Hunter, 2010).

Furthermore, Frawley and Malcom (2009) found that the quality and value of fine wool are more sensitive to faults than coarser wool, fine wool generally being more difficult to process. There is also a higher expectation of quality with fine wool, both at the processing and final product level. This has particularly significant ramifications for fine and superfine-wool producers, as large discounts are applied where tests show unacceptable levels of quality defects, such as vegetable matter or poor staple strength. Such discounts can dramatically decrease wool income (McGregor, 2007) and profitability.

The average diameter of the wool fibre is a primary determinant of fibre quality, and is directly related to price and processing performance, as well as application (Khan et al., 2012). Depending on the intended use of the fibre, apart from fibre diameter, there are other characteristics, the presence or absence of which may define fibre quality, such include staple length, pigmentation, medullation and crimp. The latter three are currently not measured on Lesotho wool and mohair, possibly because the buyers of Lesotho wool and mohair do not require such information to make a buying decision. Figure 3.2 is an example of how the stated attributes can have an influence on the wool price at the point of sale at the auction.

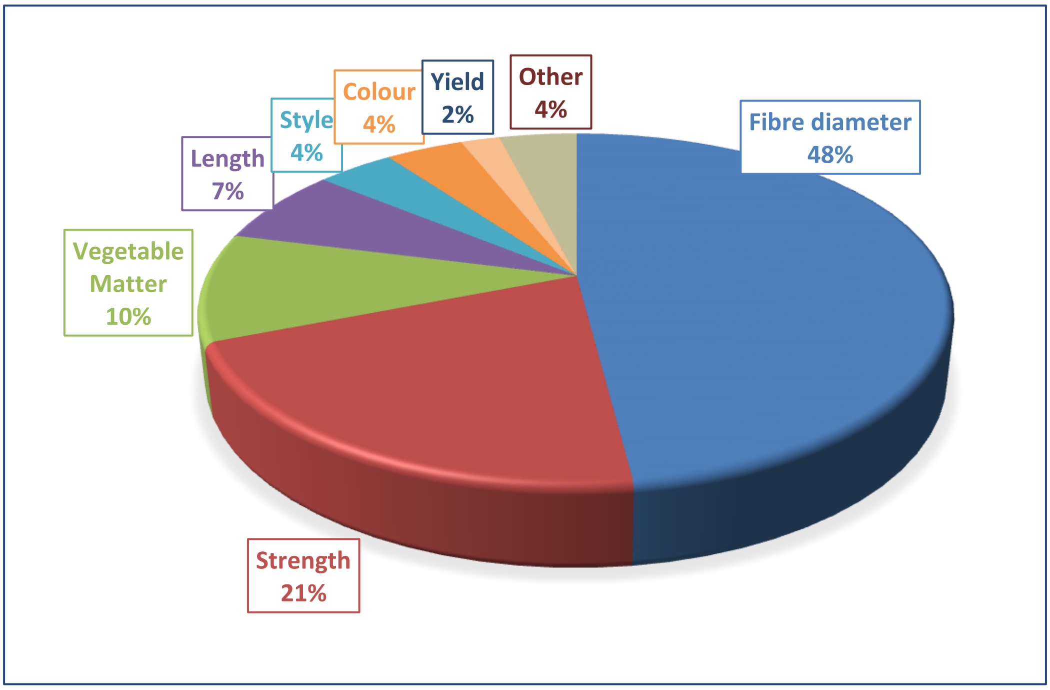


Figure 3.2: Attributes influencing auction clean wool price (McGregor, 2007, Botha and Hunter 2010)

When the fibre quality meets the buyer’s preferences, the demand for such a fibre increases, and so does its selling price. An increase in price stimulates production, resulting also in an increase in employment and revenue.

3.2.1.1 Fibre Diameter

Fibre diameter (FD) and staple length are the main quality attributes measured by the South Africa Wool Testing Bureau (WTB) on Lesotho wool as requested by the producers, both being known to influence the price and quality of wool (McGregor, 2007 and Botha and Hunter 2010). Hence, the focus will be on them (mostly FD), in this study as contributing factor in the prickle sensation. It is worth noting, however, that initially the farmers/wool producers did not request the measurement of staple length, and hence it was not measured. This, however, changed as staple length measurements began during 2008/2009. The characteristics of Lesotho wool; fineness and length in particular, indicate that it is most suitable for worsted clothing fabrics, and that it may even be suitable for fine woollen fabrics as well as for machine and hand knitted fabrics.

Fibre diameter is widely acknowledged as the most important wool characteristic when assessing wool quality and value (Lee et al., 1996; Edriss et al., 2007; Kelly et al., 2007; Rowe, 2010), accounting for about 50% (Figure 3.2) even up to 75%,of the sale price of clean wool (Jones et al., 2004; Cottle, 2010; Mortimer et al., 2010). Mean Fibre diameter (MFD) and diameter distribution provide a measure of the finest yarn which can be spun (Warn et al., 2006; Cottle, 2010), as well as the handle and skin comfort of the ultimate garment. Fine wools can be processed into fine yarns, which are suited for high value clothing textile end uses (Warn et al., 2006; Rowe, 2010), producing fabrics which are of characteristically light weight, soft, with superior handle and drape (Cottle, 2010). Coarser wools on the other hand are particularly suited for less luxurious and lower priced applications, such as household textiles, for example carpeting, outerwear and bedding (Poppi and McLennan, 2010).

According to Petrie (1995), the properties of wool not only determine its price but also the products for which it is suitable, Figure 3.3 shows the broad applications of wool according to fibre diameter. From Figure 3.3 it is apparent that the fibre diameter required for making worsted fabrics is within the fineness range from about 17 µm to 27 µm, which represents the range within which Lesotho wool falls. The woollen and worsted systems of processing are both used for the production of clothing fabrics, including garments worn next to the skin. Lesotho wool is yet to be scientifically assessed for suitability in clothing, blankets and upholstery, as well as in other household items.

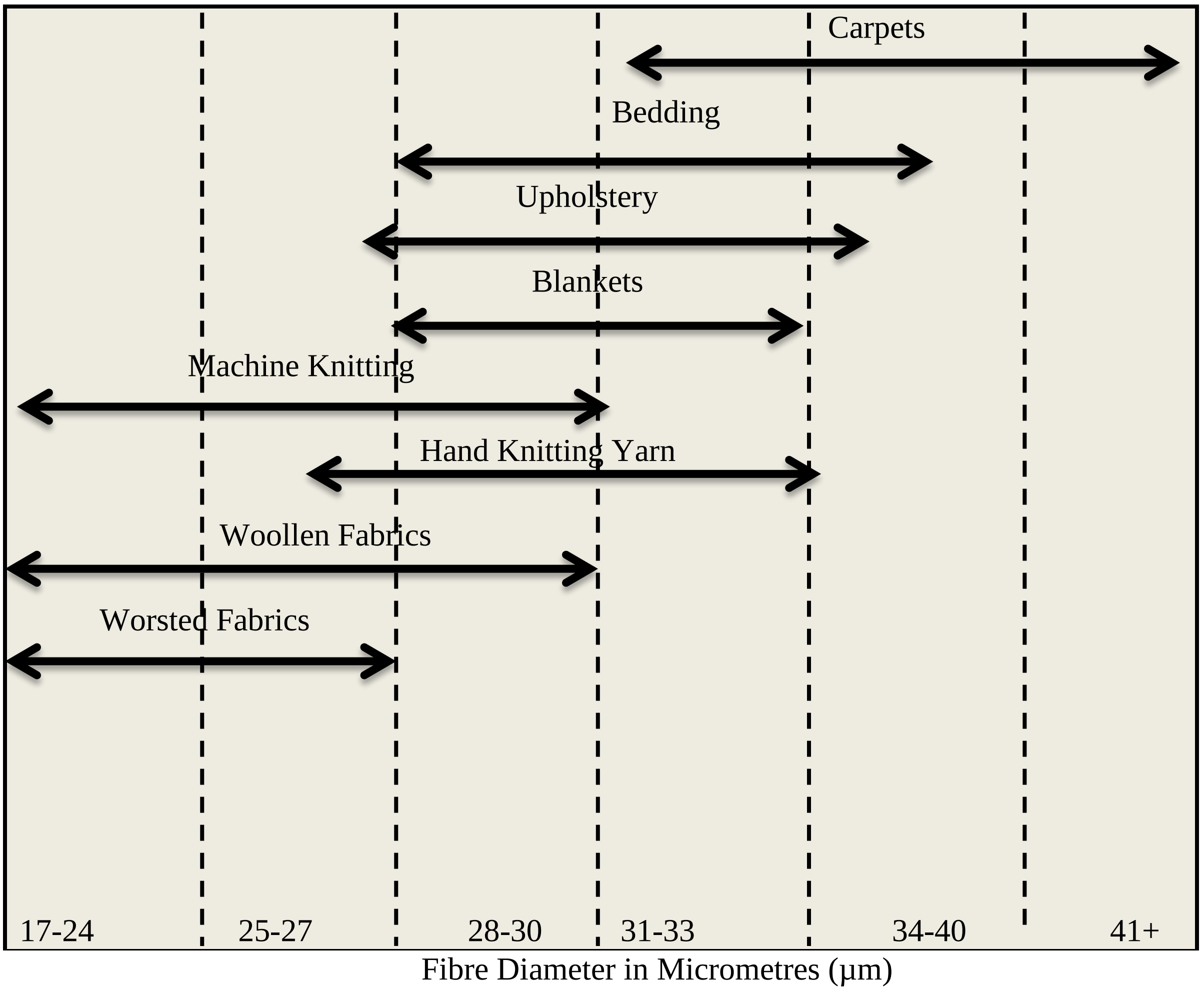


Figure 3.3: The ultimate use of wool according to fibre diameter (Petrie, 1995)

3.2.1.1.1 Measurement of Fibre Diameter

Fibre diameter refers to the average width (diameter) of the fibre cross section, which is measured in micrometres (µm), generally referred to as micron, either by airflow, a conventional microscope, laser or image analysis (IWTO, 1995; Cottle, 1991; Cottle, 2010; Poppi and McLennan, 2010; Rowe, 2010).

Fibre diameter (FD) is today measured relatively routinely, rapidly, accurately and cheaply, using any of the following instruments: 1. Sirolan-Laserscan™ fibre diameter analyser, the most commonly used technology, whereby a laser quantifies the FD values; 2. Optical Fibre Diameter Analysis (OFDA), using an automated scanning light microscope and image analysis; and 3. Airflow, which uses the airflow through a plug of wool fibres as a measure of diameter FD. The latter has become less utilised with the advent of the two previously mentioned instruments, which are not only more efficient and accurate, but also provide valuable additional information, such as fibre diameter distribution, Coarse Edge (CE) and Comfort Factor (CF) (Larson, 1992; Hatcher and Atkins, 2000; Botha and Hunter, 2010; Tester, 2010; Li et al., 2011).

3.2.1.2 Staple Length

The measurement of wool staple length (SL) has become increasingly important in terms of wool quality and value (Edriss et al., 2007; Valera et al., 2009; Gillespie and Flanders, 2010). It is usually expressed in millimetres (mm) (Thompson et al., 1988), and is mostly measured using the CSIRO 'Automatic Tester for Length and Strength (ATLAS) instrument (Thompson et al., 1988; Pfeiffer and Lupton, 2001). The staple length is generally measured from the base to the tip of the staple, without stretching it (Schoenian, 2015). Staple length is linked to wool processing performance, longer wools, up to about 90mm in length, are generally more valuable, as they tend to be easier to spin, with fewer stoppages and spinning and breaks, and ultimately can form stronger and more even yarns, provided they are not "overlong" (Angel et al., 1990; Wood, 2003; Edriss et al., 2007; Wood, 2010). Shorter wools, or high levels of short fibres, are more difficult to process and tend to result in fuzzing and pilling on the fabric surface, as well as fibre loss both during processing and use (Wood, 2003; Valera et al., 2009; Cottle, 2010).

Staple length plays a role in determining the processing and fabric manufacturing systems used (weaving or knitting), and end use of the wool. Longer wools (60 – 70 mm) are generally processed on the worsted system into woven products, while shorter wools (50 mm and shorter) tend to be processed into yarn on the woollen system which is then mainly used for knitting.

3.2.1.2.1 Staple length measurement

Although there are a number of instruments that can be used to measure staple length, the Automatic Tester for Length and Strength (ATLAS) is by far the most commonly used, particularly for trading purposes. In this system of routine measurement, staple length is measured by conveying the staple, tip first, through a vertical array of eight light beams, the distance the conveyor moves, while the light beams are interrupted, providing a measure of staple length. All the sampled staples are measured for length, regardless of the staple dimensions. The IWTO-30-2007 Staple Length and Strength for Greasy Wool Standard requires that a minimum of 55 staples be measured for length per sample to produce a certified result.

Lesotho wool and mohair only started being measured for staple length during the 2007/2008 shearing season; its introduction was most probably as a result of buyers requesting this to assist them in their purchasing decisions.

3.2.1.3 Staple strength

A general definition for staple strength (SS), is the strength shown by a staple specimen subjected to a tensile force or tension, generally expressed in terms of a force per unit cross-sectional area (AWI, 2007). Some common units used to express the strength are Newtons per square metre (N/m^2) and pounds –force per square inch (psi). Nevertheless, in textiles in general, and staple strength in particular, staple strength is expressed in Newtons per kilotex (N/ktex). The term tensile strength is often used interchangeably with staple strength, the latter being defined as a measure of the force required to break a wool staple of a given thickness (in kilotex), recorded as Newtons per kilotex (N/ktex). Fibre strength determines wool's ability to withstand vigorous mechanical processes which imparts stresses and strains on the fibre. Staple strength relates to the processing efficiency of wool, particularly the amount of fibre breakage and wastage during combing (Scobie et al., 1996). It has become one of the most important characteristics for determining the value of greasy wool and the average fibre length that will be achieved when the wool has been processed into wool top.

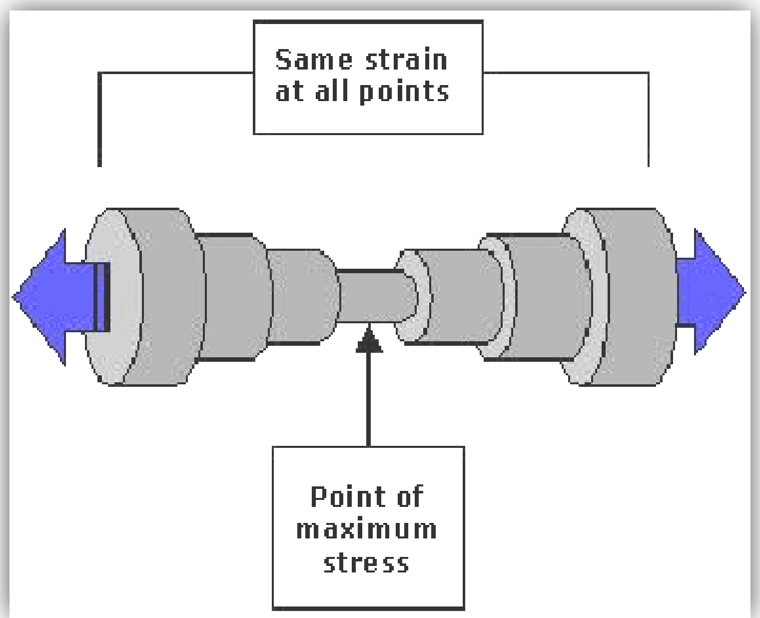
Staple strength is an important driver of merino fleece value, and has been steadily growing in importance over recent decades (Swan, 2012). Because of the value attached to staple strength, wool growers can expect increasing trade recognition and preference for wool of high staple strength and low mid-break (Snowder, 1992, Cottle, 2010 and Holman and Malau-Aduli 2012), auction data showing that prices generally increase as staple strength increases. The presence of tender wool, or wool with a break (weak or tender place) along the staple of the fibre (weak or thin fibre segments), greatly diminishes the value of the wool fleece (Schoenian, 2015). According to AWI (2007) the clean price of 17.5 µm wool declined by about 1 % for each unit decrease in staple strength below 40 N/ktex. Generally, wool with a staple strength less than 30N/ktex has a weak point (tenderness or “break”) somewhere between the ATLAS jaws.

In cases where the ASTM D2524-13 and IWTO-30-2007 standard methods of testing are used, both the staple length and strength are measured by one testing machine (ATLAS). In this case, after the length measurement has been made, the staple is picked up by two rubber belts which feed it through to a jaw which grips the tip of the staple. The jaw then moves away until the base of the staple is clear of the rubber belts. In other cases, IWTO-32-2005 may be used for bundle strength testing of wool fibres (IWTO, 2015). The tip jaw moves away until the staple is broken in two. The peak force required to break the staple (*measured in Newtons (N)*), is used to calculate the staple strength (ASTM, 2013 and IWTO, 2007).

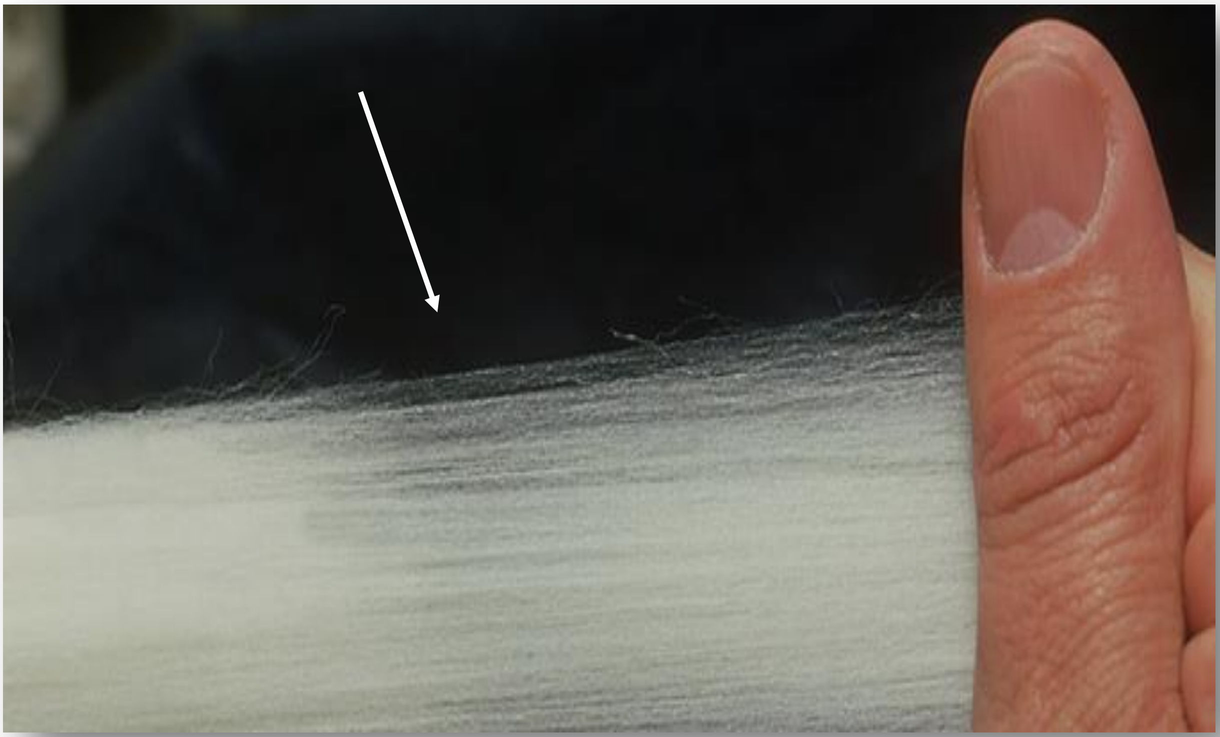
3.2.1.3.1 Point/position of break (POB)

The Position of Break (POB), measured in conjunction with staple strength, is a measure of the position along the staple (base, mid or tip) where it will break, given enough force. Both sections of the broken staple are weighed after the strength test, the results being used to determine whether the staple broke at its base, middle or tip (regions). The POB indicates to the processor where fibres are likely to break during processing, and the length of the broken fibre sections, and also that in the top. For example, if a staple breaks at the tip, then fibre breakage during processing will result in broken fibres being either very short or rather long (most of the short fibres will be probably lost as card waste or combing noil). If the staple breaks in the middle, both fibre sections will be about equal length and relatively short. The POB is reported in terms of the percentage of staples which break in either the tip, middle or base thirds of the staple. From the processors point of view, the worst case would result if the majority of staples break in the middle; this drastically reduces the fibre length (Hauteur) in the processed top. Research has shown that Hauteur (i.e fibre length in the top) is closely related to the average staple length, staple strength and POB of the greasy wool. However, this is only of major importance to the processor if the staple strength of the sale lot is low (AWI, 2014). The point at which the fibres break is indicated by an arrow in Figure 3.4. Staple strength and mid-break percentage both largely determine the combing performance and top length characteristics.

According to AWI (2015), the price differences associated with POB can be seen across the entire clip. In fine wools, differences of around 150 cents per kg are possible between a very low mid-break of single figures, and a mid-break in the 80 to 90% range. Most mills now specify a maximum percentage mid-break for a delivery; this requirement makes POB an important parameter for both woolgrowers and buyers.



a) Diagram showing a fibre stress point (Australian Wool Innovation Limited, 2015).



b) Stretched wool staple showing POB (AWI, 2015).

Figure 3.4: Point of Break indicated and illustrated in diagrams a) and b).

3.2.1.4 Style

Style represents an immeasurable (subjective) means of identifying wool quality as described by AWEX-ID (Table 3.1), style being identified by numbers, referred to as Style Codes, an increase in numeric value indicating a decline in wool quality. **S**tyle Codes are described as a ranking scale, related to the visual appearance of the wool. AWEX-ID uses seven Style Codes from highest (1) to lowest (7), although the Wool-cheque restricts one to Style Codes 3 (Spinners) to 7 (Inferior/Stain). Style 5 is the most widely occurring style in Australia. Style 4 types are usually grown in the higher rainfall areas, while drought affected wool, with medium-to-heavy amounts of dust, will typically be appraised as a Style 6. Table 3.1 describes each wool fleece style according to its visual characteristics (AWI, 2015). These grades used for the measurement of style are, however, subjective, and not measurable as yet. It is also worth noting that style has a negligible effect on the processing performance of the fibres.

Table 3.1: Wool Style description according to AWEX-ID (Australian Wool Innovation Limited, 2015)

Style	Density	Character (crimp definition)	Length regularity	Tip type	Visual colour	Visual penetration of staple	Indicative yield range
3 Spinners	Dense	Good	Good	Square	White	Light	76% -86%
4 Best	Good	Good	Good	Square, some tippiness	White, some cream unscourable	Light (5-10%)	69%-79%
5 Good	Good, some thinness	Good, fair	Some variation	All	Good creamy unscourable	Light medium (8%-25%)	62%-73%
6 Average	Increasing thinness	Good, fair, poor	Some variation	All	Good creamy unscourable	Medium heavy (25-60%)	53%-63%
7 Inferior	Thin wasty open	Good, fair, poor	Some variation	All	Good creamy unscourable	Heavy (60%+)	30%-55%

Although there are cases in South Africa where the above codes are used, South Africa has its own set of specific codes also used to brand the stained, lox and various other attributes, these being classified according to location on the animal and miscellaneously.

3.2.2 General properties of wool

Wool is one of the preferred as a natural fibre mostly for its biodegradable nature (Woolmark, 2017); some of its properties are described below.

1. **Comfort:** wool is generally a poor conductor of heat. This property is preferred in wool for outer garments worn mostly in cold weathers and it makes wool an insulator. This is one reason wool is commonly used in winter clothing. Wool is also highly absorbent and wool can absorb moisture quickly without feeling damp, garments made from wool can be worn comfortably in the rain but cannot replace rain clothing.
2. **Resilience:** Wool has a notable level of elasticity as a result of the helical structure and the overlapping scales on the surface of wool fibres. Therefore garments made from wool regain their shape after being washed. To retain its shape wool garments have to be washed using the kneading and squeezing method and dried on a flat surface.
3. **Flammability:** similarly to human hair, wool is easily damaged by high temperatures; this makes hot water unsuitable for washing wool. However wool does not catch fire easily, instead it smoulders when set alight.
4. **Shrinkage**: Wool shrinks easily when friction, moisture and temperature changes are applied. The application of these changes in conditions may lead to the wool scales interlocking and being bound together permanently to product a matt of fabric. A process called felting used for fabric construction when done intentionally. Great care must therefore be taken when washing wool to avoid damaging it.
5. **Breathability**: Wool is highly breathable; it can absorb sweat and remain relatively comfortable.
6. **Strength**: Relative to other keratin fibres wool is weak, and it becomes even weaker when it is wet.
7. **Soil resistance:** Owing to the fluffy surface wool has, it soils relatively easily.
8. **Others**: Unless it is treated, wool is easily damaged by moth, bacteria and mildew especially if it left with notable moisture in it. It is also easily damaged by alkalis and bleaches but is

resistant to mild acids.

3.2.3 Lesotho wool production

Lesotho wool production figures relate to the actual weight of greasy fibre produced in the country. The total amount of wool produced nationally is usually recorded, for purposes of this study, average percentage yield is estimated for each district. This is done by dividing the average yield by the number of animals.

3.2.3.1 Yield

Two measures of the amount of "clean wool" are generally used in commercial trading, namely Yield and Wool Base (WB), Yield being defined by SGS (2011d) as the amount of useful (clean) fibre that can be obtained from a known weight of greasy or raw wool. Wool base is the amount of dry wool theoretically available from the greasy wool, defined as the oven-dry weight of wool fibre, free of all water-soluble matter, grease, minerals and alkali-insoluble matter; generally referred to as vegetable matter. In essence, therefore, wool base is the amount of pure dry (bone dry) wool fibre, expressed as a percentage of the total weight of greasy material, it can accurately be determined by scouring core samples, determining the oven dry weight and then the residual impurities can be measured. This process is essential if the tested lot is intended for commercial use. It is, therefore, the weight of clean wool after the removal of all impurities, both natural and acquired. Yield, on the other hand, estimates the quantity of usable wool fibre in a lot (New Zealand Wool Testing Authority, 2014). Yield is the amount of wool plus residual impurities left after scouring. It is usually expressed as a percentage of the original "greasy" fleece weight. "Shrinkage" in wool is comprised of wool grease also known as lanolin, sand, dirt, dust, and vegetable matter (VM). Wool Yield can vary from about 40 to 70 %, and is affected by many factors, both genetic and environmental (Schoenian, 2015). Yield is also commonly referred to as clean washing yield in many reports.

The measurement of Yield and Wool Base is laborious, involving a number of stages, including coring, batching, greasy sub-sampling, scouring, drying, residual sub-sampling, VM dissolving and dissection, residual grease extraction and wool base calculation (AWTA, 2002). The calculation of Yield involves adding an allowance for moisture, expressed as regain, which is the weight of added moisture expressed as a percentage of the wool base, plus the allowance for the residual ash and alcohol extractives. The raw wool is generally traded on clean wool fleece present (CWFP) basis, traditionally consisting of wool base (86 %), moisture (12 %), residual grease (0.5 %) and alcohol extractable matter (ASI, 2000). To calculate the CWFP, ASTM uses a regain of 13.64 %, and ash and alcohol extractives of 2.27 %, the formula used for the calculation being: ASTM CWFP (%) = $\frac{[WB \times (100 + Regain\%)]}{(100 - 2.27)} = \frac{WB \times 113.64}{97.73}$

$$= WB \times 1.1628 \quad (8)$$

3.2.3.2 Clean Fleece Weight

Clean fleece weight (CFW) refers to the total greasy wool weight minus grease, suint (as defined in the contextual terms), dust and vegetable matter contaminations, expressed as a percentage (Thornberry and Atkins, 1984; Jones et al., 2004; Rogers and Schlink, 2010). In addition, CFW thus refers to the yield of usable wool fibres present within unprocessed greasy wool (Cottle, 1991). Hence, it is a function of non-fibre levels within a fleece (Thornberry and Atkins, 1984; Rogers and Schlink, 2010). Hatcher et al., (2008) investigated the potential use of post-shearing applied sheep coats and found that their utilisation reduced levels of dust and vegetable contamination within a fleece, proving more effective in specific environmental and seasonal conditions. This finding may benefit local (Lesotho) farmers, because CFW has some influence in determining the commercial value of wool (Banks and Brown, 2009; Mortimer et al., 2010). Originally, CFW was determined by scouring a whole individual fleece (Johnson and Larsen, 1978), but this process was time consuming and expensive. Instead, it has been found that using just a small representative sample, commonly taken as a 'core sample', from a wool bale (Johnson and Larsen, 1978), can provide a highly accurate indication of CFW (Sidwell et al., 1958).

3.2.3.3 Vegetable Matter (VM)

Additionally, vegetable matter (VM) is one of the residual impurities found in wool, and can be defined as the oven-dry mass of ash-free ethanol-extractive-free burrs including hard heads, twigs, seeds, leaves and grasses present, expressed as a percentage of the greasy mass of the sample. Vegetable matter, in its different forms, contaminates textiles and it is very undesirable, and very tedious and expensive to remove. Consequently, VM in raw wool is heavily discounted in the auction room. It is possible for the value of contaminated wool to be 50% or less than similar wools with low levels of VM. It is therefore, in the interest of farmers, wool brokers and textile manufacturers that VM contamination is minimised.

As sheep come into contact with pieces of burrs, seed, shives, leaves, twigs and grasses, and other plant (cellulosic) matter, all commonly known as vegetable matter (VM), the above remains on the surface and within the fleece of sheep. Finer wools are more prone to VM contamination, especially burr entanglement and its adherence; this increases the carding and spinning waste (Singh et al., 1983). The cellulosic matter forms part of the impurities found in wool, and depends on the characteristics of the regular grazing site of the livestock. For instance, it has been recorded that hemp, sisal and agave fibre material were recovered from livestock, which grazed at the sites where such fibres were abundant (ASTM, 1997). In the AWEX-ID typing system, vegetable matter is grouped into seven main types, as shown in Table 3.2. VM is partially responsible for low yields. Because of the presence of other non-wool matter in wool, total residual impurities can basically be expressed as follows:

$$\text{Total residual impurities} = \text{Alkali soluble \%} + \text{Ash Residue\%} + \text{Fatty Residue\%}$$

Vegetable matter remains the most common and important type of impurity. It has a notable impact on the commercial processing of wool, since its removal, during processing, can be costly, and may possibly need the wool to undergo an additional carbonising process, depending upon the severity and type of VM present. Carbonising is a relatively complicated and expensive process, where wool passes through sulphuric acid bowls and drying and baking ovens before rollers crush the now brittle VM. This process is time consuming and usually involves comparatively high fibre losses and potential fibre damage (AWTA, 2002). VM is therefore another component of wool quality, also impacting negatively on yield, because the removal thereof often reduces the total percentage of fibre realized, since a certain amount of fibre tends to be removed with the VM.

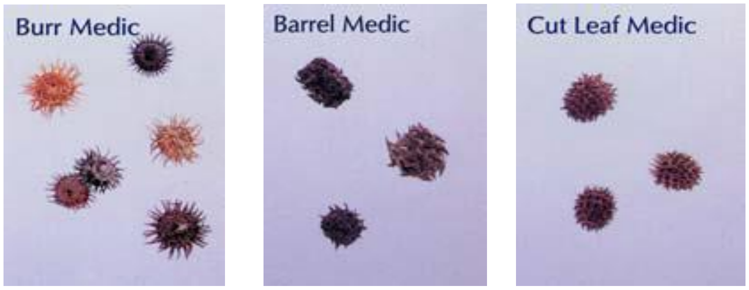
The amount of VM in greasy wool influences the yield; the amount and type of VM affecting the method, speed and cost of processing (AWTA, 2014). Many types of VM can be readily removed by machinery throughout processing; the total cost of attaining clean wool fibre being a crucial consideration in the value of raw wool. Table 3.2 gives the different types of vegetable matter found in wool, with both AWTA and AWEX-ID abbreviations commonly used in wool production and quality assessment being shown. The type of VM found in wool also determines the extent and complexity of its removal.

Table 3.2: Categories of Vegetable Matter found in Wool (AWI, 2017)

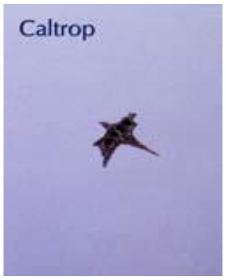
AWTA Categories	**AWEX-ID**	**Types of Vegetable Matter (VM) in the AWEX-ID Typing System**
B	**B**	Burr: barrel medic, burr medic (B B)
B/E/S/H	**E**	Seed: sub clover, carrot seed, scotch thistle
S	**S**	Shive: barley grass, wild oats (S S)
H	**N**	Noogoora burr (H N)
H	**T**	Bathurst burr (H T)
	M	Moit (M)
S	**F**	Bogan Flea (S F)

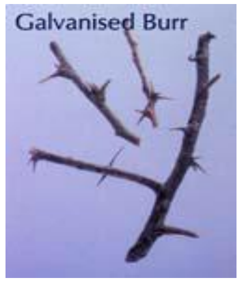
Figure 3.5, shows pictures of the different types of VM likely to be found in wool. It is the shape, nature and appearance of each type of VM, which largely determine the difficulty of its removal from the wool, this influencing the cost of removal and discounts such a contaminated fleece attracts.

Most of the types shown in Figure 3.5 are likely to be found in Lesotho wool as there are plants yielding similar seeds, barks and stalks growing naturally in Lesotho highland areas. Most farmers rear sheep in the highland areas because of the abundance of pastures. The grasses are mostly found in the lowlands and foothills.

a) 

B B

b) 



H E

c) 

S E

d) 

B E

e) 

S S

f) 

H N

g) 

H T

h) 

S F

Figure 3.5 {*a) to h)*}: Major Vegetable Matter Types. *Symbols in red are the ones used by AWTA Categories and black by AWEX-ID* (AWTA Limited, 2014) www.woolwise.com/wp.content/uploads

The burr (B) type of vegetable matter is relatively easy to remove, as they locate mainly on top of the fleece or fibre. Care still has to be taken though, because they can possibly shatter and spread throughout the slivers after being processed. Nevertheless, a high percentage of this type of VM is usually tolerated, especially the "medic group". This could be attributed to the fact that thicker VM particles can be removed more efficiently than thinner ones (Atkinson, 1986). The Shive (S) type is fibrous and most difficult for processors to remove, since they align with the fibre during combing and can pass through to the final fabric, resulting in the largest discounts (AWTA, 2002). In its classification, AWTA puts Seed and Shive (S) together in one class, there being another class, referred to as Hard Heads and Twigs (H) (McGregor, 2003a). Nevertheless, all forms of plant matter are included in the classes.

3.2.3.3.1 Vegetable Matter Management Tips

There are a number of ways to reduce VM levels in a wool clip. The AWI's market intelligence in Woolcheque (2014) gives some helpful tips in grazing and shearing, also suggesting the use of sheep coats. The VM in the fleece may be reduced effectively by employing preventative VM management strategies and occasionally even plucking it out manually, as practiced by some farmers in Lesotho. It has been estimated that the Australian wool clip used to contain about 10 million kilograms of VM in each season (AWTA, 1986).

3.2.3.3.1.1 Grazing

According to Brownlee and Denney (1985), the conditions under which sheep graze, including the type and density of plants and rainfall, greatly affect the amount and type of VM in the fleece. Managing the grazing pressure (stocking rate) can also alter the type and amount of vegetable matter (Fleet and Langford, 2013). There are a number of strategies that can help to reduce VM, including herbicide spraying, to modify the composition of the pasture land (Brownlee, 1973), and cutting the plants at key times of the year. Changing pasture types can also be helpful, although this may have other adverse long-term management implications. Matching the stocking rate to carrying capacity of the pasture-land during the year, and cell grazing, contribute positively to the reduction of VM contamination in fleeces.

3.2.3.3.1.2 Shearing

To reduce the percentage of VM, shearing can be timed so that sheep carry short wool at the time of greatest exposure to seeds, burrs and other contaminants (AWI, 2014). The sheep should therefore be shorn before seeds mature. The frequency of shearing also has an impact on the levels of seed and burr in the wool; although more regular shearing, done more than once per year, may prove uneconomical. This practice can, however, reduce the chances of wool contamination and VM levels in fleeces. The decisions regarding the shearing options, as a preventative measure of VM, must be done with the pasture systems in mind and the species of plant in a specific pasture-land, since different species do not mature and scatter seeds at the same time (Warr and Thompson, 1976). While it can be tempting to skirt heavily at shearing time to reduce high levels of VM in fleece wool, studies have shown that this practice is not economically efficient (AWI, 2014).

3.2.3.3.1.3 Sheep coats

An AWI study, involving1200 sheep in Western Australian (AWI, 2014), found that VM can be significantly reduced by using sheep coats. Fleeces from non-coated animals had an average VM of 2.0 %, while fleeces from coated sheep had an average of 0.7 %. Sheep coats improved the value of the wool sold by an average of $3.40 per head, and in some cases by up to $8.51 per head (Hatcher et al., 2003). Sheep coats not only reduce VM levels but also increase yield, as residual impurities are generally reduced (Brownlee and Denney, 1985). Fleece rotting is also reduced by sheep coats (AWI, 2014)

The major benefit of using sheep coats is the reduction of contaminants in greasy wool, and this reduction can reduce losses in carding and improve the quality of the top produced. AWI (2014) reported some of the identified positive effects that the use of sheep coats have on the fleece, including:

- Some raw wool characteristics are positively influenced by the practice of coating sheep, especially VM, yield and weathering. In cases where VM is a problem, the VM levels are reduced to "Free or Nearly Free" (FNF) levels, i.e. less than 1 % VM for sheep coated for 12months. Coating sheep tactically for 6 to 7 months, reduces the average VM by approximately 2 % on average.
- Style is also positively impacted, usually improving by approximately one style grade on average.
- Carding losses are reduced by coats, most likely as a result of reduced tip weathering and VM levels.
- Romaine tends to be lower for wool from coated sheep, with Top and Noil yield significantly increased, again as a result of improved wool quality.

As already mentioned, VM does not only impact the quantity, but also the quality of raw wool, aspects such as style, weathering and reduced carding losses, representing some of the positive quality impacts and advantages of using sheep coats.

3.2.3.3.2 Testing tops for Vegetable Matter

The ASTM test method D1770 is suitable for determining the pieces of vegetable matter by size; class and number, number of neps and the number of coloured fibres. This standard may also be used for the acceptance testing of commercial shipments of wool top, as it is applicable to wool tops in any form (ASTM, 2012). Coloured fibres in wool tops can be described as those fibres having a colour or shade differing from the normal colour or shade of the fibre mass (fibre population). To sample the wool tops for this test, a length of specified mass, taken at random from a length of wool top, is selected as a laboratory sample (ASTM, 2000). The Wool Testing Authority Europe (WTAE) has a specialised computer system that calculates the percentage for each subsample, and merges them to calculate the average for each individual test.

The procedure followed in ASTM D1770-94, involves the examination of each specimen for neps or pieces of vegetable matter, and classifying them by size, using visual comparison with a specified standard size chart. The numbers of each impurity are recorded, for each specimen, then averages are calculated from the recorded data (ASTM, 2012).

Although the overall vegetable matter (VM) content is expressed as a percentage, its content is first calculated by weight, it is important to note that the different categories will have different weights, dependent upon their apparent size and volume (WTAE, 2014). Figure 3.6 shows vegetable matter, of the same weight but different classes, found in wool.

Figure 3.6: Different Types of Vegetable matter found in wool (Wool Testing Authority Europe, 2014).

3.2.3.4 Value of Lesotho wool

The quantity of wool fibre produced will obviously have an influence on the total monetary value realised in each sale season. Nevertheless, the quality of the fibres, as also the demand and supply, all have a very notable impact in determining the auction price. As an example, the demand for Lesotho wool was really low during the 2009/2010 season (SARC Department, 2013), with the monetary value realised being correspondingly low.

3.2.4 General - Wool processing systems

Both staple length and strength significantly influence the processing of wool. There are essentially two main wool-processing systems, namely the worsted and woollen systems, the distinguishing feature of the worsted system being the combing process. When used in its broadest sense, combing embraces all operations employed in top making. As a single process, it is, however, indispensable in the production of worsted yarns. The combing process aligns the fibres more parallel and removes neps and short fibres' undesirable for the smooth finish of worsted yarn, as well as stubborn impurities, such as the residual vegetable matter.

The worsted system essentially consists of two processing stages, namely top-making and spinning, the system entailing scouring, carding, gilling, combing, drawing, roving and spinning, wool tops being converted into rovings which are then spun into yarn, usually employing ring spinning. The worsted processing system generally produces smooth yarns and fabrics (Celanese Acetate, 2001). The woollen processing system is much shorter than the worsted system, involving scouring, sometimes carbonizing, carding and spinning, generally producing more bulky, coarser yarns, with the fibres in woollen yarns being more randomly arranged than those in the worsted yarns (Celanese Acetate, 2001 and Mouqeet, 2011). Figure 3.7 illustrates the various steps involved in the woollen and worsted processing systems.

Fabrics produced from worsted yarns are not necessarily superior to those produced from woollen yarns (Johnson, 2012), each type of yarn being suitable for a specific type of fabric. Tweed is an example of a woollen fabric; gabardine is an example of a worsted fabric. Often worsted fabrics are used in the manufacturing of woven apparel, some carpets and fine upholstery while woollen yarns are often used in knitting and in the production of tufted carpets and velours.

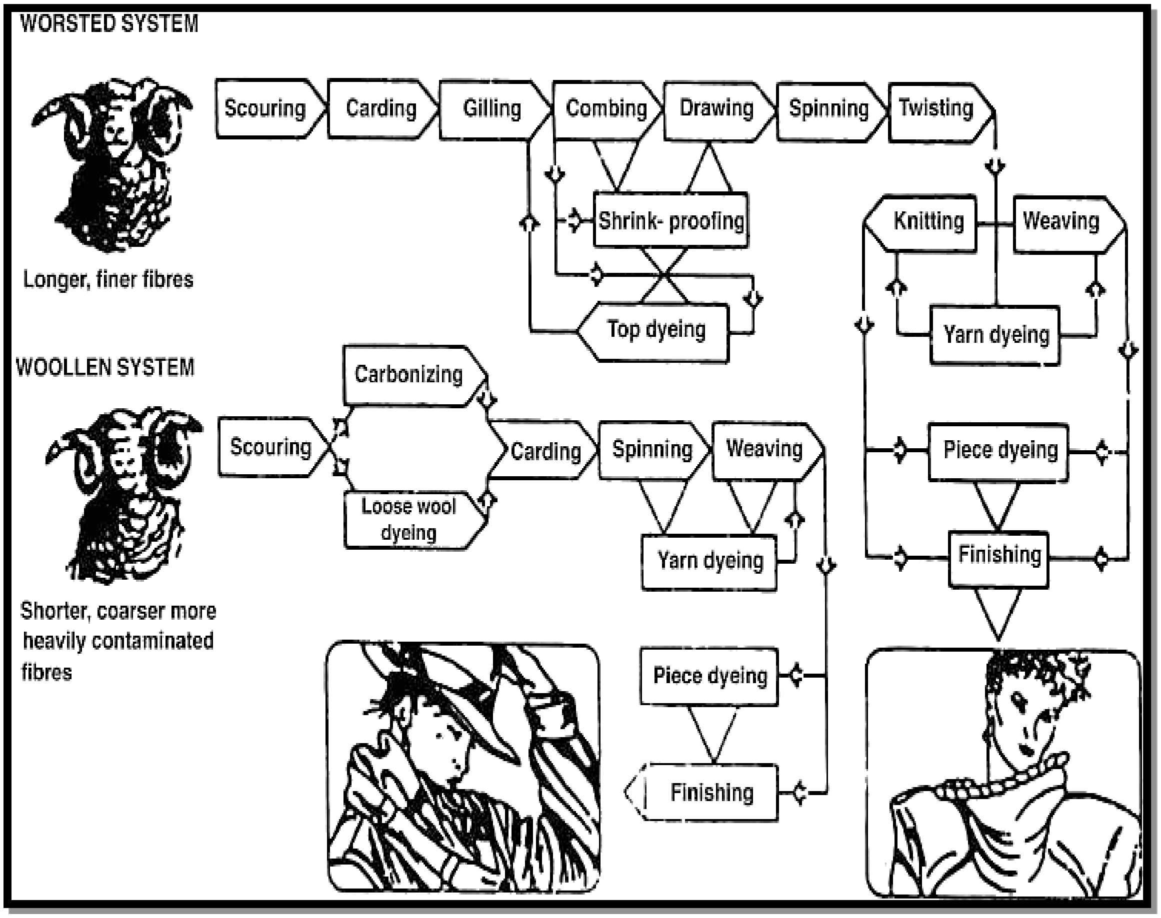


Figure 3.7: Steps involved in woollen and worsted wool processing. Whiteley, (1987).

3.3 MOHAIR CHARACTERIZATION

3.3.1 Overview

Alongside wool, most Lesotho farmers also produce mohair, the lustrous fleece of the Angora goat. It is one of the most important specialty **animal fibres,** even though it represents less than 0.02 % of the total **world fibre production.** Mohair fibre is largely produced in South Africa (the main producer) and with Lesotho the second largest producer, as well as in the United States of America (Texas), Turkey, Argentina, Australia and New Zealand, South Africa presently accounting for almost 50 % of the world production of mohair.

The surface structure of mohair is similar to that of wool, both being covered by a layer of cuticle cells, known as epidermal scales. These cells overlap each other, with their exposed edges towards the tip of the fibre (Fraser, 1972 CSIRO, 1987 Smith, 1988 and Hunter, 2002). Although mohair is similar in appearance to wool under a microscope, the epidermal scales of mohair are generally less pronounced than those of wool. They are anchored much more closely to the body of the fibre; this arrangement makes the scales less prominent and only faintly visible, making mohair smoother than wool and giving the fibre its well-known characteristics of smoothness, low directional friction, low felting, high lustre and gloss (Hunter, 2010 and Petrie, 1995). The cuticle scales are quite thin and flat, generally being less than about 0.6μm and typically 0.4μm in average thickness (height), and hardly overlap (Hunter, 2010). Another difference between wool and mohair fibres is that the mohair fibre is almost perfectly round while the wool fibre is slightly elliptical. Figure 3.8 illustrates a fine structure of mohair fibre schematically. (see appendix 7 for comparison).

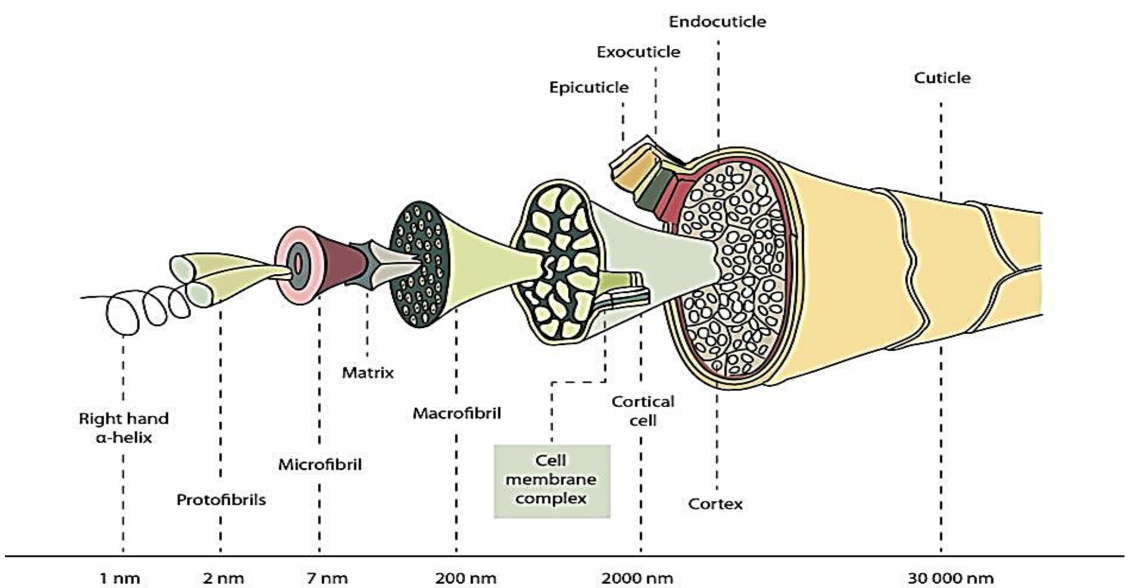


Figure 3.8: Mohair fibre structure (Hunter, 2010)

3.3.2 Mohair Characteristics

Mohair has special textile properties, being particularly known for its outstanding lustre. There are many reports dealing with the relationship between mohair attributes and processing. While mohair production can be profitable to farmers, there are severe price discounts for faults and poor quality. Genetics is known to affect mohair quality, with no apparent fundamental relationships between body size and mohair quality characteristics apart from fibre diameter (McGregor et al., 2013 b).

Mohair fibres are not good conductors of heat and provide good insulation, even when wet. Mohair easily absorbs and releases moisture, moving perspiration away from the skin for evaporation; this is one of the reasons why it is comfortable to wear in both cold and hot weather (Hunter, 2010), and why bacteria do not proliferate on mohair. Nevertheless, it is important to mention that air is a much better insulator of heat than mohair and that the amount of air entrapped in a textile material is far more important than the type of fibre, in terms of thermal control.

According to Jenschke (2001), some of the properties that mohair possesses include the ones listed below. The first five mohair properties listed are more valuable commercially, while those listed thereafter, may make mohair products to be preferred by ultimate consumers relative to textiles made from other fibres.

3.3.2.1 Commercially important mohair properties

1. **Lustre**: Mohair completely absorbs dye without losing lustre, making possible the brilliant colours which generally tend to resist fading with time or hard wearing, a consequence of the ability of lustre to reflect light which in turn yields bright colours.
2. **Moisture transfer**: Mohair absorbs and releases moisture easily, moving perspiration away from the skin and making it comfortable to wear in all types of weather. In addition, mohair is breathable, resistant to odour; soil; shrinkage and blisters.
3. **Easy to Wash** – Mohair's smooth fibres (low directional frictional effect) do not felt easily, resulting in less shrinkage than wool during laundry. Garments may be washed in tepid water containing a mild "hand-washing detergent," without felting. Mohair garments may be tumble dried in a pillowcase on a low, "gentle" setting. The relatively smooth surface of mohair also makes it a bit difficult for bacteria and dirt to settle on it.

4. **Insulating capacity**: Hollow fibres do not conduct heat, but provide good insulation even when wet. This only applies, however, to the medullated fibre component of mohair, which is relatively low in good quality mohair.
5. **Lightweight** – Mohair textiles are more likely to be lightweight in relation to textiles made from other fibres, making it possible for mohair to be made into cool fabrics, perfect for summer clothing.

Other properties contributing to the preference of mohair products

6. **Durability**: Mohair fibres can be twisted and bent repeatedly without sustaining severe damage. This is attributed to mohair's pliable (flexible) structure as opposed to a rigid (stiff) one (Hunter, 1993).
7. **Comfort:** Mohair fabric and yarn are non-allergenic, even to people with a sensitive skin, but can cause prickle. This is, however, dependent upon the diameter and length of the protruding fibre, since relatively coarse (>30 µm) and short protruding fibres can cause prickle.
8. **Strength**: Mohair also has a high tensile strength (Petrie, 1995), being stronger than steel of the same weight.
9. **Elasticity**: Mohair is extremely elastic and can stretch up to 30 percent of its length and still spring back to its original shape (Hunter, 1993).
10. **Non-flammability**: Mohair will not burn unless exposed to direct flame, when burning it forms an ensurelative char which inhibits further spread of the flame. It tends to be self-extinguishing.
11. **Soil Resistance:** mohair resists soil well; this is because dust does not settle on mohair's slippery fibres. The dust that usually adheres at the intersections of woven fabrics can be removed from mohair products easily by shaking or brushing Hunter, 1993).

3.3.2.2 Mohair applications

Mohair is fairly versatile and may be applied in various products. Mohair is highly sought after for both clothing and home furnishings, used alone or blended with other fibres, notably wool. Mohair application in textiles goes back many centuries (Hunter, 1993). Other properties of mohair include high sound absorbency which makes it suitable for modern and antique designs for homes and public places in cold and warm seasons (BAGS, 2015). With its versatility; mohair has also been used successfully to make accessories, like hats, scarves, lounging boots and slippers; throws and blankets; carpets and rugs; and children's toys. The use of mohair in furnishing fabrics and hangings is advocated (Hunter, 1993). Through the ages, mohair is still appealing, and it remains a classic fibre, adapting well to new fabric and style interpretations.

A range of skillfully crafted pieces, which are less functional but harness the excellent qualities of this natural fibre, can be developed. According to Hunter (1993), the traditional "must-have" mohair products include stoles, blankets, scarves, travel rugs, ladies wear in fancy yarns, ladies couture clothes and mohair velour for furniture. Mohair garments hold their shape and resist wrinkling. The approximate relative applications of mohair are given in Table 3.3

Table 3.3 Recorded composition of the mohair clip application (Hunter, 1993)

Type of hair	Fashion application	% of clip	Competing fibres	Comparative non fashion value
Superfine and fine kid(24-28µm)	Variety of men and ladies wear. Highly sought after	**3**	Superfine wool, cashmere, alpaca, Angora rabbit hair	Limited production keeping the value relatively good
Kid (29-30 µm)	Men's and ladies wear. Sought after	13	Fine wool	Fair
Young goat (31-34 µm)	Men and ladies' wear household soft furnishings. Sought after	12	Wool and artificial fibres	Limited
Fine Adult (34-36 µm)	Knitting industry and brushed products. Limited when knitting is not fashionable	20	Wool and artificial fibres	Limited
Strong Adult (37-40 µm)	Brushed products, carpets and curtains. Other applications limited	50	Lustre wool and artificial fibres	Extremely limited at price of or lower than carpet wool

3.3.3 Mohair Quality

The end-uses, textile product quality and textile performance of mohair are determined and restricted predominantly by the quality characteristics of the raw fibre (Lupton 1993, McGregor et al., 2012, and McGregor et al., 2013b).

This section discusses the quality of Lesotho mohair fibre in relation to global standards. The limitation has been that only a few Lesotho mohair quality characteristics are measured, making comparison and benchmarking with other countries difficult and incomplete.

Mohair quality is closely associated with the price at which it is sold; it is common, therefore, to regard a high price as an indication of high quality mohair. While prices are also influenced by the demand at the time of sale, more often both price and quality are related to the characteristics or traits of the fibre, mainly fibre diameter, staple length, lustre, softness, style, character, level of contamination, clean yield and freedom or near freedom from kemp (Petrie, 1995). According to McGregor (2000), for mohair to attain the maximum price, a number of properties such as diameter, length, medullation, colour and contamination (in terms of vegetable matter) have to be at desired levels. The ideal levels of these attributes are given in Table 3.4, mohair that meets these standards being more likely to attract maximum prices (McGregor, 2000).

Table 3.4: Attributes of raw greasy mohair likely to attract the maximum price (McGregor, 2000).

Attribute	Maximum prices are received for
Mean fibre diameter	Kid mohair < 26 micrometer
Staple length	> 7.5 cm
Medullation	Visibly free, < 0.1%
Fibre colour	White
Style and character	Good style and good character
Contamination	Less than 1% vegetable matter

The extent to which the mohair quality attributes affect processing and influence market discounts, is reported in mean percentages in Table 3.5 (McGregor, 2000).

Table 3.5: Influence of Selected Attributes on Mohair market discounts and processing (McGregor, 2000).

Attribute	Range of discounts	Effects on processing
Mean fibre diameter	up to 45%	50 to 300%
Fibre length	up to 18%	25 to 40%
Medullation	up to 20%	50 to 100%
Style and character	up to 40%	5 to 50%
Contamination	up to 50%	30 to 70%

3.3.3.1 On-farm assessment of mohair quality

Although accuracy and uniformity are not always ideal, the objective assessment of mohair is best. Nevertheless, most farmers can only assess the fibre traits subjectively on their farms. Some of the mohair traits that can be assessed subjectively in fleeces, include staple length, staple definition, staple crimp (wave) frequency, staple crimp (wave) uniformity, staple tip appearance, lustre and vegetable matter content. Visual inspection is used to assign mohair style grades and staple length categories during mohair marketing (van der Westhuysen et al., 1988 and Clancy, 2005). Style grading often includes a number of staple characteristics, such as the number of crimps or waves per centimetre, staple style, described as the number of ringlets or twists per centimetre, and staple lock uniformity, staple tip definition, uniformity of staple length, lustre and dust penetration. According to one study, assignment of a poor mohair style typically results in a discount of about 22 % compared with average style mohair, after accounting for other fleece quality attributes (McGregor and Butler, 2004).

In Lesotho, the quality of mohair is currently assessed subjectively by traders for their own trade decision-making process, fleece mass (weight) being the only attribute measured objectively in order to determine production in the sheds. For objective assessment, except in 2018 when all the wool and mohair were only sold locally, for years Lesotho mohair has been sent to South Africa to be tested at the Wool Testing Bureau in Port Elizabeth, Eastern Cape. The differences in the curvature/crimp of mohair and wool are illustrated in Figure 3.9. wool curvature (crimpiness) is one of the properties evaluated subjectively by viewing the extent of the crimp, and assumptions drawn based on the common believe that curvature is directly associated with crimp, the extent of which is often determined by the mean fibre diameter and breed of sheep in the case of wool. The concept of curvature is only mentioned here because even though curvature/MFD is not a perfect relationship, and the fact that there are many other factors at play in this relationships, such as the type of sheep, season, farm/farming practices, fibre length growth and others; curvature is still used as a means of subjective assessment of fineness in Lesotho. This is generally done by the local private traders mostly for wool though.

