Australian Cashmere - attributes and processing

A report for the Rural Industries Research and Development Corporation

by B. A. McGregor

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Foreword

Cashmere is a rare natural fibre, renowned for its softness. A commercial Australia cashmere industry was established during the mid-1980s. During the 1990s, there has been industry demand for research into fibre properties required by processors to produce yarn, fabric and garments demanded further along the value-adding chain and to investigate blending of cashmere with other natural fibres.

The key areas that were investigated in this report were:

- the quality of cashmere available to spinners and the attributes of Australian cashmere compared with cashmere from traditional sources
- the processing of Australian cashmere from raw fibre to knitted fabric
- the effect on textile product quality of blending Australian cashmere with different types of superfine Merino wool
- the quality and processing of short cashmere by-products
- a number of nutritional management practices that may affect certain raw cashmere fibre attributes.

In order to address the critical issues raised by industry the project has utilised facilities and samples from a wide range of sources. This has been done during a time of upheaval in the Australian textile research sector that posed extra challenges to the researcher.

This project was funded from industry revenue that is matched by funds provided by the Federal and Victorian Governments. This report, a new addition to RIRDCs diverse range of over 800 research publications, forms part of our Rare Natural Fibres R&D program, which aims to facilitate the development of new and established industries based on rare natural fibres.

Most of our publications are available for viewing, downloading or purchasing online through our website:

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- purchases at www.rirdc.gov.au/eshop

Simon Hearn
Managing Director
Rural Industries Research and Development Corporation
Acknowledgements

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The cheerful assistance of a number of dedicated and very hard working luxury fibre producers is gratefully acknowledged. I thank the Australian Cashmere Growers Association Ltd. officer bearers and staff (including Mrs. Carolyn Gould and chief fibre classer Mr. Noel Waters) and Mr. Stan and Mrs Bev Cooper of Belisa Cashmere, Kellyville, NSW, for their great support. Mr. Philip Toland and Mr. Greg Roberts are thanked for providing access to their flocks to select soft fine wool for this project.

I thank my former colleagues of the Fibre Quality Department at the Victorian Institute of Animal Science for their assistance. Managers and staff at the Australian Wool Testing Authority in Guildford, NSW and at North Melbourne, Victoria provided access to testing equipment and samples. Mrs Elsbieta Zahorska helped me undertake the KESF testing at UNSW. Mr Robert McLaughlin, International Fibre Centre Brunswick, provided access to their equipment.

A large number of companies and individuals willingly provided samples of their fibre and I gladly thank them for their support in particular Iran Cashmere Company, Rosewell Cashmere, Seal International Ltd, Dawson International, Dr A James, Dr T Madeley and Dr D Stapleton and the companies that wished to remain anonymous.

I would like to especially thank Ms Helen Daly and Dr Bill Sherwin, Ms Diana Picone and Dr Vincent Murray and their families for their support during and after my family’s stay in Sydney. I also thank my family for their understanding during my frequent trips interstate, for early morning departures and late night arrivals.

About the author

As a Senior Scientist, Bruce McGregor has specialised in improving the production and quality of speciality animal fibres and goat meat. He has been directly involved in the development of the mohair, cashmere, and alpaca industries with research, on-farm development and extension programs aimed at overcoming constraints to the development of viable industries. He has published over 250 research, technical and advisory articles on these subjects. Bruce has visited cashmere producing regions of Asia, alpaca producing regions of South America, and mohair producing regions in several countries. Appointed Head of the Fibre Quality Department, Victorian Institute of Animal Science, Agriculture Victoria in 1995 his work included managing research programs into Higher Quality Export Fine Wool, Minimising Chemical Residues in Wool and Fibre Testing Services. Bruce is also a member of the Editorial Advisory Board of the international scientific research journal Small Ruminant Research. He is a past president of the Victorian Branch of the Australian Society of Animal Production. In 1996 he received the Gold Award for a scientific paper at the 6th International Conference on Goats.
## Abbreviations

