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**OBJECTIVE MEASUREMENT OF COLOUR
IN NATURALLY PIGMENTED WOOL**

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A thesis submitted for the degree of
Master of Applied Science (Animal Science)
at Massey University, Palmerston North,
New Zealand

March 2000

ABSTRACT

This thesis examines some issues important in considering production of naturally-pigmented wools in New Zealand. Major wool characteristics are reviewed in terms of processing requirements. Statistics of New Zealand production of naturally-pigmented wools are limited, as are data relating to the number and colour of black and coloured sheep farmed in New Zealand. Objective measurements are not widely used by the wool growers; in addition, the lack of a recognised colour standard for these wools limits the marketing of sale lines.

The major characteristics of black and coloured wool samples sourced from three regions of New Zealand were analysed and presented. In the absence of a colour standard, tristimulus values (XYZ) and CIELAB ($L^*a^*b^*$) values were measured using a spectrophotometer. The CIELAB scale provided better distinctions between black, brown and grey wools which had been subjectively graded into categories labelled 'light', 'medium', 'dark', and 'moorit'. CIELAB values for each colour grouping are proposed.

To meet the requirements of wool processors, sheep breeders need to supply wools to specification. Wool production objectives are discussed in line with selection objectives, selection criteria and selection methods.

The linkages between farmers and processors are reviewed in the light of existing New Zealand practices. The role of the Black and Coloured Sheep

Breeders' Association of New Zealand, wool buyers, wool brokers and auction houses is examined. In view of the limited quantity of naturally pigmented wools available in commercial (>500kg) quantities, the study suggests that the Association introduce a brand name for the wools produced by its members and establish one sale location only as a means of raising quality standards and the availability of marketable quantities.

ACKNOWLEDGEMENTS

This study would not have been possible without the support and encouragement of many people and organisations.

My sincere thanks are extended to my supervisor, Professor H.T. Blair, Institute of Veterinary, Animal and Biomedical Sciences, Massey University, and co-supervisor, Dr G.A Wickham, for their generous assistance throughout the course of my work. Their knowledge of sheep and wool processing was inspiring and invaluable and ensured I gained better understanding and enjoyment from this project.

Financial assistance was gratefully received from the Massey University Graduate Research Fund and the Massey University Institute of Veterinary, Animal and Biomedical Sciences Graduate Travel Fund. The latter assisted in funding my attendance at the 5th World Congress on Coloured Sheep in Geelong, Australia where I gained an understanding of the global coloured sheep and wool markets and benefited from meeting coloured wool growers from other countries.

I would like to extend my appreciation also to the many members of the Black and Coloured Sheep Breeders' Association of New Zealand who willingly provided wool samples, discussed their sheep and wool production programmes, and shared their knowledge and experiences with regard to the genetics of New Zealand's coloured flocks. In particular I thank Bruce

Anderson, Cheryl Eldridge, Fiona Gardner, Don and Leila Graham, Ray Leslie, Roger Lundie and Dr. Roland Sumner without whose co-operation this thesis would not have been so broad ranging.

Valuable insight into the requirements of wool buyers, processors and manufacturers was provided by, Peter Chatterton, Lyn Finch, Alan Jones and Bill Regnault whose experience of New Zealand's wool industry and natural-coloured wools was appreciated.

To Emeritus Professor A.N. Bruere, my thanks for the friendship, support, encouragement and advice throughout the period of my research. The informal discussions and exchange of ideas contributed significantly to the completion of this study.

Finally, I could not have contemplated this thesis without the support and patience of my husband, John Nelson. Part-time study requires many adjustments to life's routines and I am fortunate in having someone who tolerates my appetite for black and coloured sheep and their wool.

CONTENTS

ABSTRACT	2
ACKNOWLEDGEMENTS	4
CONTENTS	6
LIST OF TABLES	10
LIST OF FIGURES	11
GLOSSARY	12
INTRODUCTION	15
SECTION I	BLACK AND COLOURED WOOL PRODUCTION IN NEW ZEALAND AND PROCESSOR REQUIREMENTS
1.1	Wool Production in Flocks of Coloured Sheep 18
1.2	The Characteristics of Raw Wool and their Place in Processing 21
1.2.1	Mean Fibre Diameter/Fineness
	1.2.1.1 Coefficient of Variation of Fibre Diameter
	1.2.1.2 Handle/Fabric Prickle
	1.2.1.3 Summary
1.2.2	Mean Fibre Length
	1.2.2.1 Fibre Length Distribution
	1.2.2.2 The Relationship of Fibre Length Distribution to Processing
	1.2.2.3 Noilage
	1.2.2.4 Summary
1.2.3	Mean Fibre Strength
	1.2.3.1 Variation of Fibre/Staple Strength
	1.2.3.2 Position of Break
	1.2.3.3 Processing Effects
	1.2.3.4 Measurement of Staple Strength
	1.2.3.5 Summary
1.2.4	Crimp Frequency
	1.2.4.1 Summary

1.2.5 Bulk and Resistance to Compression

1.2.5.1 Summary

1.2.6 Medullation

1.2.6.1 Summary

1.2.7 Yield

1.2.7.1 Summary

1.2.8 Colour

1.2.8.1 The Measurement of Colour

1.2.8.2 Yellowing

1.2.8.3 Summary

SECTION 2 THE CHARACTERISTICS OF BLACK AND COLOURED WOOLS GROWN IN NEW ZEALAND

2.1	Introduction	56
2.2	Materials and Methods	57
	2.2.1 Test Samples	
2.3	Test Methods	59
	2.3.1 Handle	
	2.3.2 Staple Length	
	2.3.3 Crimp Frequency	
	2.3.4 Staple Strength	
	2.3.5 Clean Scoured Yield	
	2.3.6 Bulk	
	2.3.7 Mean Fibre Diameter	
	2.3.8 Prickle Factor	
	2.3.9 Medullation	
	2.3.10 Colour	
2.4	Statistical Analysis	64
2.5	Results and Discussion	67
	2.5.1 Mean Fibre Diameter	
	2.5.2 Handle	
	2.5.3 Prickle Factor	
	2.5.4 Staple Length	
	2.5.5 Staple Strength	
	2.5.6 Crimp Frequency	

2.5.7 Bulk	
2.5.8 Yield	
2.5.9 Colour	
2.6 Comparison of XYZ and CIELAB1976 Colour Scale Results	80
2.7 Summary	81
SECTION 3 THE OBJECTIVE MEASUREMENT OF COLOUR IN BLACK AND COLOURED WOOLS	
3.1 Introduction	83
3.2 The Objective Measurement of Non-White Wool Colour	85
3.3 Materials and Methods	89
3.4 Statistical Analysis	90
3.5 Results and Discussion	91
3.6 Summary	100
SECTION 4 WOOL PRODUCTION OBJECTIVES FOR BLACK AND COLOURED SHEEP BREEDERS IN NEW ZEALAND	
4.1 Introduction	103
4.2 The Processing of Wool for Manufacturing	104
4.2.1 The Processing of Wool for Manufacturing	
4.2.2 Wool Processes used in the Apparel Industry	
4.2.2.1 The Woollen System	
4.2.2.2 The Semi-worsted System	
4.2.2.3 The Worsted System	
4.2.3 Black and Coloured Wool Processing	
4.3 Methodology	111
4.3.1 Establishing a Selection Programme	
4.3.1.1 Selection Objectives	
4.3.1.2 Selection Criteria	
4.3.1.3 Selection Methods	

4.4	Discussion	116
4.4.1	Selection Objectives for Improvement of Wool Quality	
4.4.2	Major Wool Characteristics for Consideration in Selection Programmes	
4.4.2.1	Mean Fibre Diameter	
4.4.2.2	Staple Length	
4.4.2.3	Bulk	
4.4.2.4	Crimp Frequency	
4.4.2.5	Yield	
4.4.2.6	Medullation	
4.4.2.7	Colour	
4.5	Summary	131
SECTION 5	SUGGESTED SYSTEM FOR PROVIDING LINKAGES BETWEEN PRODUCERS AND PROCESSORS WITH MORE ACCURATE SPECIFICATION OF THE WOOLS REQUIRED	
5.1	Introduction	136
5.2	Recently Established Agriculture-based Enterprises in New Zealand	137
5.2.1	Sheep Dairying	
5.2.2	Dairy Goats	
5.2.3	Alpacas	
5.3	Examples of Coloured Wool Enterprises in Australia and Europe	140
5.4	Methodology	141
5.4.1	The Role of Wool Pools, Wool Brokers, Auction Houses and Processors	
5.4.2	The Role of the BCSBANZ	
5.5	Summary	147
CONCLUSIONS		149
FUTURE RESEARCH		150
APPENDICES		151
REFERENCES		160