Figure 3.9: Wool and mohair curvature (crimp) assessment (Land Learn, 2017)

3.3.3.2 Mohair Fibre Diameter

Market valuation of mohair is largely based on the fibre diameter and staple length, finer and longer mohair being generally more highly valued (McGregor and Butler, 2004). Mean fibre diameter is the main parameter that determines the quality and price of raw (greasy) mohair (McGregor 2007, and Botha and Hunter 2010), maximum prices being paid for 24 to 26 μm mohair. On average, mohair prices fall by about 5 % for each 1 μm increase in the mean fibre diameter. Mohair fibre diameter has been identified to have a significant influence on its price (Van der Westhuysen, 1982) which seems to stabilize at about 34 micrometer, at about 55 % of the maximum prices. The fibre diameter also influences top-making and spinning performance markedly (Strydom and Gee, 1985), affecting the maximum spinning speed, as well as a number of yarn and fabric properties (Hunter et al., 1985). The more desirable properties are generally associated with finer mohair (McGregor, 2000).

Demand for relatively coarse mohair, for use in tropical suiting material for Japanese markets, declined during the 1980s, due to the development of cheaper alternative yarns, using crossbred wools from New Zealand. Part of the reduced demand is based on the increased focus on comfort properties of textiles, in particular the perception of prickle in mohair fabrics (McGregor, 2007). The highest prices are nearly always paid for fine kid mohair. Mohair fibre diameter increases with goat age, this necessitates that, if fibre diameter is not measured on farm, the classification of mohair on the farm be done according to age group (van der Westhuysen, 2005). Table 3.6 shows a detailed classification of mohair fibres, and quality description of the mohair fibre by diameter. The great influence fibre diameter has on price is due to its role in determining processing performance and end use (Hunter, 1993).

Table 3.6: Mohair Grading according to Fibre Diameter

Quality Description	Mean fibre Diameter in micrometres (μm)
Super Fine Kid	24 – 26
Fine Kid	27 – 28
Good Kid	29 – 30
Super Fine Yearling	31 – 32
Good Yearling	33 – 34
Super Fine Adult	35 – 36
Good Adult	37 – 39

(BAGS, 2015).

Mohair classification in South Africa, is given in three ways, namely according to fineness, and animal age (see Table 3.7). Mohair is further classified according to length and strength at the same time; the three grade categories being broken down into quality sub-categories (see Table 3.8).

Table 3.7: South African classification of mohair (NAMC, 2012)

ANIMAL AGE (months)	GRADES	MFD (μm)
Kids (≤12)	Super fine Kid Fine Kid Kid	<26 26 – 27 28 – 30
Young Goat (up to 18)	Young Goat	27 - 34
Adult Goat (up to 24) and older	Fine Adult Adult	30 -34 >35

Table 3.8: South African mohair classification according to staple length and fibre fineness (NAMC, 2012)

	DESCRIPTION	SYMBOLS	MEASUREMENTS(mm)
Kid	**Good long fine**	**A/B**	**A ≥ 150**
	Average long fine	**A/B**	**B = 125-150 ⟵Ideal**
	Good long strong (coarse)	**A/B**	**C = 100-125**
	Average long strong(coarse)	**A/B**	**D = 75-100**
	Good medium fine	**C**	**E = 50-75**
	Average medium fine	**C**	
	Good medium strong(coarse)	**C**	
	Average medium strong(coarse)	**C**	
Young Goat	**Good long fine**	**A/B**	
	Average long fine	**A/B**	
	Good long strong(coarse)	**A/B**	
	Average long strong(coarse)	**A/B**	
	Good medium fine	**C**	
	Average medium fine	**C**	
	Good medium strong(coarse)	**C**	
	Average medium strong(coarse)	**C**	
Adult Goat	**Good long fine**	**A/B**	
	Average long fine	**A/B**	
	Good long strong(coarse)	**A/B**	
	Average long strong(coarse)	**A/B**	
	Good medium fine	**C**	

	Average medium fine	**C**	
	Good medium strong(coarse)	**C**	
	Average medium strong(coarse)	**C**	

3.3.3.3 Mohair Staple Length

Assessment of greasy (raw) mohair fibre length is generally based on the staple length, which tends to overestimate the mean length of the fibres in the staple (McGregor, 2000). In fact, after processing, the mean fibre length may be only 75 to 60 % of the greasy fibre staple length. There is also a wide variation in the length of mohair fibres after processing.

Fibre, or staple, length has an effect on the price, because it affects top-making and spinning performance. Longer fibres, up to a certain maximum length, can be spun at faster speeds and require less twist for the production of commercial yarns, longer fibres also enabling finer yarns as well as superior fancy yarns to be spun for special knitwear products. Better quality fabrics, with fewer tendencies to pill and prickle, can also be achieved with longer fibres. It is also generally cheaper to produce yarns with longer fibres, as the process becomes less intensive with reduced fibre wastage.

Mohair buyers are not as critical about staple length as they are about fibre diameter, mohair longer than 10 cm in staple length generally being preferred (McGregor, 2000). Mohair, measuring about 15 cm in staple length generally attracts the maximum price, although it represents only a relatively small proportion of the traded fibre. Mohair ranging in length from 7.5 to 15 cm, represents about 55 % of the trade, and receives about 92 % of the maximum price, while that measuring 5 to 7.5cm receives about 83 % of the maximum price.

Lesotho mohair is shorn once a year; leading to a relatively long staple length, which counts in its favour, although this is associated with the disadvantage of the mohair becoming coarser as the goat ages

3.3.3.4 Mohair Medullation

Medullation, more specifically the objectionable medullated "kemp" type, is one quality attribute of keratin fibres fairly common in mohair, more particularly in poorly bred Angora goats. High percentages of objectionable medullated fibre (kemp) in the fleece, lower the value of such a fleece. The occurrence of medullation, more specifically objectionable medullated fibres, can negatively affect a number of quality related properties, appearance, including fibres lighter in appearance after dyeing, and processing quality (Wildman, 1954, Balasingam, 2005, Davidson 2011, ASTM 2013, and Hunter 2013). Nevertheless, one needs to distinguish between medullated and objectionable medullated "kemp" type fibres, the latter and not the former representing the real problem. The details about the definition of medullation, its causes, measurement, management and the specific manner in which each of the fibre properties are affected can be found in Chapter 4, which reviews the literature on medullation.

3.3.4 Mohair Production

Global mohair production figures are given in Table 3.9. The latest statistics report that in 2018, South Africa produced the most mohair in the world accounting for some 47% of global production while Lesotho ranked second with a production of about 17% (Mohair SA, 2018).

Table 3.9: Mohair production (greasy) in million kilograms (Mohair South Africa, 2018).

Year	South Africa	Lesotho	USA	Argentina	Turkey	Australia	New Zealand	Other	Total
2005	3.6	0.6	0.8	0.3	0.3	0.2	0.2	0.3	6.2
2006	3.4	0.75	0.8	0.4	0.3	0.2	0.1	0.2	6.1
2007	3.00	0.75	0.55	0.45	0.35	0.20	0.10	0.20	5.60
2008	2.90	0.75	0.50	0.45	0.35	0.20	0.05	0.10	5.30
2009	2.60	0.75	0.50	0.70	0.30	0.20	0.10	0.20	5.30
2010	2.30	0.75	0.48	0.70	0.17	0.18	0.05	0.20	4.80
2011	2.23	0.75	0.35	0.70	0.15	0.16	0.05	0.20	4.60
2012	2.32	0.77	0.21	0.60	0.19	0.16	0.05	0.30	4.60
2013	2.40	0.80	0.15	0.50	0.26	0.17	0.03	0.20	4.50
2014	2.45	0.80	0.15	0.60	0.20	0.17	0.02	0.32	4.71
2015	2.48	0.73	0.15	0.60	0.30	0.12	0.02	0.35	4.75
2016	2.48	0.76	0.15	0.60	0.22	0.12	0.02	0.35	4.70
2017	2.40	0.80	0.15	0.65	0.30	0.12	0.02	0.35	4.79
2018	2.24	0.80	0.23	0.71	0.34	0.06	0.03	0.35	4.76

The mohair market share of the various countries for 2016 is summarized in Figure 3.10. South African mohair is regarded as the best quality and there is a high demand for it, particularly in China, Italy, USA, Taiwan, Bulgaria, Japan, Egypt, India and Korea (Mpyana, 2017).

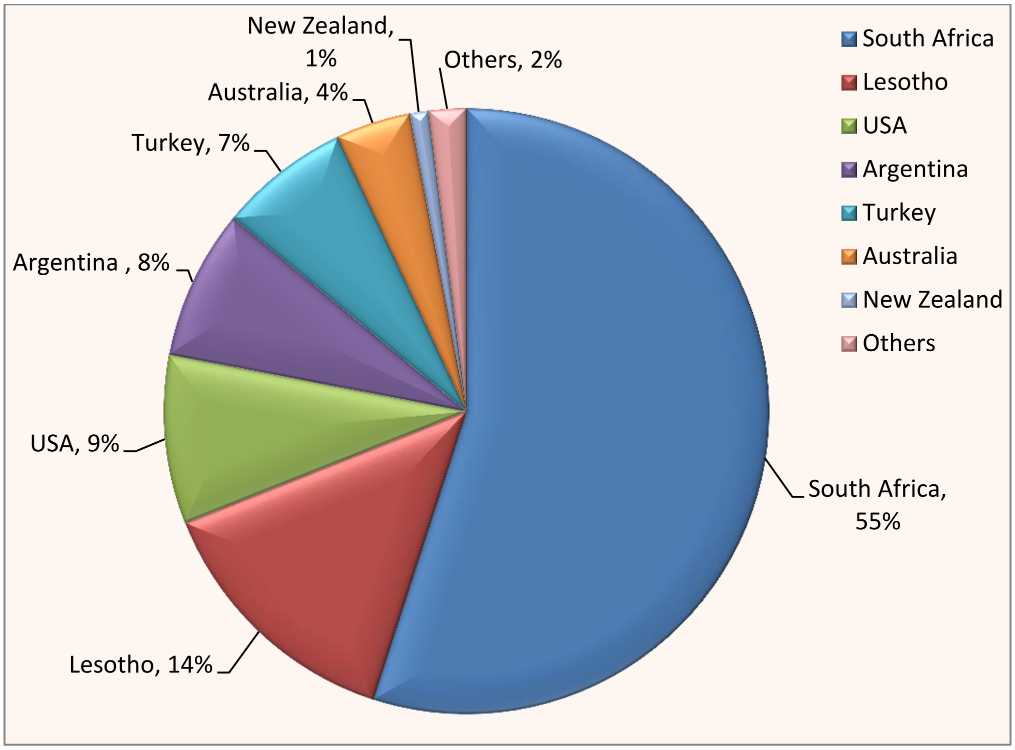


Figure 3.10: Mohair world production market share in 2016 (NAMC, 2017)

The early 2018 mohair sales in South Africa realised an average price of R291/kg across all types. The highest price paid during the June auction (summer sales) in South Africa was R630.00/kg for good style 23 µm Kid mohair (Mohair SA, 2018). According to Mohair SA (2018), the weaker SA currency and the very good quality of the clip contributed towards the 4.5 % market gain, the on-going drought causing fears of low production resulting in the buyers competing for the mohair on offer. Percentages of mohair imported by South Africa from different countries are shown in Figure 3.11, Australia being the highest mohair exporter to South Africa at 37.7 %, the USA at 29.1 % while Lesotho's mohair exports to SA have declined from 45 % in 2013 to 15.8 % in 2016 (NAMC, 2017).

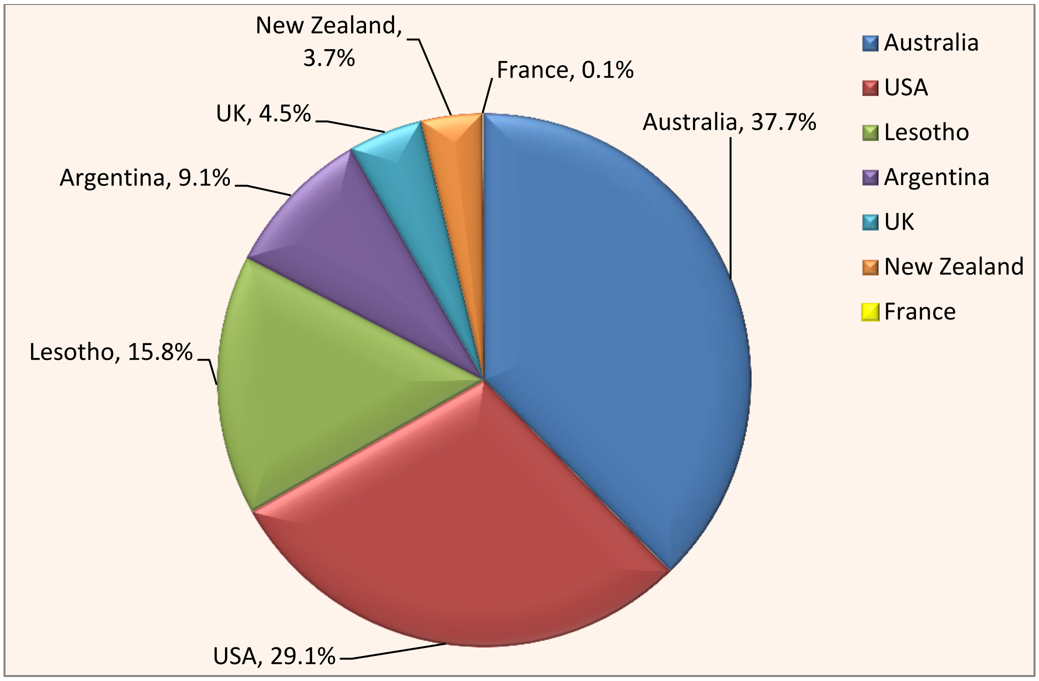


Figure 3.11: South African mohair imports (NAMC, 2017)

3.3.5 Value of Lesotho Mohair

The total value of the Lesotho mohair clip is influenced by both the quantity and quality of the fibre produced, with supply and demand also playing an important role in determining the auction price. Cavanagh (2014) reported that, in 2014, a strong interest and an increase in fashion demand for mohair, coupled with a world shortage of mohair, increased mohair prices, to the benefit of the fibre producers. It is common for mohair prices to increase significantly as fashion demand grows, irrespective of the normal quality attributes of the fibre.

CHAPTER 4
A REVIEW OF MOHAIR MEDULLATION

4.1 INTRODUCTION

All animal fibres are formed with an outer layer of cuticle cells and an inner core of cells forming a cortex, some also containing a central, partialy hollow centre called medulla. True mohair fibres are characterised by their solid nature (i.e. without a medulla) as well as translucent appearance. The fibres produced by the primary follicles of the Angora goat and animals, generally also contain a medulla, namely a hollow core of dead cells or cell residue filled with air, this adds to the insulation ability of the fibre and to its opaque whitish appearance. Lupton et al., (1990) described kemp as an extreme form of medullated fibre, which is usually visible to the naked eye, kemp generally being shed by the animal. In practice, the classification of medullated fibres, into either kemp or medullated fibres, is done in consideration of the fibre origin, fibre length, and medulla type as well as fibre diameter (Sienra et al., 2011). It is now more common to refer to the extreme forms of medullated (i.e. kemp type) fibres as "objectionable medullated fibres", since it is not always possible to determine whether the fibre has been shed or shorn when examined subsequent to shearing, which is the key criteria and definition of kemp fibres. According to Blyth (1926), the term kemp was used loosely to describe coarse fibres of any kind in the fleece, mostly found in the mountain breed, different from others on account of its coarseness and because it is usually found lying loose in the fleece, especially at shearing time.

4.2 MEDULLATED FIBRE GROWTH AND DEVELOPMENT

Objectionable medullated (kemp-type) fibres are believed to be a consequence of the primitive origin of breeds of animal. Roberts (1926) reported that, in a similar manner to the primitive varieties of fleece, most mammals possess two coats, namely an outer coat of protective hair, which tend to be medullated, and an inner warmth-retaining (thermal insulation) coat of fine hair, which tends to be non-medullated. In this respect, medullation is largely hereditary. According to Roberts (1926), objectionable medullated fibres (kemp), resemble the hairs on ancestor breeds in many ways.

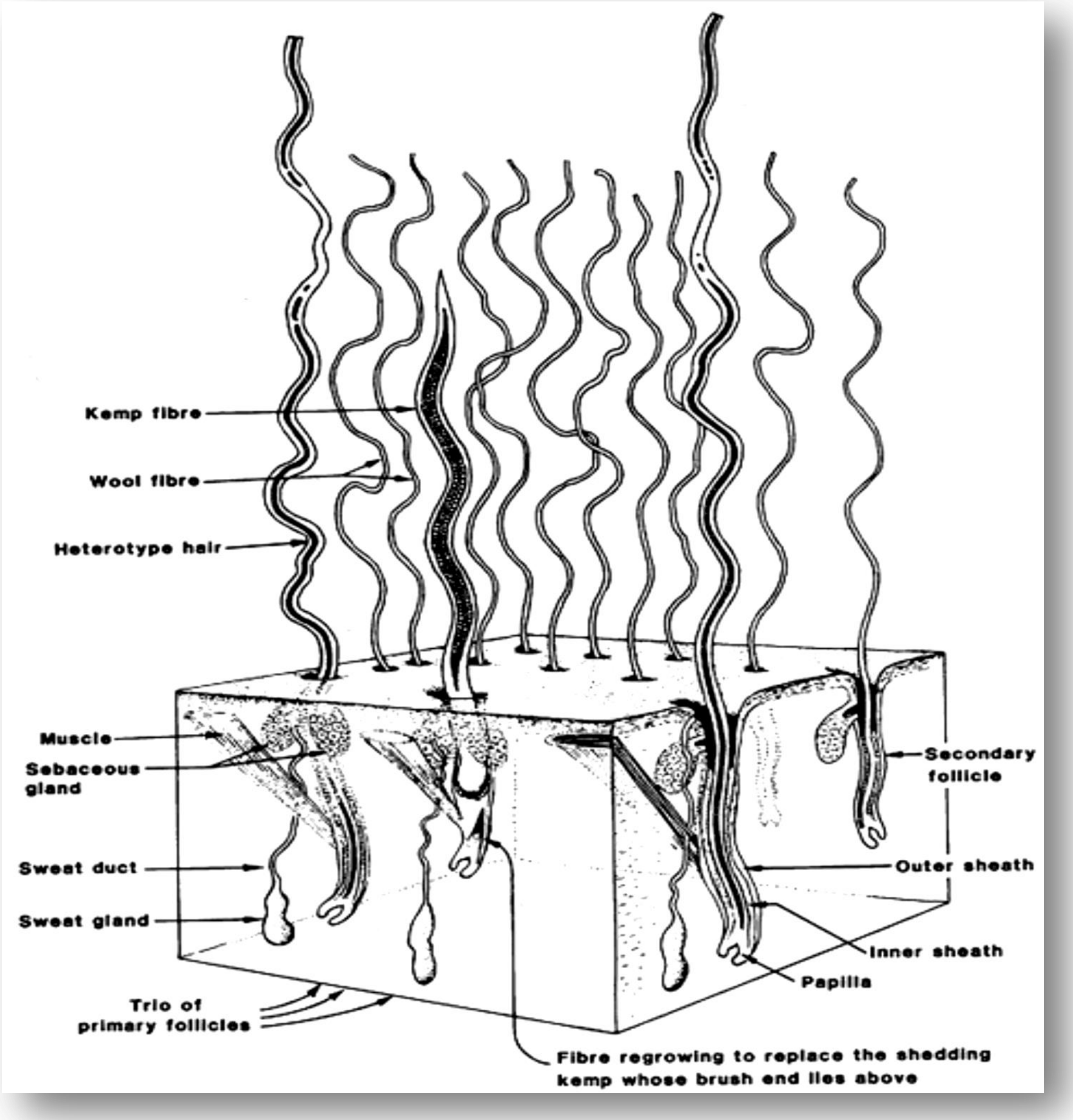


Figure 4.1: Stereo diagram of an idealized wool follicle group to show the three types of fibre grown and the two types of follicles in the skin (Ryder and Stephenson 1968).

Mohair fibres develop from within the structures, known as follicles, in the Angora goat skin, similar to that of wool illustrated in Figure 4.1. In this context, it is important to understand the follicle development and the impact they have on mohair fibre development as well as the influence they have on medullation. According to Bassett (1986) the follicles begin to develop within 60 to 70 days of foetal development, and the development starts at the head, moving backwards and downwards on the body. The primary follicles develop first, while the secondary follicles develop towards the end of the gestation period and sometimes also after birth. Due to their earlier development, the primary fibres become thicker than the secondary fibres, which develop from smaller follicles clustering around individual primary follicles. The primary follicles end up bigger than the secondary follicles (Bray, 2004). The primary follicles in Angora goats, and in most animals, produce medullated fibres (including kemp) while the secondary follicles mostly produce non-medullated "true" mohair fibres, although some earlier developing secondary follicles also produce gare fibres, these are the long hairy coarse fibres usually found in the crotch area of a fleece (Ibraheem et al., 1993). Gare fibres are easy to identify because of their straight appearance (no crimp), they also have a relatively shiny surface. Figure 4.2 shows the primary and secondary fibres developing from their respective follicles (Maddocks and Jackson, 1988 and Galbraith, 2010).

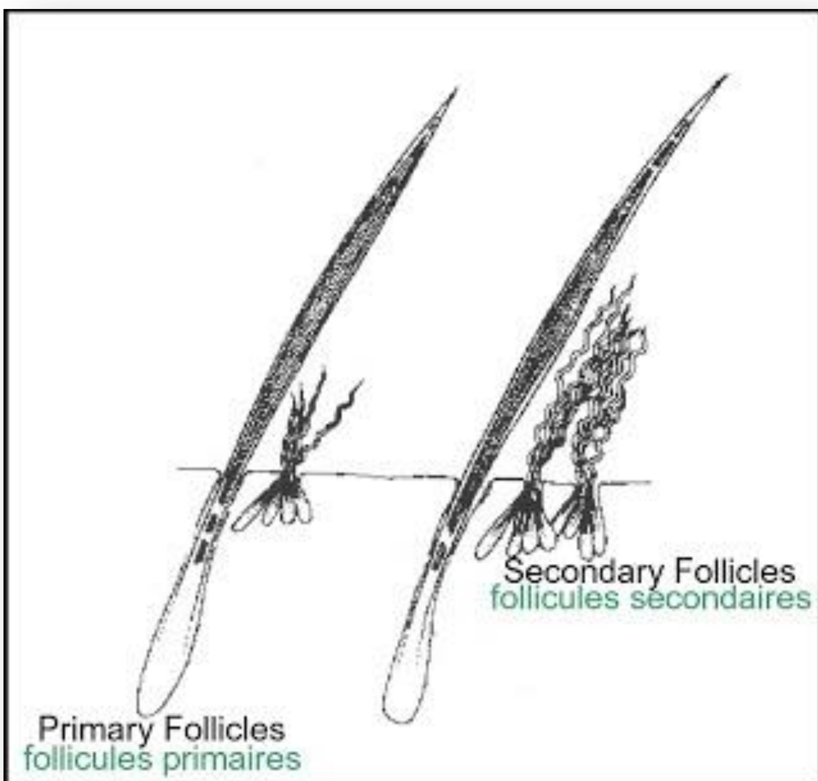


Figure 4.2: Primary and secondary follicles (Maddocks and Jackson, 1988 *the spinning shepherd*)

The medullary cells are formed at the vault of the papilla of the primary follicle, illustrated for non-medullated hair follicles in Figure 4.3; these cells being curbed to the central region of the fibre, as it develops up through the follicle (Davidson, 2011). These cells may break down before the fibre emerges, and if this happens, the centre of the fibre will be empty. Secondary fibres, on the other hand, grow from secondary follicles, and can be identified by their singular wax gland, absence of sweat glands and the pill-erector muscle. Secondary fibre can also be medullated without this being visible to the naked eye. Regarding the development of objectionable medullated fibres, Davidson (2011) suggested that the structure found in medullated fibres, normally referred to as guard hair, is probably an inheritance from primitive ancestors for which these fibres serve as protection under extreme climatic conditions.

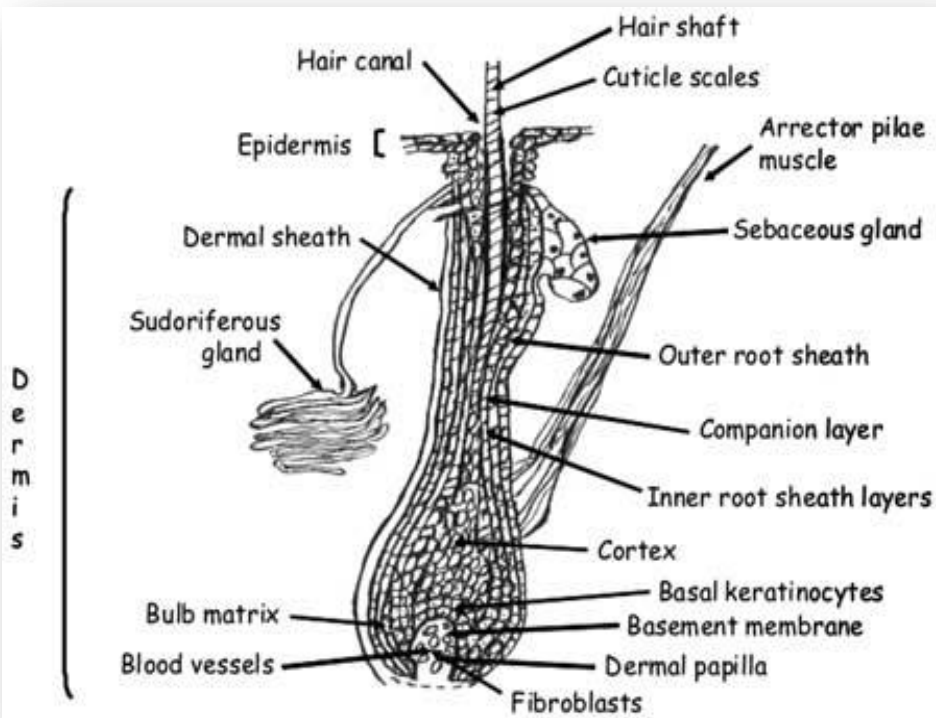


Figure 4.3: Diagrammatic representation of a non-medullated mammalian primary anagen hair follicle (Galbraith, 2010).

Scobie and Woods (1992) proposed a theoretical mechanism for the production of medullated fibres, in which medulla formation is explained as a consequence of a competition between fibre follicles for keratin precursors, such that, when fibre volume production exceeds available precursors, the follicles produce fibres with medullae. Furthermore, Auber (1952) described the formation of cells, which lead to medullae, as being high in fluid content, implying that keratin precursors are in low supply, in a way akin to oedema formation in response to low plasma protein concentrations elsewhere in the body (Auber, 1952; Radostits et al., 2007; Scobie and Woods, 1992; and McGregor et al., 2013). Medullated, particularly objectionable medullated, fibre levels are partially contributed to genetically, with the highest levels observed only shortly after the birth of the Angora goat, since such fibre are generally shed soon after birth, and the follicles which produce them become inactive.

Levels of medullation in mohair from different countries of origin differ greatly; this is believed to be due to differences in production parameters. Environmental animal production parameters, including nutrition; rainfall and age can influence the extent of medullation (Ng'ambi et al., 2009). According to Khan et al., (2012) nutrition is important in fibre production, stating that variations in the nutrition supply to the follicles can exert a considerable influence on the rate of fibre production and characteristics of the fleece. There is however, insufficient evidence and confusion on the specific causes of medullation and variations in the extent of contamination. The inability to conclude on this topic can be attributed to the lack of precision of the test methods developed to date and poor sampling procedures, variation among samples, short-term studies, deprived experimental designs, lack of funds and limited number of animals that in the end are not necessarily representative of the population being tested (McGregor et al., 2013a). What is fairly clear, however, is that medullated fibre levels, particularly kemp type fibres, can be significantly reduced by proper breeding practices (i.e. genetically).

Not all medullated fibres are completely objectionable; this depending upon the degree of visual difference between the medullated fibre and the fibres from the general population, the extreme state of this is called "kemp" or objectionable medullated fibres and is the most undesirable. These fibres have a different appearance and other characteristics compared to the pure mohair fibres from the same fleece, and are found in most animal fibres, such as wool and mohair. As a result of their unwanted appearance; kemp fibres are regarded and defined as objectionable fibres (Hunter, 1987). According to Balasingam and Mahar (2005), kemp fibres can also be referred to as objectionable medullated fibres and described as chalky-white in appearance even after dyeing. This is a result of the presence of an air-filled cellular network within the medulla which reflects and refracts incident light differently from true (i.e. solid) fibres, resulting in paler shades if both types of fibres are exposed to the same colour and type of dye (Hunter et al., 2013).

According to the ASTM definition (given in ASTM D2968-89) a "kemp" fibre is a medullated animal fibre, in which the microscopically measured diameter of the medulla is 60 % or more, of the fibre diameter, Med fibre, on the other hand, is a medullated animal fibre in which the medulla is less than 60 % of the fibre diameter, while a medullated fibre is an animal fibre that includes a medulla in its original state and therefore includes both kemp and Med fibres (ASTM, 2013). In extreme cases, over 65 % of the volume in medullated fibres could be occupied by airspace, cell residuals and air, depending on the size of the medulla, the figure gives an idea of the medullated fibre appearance and relationship of the fibre cell layers (see Figure 4.4). Hunter et al., (2013) stated that it has generally been assumed that the medulla diameter to fibre diameter ratio is the main criterion which distinguishes visually objectionable medulla (kemp type) fibres from the non-objectionable, although this is not always the case.

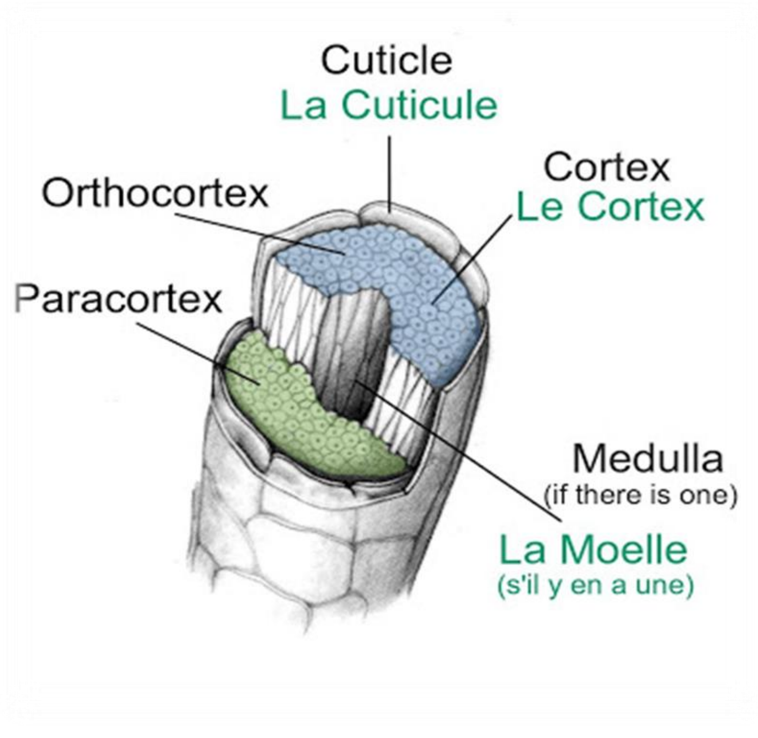


Figure 4.4: Cross and longitudinal section of a medullated wool fibre (Fournier and Fournier, 1995).

Medullated fibres, particularly in their extreme form, referred to as kemp or objectionable medullated type fibres, are undesirable in high quality mohair and wool products, since they tend to appear visually different to the non-medullated fibres, both before and after dyeing, which can constitute an unwanted flaw or fault, particularly in high quality fabrics and garments. It is, however, a desirable or beneficial characteristic in certain products, for example in carpets and Harris Tweeds. According to Lupton and Pfeiffer (1998), the presence and the degree of medullation represent an important selection criterion for Angora goats and certain breeds of sheep. In mohair, the presence of detectable medullated fibres reduces the value of the fleece (Hunter, 1993). Falk (2011) stated that the presence of kemp is a serious fault in a fleece, and a conscientious breeder should not use such animals for breeding. Generally, the best quality grades of mohair, used mostly for clothing, aim for objectionable medullated (kemp) fibre levels of 0.3% or less by number (SGS, 2011a).

4.2.1 Location of Medullated fibres on the animal

In the case of sheep, medullated fibres are usually found around the head and over the bare patches of the inner legs, these will be more or less distributed throughout the fleece in some sheep than others (Duerden, 1926). Kemp is always present in the fleece of the Angora kid and may also occur in lesser or greater quantities in the fleece of the adult (Venter, 1959).

4.3 IDENTIFICATION OF MEDULLATED FIBRES

SGS Wool Testing Services (2011a) and Sienra et al., (2011) made a distinction between kemp and medullated fibres, namely that kemp fibres are generally highly medullated and short and are shed into the fleece, while medullated fibres can be described as those that have a medulla in their original state but are not shed nor visually detectable. Davidson (2011) added that medullated fibres have a central core which may be continuous, interrupted, or fragmented (see Figure 4.8).

Medullated fibres tend to increase in diameter as the fibre diameter increases SGS (2011b). Due to their partially hollow centres, medullated fibres are generally of a lower density than the normal/true (i.e. solid) fibres. Medullated fibres, from the primary follicles, tend to be coarser than those from the secondary follicles, the coefficient of variation of fibre diameter (CVD) generally increasing as the degree of medullation increases. Where the medulla diameter approaches that of the fibre; the fibre tends to become flattened, and lighter in weight, brittle, whiter and chalky in appearance as can be seen in Figure 4.5. Under a microscope, medullated fibres appear dark when viewed under a micro-projector; the air filled cell walls of the medulla appear black as they reflect light. When the mounting medium, such as immersion oil, is absorbed into the fibre medulla, the medulla will become transparent (Smuts and Hunter 1987, and Siena et al., 2011).

Figure 4.5: Visual kemp fibres seen on the right side of the measuring tape (Fleet, 2008)

McGregor et al., (2013), found that medullated fibres largely responded to average fleece-free live weight (FFLwt, of the animal), even after adjusting for MFD. This implies that, within a flock, larger animals generally have more medullated fibres than smaller animals, even when the mohair fibre dimensions are the same. They concluded that medullation responds largely to the live weight of the animal and to mean fibre diameter (MFD), these responses are, however, largely functionally separate.

4.3.1 Distinguishing between Kemp and medullated fibres

Among other attributes, kemp and other medullated fibres differ according to the extent and nature of the medulla. The definitions of kemp and medullation have been given at the beginning of this chapter.

a) Root b) Tip

Figure 4.6: Extreme ends of kemp fibres in wool (Duerden, 1924).

Balasingam (2005) described medullated fibres as being intermediate between normal non-medullated and the objectionable medullated (kemp type) fibres, generally being longer than kemp fibres. The main feature of a kemp fibre is the wide, often latticed, medulla occupying most of the width of the fibre, so that the cortex forms only a narrow ring around the medulla (Roberts, (1926), Petrie, (1995) and Balasingam, 2005). Medullated fibres tend to shed less frequently than kemp fibres which are moulted (shed) into the fleece with a different root, known as a brush (see Figure 4.6). Kemp fibres which are shed and not shorn (not cut), have a pointed tip and a "brush" type root end (Duerden, 1924 and Balasingam, 2005). Figure 4.6 shows the brush root (a) and the pointed tip (b) of a kemp fibre in wool. Usually, fibres from a normal clipped fleece would be expected to have two cut ends. While the skin end may have a fairly clean cut, the other end, which was cut the previous year and is now at the tip of the fibre, tends to be worn out or frayed (Balasingam, 2005).

4.4 CLASSIFICATION OF MEDULLATED FIBRES

The classification of medullated fibres is generally based on the characteristics of the medullae at the centre of the fibres. Figure 4.7 shows the basic classification of medullae as found in animal fibres (Wildman, 1954).

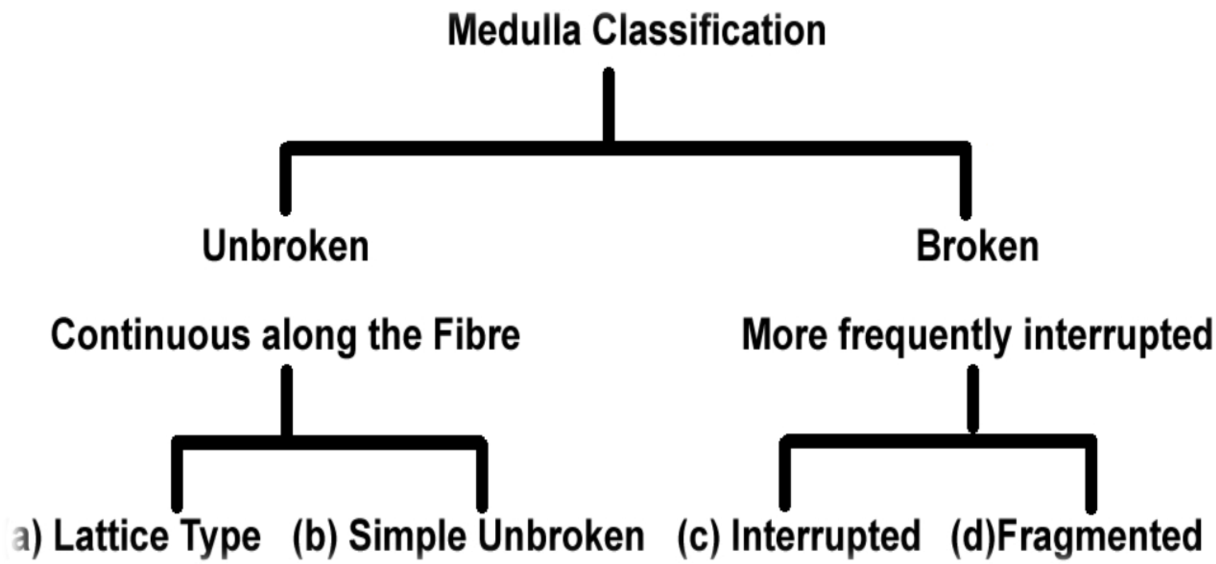


Figure 4.7: The classification of types of medullae (Wildman, 1954).

4.4.1 The major classes of medulla (see Figures 4.7 and 4.8):

The first two classes, a) lattice type and b) simple unbroken type, fall in the main class of unbroken, also known as continuous, and sometimes long fibres.

a. Lattice type

This type of medulla is very wide relative to the total width of the fibre, and consists of a network of keratin 'crosspieces' which outline polyhedral shaped spaces, each of which is continuous with its neighbours. A mixture of gases and cells occupies the spaces within the medulla. When viewed through transmitted light in a microscope, a lattice medulla appears dark. The lattice type of medulla is present in many coarse fibres that continue to grow from sheep (e.g., of some mountain breeds), in coarse kemp fibres, and in coarse outer coat fibres from several mammals, such as reindeer, and red deer (Wildman, 1954).

b. Simple unbroken

This type of medulla consists of a simple continuous central canal, thin or thick (wide), but usually not as thick as the lattice type: it appears dark when viewed through transmitted light. This type occurs in a wide variety of animal fibres (Wildman, 1954).

c. Interrupted medulla

This type of medulla is relatively narrow and completely interrupted or bridged at irregular intervals by cortical cells, and occurs in many fibres, such as those of medium quality, for example, in Romney Marsh wool (Wildman, 1954).

d. Fragmental Medulla

In this category, the medulla is intermittent, occurring only irregularly as fragments in the centre of the fibre (Wildman, 1954). These are also referred to as hetero-type and their strength and toughness decrease as the medulla volume increases (Rama Rao and Chopra, (1985)).

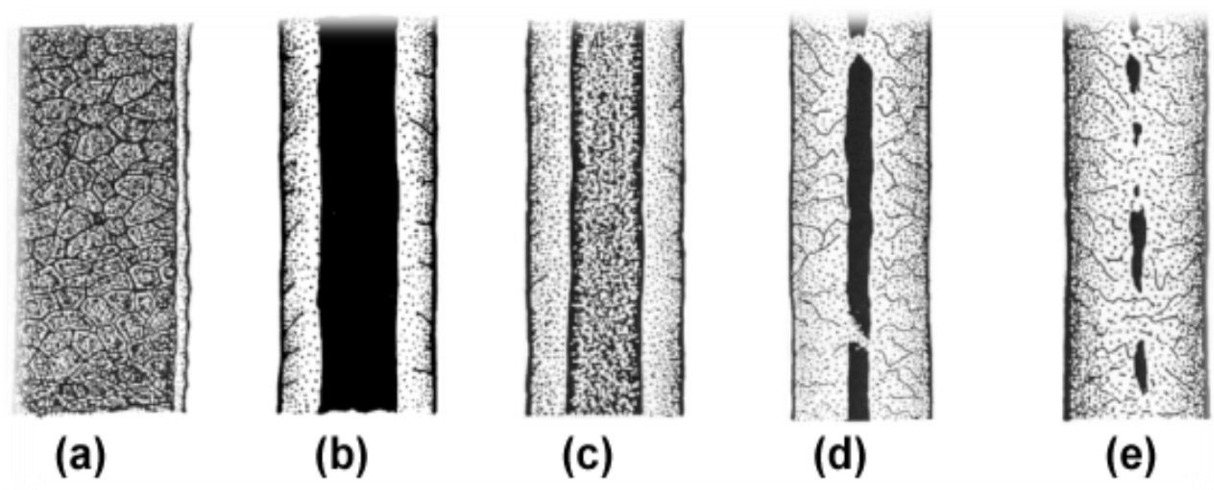


Figure 4.8. Diagrammatic representation of different types of medullae (ASTM 1992).

Figure 4.8 illustrates the different types of medullae in medullated fibres, as just described and can be summerised as follows:

a) Unbroken (wide) lattice, also called continuous kemp fibre (usual appearance when not in filled by mounting medium)

b) Simple unbroken, also called continuous medullated. Medium width (usual appearance).

c) Simple unbroken. Medium width (appearance when in-filled by mounting medium)

d) Interrupted medullated fibre.

e) Fragmented medullated fibre.

According to Khan (1974), medullae generally appear in a fragmental form beyond 32 ± µm in wool, and become continuous at about 51 µm ± 15 µm, with increased diameter. In heterotypical fibres, the diameter and length of the medullated fragments go on increasing almost continuously, until the medulla becomes continuous. In the case of fully medullated fibres, the medulla diameter increases rapidly until the fibre diameter is about 100 µm. The medulla can occupy more than 85 % of the fibre diameter in extreme cases, as shown in Figure 4.8 (a) for the lattice type medulla.

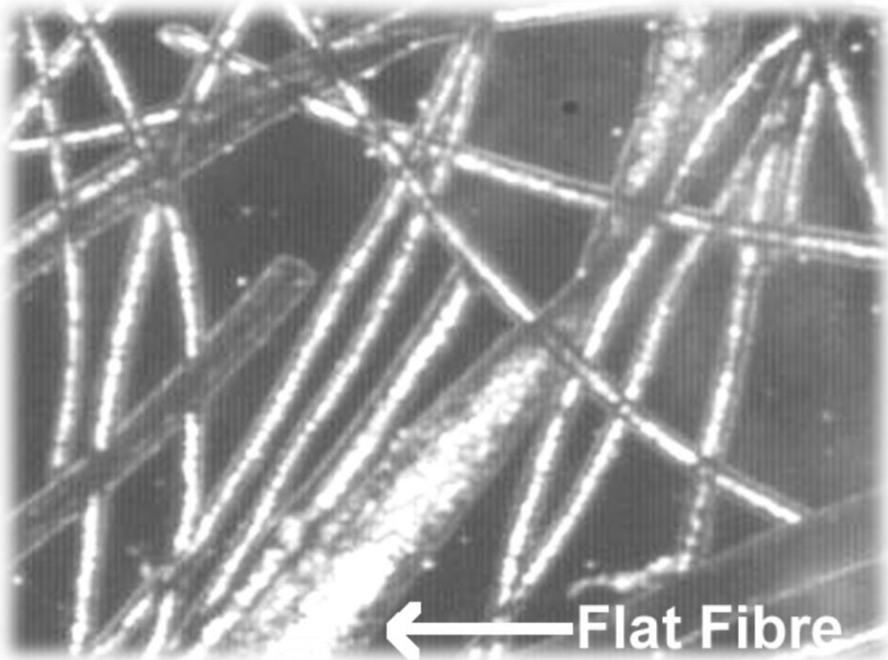
4.4.2 Gare Fibres

Gare refers to the long hairy coarse fibres which may be found in the crotch area of a fleece. As these fibres lack crimp, they are easily detected because they may be shiny and are either partially or totally medullated, unlike guard hair which is also a category of medullated fibres grown by goats and camelid animals as a protective fibre for the fine under-down (Stapleton, 1976). Fibres that contain non-continuous (fragmented, interrupted or broken) medullae are generally referred to as heterotypic or 'gare' fibres (Smuts et al., 1983). These are generally produced in well-bred Angora goats by the primary follicles (Margolena and Virginia, 1966 quoted by Hunter and Botha, 2011), but may also be produced by the secondary follicles in poorer flocks (Stapleton, 1976 quoted by Hunter and Botha 2011). They are longer than kemp fibres (Davidson, 2011). In the Cashmere goat, they are the coarse fibres forming the primary outer coat of the two coated primitive fleece. The gare fibres are generally very coarse in diameter, with a broad medulla cell within.

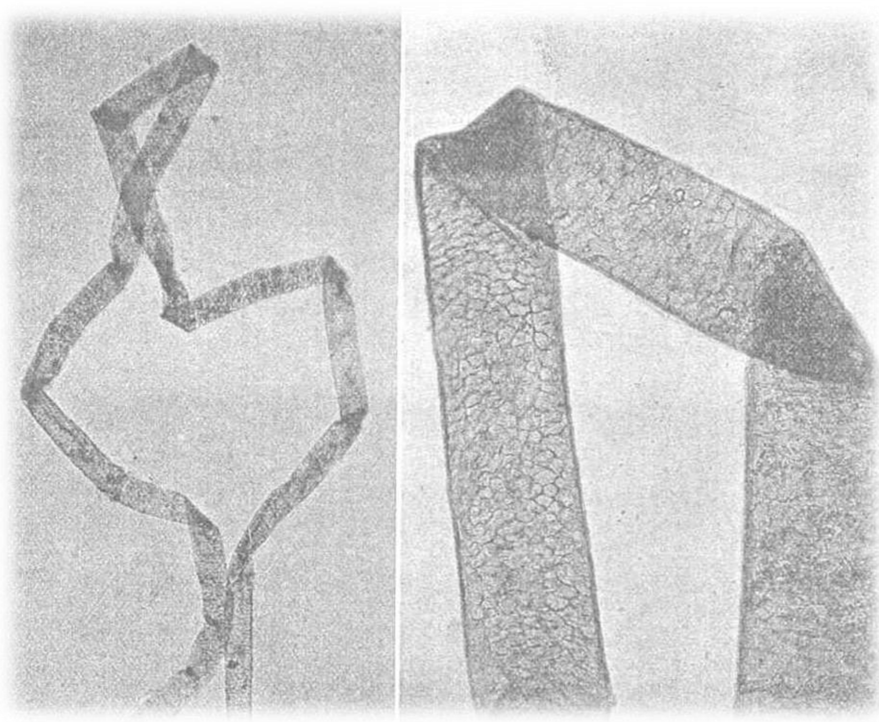
4.4.3 Flat Fibres

Another category of medullated fibres is that of 'flat fibres'. Priestman (1911) identified flat kemp fibres (see Figures 4.9 (a) and (b)) in certain East Indian wools, which appear lighter than the other wool fibres after dyeing, although there was little difference in actual depth of colour. Bowman (1908), quoted by Bliss (1926), referred to ‘flat’ kemp fibres, but which seemed to have been incomplete or partial kemp. Flat fibres are highly medullated, their medulla diameter being almost the same as that of the fibre itself. They therefore, have very thin walls which tend to collapse into a flat ribbon (Figure 4.9 (b)), the large medulla in this type of fibre causes the flat fibres to collapse, they are generally chalky white in appearance, even after dyeing (Priestman, 1911, Bliss, 1926, Bowman, 1908; Bliss 1926; Balasingam, 2005; and Hunter and Botha 2011). Blyth (1926) also reported that the shape of these fibres prevents all waviness in a horizontal plane, and that if they are bent they act exactly as a tape or an empty hosepipe would do, as they turn over, forming an angle at each bend, the optical characteristics of flat fibres being completely different to those of ordinary kemp or other highly medullated fibres. The angles at each bend resemble a ribbon as well; with easily noticed scales showing on the flat fibres (see Figure 4.9(b)). These medullated fibres would have been difficult to identify if it had not been for the very obvious way in which the scales on the outer surface show under the microscope (Figure 4.9(b)), the erratic shape of flat medullated fibres is possibly the reason they are not easily identifiable (Bliss, 1926).

Another characteristic of flat medullated fibres is that they will generally float on water, while true kemp fibres will generally sink; this will happen unless they are boiled to displace the air they contain. Hunter (1987) also observed certain thin walled medullated fibres to have a flattened (bean shaped or ribbon like) appearance but which Hunter (1987) and Balasingam (2005) thought may have been caused during processing or handling of the fibres.



(a) Flat fibre as shown on the OFDA (www.OFDA.com, 2004)



(b) Structure of flat fibres (Bliss, 1926, and Priestman, 1911).

Figure 4.9: Flat kemp fibres

4.5 ASSOCIATION BETWEEN MEDULLATION AND CERTAIN TEXTILE PROPERTIES

The presence of medullation alters the nature and characteristics of wool and mohair, the magnitude of the effect depending on the extent, size and type of medulla, some of the effects being discussed in the following sections.

4.5.1 Dye absorbency

Highlighted medullated fibres normally appear lighter or paler in shade than the rest of the fibres after dyeing, even though there is very little, or no, difference in depth of colour when viewed under a microscope. Blyth (1926) argued that objectionable medullated wool fibres and true wool fibres dye almost equally well, and that the apparent lightness of medullated or kemp type fibres is due to the way medullated fibres refract and reflect light, a concept which has been investigated and expanded by later studies, some of which are discussed below. It has also been reported that certain kinds of black dyes seemed to swell the flat kemp fibres up to nearly round section again (Blyth 1926).

The different (lighter) appearance of kemp fibres in dyed samples is ascribed to an optical effect, due to the reduced distance the light passes through the dyed fibre wall and the refraction and reflection of light at, and within, the medulla (Balasingam and Mahar, 2005, Smuts and Hunter, 1987, SGS, 2011b and Smuts et al., 1983)). Hence, the differences between the refractive index of the solid keratin wall of the medullated fibres and that of the partially hollow medulla, and shorter light path length through the dyed fibre wall, rather than poor ability of the “wall” of the medullated fibre to absorb dye, are thought to be largely responsible for the distinctly different appearance of kempy fibres after dyeing. In the light of this, the assumption is reasonable, that the appearance of the medullated fibre will be related to the surface area of the medulla relative to that of the fibre. The contrast between medullated and true fibres becomes more obvious when the depth of colour saturation increases, pastel shades reportedly producing the least obvious effects. Since the keratin arrangement of the fibre is interrupted, resulting in the “hollow” (i.e. medulla), in the centre of the medullated fibre, the response of the fibre towards light is also altered. The chalky appearance of the medullated fibre is believed to be a result of such alteration in the arrangement of the key component of the fibres, the keratin (SGS, 2011 a).

4.5.2 Effects of medullation on fibre processing

It was reported, as early as 1917 (Anon, 1917), that, when left in the mohair clip the presence of the coarse kemp resulted in poor spinning and also in a poor quality of yarn, since the fibres tend to migrate to the surface of the yarn or the fabric, being thick, short, brittle, stiff, and rigid, the characteristics which make them unappreciated by spinners (Hunter, 1993).

Medullation levels of over 15% (by number) make the disparity in fibre diameter, between medullated and non-medullated fibres, very important and is more likely to have an impact on the processing performance of such affected fibres (Lang 1950). It appears that medullation levels of up to 6% do not affect the processing properties of fibres and do not have a marked effect on the appearance and handle of either woven or knitted fabrics (Khan, 1974). Singh et al., (1980) stated that medullation is one of the important attributes of wool when deciding on its suitability for processing and selection of individual animals for breeding. Rama-Rao and Chopra (1985) suggested that medullated wool fibres generally exhibit poor mechanical properties, the degree of weakness depending largely on the extent of the medulla in the fibre.

In many aspects, the performance of fibres, during processing can be directly linked to the fibre diameter distribution (Mayo et al., 1994), which is highly impacted by the presence of kemp/medullated fibres in the lot. Excessive levels of medullation tend to impact negatively on processing yields; and also the spinning performances and are considered undesirable, although Lang (1950) suggested that up to 15% medullation levels in wool should not cause difficulty in spinning. Medullated fibres, particularly the kemp type, which are generally much thicker than the true fibres, tend to lie on the surface of the yarn or fabric. Therefore, the visual and other effects they produce can be out of proportion to the actual quantity present.

4.5.3 Fibre Style and Character

Medullation levels are reflected to some extent in the Style and Character of mohair. Style refers to the solid twists or ringlets in mohair staples, while Character refers to the crimp or waves in the staple (Hunter, 1993 and McGregor and Butler, 2004). A good and preferred quality mohair has a balance between these two attributes, this balance is reflected in an evenly crimped staple, while the fibres in a staple are symmetrically and spirally twisted forwards and backwards ending in a blunt point that turns back (Hunter, 1993). This balance is important, since it affects the value of the fibre. According to McGregor (2000), South African mohair with average Style and Character receive about 87 % of the maximum value, while mohair classed as having a variable to poor Style and Character receives only 60 % of the maximum value. According to Minikhiem et al., (1995), objectively assessed Style provides an indication of kemp in a mohair top and Character is related to average fibre diameter, diameter variations and med content of the top.

4.5.4 Staple length

Staple length used to be believed to be related to medullation levels in wool, since the coarser fibres, which measured shorter in length after the carding test, tended to be the highest in medullated wools. Nevertheless, some of the longer fibres also showed similar increase in the total number of medullated fibres; hence staple length is not much of an indicator of the presence of kemp or medullation (SGS, 2011b). McGregor et al., (2013) found that the incidence of medullation is not related to fibre length, but is strongly related to mean fibre diameter.

4.5.5 Fibre Diameter

There tends to be a strong association between degree of medullation and fibre diameter. The diameter of medullated fibres is generally greater than the average diameter of the parent population, this being even more so for kemp and objectionable medullated fibres. Hunter et al., (2013) found that the Medulla Ratio (med ratio) for the objectionable medullated fibres tend to increase with an increase in fibre diameter, from roughly 0.45, at a fibre diameter of 40 µm, to about 0.8, at a diameter of about 160 µm. They reported that the diameter of the objectionable medullated fibres was rarely, if ever, lower than the average fibre diameter of the parent fibre population.

Furthermore, the ratio of medulla diameter to fibre diameter was found to be relatively variable, even though a common trend is for medulla diameter to increase with fibre diameter. Roughly above 100/tm, all medullated fibres are objectionable (kemp). While diameters ranging from 20 to 30 µm, all medullated fibres are med. Fibres with diameter below 20 ~µm are solid because there is no medullation in them (Lupton et al., 1991)

According to Glass (2000a), in the case of wool, the mean and standard deviation of the medullated fibres were 42.7 µm and 9.8 µm respectively, most medullated fibres being much coarser. Balasingam and Mahar (2005) reported that the mean fibre diameter (MFD) and mean medulla diameter of kemp fibres were in the range of approximately 45 µm – 55 µm and 25µm – 35 µm, respectively. Hunter et al., (2013) reported however, that the diameters of the objectionable medullated fibres in mohair vary from about 60 to over 100 µm. It can be concluded that objectionable medullated fibres tend to be coarser and have larger medulla diameters, on average, than the corresponding non-objectionable medullated fibres, while their medulla lengths are similar (Petrie, 1995).

4.5.6 Stiffness

King (1967) found that the medulla in "kemp" fibres increased their bending modulus considerably, i.e., it acted like a hollow pipe. The high volume of 65 % or more, occupied by the medullae in objectionable medullated fibres, reduced the elasticity and handle of the affected fibres (Mayo et al., 1994 and SGS, 2011b), making them more rigid. Medullation imparts a crisp handle and an improved wear performance in some wool carpet styles; resulting in increased resistance to compression, and improved appearance retention as a result of the hollow core (Petrie, 1995). This makes kemp desirable in carpet wool, while it is objectionable in clothing (SGS 2011a).

4.6 MEASUREMENT OF MEDULLATION AND KEMP

It has been generally agreed that the golden standard for measuring the degree of medullation should be based on volume (Auber, 1952; Khan, 1974; Scobie and Woods, 1992; and McGregor et al., 2013). Nevertheless, there are different methods suitable for the measurement of medullation in textile fibres, although, to date, only the Optical Fibre Distribution Analyser (OFDA) and projection microscope have found general acceptance for the measurement of medullation on a routine basis.