### Summary of abbreviations and their units

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
<th>Units</th>
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<tbody>
<tr>
<td>ACGA</td>
<td>Australian Cashmere Growers Association</td>
<td></td>
</tr>
<tr>
<td>ACMC</td>
<td>Australian Cashmere Marketing Corporation</td>
<td></td>
</tr>
<tr>
<td>AWTA</td>
<td>Australian Wool Testing Authority</td>
<td></td>
</tr>
<tr>
<td>BR</td>
<td>Blend ratio</td>
<td></td>
</tr>
<tr>
<td>CF</td>
<td>Cover factor</td>
<td></td>
</tr>
<tr>
<td>CM</td>
<td>Cashmere</td>
<td></td>
</tr>
<tr>
<td>CV</td>
<td>Contamination vegetable matter (of cashmere bales)</td>
<td></td>
</tr>
<tr>
<td>CV(D)</td>
<td>Coefficient of variation of mean fibre diameter</td>
<td>%</td>
</tr>
<tr>
<td>CV(H)</td>
<td>Coefficient of variation of Hauteur</td>
<td>%</td>
</tr>
<tr>
<td>CVm</td>
<td>Coefficient of variation of mass</td>
<td>%</td>
</tr>
<tr>
<td>CWY</td>
<td>Clean washing yield</td>
<td>%/w/w</td>
</tr>
<tr>
<td>CY</td>
<td>Cashmere yield in greasy fibre</td>
<td>%/w/w</td>
</tr>
<tr>
<td>Extn</td>
<td>Extension</td>
<td></td>
</tr>
<tr>
<td>FC</td>
<td>Fibre curvature (OFDA measurement)</td>
<td>°/mm</td>
</tr>
<tr>
<td>FL</td>
<td>Fibre length</td>
<td>mm</td>
</tr>
<tr>
<td>F&gt;30 μm</td>
<td>Percentage of fibres coarser than 30 μm</td>
<td>%</td>
</tr>
<tr>
<td>H</td>
<td>Hauteur</td>
<td>mm</td>
</tr>
<tr>
<td>HE</td>
<td>Hygral expansion</td>
<td></td>
</tr>
<tr>
<td>HL</td>
<td>Length of the longest fibres in Hauteur measurement (defined as either longest 5 or 1% of fibres)</td>
<td>mm</td>
</tr>
<tr>
<td>LAC</td>
<td>Length after carding</td>
<td>mm</td>
</tr>
<tr>
<td>LCW</td>
<td>Low crimp wool</td>
<td></td>
</tr>
<tr>
<td>Med</td>
<td>Medullated fibres</td>
<td></td>
</tr>
<tr>
<td>MFD</td>
<td>Mean fibre diameter</td>
<td>μm</td>
</tr>
<tr>
<td>OFDA</td>
<td>Optical Fibre Distribution Analyser</td>
<td></td>
</tr>
<tr>
<td>Re</td>
<td>Resistance to compression</td>
<td>kPa</td>
</tr>
<tr>
<td>RH</td>
<td>Relative humidity</td>
<td>%</td>
</tr>
<tr>
<td>RIRDC</td>
<td>Rural Industries Research and Development Corporation</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>Staple length</td>
<td>cm</td>
</tr>
<tr>
<td>SS</td>
<td>Staple strength</td>
<td>N/ktex</td>
</tr>
<tr>
<td>SW</td>
<td>Standard wool</td>
<td></td>
</tr>
<tr>
<td>Ten</td>
<td>Tenacity</td>
<td>cN/tex</td>
</tr>
<tr>
<td>TF</td>
<td>Twist factor</td>
<td></td>
</tr>
<tr>
<td>Tm</td>
<td>Fabric thickness Tm at maximum pressure of 50 gf/cm²</td>
<td>cm</td>
</tr>
<tr>
<td>Um%</td>
<td>Uster mass</td>
<td>%</td>
</tr>
<tr>
<td>VM</td>
<td>Vegetable matter contamination</td>
<td>%</td>
</tr>
<tr>
<td>WT</td>
<td>Wool type</td>
<td></td>
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Executive Summary

Introduction
The Australian cashmere industry began in the 1970s, expanded during the 1980s with support from international processors. It has struggled during the 1990s following disruption in traditional markets. There is a strong desire to process cashmere in Australia but knowledge of cashmere processing is limited and kept as a secret by international processors. The quality of Australian cashmere has been under threat by moves to change the international definition of cashmere that would put Australia at a serious marketing disadvantage.