LIST OF TABLES

Table 1	Distribution of breed types and numbers of black and coloured sheep flocks in New Zealand	19
Table 2	Size of coloured flocks in New Zealand	20
Table 3	Wool characteristics of importance to apparel processors	22
Table 4	The effects of high-crimp fibre	42
Table 5	Comparison of least squares means of wool characteristics between Fine and Crossbred wool types	68
Table 6	Comparison of least squares means of wool characteristics by breed and region	69
Table 7	Mean colour values of Fine and Crossbred wool types by region and breed	77
Table 8	Mean colour values of test samples	92
Table 9	Mean colour values of grey wool samples	93
Table 10	Regression of colour by region and breed	94
Table 11	The classification of hypothetical XYZ and CIELAB colour values into Light, Medium and Dark colour categories	95
Table 12	Correlations between colour results in the XYZ tristimulus and CIELAB colour scales	97
Table 13	Measurement values for distinguishing colour variation in naturally pigmented wools	102
Table 14	Heritability of wool characteristics	117
Table 15	Major wool characteristics of New Zealand coloured sheep breeds	118
Table 16	Selection criteria for wool improvement by sheep breeding	135

LIST OF FIGURES

Figure 1	Samples of crimp patterns	40
Figure 2	Samples of crimp patterns	41
Figure 3	Paint colour charts showing variation in lightness, hue and saturation	87
Figure 4	CIELAB values of brown wool samples	98
Figure 5	CIELAB values of grey wool samples	99

GLOSSARY

BCSBANZ	The Black and Coloured Sheep Breeders' Association of New Zealand.
britch	Wool from the britch or lower thigh of the sheep.
bulk	The volume occupied by wool fibres at a prescribed load. Often referred to as the 'springiness' of wool.
carding	A process whereby, after scouring, the fibres are opened out, blended and straightened.
CIE	International Commission on Illumination (Commission Internationale d'Eclairage).
combing	A process in worsted manufacture in which the fibres are straightened and laid parallel, and the short fibres removed as noils along with vegetable contaminants.
count	The thickness of a yarn
crimp	Natural undulations along wool fibres.
crossbred (XBD)	A term given to New Zealand's long staple, lustre wools specifically varying in mean fibre diameter from 27-40+ μ , irrespective of breed or cross.
culling	The disposal, by slaughter or sale, of sheep no longer required in a flock.
gilling	A process of drawing slivers through machines that partially align the fibres. Used in worsted and semi-worsted processing.
greasy wool	Wool in its natural condition as shorn from the sheep.
halfbred (1/2BD)	Wool taken from sheep with half Merino in the breeding.
handle	The quality of wool as judged by touch.
hue	"That attribute of a colour by which it is recognised as a red, a green, <i>etc.</i> , and which is dependent on its dominant wavelength, and independent of intensity or lightness" (The New Shorter Oxford English Dictionary).

kemps	Straight, brittle, and often hairy, fibres which are shed in the fleece.
micron (μ)	Micrometer (one millionth of a metre). The unit of measurement of the fibre diameter of wool.
MSBSA	The Melanian Sheep Breeders' Society of Australia.
neps	Small lumps or knots of wool produced during processing.
noil	Short and broken fibres removed from wool during combing.
objective	Refers to measurements which are made according to recognised standards and means.
pillling	Appearance of small balls of 'fluff' on the surface of fabric due to wear and/or rubbing.
roving	A sliver of wool drawn out and slightly twisted.
SACSOS	The South Australian Coloured Sheep Owners' Society Inc.
saturation	The intensity of colour.
scouring	The washing of wool to remove all or most non-wool contaminants.
SDANZ	The Sheep Dairy Association of New Zealand.
skirting	The removal of processing faults from the edges and within the fleece.
sliver	A continuous strip or band of loose, untwisted fibres after carding.
sound	Wool of good tensile strength along the full length of the staple.
spinnability	The ease with which fibres are spun into yarn.
subjective	Refers to the estimation of grade by hand and eye.
suint	The water-soluble component contaminating raw wool.
tear	The ratio of tops to noils in combing.

tender	Wools which are in some degree deficient in tensile strength along the staple due to a gradual or sudden check to the growth of the fleece.
tex	a system of defining the weight (thickness) of yarn in grams per kilometre.
top	A continuous band or ribbon of combed fibres laid parallel in an untwisted condition and in ball form; all short and weak fibres (noil) and vegetable matter have been combed out.
unsound	Wools deficient in tensile strength whether by tenderness or break.
vegetable matter	A term describing varieties of vegetable matter which may contaminate wool.

INTRODUCTION

The production of black and coloured wool in New Zealand is the domain primarily of small farmers, many supplying the hand-craft market, but most is used in large-scale yarn processing. An increasing demand exists for natural-coloured wools suitable for the manufacture of apparel products. To fully satisfy those who create this demand, it is necessary to provide wools which meet processing specifications.

The requirements of the commercial (*i.e.* large scale processors and manufacturers) and hand-craft sectors differ in that commercial technology is able to both remove some 'faults' during processing and to mask others. By contrast, the hand-crafter looks for visually 'perfect' wool.

Apparel products are produced from a range of wools. Most of these wools are under 30 micron mean fibre diameter, although stronger wools may be used to achieve special effects in the finished garment, *e.g.* in tweeds. The main breeds of sheep producing wool for apparel manufacture are the Merino and its crosses (Polwarth, New Zealand Halfbred, Corriedale), plus the Down breeds, fine Perendale and fine Romney.

The methods utilised to select wool for commercial apparel processing have undergone dramatic change, particularly in the last twenty years. For centuries, the suitability of batches of wool for particular uses was assessed

subjectively by 'hand and eye'. Wool characteristics were ranked by terms such as quality, style, and character. A system, known as the Bradford Quality Number or Count, was used to grade for fineness and expressed the spinning capacity of the wool in numbers ranging from 30 to 90. A fine wool, which would give a greater length of yarn, had a high number while a strong (coarse) wool, which would produce a lesser length, had a lower number. In New Zealand the numbers ranged from 36 (strong) to 90 (fine).

The assessment of Quality Number was made on the basis of staple crimp size, lustre and handle. Generally, smaller crimps and soft handle indicated a fine wool while the presence of greater lustre indicated a stronger wool. The factors had to be balanced against each other when determining the Quality Number as well as the breed/breed-type of sheep producing the wool. The skill required to assess Quality Number was learned over many years of practical experience. While those working in the wool industry understood the gradings given, such assessments lacked definite boundaries and were dependent upon not only the ability and experience of the person assessing the wool, but also the importance that person gave to particular characteristics.

The more recent development of an increasing number of objective measurement techniques, using standard and recognised means, has enabled the processors to better define parameters relating to processing performance.

This project was undertaken in five sections. The first attempts to provide production statistics for black and coloured wool in New Zealand and to

estimate processor requirements in terms of means and variation in objectively measured as well as subjectively assessed traits. In Section Two the results of tests on samples of black and coloured wools sourced from throughout New Zealand are presented and discussed. Section Three concerns the establishment of an objective measurement scale for measuring colour in black and coloured wool and the variation within colour ranges. The fourth section examines potential wool production objectives for breeders of black and coloured sheep that are consistent with processor requirements, and Section Five suggests a business organisation/system providing the linkages between producers and processors with more accurate specification of the wools required.

SECTION 1:

1.0 BLACK AND COLOURED WOOL PRODUCTION IN NEW ZEALAND AND PROCESSOR REQUIREMENTS

1.1 WOOL PRODUCTION IN FLOCKS OF COLOURED SHEEP

The Black and Coloured Sheep Breeders' Association of New Zealand Inc. was established in 1976. The primary objective of the association continues to be "the encouragement of the breeding, owning and improvement of all breeds of black and coloured sheep in New Zealand and the production of good wool types suitable for hand-crafts and commercial uses" (BCSBANZ, 1999).

Many coloured sheep flocks in New Zealand originate from occasional black and coloured lambs born into white flocks rather than from coloured stock purchased from a coloured sheep stud or flock.

An opportunity exists to improve the quality of wool produced and to develop niche apparel markets suited to the black and coloured wool types grown in New Zealand and to processors'/ manufacturers' requirements. To achieve this objective, breeders need an improved method of assessing wool colour as the specifications are different from those for white wool.

Data relating to the number of black and coloured sheep in New Zealand is at best "sketchy". Currently (1999) members of the Association farm 9781 sheep in 152 flocks, varying in both breed-type and size of flock (Table 1).