One of the first qualitative tests for medullation, reported by Elphick (1932), depended upon the fact that when wool (also mohair) fibres are immersed in a liquid of approximately the same refractive index, i.e. ≈ 1.55 [e.g. benzene, ortho-dichlorobenzene (Bray 1942, quoted by Hunter and Botha 2011) and benzyl alcohol] as keratin, the non-medullated fibres are rendered invisible, whereas the medullae of the medullated fibres, being filled or partly filled with air, show up as white streaks. The light is subjected to refraction and reflection, mainly at the boundary between the medulla and cortex, when the refractive index of the liquid and the keratin are well matched (Swart et al., 1983), to quantify the degree of medullation. This causes the scattering of light, and is used in 'Medullameter' type instruments. The scattering by large particles, compared to the light wavelength, is extremely complex (Sternotte, et al., 1988, and Vanous, 1978), the scattering pattern being characteristic of the size and shape of particles (i.e. the medulla cells in this case). The ideal immersion medium has to satisfy five criteria according to Sternotte *et al.*, (1988) *viz*. (i) a refractive index close to that of keratin, (ii) low viscosity (iii) density; (iv) reasonably cheap and (v) weakly to moderately toxic. No single liquid was originally found to meet all the above requirements, hence Sternotte *et al.*, (1988) investigated the possibility of mixing two or more solvents, and they found a ternary blend, comprising benzyl alcohol, o-dichlorobenzene and o-xylene, appropriate. Table 4.1 gives the refractive indices of wool and mohair and some liquids of similar refractive indices.

Table 4.1: Refractive Indices of Relevant Fibres and Liquids (Smuts et al., 1983)

FIBRE/LIQUID	REFRACTIVE INDEX*
Wool	**µm $\frac{II}{S}$: 1,553 to 1,555** **µm $\frac{I}{S}$: 1,542 to 1,546**
Mohair	**µm $\frac{II}{S}$: 1,5579 to 1,5638** **µm $\frac{I}{S}$: 1,5474 to 1,5546**
Benzyl Alcohol	**1,5404 at 20º** **1,584 at 25º**
Ortho-dichlorobenzene	**1,5515 at 20º** **1,5491 at 25º**

*__ µm $\frac{II}{S}$ and µm$\frac{I}{S}$: are the average refractive indices for light vibrating parallel and perpendicular to the fibre axis, respectively (Hunter and Botha, 2011)

The following methods have been applied to the measurement of medullation in mohair and other animal fibres:

1. Microscopic Counting Method
2. Specific Gravity Method
3. WRONZ Medullameter
4. SAWTRI Medullameter
5. Near Infrared Reflectance Spectroscopy (NIRS)
6. Optical Fibre Diameter Analyser (OFDA)
7. Original AWTA Ltd Method
8. AWTA Ltd Benzyl Alcohol Test Method

4.6.1. Microscopic Counting Method

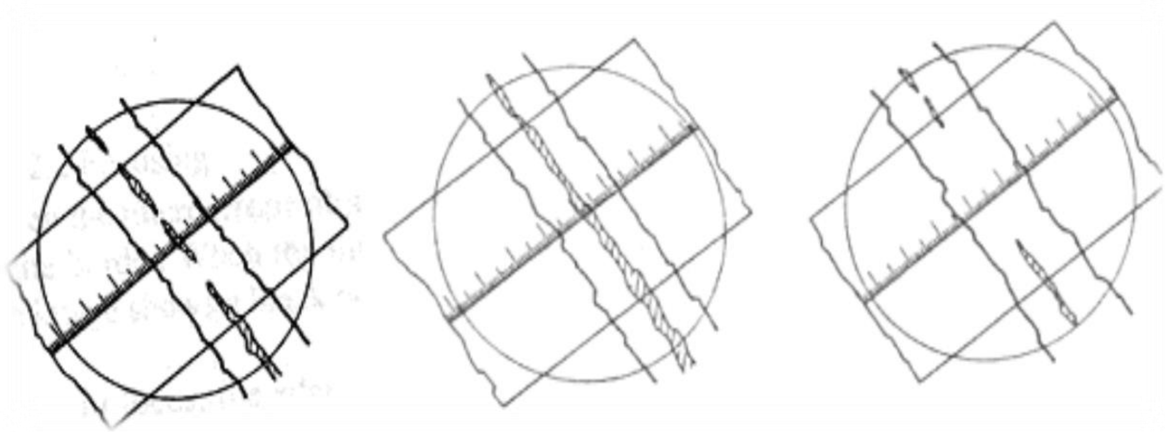
Balasingam (2005) described the microscopic techniques (Figure 4.10) as a direct medullation measurement method by means of which different types of medullation and medulla diameter distributions may be measured and recorded, it is also internationally accepted as a medullation reference method for wool for certification purposes (IWTO-8-97, 1989). The number of medullated images is calculated as a percentage of the total number of images examined, while the standard error is calculated as the percentage of the medullated fibres. The standard error formula is given by:

$$\text{S.E.} = \sqrt{\frac{m}{n}\ (100 - m)} \qquad (4)$$

Where n = total number of fibres examined;

m = percentage of medullated fibres. (Adopted by IWTO, 1964)

This method is, however, slow and operator intensive, and it measures only one characteristic of medullation, namely the percentage volume of the fibre occupied by the medulla (Wool Science Review, 1954).



a) Narrow medulla b) Continuous Medulla c) No medulla

Figure 4.10: Fibre images of different types of medulla under microscopic projection (IWTO-8-97, 1989).

The ASTM standard definitions have been commonly used as a basis of reference in different methods of measuring medullation. The following are the standard test definitions for medullated fibres in wool and other animal fibres by micro projection (ASTM Standard D2968-89, 1989):

- Medullated fibre – an animal fibre that in its original state includes a medulla.
- Med fibre – a medullated animal fibre in which the diameter of the medulla is less than 60% of the diameter of the fibre.
- Kemp fibre (Objectionable Fibre) – a medullated animal fibre in which the diameter of the medulla is 60% or more, of the diameter of the fibre (i.e. the Med Ratio is ≥ 0.6).

4.6.2 Specific Gravity Method

The specific gravity method assumes the whole medullae to be completely occupied by air, there then being a direct relation between the percentage volume of the fibre occupied by medulla, the specific gravity of the sample (D_m) and the specific gravity of medulla-free wool (or mohair) which is keratin (D_k). The formula can be expressed as follows:

$$\text{Percent fibre volume occupied by medulla} = \frac{100\,(\mathrm{D}k - \mathrm{D}m)}{\mathrm{D}k} \tag{5}$$

Obviously, from the formula, D_k and D_m must be determined to a high degree of accuracy because the percent medulla volume is proportional to the difference between the two values. The experimental determination of D_m by existing methods is certainly not sufficiently sensitive to show up the small amounts of medullation which can be estimated by medullameter and microscopic methods (Wool Science Review, 1954).

4.6.3 WRONZ Medullameter

The first medullameter type instrument, based on the method of Elphick (1932), was devised in 1937 by McMahon (1937), whereby the visual judgement of the whiteness of a medullated sample was replaced by the photoelectric measurement of reflected light. Hunter and Botha (2011) reported that WRONZ was improved by Belin and Goldstone. Made to become a more modern, and user friendly, designs were proposed by WRONZ in 1983, and by SAWTRI in 1985. These types of instruments are calibrated against area medullation, as determined by the projection microscope method. The measured medullation represents an overall or mean value, as these instruments do not distinguish between a large number of finely medullated fibres and a small number of heavily medullated fibres, such as kemp or objectionable medullated fibres. In these methods, the light is generally measured in one particular direction, vertical to the illuminated sample (Sternotte et al., 1988).

The WRONZ Medullameter (see Figure 4.11) is an instrument used to measure medullation, a similar method first being proposed by Elphick in 1932, for estimating “hairiness” (medullation), in wool (ASTM, 1986). Subsequently, this method was replaced by the photoelectric measurement of reflected light (Sternotte et al., 1988).

The measurement is achieved by immersing wool or mohair fibres in a liquid, such as a Benzyl Alcohol (31%) and aniseed oil (69%) mixture; the refractive index of which is equal to that of wool and mohair. When the fibres are immersed in a medium of refractive index which is equal, or very close, to that of the fibre, there is little (if any) reflection of light at the medium/fibre interface (Balasingam, 2005; and Hunter and Botha, 2011). If, however, a medulla, which is substantially filled with an air void, is present, light reflection occurs at the keratin/medulla interface, the amount of light reflected being related to the total, or overall, degree of medullation (total surface area of the medulla) present in the sample. The main principle upon which it functions is the exposure of the medulla by rendering the surrounding fibres invisible.

In the WRONZ Medullameter, the sample is illuminated by a diffuse light source, and the amount of light reflected, refracted and transmitted is measured by a photo-electric detector. A single milli-volt output, indicating the level of light detected (i.e. reflected etc.), is produced. This value is transformed mathematically to produce a measure of the degree of medullation. Balasingam (2005) and Hunter and Botha (2011), stated that, because the degree of overall medullation is expressed as an index, calibrated against the projection microscope, this method represents an indirect measurement of the level of medullation in a sample. The reading of the WRONZ Medullameter is directly proportional to the total projected areas of the medulla as a percentage of the total projected areas of the fibre:

$$\text{Med} = a.D/d \qquad (6)$$

Where Med = medullation as measured on the WRONZ Medullameter

D = diameter of the medulla,

d = corresponding diameter of the fibre and

a = constant

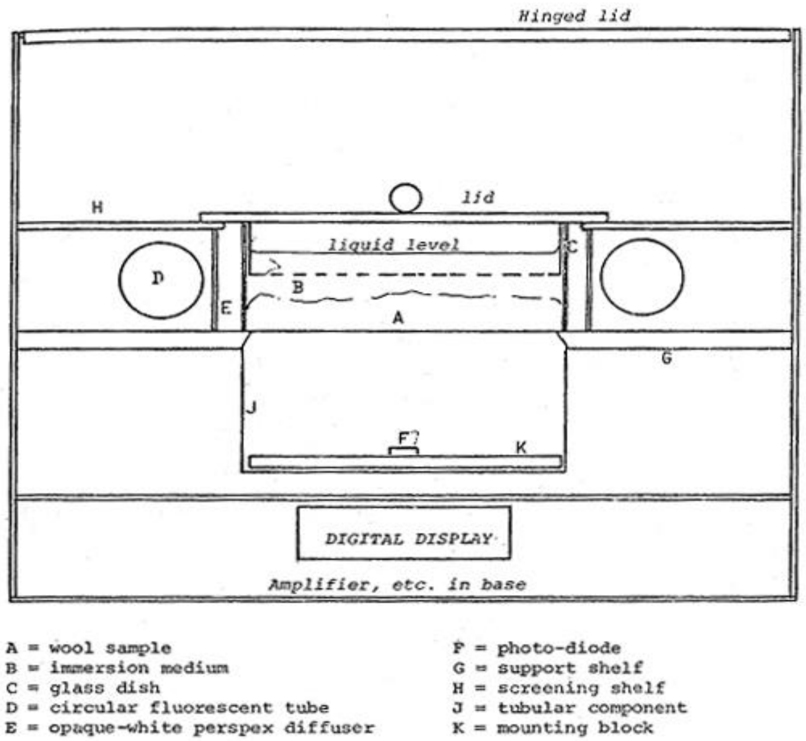


Figure 4.11: Diagram of WRONZ Medullameter (Lappage and Bedford 1983).

The medullation reading of the WRONZ Medullameter represents the total medullation present in the fibre specimen. Such a Medullameter reading provides a rapid method for measuring overall medullation in wool and other keratin fibres, and to some extent, also of the objectionable medullated (kemp type) fibre content of the sample. As already stated, this instrument does not, however, distinguish between a large number of finely medullated fibres and a small number of heavily medullated fibres, and also requires frequent calibration (Hunter and Botha, 2011).

4.6.4 SAWTRI Medullameter

A number of studies have been carried out with the aim of finding a rapid and reliable method of screening mohair samples for degree of medullation as well as the possibility of using the medullameter principle to provide a measure of kemp levels (Smuts et al., 1983 and Hunter *et al.,* 1990). A Medullameter, based on a WRONZ design (Smuts et al., 1983), was constructed at SAWTRI (see Figure 4.12), a quick and easy method being devised to check and calibrate the instrument and to ensure reproducible results.

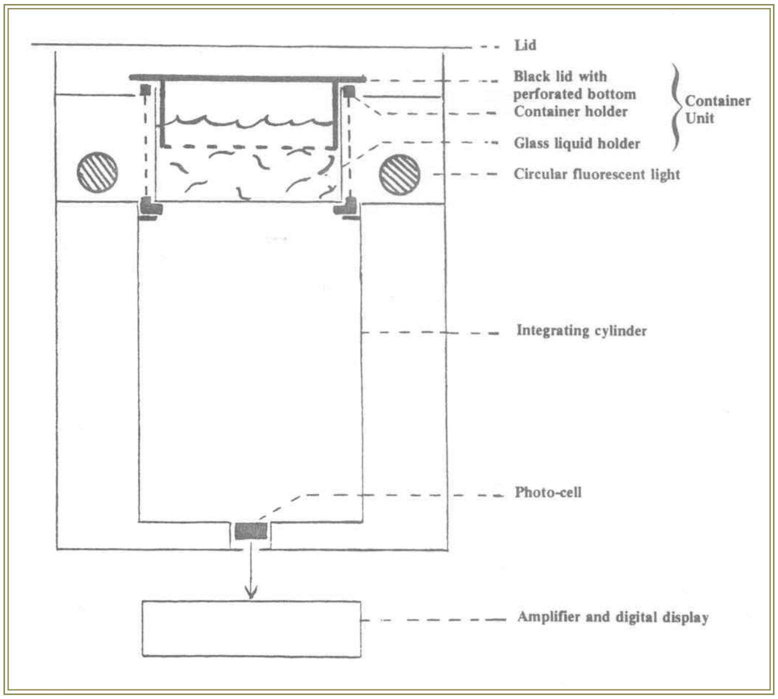


Figure 4.12: Diagram of Medullameter constructed at SAWTRI (Smuts et al., 1983).

Provided that certain precautions are taken, accurate estimates of the degree of medullation, in terms of the SAWTRI Medullameter reading, could be obtained fairly quickly, and with relative ease, about six to eight measurements per hour being possible (Smuts et al., 1983). Sample preparation (i.e. cleaning of greasy mohair and sampling) was important and needed special attention, and a simple scouring technique, avoiding the use of alcohol (since it caused the fibres to appear milky when immersed in the benzyl alcohol) was recommended. Although the Medullameter reading was shown to be related to various other measures of medullation, in particular to percentage area medullation; it should rather be regarded as a unique measure of the degree of medullation of a sample (Smuts et al., 1983). Hunter et al., (1983) reported that the SAWTRI Medullameter reading mainly provides a measure of the fibres with a med ratio >0.6.

Hunter *et al.,* (1990) found a fairly good correlation between the Medullameter values and the subjectively determined degree of objectionable fibres counted visually. It was concluded that, as a rapid screening test, aimed at estimating the degree of medullation and perhaps also of objectionable medullated fibres, the Medullameter would probably be adequate (Smuts et al., 1983, and Hunter *et al.,* 1990). Nevertheless, it was not regarded as suitable for obtaining an accurate measure of the objectionable medullated fibre levels, particularly at the lower, and more critical, levels of such fibres.

4.6.5 Near Infrared Reflectance Spectroscopy (NIRS)

Accuracy of measurement at all levels of medullation, especially the low levels, time and cost as well as measurement, have been the main concerns which stimulated the search for a more efficient and objective method of measuring medullation, this ultimately leading to the NIRS method being developed (Boguslavsky et al., 1992). The original analysis used an Infra-Alyzer 400R spectrophotometer because it was capable of measuring reflections at nineteen discrete wavelengths, ranging from 1.4 to 2.4 µm, the sample preparation being done according to IWTO—8—61(E); Table 4.2 shows the parameters estimated by NIRS.

Table 4.2: Parameters estimated by Near Infrared Reflection Spectroscopy

Parameter symbols	Parameters description
d_w	Mean fibre diameter
$\sigma_w{}^2$	Variance of fibre diameter
$d_m{}^2$	Mean medulla diameter
$\sigma_m{}^2$	Variance of medulla diameter
N_w	Total number of fibres measured
N_m	Total number of medullated fibres measured

To estimate the percentage of fibre volume occupied by medullae, Bray's formula was applied as follows:

$$\text{Percentage of fibre volume occupied by medulla} = \frac{N_m}{N_w} .100. \frac{d_m{}^2 + \sigma_m{}^2}{d_w{}^2 + \sigma_w{}^2} \qquad (7)$$

(Ranford et al., 1987)

The NIRS is an empirical method, which uses statistical inference to calibrate the reflections of selected near infra-red wavelengths across a spectrum using samples with known levels of medullation in the sample. The matching of wavelengths to particular levels of medullation was "made purely on statistical performance" (Ranford and Hammersely 1991 cited by Lee 1999). Calibrated NIRS instruments can be used to measure the level of medullation of wool within the calibration range (Lee, 1999). Boguslavsky *et al.*, (1992) developed a novel method of obtaining a measure of total medullation, which involved immersing the mohair sample in a liquid of the same refractive index as the mohair (e.g. benzyl alcohol) and then measuring the sample by NIR, after the necessary calibration and validation against the SAWTRI Medullameter. This novel method of measuring medullation in mohair combined the main idea of the medullameter method with the potentialities of NIR spectrophotometry, and eliminated the limitation of the conventional NIRA that are influenced by the light signal reflected from fibre surface, yet still takes the same amount of time (Boguslavsky *et al.*, 1993). This method appeared to be more accurate than other methods, but still only measured total medullation, and did not distinguish between the different types of medullated fibres.

4.6.6 Optical Fibre Diameter Analyser (OFDA)

The Optical Fibre Diameter Analyser, popularly known as the OFDA, was developed with research support from several international organisations, being the only image analysis Test Method to be recognised by the International Wool Textile Organisation (IWTO). The OFDA100 was the first automatic instrument to measure fibre opacity. Fibre opacity is directly related to the ability of each fibre to transmit light, and is determined by the fibre shape, internal structure, colour and surface quality. In white animal fibres, the main cause of opacity is medullation or hollow fibres.

According to Brims and Peterson (1994), quoted by Hunter and Botha (2011); the OFDA 100 measures the "opacity" of individual fibres, this being related to their medullation, fibre opacity being defined as the ability of a fibre to transmit light perpendicular to the fibre length. Fibre opacity is calculated by summing the light transmitted by the fibre in dark field mode, normalised by dividing by the fibre diameter. For the purposes of providing a base for calibration, a fibre is 0% opaque when the amount of light transmitted by the fibre is the same as that transmitted by a glass fibre of the same diameter. This normalised number is converted to an Opacity % by calculating its ratio to a calibrated sum for a glass fibre. An opacity of 80% is generally regarded as representative of the normal medullated fibre population. Medullated fibres that have collapsed, i.e., flat fibres, may have lower opacity values (Brims and Peterson 1994; Balasingam, 2005, and Hunter and Botha, 2011).

Figure 4.13 illustrates the three cases of fibre cross-section under dark field illumination, from which it is apparent that the greater the ratio of the medulla diameter to the outside (i.e. fibre) diameter, the greater the opacity, due to the internal reflection from the medulla (Brims and Peterson, 1994).

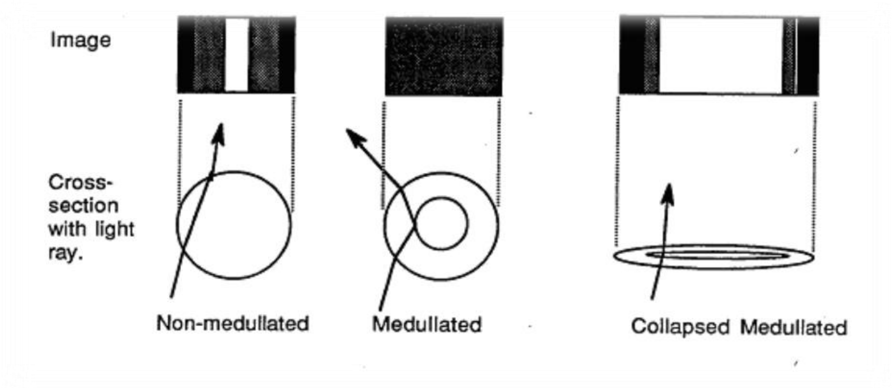


Figure 4.13: Fibre image under dark field illumination (Brims and Peterson, 1994).

A fibre with a medulla diameter that is almost the same as the fibre diameter will have a very thin wall and will collapse to a flat ribbon, these fibres being defined as “flat fibres”. The flat surfaces allow the light through, but the width of the central light band is greater than that of a non–medullated fibre (Brims and Peterson 1994). This allows the OFDA software to divide fibres into 3 classes (see Table 4.3), depending on their dark field image, which is also reflected in the IWTO standard procedure for the OFDA (see Table 4.4).

Table 4.3: OFDA classification of medullated fibres

Medullation classification by OFDA	**Classification criteria**
Medullated	Opacity > medullation threshold (80% used here)
Non-medullated	(Opacity<medullation threshold) and (light width<40µm)
Flat	(Opacity<medullation threshold) and (light width>40µm).

Hunter and Botha (2011) reported that the OFDA instrument was modified to incorporate an illumination attachment and software enhancement, the attachment providing a second (dark field) illumination system which highlights the medulla at the expense of the rest of the fibre. By alternating the two illumination systems as the OFDA slide is traversed, medullation (opacity) measurement is performed simultaneously with the fibre diameter measurement.

Lupton (1996) and Qi et al., (1994) showed that some 10,000 fibres/sample (or even 15,000) needed to be measured to achieve the required degree of accuracy Qi et al., 1994). When this is done, a linear relationship existed between OFDA measured kemp and projection microscope (PM) kemp, and between their respective total medullated values. The OFDA objectionable medullated values are about 50% that of the PM values. Maher (1996), however, showed that there was little benefit to the precision of any of the OFDA parameters measured (mean fibre diameter, standard deviation of diameter, mean opacity, standard of deviation of opacity, objectionable fibre count, mean diameter of objectionable fibres, flat fibre count and medullated fibre count) to be gained by measuring each slide more than once, or from measuring more than two slides.

Total medullation is the sum of normal medullated and flat medullated fibres, usually expressed per 10,000 snippets counted or % by number (Table 4.4). Peterson and Gherardi (1996), quoted by Hunter and Botha (2011), concluded that lack of precision in the projection microscope measurements was probably mainly responsible for the poor correlation between OFDA and projection microscope results for percentage medullated fibres.

Table 4.4: IWTO–57-98 Standard Definitions for OFDA measurements of medullation

Medullation Standard	**Measurement Definition**
Flat medullated fibres	Fibres with Opacity <80% that produce a wide light band (>40µm) under dark field illumination and have diameter>60µm
Objectionable medullated fibres	Fibres with Opacity > 94% and diameter>25µm
Normal medullated fibre	Fibres with opacity ≤ 80%

4.6.7 Original AWTA Ltd Method of Medullation Measurement of Core Samples

In the early 1980s CSIRO developed an instrument, the Dark Fibre Detector (Figure 4.14), and associated method, for detecting the level of dark (sometimes medullated) fibre contamination in a wool top. This method is based on visual detection and comparison of the brightness of the detected medullated fibre to that of medullated fibre No. (3) of the AWTA Ltd medullated fibre reference web. The fibre samples, of about 10g each, are viewed on a pair of slides between which they are placed for evaluation. The ASTM D2968-89 definition of an objectionable fibre was used in this trial. The Research and Development Division of AWTA Ltd developed a reference web to quantify the commercial occurrence of medullated fibre contamination (Mahar, 1996). The medullated fibre reference web consisted of five different medullated fibres and a thin strip of nylon bale filament. Fibres with brightness equal to, or less than, medullated fibre level 3 were considered as contaminant medullated fibres (Balasingam, 2005). Figure 4.15 shows the viewing glass plates separated from the fibre detector. On this figure the screen and the fields through which fibres are observed can be seen clearly.

In 2001, research was undertaken by AWTA Ltd and the South Australian Research and Development Institute (SARDI), on contamination of Merino wool caused by contact with one breed of exotic sheep, the Damara (Sommerville, 2009, Mahar et al., 2001). A key outcome of this research was that contamination from this source is detectable in the core samples routinely used for yield and diameter testing, thus allowing a test to be developed for woolgrowers.

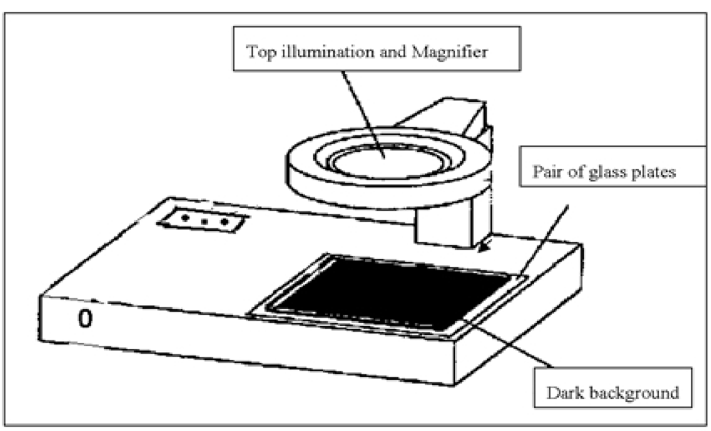


Figure 4.14: Modified CSIRO Dark Fibre Detector for medullation measurement (Balasingam, 2005).

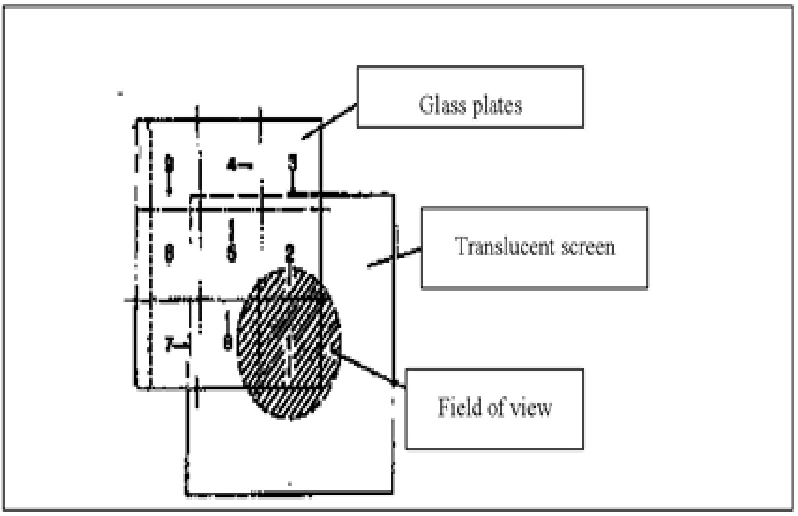


Figure 4.15: Measurement of glass plates (Balasingam, 2005).

4.6.8 AWTA Ltd Benzyl Alcohol Test Method

AWTA Ltd introduced a new method for medullation measurement in July 2004; namely the AWTA Ltd Benzyl Test method, based on research by CSIRO (AWTA et al., 2004), which works on the following principle: When normal (solid) white fibres are immersed in a solvent of the same, or very similar, refractive index as the fibre, they become transparent and very little reflection occurs. Wool fibres are virtually transparent when immersed in benzyl alcohol, since it is a clear colourless liquid with a Refractive Index (R: I) of 1.540, which is very similar to that (1.553) of wool (Faust 1954). Due to their internal medulla, with a different refractive index, medullated fibres continue to reflect incident light so that against a black background they appear white in benzyl alcohol. Unlike the original AWTA Ltd method, this newer version of the method involves a solvent (benzyl alcohol). This method is also based on a visual detector, after being detected, the brightness of the medullated fibre is compared with the medullated fibre from the AWTA Ltd Medullated Fibre Reference Web (see Figures 4.16).

Figure 4.16: The Modified Dark Fibre Detector for AWTA Benzyl Test Method (Australian Wool Innovation Project, 2005)

4.7 COMPARISON OF EXISTING MEDULLATION MEASUREMENT METHODS

The projection microscope method is a direct method of measuring medullation but is unsuitable for extensive use in both commercial and research, due to the time, labour and cost involved in measuring a large number of representative fibres or fibre snippets. The average time taken by two operators to measure 500 fibre sites is approximately two hours, and the method also relies on a considerable amount of interpretation by operators (Lee et al., 1996).

The WRONZ Medullameter and Near Infrared techniques are rapid indirect methods. They count/measure all medullated fibres, not just those fibres which are regarded as contaminants or objectionable. These methods are still not commercially acceptable for accurate high volume testing, particularly of objectionable medullated fibres. They need microscope measurement results for calibration and they do not differentiate between the different types of medullation. A later version of NIRA testing, proposed by Boguslavsky et al., (1993), combines the main idea of the Medullameter method with potentialities of NIR spectrophotometry, and it is therefore more accurate at low levels of medullation. Nevertheless, it has not been adopted for routine or research purposes.

The OFDA method differentiates between the different types of contaminating fibres, but is not a direct method of detecting medullation and the sample size for each measurement is very small (10,000 snippets in each measurement). Hansford (2003), in her review, noted that the OFDA100 is not commonly used in Australia for the measurement of medullation, and that the OFDA100 overestimates the medullation in merino wool. The AWTA Ltd methods are commercially available, although the original method is labour intensive and time consuming and is thus extremely costly. Due to the small size of specimen (0.25g-0.5g) that can be examined at one time, several (20-40) such specimens must be examined to achieve the level of accuracy required.

Compared to the other methods, the new AWTA Ltd benzol test method is commercially acceptable because it tests a large sample size of (20g) relatively quickly. The medullation of several hundred thousand fibres is seen at a glance, and only fibres that are considered to be a cause of contamination (objectionable) are measured. Even though several methods are available, all methods depend on the ASTM definition of the threshold level contamination to calibrate or evaluate their measurements. Currently, no research has established that the ASTM D2968-89 definition of a threshold level for medullation contamination is entirely suitable for merino wool (Balasingam, 2005).

CHAPTER 5

5. A REVIEW OF PRICKLE SENSATION FROM WOOL TEXTILES

5.1 INTRODUCTION

As already mentioned, comfort, defined as an absence of discomfort, is an important consideration in the selection of clothing, particularly for next-to-skin clothing. Sykes (1987) and Hyun et al., (1991) defined comfort as a recognisable state of feeling, although having no identifiable sense organ, such as is the case for the basic five senses of sight, hearing, smell, taste and touch. Comfort relates, in some respect, also to perceptions of being luxurious and expensive.

Garment comfort is neither a physical property nor a non-concrete image, rather a composite perception, encompassing the individual, a specific environment and a preference of one alternative over another (Wang et al., 2003). Essentially, comfort is an imperceptible concept, associated with the interaction of a garment with the skin in all its complexities, and includes physiological and physical elements of the wearer, ambient conditions and fabric and garment properties. The extent to which individual consumers experience comfort varies tremendously (Broega et al., 2010; McGregor et al., 2013; Tester et al., 2014; and Naebe et al., 2014). It can be concluded that comfort is not directly measurable, rather are the attributes that influence it measurable. It is not a clearly definable property of the garment *per se*, but is influenced by various fibre, fabric and garment properties, as well as external and wearer related parameters.

The key factors influencing perceived comfort include, but are not limited to, sensorial aspects, body dimensions and movements, garment design and even aesthetic appeal (Naylor et al., 2014). The key terms used to describe comfort include hot, cold, wet, clammy, prickly, itchy, heavy, and rough. According to Stanton et al., (2014), the important aspects of clothing comfort can be grouped into the following categories:

- ***Sensory comfort*** – Have to do with the sensations arising when a garment comes in contact with the skin.
- ***Thermo-physiological components*** – Those that are attained from a comfortable thermal

and moisture conduct.

- ***Ease of movement*** and
- ***Aesthetic appeal***- This includes the perception of clothing by the eye, hand, ear and nose, and which contribute to the overall well-being of the wearer.

Generally, comfort studies aim at addressing its understanding and value, its physical parameters and means by which it can be measured. These areas ultimately form the categories of all comfort studies (Liao et al., 2011). A framework of comfort sensation studies is illustrated in Figure 5.1, indicating the relationship between the categories.

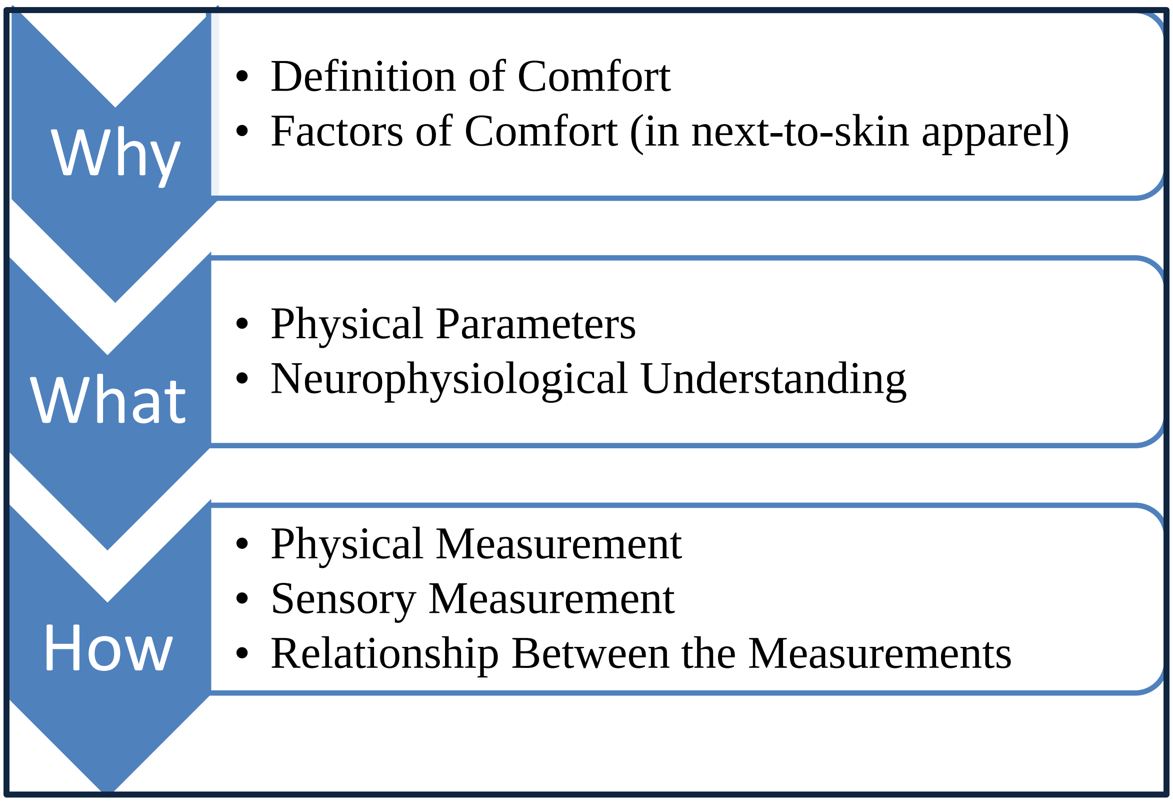


Figure 5.1: Framework of Comfort Sensation Studies (Liao et al., 2011)

Handle, which refers to the feel or softness of a fabric, is another important factor in terms of wearer comfort and satisfaction. It is mainly influenced by fabric weight, stiffness, thickness, density and other yarn and fabric construction parameters, with the mean fibre diameter of the wool playing an important role in determining the fabric stiffness. Nevertheless, it is important to emphasize that handle does not provide an accurate measure of how comfortable the fabric will be when it is worn next to the skin.

The focus of this part of the study, and literature review, is on prickle and covers aspects relating to the perception and experience of prickle, the subjective and objective assessment of prickle, factors which influence prickle and ways of reducing, or even eliminating prickle. It is worth noting however, that there is a vast literature on prickle and reference is made only to some of the key aspects, studies and findings for purposes of this study. Furthermore, it is also important to mention that some later research findings identified errors in some of the earlier studies and findings.

5.2 WOOL PRICKLE

5.2.1 Introduction

Wool has both advantages and disadvantages with respect to sensory properties, especially in terms of modern consumer trends and requirements. Its main advantages include its good comfort and moisture management properties as well as its "green" image. Next-to-skin comfort is a key and additional feature of customer satisfaction for garments which come in contact with the skin of the wearer. Comfort demands, both sensorial and functional, have increased in recent decades, particularly with regard to garments made from animal fibres (Naebe et al., 2013a). Li (1998) stated that wool was traditionally perceived as the most suitable fibre for the formal wear market. Nevertheless, one of the main disadvantages associated with wool is its reputation of being scratchy or prickly, and even allergenic, with the result that many consumers steer clear from purchasing clothing containing wool, more particularly when it will be worn next to the skin (Li, 1998). The structure of each wool fibre, however, is not biologically uniform; it depends mostly on the sheep genetics, growing environment and their management, they in turn determine the physical characteristics of the wool fibres (Holman and Malau-Aduli, 2012, Warn et al., 2006, Poppi and McLennan, 2010). Wool competes with a number of other fibres, both natural and manmade, some of which inherently possess the desired prickle free characteristics. For wool to succeed in the modern market, product development has become a priority, and not just an option, as wool cannot rely solely on its traditional positive image and attributes to satisfy modern consumers. Furthermore, any negative attributes, real or perceived, associated with wool, need to be addressed and rectified where possible. Reducing prickle, even possibly eliminating it, is one of the innovations necessary for the next-to-skin clothing markets, notably underwear, where wool has not previously been popularly used, except for the extremely fine wool.

The prickle sensation associated with wool fabrics has been a concern to most consumers; resulting in extensive research being undertaken by the CSIRO (1994) in Australia and also other researchers, to identify the causes of prickle, and ways of reducing it. Such research has conclusively shown that prickle (or scratchiness), often associated with wool, is not due to an allergic reaction, but is rather related to the stiffness of the fibres. It emerged that the presence of relatively coarse wool fibres, referred to as the coarse edge (generally taken to be fibres coarser than 30 μm), are generally responsible for the sensation of prickliness. The more detailed expansion of this concept continues later in this chapter.

The role of the skin, in the perception of prickle, as well as the associated physiological and mental response processes, are all important in understanding prickle, and so are the skin/garment interaction and sensitivity of different individuals which ultimately determine prickle sensation and perception directly. By its very definition, perception is a subjective concept, and generally so are the methods of assessing prickle, although research has led to certain objective methods of assessing prickle and its perception. Nevertheless, it remains important to properly assess the suitability of these methods.

5.2.2 The concept of prickle

Consumers are presently more informed with respect to decision making than they were previously and they can now make much more informed choices when selecting clothing items to purchase. As already stated, prickle is an important cause of garment discomfort and can be a factor limiting the use of certain types of wool in clothing or upholstery products which come into contact with the skin (Matsudaira et al., 1990), with over 50% of people in key markets associating prickle with wool (Praëne et al., 2007; and McGregor et, al., 2015). Prickle can be described as the unpleasant prickly or scratchy sensation associated with certain fabrics. Kennins (1992) explained that the prickle evokes the desire to scratch in a similar manner itch does, and may be described as “pricking with many needles”, the associated degree of discomfort varying from one person to another and the wear conditions. Botha (2005) defined prickle as a sensation often complained about by consumers with respect to garments worn next to the skin, notably underwear, especially in the case of wool fabrics. According to Naylor (2010), fabric-evoked prickle sensations are sometimes linked to wool and wool blend fabrics worn next-to-skin. To be in a better position to produce a product that consumers are willing to purchase, wool producers and manufacturers need to understand and address prickle.

In the early years, prickliness and itchiness were not well understood and would often be associated with wool garments, and considered to be an allergic reaction (Hellier, 1960). Research by Garnsworthy et al., (1988 a) in Australia, however, showed that the prickle related uncomfortable sensations, sometimes associated with wool, had nothing to do with an allergic reaction. This therefore, necessitated further research on the exact mechanism and cause of prickle. Research carried out since the 1980s has shown that the neuropsychological basis for fabric-evoked prickle is neither an allergic reaction nor a result of chemicals released from wool. Instead, it is the mechanical stimulation of particular nerve cells close to the skin surface, by the fabric, inducing a low-grade activity in a group of pain nerves, manifesting itself as prickle (CSIRO, 1987; Kennin, 1992 and Veitch and Naylor, 1992). IWTO, (2017) and Zallmann et al., (2017) described the differences between allergy and prickle sensation.

5.2.3 The Sensation and mechanism of prickle

The prickle sensation is realised through the skin as a sensory organ, it is therefore, important to understand the relevant mechanism involved in perceiving itch and pain by the skin.

5.2.3.1 The Skin as a sensory organ

The skin is the first and most important point of contact with any external stimulus, in this case a fabric. The skin, as the intermediary between the nervous system and the environment, becomes itself the sense organ, and as far as pain nerve endings are concerned, no other specialized organ than the skin tissue surrounds the endings (Jiyong et al., 2011 and Bishop 1948). As one of the sensory organs of humans, the skin is obviously not passive in terms of prickle sensitivity, which justifies the subjective manner with which prickle is usually measured. A later section of this chapter deals in more detail with the perception of prickle, and the human skin.

Limin and Chongwen (2004) reported that the receptors responsible for fabric-evoked prickle are very close to the surface of the skin, which means they are located in the superficial layer of the skin, making them easily triggered, even by relatively weak prickle stimuli. Furthermore, the response of these receptors is on a low level, thus resulting in sensations of prickle rather than pain.

Even though prickle is felt on the skin surface, the actual feeling is a process that normally starts a long way before the fabric actually comes into contact with the skin, as illustrated in the sensibility model of Youngjoo and Chunjeong (2001) in Figure 5.2. The fabric (stimulus) is first observed, or felt by the hand (sense organ), and, through a psychological process (sensation), a decision is made about the expectations from the garment (perception). Then, depending on the previous stage of this process, some feelings are formed and stored in the memory. Figure 5.2 illustrates the entire process in the formation of sensibility.

The levels of the complex process of prickle sensibility formation is psychological, starting from hand to sensibility, the stages are divided into four steps; sensation, perception, cognition and feeling of sensibility. Sensibility is achieved through this process; it is also through this complex process that emotions of refinement, high quality and comfort are formed. As the sense organ is not part of the brain, the hand-feel or touch is only the beginning of the process, further steps occurring in the brain. It is, therefore, not correct just to use touch alone in assessing sensibility (Youngjoo and Chunjeong, 2001).

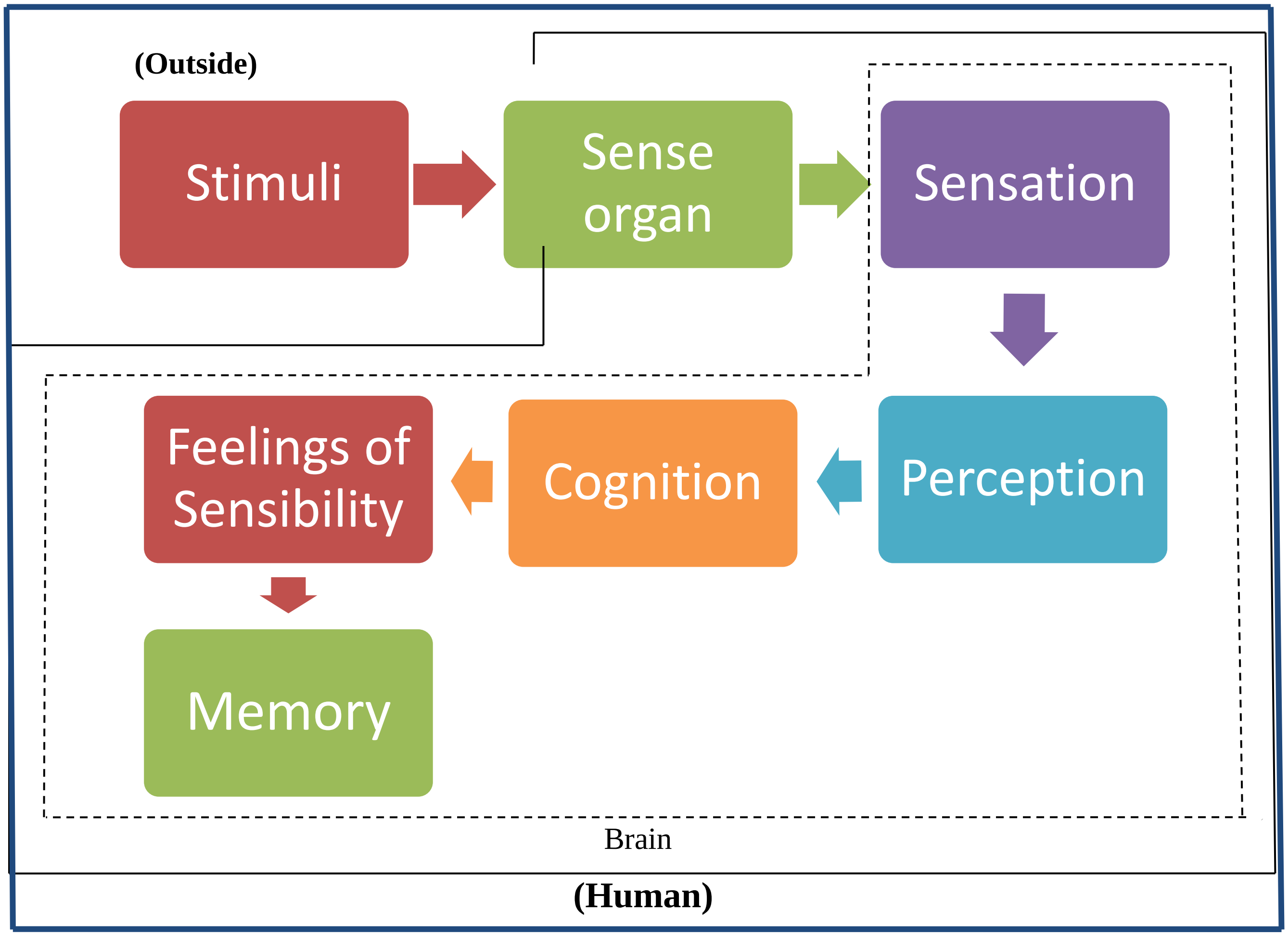


Figure 5.2: Model of Creating Sensibility (Youngjoo and Chunjeong, 2001)

The neurophysiological experiments by Garnsworthy et al., (1988), revealed that the coarse fibres in fabrics have the ability to activate pain-sensing nerve fibres in the skin, which the body interprets as prickle, even though it is at a low level. Their experiments showed that a force between approximately 0.75 mN and 1.0mN (which corresponds to ≈ 30 μm wool fibre diameter), when applied to the skin, would suffice to trigger the relevant nerve responses (Garnsworthy et al., 1988 and Naylor, 1992), this being the critical threshold force required to evoke prickle when applied to the skin by the fabric, more specifically the fibres protruding from the fabric surface. The report by Garnsworthy et al., (1988) dispelled the misconceptions that prickle is an allergic reaction towards wool, explaining that it is rather the stimulation of the Aδ nerve endings by a stiff wool fibre (of diameter ≥ 30μm), which results in the prickle sensation.

Hu et al., (2011) stated that most studies on fabric evoked prickle are now guided by the hypothesis and work of Garnsworthy et al., (1988). The neurophysiological experiments, along with the critical buckling force of fibres, by Garnsworthy et al., (1988) and Kennins (1988), confirmed that fabric evoked prickle is a mechanical action resulting from the individual fibre end protruding from the fabric surface acting on the skin, with the pain receptors situated in the skin being responsible for the sensation of fabric-evoked prickle (Garnsworthy, 1988 and Naylor, 1992). Limin and Chongwen (2004) described the mechanism of fabric evoked prickle as a group of skin receptors, termed polymodal nociceptors, which respond to potentially skin-damaging mechanical, thermal and chemical stimuli. Fabrics produce a sensation of prickle when they trigger the skin receptors.

The human skin has many nerve endings, of varying thickness, situated just below the outermost layer of the skin, called the dermis (see Figures 5.3 and 5.4). The size of these nerve endings can vary from less than 1μm to 20μm (Kennins, 1992). These nerves are further categorised into three groups, the description of these groups, according to Kennins (1992), being as follows: The first and largest group (Aβ) mediates sensations, such as touch, vibration and texture. The second group (Aδ) mediates touch, cold and pricking pain, while the third group (C) mediates sensations of warmth, and pain from heat, chemicals and mechanical injury (see Figure 5.3). The narrow nerve endings present in the (Aδ) group are responsible for receiving the pain sensations; the detection of prickle depending largely on the ability of these endings to feel the sensations from the external stimuli. Individual skin types vary in terms of sensitivity, according to the number and location of the nerve endings beneath the skin surface and the nature of the skin itself (Kennins, 1992, Bishop, 1948 and Jiyong et al., 2011). The number and location of these nerve endings vary in individuals, and this brings about the difference in individual sensitivity; the differences in sensitivity, lack of oxygen and chemicals, make it possible to establish the type of sensory information sent to the brain by each of the nerve groups (Kennins, 1992). Figure 5.4 shows a detailed skin diagram, illustrating parts of the skin located in the different layers.

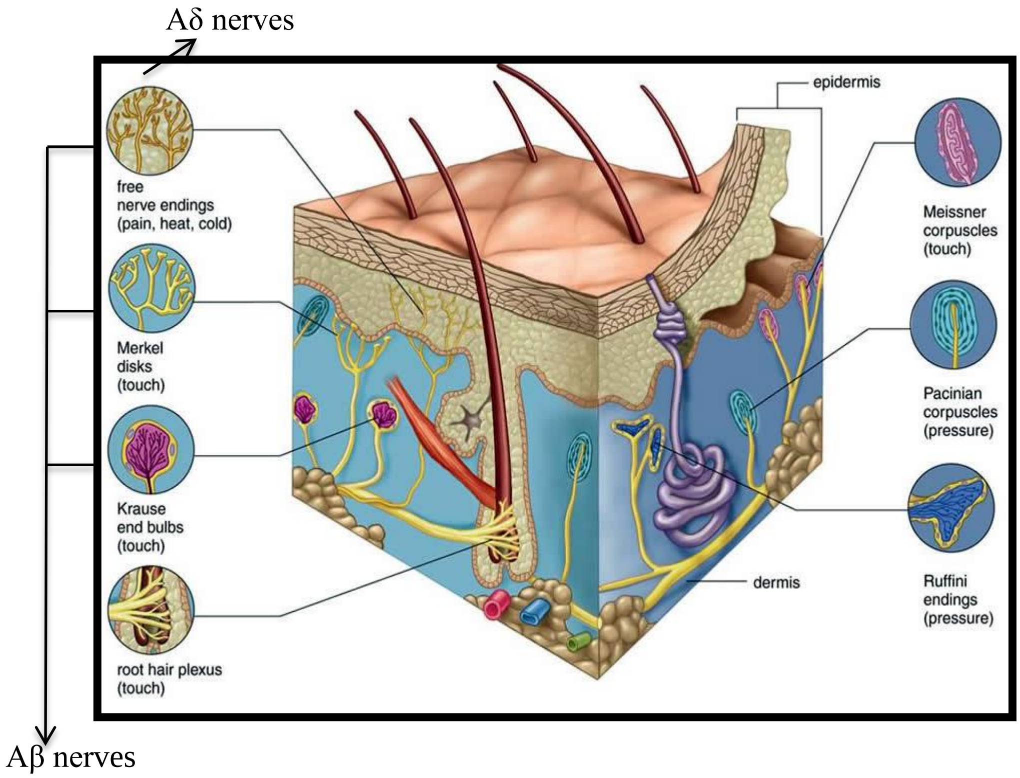


Figure 5.3: The Sensory System (classes.midlandstech.edu, 2014)

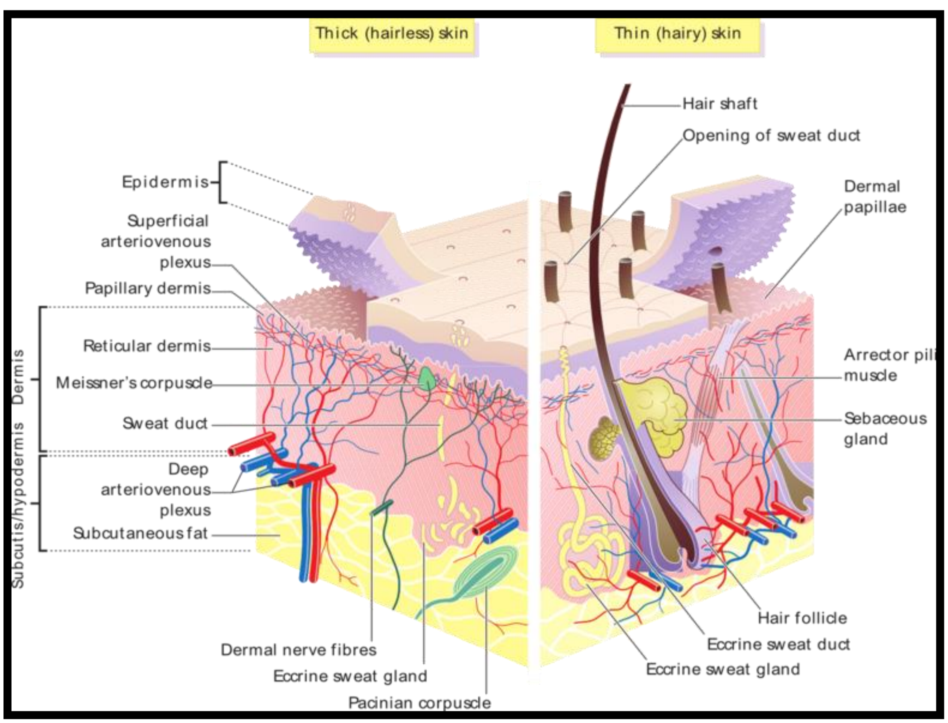


Figure 5.4: Longitudinal-section of the Human Skin (Commons Wikimedia, *sourced September 2017*)

5.2.3.2 Skin Properties Influencing Prickle Sensitivity

The skin is efficient in protecting our bodies from the external environment, but it is also an important site for the perception of various stimuli. The function of the sensory neurons of the peripheral nervous system and many primary afferent fibres to the skin (See Figure 5.5) enable this perception (Ikoma et al., 2006). Afferent fibres are the ascending pathways transporting sensory information from the peripheral (sensory organs) to the central system in humans (Boulais and Misery, 2008). The properties of the skin contribute significantly to the sensitivity and intensity of fabric-evoked prickle. Those identified from previous research, include skin hardness and age, skin temperature and humidity as well as the depth, density and sensitivity of nerve endings. It is also believed that individual differences in the brain can influence the sensitivity to prickle, and therefore prickle sensation (Downar et al., 2002).

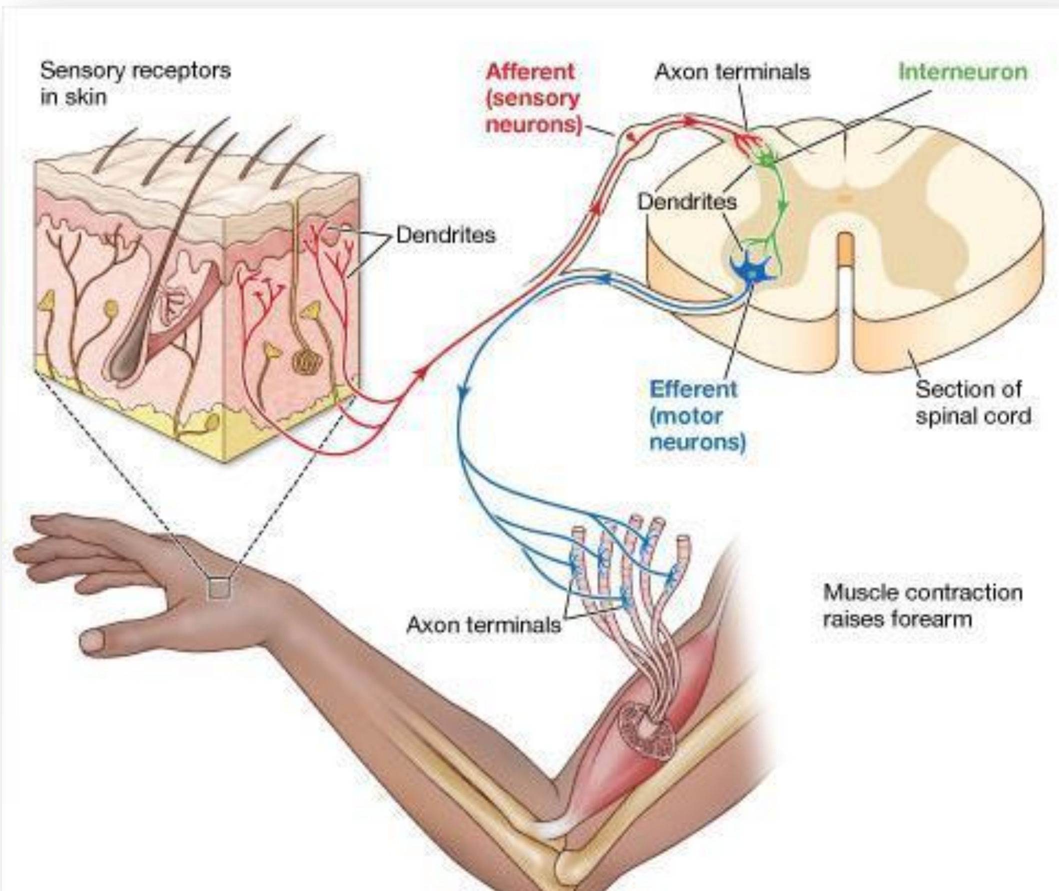


Figure 5.5 Illustration of sensory (afferent) and motor (efferent) nerves *(craftbrewswag.info sourced September 2017)*

5.2.3.2.1 Skin hardness: According to CSIRO (1987), as the outermost layer of the skin's epidermis, called the stratum corneum, becomes harder; the level of skin deformation due to an external force diminishes (Limin and Chongwen, 2004). The skin usually hardens with increasing age, making the adult skin generally less sensitive than that of children, prickle sensitivity progressively decreasing with increasing age. Exposure to manual work can also contribute to the hardening of the skin, most manual workers being less sensitive to external stimuli, thereby obviously influencing the individual prickle perception (Limin and Chongwen, 2004). This could be the reason why females, who generally have a softer and more flexible skin than their male counterparts, are more sensitive to prickle, why sedate workers are more sensitive than their manual worker counterparts due to the harder skin of the latter, and similarly babies' skin responds more readily to stimulation, as it is softer and thinner. Hence, the requirement for softer fabrics in babies layette (a collection of new-born baby's clothes) in general .