Cashmere needs special processing. The raw fibre must be dehaired to separate the fine soft cashmere from coarse and worthless hair. Little was known about the dehairing performance of Australian cashmere. Following dehairing, cashmere has normally had short fibre lengths that have been suitable for only woollen spinning. The woollen spun yarns are bulky and have restricted uses as a result of potentially poor wear characteristics. Limited evidence suggested that Australian cashmere had the potential for processing on the worsted spinning system. This requires a different processing route that results in longer fibres for spinning into finer and stronger yarns more suitable for modern textiles. During the 1990s, five new textile firms were established to process Australian cashmere. They have raised important questions about the costs of dehairing and spinning and the use of short cashmere by-products produced from these processes. The value of blending cashmere with other fibres and the suitability of different types of fine wool, available in Australia, for blending with cashmere, have also been common questions. A Review and Interpretation of Existing Research on Raw-Fibre-to-End-Product Properties and Performance of Goat Fibres was commissioned for RIRDC in 1991 and observed that there “is an urgent need for process development”.

Research Objectives and general approach
As there was little objective information to assist either the Australian cashmere industry or the new textile businesses, the following project was conceived and completed. The project objectives were:
1. To improve the utilisation of short fibre length cashmere in textiles by determining the effect of blend ratio in blends of cashmere with wool or cotton on yarn and knitted fabric quality.
2. To determine the effects of using superior handling wool in cashmere/wool blend yarns on the textile properties of yarns and fabrics.
3. To identify preferred nutritional management practices for cashmere and mohair goats to optimise the textile properties of raw fibre, yarn and fabrics.

The following general process outlined in the original submission was carried out:
1. a review of literature pertaining to cashmere quality, cashmere processing and other aspects of this project was conducted
2. a survey was conducted of the quality and attributes of processed cashmere fibre available for spinners
3. Australian cashmere was purchased, characterised and processed into top, blended with different Australian fine wool, spun and knitted
4. short fibre by-products from the cashmere processing were blended with cotton and processed into experimental yarns
5. extensive testing of the yarns and fabrics was completed
6. testing of cashmere and mohair fibre derived from various known sources and past experimental samples.
Survey of cashmere textiles available for spinners
Samples of commercial lots of dehaired cashmere (n = 117) and cashmere tops (n = 25) were obtained from manufacturers in Europe, Iran, China, Australia, New Zealand and the USA. Samples of fibre classed as cashgora by cashmere marketing agencies in Australia, New Zealand and the USA were also taken.

The project has demonstrated that Australian cashmere has undoubted high quality fibre attributes. Compared to other sources of commercial cashmere in the survey Australia produced the longest dehaired cashmere. The cashmere has medium fibre diameter that can be used to produce new textile products not commercially available elsewhere. When processed, this cashmere produced tops with fibre attributes that place them at the highest level of international cashmere textile products.

The project demonstrated that the curvature of cashmere fibre is different in each major producing region of the world. Australian cashmere has low fibre curvature and a correspondingly low resistance to compression. In wool, low resistance to compression leads to softer fabrics. Potentially Australia has the softest cashmere in the world. The project also demonstrated that cashmere and cashgora are different products and they can be differentiated on the basis of fibre attributes.

Worsted processing of Australian cashmere
Cashmere typical of Australian produced fibre was purchased and processed. Superfine Merino wool with greatly different raw fibre softness attributes was carefully selected, processed, blended with the cashmere and spun into worsted yarn. The yarns were knitted into different fabrics and subjected to intensive objective testing.