Table 1: Distribution of Breed Types and Numbers of Black and Coloured Sheep Flocks in New Zealand
(BCSBANZ 1996 & 1999).

<u>Percentage of Breed Type by Property</u>		
	<u>1999</u>	<u>1996</u>
Merino/Merino cross	32%	36%
Romney/Romney cross	59%	62%
Perendale/Lincoln, English Leicester, Finn, Gotland, Down-cross	9%	2%
Number of:		
Registered Stud Flocks	24	27
Commercial Flocks	128	148
Sheep	9781	11005

The figures in Table 1 reflect only those sheep farmed by members of the BCSBANZ, although not all members supply details of breeds and the number of sheep they farm (BCSBANZ, 1999).

The genetic base for coloured sheep in New Zealand is small when compared with the number of white sheep farmed (approximately 44 million in 1999) . The

small flock size (Table 2) limits genetic progress; the major criterion is often colour rather than particular wool characteristics, conformation excellence, fecundity, *etc.*

Table 2: Size of Coloured Flocks in New Zealand
(BCSBANZ, 1999)

% of National Coloured Flock	No. of Sheep per Farm
63%	< 50
23%	51 - 100
9%	101 - 200
2%	201 - 300
3%	301 +

The total tonnage of coloured wool production in New Zealand is, at best, a "guess-timate". The reason for the lack of accurate data relates to the various selling methods employed by growers. Private sales for hand-craft use are seldom recorded in official documents. Wools of New Zealand has no data relating to sales of coloured wool, other than the amount of black/dark fibre identified in sale lots of white wool. Throughout the country, 'pools' have become established as a means of selling pigmented wool. Growers deliver their wool to the pool where it is sorted into fineness and colour lines prior to sale or tender. The South Island Wool Pool (SIWP) is a privately-owned company which is in contrast to others in the North Island which are operated with volunteer labour provided by individual branches of the BCSBANZ. Wool brokers throughout the country also handle black and coloured wool, most of

which is sold by auction. Volumes handled by the Association's pools may be included either entirely, or in part, in statistics provided by auction houses. Should a branch pool be unable to sell its wool privately, the bales may be forwarded to an auction house for selling.

1998 figures suggest approximately 110,000kg were sorted into sale lines by wool pools (Leslie, 1999; BCSBANZ, Personal Communication, 1999). The 'hobby' preference for farming black and coloured sheep contributes to the lack of reliable statistics therefore the total number of animals producing black and coloured wool in New Zealand is known with poor precision. The volume suggested here would equate to approximately 25,000 animals but no reliable data exists to confirm or deny this population estimate.

1.2 THE CHARACTERISTICS OF RAW WOOL AND THEIR PLACE IN PROCESSING

Fleeces grown by different types of sheep are identifiable by characteristics of their respective wool fibres. For example, over a twelve month period of growth some breed-types produce long, coarse, lustrous fibres while others produce shorter, finer, chalk-coloured fibres. In order to provide a description of a particular batch of wool, the characteristics considered important in textile processing are either subjectively assessed or, as is the more recent commercial practice, objectively measured. The main wool characteristics, important in apparel processes, are listed in Table 3:

Table 3: Wool Characteristics of Importance to Apparel Processors

Wool Characteristic	Abbreviation
Fineness/Mean Fibre Diameter	MFD
Staple Length/Mean Fibre Length	SL/MFL
Staple Strength/Mean Fibre Strength	SS/MFS
Colour	COL
Crimp Frequency	CRF
Bulk/Resistance to Compression	BUL/RC
Medullation	MED
Yield	YLD

The importance of a characteristic is determined by a combination of the processing system employed and the desired end-product. The major effects of each characteristic on wool processing will now be discussed.

1.2.1 Mean Fibre Diameter/Fineness

Fineness, measured by the mean fibre diameter (MFD) of a wool lot, has long been considered the most important characteristic from the standpoint of quality and commercial value in apparel wool. The MFD of a batch of raw wool largely determines the potential fineness of the yarn which can be spun and, in the final fabric, affects handle, weight and appearance. Finer diameter wools tend to give softer and, if desired, finer products.

Fibre diameter is unaltered by processing, unlike fibre length and strength. However, research into the relationship between fibre fineness, length and crimp patterns led to an understanding and appreciation of the variations which occur within and between staples, fleeces, sale lots and breeds (Roberts, 1931; Rottenbury *et al.*, 1983). The subsequent development of objective measurements has enabled processors to more easily identify such differences in wool lots.

1.2.1.1 Coefficient of Variation of Fibre Diameter (CVD)

The range and variation of fibre diameter in a batch does affect processing, frequently in conjunction with other characteristics. There is a strong correlation between the standard deviation of mean fibre diameter and the mean diameter for tops ranging from 17-30 microns mean fibre diameter (Bow & David, 1992).

For apparel wools, the coefficient of variation of fibre diameter (CVD) ranges from 20-27% (Lunney, 1983; Bow & David, 1992; Lamb, 1992). The CVD affects the number of fibres in the cross-section of a given count and therefore the probability of yarn breakage (ends-down) when spinning near the limit of the count (which is rare in practice). Use of wool with a CVD of 28%, in comparison with using wool of the same mean fibre diameter but a CVD of 25%, can increase ends-down from 10 to 14 per 100 spindle hours (Downes, 1975b). Ten ends-down per 100 spindle hours is treated as the maximum acceptable in commercial production. Allowing for a 'safety margin', a limit of 35 fibres is increased to 40-45 fibres per cross-section to allow for imperfections in the spinning machinery and abnormalities in the sliver being spun.

Yarn properties are not greatly affected by CVD, a measure considered by Lamb (1992) to be about one-fifth as important as mean fibre diameter (micron). His observations indicated that a reduction in CVD from 25% to 20% would enable a processor to use a 21 micron wool instead of a 20 micron wool. The strength and evenness of the resultant yarn, as well as spinning performance, could be expected to be the same. Alternatively, if the 20 micron wool (CVD 25%) was used, CVD would not necessarily be the sole cause of reduced spinning performance or yarn irregularity, but it could affect yarn strength and extension at break.

1.2.1.2 Handle/Fabric Prickle

The handle of woollen fabrics and garments is of major importance to manufacturers and consumers. A harsh handle or scratchy sensation experienced by some people can result in a life-time preference for other fibres, particularly cotton. Handle has not been an objectively measured trait because of the difficulty in assessing softness of handle by mechanical or technological means. Instead, handle has been assessed by asking people to rate fabrics made from differing yarns and yarn blends. This may have been according to a scale of 1-10 or simply by nominating the softer of a pair of samples. Studies of the role of fibre diameter in the perception of harshness or 'prickle' has resulted in a better understanding of the factors involved and the means by which prickle may be almost eliminated.

Coarse fibre ends tend to come to the surface of yarn during spinning creating a 'coarse edge'. These coarser fibre ends can evoke fabric prickle and discomfort for the wearer (Holcombe, 1986; Matsudaira *et al.*, 1990; Naylor, 1992a). Finishing processes, such as singeing, cropping, pressing and raising,

can significantly alter the properties of the surface of fabric. In addition, handling characteristics may be improved by chemical treatments, such as the use of softening agents, as well as by changing the structure of both the yarn and fabric, e.g. by altering the levels of twist (Bow & David, 1992). By contrast, dyeing can increase the number of protruding hairs and subsequently increase prickle effect.

An investigation into the effects of blending fibres of varying fineness and length on the handle of knitted vests (Rolando & Townend, 1962) indicated that as little as a 10% coarser-fibre content could be detected by both specialist as well as inexperienced textile personnel. Similar results were obtained by Baudinet & Jowsey (1978) using New Zealand wool of 23, 26, 29, 31 and 33 microns, covering most of the wool used in apparel processing in New Zealand.

There is no simple method of measuring the distribution of fibre ends protruding from a fabric but the percentage of fibres greater than 30 microns ($\%>30$ microns) has become an indicative criterion of likely fabric-evoked prickle (PF). When 5% or more of fibres are >30 microns, prickle is assumed to be detectable to a point beyond which fabric manufacturers will receive complaints from end-users as a result of skin irritation. This is particularly so with fibres >40 microns (Naylor, 1992a; de Groot, 1992). Should the amount of coarse edge increase, even by as little as one percentage point, the perception of prickliness will increase also (Naylor, 1992b).

Naylor *et al.* (1995) studied the coarse edge of 20-24 micron Australian wool and concluded that a one micron change in MFD had the same effect on the coarse edge as an approximate 3-8 percentage point shift of CVD. This study confirmed the earlier finding by Naylor (1992) of the strong correlation between skin comfort and the coarse edge in fibre diameter distribution.