5.2.3.2.2 Moisture*:* Moisture on the skin is an additional factor influencing the manner in which the skin reacts to external stimuli (Limin and Chongwen, 2004). The CSIRO (1987) reported that the presence of moisture, or perspiration, on the skin, or even an application of moisturiser, significantly increased prickle sensation due to the softening of the skin. Kennins (1992) agreed with this, adding that wetting the skin resulted in an increased indentation by a set force. Limin and Chongwen (2004) found that the moisture level in the skin influenced prickle sensitivity or intensity. In the light of the above reports and conclusions, it is obvious that prickle, or sensation intensity, is enhanced when water or skin moisturisers are applied to the skin due to the fact that they soften the stratum corneum, which then indents more easily. It has been found that the neural basis for the prickle sensation increased with increasing skin temperature, moisture and exercise induced sweating (McGregor et al., 2014).

5.3 ASSESSING PRICKLE

The assessment of prickle has mostly been done subjectively in the past, since it is a perceived sensation on the skin, and rather subjective, the perception of prickle varying from one person to the other, making it difficult to obtain reproducible and reliable results in such a way (Matsudaira et al., 1990). Research focus has, therefore, shifted to objective instrument measurement of prickle, with new measurement instruments being developed which make prickle and other fabric handle related attributes easier to measure and research. Nevertheless, while the subjective measurements remain time consuming and non-repeatable, they are still considered best for providing a true picture of the actual feel of the fabric on the skin, although if used alone, the results may not be representative, reliable or sufficient (McGregor et al., 2014). Assessment of handle and comfort is a complex and subjective task, which often yields results that may not be very reliable. According to Tester et al., (2013), the Kawabata system (Kawabata, 1980) came closest to an acceptable commercial evaluation system for fabric prickle. One possible reason for the reliability of the Kawabata system for fabric handle is because it focuses on a single class of fabrics at a time, this in turn limited the interactions of the measured properties and the subjective perceptions thereof. The objective tests generally only measure the factors external to the skin (e.g. fibre and fabric), whereas the actual nature and response of the skin also play a role in the sensation of prickle experienced by the wearer, these being assessed subjectively. In the final analysis, a wearer trial is still the established method to measure human sensory response for the next to skin comfort of garments. However, objective measurement validates results and makes studies repeatable, although the actual skin responses cannot be completely omitted in the assessment of prickle. McGregor et al., (2014), for example, showed that sleeve wearer trials, when used in association with the Wool ComfortMeter, offer the potential to improve the predictions made of wear trial prickle discomfort. The development of the Wool ComfortMeter™ and Wool HandleMeter™ allows the measurement and fairly accurate prediction of the skin comfort of garments, specifically the perception of fabric evoked prickle (Tester et al., 2013).

Prickle related comfort (or the level of prickle) can be measured with a device, the Wool ComfortMeter (developed by the Sheep CRC in Australia). The device primarily measures the resistance to bending of the fibre ends protruding from the fabric surface. Comfort is strongly related to mean fibre diameter, with wools having an average fibre diameter of less than 18 micrometres (µm) generally very comfortable, and wool becoming less comfortable as the mean fibre diameter increases (Sheep CRC, 2014).

5.3.1 Subjective testing

As already stated, the very description of prickle, as a perceived sensation on the skin, complicates the measurement thereof. Kennins (1992) and Veitch and Naylor, (1992) agree that the forearm test is the most commonly used subjective method for testing prickle. The reason for its popularity is because research has shown that the prickle sensation is associated with the small nerve fibres, which predominates on the forearm. Testing prickle on the forearm, when the nerves are blocked with a blood pressure cuff, results in touch sensations being lost, while pain, temperature and the fabric evoked prickle sensations remain for about 20 minutes of block progress. If, when the nerves were blocked and certain touch sensations could not be sensed, the fabric evoked prickle could still be experienced at the forearm, then the forearm is sensitive to this kind of prickle. It was concluded that the forearm is the most preferred and reliable position for testing prickle. The onset of complete anaesthesia or simply lack of sensation was experienced around the 36th minute, as shown in Figure 5.6, and after about 40minutes all sensations were lost, indicating that prickle sensations are associated with the small nerve fibre ends (Kennins, 1992).

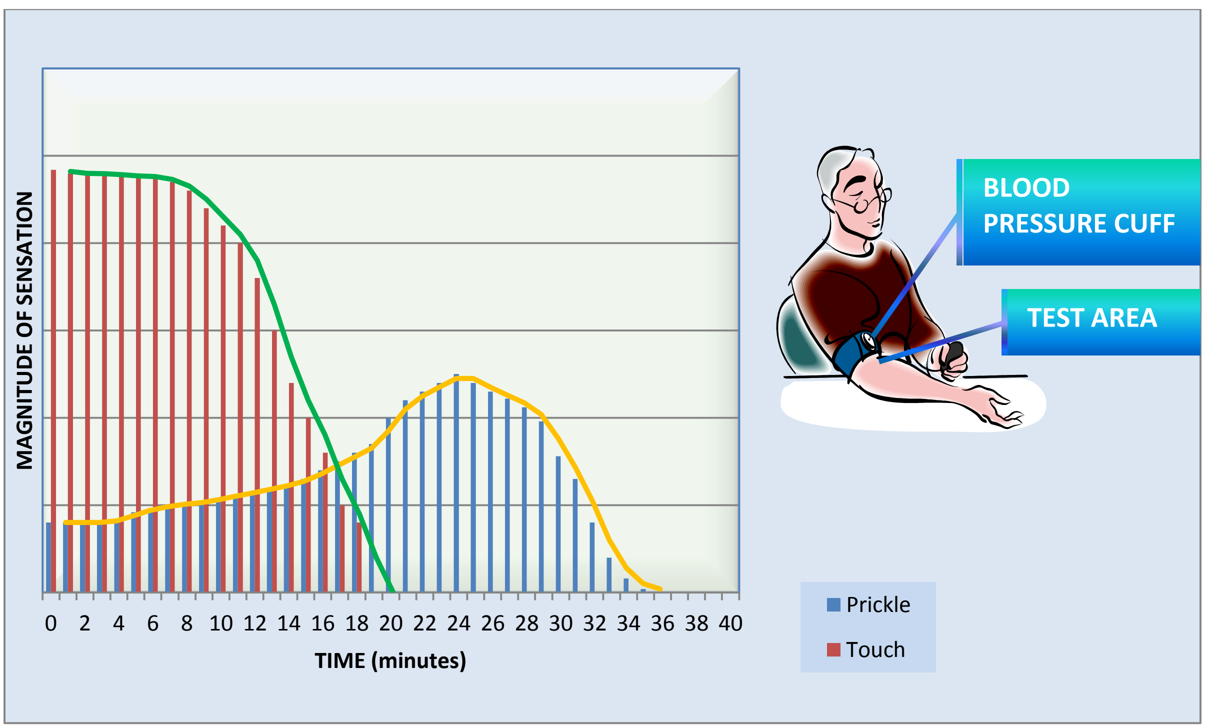


Figure 5.6: Approximate time course of loss of prickle and touch sensations on forearm during nerve pressure block at the upper arm (Kennins, 1992).

In as much as subjective tests can not completely be quantified, due to the complexity of the comfort perception associated with the interaction of a garment and the skin, as described by McGregor et al., (2013 c), the subjective tests are still valuable and therefore, cannot be ruled out completely in the measurement of prickle.

5.3.2 Objective testing of prickle

Until recently, some objective test methods, used to measure fabric evoked prickle, have been largely limited to scanning electron microscopic views of the textile surface or measurements of the bending stiffness of fibre ends sticking out of the fabric being tested. In most of these methods, derivation or interpretation was carried out by the observer on the basis of specific fibre topography, to determine whether the mechanical influences could cause skin irritation or not. The methods were, therefore, very subjective and the results could not be accurately quantified, since conclusions drawn about the response of the human skin based on calculations and measurements done elsewhere, not on the skin, where the irritation actually takes place, cannot entirely be objective (Hofer, 2006). There are, however, new developments in the objective measurement of prickle, resulting from research involving measuring what is believed, and proven to be, the causative factors of prickle. Formulae, for calculating the prickle that can be expected when wearing a particular fabric, have also been derived (AWTA, 2013). The following is an example of such a formula;

$$Z_X = \frac{X - X_m}{SD_X}$$

Given that:
Z = Variable
X_m = Values of mean fibre diameter
SD_x = Standard deviation

Due to the disadvantages associated with all subjective tests, including prickle, it was important to develop more objective tests, considerable research was directed to this end, particularly at the CSIRO in Australia. Matsudaira et al., (1990) noted, with concern, that as long as the prickle tests are done subjectively, they are time consuming and results are not repeatable because of the variation in the individual consumer panellists who differ noticeably in their responses to the prickle sensation. While no single method can be all encompassing and the best; using and comparing objective and subjective methods are therefore, advisable. Some of the instruments, which have been used in the past, as well as the ones recently developed to measure comfort and prickle, are listed (in no particular order) and discussed below:

- Laser Hairiness-Meter
- The Hand-held sensor
- CSIRO Wool ComfortMeter
- The Wool HandleMeter
- The Griff Tester
- Pharb Ometer

5.3.2.1 Laser Hairiness Meter

Prickle may be objectively assessed by, for example, using low-pressure compression-testing, and laser counting of hairs protruding from the fabric, the fibres protruding from the fabric surface being counted using a laser hairiness meter. This meter was developed specifically for the measurement of the number of hairs or fibres protruding from the pile of a carpet. Figure 5.7 is a simplified diagram of a laser hairiness meter (Matsundaira, 1990).

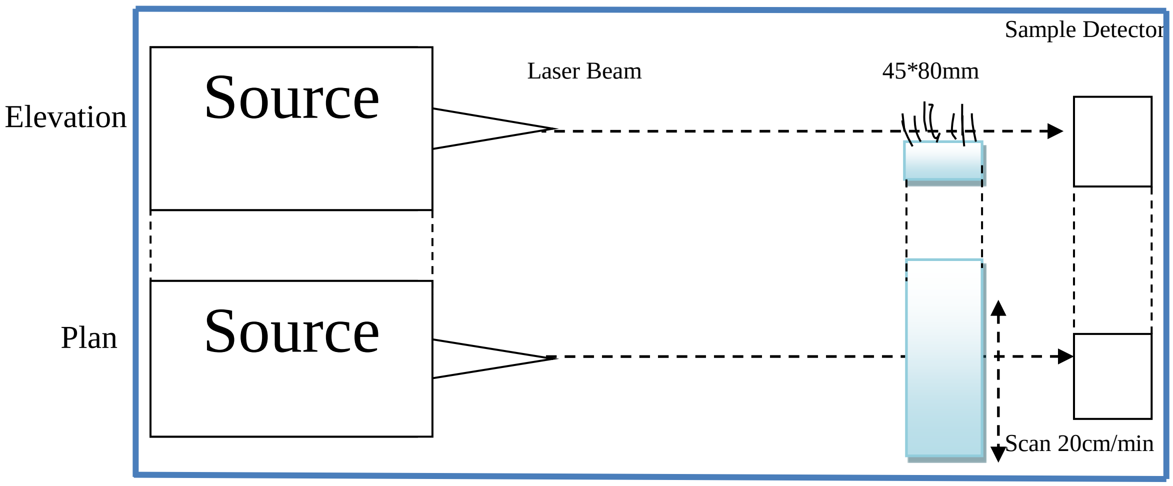


Figure 5.7: A Laser hairiness meter (Matsudaira et al., 1990)

The interruptions of the laser beam by the protruding fibres are detected and counted. The sensitivity of the instrument is a key factor in the accuracy of the measurement. Because the finer and relatively transparent fibres are not reliably counted, unless three or more of them fall within the beam, the instrument is unable to provide an absolute measure of the number of protruding fibres. The bias in favour of the coarser, stiffer fibres could be regarded as advantageous in the context of obtaining a measurement that may relate to prickle, since it is generally only the very coarse fibres (eg ≥ 30 µm wool) which cause a prickle sensation (Matsudaira et al., 1990).

5.3.2.2 The Hand-held sensor

The Hand-held sensor, Wool HandleMeter and CSIRO Wool ComfortMeter devices have been developed and introduced to the market relatively recently for objective hand-held prickle measurement and will be discussed in some detail. Ramsay et al., (2012) reported the development of a new technique and prototype instrument (the Hand-held sensor) for rapidly assessing the propensity for fabric-evoked prickle by measuring the stiffness of the fibres protruding from the fabric surface. The development of this instrument for measuring prickle was motivated by the theoretical consideration that measuring the prickle propensity of a fabric or garment is a difficult task, with the primary assessment being subjective (sensory) responses from wearers. From a research perspective, collection of this type of data is both time consuming and relatively expensive. An engineering perspective explanation of prickle is that there is a mechanical action by the stiff fibre end protruding from the fabric similar to simple Euler rods, these fibre ends are described by Ramsay et al., (2012) as simple columns under compression that will either buckle or bend depending on the position and direction from which pressure is applied.

Buckling differs from bending, mechanically and in principle, in the case of Euler buckling, the force is applied to the top of the fibre parallel to the fibre axis, as illustrated in Figure 5.8, while, in the case of bending, the external force is applied perpendicular to the axis of the cantilever, with the bending stiffness of an individual fibre being proportional to:

$$Ed^4/\ell^3 \quad (1)$$

Where: E is the Young's modulus of the material,

d is the fibre diameter (µm) and

l is the length of the protruding fibre end (mm).

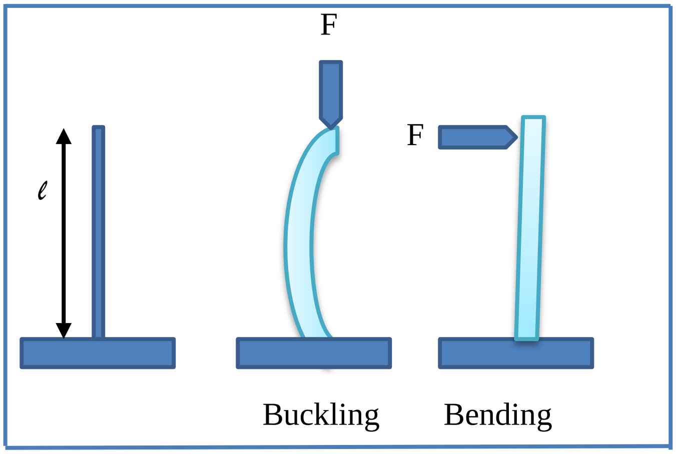


Figure 5.8 Measures of fibre rigidity (Ramsay et al., 2012).

According to Ramsay et al., (2012), the accepted working hypothesis, consistent with a large number of published studies, is that stiff fibre ends, protruding from a fabric surface and contacting the skin during wear, act mechanically as simple Euler rods. If the fibres are able to sustain sufficient amount of force, before buckling, they trigger the nerve endings (pain receptors), resulting in the ‘prickle’ sensation. Therefore, the stiffness of a protruding fibre largely determines how it impacts the skin. Fibre stiffness can be represented as the flexural rigidity of the fibre, defined as the couple needed to bend the fibre, expressed mathematically as follows:

$$\text{Flexural rigidity} = (1/4\pi)\,(\eta E T^2/\rho) \qquad (2)$$

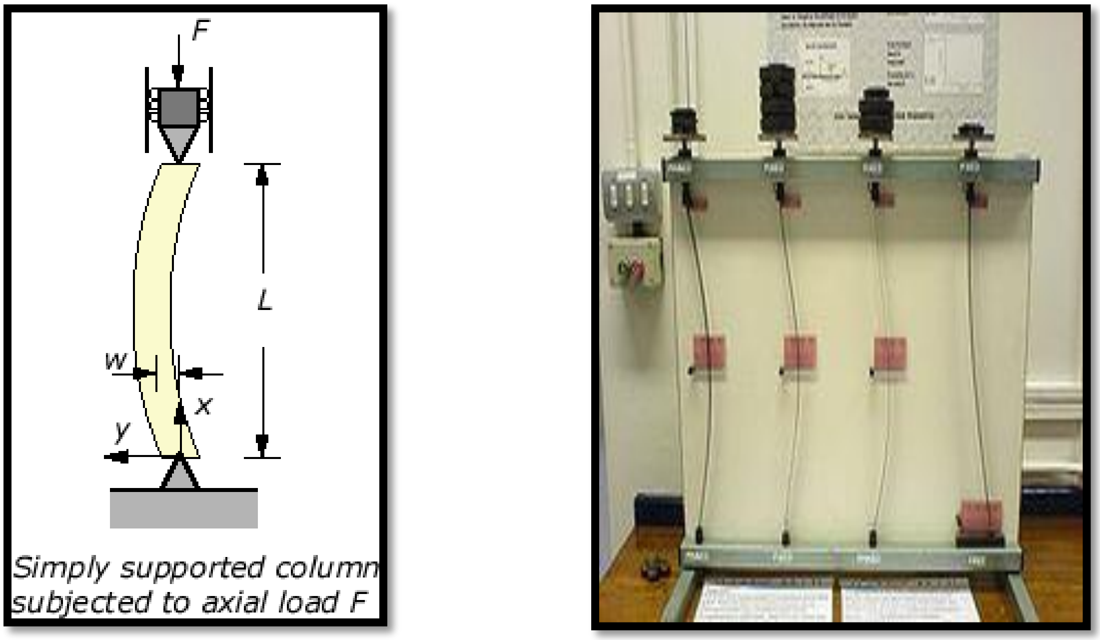
Where, η = fibre shape factor (≈ 1 for a completely round or circular fibre)

E = fibre specific shear modulus,

T =fibre linear density (tex),

ρ = fibre density (g/cm^3)

According to Ramsay et al., (2012), modes of deforming a cantilever, well defined from an engineering perspective, often refer to the case of Euler’s buckling, in which the force is applied to the top of the fibre and parallel to the fibre axis, as illustrated in Figure 5.9 (a). In such a case, buckling will occur when the applied force is greater than a particular threshold, which is proportional to Ed^4/l^2 (where E is the Young's modulus of the material, d is the fibre diameter and l is the length of the protruding end).



(a) (b)

Figure 5.9: An illustration of the different "Euler" buckling modes. The model shows the effect of the boundary conditions on the critical load of a slender column.
(www.efuda.com/formulae/solid_mechanics/columns/columns.cfm)

The fibre ends protruding from the fabric surface are of various modalities; meaning that they can, for example, have different shapes, different lengths, different diameters and different inclinations to the surface of the fabric. In addition to these factors, fibre curvature has also been shown to influence, to some extent, the mechanical, wear and handle related attributes of fabrics, when certain variables are controlled (Tester et al., 2014). From the above information, it is clear that not all fibre ends can deform the skin sufficiently to trigger the receptors responsible for prickle.

5.3.2.2.1 Fibre Diameter/Coarse Edge

The description and illustrations of Euler's buckling theory basis and calculations by Naylor (1992), as well as work by various authors, made it widely accepted that the percentage of fibres greater than about 30µm, in the fibre diameter distribution, termed coarse edge, is the critical parameter in determining prickle. Naylor (1992) illustrated that the thicker shorter fibres sustain a larger force before buckling, using the following appropriate formula:

$$F_B = \frac{\pi^3 E D^4}{31.4 l^2} \tag{3}$$

Where

F_B is the buckling force

E is the Young's modulus (5.4Pa for conditioned wool)

D is the diameter of the fibre

l is the free fibre length

This calculation led to the hypothesis that it is the coarse fibres in the wool fibre diameter distribution which are responsible for prickle, and as already mentioned, the nerve cells responsible for the prickle sensation are triggered at a threshold force on the skin of the order of 0.75 Nm (Garnsworthy et al., 1988).

The strong similarity between the equation for bending of a cantilever and that for buckling force of the Euler column is an indication that measuring the bending stiffness of the protruding surface fibre ends should be a good substitution for a measurement of their buckling characteristics (Ramsay et al., 2012). Evidently, both equations are proportional to the Young's modulus of the material, both increase as a function of the fourth power of the diameter of the column, contextually the fibre, and both are an inverse function of the third power of the column length which represents the protruding fibre length.

Ramsay et al., (2012) research team's approach for the development of the Hand-held sensor instrument was based upon the bending mode of deformation. The principle of measurement of this device is based on the forces on the "pick-up guitar." The process description is as follows; a tensioned wire is drawn over the surface of a fabric to interact with the group of protruding fibres, in contact with it, as it traverses across the fabric surface. The force exerted on the wire is determined from the deflection of the wire as it interacts with the fibres. These small movements of the wire are detected by imposing a static magnetic field across the wire and measuring the induced current as the wire moves through the magnetic field (Ramsay et al., 2012). When a fibre, with sufficient rigidity, deflects the wire from its original position, a small electric signal is generated in the coil of the guitar pickup shown in Figure 5.10. Ramsay et al., (2012) concluded that the hand held sensor was able to rank acrylic fabrics in exactly the same order as the ranking obtained from forearm tests. Hence, it provided a new approach to the measurement of fibre stiffness, and offered great potential for quickly and reliably assessing the prickle propensity of a knitted and woven fabric when used in next to the skin garments. The work was supported by CSIRO and the Australian Cooperative Research Centre (CRC) for Sheep Industry Innovation.

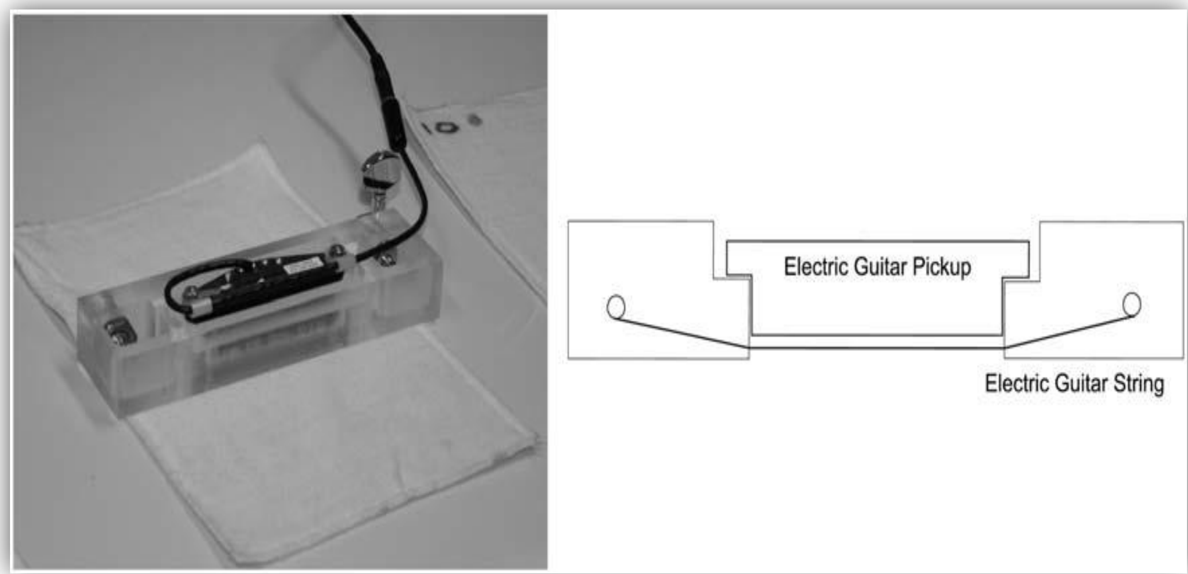


Figure 5.10: Hand-held sensor and schematic cross-section drawing. (Ramsay et al., (2012)

5.3.2.3 The Wool ComfortMeter

This relationship between the buckling force and bending stiffness has been utilised in designing the Wool ComfortMeter (WCM) device to evaluate the prickle related comfort of wool fabrics, based on a measurement that is sensitive to variations in the bending rigidity of fibres protruding from the fabric surface. Using the basis of the Euler's buckling theory, and its similarity to the equation of the bending stiffness of a rod, the CSIRO in Australia developed the WCM for the

Sheep CRC, to enable objective evaluation of fabric-evoked prickle which has traditionally been evaluated subjectively (Naebe et al., 2013a).

The WCM essentially counts the number of fibres protruding from the fabric that can cause discomfort (i.e. a prickle sensation). As the number of these increases, so does the level of discomfort. The principle involves a tensioned fine metal wire mounted in a recording head, which scans the surface of a fabric (See Figures 5.11 and 5.12). The wire interacts with fibres protruding from the fabric surface and is sensitive to the bending rigidity variations of the fibres. The very small movement (deflection) of the wire is detected by imposing a static magnetic field across the wire and measuring the induced current as the wire moves through the magnetic field. This gives a value that is related to the number and stiffness of coarse fibres protruding from the fabric.

The readings of the WCM were shown to be strongly correlated with the average prickle ratings assigned by the wearers participating in the study (McGregor et al., 2013; McGregor and Naebe, 2013; and Ramsay et al., 2013).

Figure 5.11: The Wool ComfortMeter (Sheep CRC, 2013)

Ramsay et al., (2012) and Naebe et al., (2013a) stated that the WCM instrument was developed as a fast and objective method for predicting wearer comfort, more specifically for predicting the fabric-evoked prickle discomfort of wool knitwear, thereby replacing the traditional subjective, lengthy and expensive wearer trials. The new instrument allows the retailers to specify a numeric value for comfort in their buying orders, this means that for the first time retailers and manufacturers have a means of objectively specifying and promoting a garment on the basis of superior comfort (Sheep CRC, 2014). The benefits of the instrument and the adoption of its specifications are significant for the general next-to-skin wool supply chain, including, but not limited to, product differentiation, product development and product quality. It is, however, mostly suitable for knitted fabrics (Sheep CRC, 2014).

Naebe et al., (2013b) explained that, although the WCM provided an objective measurement of the fabric-evoked prickle discomfort rating given by wearers, the comfort properties of textiles are affected by other factors, such as thermal and moisture transmission, air permeability, size, fit, aesthetics and static electrical properties. Hence, the instrument is best operated under standard atmospheric conditions for textile testing, namely 65% RH and 20°C. In summary, it can be stated that fabric constructions with less mobility and shorter protruding fibres will generally be more prone to prickle.

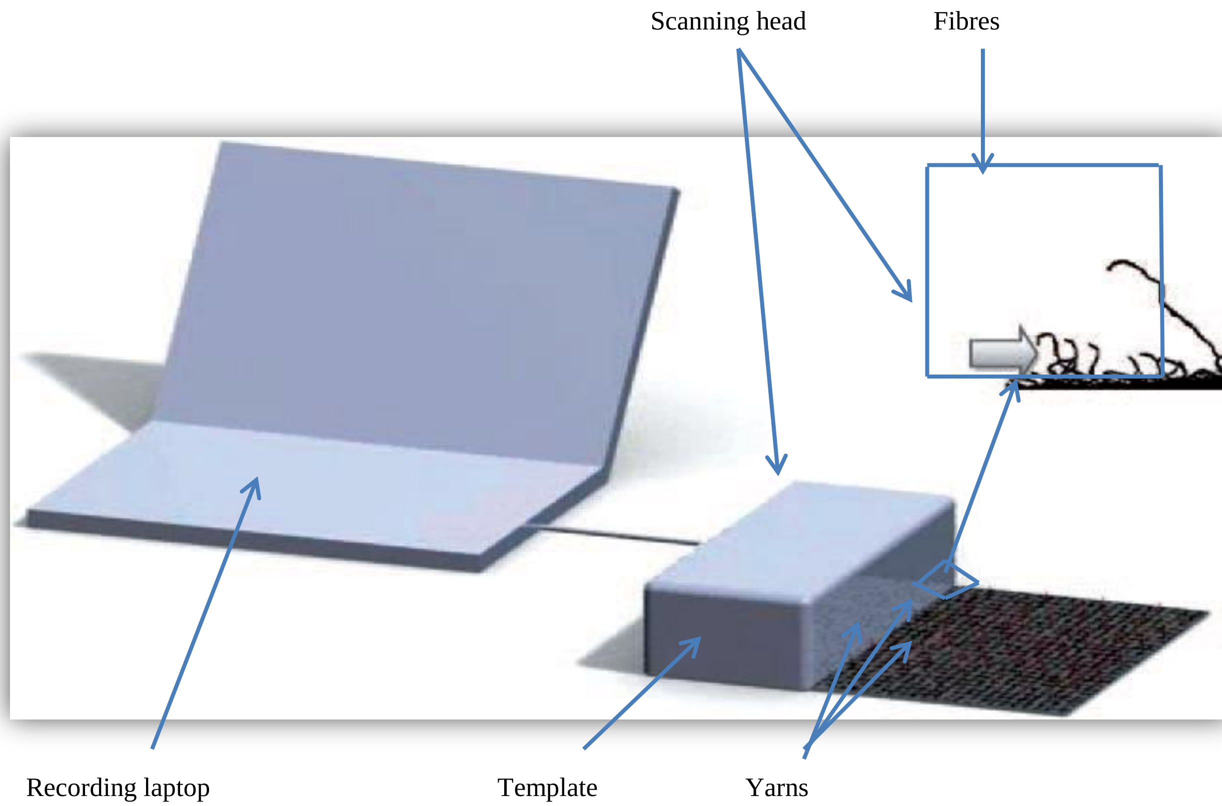


Figure 5.12: Schematic of the Wool ComfortMeter device. (Naebe et al., 2013a)

5.4 FACTORS CONTRIBUTING TO PRICKLE

Various factors or parameters are important for the prediction of the prickle of fabrics, these include fibre properties (e.g. fibre diameter, curvature and type), yarn properties (e.g. yarn twist linear density and structure), fabric properties (e.g. fabric structure, tightness, thickness, and mass per unit area) and fabric finishing treatment (Naylor and Phillips, 1997; McGregor et, al., 2015).

5.4.1 Fibre Properties

Although certain fibre properties, notably fibre diameter, more specifically fibre stiffness, influence the existence and extent of prickle; they are not solely responsible for the prickle characteristic of a fabric (McGregor et al., 2013; McGregor and Naebe, 2013; Naebe et al., 2013a; and Naebe et al., 2013b). It is common knowledge that the finer the wool, the better the next-to-skin comfort due to the lower stiffness of finer fibres. This rule, however, is applicable when yarn and fabric constructional parameters and other fibre properties are constant. For fibre properties to have a major influence on fabric comfort and handle means they have to complement high levels of interaction occurring at the yarn and fabric level after the processes of scouring, combing, spinning, weaving or knitting, dyeing and finishing (Tester et al., 2014). According to Tester (2010) quoted by McGregor et al., (2013), only 60 % to 70 % of next-to-skin comfort is due to the fibre diameter of the wool used in the fabric, the rest being accounted for by processing and other factors (McGregor et al., 2013).

As already discussed, the CSIRO (1987) identified two fibre properties; namely fibre diameter and projecting length, ultimately as reflected in the fibre buckling force or coefficient, which influence the pressure or force from the fibre ends and therefore, the probability of a wool fabric causing skin irritation or prickle. As previously discussed, the nerve pain receptors are activated when the pressure from fibre ends against the skin exceeds a force of about 100 mN, this being a function of the buckling force. Research showed that fibres, which bend or buckle before exerting a force of about 100 mN against the skin, would not be a major source of prickle stimulus, such fibres largely being finer than 30 μm (Hansford, 1992). Therefore, finer and longer fibres, protruding from the fabric surface are less likely to cause prickle. This is because they bend and buckle more easily, tests having shown that reasonable comfort can be achieved with wool against the skin if the mean fibre diameter is 21 μm or lower, and fabrics with a loose construction are used. A study of knitwear prickle, as a function of mean diameter, using commercially available wool tops, showed that the finer (19 μm) wool samples were not prickly and that prickle increased with mean diameter (Naylor et al., 1997). In the light of the above findings, suffice it to say that the coarse edge i.e. those fibres able to equal or exceed the 100mN threshold are, largely contribute to the prickle discomfort in wool garments, since the length and mobility of protruding fibres also play an important role (Garnsworthy et al., (1988a), Garnsworthy et al., (1988b), Naylor (1992), and Veitch and Naylor., (1992). Later studies, on the contrary found that not only coarse fibres cause fabrics to evoke prickle, for instance based on the Euler's formula, Naebe et al., (2015) discovered that even fibres as fine as 10μm can reach a threshold force to cause prickling if they have free projecting length short enough above the yarn surface.

5.4.1.1 Fibre Diameter

Research has shown that prickle is significantly correlated with the mean diameter of the fabric surface fibres, and that it increases with increasing mean diameter of fibres protruding from the fabric surface. According to Gehui et al., (2003), the percentage of fibres greater than a threshold diameter determines the prickliness of a fabric. Botha, (1992), Wang et al., (2000) and SGS, (2011), revealed that the standard deviation, as also the coefficient of variation of diameter (CV_D), for wools of the same diameter can differ if the samples are from different origins,. Earlier research by Miao et al., (2002), suggested that the mechanical forces that protruding coarse fibre ends exert on the skin, caused fabric prickle. Yuqing et al., (2004) showed that the sensation is not associated with any specific type of fibre but with any fibre that can exert sufficient pressure on the skin. Jiang et al., (2007) also found that 30µm was an important threshold, in terms of the prickle of worsted wool knitted fabrics, and that the prickle of such fabrics could be predicted from the percentage of surface end fibres, having an end diameter of about 30 µm or greater.

Illustratively, worsted single jersey fabric, containing wool with a mean diameter of 23.2 µm and a CV_D of 16.4 %, is less prickly than a similar fabric made from wool of 21.5µm and a CV_D of 21.7%. This was ascribed to the fact that the wool in the less prickly fabric had relatively fewer fibres coarser than 30 µm; 3.6 % versus 5.0 %, respectively (SGS, 2011c). In the case of worsted woven wool fabrics, the critical value of fibre diameter appears to be 26 µm, which is less than the value of 30 µm for worsted knitted wool fabrics. Notably, 26 µm can be an important value for woven fabric roughness and slight prickle. Anything higher than that is bound to be prickly. The following diagram illustrates the effect of the surface fibre diameter on the skin surface.

From Figure 5.13, it is apparent that the fabric on the right side has a thick fibre that protrudes vertically from the fabric surface and which can carry a load (weight) of the fabric while still remaining upright, therefore acting like a stiff rod instead of buckling. If the force, such a fibre exerts on the skin is approximately 100 mN, or more, near-surface nerve pain sensors are triggered in the skin, which causes a sensation of pain or prickle.

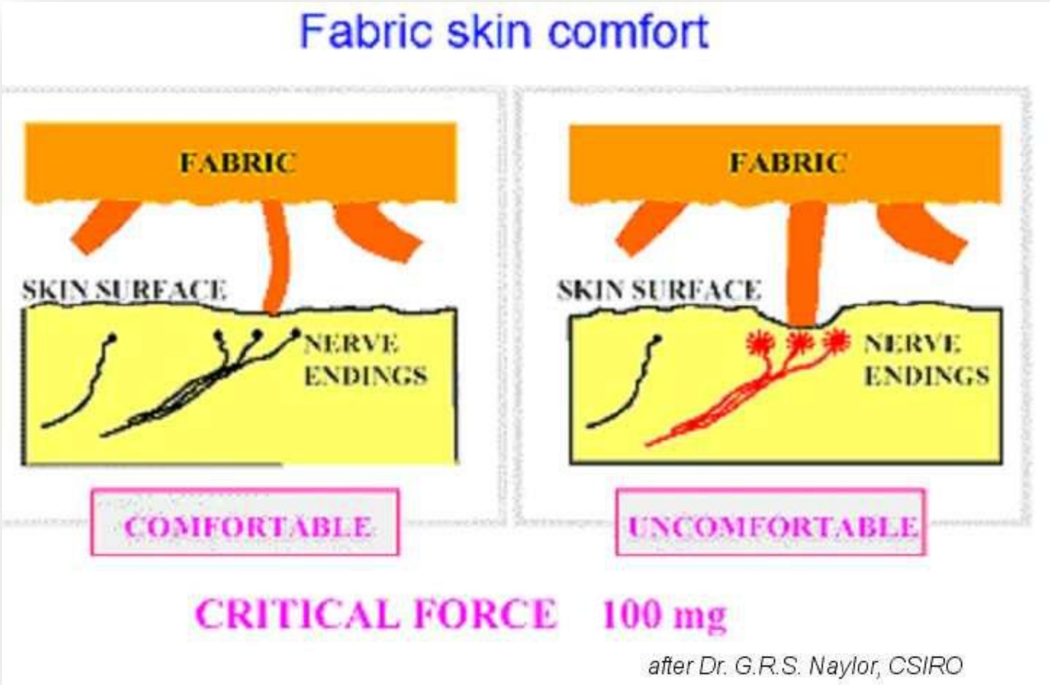


Figure 5.13: Skin comfort illustrated (Naylor, 1992)**.**

5.4.1.2 Other Modalities of Projecting fibres

As already stated, the fibre ends on the fabric surface have various modalities, including different shapes; different lengths and different inclinations to the fabric surface, and therefore, not all fibre ends of a specific stiffness or diameter, will trigger the receptors responsible for prickle. Fabric surface fibres that are curly, bent or curved are less likely to cause enough skin deformation (indentation) to trigger prickle, since they cannot support a sufficient load to indent the skin, even if they have a relatively large diameter. Similarly, regardless of their diameter, the surface fibres that lean slightly i.e. are inclined and not perpendicular to the fabric surface, cannot apply enough pressure to the skin to deform it sufficiently to trigger the nerve cells. Only fibre ends with a large diameter projecting vertically, or almost vertically, from the fabric surface are likely to trigger the pain receptors (Limin and Chongen, 2004). Furthermore, projecting fibres not firmly held in the fabric structure may also not cause prickliness; this could be caused by the fibres moving within the fabric, thereby accommodating a larger force.

As already discussed, and evident from the Euler's buckling model, the length of the protruding fibres is of importance in prickle sensation, longer protruding fibres being less likely to cause prickle. On the other hand, however, those surface fibres that are too short to deform or indent the skin sufficiently to activate relevant nerve endings i.e. pain receptors, will not cause prickle either. Within this context, it should be noted that, according to Naebe et al., (2014), if fibres shorter than 1.0mm could interact with the skin when the garment is skin tight and there is movement of the fabric relative to the skin, then even fibres finer than 20µm would be capable of triggering the prickle response.

Fiber curvature can also influence fineness of wool fibres; it is a trait of raw Merino wool also known as the characteristic crimping of the fibres has been of substantial interest to wool producers, because low staple crimp is correlated with softness of handle or low resistance to compression of both raw and scoured wool. According to McGregor et al., (2015b) staple crimp is correlated with the MFD in wool, even though the correlation differs between farms. Staple crimp can be objectively measured as fibre curvature using contemporary laboratory mechanisms.

5.4.2 Yarn and Fabric Construction

Despite a significant body of research, many questions still remain unanswered regarding the influence and interaction of a number of fibre, yarn, and fabric variables or parameters on garment comfort, although is it known that the degree of discomfort is related to the yarn and fabric construction (Naylor and Phillips, 1997). For example, De Boos et al., (2001) and Naylor and Phillips (1997), found that plain woven trousers were less comfortable than single jersey fabrics of the same wool. They found that, to achieve the same level of skin comfort as a single jersey fabric, a plain-weave fabric requires wool approximately 3µm finer than that in the single jersey fabric. They attributed this finding to the fabric structural differences holding (anchoring) the fibres in place to dissimilar tautness, which allowed the projecting fibres to move to different extents. Clearly therefore, tighter or more compact, yarn and fabric structures will increase the probability of prickle.

It has been reported (Sheep CRC, 2013) that, although prickle is almost always associated with the fineness of the wool fibre and fleece as a whole, it is also affected by the manner in which the fibres are spun into yarn and the way the fabric is finished, since these affect the number and length of fibres protruding from the yarn and fabric surface, as well as the mobility of the fibres. In one study, McGregor and Naebe (2013) investigated the effects of fibre, yarn and fabric properties, such as loop length and low-stress mechanical properties, on the comfort of single jersey fabrics, containing cashmere and either low or high crimp superfine wool (of about 17µm) or blends of cashmere and these wools. They found that fabrics with a tighter structure were less comfortable, as measured by means of the WCM.

5.5 REDUCING PRICKLE

According to Matsudaira et al., (1990), it is common knowledge that prickle can be reduced by fabric finishing treatments, such as singeing, cropping, pressing and raising. Because of the subjectivity nature of prickle assessment, it is difficult, however, to obtain reliable and repeatable results due to individuals differing greatly in their response to prickle. One of the ways of reducing, and even possibly eliminating, the prickle of a fabric worn next to the skin is by decreasing the high load supporting fibre ends per unit fabric area. Decreasing the total number of fibre ends on the surface, by reducing the overall hairiness of the fabric surface as much as possible, can accomplish this. It can also be achieved by decreasing the bending load the fibre ends can support, before they buckle, in this way the relative number of the fibre ends that can trigger the skin pain receptors is decreased. In that way the summation of the stimuli to the pain receptors is reduced, which can reduce or even possibly eliminate prickle. The above efforts may be achieved at different stages, namely fibre, yarn and fabric stages, with fabric construction and finish important within this context.

5.5.1 Reducing Prickle at Fibre stage

As already mentioned, the main fibre factor affecting prickle is the fibre stiffness, or resistance to buckling, which is essentially a function of the fibre diameter to the power of four, all other factors (notably Young's modulus and fibre length) being constant. It, therefore, follows, that reducing the fibre diameter is the obvious and most effective practical way of reducing prickle, or else using a fibre with a lower bending modulus or inherent stiffness. In addition, however, fibre stiffness can also be reduced by manipulating the fibre elasticity or bending modulus in some way, for example by softening the fibre. Softening the fibre ends; and decreasing the bastion or support of the fibre ends, ensure a reduction in the bending modulus and resistance of bending of the fibres, thereby rendering them less capable of triggering the prickle sensation (Limin and Chongwen, 2004). Bishop et al., (1998) used proteolytic enzymes to reduce the wool fibre stiffness, and consequently the fibre buckling load and hence the prickle sensation. Miao et al., (2000) reported that the reduction of the weight bearing capacity of the fibres, through an appropriate treatment, could contribute a great deal to the elimination of prickle. Nevertheless, care must be taken not to reduce the durability and other desirable properties of the fibre in the process.

In their study conducted in Australia, McGregor et al., (2015c), concluded that the finest wool was that with 17.4 µm of fibre fineness. Unless treatment is done on woollen fabrics, for these fabrics to be prickle free woollen fabrics essentially need to be fine.

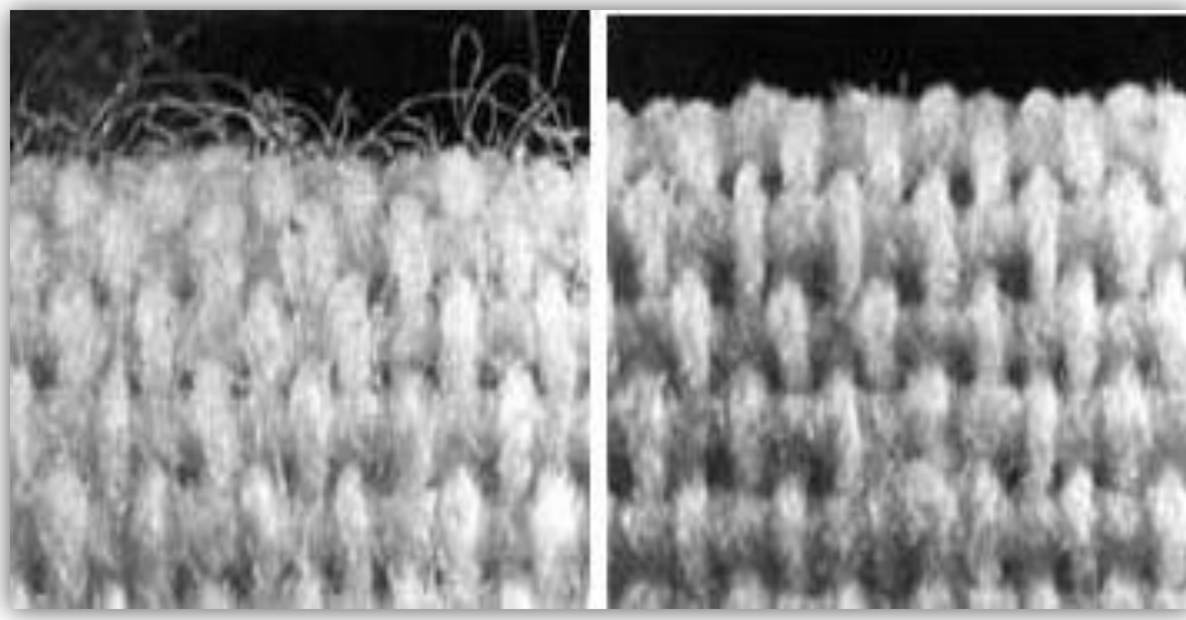
5.5.2 Reducing Prickle by Modifying Yarn Structure

Increasing the fibre mobility and projecting length and reducing the number of fibres protruding from the yarn (i.e. hairiness), can reduce the prickle effect. Subramaniam and Mohamed (1992) explained that the wrap spinning technology had certain advantages, including greater yarn covering ability, higher yarn tenacity; higher uniformity and possibility of using coarser fibres for finer yarns without causing a prickle effect. Due to helical wrapping of the filament and its radial pressure, the necessary cohesion between the individual staple fibres is improved and hairiness and exposed fibre ends are reduced. Miao et al., (2000) found that wrap-spun yarn caused less prickle than conventional ring-spun yarns, the wrap-spun yarn consisting of non-twisted parallel bundles of staple fibres, held together by helically wrapped filament. The Compact spinning technology reduces the yarn hairiness and therefore also the number of the high load supporting fibre ends protruding on the yarn surface, even their leaning angle (Limin and Chongwen, 2004), together these operations can reduce prickle.

5.5.3 Reducing Prickle by Modifying Fabric structure

Limin and Chongwen (2004) identified the following specific fabric related measures to reduce prickle: Decreasing the hairiness of the fabric surface, decreasing the angle of inclination of the fibre ends to the fabric surface, softening the fabric with chemical processes, such as alkali and ammonia, raising; sand washing; softening with enzyme or any other softening agent, as well as decreasing the tightness of the fabric.

Reducing the yarn twist and fabric tightness are beneficial, since it decreases the support of the fibre ends fixed on the fabric surface, as well as the inclination of the fibre ends. This has a positive effect on fabric prickle. Singeing is very effective in controlling the number of high load supporting fibre ends that cause prickle, but improper control of singeing can actually increase, rather than reduce, prickle (Limin and Chongwen, 2004), since it can reduce the fibre length and thereby increase the force the short fibres can support before they buckle. Figure 5.14 illustrates the reduction in fabric hairiness caused by the singeing process.



a) Fabric before singeing b) Fabric after singeing

Figure 5.14: Effect of singeing on fabric hairiness *(Picture by* Osthoff-Senge 2008*)*

Hussain (2008) indicated that singeing results in a cleaner and smoother fabric surface, potentially producing less prickly fabrics, it being common knowledge that a fabric with a smooth surface has less chance of causing prickle. Fabric surface treatments can also have an effect on fabric prickle. Naebe et al., (2013c) found, for example, that silicone polymer significantly reduced the Wool ComfortMeter (WCM) values and, therefore, by implication, the fabric evoked prickle. This was ascribed to the silicone coating reducing the number of protruding fibres on the fabric surface by gluing the protruding fibres together. They also reported that, although silicone is usually associated with increased fabric softness, whereas plasma treatment is associated with increased fabric harshness, the WCM tests did not show any significant differences between plasma treated and the untreated fabrics.

5.5.4 General

The friction coefficient between the skin and textiles depends on the nature of the skin and the fabric material and the interaction between them (Ampuero and Deler, 2002). Combining the right fibres in the correct way can result in the desired skin and fabric interaction perceived as comfort. For example, blending fibres capable of evoking prickle (coarse wool) with finer prickle-free fibres can reduce the overall level of prickle.

CHAPTER 6

6. EXPERIMENTAL

6.1 INTRODUCTION

The chapter comprises two sections, dealing with the experimental details for the wool (section 6.2) and mohair (section 6.3) respectively. The chapter provides details of the data and samples used in the study, as well as of the procedures employed to prepare the samples and the tests and analysis conducted to address the set objectives.

6.2 ANALYSIS OF LESOTHO WOOL CLIP

The analysis of the wool clip produced in Lesotho is divided into two parts, the first part (6.2.1) dealing with the development of a database, covering production, price and quality related data and trends over the past ten years, while the second part (6.2.2) focuses on fabric prickle related aspects.

6.2.1 Lesotho wool database

All the Lesotho wool data available in the South African wool database was used as secondary data (i.e. data sourced, yet not originally collected, by the author of this study) for the analysis and development of the database. This data was generated as the Lesotho wool auctioned by the broker (BKB) in Port Elizabeth, South Africa; was tested at the Wool Testing Bureau (WTB) to develop the sales catalogue for the buyers. WTB uses AWTA approved laser scanner for some of the tests (see Appendix 5). Prior to 2018, the amount of wool auctioned by BKB accounted for about 90% of the wool produced in Lesotho, and all the ten districts exported their wool through this broker (BKB).

There is still some wool that is not accounted for, since some farmers sell their wool to private traders in Lesotho or use the fibre for some crafts, especially in the urban areas (lowlands), the relevant details generally not being recorded, making the acquisition of data unreliable. This study covered a ten year period, from 2007 to 2017, it being assumed that ten years would give an adequate picture of the production and quality trends of Lesotho wool.

6.2.1.1 Sample selection for database development

Statistical information on Lesotho wool, covering the period from 2007 to 2017 was sourced from Cape Wools South Africa (CWSA), which compiles such statistics for South African as well as Lesotho wool. It is worth noting that, until 2018, Lesotho wool was sold together with that of South Africa, thereby essentially forming part of the South African wool clip, making it difficult to track Lesotho wool to its ultimate destination and final product.

The statistical information obtained covered the sales analysis, in terms of the quality, quantity and price of the wool sold at the auction, the relevant quality and price related attributes being greasy fibre mass (weight), fibre diameter, staple length, and vegetable matter content, yield and staple strength. The analysis the data was so structured that the Lesotho wool trends could be compared with those of South Africa (SA) and Australia which have been taken as the benchmark in this respect. Table 6.1 gives the production and mean fibre diameter of greasy wool for Lesotho, South Africa and Australia (2007 to 2017), while Tables 6.2 to 6.11 provide further detailed information for Lesotho wool i.e. more detailed breakdown (Cape Wools, 2017).

Table 6.1: Greasy wool production (mkg) and fineness (mean fibre diameter- MFD in µm) for Lesotho, South Africa and Australia (2007 to 2017) period.