The project has characterised the processing performance of known cashmere. The performance and yields of different cashmere products during dehairing and combing has been documented for industry. Cashmere fabric made from the worsted spun yarn had different properties to that obtained from traditional superfine wool and from soft low crimp superfine wool. Blending cashmere with wool altered the textile properties of the wool fabrics. The evidence obtained suggests that if cashmere wool textiles are to be manufactured then the use of low crimp superfine wool will produce knitwear with more “cashmere like” properties than that obtained using traditional high crimp superfine wool.

Processing of short Australian cashmere by-products
Short dehaired Australian cashmere and the combing waste (noil) produced in the worsted processing of cashmere was blended with Australian cotton and spun using modern rotor spinning equipment. The project demonstrated that it is possible to spin these blended yarns but difficulties were encountered when high cashmere content yarns were spun. Recommendations have been made on the commercial viability of rotor spinning short cashmere/cotton blend yarns.

Effect of management practices on cashmere and mohair properties
This work was restricted to a brief examination of previous research samples and other samples of known origin. These samples were measured for characteristics that may affect textile properties relevant to this project, namely fibre curvature, resistance to compression and staple fibre length.

The project demonstrated that nutrition did affect cashmere and mohair fibre curvature. Increasing cashmere production and increasing cashmere length were related to a reduction in cashmere fibre curvature. This is likely to explain some of the findings in the survey of the quality of international cashmere as the desire in Australia to produce longer cashmere is highly correlated with a decline in cashmere fibre curvature. This may have adverse consequences. For mohair the effects on fibre properties were regarded as not of commercial significance.

Conclusions
The results provide strong support for all the hypotheses examined.
Implications
The following implications of the project were identified:
1. The project has demonstrated the high fibre quality of Australian cashmere.
2. The project has helped provide a better definition of cashmere and cashgora.
3. The project has established the use of length testing for defining product quality of Australian cashmere.
4. The project began objective benchmarking of the quality attributes of processed Australian cashmere.
5. The project has assisted in the selling of dehaired Australian cashmere and the processing of Australian cashmere rather than offering raw cashmere for sale and export.
6. The project has provided clearer processing options for Australian cashmere and has assisted processors of Australian cashmere to become more commercial.
7. The project provided data on new product development of pure and blended cashmere.
8. The project demonstrated that the Australian Cashmere Marketing Corporation can deliver to objective specification of Australian cashmere and can deliver long fibre length cashmere suitable for worsted processing.
9. That nutritional management of cashmere goats can be manipulated to alter a number of attributes of relevance to textile performance.

Recommendations
On the basis of the findings of the project the following recommendations were made:
1. That the Australian Cashmere industry actively promotes the demonstrated quality attributes of Australian cashmere to enhance the sale value of their product and to encourage new producers.
2. That the Australian Cashmere industry actively participates in the international debate on the definitions of cashmere and cashgora to ensure that Australian cashmere is not devalued in the market.
3. That the Australian Cashmere industry focuses on improving cashmere length during production, in preparing cashmere for sale and during the processing of cashmere in Australia.
4. That the cashmere industry adopts Benchmarking practices to provide information on processed product quality.
5. That the Australian Cashmere industry reviews their classing practices in order to ensure the most cost-effective fibre classing, lot building and processing procedures.
6. That any processing trials to enhance worsted processing of cashmere in commercial works should focus on producing strong yarns suitable for commercial knitting.
7. New product development work should investigate the use of filament fibres and further develop products for short cashmere.
8. That the results of this project be extended to the cashmere industry and published.
9. That during the development of any cashmere/wool blend textiles that the Australian Cashmere industry work with the producers and processors of soft superfine wool in order to commercialise new products that exploit the natural attributes of both fibres.
Chapter 1
Introduction

1.1 Cashmere industry development

Cashmere became an industrial raw material during the 19th century when trade in commercial quantities of raw fibre began between Asia and Europe. Valerie Audresset SA, Louviers, France claim to be the first in 1836 to commercially spin cashmere. From 1906 Dawson International began purchasing cashmere from China having invented the first commercial dehairing machinery (Blackburn 1990) but was restricted to purchasing fibre from Beijing and Tianjing. From 1978, when trade was liberalised, Dawson International began to buy cashmere from the provinces.