Earlier research suggested measures of CVD and %>30 microns were useful indicators of commercial significance (Lunney, 1983). Dolling *et al.* (1992) used Australian Merino fleeces to study the effects on handle, and in particular the prickle of fabrics, differing in mean fibre diameter and CVD. Two groups of fleeces with similar characteristics (mean fibre diameter, diameter distribution, staple length and strength) were selected and processed into fabrics. One group had MFD of 23.2 microns and CVD 16.4%, while the other was 21.5 microns and 21.7% respectively. The group with the higher MFD was perceived to be less prickly than the finer group, which the researchers deduced was caused by two factors. The fabric made from 23.2 micron MFD wool had a lower CVD as well as a lower %>30 microns (3.6% versus 5.0%). The combination of low variability of fibre diameter and low coarse fibre content was associated with a reduced prickle factor by assessors. For this reason, the measures of MFD, CVD and %>30 microns are considered important characteristics in apparel wool. They assume greater importance than many other characteristics because of the level of acceptance of softer, smoother fabrics by end-users.

In another comparison of three tops in which all characteristics except the CVD were matched, an association was evident also between CVD and fabric bending rigidity, smoothness and perceived prickle (de Groot, 1992).

Mean fibre diameter has a much greater effect on the softness of handle when worsted spun than any other fibre characteristic. Increasing CVD by 10% can be expected to increase fabric stiffness (rigidity) by approximately 20%, and has been likened to an increase in mean fibre diameter of around 4% (Roberts, 1961).

1.2.1.3 Summary

Mean fibre diameter is justifiably ranked as the most important characteristic in apparel processing. MFD largely determines the fineness and associated softness of the yarn which can be spun. The CVD of fibre diameter expressed in a processing batch occasionally also has an important contribution to handle and wearer comfort. Differences between lines in MFD tend to mask the effects of other properties, such as CVD, the coefficient of variation of length (CVL), and crimp frequency (CRF) (Bastawisy *et al.* 1961).

Mean fibre diameter, coefficient of variation of mean fibre diameter and the percentage of fibres greater than 30 microns can be measured using instruments such as the Optical Fibre Diameter Analyser [OFDA] (Baxter, 1992).

1.2.2 Mean Fibre Length

The importance of mean fibre length measurements is based upon the following findings (Whan, 1972; Marler, 1992;):

- mean fibre length in greasy wool is highly correlated with the mean staple length in the same greasy wool.
- between fleece wool lots of a particular style, mean fibre length of tops produced is highly correlated with the mean staple length of the greasy wool
- mean fibre length in the top is influenced by the staple strength of the greasy wool.

- the percentage of noilage achieved during processing is influenced by the staple strength of the greasy wool.
- the position of break has an influence on the mean fibre length of the top.

Fibre length is a major influence in choosing the process by which wool will be spun into yarn and is considered the second most important characteristic (after fibre diameter) influencing spinning performance and yarn properties. In all stages of processing (card sliver, tops and yarns) fibre length is measured and used to specify the material. Very good linear relationships exist between mean fibre length in tops ($r=0.97$) and mean staple length in greasy Merino wool (Bow 1979; Rottenbury, 1979). Processing factors, such as scour conditions, card types/settings and fibre breakage alter fibre length. Other characteristics such as fibre diameter, staple strength and VM content also contribute to the fibre length in the finished top. Fibre length tends to reduce with decreasing fibre diameter, decreasing staple strength, and increasing levels of VM contamination (due to breakages during removal of same).

1.2.2.1 Fibre Length Distribution

Fibre length distribution in combed wool samples can be measured using an almeter. The results assist in the prediction of processing performance and the mean fibre length and coefficient of variation of fibre length can be estimated. The almeter provides measures of mean fibre length in terms of both 'hauteur' and 'barbe', in addition to an estimate of short-fibre content. Barbe is based on the percentage of fibres by weight having a length equal to or larger than a given value whereas the estimation of hauteur attempts to correct for the heavier weight of longer fibres. The hauteur measure is used in Australia because of the predominance of Merino-type wool for worsted processing. The

barbe measure is preferred in New Zealand and reflects the dominance of crossbred wool and the practice of blending different wool types to meet buyer specifications (Wood *et al.*, 1988).

The mean fibre length of wool top is important as it affects the strength, appearance and surface characteristics of the yarn spun from it, and therefore the quality of the final product, often a garment (Douglas *et al.*, 1985). Over a three year period from 1981-1984, a total of 14 mills in 12 countries took part in the Trials Evaluating Additional Measurements (TEAM) Project, conducted jointly by the Australian Wool Testing Authority Ltd, CSIRO Division of Textile Physics and Australian Wool Corporation (Douglas, *et al.*, 1985). Raw wool measurements of staple length, staple strength, position of break and clean colour were made from commercial consignments of combing wool to supplement core-test information of yield, vegetable matter (VM) content and MFD. Processors co-operated by providing processing results and top measurements. The project's aim was to determine the relationships between processing performance and raw wool characteristics and thereby evaluate the usefulness or otherwise of such data for sale purposes. A further TEAM Project (TEAM-2) operated from 1986-1988 and concentrated on the analyses required to predict top hauteur, coefficient of variation of hauteur and noil (Douglas, 1989).

As a result of these extensive evaluations, it was found that the relative importance of a particular raw wool characteristic, or group of characteristics, was different in each of the participating mills in the trial, and was dependent upon the types of wool being processed. In general terms, diameter, staple length, staple strength and vegetable matter base were shown to be important raw wool characteristics affecting fibre length in the top. From this study, a general formula was derived for predicting fibre length in the top but the

formula differed from mill to mill because of factors such as scouring (make and age of equipment), processing lines (e.g. differing cards and combs), influences caused by time (high and low throughputs, delayed maintenance, setting changes, new equipment), and the equipment/method of measuring fibre length in the top.

The prediction formulae published in the final TEAM Project report were:

Fleece Wool: $H = 0.70MFD + 0.45SL + 0.41SS - 5.7$

Skirtings: $H = 1.53MFD + 0.40sSL + 0.32SS - 20.1$

H = Mean Fibre Length of the top (hauteur) in mm;

MFD = Mean Fibre Diameter of the greasy wool in microns;

SL = Mean Staple Length of the greasy wool in mm;

SS = Mean Staple Strength of the greasy wool in N/ktex

Fibre diameter and percentage of middle breaks also contributed to the hauteur, while vegetable matter base had a smaller effect.

From a wide range of wool types, a reliable predictor of processing performance was derived for individual mills. Objective measurements can be important factors in the buying strategy of wool manufacturers, in quality control and in production planning (Douglas, *et al.*, 1985).

From these studies the characteristics of over-riding importance in the prediction of hauteur were staple length and staple strength. Bell (1984) estimated that, second to fibre diameter, fibre length (hauteur) and its distribution contribute about 25% of the value of a top.

1.2.2.2 The Relationship of Fibre Length Distribution to Processing

As the variance of fibre length within staples of Merino wool is so small, relative to the variation resulting from fibre breakage during processing, there is little incentive for breeders to produce sheep with fibres of more uniform length.

Some variation in fibre length is considered essential for effective spinning (Bastawisy *et al.*, 1961; Hunter, 1980). Approximately 20% of the variation in fibre length in tops is due to the variation in the raw wool; the other 80% is usually due to blending and/or fibre breakage during carding and combing. The nature and extent of fibre breakage is dependent upon mill procedures but fibre breakage during processing drastically alters the fibre length characteristic of a wool. Rottenbury *et al.* (1986) reported that in typical worsted carding, 40% of the fibres break. Breakage at the carding stage is often reflected in more noil during combing than in the mean fibre length of the top (Downes, 1975a).

Yarn breakage is increased during spinning if there are too many short fibres, while extra-long fibres can wrap around the rollers. The distribution of fibre length affects yarn appearance because short fibres tend to migrate to the outside of the yarn. If free ends of short fibres protrude from the yarn, pilling can result (Teasdale, 1985), while long, coarse fibres protruding from the yarn surface frequently cause prickles. When the coefficient of variation of fibre length (CVL) is less than 13%, spinning performance deteriorates. However, if using wool above 20% CVL, a further increase in CVL is nearly always associated with an increase in the frequency of neps in the yarn (Bastawisy *et al.*, 1961).