	Lesotho (mkg)	**MFD (µm)**	**South Africa (mkg)**	**MFD (µm)**	**Australia (mkg)**	**MFD (µm)**
2007/2008	3.6	20.3	30.5	21.4	424.5	21.2
2008/2009	3.4	20.5	42.0	21.4	384.4	21.5
2009/2010	3.1	20.3	42.3	20.2	364.1	212
2010/2011	3.7	20.1	40.8	20.2	372.1	21.5
2011/2012	3.7	20.2	40.1	20.1	359.6	21.2
2012/2013	4.1	20.2	43.8	21.3	369.8	21.2
2013/2014	4.2	19.8	45.6	21.0	353.7	20.7
2014/2015	3.8	19.9	45.6	21.0	365.6	21.0
2015/2016	5.4	20.0	43.3	21.1	340.0	21.0
2016/2017	6.2	20.0	45.9	21.2	279.3	20.8

Table 6.2: Lesotho Wool Clip and Sales Analysis by District for 2007/2008

DISTRICT	Realisation		Greasy Price (R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy Mass (kg)	*Sales Value(R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*Average*	*High*	*Low*	*Average*
BEREA	55 669	1 573 283	54.00	9.00	28.26	21.5	16.9	20.3	64.2	32.9	50.6	67	4.65	0 .35	1.79
MAFETENG	997 062	22 783 787	55.20	7.00	22.85	22.8	16.9	20.5	64.4	31.6	51.0	58	7.10	0 .25	1.80
MASERU	402 663	13 123 144	59.00	10.20	32.59	22.3	16.7	20.2	69.8	26.8	55.9	65	7.61	0 .12	1.43
MOHALES HOEK	260 483	7 924 829	51.30	7.30	30.42	22.4	16.7	20.3	67.4	31.8	53.1	64	7.37	0 .37	1.65
QUTHING	379 648	12 073 080	59.90	9.00	31.80	23.6	17.0	20.7	68.6	34.0	56.2	64	9.05	0 .22	1.55
QACHAS NEK	142 736	4 443 156	54.90	10.40	31.13	21.7	17.3	20.0	65.5	40.4	54.2	64	6.77	0 .17	1.68
LERIBE	159 078	5 619 238	59.30	8.00	35.32	22.8	17.0	20.3	67.6	35.9	57.8	69	6.72	0 .25	1.20
BUTHA-BUTHE	215 717	7 373 106	57.40	11.45	34.18	22.4	17.0	20.3	67.9	34.8	57.7	67	3.65	0 .14	1.21
MOKHOTLONG	607 540	21 043 363	58.60	11.15	34.64	22.6	16.8	20.5	67.7	35.0	57.8	68	3.75	0 .18	0.99
THABA TSEKA	351 223	12 286 381	53.60	7.80	34.98	22.6	16.6	20.0	66.6	34.2	55.5	68	5.46	0 .28	1.25
Average	-	-	**56.32**	**9.1**	**31.6**	**22.5**	**16.9**	**20.3**	67	33.7	55	**65.4**	**6.21**	**0 .23**	**1.46**
Total	**3 571 819**	**108 243 367**	-	-	-	-	-	-	-	-	-	-	-	-	-

VM = Vegetable Matter

Table 6.3: Lesotho Wool Clip and Sales Analysis by District for 2008/2009

DISTRICT	**Realisation**		**Greasy Price (R/kg)**			**Mean Fibre Diameter (µm)**			**Yield (%)**			**Staple Length (mm)**	**VM (%)**		
	Greasy Mass (kg)	*Sales Value(R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*(mm)*	*High*	*Low*	*Average*
BEREA	7 6 787	1 377 572	38.05	2.00	17.94	22.1	18.5	20.6	65.1	30.8	51.3	65	7.20	0.59	2.42
MAFETENG	393 923	5 809 933	39.90	1.00	14.75	22.7	17.3	20.4	64.8	28.0	50.4	57	7.51	0.25	2.04
MASERU	482 574	10 030 824	43.80	1.50	20.79	23.1	17.0	20.4	71.1	33.8	57.0	66	14.80	0.19	1.74
MOHALES HOEK	303 405	5 840 850	39.60	3.00	19.25	22.0	17.5	20.4	69.9	30.8	53.2	64	9.73	0.32	2.03
QUTHING	401 322	8 171 428	39.35	3.00	20.36	22.9	17.1	20.7	68.3	35.6	57.2	64	8.42	0.18	1.73
QACHAS NEK	182 974	3 460 325	38.60	5.00	18.91	22.6	16.8	20.3	65.8	38.2	53.7	63	7.27	0.21	1.88
LERIBE	194 677	3 885 393	41.10	3.50	19.96	23.4	17.5	20.6	66.0	34.9	56.5	68	7.68	0.24	1.59
BUTHA-BUTHE	246 887	4 701 956	39.60	1.50	19.04	22.4	16.9	20.6	66.7	33.0	56.1	66	5.76	0.14	1.43
MOKHOTLONG	666 445	13 756 630	43.00	3.00	20.64	22.7	16.9	20.6	67.6	35.2	56,3	68	6.53	0.26	1.14
THABA TSEKA	425 132	9 117 443	43.50	13.00	21.45	23.1	16.6	20.3	67.7	32.9	55.2	68	5.23	0.32	1.40
UNKNOWN LESOTHO	1 400	18 859	16.60	9.00	13.47	21.7	19.9	20.6	59.8	54.9	57.1	74	1.48	0.81	1.21
AVERAGE	**-**	**-**	**38.5**	**4.10**	**18.8**	**22.6**	**17.5**	**20.5**	**66.6**	**35.3**	**54.9**	**65.7**	**7.4**	**0.3**	**1.7**
TOTAL	**3 375 524**	**6 6 171 214**	-	--	-	-	-	-	-	-	-	-	-	-	-

Table 6.4: Lesotho Wool Clip and Sales Analysis by District for 2009/2010

DISTRICT	Realisation		Greasy Price(R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy Mass(kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*Average*	*High*	*Low*	*Average*
BEREA	80 513	2262 764	47.40	7.50	28.10	21.9	17.9	20.3	65.6	30.1	53.4	66	7.95	0.43	2.32
MAFETENG	161 365	4068 089	46.15	3.90	25.21	22.6	17.7	20.1	66.6	30.9	52.5	61	7.26	0.31	2.12
MASERU	478 873	16365 620	53.00	6.00	34.18	22.2	16.5	20.1	75.0	32.8	60.5	64	1.96	0.18	1.61
MOHALES HOEK	283 857	8415 307	50.00	4.00	29.65	22.3	17.1	20.2	69.4	33.7	56.8	63	8.55	0.36	1.87
QUTHING	409 518	13189 907	50.10	16.00	32.21	22.6	17.2	20.5	71.4	38.4	59.5	63	9.55	0.13	1.69
QACHAS NEK	151 021	4996 784	48.25	8.10	33.09	22.9	17.1	20.1	67.1	42.4	57.8	64	8.37	0.24	1.64
LERIBE	203 875	7024 045	50.05	7.00	34.45	23.0	16.4	20.3	68.8	35.2	59.8	66	7.60	0.22	1.56
BUTHA-BUTHE	244 711	8304 701	50.30	9.00	33.94	21.8	16.9	20.2	69.2	41.1	59.6	67	5.66	0.12	1.29
MOKHOTLONG	682 178	22398 253	49.30	12.00	32.83	22.8	16.4	20.2	72.2	35.6	59.2	66	4.59	0.11	1.07
THABA TSEKA	406 803	14102 023	50.20	8.00	34.67	22.6	16.4	20.02	70.1	35.0	59.0	67	4.87	0.25	1.27
UNKNOWN	3 357	68451	22.00	18.50	20.39	21.1	20.8	20.9	55.1	48.5	52.5	67	1.97	1.18	1.40
AVERAGE	**-**	**-**	**47.0**	**9.1**	**30.8**	**22.4**	**17.3**	**20.3**	**68.2**	**36.7**	**57.3**	**64.9**	**7.5**	**0.32**	**1.62**
TOTAL/	**3106 070**	**101195944**	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.5: Lesotho Wool Clip and Sales Analysis by District for 2010/2011

DISTRICT	Realisation		Greasy Price (R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy Mass (kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*(mm) Average*	*High*	*Low*	*Average*
BEREA	101 569	3 394 121	79.80	11.00	33.42	21.3	17.3	20.1	65.8	34.5	51.3	63	6.93	0.50	2.64
MAFETENG	277 874	8 950 752	70.00	5.00	32.21	22.4	17.2	20.2	67.2	32.1	51.3	58	9.19	0.41	2.24
MASERU	533 309	22 135 266	87.00	15.00	41.51	22.0	16.4	20.0	71.6	33.6	57.9	64	12.15	0.15	1.84
MOHALES HOEK	514 246	17 991 767	76.95	6.00	34.99	22.0	17.2	20.3	71.6	31.6	53.2	60	8.65	0.28	2.00
QUTHING	459 357	17 210 609	89.50	7.00	37.47	22.4	16.7	20.5	69.2	28.7	55.9	60	8.42	0.21	2.05
QACHAS NEK	173 765	7 206 801	86.00	23.10	41.47	21.8	16.6	19.9	66.3	37.8	54.4	63	6.54	0.28	1.96
LERIBE	231 946	9 976 928	89.00	26.00	43.01	22.9	16.7	20.2	69.0	35.6	57.0	68	7.58	0.22	1.62
BUTHA-BUTHE	262 553	11 507 211	9.50	15.00	43.83	22.2	16.0	20.0	68.1	39.7	57.4	66	6.23	0.24	1.57
MOKHOTLONG	690 362	31 841 543	87.50	13.00	46.12	22.5	16.1	20.0	66.8	35.8	57.0	65	4.34	0.12	1.10
THABA TSEKA	450 217	20 833 380	87.50	17.00	46.27	23.0	16.6	19.9	66.7	37.5	57.1	67	4.61	0.31	1.35
AVERAGE	-	-	**84.7**	**13.8**	**40.0**	**22.3**	**16.7**	**20.1**	**68.2**	**34.7**	**55.3**	**63,4**	**7.5**	**0.27**	**1.,8**
TOTAL	**3695197**	**151048377**	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.6: Lesotho Wool Clip and Sales Analysis by District for 20011/2012

DISTRICT	Realization		Greasy Price (R/kg)			Mean Fibre Diameter(µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy Mass (kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*Average*	*High*	*Low*	*Average*
BEREA	114 839	5 734 918	80.00	13.00	49.94	21.7	17.7	20.1	70.0	32.1	55.8	6 2	7.32	0.55	2.23
MAFETENG	211 098	9 225 448	83.50	7.00	43.70	22.2	17.1	19.9	69.3	30.9	54.0	5 9	7.93	0.56	2.45
MASERU	525 574	29 911 866	92.10	5.00	56.91	22.5	16.6	20.0	74.0	36.8	60.3	6 4	9.92	0.14	1.71
MOHALES HOEK	562 968	24 825 658	86.30	16.00	44.10	22.0	17.1	20.3	73.1	33.5	55.0	5 8	9.24	0.35	2.02
QUTHING	405 352	21 540 398	76.95	16.00	53.14	22.2	16.9	20.3	70.3	34.1	58.7	6 1	8.93	0.17	1.92
QACHAS NEK	197 334	10 209 204	78.00	13.00	51.74	21.6	16.9	20.1	68.7	36.2	56.2	6 3	7.92	0.21	1.82
LERIBE	253 975	14 232 088	77.90	33.30	56.04	23.2	17.4	20.4	69.8	41.0	59.4	6 5	5.58	0.20	1.48
BUTHA-BUTHE	275 071	14 859 712	80.00	8.00	54.02	22.5	16.9	20.4	68.4	37.1	57.8	6 6	5.08	0.22	1.35
MOKHOTLONG	709 301	37 838 847	80.60	10.00	53.35	23.1	17.1	20.4	68.3	34.0	57.0	6 6	5.46	0.29	1.21
THABA TSEKA	461 691	25 937 760	75.70	9.00	56.18	21.9	16.7	20,1	71.9	37.0	57.9	6 5	7.32	0.17	1.32
UNKNOWN LESOTHO	3 149	93 995	32.00	24.00	29.85	20.7	20.3	20.4	54.5	48.0	52.7	5 9	2.98	2.46	2.60
AVERAGE	-	-	76.6	14.0	50.0	22.2	17.3	2 0.2	69.0	36.4	56.8	6 2.54	7.0	0.48	1.83
TOTAL/	3720 351	194409 894	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.7: Lesotho Wool Clip and Sales Analysis by District for 2012/2013

DISTRICT	Realization		Greasy Price(R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM%		
	Greasy Mass (kg)	*Sales Value (R)*	*High*	*Average*	*Low*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*Average*	*High*	*Low*	*Average*
BEREA	144 561	7 778 260	78.95	12.00	0.54	22.1	17.3	20.2	67.5	38.5	55.0	65	5.38	0.27	1.55
MAFETENG	193 819	9 934 091	74.10	27.10	0.51	21.4	17.1	20.0	68.4	33.7	54.2	63	7.77	0.31	1.65
MASERU	607 143	36 611 892	87.30	15.00	0.60	22.9	16.4	20.0	72.1	39.5	60.7	65	9.28	0.23	1.52
MOHALES HOEK	734 716	36 356 363	85.15	18.80	0.49	22.1	16.3	20.8	72.5	34.5	57.6	61	8.39	0.29	1.87
QUTHING	413 655	24 047 965	87.10	10.00	0.58	22.3	16.8	20.4	73.0	35.0	60.4	62	8.62	0.18	1.65
QACHAS NEK	187 842	10 784 508	78.00	12.00	0.57	22.7	16.0	20.3	70.1	38.9	59.2	64	7.95	0.20	1.68
LERIBE	358 107	21 295 280	83.60	12.00	0.59	23.7	16.1	20.1	71.6	37.7	59.7	65	6.91	0.26	1.30
BUTHA-BUTHE	276 750	16 626 329	86.95	10.00	0.60	21.4	16.2	19.9	68.7	36.6	59.6	65	5.63	0.22	1.35
MOKHOTLONG	699 879	42 477 938	82.00	15.00	0.61	23.2	16.2	20.0	69.1	35.8	60.0	66	5.84	0.18	0.98
THABA TSEKA	485 746	29 521 431	81.65	15.00	0.61	23.4	16.3	19.9	70.0	37.9	59.4	65	6.81	0.17	1.29
AVERAGE	**-**	**-**	**82.5**	**14.7**	**0.6**	**22.5**	**16.4**	**20.2**	**70.3**	**36.8**	**58.4**	**64.1**	**7.3**	**0.23**	**1.55**
TOTAL/	**4102 217**	**235 434 057**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Table 6.8: Lesotho Wool Clip and Sales Analysis by District for 2013/2014

DISTRICT	Realisation		Greasy Price (R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy Mass (kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Ave*	*Ave*	*High*	*Low*	*Ave*
BEREA	149 294	7 675 699	78.00	17.00	51.41	22.6	17.3	19.9	66.7	34.0	5 2.9	64	6.66	0.64	2 .40
MAFETENG	2 37 852	11 755 083	77.00	37.40	49.42	22.2	16.7	19.5	68.0	32.3	5 1.0	63	9.10	0.24	1 .65
MASERU	6 08 028	36 528 184	84.70	15.00	60.08	22.2	15.8	19.6	71.8	35.7	5 8.6	64	10.99	0.16	1 .78
MOHALES HOEK	5 32 133	26 063 513	77.55	3.00	48.98	22.3	16.6	20.0	69.1	33.4	5 3.9	60	10.32	0.27	1 .95
QUTHING	4 12 085	23 151 089	82.30	24.05	56.18	22.2	16.5	20.2	70.1	34.1	5 8.0	62	10.38	0.16	1 .94
QACHAS NEK	2 15 886	11 765 200	82.00	17.00	54.50	22.8	15.7	19.6	69.7	35.7	5 5.1	62	10.58	0.35	1 .94
LERIBE	421 606	22 850 880	77.50	13.00	54.20	23.2	16.0	19.9	68.3	33.9	5 6.4	65	7.73	0.30	1 .70
BUTHA-BUTHE	2 94 807	16 401 874	77.30	41.10	55.64	22.0	15.5	19.7	68.2	34.3	5 7.7	65	5.72	0.24	1 .62
MOKHOTLONG	7 65 877	42 296 894	80.60	36.00	55.23	22.5	15.4	19.7	70.2	33.3	5 5.8	64	5.04	0.15	1 .27
THABA TSEKA	5 24 300	30 518 945	81.10	20.00	58.21	23.9	15.5	19.5	71.6	36.1	5 6.0	65	8.19	0.26	1 .36
AVERAGE	**-**	**-**	**79.81**	**22.4**	**54.4**	**22.6**	**16.1**	**19.8**	**69.4**	**34.3**	**55.5**	**63.4**	**8.5**	**0.28**	**1.76**
TOTAL/	**4 161 866**	**229 007 361**	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.9: Lesotho Wool Clip and Sales Analysis by District for 20014/2015

DISTRICT	Realisation		Greasy Price (R/kg)			Mean Fibre Diameter (μm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy Mass (kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Ave*	*Average*	*High*	*Low*	*Average*
BEREA	144 819	6 906 564	71.90	12.00	47.69	21.8	17.7	19.9	67.1	30.8	53.1	62	7.56	0.78	2.73
MAFETENG	319748	14777003	76.30	32.10	46.21	23.9	17.1	19.9	71.8	35.5	54.8	58	7.55	0.48	2.10
MASERU	578964	33586117	78.00	28.00	58.01	22.4	16.2	19.9	72.1	37.6	60.2	64	11.77	0.19	1.77
MOHALES HOEK	237965	12605991	74.30	10.00	52.97	22.3	16.5	20.0	69.5	35.7	57.5	61	7.81	0.29	2.13
QUTHING	372883	21892636	83.10	22.00	58.71	23.1	16.4	20.3	70.6	36.5	59.1	61	11.32	0.14	1.87
QACHAS NEK	197925	10171816	75.60	26.10	51.39	21.6	16.8	19.9	68.7	39.0	56.1	61	9.16	0.17	1.87
LERIBE	440214	21941067	72.90	12.00	49.84	22.9	16.0	20.0	70.4	29.5	57.0	61	7.84	0.19	1.90
BUTHA-BUTHE	278859	14860992	75.00	22.10	53.29	22.1	16.2	20.1	68.6	42.5	58.0	63	5.72	0.24	1.63
MOKHOTLONG	706912	37808511	70.90	15.20	53.48	23.0	16.0	19.9	66.1	34.4	57.3	62	4.81	0.15	1.21
THABA TSEKA	529690	29787658	75.00	20.00	56.24	22.1	16.1	19.8	68.9	33.5	57.7	63	6.19	0.22	1.48
AVERAGE	**-**	**-**	**75.30**	**19.95**	**52.78**	**22.52**	**16.5**	**19.97**	**69.38**	**35.5**	**57.12**	**61.6**	**7.97**	**029**	**1.87**
TOTAL/	**3807980**	**204338354**	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.10: Lesotho Wool Clip and Sales Analysis by District for 2015/2016

DISTRICT	Realisation		Grease Price (R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy mass (Kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*Average*	*High*	*Low*	*Average*
BEREA	132910	9356941	100.6	29.00	70.4	22.4	17.3	19.8	69.3	32.2	54.9	62	5.34	0.54	2.09
MAFETENG	1282146	78824054	96.1	-	61.48	23.3	0.0	20.1	68.9	0	53.9	58	8.48	0.00	1.97
MASERU	625650	49126132	109.0	25.00	78.52	22.1	15.9	19.7	74.5	33.6	59.8	65	11.63	0.22	1.58
MOHALES HOEK	231653	17383423	111.4	16.10	75.04	21.7	16.6	20.0	72.1	34.4	57.8	61	8.40	0.28	1.84
QUTHING	383256	39463054	112.9	12.00	79.48	22.8	16.6	20.2	72.0	31.9	59.7	62	8.08	0.16	1.69
QACHAS NEK	138996	10528362	106.8	34.10	75.75	22.3	16.2	19.7	69.6	34.5	57.1	63	8.96	0.19	1.69
LERIBE	463011	33255323	108.8	15.00	71.82	22.3	17.8	20.1	73.1	31.4	56.8	63	6.05	0.61	1.68
BUTHA-BUTHE	284927	22395247	109.5	-	78.60	22.1	16.3	20.1	66.9	33.1	57.3	64	6.32	0.21	1.58
MOKHOTLONG	767766	61430945	108.0	25.50	80.01	22.8	16	19.9	68.2	28.9	56.5	64	5.58	0.16	1.22
THABA TSEKA	558949	44833550	108.3	20.10	80.21	22	16	19.7	70.0	30.7	57.3	64	7.28	0.18	1.36
UNKNOWN	519916	30341025	114.1	31.00	58.36	30.6	16.7	20.8	75.3	32.9	55.6	56	11.5	0.32	2.11
AVERAGE	-	-	107.8	18.9	73.6	23.1	15.0	20	70.9	29.4	56.9	62	7.97	.26	1.71
TOTAL/	5389179	387938055	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 6.11: Lesotho Wool Clip and Sales Analysis by District for 2016/2017

DISTRICT	Realisation		Greasy Price (R/kg)			Mean Fibre Diameter (µm)			Yield (%)			Staple Length (mm)	VM (%)		
	Greasy mass(kg)	*Sales Value (R)*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*High*	*Low*	*Average*	*Average*	*High*	*Low*	*Average*
BEREA	144 612	11603621	109.80	25.90	80.24	22.4	17.3	20.1	69.1	35.0	57.4	66	7.68	0.25	1.99
MAFETENG	1951775	131733666	109.00	23.00	67.49	24.2	17.2	20.6	68.2	13.2	55.2	61	12.52	0.34	2.04
MASERU	749991	65192218	133.00	30.00	86.92	23.3	16.1	19.8	73.0	35.7	60.1	67	10.25	0.10	1.68
MOHALE'S HOEK	370122	28170267	115.00	15.00	76.11	22.7	16.2	20.1	70.4	34.1	56.6	63	8.20	0.45	2.03
QUTHING	412969	34399756	138.50	39.00	83.30	23.2	16.8	20.2	70.3	38.1	59.4	65	8.87	0.19	1.89
QACHA'S NEK	192906	15853501	121.60	35.00	82.18	22.3	15.9	19.6	70.3	40.8	56.9	64	8.06	0.25	1.80
LERIBE	563 206	42384298	124.9	5.00	75.26	23.1	16.2	20.3	74.8	33.9	56.8	64	7.04	0.23	1.64
BUTHA-BUTHE	315 335	25798451	125.10	20.00	81.81	22.6	16.1	19.9	70.0	38.3	58.2	65	7.83	0.23	1.81
MOKHOTLONG	855495	72029024	126.00	31.80	84.20	22.5	15.9	19.8	68.9	35.9	57.5	64	5.12	0.11	1.13
THABA-TSEKA	605454	52048047	125.60	20.10	85.97	22.6	15.8	19.6	69.7	33.4	57.9	66	6.33	0.22	1.23
AVERAGE	-	-	113.0	24.5	80.4	22.9	16.4	20.0	70.5	33.8	57.6	64.5	8.19	0.24	1.72
TOTAL/	6 161 864	479212848	-	-	-	-	-	-	-	-	-	-	-	-	-

6.2.2 Prickle Evaluation

The sensory evaluation procedure, as described below, was followed to assess prickle. Sensory evaluation is defined as; "a scientific discipline used to evoke, measure, analyse and interpret reactions to those characteristics of the textile products, as they are perceived by the senses of sight, smell, taste, touch and hearing" (Hashmi, 2007). It is common knowledge that the human body exhibits high tactile prickle sensitivity, or physiological stimuli when in contact with fabric materials (Asad et al., 2016). Therefore, the use of humans becomes important in the measurement of product attributes that can only be perceived by human senses (Gengler, 2006).

In this study**,** the forearm was preferred for the prickle evaluation and used because of its convenience and sensitivity. Wang et al., (2007) also showed that there are highly significant correlations between the forearm and upper arm prickle test results. The forearm test is also quick and easy enough to use (Kennins, 1992). The sensory evaluation for prickle was conducted by the researcher as described later.

6.2.2.1 Sampling procedure

Samples were drawn from the 2013/2014 season Lesotho wool clip sent for auction. Farmers registered with National Wool and Mohair Growers Association of Lesotho (NWMGA) from all the districts had their wool sent to BKB for auction. The wool was core sampled and tested by the WTB, the fibre diameter ranging from 16.9µm to 22.2µm.

The samples were further stratified into fibre diameter ranges as shown in Table 6:12, the samples being taken from each available range as shown in Table 6.12. The number of samples was not determined prior to the sampling procedure, rather the representation of the samples.

Table 6.12: Sampling matrix

Item	Fibre diameter range (µm)	Number of samples
1	16 – 16.4	0
2	16.5-17	1
3	17.1-17.4	1
4	17.5-18	0
5	18.1-18.4	2
6	18.5-19	0
7	19.1-19.4	2
8	19.5-20	1
9	20.1-20.4	2
10	20.5-21	3
11	21.1-21.4	1
12	21.5-22	3
13	22.1-22.4	1

Wool sample selection was such as to cover the range of fibre diameters constituting the bulk of the 2013/2014 Lesotho wool clip on sale at the time of data collection. Accordingly, eighteen greasy wool samples (n=18), of mean fibre diameter ranging between 16.9µm and 22.2µm (see Table 6.13) were selected for the prickle evaluation. The samples were drawn from bale lots from different regions (where appropriate), according to the required fibre diameter, The samples already had their fineness characteristics measured for certification purposes by the Wool Testing Bureau (WTB), prior to their selection and sampling. Table 6.13 shows the selected details of the samples, particularly the mean fibre diameter (MFD), Comfort Factor (CF) and the yarn linear density (tex). The linear density (tex) was calculated from the weight of 10m yarn for each wool sample.

6.2.2.2 Sample preparation

The wool samples were washed manually, hand combed and hand spun at a local handicraft centre, called Hatooa-Mose-Mosali in Teyateyaneng Lesotho, with special care being taken to ensure that batches did not become mixed. Hand spinning had to be resorted to because of the small sample available, and the lack of suitable machinery to convert small batches of wool into yarn. Three experienced spinners were involved in the spinning on a manual spinning wheel. Attempts were made to spin the yarns, from the different samples, to the same nominal linear density (tex), but this was difficult using hand spinning (see Table 6.13). Hand spinning also did not produce a very even yarn. This, together with the differences in yarn linear density, presented problems when investigating the effects of Comfort Factor and /or MFD on the subjectively assessed comfort of the knitted sleeves. Each of the 18 yarns was knitted into a plain single jersey sleeve (±20cm each) with a rib (see Figure 6.1) on a manually operated flatbed knitting machine, located at the Incubation Centre at the Second Avenue Campus of the Nelson Mandela University (NMU). The sleeves were knitted straight and each sewn so as to form an under-arm seam. Four sleeves were produced from each of the 18 yarns.

Table 6.13: Prickle evaluation sample details (n=18)

Sample	Region	Yarn Linear Density (Tex)	Mean Fibre Diameter (µm)	CV of MFD (%)	Comfort Factor *CF (%)
1.	Highlands	544	16.9	22.3	99.4
2.	Foothills	537	17.3	23.4	98.9
3.	Highlands	484	18.1	28.4	98.1
4.	Foothills	584	18.2	21.9	99.6
5.	Foothills	674	18.2	23.6	98.9
6.	Highlands	573	19.1	22.9	98.6
7.	Foothills	554	19.3	23.3	98.1
8.	Lowlands	457	19.9	23.4	98.1
9.	Lowlands	724	20.1	22.0	97.9
10.	Foothills	689	20.3	23.1	97.3
11.	Foothills	477	20.5	25.3	97.1
12.	Foothills	734	20.5	24.3	97.1
13.	Lowlands	612	20.7	24.3	96.9
14.	Highlands	496	21.1	26.9	95.2
15.	Highlands	452	21.5	27.5	93.2
16.	Highlands	491	21.6	27.0	94.5
17.	Highlands	605	21.7	22.0	95.5
18.	Highlands	475	22.2	22.1	94.4

*CF - Comfort Factor: The percentage of wool fibres with a diameter less than 30 micrometres (Malau-Aduli and Akuoch, 2010).

CV -The coefficient of variation, expressed as a percentage

Tex - The mass in grams of 1000 m of yarn (i.e. g/1000 m)

Figure 6.1 shows a photo of one of the wool sleeve samples with a schematic diagram of the sleeve. The sleeves were knitted ±20 cm long (inclusive of the rib part) and 40 wales wide as indicated in Figure 6.1.

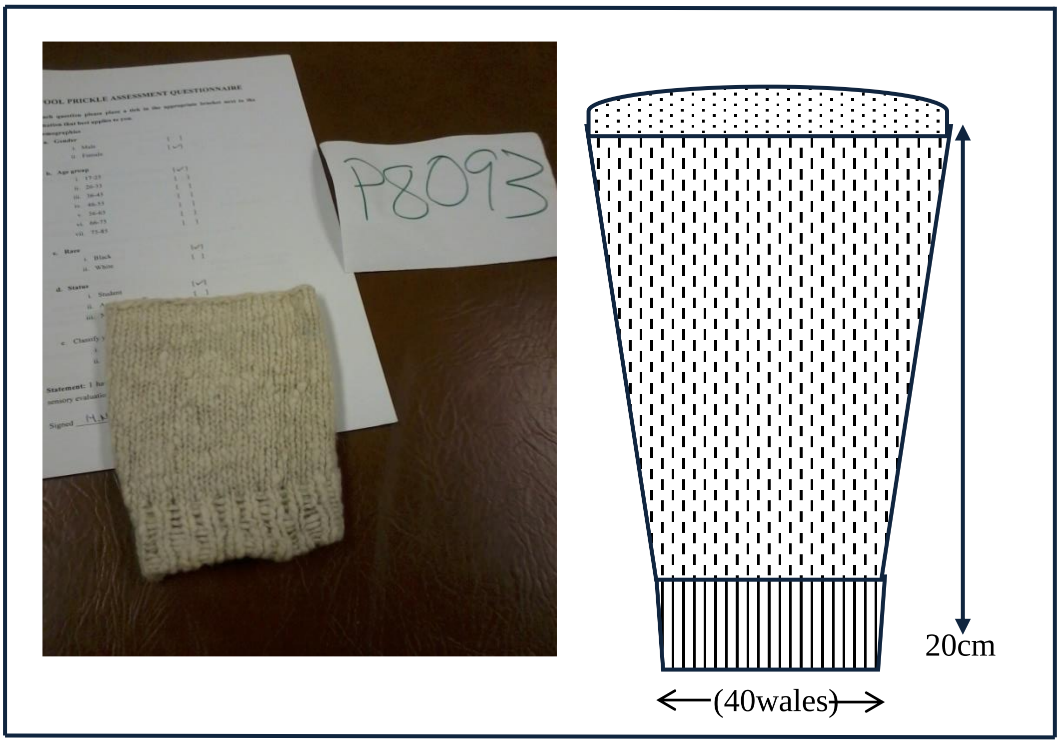


Figure 6.1: A photograph and schematic diagram of a sleeve sample *(picture by Maqalika, 2013)*

6.2.2.3 Evaluating Prickle

The sensory evaluation of the sleeves entailed the panel assessment of the prickle of the sleeves and preference. Using humans as a medium for such evaluation helps to quantify handle and sensibility, based upon a psychological process and an acquired emotion of refinement and comfort (Youngjoo and Chunjeong, 2001).

6.2.2.3.1 Selection of prickle assessment panellists

For the sensory (prickle) evaluation, twenty-four (n=24) members (16 students and 8 staff members) of the National University of Lesotho (NUL), in the Faculty of Agriculture, were selected to form the “prickle evaluation panel”. The panel consisted of eight (8) male and fourteen (14) female members, with ages ranging from 25 to 62 years. The members were selected after a screening test, involving their interests, availability and willingness to participate, each being required to sign the necessary consent form. The screening test assessed tactile acuity, this being considered essential, since sensitivity varies significantly with age, degree of skin hydration and other skin related factors (Civille and Dus, 1990). Table 6.14 indicates the specific personal attributes that the screening test assessed.

Table 6.14: Criteria used to select the prickle assessment panellists

ATTRIBUTES THAT QUALIFIED PERSONS TO FORM PART OF THE WOOL PRICKLE EVALUATION PANEL	
1.	No callouses on the hands and fingers
2.	No dry or chapped skin
3.	Not on any drug therapy
4.	Ability to detect and describe sensorial attributes of fabrics and mostly differentiate between intensities (levels)
5.	Interest in the activity
6.	Availability
7.	Willingness to participate

6.2.2.3.2 Training the panellists

The panel members participated in a one-morning training session, during which the objectives of the study and the evaluation technique were explained in detail. During this training session, the necessary consent forms were also signed. The hedonic scale was described to the panel, it's use being demonstrated. Furthermore, the sensory attributes to be assessed were described to the participants. Table 6.15 lists and defines the sensory attributes employed in the testing contextually. The procedure for assessing prickle on wool sample sleeves was also demonstrated.

Table 6.15: Contextual definitions of attributes used for the descriptive analysis of the sleeves

Attribute	Definition/Description
Softness (hand)	State of pliability and absence of stiffness in the sample.
Gritty	The amount of picky particles on the surface of the sample, used to describe softness and smoothness of samples.
Itchy (prickle)	Creating an urge to scratch when worn next-to-skin.
Harshness	State of being rough and lacking softness.
Comfortable	A state where no unpleasant sensations are experienced.
Appealing	Generally gives a pleasant feeling to panel members, such that a product similar to the sample could be preferred.

6.2.2.3.3 The sensory evaluation procedure (the actual tests)

Each of the 24 panel members was presented with each of 18 knitted wool sleeves, meaning each of the 18 samples was evaluated 24 times, although it was evaluated by different panellists each time. Each panel member was asked to wear each sleeve *(a sample of a given fibre diameter)* only once on their right forearm for a single sample test at one time, to obtain an estimate of prickle (Kennins, 1992). Each member was further requested to lightly stroke the sleeve while still on the forearm, with one hand using gentle up and down motions. They were to wear each sleeve alone and record their perceptions before changing to the next sleeve (see Figure 6.2).

Each member evaluated 5 samples consecutively in the first session and 4 samples consecutively in the second session of each of the two days of the trials (i.e. 18 samples in all). Each member would find 5 (or 4) different sleeves in a cubicle at a time and had to rank each of them on the seven-point Hedonic Scale given to them.

A Hedonic Scale is a type of scale with which judges/participants indicate the extent of their like or dislike (positive or negative perceptions), for a particular sensory characteristic of a given product. Table 6.16 gives the Hedonic scale used for the sensory evaluation, each member having to tick a box appropriate to their responses for each sample. The seven-point scale posed the two extremes of the attributes measured on either side of the scale, where “1” represented the positive extreme, “7” the negative extreme and “4” a neutral response.

Table 6.16: Hedonic Rating scale used for the tactile attributes tested in sensory evaluation

Attribute Rating	Tactile Attribute 1	Tactile Attribute 2	Tactile Attribute 3	Tactile Attribute 4
	Hand	*Prickle*	*Preference*	*Appeal*
1	Extremely soft	No prickle at all	Very highly preferred	Extremely appealing
2	Soft	Very slight prickle	Highly preferred	Highly appealing
3	Slightly soft	Slight prickle	Preferred	Appealing
4	Moderately soft/harsh	Moderate prickle	Moderately preferred	Moderately appealing
5	Slightly harsh	Strong prickle	Slightly preferred	Slightly appealing
6	Harsh	Very strong prickle	Very slightly preferred	Very slightly appealing
7	Extremely harsh	Extremely strong prickle	Least preferred	Least appealing

The various samples were displayed on similar tables and labelled with a unique numbering system which did not reveal the properties of the sample or any differences between samples. For the entire test, the same room (conditioned) was used to avoid differences in lighting and temperature. As already mentioned, the evaluation process involved wearing the sleeve, stroking it over the forearm lightly and carefully noting the sensation felt on the questionnaire form provided.

6.2.2.3.4 Analysis

The sensory trial results were then related to the calculated Comfort Factor. Data were analysed and presented in the form of charts, showing the extent to which the panel members' perceived prickle for the different sleeve samples.

6.3 ANALYSIS OF LESOTHO MOHAIR CLIP

As in the case of wool, the analysis of Lesotho mohair is dealt with in two parts, the first part (6.3.1) dealing with the database development and the second part (6.3.2) dealing with medullation. It is worth noting that this data on Lesotho mohair are generated and compiled almost entirely in neighbouring South Africa, as the mohair auctions for export activities are conducted in South Africa by contracted agents, notable BKB. Furthermore, unlike for Lesotho wool, information and statistical data for Lesotho mohair are not only limited but also not categorised into the ten (10) national districts, making it impossible to compare regions and districts.

6.3.1 Lesotho Mohair database

Lesotho mohair statistical data, covering a period of ten (10) years (2005/2006 to 2014/2015) were sourced from BKB, the only source of such data. The Lesotho mohair clip is objectively assessed by the WTB in Port Elizabeth South Africa, on the basis of mean fibre diameter, yield, and length. With only limited data available locally, an overall comparison with mohair produced in other countries, such as South Africa and Australia, is difficult, since other important information, such as the age of the goat (usually three categories of Kid, Young Goat and Adult), Style and Character, is lacking. For mohair as for wool, fibre diameter (μm) plays the major role in determining both quality and price (BAGS, 2015). Table 6.17 provides the information on the measured attributes for Lesotho mohair for the period 2005/06 to 2014/15; only information on mean fibre diameter, clean yield, staple length, greasy mass and average price being available.

Table 6.17: Lesotho mohair clip analysis

Shearing Season	Mean Fibre Diameter (μm)	Clean Yield (%)	Staple Length (mm)	Greasy Price (R/kg)
2005/2006	30.2	79	137	43.09
2006/2007	29.9	82	138	49.59
2007/2008	29.5	84	136	37.68
2008/2009	29.5	83	133	34.84
2009/2010	29.6	78	134	41.71
2010/2011	29.7	73	138	52.48
2011/2012	29.8	74	136	68.39
2012/2013	29.5	81	132	53.49
2013/2014	29.3	80	134	78.83
2014/2015	29.7	80	146	130.02

***As it has already been stated in the early chapters, the mohair trading changed in a major way which made the data inaccessible from 2015/2016.** Consistent data for mohair production could not be accessed at the time of the study.

6.3.2 Mohair Medullation

6.3.2.1 Sampling

With the permission of the Lesotho Wool and Mohair Growers Association (LWMGA) and authorization by their broker- BKB, all of the 194 cored mohair samples (n=194) available at the Wool Testing Bureau (WTB) in Port Elizabeth for the 2013/2014 season were used for the evaluation of the level of medullation in Lesotho mohair clip for that season. These samples were representative of the Lesotho mohair clip for that year and should give a fair indication of the quality of Lesotho mohair in terms of medullation.

6.3.2.2 Sample preparation for testing mohair medullation

The original cored samples were cored again using a mini-corer to give a homogenous and representative sample of 2 mm snippets required for measurement on the OFDA according to the IWTO testing standards IWTO-57-98 (see Section 6.3.4).

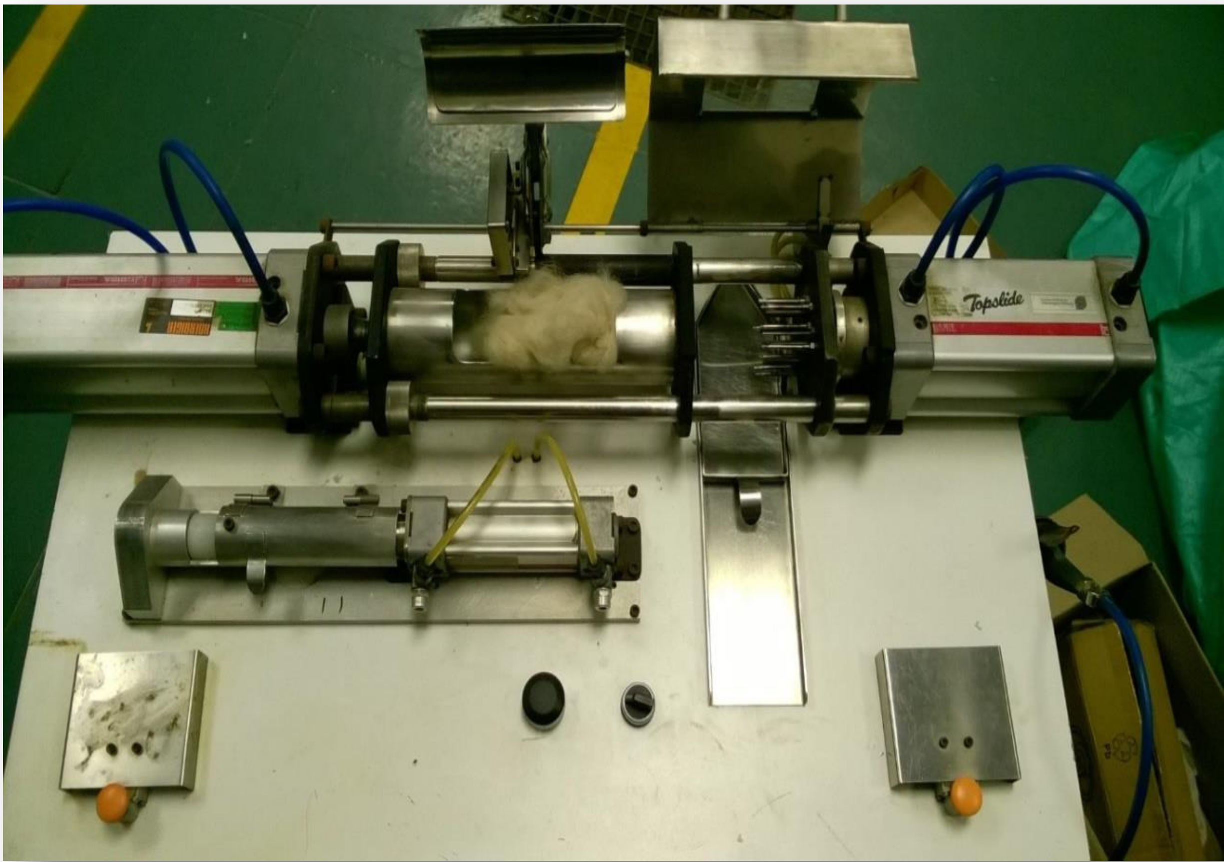


Figure 6.2: The Mini-coring machine (picture by CSIR, 2015)

The mini-cored sub-sample (test-specimen), provide a representative 2 mm snippet sample of sufficient mass suitable for medullation measurement on the OFDA. The snippets were cored from the scoured and conditioned mohair samples as it is required by the IWTO standards, these were then spread uniformly over the surface of the OFDA sample slide; using the spreader provided with the OFDA ensemble. Figure 6.2 shows a photograph of the mini-coring machine at CSIR in Port Elizabeth which was used for preparing the 2mm snippets required for medullation testing on the OFDA. The various fibre snippets were stored in glass tubes and conditioned overnight before they assessed. The slide was placed in the tester, the snippets being held in place by the slide cover (IWTO, 1998). The fibres were conditioned at 21 ºC (±2) and tested at the same, and internationally accepted, moisture content (regain). No prevented differential adherence to the sides of the glass tubes was observed.

6.3.3 OFDA Measurement of medullation

The OFDA 100 (Figure 6.3) was used for the measurement of the mohair snippets. It is an automated microscope, specifically designed to measure, using image analysis, fibre snippets spread over a glass slide, at upwards of 4,000 measurements/minute (SGS Wool Testing services 2011). The OFDA can also be used to measure medullated fibres in terms of the type and extent (in percentage) of medullation, fibre opacity and curvature. One slide from each of the 194 samples, at least 4,000 snippets per slide, was tested for mean fibre diameter MFD, standard deviation of fibre diameter (SD), coefficient of variation (CV) of fibre diameter, mean opacity, number of medullated fibres, number of objectionable medullated fibres, number of flat medullated fibres, mean medulla diameter, fibre curvature, as well as the percentage of fibres coarser than 30 µm.

Figure 6.3 shows the complete OFDA assembly, consisting of various components, such as the microscope, with electronically controlled stage and video image capture circuit board, sturdy fibreglass carrying case, automatic spreader to spread snippets onto slides, guillotine to cut snippets (used for tops), monochrome video monitor to display fibre images, hinged glass slides, graticule calibration slide and polyester reference slides also. Included in the assembly, are the sundry accessories, namely the computer and printer which may be customer supplied, minimum system 486DX2-66, 400MB hard disc, 8MB RAM, MSDos 6.22, mouse, VGA colour screen, Epson FX or HP PCL compatible printer (Hornik, 2012).

OFDA100 functions basically on the principle of image analysis, as described in ASTM D2968-95, and IWTO-47 for determining the percentage of medullated fibres in wool and other fibres, such as mohair, cashmere, alpaca, camel and other various forms of hair (ASTM, 1995, IWTO, 1995 and SGS, 2014). As the OFDA scans the slide in the opacity measurement mode, it obtains a dark field image and the normal bright field image of each frame almost simultaneously. It does this by firing the normal bright field light emitting diode (LED) and then waiting about 200 micro seconds before firing the ring of five (5) dark field LEDs, for the time set under dark field flash length. The bright image is captured into a memory buffer number 0 on the video digitiser card in the computer, and the dark field image is captured into the memory buffer 2, on the same card (Lupton and Pfeiffer, 1998).

Figure 6.3: Optical Fibre Diameter Analyser OFDA100 (picture by CSIR, 2015)

Figure 6.4 shows an image taken from a normal measurement run of the OFDA. It is an actual fibre recognition screen; measurement points are shown by the white lines crossing the fibre, although the actual diameter measurement is made perpendicular to the fibre at those points. In the OFDA image used for measuring fibre opacity, the opaque, medullated fibres appear dark.

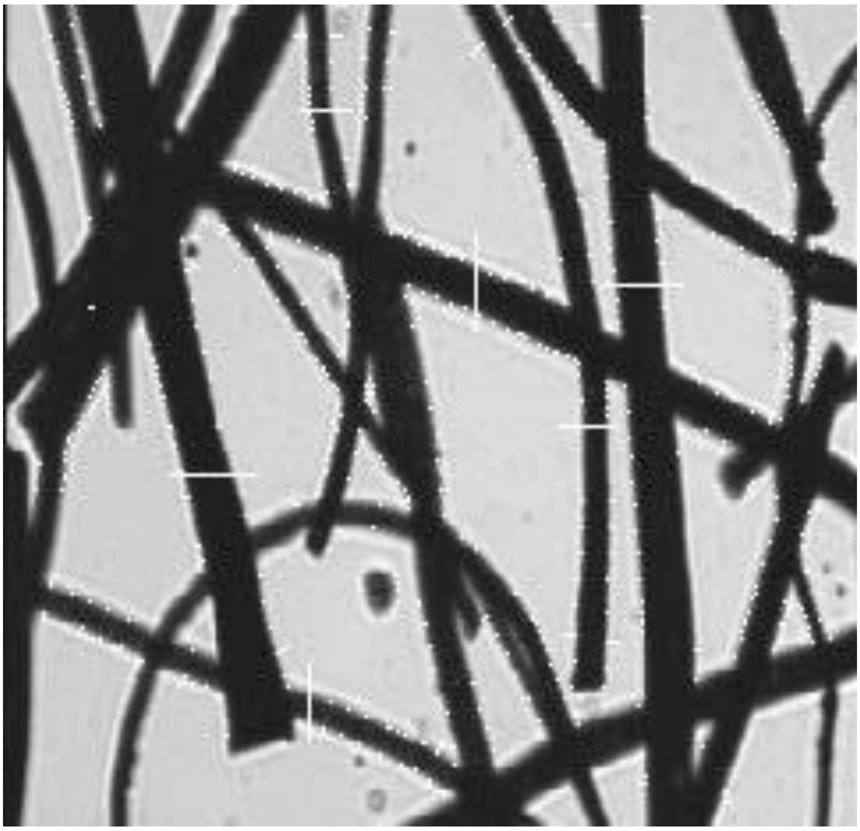


Figure 6.4: Distinct image of Fibre Measurement Points (SGS, 2014)

The snippets of each sample were evenly spread on a slide, using the OFDA spreader, in preparation for measurement; each slide was then covered by the other slide, hinged onto the first part of each slide, without disturbing the fibre snippet arrangement.

Following the ASTM D2968–95 standard test method for Medullated and Kemp fibres, opacity measurements were done on 4,000 fibre snippets per test specimen. The measuring intervals could be seen on the screen in white lines crossing the fibres, though the actual measurement was done lengthwise (see Figure 6.5). One slide was measured for each sample.

As already mentioned, the following OFDA parameters were used in this study to characterise the samples; MFD, SD, CV, percentage of fibres coarser than 30µm, number of medullated fibres, number of flat medullated fibres, number of objectionable medullated fibres, mean medulla diameter, mean opacity, % of medullated fibres by volume and fibre curvature (see Table 6.18).

Table 6.18: Mohair Attributes Measured by OFDA 100 (n=194×4,000)

1	**Fibre Attributes**
2	MFD (µm)
3	CV (%)
4	Number of Medullated fibres (%)
5	Number of Flat Medullated
6	Number of Objectionable Medullated
7	Curvature (deg/mm)
8	Mean Opacity (%)

*The attributes in Table 6.18 have been defined under contextual definition of terms in the opening pages of this thesis.

CHAPTER 7

7. RESULTS AND DISCUSSION

7.1 LESOTHO WOOL

For this study, only those selected and tested attributes of Lesotho wool and mohair fibre relating to their monetary/market value and production, and being measured, have been recorded and analysed. These include fibre diameter, staple length, production, yield and vegetable matter

7.1.1 Lesotho wool Production trends

7.1.1.1 Average greasy wool production

Figure 7.1 illustrates Lesotho greasy wool production and the number of sheep over the past ten years. As can be seen, greasy wool production in Lesotho fluctuated between about 3 and 4mkg from 2007/08 to 2014/15 and then increased to over 5mkg in 2015/16 about to reach over 6m/kg in 2016/17. Southern Africa and Lesotho regularly experience dry periods (drought), resulting in a drop in nutritional levels which result in a decrease in wool production (Kuenza et al., 2015). It is common knowledge that drought results in deterioration of pasturelands, which in turn impact on the nutritional content of the animal feed (Rust and Rust, 2013). Most farmers in Lesotho depend on pasturelands for animal feed, the pasturelands being strictly rain fed. With little or no supplementary feeding, the type and amount of feed available to the animals are compromised during periods of drought.

Wool growth in the merino sheep breed, the main breed in Lesotho, is known to be responsive to nutritional variations throughout the year (Adams and Cronje, 2003). This seems to be true for Lesotho wool production in the sense that, as the rainfall levels in Lesotho increased after 2015/16 (The World Bank Group, 2017), the pastures improved, resulting in improved vegetation in the pastures as well as the nutritional value thereof. This is evident in the significant increase in wool production, per sheep, since the number of sheep decreased by about 5% (see Figure 7.1), in both 2015/16 and 2016/17.

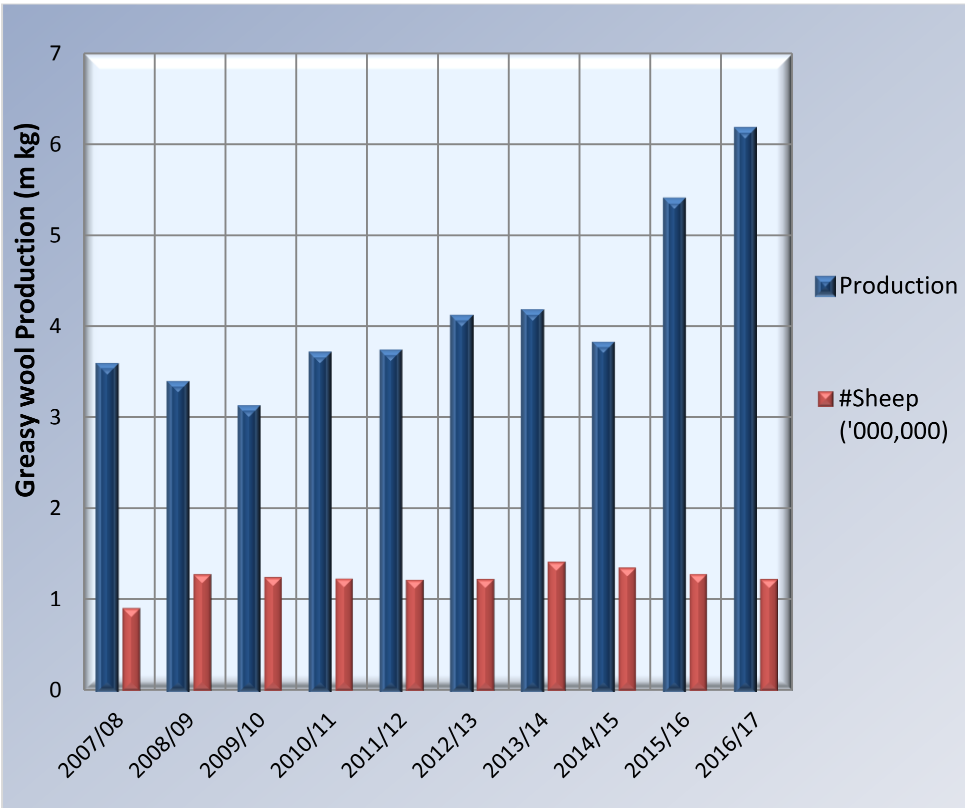


Figure 7.1: Trends in Lesotho Greasy Wool Production and Number of Sheep (2007-2017)

This can be ascribed to the educational campaigns and endeavours to attract more revenue as well as breeding practices and experience that came with years of involvement and exposure through the Lesotho Wool and Mohair Growers Association (Matla, 2014). The mandate of LWNGA has evolved over the years since its inception in 1966. Coupled with the most recently introduced wool and mohair promotion project, the positive developments in Lesotho wool and mohair become inevitable.

7.1.1.2 Greasy wool production by district

Lesotho farmers are encouraged to farm with merino sheep; certain farmers striving towards an entire flock of merino sheep only. The regional location of the districts seem to contribute towards the variations in production and possibly also quality.

The greasy wool production in the various districts is plotted in Figure 7.2. Differences in social and climatic conditions between the districts, determined by the regions in which they are situated, influence wool production greatly. For example, Berea and Mokhotlong represent the extremes in terms of production, with Berea having the lowest and Mokhotlong the highest wool production, in the ten-year period. Mokhotlong is located in the highlands while Berea is mostly in the lowlands. The districts located in the mountain or highland region, about 1.500 to 1.800m above sea level, namely Thabatseka, Mokhotlong and Qacha's Nek, experience extremely low temperatures in winter which also start earlier than in other regions. The altitude adds a moderating effect to the climatic conditions (Lu et al., 2010), this makes crop production difficult in the highlands; it is inevitable that most farmers in the highlands resort to livestock farming since the pastures in the highlands have the favourable environmental conditions suitable for extensive small stock production (Mokhethi, 2016). Pastures are more abundant in the highlands than in the lowlands and foothills; the distinct sloping topography typical of the highlands, make it unsuitable for residential and crop production purposes (Mekbib et al., 2011). More land is also available, due to people migrating to the lowlands for better employment and educational opportunities. Many farmers in the lowlands take advantage of the greater availability of land in the highlands and relocate their animals to the highlands during warmer months, bringing the flock back the flock only in winter when the highlands become extremely cold.

Livestock farming is culturally more valued in the highlands than in other regions. In the highlands, a man's wealth is still measured by the number of sheep he owns. The prestige attached to a flock of sheep in the highlands encourages sheep husbandry especially since most men in the region have not attained a reasonable level of education. Also, with the mines in South Africa retrenching workers from Lesotho, wool production becomes an obvious option. These factors are mostly responsible for the higher production in the highland regions, the merino sheep population in the highlands being usually larger than that in the lowlands and foothills (FAO, 2005). This explains the consistently higher production of Mokhotlong in the highland compared to that of Berea and other districts in the lowlands.

From Figure 7.2, it is apparent that wool production in Mafeteng and Mohale's Hoek fluctuated the most. These districts are situated in the part of the country where the Senqu valley is, which affects the climatic conditions of the area since it is vulnerable to water scarcity and its climate varies significantly often resulting in poor pastures. (BOS, 2007; Lesotho Water Commission, 2008; and FAO, 2008). It is therefore understandable that wool production in Mohale's Hoek fluctuates to the extent shown in Figure 7.2. The other districts generally maintained their relative stable production over 10 year period to some extent. Mohale's Hoek and Mafeteng are not considered to be economically viable for wool production because of the unfavourable agricultural conditions prevailing in these two districts. Wool production in the Berea district was consistently the lowest; being situated in the lowlands, it is generally susceptible to drought, which generally seems to be more severe in the lowlands than in the highlands due to large areas of bare land and constructions (Mekbib, 2011) and (Alotsi, 2017). Pastures in the lowlands are generally insufficient and unsuitable for sheep, it is for this reason most farmers keep their flocks in the highlands in cattle posts usually in communal kraals (Annor-Frempong, 2008) mostly during warm seasons as already stated.

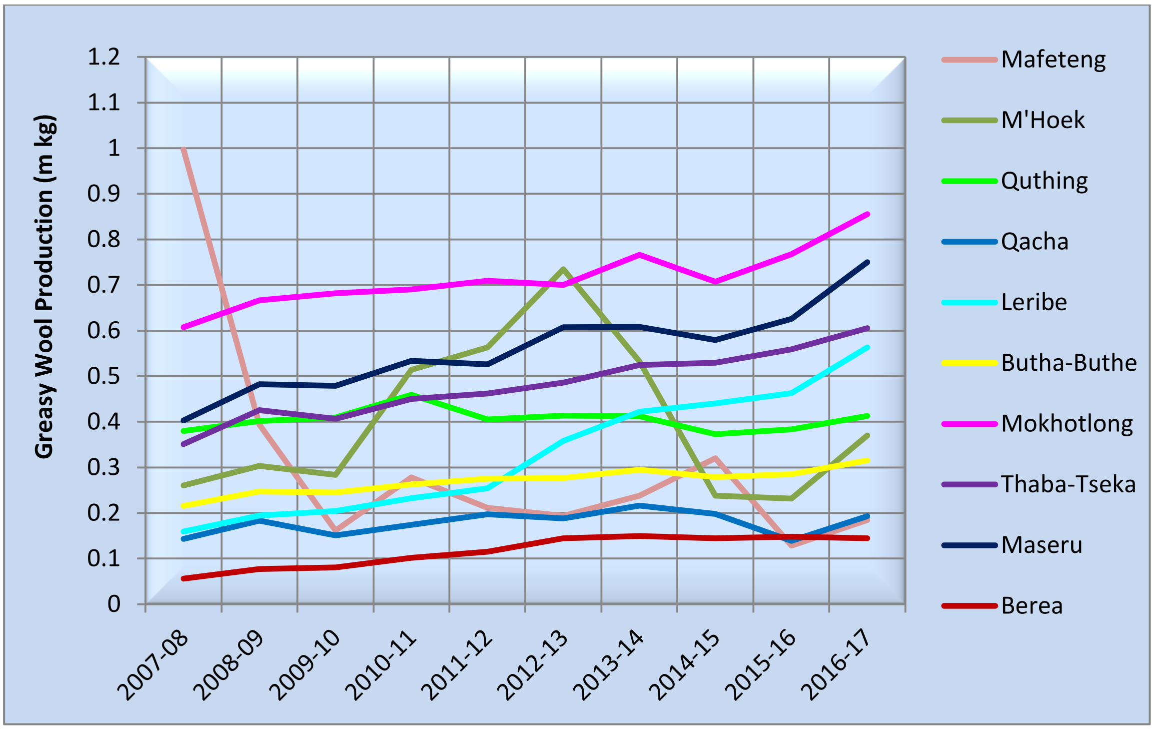


Figure 7.2: Wool Production for the different districts‘000)

The lowlands are generally dry (Lesotho Meteorology Services, 2016), usually resulting in low nutrient content levels in pasturelands. Furthermore, dense population distribution in the lowlands leaves a smaller proportion of land for pasture, a larger part of the land being used for residential and offices due to urban migration. Farming interest is low because there are various options available to earn a living in the lowlands. This in turn, lowers the amount of wool produced.

7.1.1.3 A comparison of greasy wool production in South Africa, Australia and Lesotho

Although wool production has increased slightly in recent years, it still remains far lower than that in the other apparel wool producing countries, namely Australia and South Africa (see Figure 7.3). This is due to the land area suitable for wool sheep farming being much smaller than that in Australia and South Africa (Henry et al., 2015). In addition, the agricultural infrastructure and conditions in the three countries are very different, Australia and SA being well developed while Lesotho is not. Australia and SA have developed economies and the required infrastructure, support, the right kind of attitude of farmers, as well as freedom to do as they find appropriate for the improvement of wool production. Most farmers in Lesotho have to travel long distances, driving the sheep to a shed to be dipped and shorn, the sheep are not kept in sheds or barns, sometimes they struggle to get the sheep dipped and some of them cannot afford other health care costs. Membership of National Wool and Mohair Growers Association has helped many farmers because most expenses can be handled communally. Other differences include the initiatives of farmers in SA and Australia take to ensure proper research and extension services are carried out; farmers fund some of the research, and extension services which is not the case in Lesotho. Furthermore, some recent government policies, supposedly to enable marketing have not been accepted by the farmers, thus resulting in an obvious instability, which affects wool sales and exports. In light of all the above stated, Lesotho farmers are placed at a disadvantage compared to South Africa and Australia.

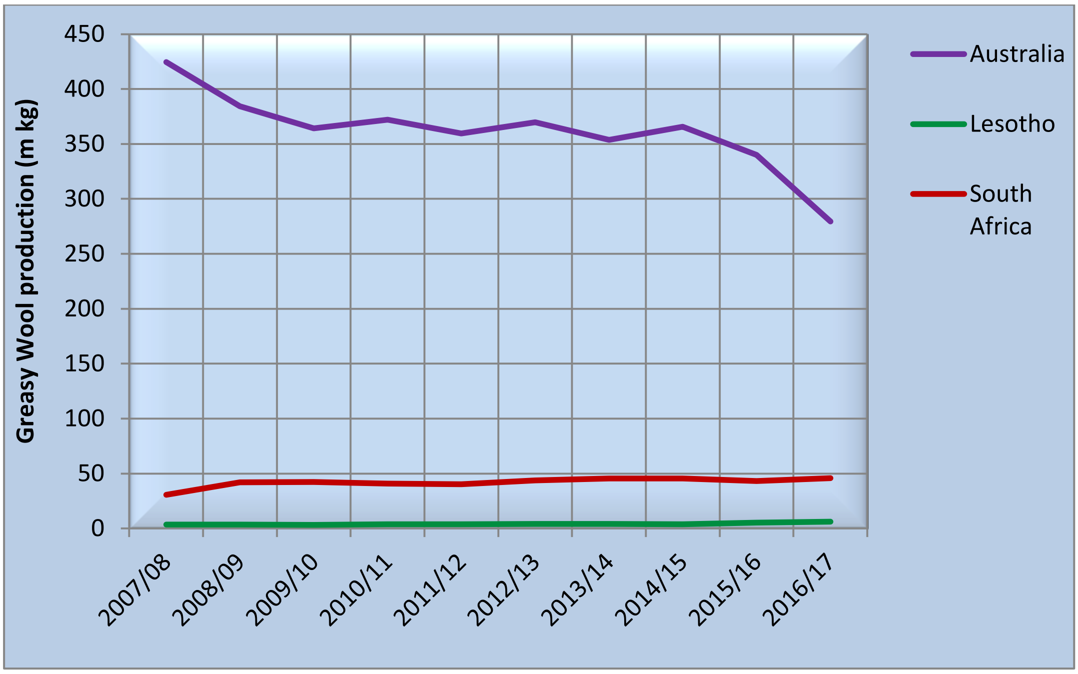


Figure 7.3: Greasy Wool Production in Lesotho, South Africa and Australia

The establishment and development of the National Wool and Mohair Growers Association (NWMGA) late in 1966 proved to be beneficial to its members; it gives a much needed backing to the farmers, by providing a platform and forum for sharing knowledge/experiences as well as new relevant and up to date farming practices. According to Mafisa, (1993), the association evolved from a grouping that was called the “scheme for progressive sheep and goat” established in 1960. It is common knowledge that farmers who are members of NWMGA are more knowledgeable and they make greater attempts to improve their flocks because they know what type and quality of fibre is required on the markets, they also understand the price benefits they stand to gain upon meeting those requirements. Unlike in SA and Australia, the agricultural and textile research focus in Lesotho seem to be driven by individual, institutional, governmental and donor interests; with farmers not contributing directly to research decisions, yet they are on the ground expected to implement the relevant recommendations of research. Furthermore, lack of appropriate infrastructure and support contributes to losses from stock theft and diseases as well as seasonal stock deaths as a result of harsh climatic conditions that often hit Lesotho farmers hard (Jordaan, 2004, and Matla, 2014). Of the three ways through which stock losses are incurred, stock theft is the most devastating, since it affects livelihoods and the national economy (Khoabane and Black, 2012, and Jordaan, 2004). Such stock losses affect wool production levels directly. Preventative measures could include keeping animals in protected sheds or barns together with smart records and better crime prevention. Both disease prevention and treatment would also beneficially affect sheep farming and wool production (Jordaan, 2004).