During the 19th century the expansion of the pastoral industry in Australia left a legacy of escaped and abandoned goats in the semi-arid regions of Australia (Holst and McGregor 1992). As a consequence of the commercial interest in expanding mohair production in Australia, the Australian Mohair Company established an upgrading program in north-western New South Wales using captured feral goats for cross breeding. In 1972, cashmere was identified on these goats (Smith et al. 1973). Attempts were then made to attract international processors to support the development of a cashmere industry in Australia (Moylan 1977).

Dawson International became directly involved in supporting the development of an Australian cashmere industry in 1980 (Anon 1981) and undertook early testing and product development trials with Australian cashmere. By 1989, Australia produced almost 70 tonne of raw cashmere fibre. The world textile depression that followed the stock market crash of 1987 resulted in serious challenges for the fledging Australian industry. Dawson International withdrew its support, sold its demonstration farm and exited Australia while at the same time establishing joint-venture companies in China. Disruptions in world trade and serious problems with quality control with Chinese cashmere resulted in market instability and depressed prices (McGregor 2000). Information flow from processors about product development and feedback to Australian producers on product quality stopped.

1.2 Defining cashmere and the quality of Australian cashmere

During the 1980s the world's leading cashmere processors purchased Australian cashmere and provided brief reports on the quality of products. Australian cashmere is regarded as being substantially free of the major contaminants grease, soil, vegetable matter impurity fibres and lice egg casings, which cause significant problems during dyeing by detracting from the appearance of the finished article. Premium Australian cashmere is also regarded as being longer than Mongolian cashmere but with a greater mean fibre diameter. International and Australian processors regard Australian cashmere as having the best handle in the world. However none of these claims are supported by objective measurement. Despite these claimed advantages there has been significant market failure in selling Australian cashmere during the past 10 years. The cashmere industry, along with the wool, mohair and alpaca industries, has identified the need to develop high quality textile products in Australia.

At the time of Dawson Internationals withdrawal from Australia a debate about the accurate identification and definition of cashmere was raging. Three International Symposia on Speciality Animal Fibres were held in Aachen, Germany hosted by the German Wool Research Institute (DWI). Based on certain fibre properties including fibre diameter and fibre cuticle scale dimensions measured using the scanning electron microscope (SEM), DWI scientists have proposed a system to define and classify cashmere (Phan et al. 1991, Phan and Wortmann 1996). As scientists have obtained greater experience with the SEM technique they have encountered some difficulty in clearly
separating cashmere fibres from different origins (e.g., Phan et al. 1991, p.11 and Phan and Wortmann 1996, p.54). Without consulting the Australian industry, the DWI scientists have proposed that “the so-called Australian cashmere” (Phan et al. 1991, p.11) be classified as “crossbred cashmere” (Phan and Wortmann 1996).

The basis for the coining of the phrase “crossbred cashmere” appears to have been reports from casual visitors to Australia who are likely to have had little knowledge of the actual animal production system in Australia, and no idea of the confusion that such a term may bring to the debate on Australian cashmere quality. The author was advised by the Executive Officer of the Australian Cashmere Marketing Corporation (C. Gould 1997) that the samples of Australian fibre studied at DWI were obtained before the Australian Cashmere Marketing Corporation developed and implemented their comprehensive quality control, fibre classification and sorting procedures (Anon 1997c). These quality assurance procedures are required prior to branding Australian cashmere with the Australian Cashmere Trade Mark and have been in place for over a decade. The proposed classification terminology has potentially serious repercussions for the Australian cashmere industry and the marketing of its products.