A study of the effect of fibre length on spinning performance when using a modern high-draft worsted-spinning method (Bastawisy, *et al.*, 1961) indicated that longer fibres can be spun to finer counts but that the number of end-breaks reaches a plateau once fibre length is longer than approximately 90mm; so that there is virtually no advantage in using fine apparel wool longer than 100mm. This research demonstrated that a decrease in fibre diameter or an increase in fibre length (up to 100mm), all other factors being constant, will result in a finer spun count.

In sale lots of greasy wool, Whan (1972) concluded that the main reduction in staple length variation resulted from the removal of the short stapled and stained wools during skirting. In addition, the uniformity of fibre-length in greasy wool lots may be quite different to the fibre-length variation in tops due to fibre breakages during processing. Indeed, the length uniformity of tops made from unskirted fleece is not significantly greater than that of tops made from skirted fleece (Lang, *et al.*, 1967). In addition, fibre-length variation in tops is only marginally affected by skirting (Teasdale, 1985). An Australian study showed an average CVL of 14% (range 7-33%) for fleece wool and 22% (range 9-50%) for skirtings, the very high values indicating unacceptable mixtures of lengths (Marler, 1992).

A study was undertaken to assess the relevance, if any, of using combing performance predictions to unusual merino and crossbred wool types (lambs wool, cast fleeces, oddments and skirtings) (Mooy, *et al.*, 1988). The results indicated that, apart from hauteur predictions, raw wool characteristics of fibre diameter, staple length, staple strength and VM content, were frequently associated with processing performance, as is the case with fleece wool. Hauteur was found to be over-predicted for short wool and under-predicted for longer wool.

1.2.2.3 Noilage

Andrews (1979) compared noil percentages from five processing batches containing long, short, medium, unclassified and a mixture of long- and short-staple length wool. The results indicated there was no difference in processing performance and that the mean noilage was the same no matter how or if the wools were classed for length. That is, a high or low variation in staple length made no difference in noilage. The first conclusion of this study was that as most of the variability of fibre length is within fleeces, classing for length can only affect variability between fleeces and not the overall variability.

A corollary was that fibre breakage during processing (particularly carding) increased variability to such an extent that it eliminated the improvement in variability achieved through classing. While classing for length is principally undertaken to increase uniformity, little is achieved by classing for length in fleece lines.

1.2.2.4 Summary

As for all traits, staple length and strength are only important if they can be related to processing performance (e.g. card waste, noilage, machine settings and speeds) and product properties (MFL and CVL in the top). The mean fibre length measurement of a top is important because it affects processing performance; long-fibre wools can be spun at faster speeds than wools with lower hauteur, while yarns made from long-fibre wools have increased tensile strength.

In 1985, the Australia-developed CSIRO Automatic Tester for Length and Strength (ATLAS) was introduced to assist in the marketing of Australian wool. The additional measurements of length and strength of greasy wool enabled purchasers to make processing decisions and to predict end-use performance (Thompson, *et al.*, 1988). This equipment is now available in New Zealand but staple length and strength measurements do not provide such useful information in many New Zealand wool types.

Length-after-carding (LAC) measurements have become important in New Zealand and are considered to be of more relevance to processors than measures of mean fibre length and CVL in the raw wool. However these measurements are seldom used in the primary stage of wool marketing.

1.2.3 Mean Fibre Strength

Fibre strength and its effects on manufacturing performance is a complex matter. Unsoundness can occur anywhere along the fibre and to varying degrees within a staple. Whether the area of break or tenderness will affect processing and the end-use of such wool is determined largely by the processing system employed and type of wool. Different manufacturing processes are used for different end-uses and unsoundness is not important in all processes.

In the worsted system the effect of unsound wool is highlighted, perhaps more than in any other, because of the short fibres which result mainly from breakages during processing and the loss of many of these in noil. By contrast, woollen processing does not involve combing and therefore fibre length is not such a critical factor (Wickham, 1968).

The strength of a wool staple is dependent upon the strength of the individual fibres within the staple and the total cross-sectional area of fibre being tested. Fibre diameter varies along and within the staple and thereby affects the strength of the staple. In a flock of sheep kept under identical conditions, there is likely to be a large range of staple strengths (Reis, 1992). All degrees of staple weakness occur naturally and are largely controlled by husbandry factors. The importance of staple strength concerns the modification of expected processing behaviour, particularly in worsted tops and the properties of those tops (Teasdale, 1985).

1.2.3.1 Variation of Fibre/Staple Strength

Staple strength variation occurs between and within sale lots as well as between sheep in any mob and within the fleece of individual sheep. A study of sources of staple strength variation (Rottenbury, 1979) found that, on average, 61% of the total mob variation was due to differences between fleeces, the remainder due to within-fleece variation. When the fleeces were subdivided into regions, the between-fleece region effect (19%) was as large as the within-fleece-region effect (20%). Exceptions to these results could be expected where there were marked differences between different regions of the fleece (e.g. mid-back versus mid-side), possibly due to environmental factors, and resulting in more important between-region effects.

1.2.3.2 Position of Break

The position of staple/fibre break (POB), or weakness, is important in processing. Staples which break in the middle, for example, are more likely to reduce fibre length (hauteur) in the top than if the staple broke near the tip or butt.

The POB is expressed as a percentage of the overall staple length from the tip. For example, if a staple broke a quarter of the way down the staple from the tip, it would have a POB of 25%. Wool with breaks near the tip or butt tend to produce higher card losses (Rottenbury, *et al.*, 1985; Teasdale, 1985).

1.2.3.4 Processing Effects

Fibre tensile strength is difficult to isolate as a single effect on spinning performance as it is usually associated with fibre diameter, finer wool tending to have less tensile strength than coarser wool.

Fibre breakage during carding is increased by fibre entanglement during scouring or dyeing, tenderness in the wool fibres, excess fibre length and high carding speeds.

Yarn tensile strength and spinning limits are primarily a function of the number of fibres in a cross section of yarn. The number of breakages increases as the number of fibres decreases (Hunter, 1980). For sound wool, the spinning potential is determined by the fibre diameter and length, the limit being around 40 fibres per cross section. Tender wools increase the percentage of short fibres; when fibres break, they may come out in the noil, leading to a higher

percentage of noil and lower tear (top:noil ratio) but not necessarily shorter lengths in the top.

Weaker fibres tend to break to a greater extent during spinning. This, along with finer diameter, limits the count (thickness) to which the yarn may be spun. Should more frequent breaks occur during the drafting operation in spinning, the effect on the finest count to which the yarn may be spun is much greater (Bastawisy, *et al.*, 1961; Roberts, 1961; Hunter, 1980).

For wool processed on the woollen system, fibre strength is often relatively unimportant because length is not as important. By contrast, for worsted processing, higher strength values are required as a weak region is more than likely to reduce fibre length. Additionally, processors want to process as fast as possible and to minimise ends-down. High throughput is incompatible with efficient processing if there is too much fibre breakage.

1.2.3.5 Measurement of Staple Strength

Fibre strength is reflected in fibre breakage during processing, therefore staple length and strength measurements allow a good prediction of fibre length in the top for 'average' processing conditions (Hunter, 1980; Bigham *et al.* 1983; Ross, 1991; Butler, 1994).

Various methods, subjective and objective, have been used to measure staple strength. Staple strength is now often measured mechanically and is usually expressed in units of Newtons/kilotex (N/ktex). It is defined as the maximum force required for the fibres in the staple to rupture, corrected for thickness of staple (Rottenbury *et al.*, 1985).

Rottenbury (1979) had earlier suggested that the average force exerted by hand (subjective strength appraisal) was approximately 30 N/ktex [range 17-48 N/ktex]. Objectively measured samples of Australian wool (predominantly Merino) vary from less than 20 N/ktex to 80-90 N/ktex. This observation brings into question the use of subjective strength appraisal. The thickness of staples selected is not consistent and may affect staple strength assessments also. The maximum force normally exerted in the hand-test is 30-40 Newtons and the thinnest staples selected approximate 2 kilotex. On this basis, the upper limit of weakness detection is closer to 20 N/ktex. Above this value, the hand-test will not distinguish the staple strength and the wool could be regarded as sound simply because not enough force is exerted for the size of staples selected. The hand-test method would, on this basis, be suitable for wool below 20N/ktex only. As processing performance deteriorates progressively as staple strength weakens, a subjective assessment will not be tested for accuracy, and therefore validity, until well into processing. This represents a serious limitation of subjective strength appraisal.

1.2.3.6 Summary

Wool fibre strength is strongly associated with fibre diameter and is largely a function of MFD or more particularly, the minimum diameter or cross-section. Finer fibres are reportedly more variable in their cross-sectional area than coarser fibres which possibly explains why fibre tenacity shows an increase with increasing fibre diameter (Hunter, 1980).