7.1.2. Clean Yield

7.1.2.1 Average Clean Yield

The average clean yield for Lesotho wool has fluctuated between about 55% and 60% since 2007/08, with, if anything, an indication of slightly increasing, from about 54% to about 58%, over the long term (Figure 7.4). This slight improvement is ascribed to improved farm management practices, such as good breeding and reducing the extent of contamination of wool. Traditionally, greasy wool is comprised of suint, grease, dirt, VM and wool. Farm practices that reduce the quantity of any of these components, except the wool, lead to an increase in yield. Such practices include sheep coats, grazing in designated pastures with less bare areas of land and contaminating plant material (VM), in which case the corresponding contamination is likely to be reduced. Such pastures are mostly found in the highlands.

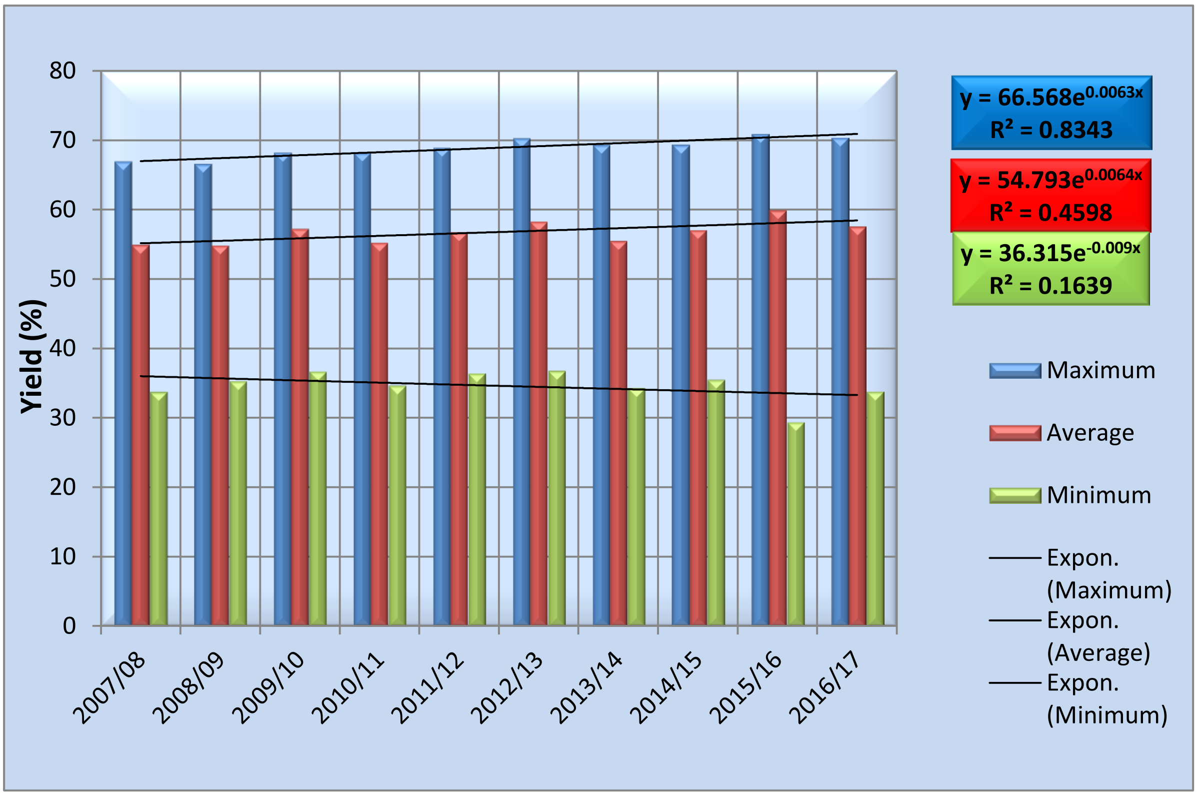


Figure 7.4: Clean Yield levels of Lesotho Wool

According to Alotsi, (2017), a livestock officer in charge of the field service workers, most Lesotho farmers have generally been heeding the advice from government, via the extension workers; which include cleaning the kraals regularly, ensuring that shearing is done in shearing sheds, where cleanliness is controlled, and standards are set. Some farmers even remove the burr by hand from the fleece before shearing, as suggested by the American Sheep Industry Association (ASIA, 2018).

7.1.2.2 Clean yield by district

The wool clean yield is plotted in Figure 7.5 for the various districts. From this figure, it is apparent that there are significant differences between districts, this being ascribed to the differences in environmental conditions, pastures, breeding and farm management between various districts. Figure 7.5 also illustrates that the yield of the various districts fluctuated fairly widely from year to year, often in phase with each other, indicating the possible influence of fluctuation in climatic and grazing conditions nationally.

The overall trend is for a slight increase in yield over the long term, as reflected in Figures 7.4, and 7.5. The Maseru district consistently produced the highest yield, while Mafeteng produced the lowest over the ten year period. Mafeteng is generally dryer than most districts (Lesotho Meteorology Services, 2017). Maseru on the other hand hosts hamlets like Semonkong, with temperatures that rarely exceed 28ºC and which can drop to below -10 ºC, it is situated in the mountain region and in the area close to one of the highest falls (192m) in the world, this fall makes a haze of mist when the water plunges the long distance increasing humidity in the area (Mekbib et al., 2011). The humidity reduces the amount of dust which constitutes the ash residual (AWTA, 2017), it can therefore, be concluded Semonkong has higher wool yield percentages possibly because it has lower ash residual content. Further research will be required to confirm this belief, and to make relevant recommendations regarding the outstanding suitability for wool sheep farming for this area, which could see Lesotho setting up "wool sheep farming center" in Semonkong. McGregor and Tucker (2010) describe suint is a combination of perspiration, water soluble salts and various fatty acids deposited on keratin fibres. This suggests that conditions like hot weather, that have a potential to increase perspiration, contribute to an increase in suint. According to Beisembay (2000), desirable suint and grease to protect the fibre and can improve the quality though not production of wool

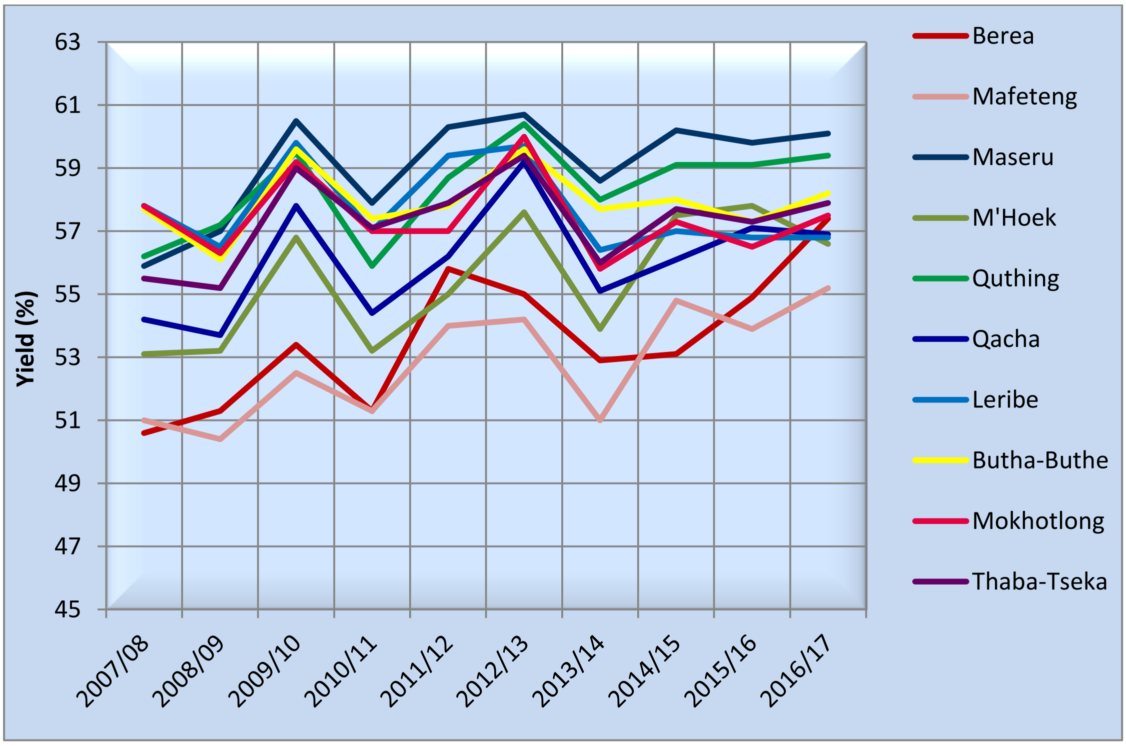


Figure 7.5: Wool yield levels according to district

Dryer districts, like Mafeteng, are characterised by abundant dust, which gets easily deposited onto, and retained in the greasy fleece of sweating animals due to high temperatures in the lowlands; naturally, dirt is easily attached to greasy wool in its crude state. Sheep fleeces in the lowlands districts namely, Berea, Mafeteng, Mohale's Hoek and parts of Maseru, are also vulnerable to crop residue from crops usually harvested at the same time as the shearing of wool sheep, and other contaminants which in turn lower the yield (Alotsi, 2017). This not being the case in the highlands. This was suggested by higher VM levels for the above mentioned districts found in this study (see next section). As expected, Mokhotlong, Thaba-Tseka, Qacha's Nek, Quthing, Butha-Buthe and parts of Maseru have the higher yield levels, located in the highlands. As already mentioned, farmers in the highlands show more concern for their farming. It is apparent therefore that their farming practices and breed selection are done carefully, thus ensuring that suint, VM levels and dirt are controlled. In this way yield will be higher.

As is can be observed in Figure 5, there were dips in 2010/11 and 2013/14 indicating low yield levels. Because Figure 7.7 shows the increased levels of VM in the same periods, it is hereby concluded that the high VM levels contributed to the low yield.

7.1.3 Vegetable matter content (VM)

7.1.3.1 Average vegetable matter content (VM)

Although the wool auction prices vary from auction to auction; they are sensitive to VM levels and other specific quality properties such as MFD and staple strength. The 4 % and 5 % VM levels in wool that usually attract 2 % and 6 % in price discounts respectively, in a period of few weeks suffered discounting as high as 10 % and 12 %, respectively. An increase in VM levels is associated with higher processing costs and lower throughputs for the processors (AWI, 2017). The only way to prevent such discounts is to reduce the VM levels in wool, and to keep them below 1.5 % where possible.

Vegetable Matter levels are determined by the type of pastures on which the animals graze, together with rainfall, which influences the degree of plant development, the conditions of the pastureland being vital for VM management (Brownlee and Denney, 1985), both in terms of the amount and type of VM present (Fleet and Langford, 2013). Large pasturelands in the highlands ease the management of grazing pressures which alters the type and amount of VM favourably (Brownlee and Denney, 1985). Matching the stocking rate to carrying capacity of the pastureland during the year contributes positively to the reduction of VM contamination in fleeces. Furthermore, for the comfort of the shorn animals, the districts in the highlands of Lesotho shear a little later, since temperatures rise later than they do in the lowlands.

As can be seen in Figure 7.6, Lesotho wool VM levels range from about 0.12 % to 9 % by weight, with an average of just below 2 % (1.5 % to 1.87 %). Levels of VM below 1.5 % attract insignificant discounts, whereas discounts occur as VM levels approach 2 % and thereafter. Since Lesotho wool has VM levels on average lower than 2 %, not very high discounts are usually attracted, although it could do so in individual cases. The high maximum levels of 6 % and higher, indicate that there is still much scope for individual farmers or groups of farmers, to reduce their VM levels through appropriate breeding and farm management practices. Wool producers need to implement better VM management strategies, especially nearing the shearing season/time, although grazing conditions may be difficult to manipulate.

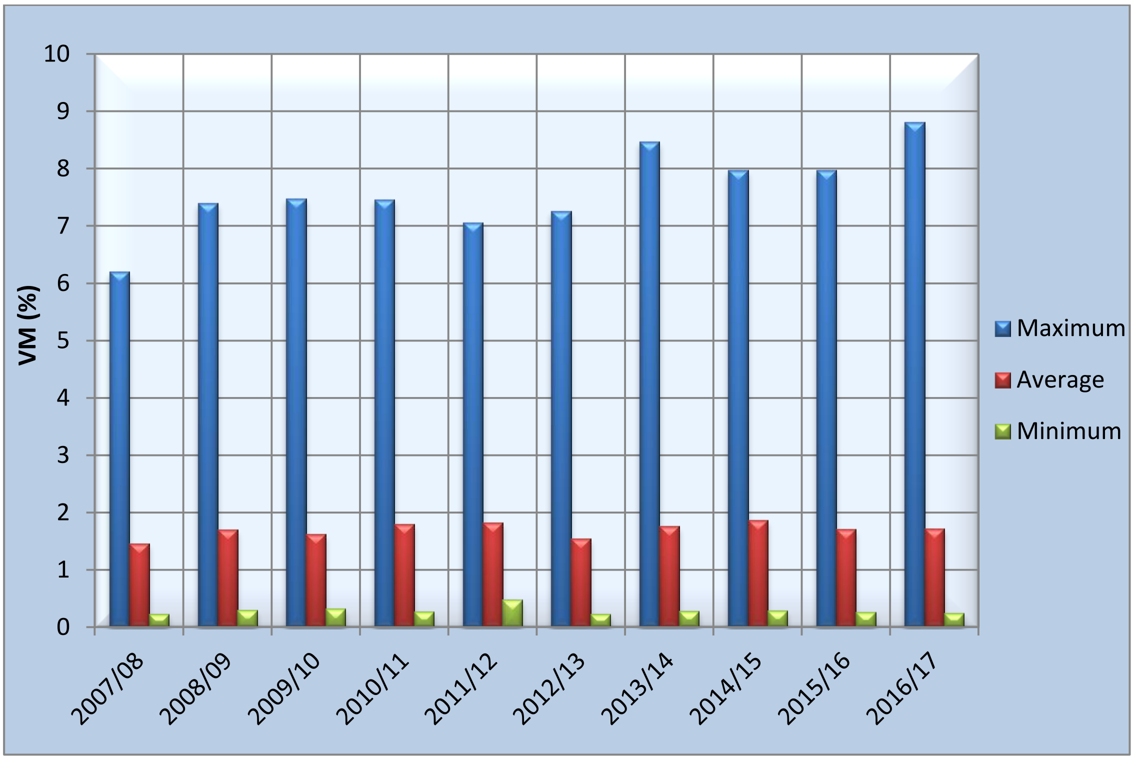


Figure 7.6: Vegetable Matter Content in Lesotho Greasy Wool (Cape Wools SA, 2017)

7.1.3.2 VM Levels in Different Districts

The lowland districts are more vulnerable to VM contamination from sources other than the pasturelands due to large scale crop production. The crop residue contributing to increased levels of VM is most common during crop harvesting, especially where harvesting is done manually. This usually happens just before the shearing time, making the wool susceptible to contamination. Sheep are often seen grazing between fields, other times the grains are carried home without separating from the plant matter. It is a common practice in Lesotho that air is allowed to blow some crop residues out of the grain, after separating grains from the plant matter; the blown residue is likely to contaminate the sheep in the compound.

The Mokhotlong and Thaba-Tseka districts produced wool with the least VM levels (see Figure 7.7). These two districts are both situated in the mountain/highlands region where the pasturelands are abundant and supposedly more suitable for livestock than those in the lowlands since growth of broad leaf plant is minimal.

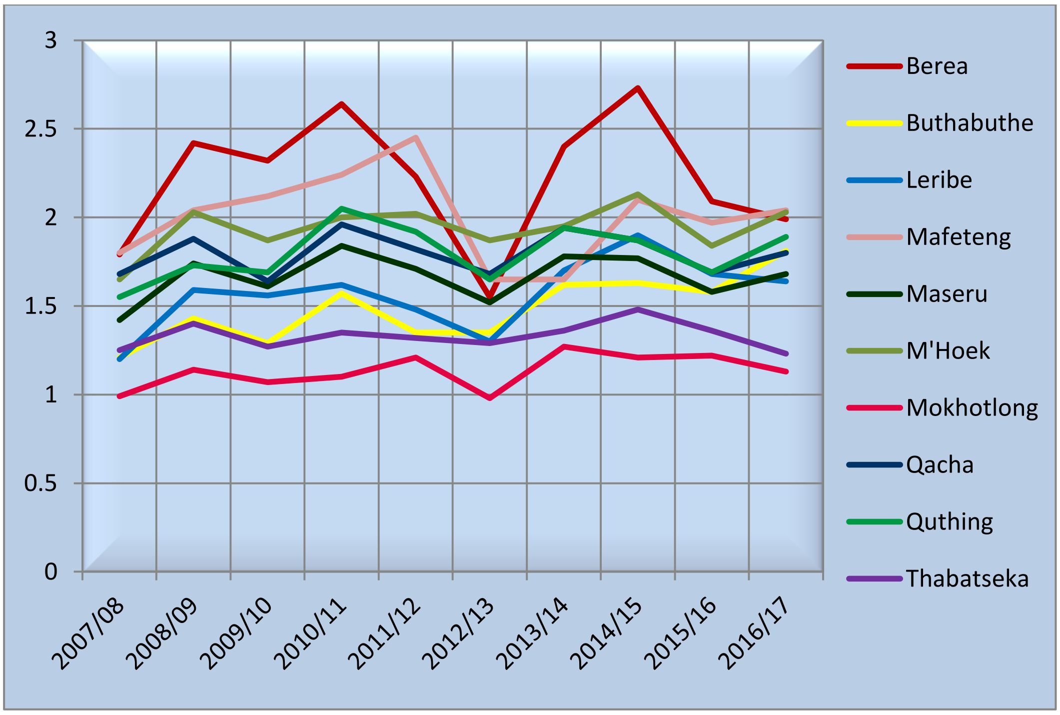


Figure 7.7: Vegetable matter content levels for the various districts

Large pasturelands in the highlands make rational grazing possible; where the infected pastures are grazed before the seeds develop (American Sheep Industry Association, 2018). Berea, Mafeteng and Mohale's Hoek on the other hand, located in the lowlands, have the high levels of VM. The general decrease in VM levels in the season 2012/13 cutting across all districts can be attributed to better rainfall and pasture management, which prevailed (Lesotho Meteorology Services, 2017). Rainfall significantly alters the constituents of the pasturelands. In rainy seasons, plants develop quickly and animals can graze on them before they form seeds, in which case the pasture will be less contaminating. Fluctuations in the VM levels are, as expected, reflected in the yield, as can be seen from the results of Berea and Mafeteng, both being rated highest in VM levels (see Figure 7.7) and lowest in yield (see Figure 7.5).

7.2 FIBRE DIAMETER

7.2.1 Average fibre diameter

Mean Fibre diameter (MFD) is the single most important quality related parameter used to determine the value of clothing wool, it also has a great influence on the price (McGregor, 2007) the finer the wool the better the textile quality and the price of apparel wool. It is therefore not surprising that, through the appropriate breeding practices, the average fibre diameter was decreased over the years, in both Australia and South Africa, with the proportion of their fine wool (i.e. <19.5 µm) increasing as a percentage of the total wool produced each year (AWTA, 2014). Nevertheless, such a trend was less apparent for Lesotho wool as can be seen from Figure 7.8 which shows the average, fine and coarse wool production in Lesotho over the past ten years.

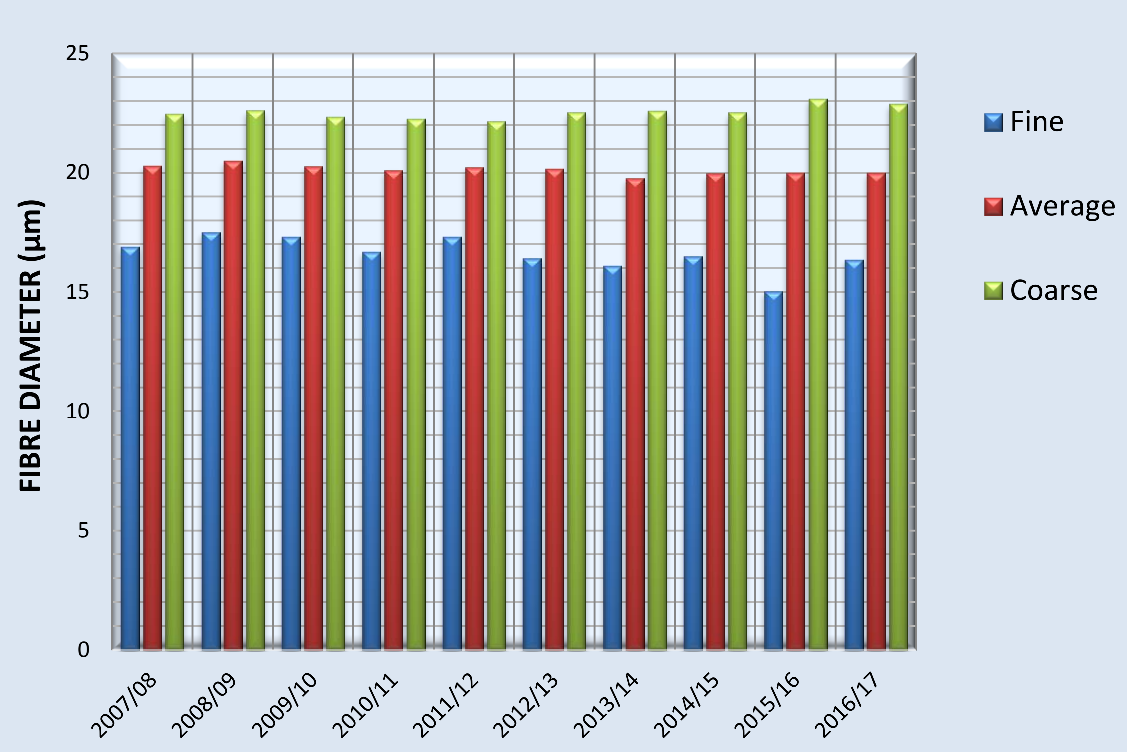


Figure 7.8: Average fibre diameter of Lesotho wool (Fine, Average, and Coarse) over the past 10 years

Figure 7.8, shows that the overall average diameter (≈19.8 µm) of the Lesotho clip hardly changed during the ten year period covered (2007/08 at 20.3 µm to 2016/17 at 20 µm). This also generally applied to the fine category which averaged 16.6µm over the ten year period. The government of Lesotho in 2012 established the Small Agricultural Development Project (SADP) in the ministry of Agriculture which is expected to end in 2018, though negotiations were underway for this project to continue. The SADP intervention has since been extended effective from June 2019 (Lesotho News Agency, 2019). According to Mokhethi (2016), one of the project's goals was to develop the wool and mohair industry through marketing support; genetic improvement of communal flocks through the introduction of quality rams; training and mentorship; SADP apparently impacted positively, (e.g. superior flocks and finer wool) on the wool quality particularly the fibre diameter as it is the main price determining quality property. The success of these attempts and others working towards the enhancement in sheep farming practices, is expected to inevitably improve Lesotho wool quality, particularly mean fibre diameter.

7.2.1.1 MFD Distribution per district

Differences in climatic and social conditions between Lesotho's districts, impact their wool quality, especially MFD. Figure 7.9 shows that the districts in the highlands (Thaba-Tseka, Mokhotlong, Qacha's Nek, and a large part of Maseru), consistently produced finer wools (lower MFD) than those in the lowlands and some foothills. This can be attributed to the fact that most pastures suitable for wool sheep are located in the highlands and the value placed on pasture management in this region, is much higher than in the lowlands (Mokhethi et al., 2015), with better breeds and fine woolled sheep being farmed there. The average fibre diameter of the wool produced in Mafeteng and Mohale's Hoek fluctuated fairly widely. Which is probably due to fluctuating soil nutrition coupled with poor and mixed breeding which are believed to have contributed to the comparatively coarser fibre diameter of Mohale's Hoek, Quthing, Leribe and Mafeteng (Alotsi, 2017). It has been reported that from 2007/08 onwards, Lesotho farmers took an interest and active role in improving their flocks as this would attract higher prices. Nevertheless, flock improvement is a gradual process, especially in Lesotho where culling is seldom done (Matla, 2014). As can be seen from Figure 7.9, there was a trend for the mean fibre diameter to decrease slightly over the past 10 years. The annual levels fluctuated almost in synchrony, probably as a result of changing climatic and associated nutritional conditions and the SADP project effects coming to play.

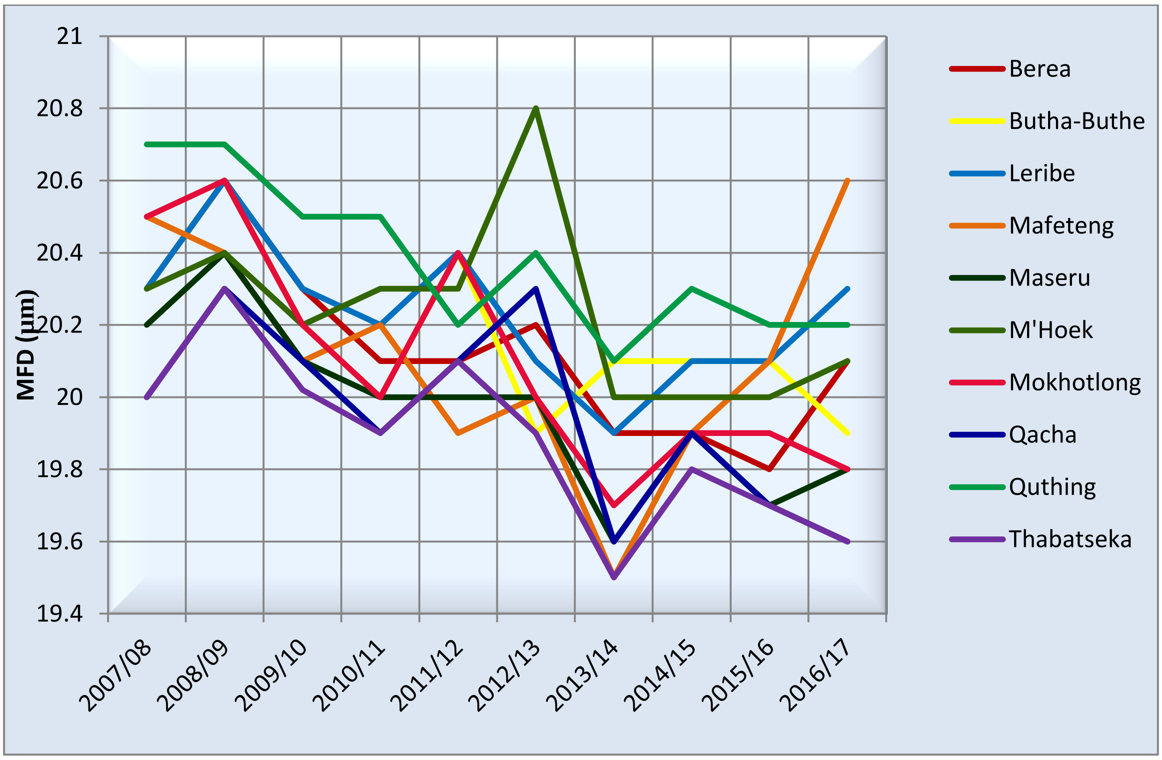


Figure 7.9: Average MFD for the various districts

Figure 7.9 shows that the average MFD was at it finest during 2013/14, when eight out of 10 districts recorded ≤20µm, probably due to low nutritional levels and/or harsh climatic conditions.

7.2.2 Comparison of Lesotho, Australia and SA MFD

Figure 7.10 compares the average fibre diameter of Lesotho wool with that of Australia and South Africa. Lesotho wool is slightly finer (19.8 µm) than Australian (21 µm) and South African (21 µm) wool. Figure 7.10 also indicates that the mean fibre diameter of Australian wool decreased slightly over the years, from approximately 21.5 µm in 2007/08 to below 21 µm in 2016/17, while that of SA decreased from about 21.3 µm in 2007/08 to 21 µm in 2016/17. The general improvement in fineness indicates efforts taken by farmers to produce apparel fibres of high quality and price which consumers demand, fine wool being particularly important for high quality clothing, particularly for that worn next to the skin (Liao et al., 2011).

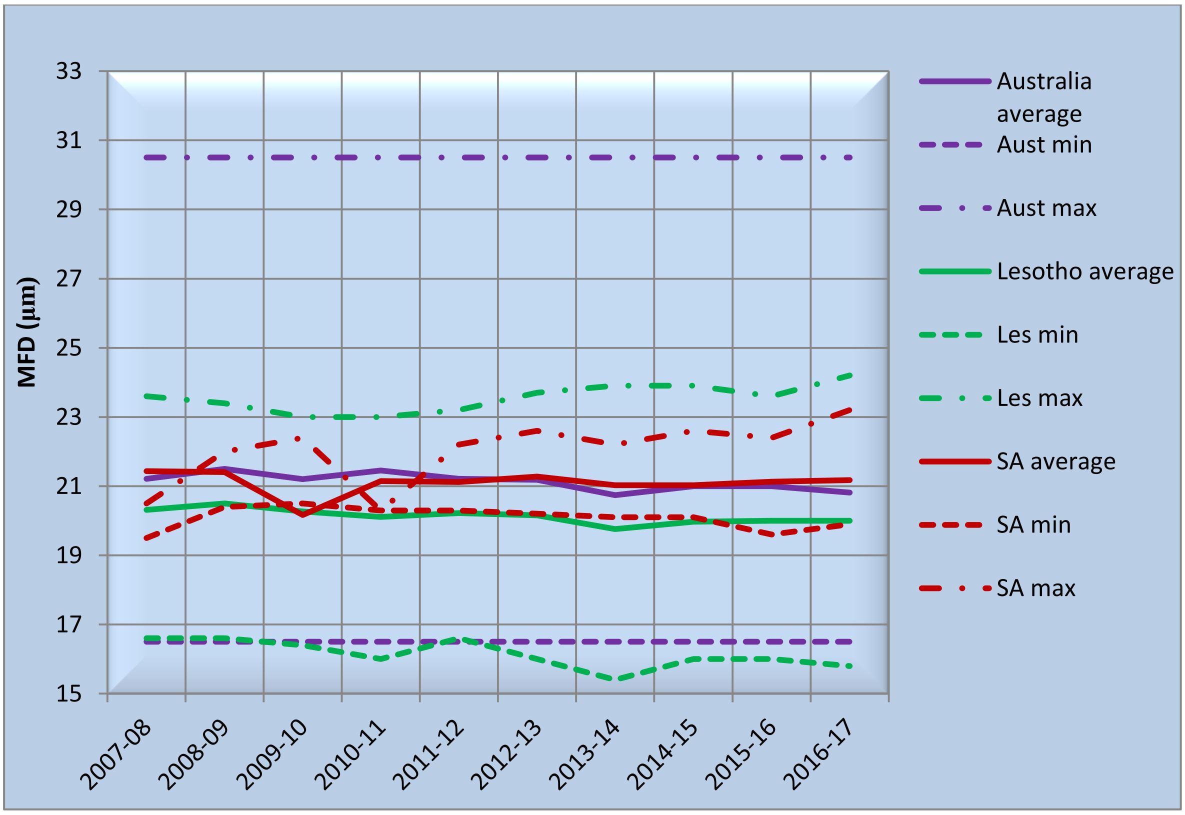


Figure 7.10: MFD for Australia, SA and Lesotho wool

7.2.3 Staple Length

Figure 7.11 shows that the average staple length of Lesotho wool ranged from about 61 mm to 66mm, which means that it falls within the class of combing wools (≥ 50 mm) used mostly for worsted yarns. Figure 7.11 also shows that the average staple length of Lesotho wool tended to fluctuate slightly from year to year, but showed an initial trend (medium term) to decrease, from around 65 mm in 2007/08 to a low of 61mm in 2014/15, after which appeared to increase again slightly to about 64 mm in 2016/17. Hence, overall, the staple length of Lesotho wool hardly changed from 2007/08 to 2016/17. The average staple length of Lesotho (63.6 mm) is slightly greater than that of South African wool (59.7 mm) but shorter than the lots Australian wool (89.1 mm) as can be seen in Figure 7.11. SA wool staple length showed a slight downward trend from about 62 mm in 2007/08 to about 59.3 mm in 2016/17, whereas Australia wool increased in staple length by about 6mm (from 85mm in 2007/08 to about 91 mm in 2016/17).

Both Australia and Lesotho shear sheep once a year, while in SA most farmers shear approximately every 8 months, this practice resulted in Lesotho and Australian wool having longer staple length compared to SA. On average, the difference between Lesotho and SA staple length for the 10 year period is about 6mm, which is small considering the fact that SA wool grows only for 8 months on average, whereas Lesotho wool grows for 12 months. If Lesotho and SA maintain the same growth rate over the same period, they should have the same staple length. Nevertheless, using the present figures as a basis, if SA shore at 12 months instead of 8months, then the wool staple would be $\frac{12}{8} \times 59.7 = 89.6\, mm$, which is much longer than Lesotho and only slightly longer than that of Australian wool. The longer staple length of SA wool, so calculated, could be due to the fact that certain farmers also shear once a year at certain times.

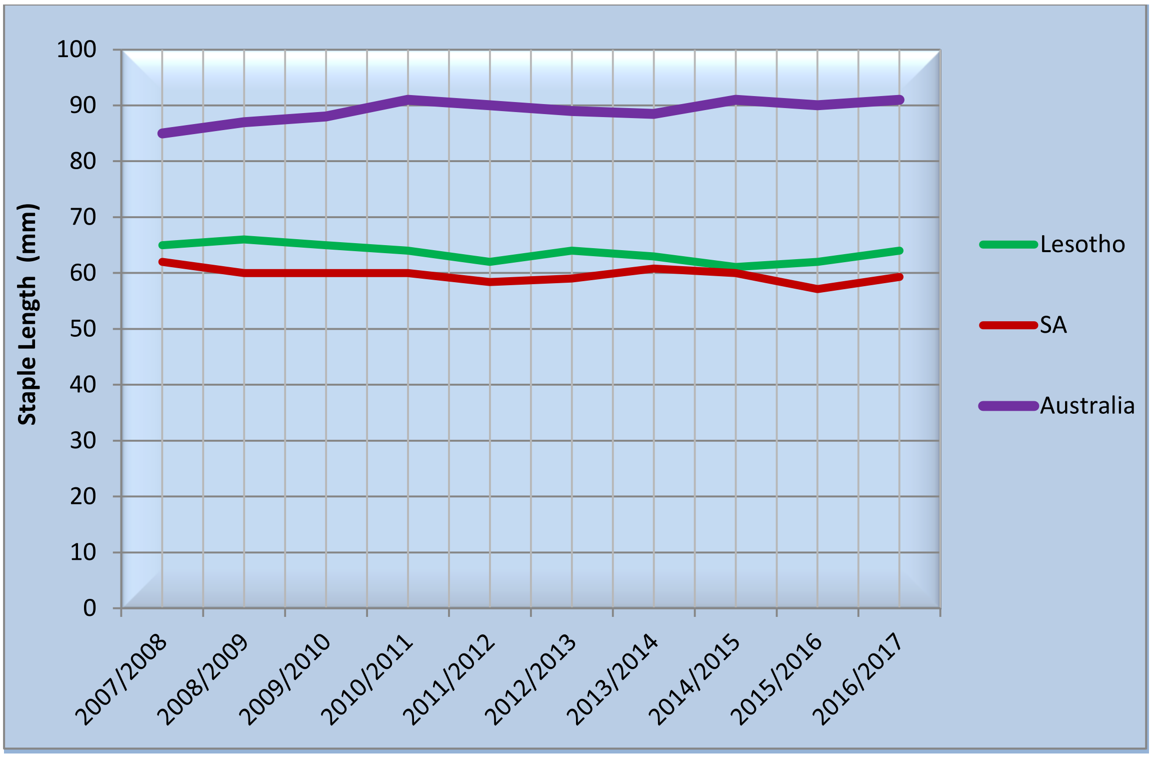


Figure 7.11: Average staple length of Lesotho, SA and Australian wool

7.2.4 Greasy wool price

The average price for Lesotho greasy wool increased from around 15 R/kg in 2012/13 to about 80.35 R/kg in 2016/17. Lesotho and SA wool price followed a similar, and in fact almost identical, pattern; they both outperformed the global market indicators (Figure 7.12). Australia wool price on the other hand has been outstandingly above the market price and the price of both Lesotho and SA. It is well known that the quality of wool influences price, particularly clean yield, fibre diameter and staple length (McGregor, 2007 and Botha and Hunter, 2011).

Lesotho and SA wool sold at their lowest of the studied decade in 2012/13, possibly due to currency fluctuations and agricultural factors that affected the quality of wool. The merino price in US dollar terms has been more restrained than the Australian dollar price due to the falling exchange rates (Woods, 2018 and AWEX, 2018), this is why the Australian wool price was not been affected in the same season (see Figure 7.12).

According to Woods (2018), there was a global decrease in wool demand, which started towards the end of 2011 picking up towards the end of 2013 to 2014. This is in line with earlier discoveries that the reduced profitability of wool resulted from the weakening demand of wool clothing as affected by rising interest rates, changing consumer tastes, increased general costs of living and relative prices of alternative and substitute fibres, constrained budgets which also forced consumers to rethink their spending priorities or opt for cheaper alternatives (Nolan and Gibbon, 2011). These then explain the low prices in SA and in Lesotho in 2012 and 2013.

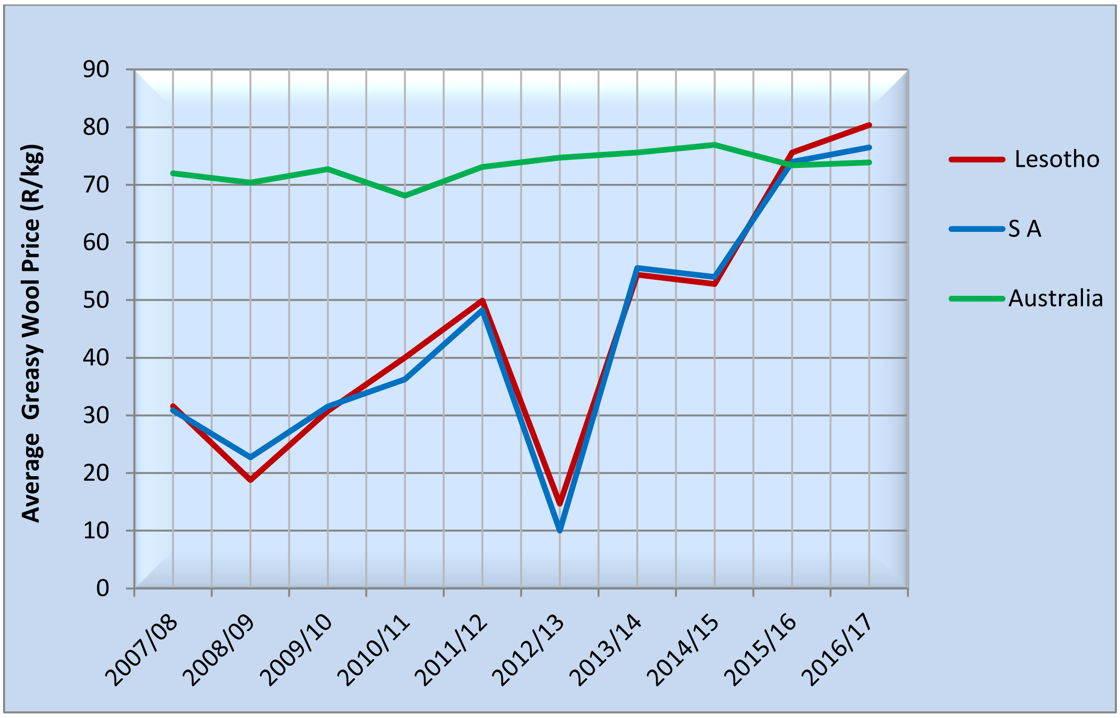


Figure 7.12: Average price(R/kg) of Lesotho, SA and Australia greasy wool over 10 years (Cape Wools South Africa, 2017)

Except for 2012/13, SA and Lesotho wool prices showed a general upward trend. Actually the average price increased over the 10 years period, except for the "dip" in 2012/2013. Comparing Figures 7.12 and 7.13 (market indicator), it is apparent that Lesotho and SA price increased in a steeper slope than the market indicator while Australia is completely above the average market price. Australia produces a lot more wool than South Africa and Lesoth and sell to the same importers, this contributed to the low sales on the wool offered in the season where the dip is noticed (Capewools, 2017). Market indicators are series of technical measures used to predict the direction of financial indices based on several analyses. The present indication is that the future of wool market is promising.

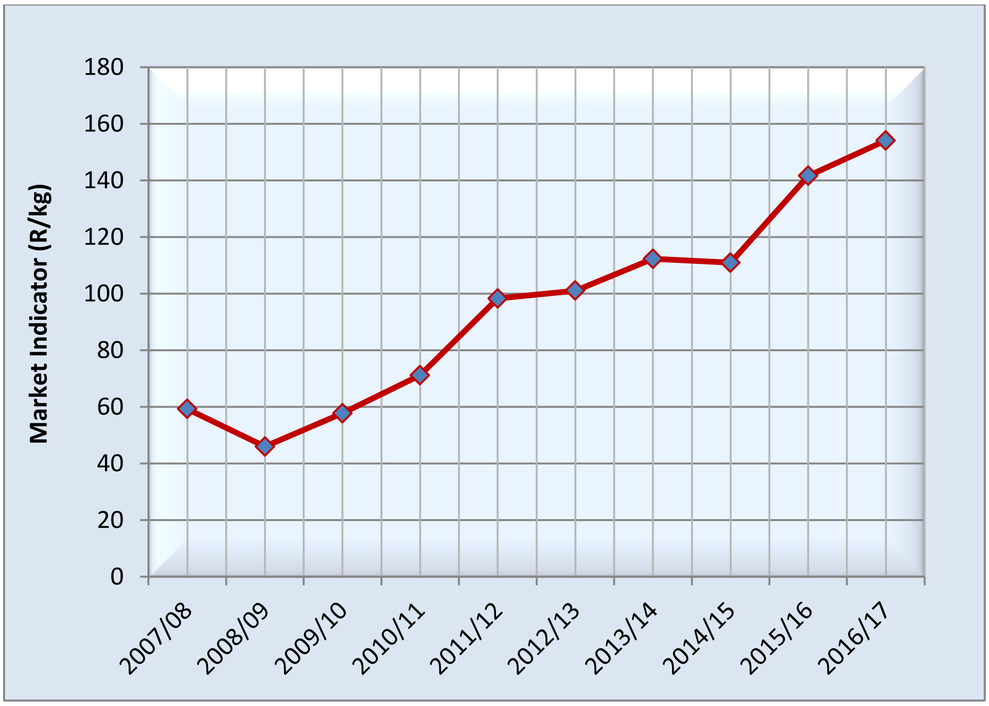


Figure 7.13: Global Market Indicator from 2007/08 to 2016/17 (*BKB, 2017 and Cape Wool, 2017)*

7.2.5 SENSORY EVALUATION RESULTS

7.2.5.1 Introduction

As discussed under Experimental, the respondents (i.e. the sensory panel) evaluated and ranked the wool samples (sleeves) according to their softness, prickle, appeal and other preferences. Results on the measurements of the above attributes are presented in this chapter section, however, only the prickle results are discussed at length in this section, it being the quality property around which the other measured attributes revolve, also the fact that it is the main focus of this study.

Table 7.1 shows the main characteristics of the samples evaluated for prickle by the sensory panellists. The prickle scores, in the last column in Table 7.1, represent the number of participating panellists who reported a prickle sensation for a particular sleeve (fabric) sample. The scores reported in Table 7.1 represent the total number of panellists who reported moderate, strong and very strong prickle for each sleeve sample. As already stated under Experimental, the seven point Hedonic scale (Likert type), used for ranking the samples had three levels on either side of the middle/neutral point. The low value of this score interprets low levels of prickle.

Table 7.1: Characteristics of sensory evaluation samples and prickle results

Samples	Mean Fibre Diameter (µm)	Comfort Factor (%)	Number of panellists and extent of prickle reported			Prickle score (n=24)*	Average weighted prickle score (%)
			Moderate Prickle	*Strong & Very Strong Prickle*	*Extremely Strong Prickle*	*Total*	
1.	19.3	98.1	1	2	0	3	12.5
2.	20.3	97.3	3	1	0	4	16.6
3.	18.2	98.9	1	2	0	3	12.5
4.	20.5	97.1	3	1	1	5	20.8
5.	18.2	99.6	1	0	0	1	4.1
6.	17.3	98.9	3	2	1	6	25
7.	20.5	97.1	2	2	1	5	20.8
8.	18.1	98.1	2	1	1	4	16.6
9.	21.7	95.5	4	5	4	13	54.2
10.	21.6	94.5	9	6	3	18	75
11.	21.1	95.2	8	7	2	17	70.8
12.	22.2	94.4	3	12	4	19	79.1
13.	21.5	93.2	4	9	7	20	83.3
14.	19.1	98.6	1	1	0	2	8.3
15.	16.9	99.4	0	1	0	1	4.1
16.	20.1	97.9	2	3	1	6	25
17.	19.9	98.1	1	3	1	5	20.8
18.	20.7	96.9	5	4	2	11	45.8

*The Prickle score: *this represents the number of panellists who reported a sense of prickle for a particular sleeve sample (out of total number of 24 panellists).*

The levels of prickle sensed by respondents are tabulated in the three middle columns. Ratings 4, 5, 6 and 7 are listed in Table 7.1, while ratings 1, 2 and 3 are not here since they represent a virtual absence of prickle sensation. Sample 5 had the lowest prickle score and 13 the highest (Table 7.1). Sample 5, with a CF of 99.6 % and MFD of 18.2 µm, only 1 respondent out of the 24 who reported a "moderate" prickle experience for the sample. The remaining 23 respondents either reported no prickle, very slight prickle or slight prickle.

Sample 13, with a CF of 93.2 % and an MFD of 21.5 µm had 20 respondents out of 24 reporting moderate or more severe prickle.

The relationship between Mean Fibre Diameter (MFD) and Comfort Factor (CF) for the wools used for the prickle evaluation is illustrated in Figure 7.14. Clearly, there is, and as expected, a good relationship between MFD and CF, this also reported by many earlier researchers (Naebe et al., 2013; McGregor and Naebe, 2013 and Malau-Aduli and Akuoch, 2013). Many researchers (Garnsworthy, 1988; Naylor 1992; Naylor et al., 1997; Miao et al., 2002; Gehui, 2003; Yuqing, 2004 and Jiang et al., 2007) have shown the link between prickle and fibre diameter and, more specifically, the coarse fibre content (Coarse Edge). The Mean Fibre Diameter (MFD) generally provides a fair indication of coarse edge (Comfort Factor), particularly if used in combination with the standard deviation or coefficient of variation (CV) of diameter (Naylor, 1992, De Boos, et al., 2001, and Botha, 2005).

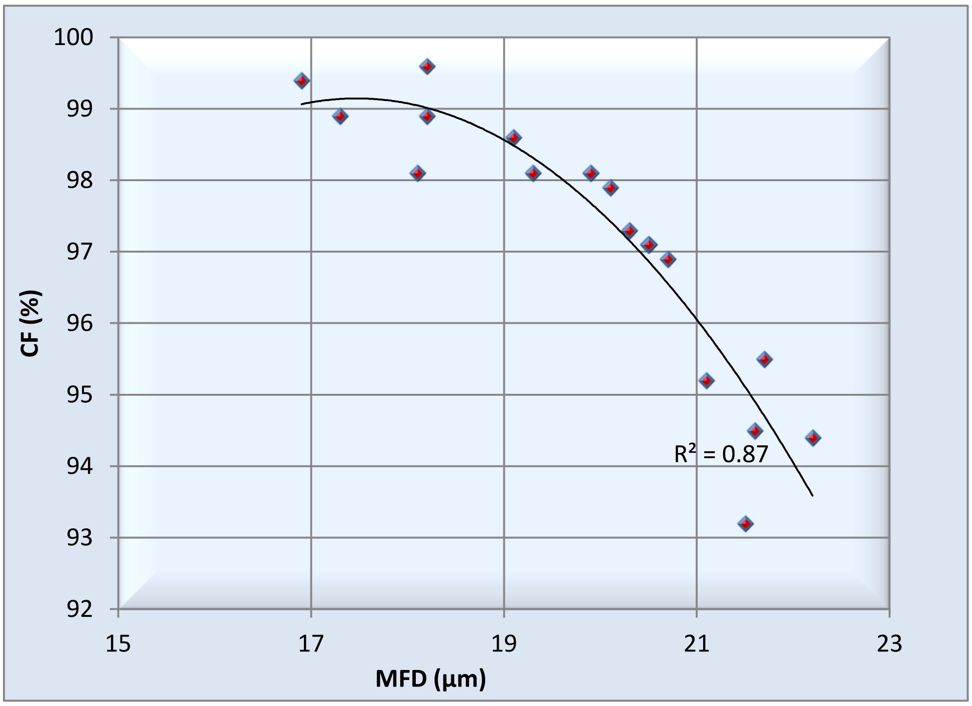


Figure 7.14: Relationship between Comfort Factor (CF) and Mean Fibre Diameter (MFD) for wools used for prickle evaluation.

The following regression equation was obtained for the 18 wool samples studied here**;**

CF = $-0.25MFD^2 + 8.68MFD + 23.3$)

The high correlation ($R^2 = 0.87$), is indicative of a close relation between CF and MFD.

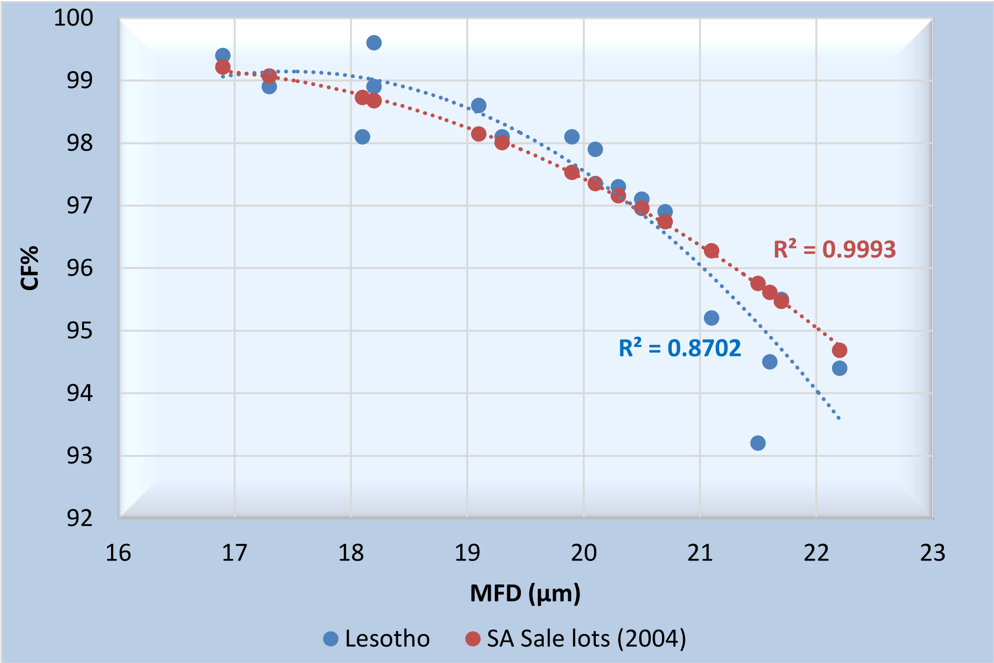


Figure 7.15: Relationship between CF and MFD for Lesotho and SA wool (Botha, 2004)

$y = -0.25x^2 + 8.68x + 23.3$ $R^2 = 0.870$ (*Lesotho*)

$y = -0.12x^2 + 4.05x + 66.4$ $R^2 = 0.999$ (*SA*)

In Figure 7.15 the results and regression being obtained for the Lesotho wool samples are plotted as well as the regression line obtained from Botha (2004), for SA wool. It can be seen that there is generally good agreement between the two sets of lines up to about 20µm. After this the Lesotho wool appeared to have a lower CF for the same MFD above, indicating that about 20 µm of Lesotho wool could be more prickly than the same diameter SA wools. This therefore, is largely a genetic (breeding) matter, since the implications are that Lesotho wools are more variable, i.e. less uniform, in diameter than SA wools.

7.2.5.2 Prickle results

The results of the subjective prickle assessment are in line with previous research findings that prickle is primarily caused by the presence of a critical number of coarse fibres i.e. coarser than 30 µm (Naylor, 2000 and Naylor and Phillips, 1997). In addition the length of the protruding fibre also plays a major role in evoking the prickle sensation (Asad et al., 2015 and Vetharaniam,et al., 2018).

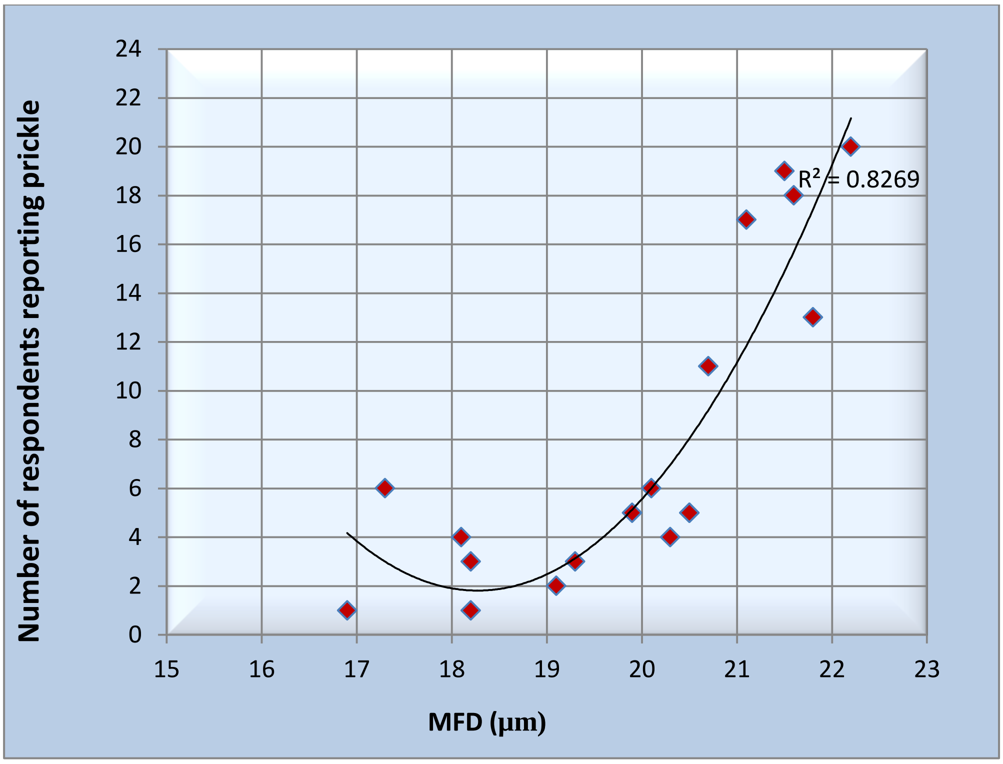


Figure 7.16: Prickle score vs MFD

In Figure 7.16 the prickle score is plotted against the MFD, and as it could be expected, there is a fair correlation between the two, since the percentage of coarse fibres (>30 µm) and Comfort Factor are related to the MFD (Naylor, 1992; Botha, 2004; Naebe et al., 2013 and Naylor et al., 2014). Nevertheless, the correlation is significantly lower ($R^2 \approx 0.6744$), than that for the CF, which is as expected since, in addition to MFD, the diameter distribution (SD and CV) play a role in determining the level of coarse fibre (CE).

In Figure 7.17, the number of respondents reporting a prickle sensation (response) for a particular sleeve sample has been plotted against the Comfort Factor of the wool used to produce the sleeve. From this figure it is apparent that there is a fairly good correlation between the two parameters, a higher CF being associated with lowest prickle, as assessed by the respondents, which is in line with the findings of other researchers (Naylor, 1992, Ramsay et al., 2012; Asad et al., 2016; Mahar et al., 2013; McGregor et al., 2015 and SGS, 2011). It confirms that the calculated CF can be used as a fairly accurate measure of prickle as experimented in practice (CSIRO, 1994).