Fibre strength is an important characteristic influencing the choice of process in which wool will be spun into yarn. An acceptable speed of processing is largely

a function of fibre strength. Yarn strength and elasticity are functions of MFD, CVD, MFL, CVL and crimp (Bastawisy *et al.* 1961).

1.2.4 Crimp Frequency

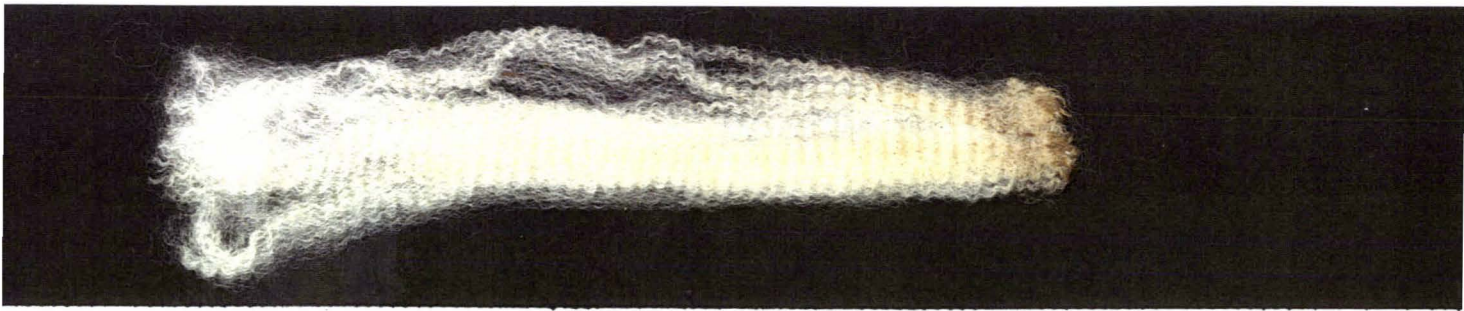
Fibre crimp is the natural waviness present in most wool fibres, the number of "waves" varying between and within sheep breeds (Figure 1 and Figure 2).

Crimp can be defined in terms of both staple crimp and fibre crimp, and some wools with high fibre crimp do not have clear staple crimp. An increase in fibre crimp generally increases resistance to compression and bulk, reduces felting of loose wool and changes the handle of loose wool.

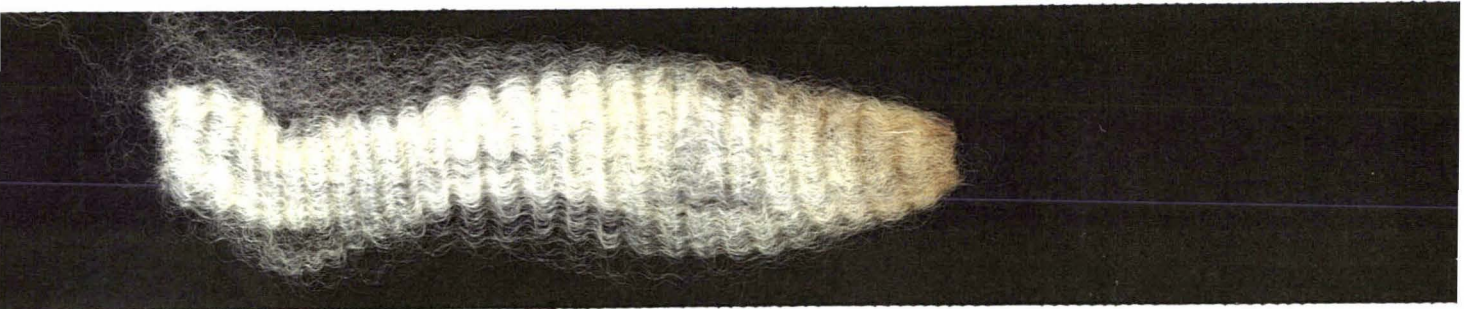
A greater number of crimps has been suggested as a means of improving the 'softness' of greasy wool and finished cloth. An increase in the number of crimps per 25mm from 10 to 15 was considered responsible for an improvement in the feel (smoothness). However, it is now considered that differences in mean fibre diameter frequently mask these effects and reduce their contribution to handle (Menkart & Detenbeck, 1957). Fibre crimp levels are usually reduced during processing but never entirely eliminated. Roberts, 1961). The significance of wool fibre crimp in worsted processing was studied by Menkart & Detenbeck (1957) and in the woollen system by Menkart and Joseph (1958). Their findings are summarised in Table 4.

Figure 1: Samples of Crimp Patterns

a) Merino: MFD = 25.5μ Bulk = $27\text{cm}^3/\text{g}$



b) Corriedale: MFD = 30.0μ Bulk = $28\text{cm}^3/\text{g}$



c) Perendale: MFD = 35.5μ Bulk = $26\text{cm}^3/\text{g}$

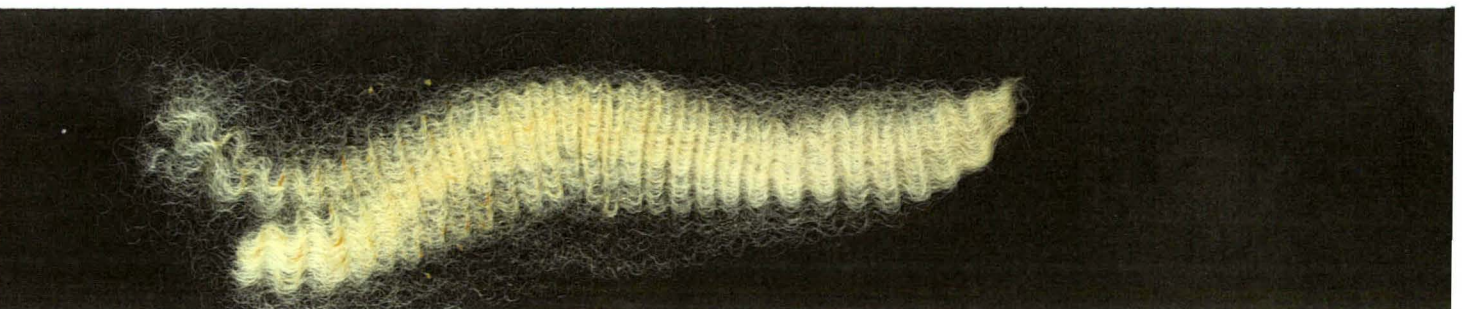
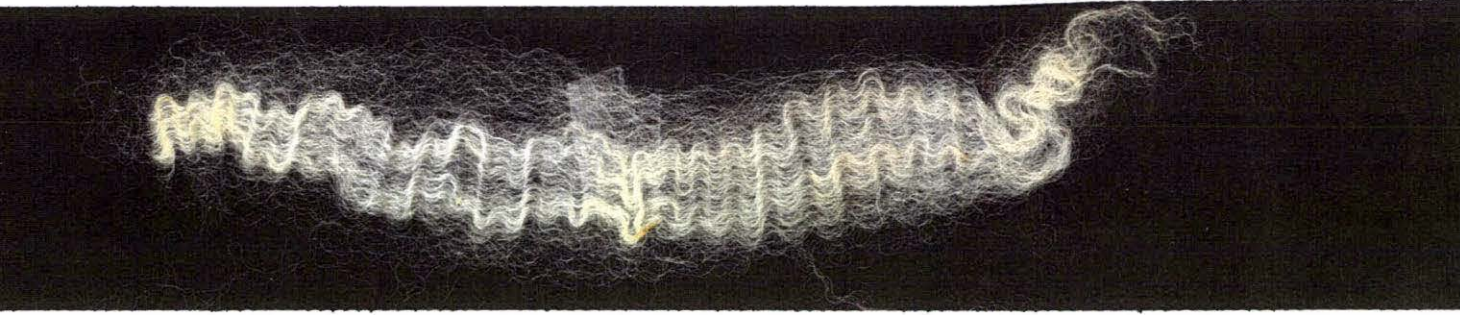


Figure 2: Samples of Crimp Patterns

d) New Zealand Romney: MFD = 36.0 μ Bulk = 22cm³/g



e) English Leicester: MFD = 40.0 μ Bulk = 18cm³/g



f) Drysdale: MFD = 44.0 μ Bulk = 22.0cm³/g

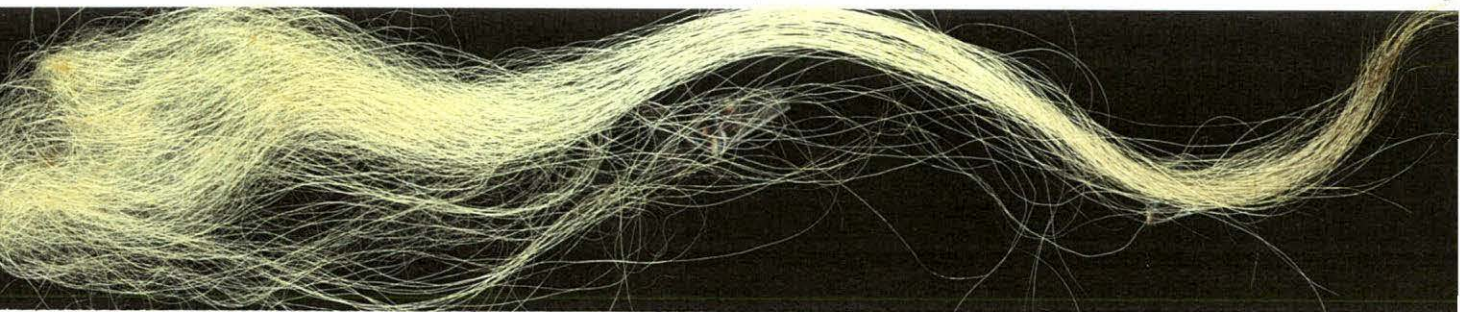


Table 4:**The Effects of High-Crimp Fibre**

(Menkart & Detenbeck, 1957; Menkart & Joseph, 1958)

Superior carding
Higher processing speed
Softer fabrics and yarns
Finer fabrics and yarns
Good wrinkle-recovery
Bulkier yarn
Lower extensional stiffness
Lower breaking extension
Lower breaking strength
Greater air permeability
Better drape
Thicker fabric (6-10%)

Overall, the two studies showed no greater effect of fibre crimp in either the woollen or worsted system. The expectation was that the more random and looser woollen structure would have allowed fibre crimp to have manifested itself more clearly.

These findings were confirmed again by Roberts (1961) who observed a detectable improvement in handle and perception of softness in both greasy wool and finished fabric where a higher number of crimps per 25mm existed.

The above results were similar to those of Lang & Sweetten (1960) following worsted processing of anomalous and normal Merino wool. The different crimp patterns were clearly seen - the anomalous-crimp wool having a lower and more irregular crimp frequency. After processing into worsted yarns and fabrics, the normal-wool products were favoured over those made using anomalous-crimp wool due to improved handle (smoother and softer) and yarn/fabric strength. The researchers noted that objective comparisons were essential to differentiate the wool for fibre diameter and strength in particular.

Bastawisy *et al.* (1961) found that with a newer high-draft spinning system low-crimp wool spun to a finer count with fewer end breakages at similar counts than high-crimp wool. They also compared low-and high-crimped nylon with low-and high-crimped wool and deduced that the more uniform roving obtained from straighter fibres (i.e. low-crimp) resulted in a more regular and stronger yarn. These results indicate that there is possibly no advantage in using high-crimp wool and that on occasion they may be inferior.

1.2.4.1 Summary

Fibre diameter is the only variable significantly correlated with fibre crimp, CVD showing no significant relation to crimp. However, despite the correlation between fibre diameter and fibre crimp, the effect on spinnability is masked when studied in conjunction with other fibre properties. Only when fibre crimp is studied on its own is the influence important. Studies have confirmed that with modern high-draft spinning systems, low crimp wools spin more evenly (Bastawisy *et al.*, 1961).

1.2.5 Bulk and Resistance to Compression

There are several systems of defining the space-filling properties of wool. Bulk is the measure used in New Zealand, whereas Australians frequently measure Resistance to Compression (Lunney, 1988).

Resistance to Compression (RC) is a measure of the resistance offered by a given mass of wool when compressed to a fixed volume.

Bulk is defined as a measure of the volume occupied by a given wool mass (cm^3/gm) when compressed by a prescribed load. It can be measured in the loose wool, core sample, sliver or yarn form. Loose wool bulk ranges from 15-40 cm^3/gm while core bulk ranges from 19-39 cm^3/gm .

Bulk, often termed 'springiness' has a significant effect on woollen-spun knitwear. The higher the bulk the 'softer' the apparent handle of the garment. This can override the effect of a slightly coarser mean fibre diameter. Similarly, in carpet manufacture, bulk is an important property in the recuperation of fibres from treading action and in the quantity of wool required to give a 'bulky' pile (Carnaby & Elliott, 1980).

New Zealand wools average between 15-36 cm^3/gm when full length, scoured and carded samples are measured. The measurement of wool bulk is a valuable indication of the potential value of the finished product as there is a positive correlation between loose-wool bulk and yarn bulk, even though yarn bulk is much lower. The single most important factor governing yarn bulk is the processing system (van Luijk, 1987) but, to a limited extent, the bulk of the raw wool is reflected in the bulk of the finished product.

There are large variations in RC among and between wools of different breeds and a strong correlation exists between RC and crimp frequency. In early processing systems, using superfine apparel wool (Merino types), RC was considered important in reducing losses through topmaking and increasing yarn strength. With the advent of modern high-speed processing, the reverse has been found to be true with higher card wastes and noilages from wool of high RC (Kurdo, *et al.*, 1986).

Wools with high RC tend to give lower scouring yields, a factor which can be understood with superfine Merino wools which have a higher wax and suint content. Kurdo *et al.* (1986) found a significant influence of RC and crimp frequency (CRF) on scoured yield, card waste, noilage, top-and-noil yield and fibre-length characteristics in tops processed from a superfine wool flock. Greater breakage of high-crimp, high RC wool during processing contributed to these effects (with the exception of scoured yield). The experiments demonstrated too that while differences in mean fibre length in tops are far less than the differences in mean staple length among the raw wool, the relationships between the two length measurements are substantially modified where large variations exist in RC measurements. For example, if the staple length of a low RC wool was 3mm shorter than that of a high RC wool the difference would be likely to increase to a 7mm difference in the top. The researchers suggested that an additional 10mm in staple length for high-crimp superfine wool may be necessary to achieve the same fibre length in tops produced from low-crimp superfine wool.

While wool of low RC gave a superior top-making performance and longer fibre length in the top, it is necessary to evaluate spinning performance and yarn/fabric quality before the significance of RC in wool textile processing is understood (Kurdo *et al.*, 1986).

1.2.5.1 Summary

The results of the Australian trials referred to above support RC measurements as being useful in the prediction of the likely topmaking performance of raw wool but other characteristics are usually of more importance for most end products

1.2.6 Medullation

Medullated fibres are those which have a hollow central cellular core, termed the medulla, instead of being tightly packed with cortical cells. As a result, there is less substance to absorb dye, resulting in medullated wools that were initially white appearing a different colour from non-medullated wools in the final product. This can be a serious fault.

The presence of medullated fibres does not mean that the yarn will be hairy. Medullation and hairiness are frequently confused. Hairy yarns, in the main, have many fibre ends protruding from the yarn (Henderson, 1968).

The significance of medullation and hairiness to growers, manufacturers and consumers was the subject of New Zealand research, based on Romney hogget wool, over fifty years ago (Townend & McMahan, 1944). Hogget wool was chosen as the most suitable raw material for the test because of its fineness. Two batches of britch- and hindquarters-wool were used. They were almost identical in terms of fineness, mean fibre length and soundness, but there was a difference between the two batches of about 4.6% of coarse, medullated fibre which was clearly visible in one raw wool lot. Following processing into dyed woven and knitted fabrics, there was no marked

difference in handle or appearance between those items produced from the less- or more-medullated wools. Despite the less medullated wool having a slightly superior spinning performance, the researchers concluded that the presence of up to 6% of coarse, medullated fibre did not appreciably affect the processing properties of sound, well-grown Romney hogget wool.

A follow-up project (Peryman *et al.*, 1952) processed into dyed fabric two batches of Corriedale hogget wool as near as identical in fibre diameter, length and soundness but differing in medullation by approximately 3.4% of "coarse hairy fibre". The medullation was not visually obvious in the hairier batch and was confined primarily to the tips. While there were no differences in appearance or handle in either the woven or knitted fabrics of each batch, some differences were apparent during processing. The medullated batch resulted in a more irregular roving and uneven yarn which caused more ends-down when spinning fine counts and a lower spinning limit. This result confirmed that of the earlier trials using Romney wool.

1.2.6.1 Summary

A measure of the percentage of medullated fibres in samples of a wool lot gives an indication of the effects likely to be encountered in processing and the end-product. A measure of CVD may provide much the same information.