Having used manual scouring and spinning made seem to have influenced the prickle results reported by the panellists. For instance the removal of all impurities including VM from greasy wool manually could not be standardised and thorough. In addition, manual spinning was also not standard. The tension of the twist for each sample may have not been the same as well as the density of the fibres spun together. This was indicated by the differences in the calculated yarn linear density (Tex) shown in the previous chapter. It is to be expected therefore that some knitted sleeves made from fine wool still registered prickle. This shortcoming in this section of the results indicates the value of standardised scouring and spinning when similar tests are conducted.

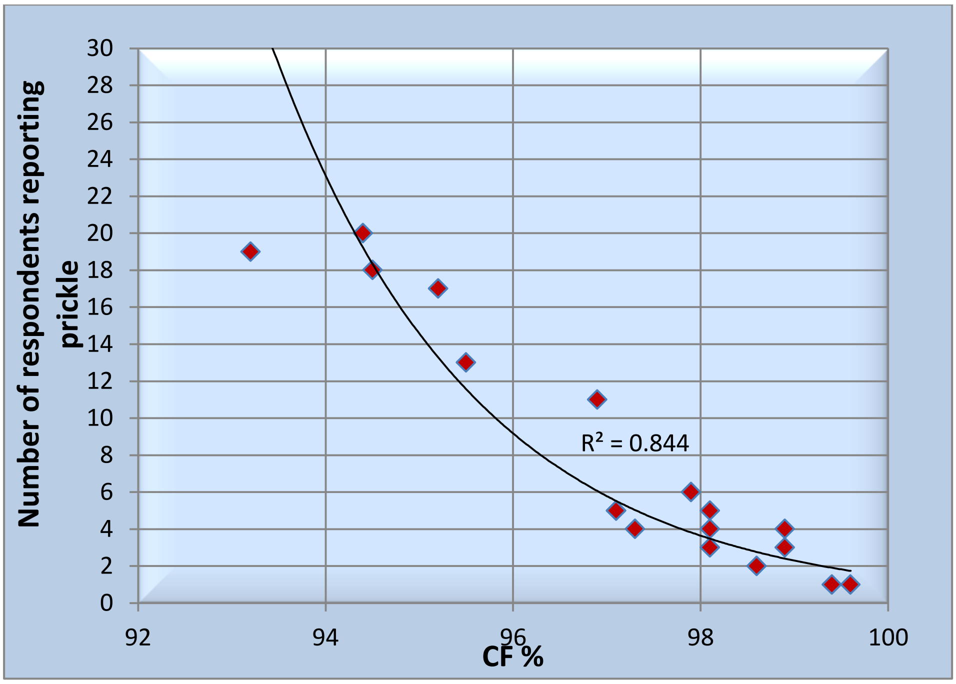


Figure 7.17: Number of respondents experiencing prickle sensation vs Comfort Factor (CF)

Since it is calculated from the MFD, the number of panellists reporting prickle was found to respond, as expected to the value of CF. the higher the CF value the less the number of panellist reported prickle on such samples. High values of Comfort Factor are expected to be an indication of preferred comfort (lack of prickle). In addition to prickle hand, appeal and preference of the participants regarding the wool samples were evaluated through sensory evaluation. Figure 7.18 shows the results on these attributes.

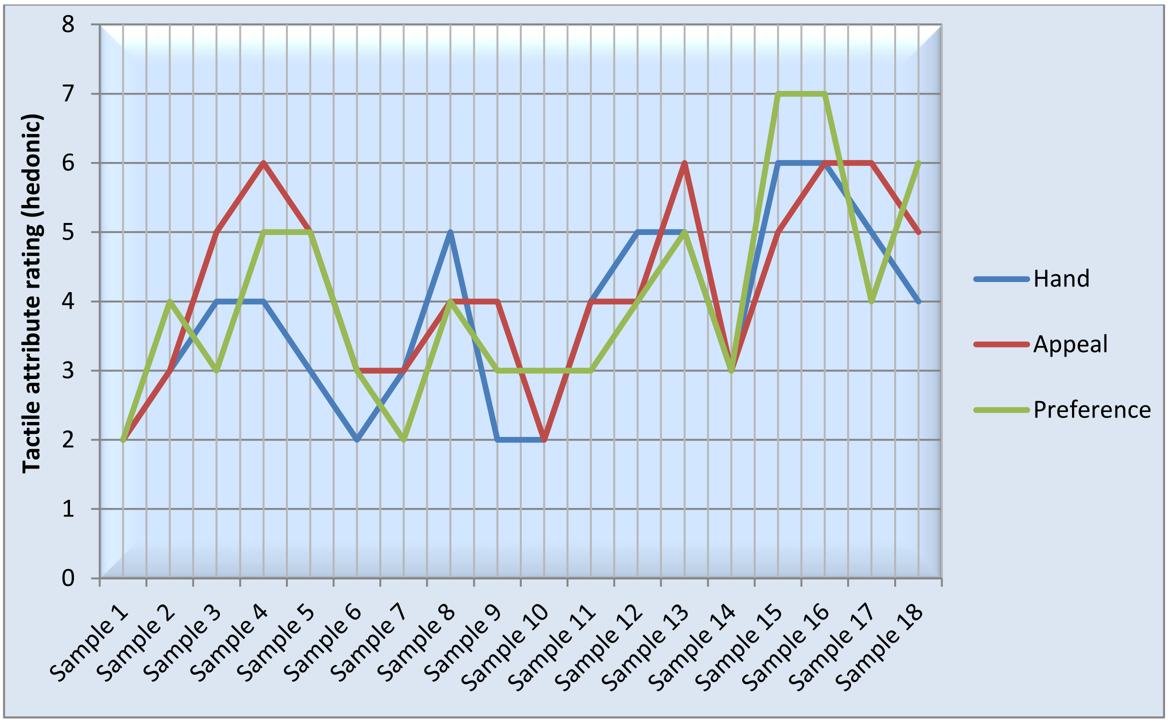


Figure 7.18: Other comfort and preference attributes on Lesotho wool

The softness; referred to as hand in Figure 7.18, appeal and preference as seen in above indicate a relatively close relationship though variations can also be noticed. These variations are a result of manual processing of samples by local weavers in Lesotho. The subjective assessment could have also played a role in the variation since the participant's age ranges and gender also varies. This is believed to have a certain influence to levels of sensitivity of the skin as a sensory organ (Dhand and Aminoff, 2015).

7.3 MOHAIR RESULTS

7.3.1 Introduction

This section presents and discusses trends in Lesotho mohair in terms of production, fibre diameter, staple length or medullation, as well as sales value, for the period 2005/2006 to 2014/2015. Due to changes in auctioning procedures, the 2015/2016 and 2016/2017 data are not available. Table 7.2 presents general information about the Lesotho mohair clip.

Table 7.2: Lesotho Mohair Clip Details (BKB, 2015)

Shearing Season	Mean fibre diameter (µm)	Average clean yield (%)	Average staple length (mm)	Average greasy price (R/kg)
2005/2006	29.6	78	141	43.10
2006/2007	29.2	79	139	49.60
2007/2008	29.5	84	136	35.58
2008/2009	29.5	83	133	30.30
2009/2010	29.6	78	134	39.77
2010/2011	29.7	73	138	50.43
2011/2012	29.8	74	136	51.34
2012/2013	29.5	81	132	51.73
2013/2014	29.3	80	134	74.93
2014/2015	29.7	80	146	130.02
Standard Dev.	***0.24***	***3.41***	***3.75***	***26.98***

(*There have been major changes in the trading of Lesotho mohair since 2015/2016. As a result of these changes, reliable data after the stated seasons could not be obtained)

7.3.2 Mohair Production Trends

The number of Angora goats and mohair production in Lesotho fluctuated over the 10 year period, being at its lowest in 2005/06 due to a serious drought experienced in 2005/2006 (Lesotho Meteorology Services, 2017), hereafter, both the number of goats and mohair production tended to show an annual increase, though not consistently until around 2013/2014, after which there was a slight increase (see Figure 7.19).

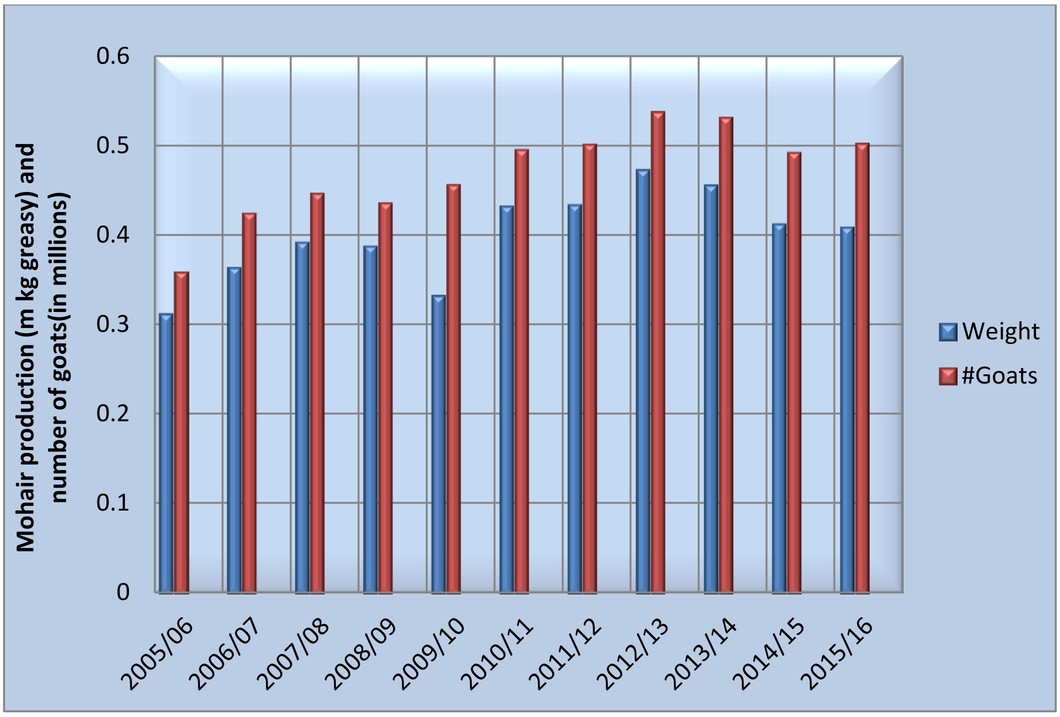


Figure 7.19: Lesotho average greasy mohair production (weight) and number of goats

In Figure 7.20, mohair production in Lesotho is compared with that in South Africa and Australia. Of the three countries, SA has the highest mohair production and Lesotho the second highest.

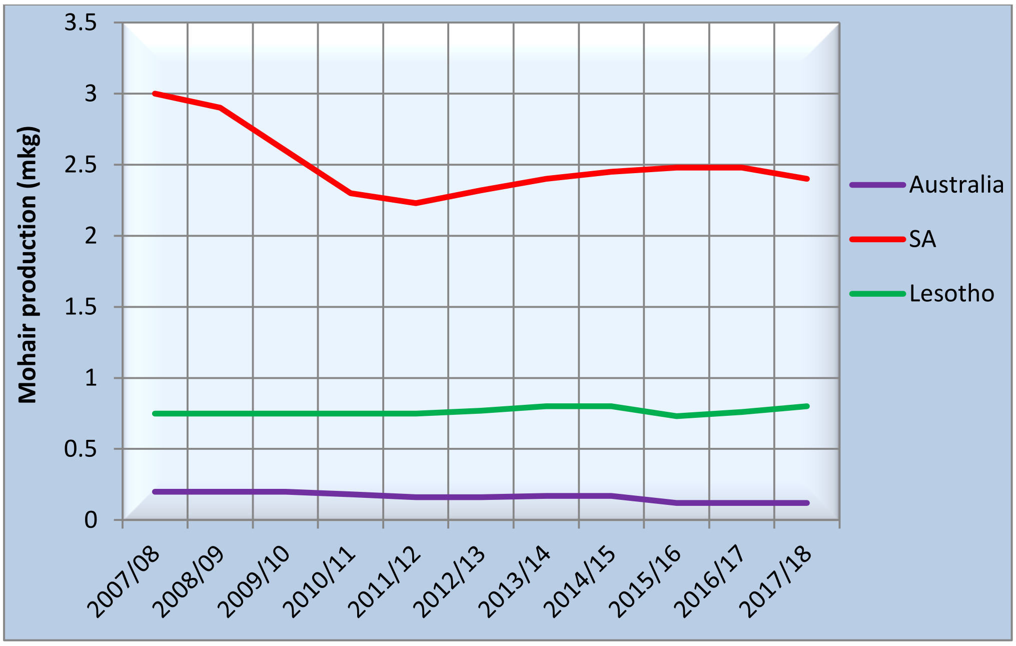


Figure 7.20: Lesotho South Africa and Australia greasy mohair production

Mohair producers in Lesotho have been working on improving their farm including breeding practices so as to improve their flock and mohair fibre quality (Alotsi, 2017). The highest production of mohair was in 2012/13, when the number of goats was also the highest for the ten year period (2005/06 to 2014/15). Increasing the number of goats may, however, not be the most suitable means of increasing mohair production, since an increase in animal stock could result in the degradation of the communal rangelands (Phororo, 1979). Another challenge in this respect is that a number of Lesotho farmers are faced with a serious stock theft problem (Mokheti, 2016). Nevertheless, a very positive development was when the Lesotho government introduced the wool and mohair promotion project in 2014. This project targeted the small scale wool and mohair producers; the education offered through this project is believed to have contributed to the positive change in mohair production and on the number of goats since then (IFAD, 2014).

Notwithstanding the positive efforts by the farmers themselves and the Lesotho government, there are still some factors constraining mohair production, including the high mortality rate of young animals as a result of some chronic diseases, the unhygienic kraals, the long distances some farmers have to walk with their flocks to the shearing sheds, stock theft and the extreme climatic conditions in the highlands. The latter is particularly important, since most sheep and goats are found in the highland due to the favourable agricultural conditions for extensive small stock production there (Mokhethi, 2016). One of the benefits the wool and mohair promotion project brought for the Lesotho farmers was the establishment of a veterinary hospital and educational material covering improved wool and mohair production strategies (Heqoa, 2018). The impact of these is expected to bear fruit over time.

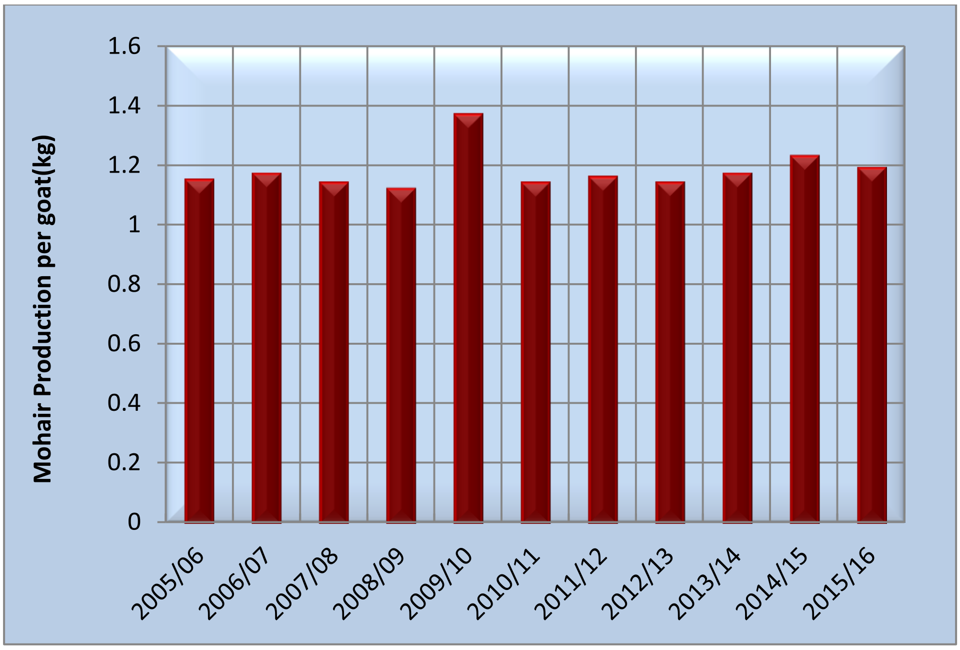


Figure 7.21: Lesotho mohair production per goat

Figure 7.21 shows that, with the exception of 2009/10, mohair production per goat remained virtually constant (between 1.15 and 1.2kg/goat), there being only slight fluctuations during the 10years (2005/06 to 2015/16). In 2009/10 there was a large increase in mohair production per goat. This may be related to the transition from the dry seasons experienced by Southern Africa from a period beginning 2004/05 until 2009/10. There were some good rains in the years that followed, but the changes were not dramatic, and previous studies conducted on Lesotho mohair production indicated only a weak correlation between rainfall and mohair production (Ng'ambi et al., 2009), in this particular case, the change in production was also very sudden and once only. Clearly, there are other factors contributing to mohair production per goat, the most important being nutritional and stress levels which are dependent upon rainfall distribution and interventions by the farmer in the form of supplementary feed as well as the climate (Eckert and Nobe, 1982 and De Waal, 1994).

7.3.3 Mohair Quality

7.3.3.1 Fibre Diameter (Fineness)

Mohair quality and price generally bear a close relationship with mohair fineness (mean fibre diameter), it is common knowledge that the finer the mohair, the better the quality and the higher the price, with mohair finer than 25/26 µm, generally much sought after and highly priced. According to McGregor (2000) mohair fibre should ideally be finer than 26 µm, which contrasts with Lesotho mohair where the lowest average MFD recorded over the 10 year period is 29.2 µm (see Figure 7.22). This is clearly an area which needs attention if Lesotho mohair is to improve in quality and price and also its position on the international market. McGregor et. al., (2012) found that mohair MFD has an allometric relationship with the cube root of live weight throughout the lifetime of the Angora goat. These two variables varied as the animals grew and after each shearing. McGregor (2010) predicted mohair MFD by using multiple regression analysis taking the average live weight for the period of fleece growth and other parameters into consideration. In their study, mohair MFD on average increased by 4.7 µm per 10 kg average fleece-free live weight of the Angora goat, they further observed that fleece free live weight alone accounted for some 76 % of the variation in mohair MFD. The fineness of the Lesotho mohair is negatively affected by the shearing only in the later stage of the goats' lives and continues well into the adult age of the goats. It is therefore important to investigate whether the relatively high average MFD of Lesotho mohair is due to the age of the goats or to the nature of the Angora goat flocks and what the role of climatic and agricultural condition is in this regard.

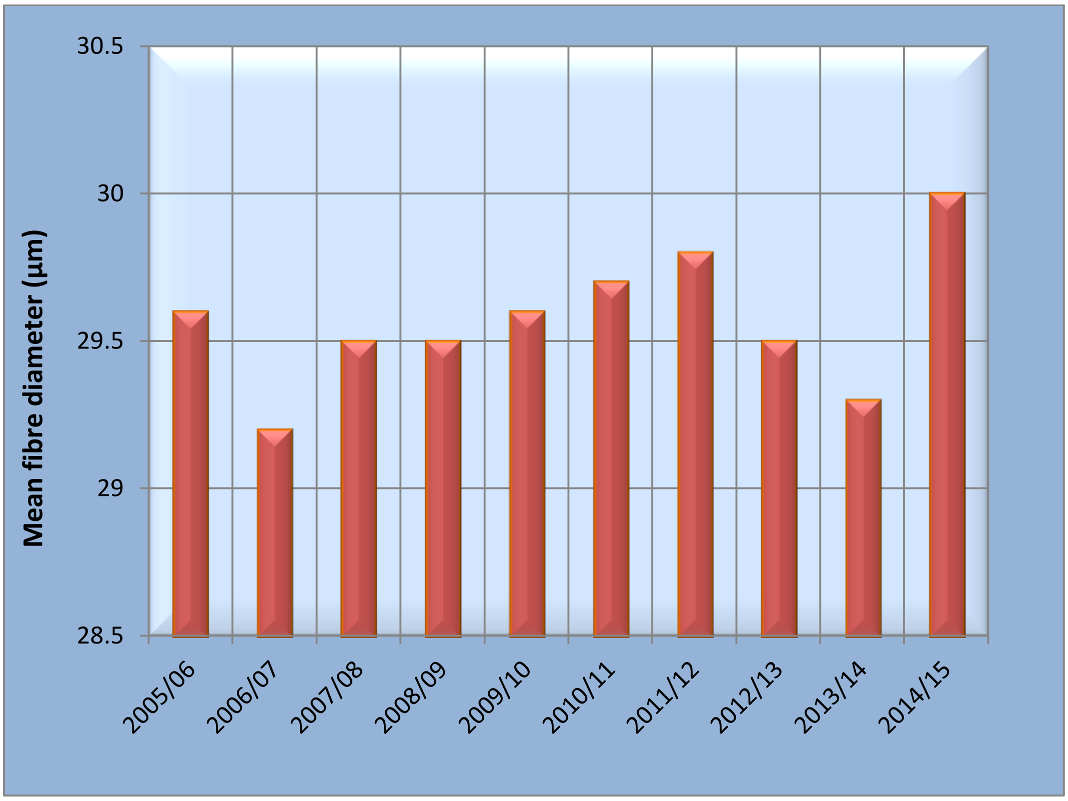


Figure 7.22 Average mean fibre diameter (MFD) of Lesotho mohair

The average fibre diameter of Lesotho mohair falls within the Young Goat category which generally ranges from about 29 µm to 30 µm (NAMC, 2012). The finest mohair on average (29 µm) was produced in 2006/07 and the coarsest on average (30 µm) in 2014/15, the latter being attributed to good grazing. According to Hunter (1993), increased nutrition generally increases fibre diameter and fleece mass. The disadvantage, however, is that unlike South Africa, Lesotho mohair is not classified according to the age of the goat when shorn. Nevertheless, the once a year, the first taking place anything from 8months after birth of the kid, shearing practice in Lesotho makes it uncommon to find kid goats being shorn in the shearing sheds of Lesotho (Alotsi, 2017). But in South Africa, the first shearing is after some 6 months in summer and again after the next 6months (i.e. ≈ 1 year after birth) in winter. Due to the late shearing of goats and climate conditions, adult Goats are shorn in shearing sheds. However, there has not been an average annual MFD higher than 33 µm recorded in the ten years of this study; possibly contributed also related to the poor nutrition (Hunter, 1993). The seemingly fine mohair fibres are not necessarily of the high quality sought after, the strength of these is questionable.

7.3.3.2 Staple length

Staple length plays an important role in determining the price of mohair, any length equal or greater than 75 mm tending to attract the highest prices (McGregor, 2000). Figure 7.23 shows that the average staple length fluctuated significantly from year to year, possibly due to fluctuating periods between the shearing times. Generally, acceptable staple length ranges from about 70 mm to 200 mm, Lesotho's average being about 140 mm, which is leaning towards the long end of the range (Mohair SA, 2017). Lesotho mohair can therefore be classified as long. While annual shearing as opposed to biannually is a disadvantage, in terms of the mohair fineness for the first year; as far as the staple length is concerned, it is an advantage.

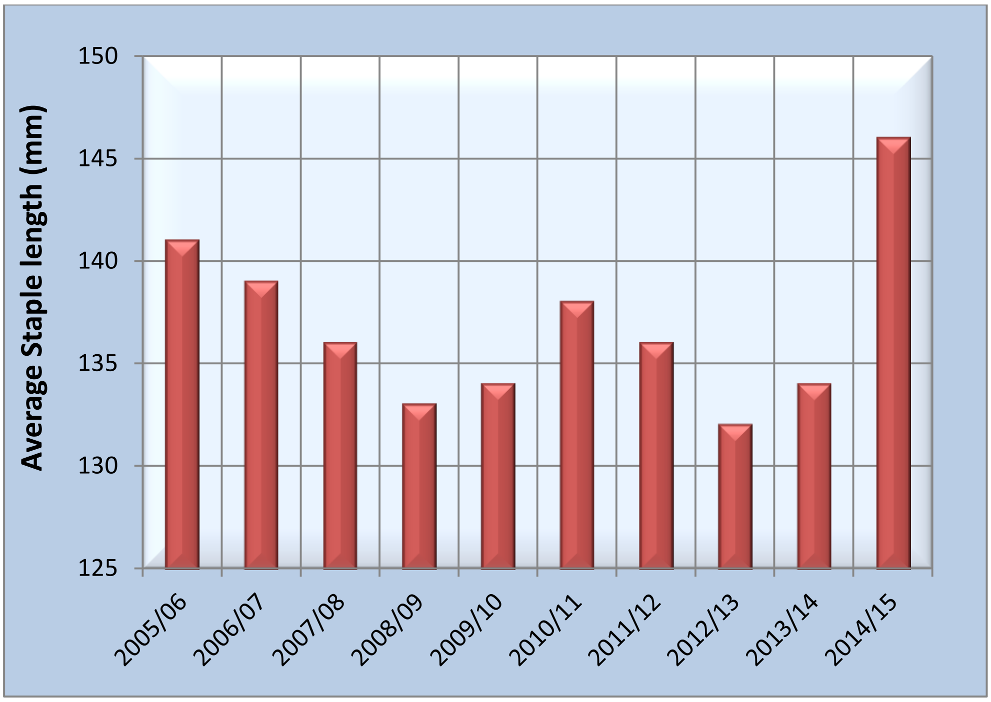


Figure 7.23 Average staple length of Lesotho mohair

7.3.4 Lesotho Mohair Price Trends

The sale price (R/kg), of Lesotho greasy mohair is shown in Figure 7.24, from which it is apparent that the price increased rather steeply after 2012/2013. This was due to a general market improvement.

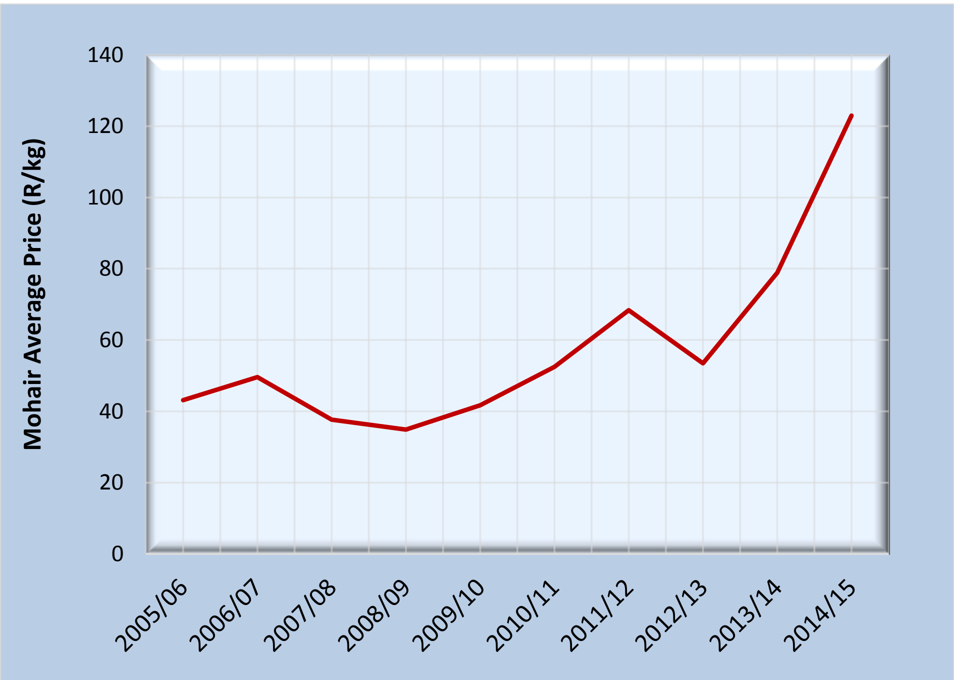


Figure 7.24: Average price of Lesotho Mohair

7.3.5 Medullation Results

The presence of medullated fibres in mohair, particularly the objectionable medullated (kemp) type, lowers its quality and price a great deal. Generally only about 0.1 % or less of objectionable medullated (kemp) fibres qualifies mohair for a high quality and consequently attracts a high price; any levels higher than this fail to attract maximum prices for the fleece (McGregor, 2000).

According to the results obtained from the assessment, the average levels of medullated fibres in the Lesotho mohair clip were found to range from above 1.9 % to 8.8 %, this is high and far above the level of 0.1 % for good quality mohair. As can be seen from Figure 7.25, the total number of medullated fibres expressed as a percentage, generally followed a normal frequency distribution.

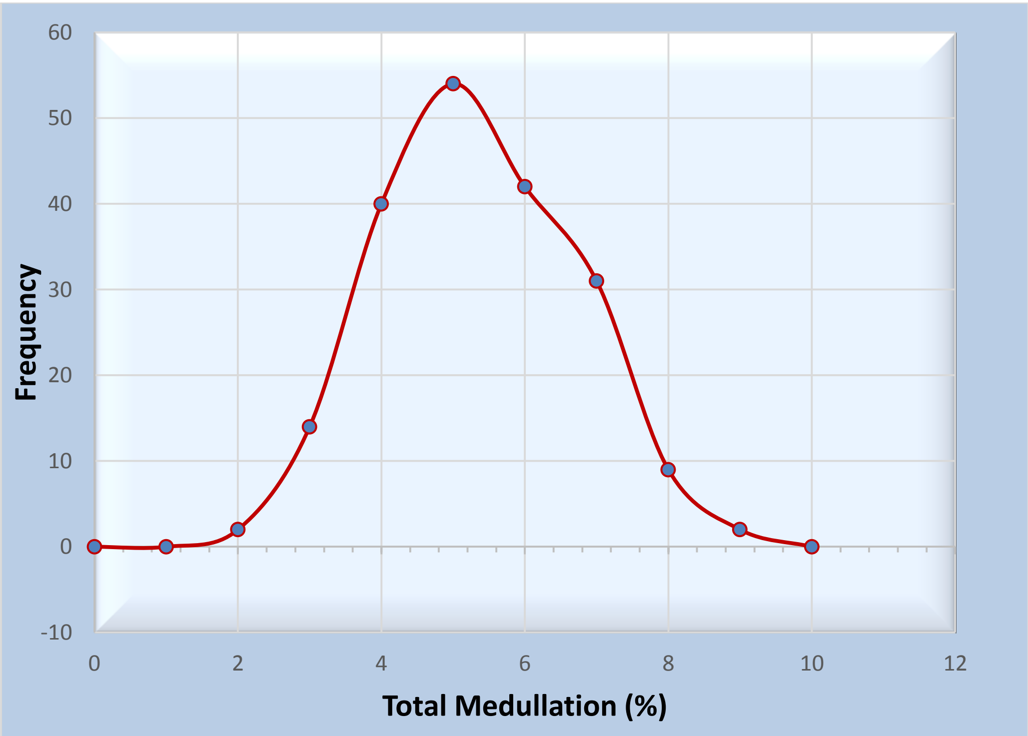


Figure 7.25: Percentage of total Medullated fibres

Even though Lesotho mohair is not categorised according to the age of the goats, the relatively older age of goats shorn in Lesotho contribute to the increase in mean fibre diameter, and McGregor et al., (2013) associate the fibre diameter with medullation level since it usually occurs in fibres coarser than 21 µm. This will be evident in the first year of shearing (first year) for objectionable medullated (kemp type) fibres.

Since the existence of medullated fibres in general is more common in poorly bred Angora goats, poor breeding (i.e. genetics) is most likely the reason for the relatively high total number of medullated fibres in Lesotho mohair. Primitive goat breeds usually have relatively high levels of total number of medullated fibres (Roberts, 1927). The indigenous goats in Lesotho, with short straight hair (Uys, 1970), became diluted by Angora goats, believed to have crossed into Lesotho around 1904, although there was not a systematic importation of improved Angora goats and breeding program at the time (Mafisa, 1993).

It is therefore clear that, proper breeding is vital for the improvement of Lesotho mohair for the global market, presently some farmers are already sourcing Angora bucks from South Africa with the assistance of BKB. It is hoped that the vigorous educational campaigns and proposed local improved breeding of sheep and goats initiated by the promotion project; will decrease the levels and frequencies of medullation in Lesotho mohair.

Certain studies had associated medullation levels with nutritional levels; for example, Nixon et al., (1991) reported that Angora goats fed with high levels of nutrition had higher levels of medullated fibres. Nevertheless, these results have since been reviewed and Lupton et al., (1992) concluded that the level of medullation is not directly associated with, or affected by, nutrient supply. The incidence of medullation is known to be phenotypically and genetically related to the size of the animal (Nicoll et al., 1989; McGregor, 2010, Bolormaa et al., 2010 and McGregor et al., 2013). Most Lesotho farmers depend on the natural pastures and vegetation to feed their goats, while most farmers in SA and other developed countries supply some feeding supplements for their animals, and sometimes also keep them in barns. Without controlled nutrition, Lesotho Angora goats are at a disadvantage. As discovered and reported by several authors (Bassett, 1986; Maddocks and Jackson, 1988; Scobie and Woods, 1992; Bray. 2004 and Galbraith, 2010), the development of both the primary and the secondary follicles determine whether the fibres will be medullated or not. There are a number of contributing factors to the development of follicles. Details of follicle development can be read in Chapter 4.

7.3.5.1. Objectionable medullated fibres in Lesotho mohair

The results show (Figure 7.26) that the number of objectionable medullated (kemp style) fibres (range between 61 -70 and 121 – 130 fibres per sample 4,000 fibres), is normally distributed. For example in one of the samples there were 417 objectionable medullated fibres i.e.10.4 % of the fibre snippets were "objectionable" which is extremely high. The frequency in Figure 7.26 indicates the number of samples (times) in which the objectionable medullated fibres were found in the indicated numbers. For instance seventy five (75) objectionable medullated fibres were found in sixteen (16) samples

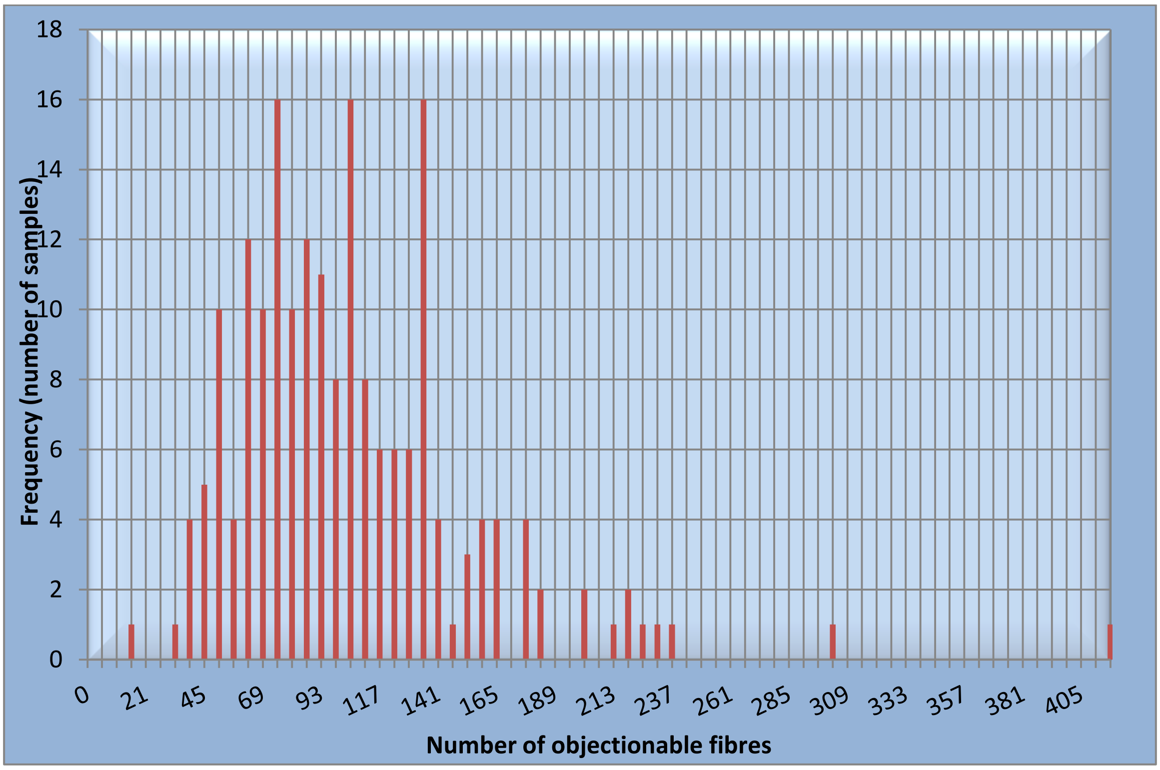


Figure 7.26: Frequency distribution of the number of objectionable medullated fibres

7.3.5.2 Flat medullated fibre levels

Generally, there are significant numbers of flat medullated fibres in the 2012 mohair clip (see Figure 7.27). The flat medullated fibres represent an extreme form of medullation and are nearly always unacceptable (i.e. objectionable). The most effective way to reduce medullation in general (objectionable, flat and medullated fibres) is selective breeding (Hunter, 2010).

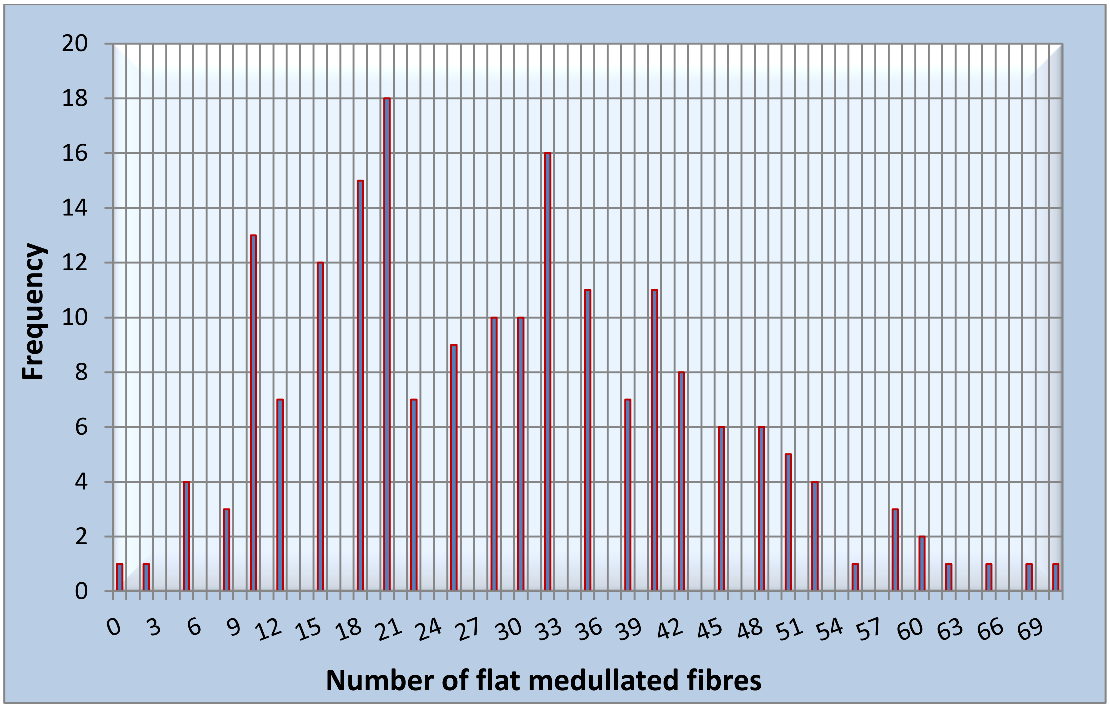


Figure 7.27: Frequency of flat medullated fibres per 4000 snippets

7.3.5.3 Interrelations between mohair tested attributes

The various parameters measured with the OFDA are showing the form of correlation matrix in Table 7.3, (a Pearson's correlation matrix), the highlighted values indicating correlations significant at 95%th level of confidence.

Table 7.3: Pearson's Correlation matrix

	Objectionable	*Flat*	*MFD(µm)*	*CV%*	*Curvature*	*Opacity*	*Med*	*Med MFD*
Objectionable	1							
Flat	0.039	1.000						
MFD	0.007	-0.087	1.000					
CV	0.761	0.010	0.065	1.000				
Curve	0.153	0.142	-0.680	0.160	1.000			
Opacity	0.299	-0.004	0.076	0.267	-0.257	1.000		
Med	0.549	0.027	0.037	0.418	-0.168	0.867	1.000	
Med MFD	0.446	-0.108	0.547	0.623	-0.120	-0.219	-0.118	1

the cerise pink cells indicate significant correlations (at 95 % level of confidence)

7.3.5.3.1 Mean fibre diameter (MFD) vs the number of medullated fibres

There is not a significant correlation between MFD and total number of medullated fibres (0.037, in Table 7.3). There, however, is a significant correlation between total number of medullated fibres and the CV of fibre diameter (FDCV), confirming that the more variable the fibre diameter is, the greater the probability of medullation, this was also observed by other researchers (Hunter et al., 2013 and Balasingam and Mahar, 2005). When working on French Angora goats, Allain and Roguet (2006) found that the incident of medullation was higher in goats with a higher FDCV.

7.3.5.3.2 Objectionable fibres vs coefficient of variation (CV%)

There is a fairly strong correlation (R^2 = 5015) between CV% and the number of objectionable medullated fibres, as illustrated in Figure 7.28, the number of objectionable medullated fibres increasing with increasing CV%, as expected. This confirms the results obtained by other researchers and indicates that breeding practices aimed at reducing objectionable (kemp type) medullated fibres will also result in reducing fibre diameter coefficient of variation (CV) and vice versa.

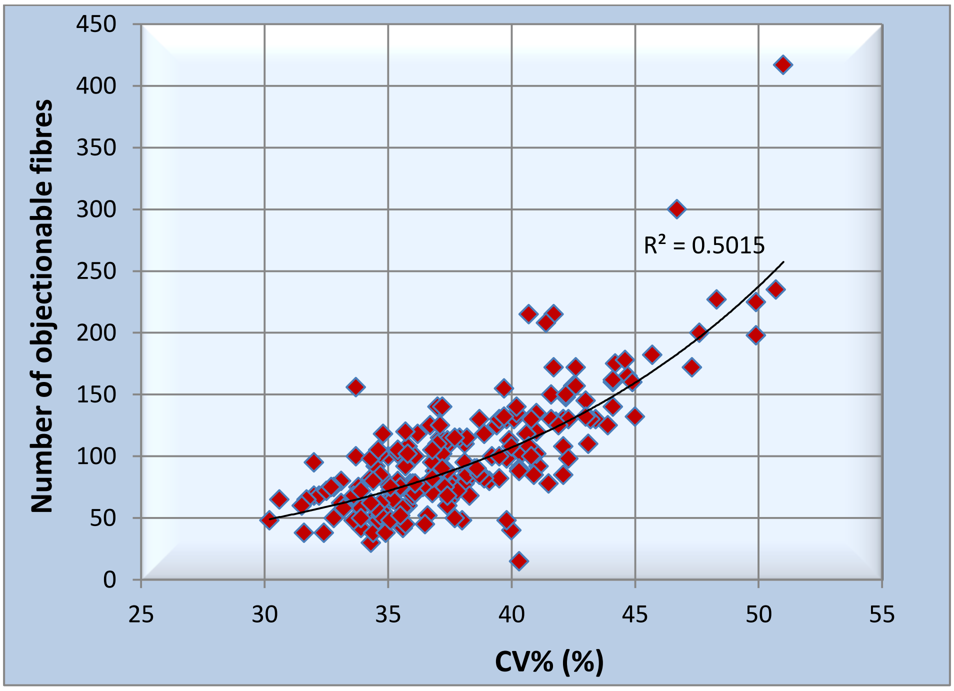


Figure 7.28 The correlation between the number of objectionable medullated fibres and fibre diameter CV%

Clearly therefore, producing a more uniform and less variable fibre diameter will produce a better quality mohair with fewer objectionable medullated fibres generally (McGregor and Butler, 2004). On farm assessment of mohair quality has proved to be helpful in this regard; even if it is subjective/visual (van der Westhuysen et al., 1988 and Clancy, 2005).

7.3.5.3.3 Number of objectionable medullated fibres vs total number of medullated fibres

Table 7.3 and Figure 7.29 show that there is a low, though statistically significant positive correlation between the number of objectionable medullated fibres and the total number of medullated fibres in general. It follows that the more medullated the sample, the more likely the incidence of objectionable medullated fibres, although the correlation is not all that high i.e. it cannot be accurately predicted from these results alone

It must once again be emphasised that medullation and objectionable medullated fibres are largely genetically determined and can be reduced by selective breeding.

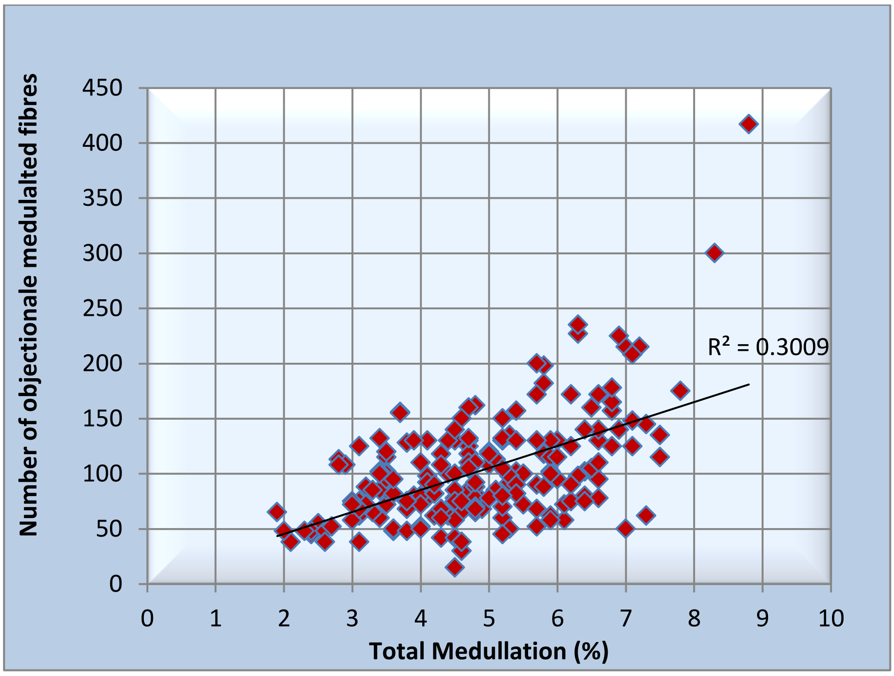


Figure 7.29: Relationship between the total number of medullated fibres vs objectionable medullated fibres

7.3.5.3.5 Population **MFD and Medullated MFD**

As could be expected, there is a correlation but not a very high one, between the diameter of the medullated fibres and that of the parent population (see Figure 7.30). This has also previously been observed (Lupton, 1990 and McGregor, 2013), medullated fibres tending to be coarser than the average non medullated fibres of the parent population.

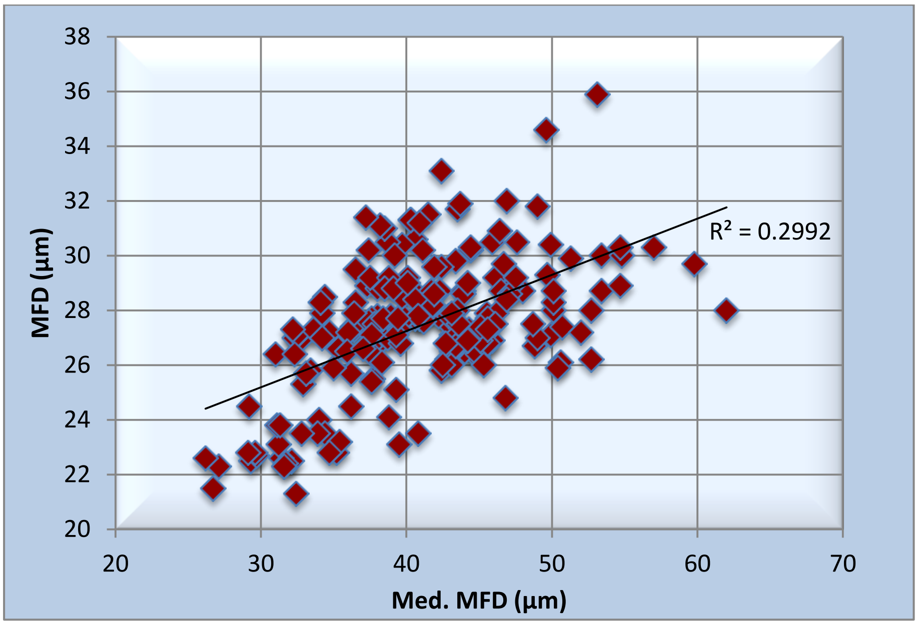


Figure 7.30: Correlation between MFD vs Medullation MFD

7.3.5.3.6 CV% of fibre diameter vs medullated fibre diameter

Figure 7.31 shows that, there is a significant correlation between the mean fibre diameter of the medullated fibres and the coefficient of variation (CV %) of the fibre diameter of the parent population.

These results are generally in line with the findings of previous researchers that medullated fibres usually coarser than the parent population and that the more variable the fibre diameter of the mohair sample is, the more likely it is to contain medullated fibres (Rafat et al., 2007 and Pinanes et al., 2018).

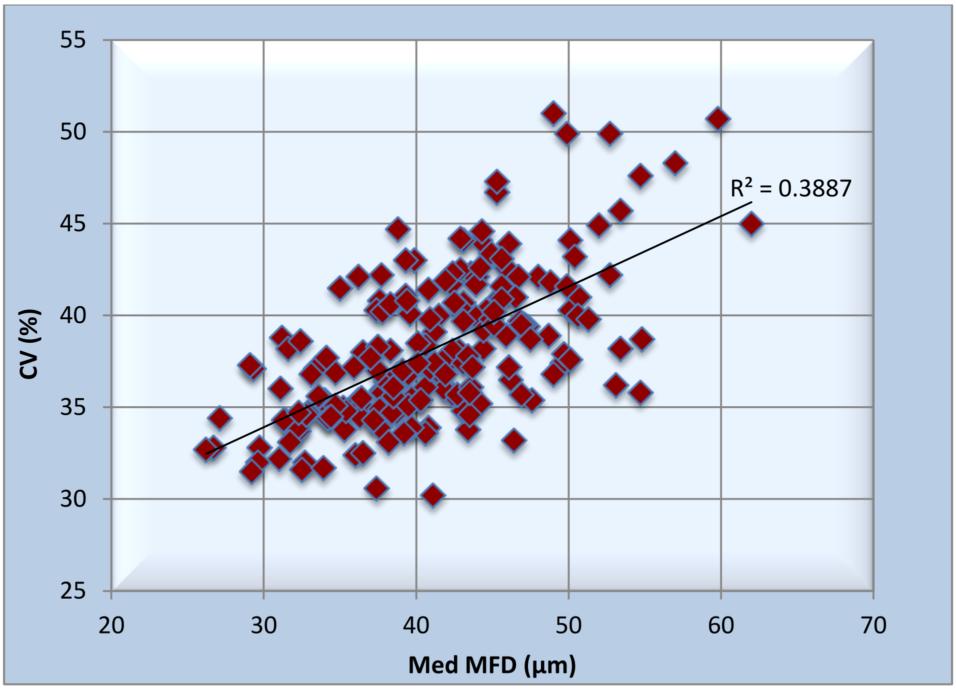


Figure 7.31: Relationship between MFD of the medullated fibres the CV% of the fibre diameter of the parent population.

CHAPTER 8
8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

8.1.1 General Observation

Mohair and wool represent two key agricultural products, contributing significantly towards Lesotho economy and employment and have the potential to contribute even more and to compete on the international market through appropriate marketing, fibre testing and production, quality monitoring, evaluation, data capturing and accessibility. There are, however, many gaps in terms of reliable and readily available data and information on Lesotho wool and mohair production and quality. This study has attempted to address these gaps, to the ultimate benefit of government, wool and mohair growers, buyers, processors, manufacturers, educators, researchers, entrepreneurs and product development.

Within this context, the accountability, updating, management and data generation of such data would need to be considered carefully. Furthermore, economic contribution of the two fibres to the local economy requires that proper policies be put into place and accounted for by a known office through an appropriate officer in collaboration with other relevant stakeholders. The ready and continuous availability of the appropriate wool and mohair data and information would play a key role in terms of improvements in production and quality, local beneficiation and market competitiveness among others. It is hoped that the results of this study and theses will stimulate the necessary initiatives and actions.

8.1.2 WOOL

It was found that production and quality of Lesotho wool are clearly influenced by the region where the sheep are farmed. Three districts, namely Mokhotlong, Thaba-Tseka and Maseru, which are largely situated in the highland region consistently, produced more and better quality wool than those districts situated in the lowland and foothill regions.

Wool production fluctuated greatly during the ten years covered, this being largely ascribed to fluctuations in climatic and associated conditions. Although the total number of sheep (≈1.2 million) stayed largely constant over the 10 year period, the greasy wool production increased from about 3 kg per sheep to about 6 kg per sheep. For example, in 2009/10 about 3 million kilograms of wool were produced by about 1.2 million sheep, while in 2016/17 just over 6 million kilograms were produced by the same number of sheep. This is ascribed to breeding and other improvements resulting from various agricultural projects aimed at enhancing wool and mohair production and quality, one example being the Small Agricultural and Development Project (SADP) introduced in 2012 has shown some positive results by 2016/17.

It was found that wool production was generally higher in the highland region, districts in the lowland and foothill regions tending to perform relatively poorly and also inconsistently. Two such districts (Mafeteng and Mohale's Hoek) were considered to be suitable for wool production, an aspect which requires further investigation.

Clean yield fluctuated slightly over the 10 year period without showing any long term trend, the overall average being about 58 % for the 10 year period, with the highland region producing a slightly higher yield than the lowland and foothill regions. The vegetable matter levels increase significantly after 2012/2013, with the lowland districts showing higher levels than those in the highlands, this being attributed to their higher rainfall leading to increased vegetation levels in this region.

The overall quality of the wool, on the basis of fibre diameter, staple length and VM level, did not change much over the 10 year period, except for a slight decrease in fibre diameter and an increase in VM as already mentioned. The wool price increased slightly from 2013/2014 and a very significant increase was observed from 2014/15 onwards.

Lesotho produces far less wool annually ($\approx 4 \times 10^6$ kg) than South Africa ($\approx 44 \times 10^6$ kg) and Australia ($\approx 360 \times 10^6$ kg), although the quality, particularly the fineness of its wool, is generally good and comparable to those produced in South Africa and Australia. The average mean fibre diameter (MFD) of Lesotho wool remained largely constant at ≈19.8 µm over the 10 year period, this being marginally lower than the ≈21 µm of South African and Australian wool the lower fineness of the diameter in Lesotho wool. No information on staple strength (soundness), important in processing, was available. It should be mentioned that this is certainly an area that needs to be addressed in future. The staple length of Lesotho wool is good (≈64 mm), comparing favourably with that of South Africa, although Lesotho sheep are shorn after 12 months and those in South Africa after 8 months wool. The average clean yield

(≈57 %) and vegetable matter levels (≈4 %) do not compare well with those of South Africa and Australian wool of ≈1 %. It was found that the wool production and quality vary significantly from district to district, this being attributed to agricultural and breeding practices and conditions.

It is recommended that a more in-depth investigation be undertaken to pinpoint more accurately the reasons for these differences and to establish current obstacles in the way of poorer performing districts which prevent better performance and how these can be removed or at the least be minimised. For example, is it merely a matter of breeding and or farm management practices which can be changed or is it due to climatic and agricultural conditions that cannot be changed? Also pastures in the lowlands and foothills are not as abundant as in the highland regions. Nevertheless, significant differences exist in quality and quantity of wool from different farmers, hence indicating a great potential for improvement through the correct breeding and farm practices.

According to the MFD values, and based on the sensory evaluation results, and Comfort Factor (CF) of Lesotho wool tested for prickle, it appears that some Lesotho wool may be suitable for next-to-skin clothing to a notable extent. It was found that the subjective assessment of prickle (forearm test) by the panel was related to the Coarse Edge (CE) / Comfort Factor (CF), confirming earlier studies.

8.1.3 MOHAIR

Globally Lesotho is the second biggest mohair producer after SA, although it's production of ≈ 0.8 m kg was much lower than that of South Africa (≈ 2.4 m kg) recorded in 2017 (NAMC, 2017). Changes in government policies from time to time can greatly influence the availability of and access to production and quality data as well as marketing in general. A general complication is that Lesotho mohair is not classified into distinct age categories e.g., Kids, Young Goats, Adults etc., as is the case with SA mohair. In addition, only two of the quality related properties of Lesotho mohair are presently measured; on a routine (trading) basis namely mean fibre diameter, and staple length, with no specific objective or subjective on farm assessment being done. There is, therefore, a need to extend the objective measurement of Lesotho mohair particularly in terms of yield and medullation.

The study showed that mohair production increased marginally over the 10 year period covered (2005/06 to 2014/15), from ≈ 0.75 million kg to ≈ 0.80 million kg. The increase mainly took place during the period from 2009/10 to 2013/14. Nevertheless, it appears that much can still be done in Angora goat flock management and breeding practices to improve production.

Because Angora goats are only shorn once annually in Lesotho against the twice annually in South Africa, the average staple length (of 140 mm), is much higher than that (80 mm) of South African mohair, and far exceeds the length of >75 mm required to attract a good price. The mean fibre diameter (MFD) remained virtually constant (≈ 29.5μm) for the 10 year period, the staple length (≈ 140 mm) only showed slight fluctuation during this period, while the clean yield showed a slight improvement from 2012/2013.