1.2.7 Yield

Yield is expressed in several ways. The most common is clean scoured yield which may be defined as the percentage of usable fibre after the removal of contaminants.

In New Zealand, wool yields range from 59-75% for Merino types, 63-76% for Halfbred wool and 68-83% for crossbred wool, although lower and higher values may occur in particularly contaminated or extremely clean fleeces of any type.

Yield is an important factor in fibre valuation. In the white wool market, a contaminant is any substance that is not white wool. Natural contaminants include grease, dirt, suint, vegetable matter and some stains. Other contaminants include synthetic fibres from wool packs, twines, non-scourable brand marks of various colours, rubbish, metal pieces/machinery, clothing, non-wool fibres such as dog hair, and black and coloured wool. Poor shed/farm management may contribute to the extent of non-natural contaminants and increase the likelihood of spinners switching to synthetic fibres, totally free of contaminants, which can be ordered to exact measures of fineness and length for delivery.

Some contaminants can affect cost. For users of black and coloured wool, natural-colour is the primary requirement but growers of both white and coloured wool should realise that the natural advantages of wool may be outweighed and out-priced by contamination in greasy wool. Processors have to consider the cost:benefit ratio between cheap wool and high processing costs. It can be more profitable to purchase the most expensive greasy wool and have low processing costs.

Vegetable matter (VM) in raw wool has two particular effects in worsted processing (Bow *et al.*, 1989). They are:

- As VM increases, more wool is removed with the VM during processing, either as card waste or noil.
- Residual VM particles contaminate combed sliver.

One of the reasons for processing VM-contaminated wools on the worsted system is that it can handle a good proportion of VM without the need for carbonising. The woollen and semi-worsted systems offer less possibility of VM removal.

The amount of 'tip' varies greatly between wools, from less than 2% for a blocky tip (preferred by processors) to over 5% for an open, wasty tip. As about 90% of the tip is removed during processing, and particularly by carding, the yield in worsted tops is significantly affected by the tippiness of the wool (Walls, 1968).

1.2.7.1 Summary

Yield is determined by breed type and the presence of natural and environmental contaminants. VM contamination in particular influences the choice of processing system employed with the worsted system best able to handle high VM contaminated wools.

1.2.8 Colour

The majority of the world's processed wools are near-white and visual appearance is an important characteristic when supplying scoured wool to a customer. Paradoxically, Cottle & Zhao (1995) stated there is no relationship between the colour of greasy wool and the colour of scoured wool. According to Marler (1992) strong relationships exist between:

- the colour of commercially processed tops and the colour measurements made on scoured and carded greasy wool samples
- the dyeing potential of greasy wool and its clean colour measurement

The whiteness of wool has a distinct effect on the dyeing process. As a rule, the whiter the wool, the clearer and/or brighter the colour of those wools when dyed. The presence of yellow or dark fibres in raw wool intended for high-fashion apparel wear can represent a serious fault, especially when dyeing with pale colours (Lipson, 1972; Downes, 1975a; Bigham *et al.*, 1984).

1.2.8.1 The Measurement of Colour

Instruments for measuring colour are of two types. Spectrophotometers measure and record the amount of light reflected in each part of the visible spectrum while colorimeters measure the amount of light reflected in selected broader regions (rather than at each discrete point) (Stewart & Hoare, 1971).

The tristimulus colorimeter (e.g. Hunterlab D25DSM and ICI Digital) and spectrophotometer (e.g. Hunterlab ColorQuest) are the common apparatus used in New Zealand for measuring the colour of near-white wool (SANZ, 1984; Hammersley, 1991). While the spectrophotometers are a recent introduction, colorimeters have been in commercial use since 1976 to measure the Commission Internationale de l'Eclairage (International Commission on Illumination)(CIE) tristimulus values X, Y, and Z which measure the reflection of white light from wool fibres in the red (X), green (Y), and blue (Z) areas of the colour spectrum. The tristimulus values are determined for Illuminant C and the CIE 1931 standard colorimetric observer (Hammersley and Thompson, 1974). Y-Z, a measure of yellowness, is used for sale purposes to identify the whiteness of wool. The Y measure is a good indicator of lightness, a high reading indicating a bright wool.

A study of fleece colour from white sheep of Romney, Coopworth and Perendale breeds (Bigham, *et al.*, 1984) found a high correlation between X and Y values and little advantage in measuring both, as X could be predicted from Y. Y and Z values were also highly correlated but neither was correlated with the Y-Z value.

A scale used more in Australia, and adopted by the CIE in 1976 for the measurement of small colour differences, is the CIELAB system, derived from the XYZ scale. This CIELAB colour space is uniform and based largely on colour differentiation systems developed by Munsell and others (Kelly & Judd,

1955). The measures are L^* (lightness), a^* (redness if positive, greenness if negative) and b^* (yellowness if positive, blueness if negative).

After lengthy consideration, the tristimulus measure was adopted by New Zealand test houses (Hammersley, 1991) although there is a high correlation between tristimulus and CIELAB wool measurements for yellowness and lightness - b^* relates to the Y-Z reading for yellowness while L^* is the equivalent of the Y value.

1.2.8.2 Yellowing

Poats & Fong (1957) observed that colour was ranked third, after mean fibre diameter and mean fibre length, among the factors affecting a white wool buyer's appraisal of the quality of a lot sample. Initially, these workers used a colour comparator to rank whiteness, followed by the use of the Gardner Automatic Color Difference Meter. This instrument measured wool colour in terms of light reflectance/brightness, redness, greenness, yellowness and blueness. It was widely used to assist in the aggregation of wool colour lots sourced from regions of variable climatic conditions in the United States of America.

It is almost impossible to assess the scoured colour or yellowness of near white wool in the greasy state. Any yellow colour present may be permanent or

scourable and it is for this reason that the test for yellowness is important in giving an accurate indication of the scoured colour.

For greasy near-white wool, the intrinsic colour of the wool fibres may be masked by grease, suint and dust which may be almost entirely removed in scouring. Permanent yellow staining, often caused by the action of suint in hot and humid conditions, is not removed in the scour and reduces the range of colours into which the wool can be dyed. Similarly, black and coloured fibres, by the nature of their unscourable colours, are an obvious fault to processors wishing to dye with pale colours.

In a study aimed at detecting unscourable yellowness in greasy wool, Thompson & Whiteley (1985) observed that mean yellowness measurements (Y-Z) of test-scoured core samples provided a more equitable assessment of unscourable yellowness than subjectively assessed samples.

Mahar & Osborne (1996) studied early stage processing effects on the colour of Australian Merino fleece wool and skirtings. Their analysis of measurements taken at greasy wool (core sample), combing (noil) and after the final gilling (top) stages showed a good relationship between the colour of cleaned greasy wool and the colour of the resulting top. In terms of average yellowness (Y-Z), the relationships were very strong ($r=0.92$). Wool brightness (Y) relationships were less strong ($r=0.69$) but nevertheless still significant. In analysing measures of brightness, there was a weak but significant relationship between the Y-Z and Y values at both the cleaned greasy wool ($r^2=0.40$) and top

($r^2=0.32$) stages. Usually, a low Y-Z value is associated with a high Y value, *i.e.* a bright wool. This study identified the usefulness of raw wool measurements as predictors of post-processing colour in tops and thereby a quality control measure. The researchers suggested that, if mill processors were unable to predict colour in tops from raw wool measurements, a processing factor may be influencing the top colour (*e.g.* overheating during drying, the presence of additives such as anti-static agents, lubricants).

Warm, moist conditions can result in non-scourable yellow discolouration in susceptible fleeces. Wools which are susceptible to discolouration may change colour on the sheep, during storage and/or during processing. Wools with a low propensity to discolour can be expected to change less than susceptible wools (Reid, 1993).

1.2.8.2 Summary

The colour of wool is important to the textile industry because it affects dyeing performance. In particular, for products dyed with pastel colours, the whiter the wool, the brighter and clearer the dyed colour. While many very yellow greasy wools can scour to produce brilliantly white tops (Turk, 1993), by contrast, a wool which is cream or yellow in the scoured state, will not dye to a clear, pale colour or a bright, dark colour.

The measurement of colour is an average measure of the lot. It does not identify variability which may occur within a lot due to poor sorting. However, it is possible to estimate the dark fibre content of a lot of near-white wool using technology such as the Optical Fibre Diameter analyser (OFDA).

Processors have built up a knowledge of the range of colour readings which are acceptable for using particular dye colours and measurements falling outside these ranges are discounted.