It was confirmed that medullated fibres tend to be coarser than the non-medullated (solid) fibres with the medulla diameter tending to increase as the fibre diameter increased. In the samples of Lesotho mohair tested, the levels of objectionable medullated fibres as measured on the OFDA 100, varied from as low as 0.4 % to as high as 11 % by number both the range and high levels being a cause for concern. Nevertheless, the occurrence of relatively low levels (0.4 %) is encouraging since it indicates that there is a great potential to reduce the relatively high levels by using the appropriate and breeding material and practices. The number of objectionable medullated fibres was found to be related to the CV of fibre diameter, thus, confirming the findings of previous researchers. As could be expected, the the mean fibre diameter of the medullated fibres generally increased as MFD of the fibre population increased. The results showed a very large proportion of mohair samples (about 90 %) contained more than about 4 % up to 10.4 % of medullated fibres and more than 40 % had > 6 % medullated fibres. South African mohair on the other hand, has medullation contamination levels notably low, about 0.1% flat medullated fibres and about 0.05% objectionable medullated fibres. A reduction in the levels of objectionable medullated fibres and medullation in general would have a positive impact on the quality and price of Lesotho mohair. This area certainly needs attention as it can have the greatest effect on Lesotho mohair quality and price

There appears to be no formal farmer training in Angora goat flock management and farming practices this needs to be addressed, since it should improve the quality and production of mohair and reduce the high mortality rate. Constraints to mohair production include chronic diseases, far distant shearing sheds, inappropriately managed pastures, lack of supplementary feeding, stock theft, unhygienic kraals and lack of barns to keep the flocks.

8.2 RECOMMENDATIONS

The following recommendations are made, on the basis of the findings of this study.

8.2.1 Monitoring and evaluation of wool and mohair trends

Based on the findings of this study, it is apparent that the local farmers in Lesotho depend solely on the broker; in this case BKB, for the quality of the wool and mohair they produce as well the market status. It is therefore recommended that relevant stakeholders collaborate to assess the trends in Lesotho wool and mohair production, quality and international markets as well as factors affecting the above mentioned. The forecasting that will be done here will potentially raise awareness, arouse interest and possibly desire to become competitive on the part of the farmers, based on the type/quality of wool and mohair that is likely to give them better returns for their efforts including issues as common as proper classing of the two fibres (wool and mohair), knowing how the local fibres fair on the international markets.

8.2.2 Further study on mohair contamination (medullation and dark mohair)

The prevalence of medullation percentage per sample stood out as a course for concern in Lesotho mohair. A detailed cause-and-effect study that should possibly lead to an interventional study is recommended, this should study the actual causes of the different forms of contamination in mohair, particularly medullation and dark colour in Lesotho mohair and strategies that can assist in the eradication of such contamination.

8.2.3 Publication of data

Accessing relevant quality and production related data and information for this study was difficult since most of it is not documented or centralised in Lesotho. Hence, most of the data had to be sourced from outside of Lesotho (e.g. South Africa and agents). The generation and documentation of comprehensive and updated data would be extremely useful to the trade, government, decision makers, brokers, buyers, researchers, existing and aspiring wool/mohair farmers, donors, developers and investors. The lack of such information contributes to the repetition of mistakes and occasionally also duplication of efforts. For example; declaring and documenting the sheep/goat breed in each farm enables monitoring and analysis of changes and improvements as well as any interventions that may be required. All relevant information should be standardised, documented and centralised as a matter of course. The availability of current and continuously updated accurate and detailed data on Lesotho wool and mohair would facilitate research, monitoring evaluation and improvement of the fibres. A clear example of the lack of data is that mohair data from 2015 onwards was inaccessible or incomplete due to major changes that had taken place in the marketing of Lesotho mohair. If data on all the local fibres are recorded in Lesotho, regardless of the marketing systems, then such data will always be available for intervention and other relevant purposes.

A way has to be found to do this successfully, but it may be difficult if not impossible while the bulk of Lesotho wool and mohair are marketed and tested outside of Lesotho. Such an agreement can be made with the brokers and the testing laboratories through the farmers to record the data to a central place (unit) in Lesotho for capture and validation.

8.2.4 Local testing of wool and mohair

There is a need for an integrated and comprehensive, preferably local, protocol and facility for testing in Lesotho wool and mohair, by an internationally accredited (e,g, IWTO) laboratory, such as the Wool Testing Bureau (WTB) in Port Elizabeth South Africa. Ideally all quality related properties that affect price should be measured. Examples include yield, fibre diameter, staple length and strength, VM and medullation, where appropriate. Other properties may be tested as and when the need arises. In this way the quality and production trends can be monitored and used to make informed decisions about measures required to counter any negative trends or perceptions which could destroy the image of the fibre. This would add confidence to the buyers of Lesotho wool and mohair and improve their global competitiveness. It will also be particularly beneficial for marketing, research, innovation and product diversification and development, with the associated benefits for trade and economic development. As a developing country, Lesotho can benefit greatly from this approach.

8.2.5 Product development

Based on the wool fabric evoked prickle results, Lesotho wool has levels of fineness that can allow development of a wide range of approved wool products. New wool and possibly mohair product development is therefore recommended. The products should be developed based on the existing market and environmental textile requirements or which explore innovative ideas and creativity. Since product development essentially requires experimental trials and textile testing for functionality; this will necessitate the establishment of a suitable laboratory or improvement of an already existing one. Ideally this should be situated in one of the institutions of higher learning, where it can be accessible and also be put to good use to enhance training and education in textiles and apparel in the country. Establishing a fashion and design school or program in existing school (s) in Lesotho could also be of great benefit. A number of new and innovative uses for wool and mohair can be found through such an initiative. Products that use relatively low quality wool and mohair can also be developed. When done on a large scale, the wool and mohair products developed can open more potential for textile clothing firms which have proven to drive the Lesotho economy in the positive direction even when the raw materials are being imported. This can be a good initiative for job creation and improving the livelihoods of locals.

8.2.6 Improved farm practices

During the course of this study, it became evident that farming practices in Lesotho are not always the same for all the various wool and mohair farmers, nor are they regulated. It is therefore recommended that more relevant and up to date farm practices (best practice) be benchmarked and introduced after the necessary in-depth investigations. This could improve both wool and mohair quality and production. Most farmers could also benefit from recent, relevant, more efficient and effective farming strategies and the necessary training should be provided and practices. Practices such as ensuring that sheep and goats are not kept close to undesirable vegetable residues, use of sheep coats, controlled/fenced farms, use of barns, proper classing of shorn wool and mohair, ensuring appropriate nutrition for sheep and goats, as well as animal welfare, should be implemented after the necessary trainings. Farm management and other practices should take the possible future effects of the climate change into consideration. In giving effect to the above, it would be necessary that individual regions and districts be further investigated to advise the farmers on practices most suitable (best practice) for the specific conditions prevailing for sheep and goat farming in their areas. This would need to cover agricultural, climatic and economic factors. The nutritional value of pastures and ways of improving it to the benefit of both the animal and fibre are of extreme importance.

8.2.7 Attitude change and education

Information sharing and “hands on” education and training, workshops etc, should be held for farmers, researchers, educators, government officials etc, so as to create a better awareness of local and international wool and mohair market requirements and the wool and mohair pipelines and value chain (from farm to consumer as well as the various activities that contribute to the sustainability and growth of the industry. This will also assist stake holders to realise the value of each role player as well as how attitudes and transparency, or lack thereof, affect the industry. Relevant extracts from this thesis could be used as a basis for such sessions.

8.2.8 Relevant policy development

The development and implementation of policies, structures and organisations that facilitate all facets of wool and mohair quality and production improvement, also for the monitoring and evaluation are recommended**.** It is apparent that there are certain appropriate policies in place, but some of which have not been implemented. Specific policies and strategies, regarding wool and mohair production and quality improvement, must be developed and implemented. These could possibly address, among other things, the requirements for wool/mohair production, places suitable for sheep/goat rearing, pasture management and permissible practices, as well as punishable ones.

It is strongly recommended that a specific policy, governing the terms of wool and mohair farming should be developed and implemented with appropriate monitoring and evaluation component to ensure proper enforcement of the same. This policy could for example, grant full autonomy to the National Wool and Mohair Association and make it the accountable authority for enforcing related regulations governing production and assessment of wool and mohair in Lesotho. The policy could specify all the requirements, including infrastructure, skills, financial ability as well as the preferences of individual practitioners and means of assessing the above. Such a policy, if implemented could prevent improper handling of animals, this is necessitated by the fact that animal welfare is currently essential if one is to stay in the trade. Since South Africa seems to be doing very well in this area, a study group visit to South African to assess the policy and system governing wool and mohair production for adoption of appropriate ones is recommended.

8.2.9 Establishment of a projects authority for wool and mohair

It is recommended that the Ministry of Agriculture and Food Security sets up a body responsible for fibre and textile related (from farm to consumer) skills training and other relevant educational campaigns and interactive sessions, as well as projects to ensure continuous running of such. The viability and suitability of these must be the responsibility of the body/authority established. One major mandate of this authority should be to marshal relevant assistance for the development and improvement of wool and mohair production, quality, processing and marketing and local beneficiation. Projects of interest would be similar to the current SADP which are run through the department of Livestock. Research to identify such projects will be essential for this authority. Such an ideally non-political autonomous authority can remain in place during changing governments and authorities, thereby ensuring more progress in fibre production and quality with benefits to the national economy as well as the wool and mohair producers and trade.

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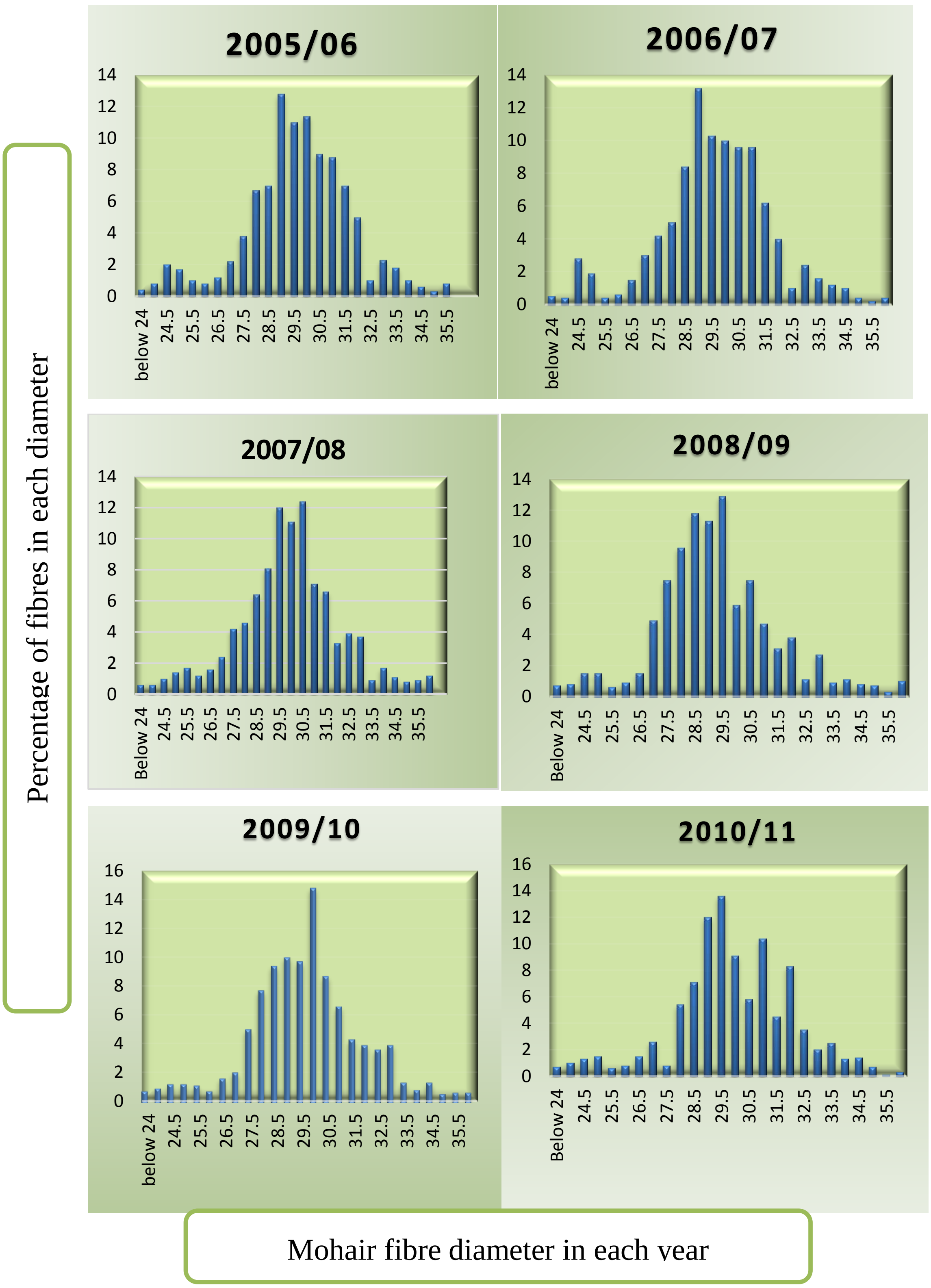
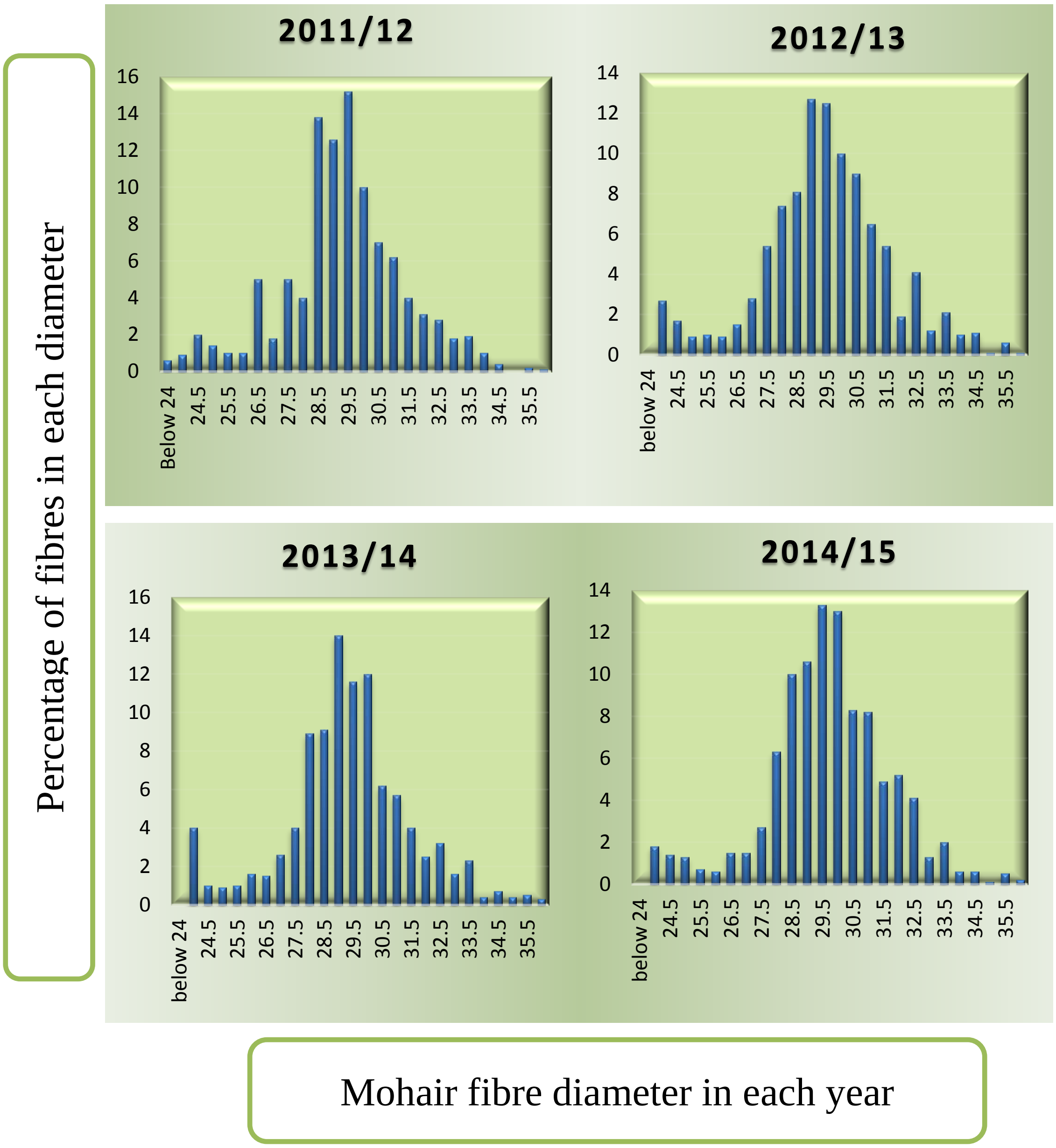
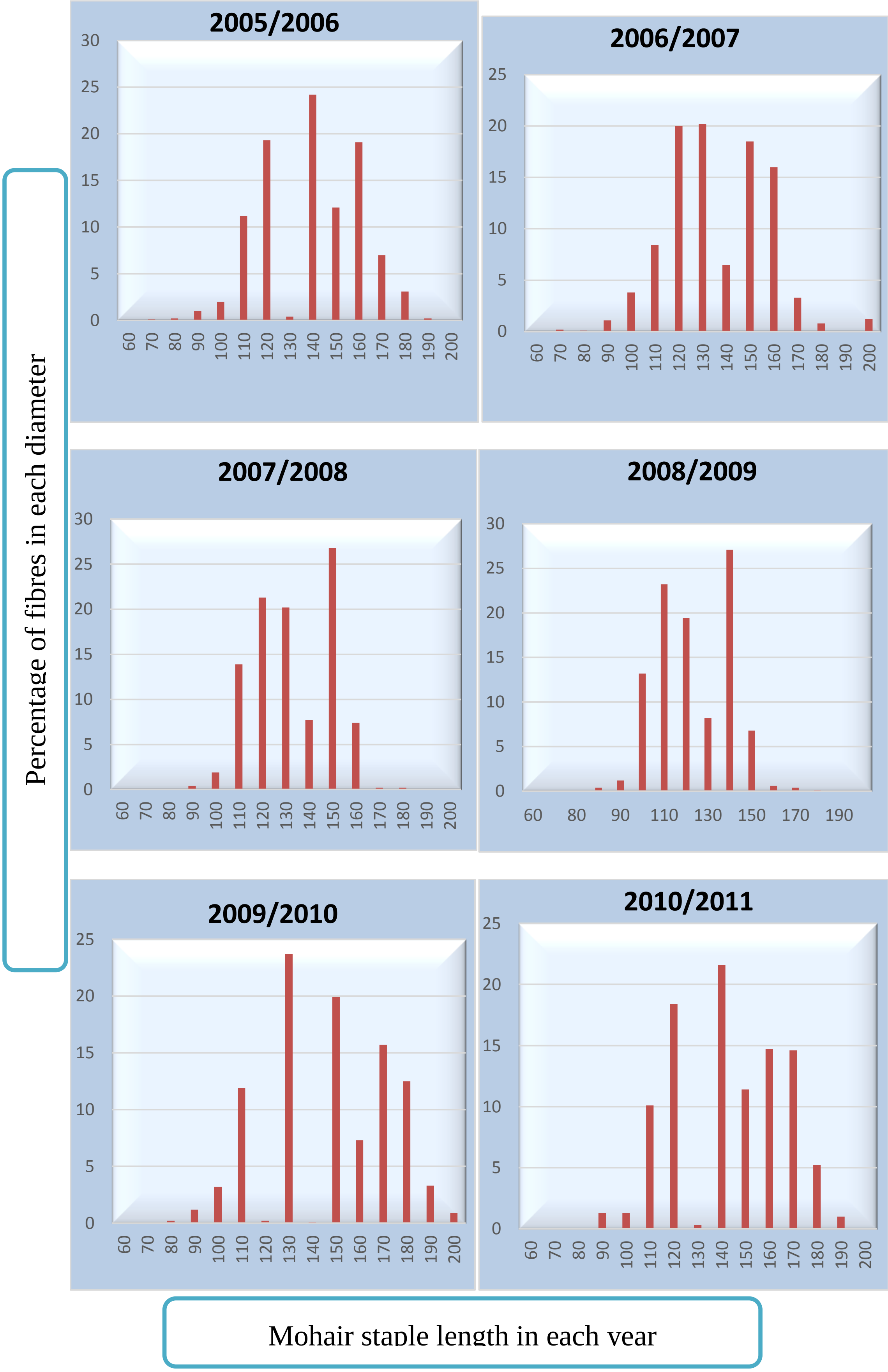
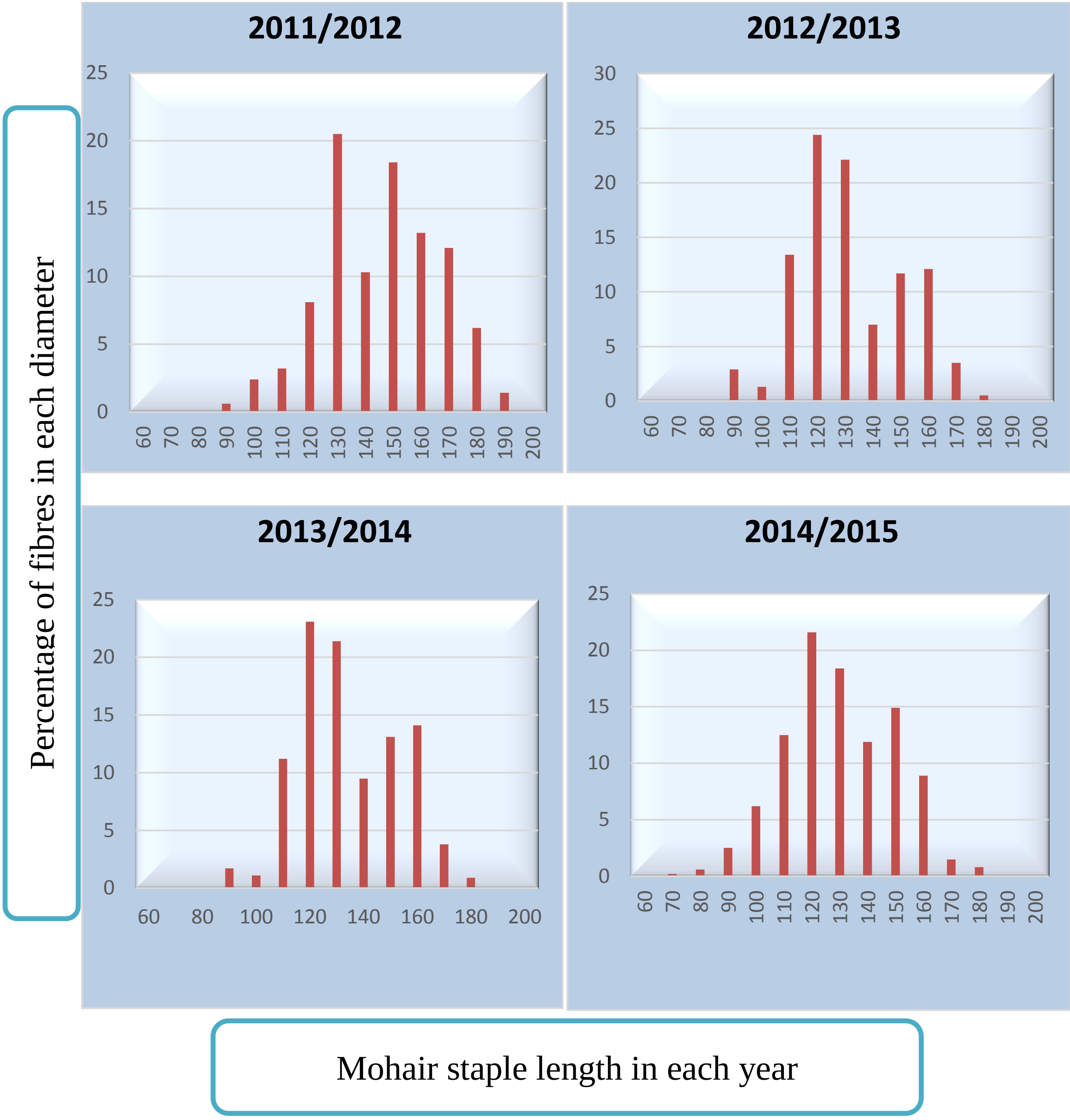
Appendix 1: Mohair fibre diameter frequency distributions for each year (2005/06 -2014/15)




Percentage of fibres in each diameter
2011/12
0 2 4 6 8 10 12 14 16
Below 24 24.5 25.5 26.5 27.5 28.5 29.5 30.5 31.5 32.5 33.5 34.5 35.5
2012/13
0 2 4 6 8 10 12 14
below 24 24.5 25.5 26.5 27.5 28.5 29.5 30.5 31.5 32.5 33.5 34.5 35.5
2013/14
0 2 4 6 8 10 12 14 16
below 24 24.5 25.5 26.5 27.5 28.5 29.5 30.5 31.5 32.5 33.5 34.5 35.5
2014/15
0 2 4 6 8 10 12 14
below 24 24.5 25.5 26.5 27.5 28.5 29.5 30.5 31.5 32.5 33.5 34.5 35.5
Mohair fibre diameter in each year

Appendix 2: Mohair staple length (mm) distribution for the different years




2011/2012
2012/2013
2013/2014
2014/2015
Percentage of fibres in each diameter
Mohair staple length in each year

Appendix 3: Details of the Mohair samples (2013/14 clip)

	Tag Reference	Job/Batch number	Class	Origin
1.	1274924	11071/001	BSTD2	TRADER
2.	1274921	11071/001	BSDY2	TRADER
3.	1274926	11071/001	BMS	TRADER
4.	1274916	11071/001	BSTD1	TRADER
5.	1274922	11071/001	BFM	TRADER
6.	1274923	11071/001	BFM	TRADER
7.	1274917	11071/001	BSTD2	TRADER
8.	1274919	11071/001	BSTD2	TRADER
9.	1274925	11071/001	BMS S	TRADER
10.	1274927	11071/001	BSTD2	TRADER
11.	1274920	11071/001	BSDY1	TRADER
12.	1274918	11071/001	BSTD2	TRADER
13.	1274933	11071/001	BFM	GROUPING
14.	1286427	11343/001	BSDY	GROUPING
15.	1286431	11343/001	BGREY	GROUPING
16.	1286432	11343/001	BGREY	GROUPING
17.	1286428	11343/001	BGREY	GROUPING
18.	1286433	11343/001	BSTN	GROUPING
19.	1287744	11415/001	BSTD2	GROUPING
20.	1287338	11401/001	BMS-STD	TRADER
21.	1287307	11401/001	BFM2	SEMIONE
22.	1287485	11401/001	BKL-BSTD	KHAFUNG

	Tag Reference	Job/Batch number	Class	Origin
23.	1288194	11401/001	BMS-STD	RAMPAI
24.	1287286	11401/001	BKS SDY	KHAFUNG
25.	1288187	11401/001	BML-BSDY	GROUPING
26.	1287367	11401/001	BFM2	PELANENG
27.	1286601	11401/001	BSTD	MOREMOHOLO
28.	1287218	11401/001	BFM-BSTD	SOSA
29.	1286569	11401/001	BML	MAKHAPUNG
30.	1287203	11401/001	BML/S-BSTD	SOSA
31.	1287101	11401/001	BML/S-BSTD	LIKOROLO
32.	1287357	11401/001	BSTD	PELANENG
33.	1287315	11401/001	BFMSDY	METELILE
34.	1287361	11401/001	BFM	PELANENG
35.	1287008	11401/001	BML-BSTD	RAMABANTA
36.	1287487	11401/001	BKS-BSTD BSDY	RAMPAI
37.	1287289	11401/001	BMS	KHAFUNG
38.	1286605	11401/001	BMS	MOREMOHOLO
39.	1287768	11401/001	BSTD2	TRADER
40.	1287155	11401/001	BSL	LIKALANENG
41.	1286577	11401/001	BFM BSTD	MAKHAPUNG
42.	1287749	11401/001	BMS	TRADER
43.	1287753	11401/001	BSTD2	TRADER
44.	1287012	11401/001	BKL BSTD	RAMABANTA

	Tag Reference	Job/Batch number	Class	Origin
45.	1287748	11401/001	BSDY1	TRADER
46.	1288185	11401/001	BML	GROUPING
47.	1287285	11401/001	BSDY	KHAFUNG
48.	1288197	11401/001	BSL	GROUPING
49.	1287152	11401/001	BML	LIKALANENG
50.	1287011	11401/001	BFM-BSTD	RAMABANTA
51.	1287466	11401/001	BML/S BSDY	RAMPAI
52.	1287403	11401/001	BSDY	MASEMOUSE
53.	1287355	11401/001	BFM-STD	PELANENG
54.	1287761	11401/001	BFM3	TRADER
55.	1287410	11401/001	BKS	MASEMOUSE
56.	1287740	11401/001	BFM	TRADER
57.	1287336	11401/001	BMS-SDY	SEMIONE
58.	1287757	11401/001	BSTD	TRADER
59.	1288203	11401/001	BSTD	GROUPING
60.	1287467	11401/001	BKS BSTD	RAMPAI
61.	1287406	11401/001	BFM3	MASEMOUSE
62.	1287337	11401/001	BML	SEMIONE
63.	1288184	11401/001	BML	GROUPING
64.	1287818	11401/001	BFM STD	THIBELI
65.	1288188	11401/001	BMS	GROUPING
66.	1287341	11401/001	BMS	SEMIONE
67.	1287030	11401/001	BSS-S	SEMONKONG

	Tag Reference	Job/Batch number	Class	Origin
68.	1287365	11401/001	BKS SDY	PELANENG
69.	1287284	11401/001	BSTD	KHAFUNG
70.	1287270	11401/001	BMS	MAKHAKHE
71.	1287154	11401/001	BKS	LIKALANENG
72.	1287405	11401/001	BMS	MASEMOUSE
73.	1287750	11401/001	BMS	TRADER
74.	1287468	11401/001	BMS	RAMPAI
75.	1287105	11401/001	BKS BSTD	LIKOROLO
76.	1287447	11401/001	BSTD	PEKA
77.	1286529	11401/001	BSDY	THABANTSO
78.	1286606	11401/001	BSDY	MOREMOHOLO
79.	1287104	11401/001	BMS	LOKOROLO
80.	1287106	11401/001	BFM BSTD	LIKOROLO
81.	1286532	11401/001	BKS BSDY	THABANTSO
82.	1287483	11401/001	BFM3-BSTD	RAMPAI
83.	1287362	11401/001	BKS STD	PELANENG
84.	1288200	11401/001	BSS	GROUPING
85.	1287130	11401/001	BSS	MOTENG
86.	1287821	11401/001	BFM1	THIBELI
87.	1288195	11401/001	BMS STD	GROUPING
88.	1287150	11401/001	BFM SDY	LIKALANENG
89.	1287306	11401/001	BKS STD	KHAFUNG
90.	1288210	11401/001	BCM	GROUPING

	Tag Reference	Job/Batch number	Class	Origin
91.	1287103	11401/001	BML/S BSDY	LIKOROLO
92.	1287742	11401/001	BSTD	TRADER
93.	1288635	11401/001	BSTD	GROUPING
94.	1287151	11401/001	BFM-STD	LIKALANENG
95.	1286604	11401/001	BKS BSDY	MOREMOHOLO
96.	1287309	11401/001	BMS-S	MATELILE
97.	1287202	11401/001	BFM BSTD	SOSA
98.	1286528	11401/001	BSTD	THABANTSO
99.	1287760	11401/001	BSTN1	TRADER
100.	1288205	11401/001	BSTD	GROUPING
101.	1287029	11401/001	BML/S-BSTM	SEMONKONG
102.	1287745	11401/001	BSTD2	TRADER
103.	1287053	11401/001	BKS-STD	KOASA
104.	1288198	11401/001	BSL STD	GROUPING
105.	1286603	11401/001	BML BSTD	MOREMOHOLO
106.	1287762	11401/001	BSDY2	TRADER
107.	1287450	11401/001	BFM – STD	PEKA
108.	1286531	11401/001	BML BSTD	THABANTSO
109.	1287480	11401/001	BML/S-BSTD	RAMPAI
110.	1287469	11401/001	BKS-STD-BSDY	RAMPAI
111.	1286984	11401/001	BMS STD	QEME
112.	1287156	11401/001	BMS	LIKALANENG
113.	1287157	11401/001	BFM3	LIKALANENG

	Tag Reference	Job/Batch number	Class	Origin
114.	1287161	11401/001	BKS STD	LIKALANENG
115.	1287291	11401/001	BSS	KHAFUNG
116.	1287359	11401/001	BSL	PELANENG
117.	1286556	11401/001	BSTD	MAKHAPUNG
118.	1287268	11401/001	BML BSTD	MAKHAKHE
119.	1287177	11401/001	BSTD	QHOLAQHOE
120.	1287134	11401/001	BKS	MOTENG
121.	1287308	11401/001	BMS	MATELILE
122.	1287363	11401/001	BMS	PELANENG
123.	1288207	11401/001	BSDY	GROUPING
124.	1288201	11401/001	BSTD	GROUPING
125.	1286607	11401/001	BFM BSTD	MOREMOHOLO
126.	1287287	11401/001	BKS-BSTD	LHAFUNG
127.	1287484	11401/001	BFM-SDY	RAMPAI
128.	1287158	11401/001	BKS-BSTD	LIKALANENG
129.	1287186	11401/001	BFM STD	MOKEMA
130.	1288216	11401/001	BGREY	GROUPING
131.	1288206	11401/001	BSTD	GROUPING
132.	1287751	11401/001	BSTD1	TRADER
133.	1287033	11401/001	BKL-BSTD	SEMONKONG
134.	1287481	11401/001	BML/S-BSTD-BSDY	RAMPAI
135.	1287741	11401/001	BFM	TRADER

	Tag Reference	Job/Batch number	Class	Origin
136.	1288190	11401/001	BMS	GROUPING
137.	1287238	11401/001	BMS STD	MASITE
138.	1287747	11401/001	BSDY1	TRADER
139.	1288202	11401/001	BSTD	GROUPING
140.	1288186	11401/001	BML/STD	GROUPING
141.	1286602	11401/001	BSTD	MOREMOHOLO
142.	1287759	11401/001	BML	TRADER
143.	1288209	11401/001	BCM	GROUPING
144.	1287482	11401/001	BMS	RAMPAI
145.	1287383	11401/001	BFM-STD	BUSHMAN'S NEK
146.	1288196	11401/001	BSL	GROUPING
147.	1288204	11401/001	BSTD	GROUPING
148.	1287404	11401/001	BSTD	MASEMOUSE
149.	1287102	11401/001	BML	LIKOROLO
150.	1287217	11401/001	BML/S-BSTD	SOSA
151.	1287819	11401/001	BSTD	THIBELI
152.	1288183	11401/001	BML	GROUPING
153.	1287471	11401/001	BFM3	RAMPAI
154.	1287129	11401/001	BSTD	MOTENG
155.	1286565	11401/001	BSTD-MATT	MAKHAPUNG
156.	1287009	11401/001	BSTD	RAMABANTA
157.	1287364	11401/001	BKS	PELANENG

	Tag Reference	Job/Batch number	Class	Origin
158.	1287282	11401/001	BKS	MAKHAKHE
159.	1286986	11401/001	BMS	QEME
160.	1287176	11401/001	BSS	QHOLAQHOE
161.	1287763	11401/001	BSTD2	TRADER
162.	1287290	11401/001	BKS	KHAFUNG
163.	1288217	11401/001	BGREY	GROUPING
164.	1288191	11401/001	BMS	GROUPING
165.	1287385	11401/001	BKS STD	BUSHNA'S NEK
166.	1286985	11401/001	BSTD	QEME
167.	1288208	11401/001	BSDY	GROUPING
168.	1287133	11401/001	BKS BSDT	MOTENG
169.	1287470	11401/001	BFM3-BSTD	RAMPAI
170.	1287034	11401/001	BKS	SEMONKONG
171.	1286561	11401/001	BSTD	MAKHAPUNG
172.	1288199	11401/001	BSS	GROUPING
173.	1287132	11401/001	BML-BSTD	MOTENG
174.	1287288	11401/001	BFM-STD	KHAFUNG
175.	1286990	11401/001	BSS	QEME
176.	1287746	11401/001	BSTD2	TRADER
177.	1287822	11401/001	BKS	THIBELI
178.	1287162	11401/001	BKS-BSTD	LIKALANENG
179.	1287465	11401/001	BML/S-BSTD	RAMPAI
180.	1287121	11401/001	BSTD	QOALING

	Tag Reference	Job/Batch number	Class	Origin
181.	1288189	11401/001	BMS	GROUPING
182.	1287153	11401/001	BSS	LIKALANENG
183.	1286530	11401/001	BFM-BSTD	THABANTSO
184.	1287310	11401/001	BML BSTD	MATELILE
185.	1286533	11401/001	BMS	THABANTSO
186.	1287769	11401/001	BSTD1	TRADER
187.	1287360	11401/001	BSS	PELANENG
188.	1288193	11401/001	BMS	GROUPING
189.	1287356	11401/001	BFM SDY	PELANENG
190.	1286566	11401/001	BMS	MAKHAPUNG
191.	1287239	11401/001	BSTD	MASITE
192.	1287283	11401/001	BSTD	KHAFUNG
193.	1285895	11319/001	BSDY	TRADER
194.	1285897	11319/001	BSTD2	TRADER
195.	1285900	11319/001	BSTD2	TRADER
196.	1285902	11319/001	BMS-S	TRADER
197.	1285907	11319/001	BFM3	TRADER
198.	1285906	11319/001	BSTD2-S	TRADER
199.	1285898	11319/001	BSTD2	TRADER
200.	1285903	11319/001	BMS	TRADER
201.	1285899	11319/001	BFM2	TRADER
202.	1285896	11319/001	BSTD1	TRADER

Appendix 4: Mohair OFDA measurements data ***(2013/2014 samples for OFDA Measurements)***

Objectionable Med fibres	**Number of flat Med fibres**	**MFD**	**CV %**	**Curvature**	**Opacity**	**Med (%)**	**MEAN Med Diameter**
40	28	31.5	40	21.1	64.5	4.3	41.5
48	20	28.3	38	24.3	64	3.6	36.5
50	48	27.9	34.4	21.4	65.2	3.6	34.2
65	10	28.6	37.5	23.3	65.5	4.8	40.7
100	20	22.5	33.7	24.1	64.8	4.4	32.1
130	20	26.3	43.4	26.8	65.6	4.7	44.9
215	15	27.1	40.7	24.3	66.7	7	43.1
100	20	22.8	35	27.7	65	4.5	35.2
78	48	26.9	38.1	23.7	65.2	4.5	38.3
182	40	28.7	45.7	24.8	66.3	5.8	53.4
15	42	26.7	40.3	21.8	65.6	4.5	44.6
80	20	27.8	39.1	25.3	66.6	5.2	41.2
65	10	30.2	30.6	20.5	65.8	4.6	37.4
78	12	27.6	35.9	25.8	65.8	4.1	37.7
80	18	27.8	34.9	23	64.9	3.9	38
68	42	26.9	32	23.7	65.8	4.9	32.7
225	68	27.1	49.9	28	66.7	6.9	49.9
130	15	28.7	42.1	22.9	65.7	5.2	48
80	12	24.5	35.4	25.8	65.4	4	36.2
72	15	24	35.4	27.8	65	4	34
82	20	22.6	34.3	28.3	64.9	4.8	31.4
85	20	27.7	38.4	20.5	65.8	4.7	40.6
72	25	27.3	35.1	25.4	66.3	5.5	36.4
92	45	27.4	34.5	25.2	65.5	5.3	36.3
108	30	26.5	42.1	27.1	65.5	5	44
75	28	29.8	33.8	22.1	63.8	3.1	43.4

Objectionable Med fibres	Number of flat Med fibres	MFD	CV %	Curvature	Opacity	Med (%)	MEAN Med Diameter
98	32	26.7	42.3	24.1	64.8	4.1	43.6
125	35	28.9	39.4	22.9	65.7	4.7	47.3
42	20	23.5	33.9	20	64.7	4.3	40.8
62	35	23.5	34.9	27.3	64.6	4.2	34.4
120	18	27.9	41	25.5	65.8	5	45.5
128	38	26.7	41.8	27.3	65.3	3.8	48.8
172	18	26.9	42.6	21.4	66.1	5.7	45.9
62	40	26.6	33.8	25	64.6	4.4	35.3
72	20	30.5	35.4	18.3	64.8	3.5	47.6
215	15	28.7	41.7	23.9	66.7	7.2	42.3
156	52	27	33.7	24.2	64.9	3.7	32.3
157	15	27.6	42.5	24.7	66.5	6.8	42.9
110	5	26.2	38.1	25.1	65	4	42.8
38	70	27.1	31.6	24.3	65.2	3.1	32.5
125	40	29.2	43.9	26.1	65.7	6.2	46.1
227	25	30.3	48.3	23.2	66.5	6.3	57
48	45	30.6	33.6	21	64.6	3.8	40.6
102	22	27.5	40.4	23.2	65.9	5.4	42.9
68	15	26.7	38.3	25.3	65.5	4.3	37.5
85	40	27	34.7	21.3	64.9	3.5	38.7
92	32	32	35.7	17.7	64.6	4.1	46.9
113	40	28.7	39.9	25.3	65.9	5.1	43.9
88	22	30.2	38.2	20.1	66	4.8	44.4
88	48	27.2	36.9	26.2	65.9	4.8	34.7
100	32	30.3	39.2	21.2	66.3	5.5	44.4
98	8	27.7	39.8	26.4	66.8	5.3	40.9
68	20	26.4	32.2	27.2	66.9	5.7	31

Objectionable Med fibres	Number of flat Med fibres	MFD	CV %	Curvature	Opacity	Med (%)	MEAN Med Diameter
42	10	27.3	35.6	24.8	65.4	4.5	33.6
85	50	23.1	38.8	28.7	65.3	5.1	31.2
198	48	26.2	49.9	27.7	66	5.8	52.7
130	25	29.7	42.1	19.1	66.4	6	46.7
52	32	27.8	36.6	26.8	66.1	4	38.9
118	10	30.5	38.9	20.5	66.1	4.7	45.9
78	45	23.8	36	26	65.7	4.8	31.1
135	58	28.7	41	21.4	65.7	5.3	46.5
235	12	29.7	50.7	25.1	65.9	6.3	59.8
75	32	28.5	35.5	23.2	65	3.8	39.7
130	40	27.7	40.8	23.1	66.5	6.6	37.6
172	40	28.6	41.7	25	67.1	6.6	43.9
30	20	28.9	34.3	20.7	65.8	4.6	37.3
130	10	26.4	39.8	26.6	65.1	4.5	44.9
102	38	25.3	34.7	27.4	67.3	6.5	32.9
145	58	27.7	43	27	67.1	7.3	39.9
140	40	26.9	44.1	28.6	66.6	6.6	44.2
160	30	26.5	44.1	31.1	66.9	6.5	43.1
148	35	25.5	42.2	30.5	67	7.1	37.7
110	18	27.8	37.5	24.5	65.8	4.7	42.2
115	65	22.5	37.1	28.9	66.4	7.5	29.3
60	35	34.6	37.4	20.3	66.6	5.2	49.6
58	28	30.4	33.9	19.8	66.3	4.5	39.7
165	8	24.1	44.7	29.9	67.3	6.8	38.8
38	55	22.3	34.4	28.6	65.6	4.6	27.1
118	32	35.9	36.2	17.2	65.6	5	53.1
102	32	30.5	35.4	21.3	67.2	6.4	38.7

Objectionable Med fibres	Number of flat Med fibres	MFD	CV %	Curvature	Opacity	Med (%)	MEAN Med Diameter
175	15	27.8	44.2	22.9	67.6	7.8	42.9
50	50	27.3	33.9	25.1	66.2	5.3	32.2
95	40	29.6	38.1	23.1	67.6	6.6	42.4
300	42	26.8	46.7	27.3	67.1	8.3	45.3
178	35	27.3	44.6	22	66.8	6.8	44.3
92	32	25.1	41.1	29.7	66.2	4.8	39.3
82	25	28.1	37.5	24.3	65.6	4.2	41.7
90	22	27.6	40.3	25.2	66.9	5.7	37.4
60	60	26.3	35.8	27.4	64.9	3.4	37.8
150	12	26.8	41.6	27	65.8	5.2	45.6
98	32	25.8	37.1	28.1	67.1	6.3	33.4
130	38	26.8	40.1	28.3	66.2	5.9	39.6
130	28	25.8	42.3	27.7	66.6	5.7	42.4
135	18	27.5	40.2	25.9	67.8	7.5	37.8
85	30	25.7	42.1	30.6	66.1	4.5	36.2
118	28	26.1	40.6	26.7	66.5	5.8	38.3
162	15	28	44.1	22	66.4	4.8	50.1
98	10	23.8	34.3	27.8	64.9	5.3	31.3
50	42	22.7	32.8	27.8	64.9	4	29.7
45	10	33.1	35.7	18.2	65.7	5.2	42.4
70	32	25.7	36.8	25.7	65.8	5.2	33.1
75	32	28.8	36.4	22.8	64.7	4.5	38
105	32	31.3	35.4	18.6	65.9	6.5	40.3
132	18	28	45	27.1	63.2	3.4	62
65	20	29	35.2	26	61.7	1.9	44.2
55	20	26.9	34.8	27.7	62.8	2.5	43.1
38	38	27.1	34.9	25.4	62.1	2.1	37.6

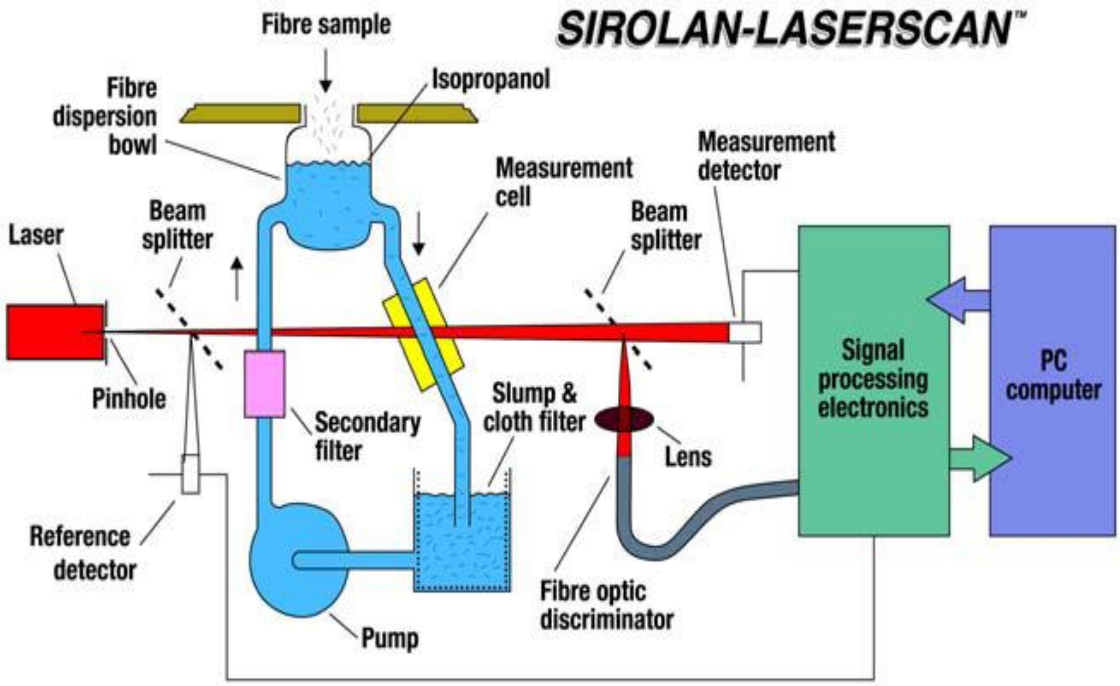
Objectionable Med fibres	Number of flat Med fibres	MFD	CV %	Curvature	Opacity	Med (%)	MEAN Med Diameter
115	22	29.3	37.9	23.9	62.8	3.5	49.7
45	30	27.9	36.5	27.1	62.8	2.4	46.2
88	28	28.3	40.3	25.5	62.8	3.2	50.1
155	28	24.8	39.7	31.6	63.6	3.7	46.8
125	52	28.7	36.7	27	63.6	3.1	41.7
417	40	27	51	31.2	64.8	8.8	49
102	42	27.4	41	26.6	63.6	3.5	50.7
75	18	28.7	37.6	25.5	62.7	3	50.1
113	22	26	37.4	25.3	63.1	2.8	43.1
48	28	28	34.6	25	62.7	2.4	43.5
108	50	26.1	40	28.4	62.3	2.9	50.6
48	10	29.9	39.8	24.2	63.2	2.6	51.3
118	25	23.2	34.8	30	64.1	4.3	35.4
85	5	27.7	40.9	24.9	63.4	3.4	45.6
62	10	22.4	33.1	34.3	63.1	3.1	31.7
65	25	23.5	31.7	28.8	63.2	3.3	33.9
72	30	26.7	37.8	29.8	64	3.2	43.4
68	38	28.2	36	27.9	64.2	3.8	41.8
100	52	26.9	39.5	25.3	63.8	3.5	45.1
85	30	30	38.2	23.7	63.3	3.4	53.4
102	50	27.5	37.2	30.7	64.6	3.4	46.1
130	42	28.6	39.5	30.6	65	4.4	47.1
130	15	25.9	43.2	27.3	64.8	4.1	50.4
95	42	23.1	36.8	31.9	63.9	3.5	39.5
82	10	28.4	39.5	29.2	64.6	4.2	46.9
52	12	27.7	34.7	24.1	63.6	2.7	38.4
75	25	22.8	35.1	31.2	64.3	3.8	34.7

Objectionable Med fibres	Number of flat Med fibres	MFD	CV %	Curvature	Opacity	Med (%)	MEAN Med Diameter
58	50	30.9	33.2	25.2	64.4	3	46.4
160	38	27.2	44.9	28.2	65	4.7	52
150	18	28	42.2	27.5	64.8	4.6	52.7
68	35	30	33.6	22.1	63.8	3.1	39.2
140	58	27.4	40.2	28.3	64.9	4.5	45.1
130	18	30	38.7	25.6	64.2	3.9	54.8
48	30	30.2	30.2	25	62.6	2	41.1
108	18	30.3	35.8	24.2	63.3	2.8	54.7
72	35	25.4	33.9	28.6	63.9	3	37.6
70	18	28.4	36.1	29.1	64.9	4.8	40.6
120	32	26.8	35.7	27.5	64.3	3.5	42.7
82	22	27.5	38.9	29.2	64.4	3.6	48.7
100	20	27.5	36.1	24.6	64.3	3.4	43.6
48	45	27.3	35.1	26.2	63.2	2.3	39.5
95	10	31.8	36.8	22.6	64.1	3.6	49
38	35	27.2	32.4	26.1	63.4	2.6	36
108	32	26	40.7	28.4	64.8	4.3	42.5
105	18	31.3	35.4	18.6	65.7	6.5	40.3
58	52	31	35.6	18.2	66.5	6.1	38.5
110	35	27.3	43.1	25.5	65	4.8	45.6
132	35	27.9	39.7	21.1	65.7	5.2	43.1
90	18	29.2	38.5	19	65.5	5.4	40.1
72	22	29.5	32.5	19.5	66.3	6.1	36.5
110	15	29.2	37	22.8	66.9	6.6	37.5
95	30	22.8	32	24.3	66	6	29.6
132	5	27.1	43	21.4	66.7	4.7	39.3
105	25	23.5	34.6	25	64.6	5.2	32.8

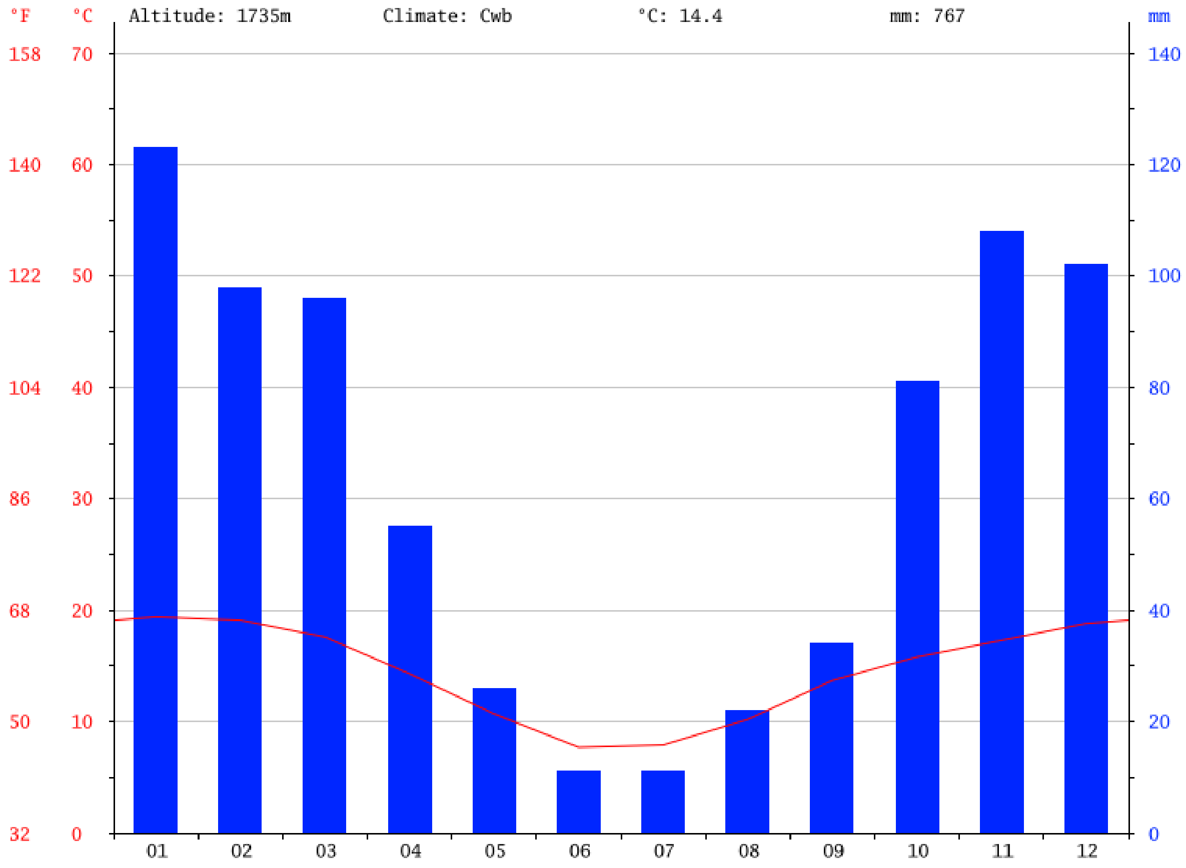
Objectionable Med fibres	Number of flat Med fibres	MFD	CV %	Curvature	Opacity	Med (%)	MEAN Med Diameter
82	62	29.2	36.8	20	66.4	5.4	38.8
130	10	30.4	41.6	20.7	65.7	5.4	49.9
75	15	22.8	37.3	23.6	66	6.2	29.1
80	8	31.1	33.1	20.6	66.8	6.4	38.2
75	48	21.5	32.8	27.2	65.3	4.6	26.7
102	40	31.7	35.8	17.1	66.2	5.9	43.5
157	35	26.9	42.6	21.5	65.5	5.4	44.2
78	20	25.9	41.5	22.9	66.7	6.6	35
78	20	28.8	36.1	22.9	66.5	5	38.5
125	2	31.2	37.1	19.1	67.1	7.1	40.9
60	20	24.5	31.5	22.7	65.1	4.3	29.2
140	32	28.8	37	21.2	67.2	6.9	39.1
68	0	27.6	37.4	22.6	66.6	4.8	41.2
75	15	22.6	32.7	27	66.5	6.4	26.2
80	30	27	34.4	24.1	66.4	5.2	34.2
200	10	28.9	47.6	22.4	66.7	5.7	54.7
62	28	26.4	34.7	24.8	66.7	5.9	32.3
208	32	27.8	41.4	23.3	67.4	7.1	40.8
52	18	27.9	35.5	25.2	67.6	5.7	36.4
115	12	22.3	38.2	31	66.4	5.9	31.6
140	45	26.5	37.2	23.8	67.3	6.4	35.9
85	12	29.2	38.7	21.6	64.6	3.3	47.5
58	38	28.5	34.5	20.4	66.4	5.9	34.4
125	48	28.6	41.9	22.4	67.2	6.8	41.9
88	25	29	37.4	22.3	66.5	5.8	40.1
62	45	31.4	34.3	19.2	67.7	7.3	37.2
90	30	31.9	37.2	17.4	66.9	6.2	43.7

Objectionable Medullated fibres	Number of flat fibres	MFD (μm)	CV (%)	Curvature (deg/mm)	Opacity	Total medullated fibres (%)	Average Mean Diameter of all medullated fibres
50	20	28.3	37.7	21.2	67.5	7	34.1
115	5	26.6	37.7	23.1	66.9	6	37
90	42	21.3	38.6	32.8	65.7	4.2	32.4
100	28	27.7	40.8	24.2	66.5	5.9	39.4
105	18	29.6	36.8	19	65.9	4.7	41.9
172	60	26	47.3	25.1	66	6.2	45.3

Appendix 5: Schematic diagram of the Sirolan-Laserscan™ (AWTA, 1999)



Appendix 6: Lesotho general climate graph



Appendix 7: A Typical structure of a wool fibre