1.3 Cashmere textile production in Australia

During the mid 1990s, Australian cashmere prices were depressed and production declined. Many believed that the future for the Australian cashmere industry lay in value adding and that increased technological information was needed (Leeder et al. 1992, 1998; Skillecorn 1993). Five small textile companies were established in Australia during the period 1992 and 1999 specifically to process Australian cashmere. Little information is available in published scientific and textile journals to assist these new companies to process cashmere efficiently. There is however, some limited information on many important subjects in conference proceedings and industry magazines. For an Australian cashmere industry to develop, reliable objective information is required on the properties and processing of cashmere and cashmere textiles. This information is required not only by processors but also to help market Australian cashmere.

The knowledge of the processing requirements of both cashmere and superior superfine Merino wool is generally kept as confidential and those who process such fibres will continue to treat their knowledge in such a way. In their “Review and Interpretation of Existing Research Results on Raw-Fibre-to-End-Product Properties and Performance of Goat Fibres” commissioned for RIRDC, Leeder et al. (1992, 1998) observed that there “is an urgent need for process development”. Leeder et al. (1992, 1998) noted that higher quality products are becoming available overseas by the development of special processing techniques, which are usually kept as in-house secrets, or by blending with other fibres, principally wool. They recommended that a wider range of products be developed with the inclusion of objective measurement of the properties of products made from goat fibres. In particular objective measurements on blends of goat fibres with other fibres are needed to define optimum blend ratios for various products.

In addition, there is little knowledge of the textile properties of raw Australian cashmere and mohair or the effects of nutritional management practices on the textile properties of the fibre apart from mean fibre diameter. In Hunters (1993) exhaustive review of mohairs properties, processing and applications (citing over 1000 references) he refers to the textile properties of mohair compared to wool, and other animal fibres including cashmere. There is almost no information on the relative merits of the textile properties of Australian grown mohair or cashmere.

1.4 Processing Australian cashmere

Cashmere must be processed to dehair the fibre, resulting in separation of the soft cashmere from the coarser and worthless guard hairs. Traditionally cashmere is processed on the woollen system that can utilise short fibres to produce soft bulky yarns. Fabrics produced from woollen spun yarns are prone to surface wear and pilling. Longer animal fibres such as wool, mohair and alpaca are
processed on the worsted system that removes short fibres by combing. The resulting longer fibres are spun to produce stronger yarns that produce fabrics of lighter weight with less propensity to pill. It was proposed in the 1980s that the length of Australian Cashmere made it suitable for worsted processing. The amount of the world's cashmere production used for worsted processing is just 10% (Skillecorn 1993).

Premium cashmere costs about $100/kg of down to purchase and deliver to the processor and in excess of $US 25/kg to dehair. Processors of cashmere have reported failure to achieve high processing yields and a reduction in length of cashmere during the dehairing process, although these observations are not documented. There has been one report of the dehairing yields of Australian cashmere (Rosewell 1993) and the original reports have been verified by the author (Table 1).

Rosewell (1993) provided data for two lots of Australian cashmere processed in Inner Mongolia. The data show that about 22% of the cashmere was lost in droppings and a further 12 to 19% was obtained in the very short 21 to 22 mm fibre length categories. The longest dehaired cashmere produced was classified as 40 mm. No definition of these length measurements has been obtained so it is not clear if they relate to length after carding (equivalent to length by number or for tops Hauteur or to length by weight or for tops Barbe or some median or midpoint length determined from a fibre draw card).

Table 1. The weight of Australian cashmere in various fibre length categories after dehairing at Bao Tau Luda Cashmere Sweater Company, Inner Mongolia calculated as the percentage of the raw fibre weight before scouring (adapted from Rosewell 1993 and original data sheets)

<table>
<thead>
<tr>
<th>Cashmere fibre length parameter</th>
<th>Weight of cashmere (% w/w of raw fibre) ¹</th>
<th>Lot 1</th>
<th>Lot 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mm medium length</td>
<td>6.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37 - 38 mm medium length</td>
<td>7.89</td>
<td>5.47</td>
<td></td>
</tr>
<tr>
<td>31 mm medium length</td>
<td>6.91</td>
<td>5.85</td>
<td></td>
</tr>
<tr>
<td>27 - 29 mm medium length</td>
<td>0.83</td>
<td>6.41</td>
<td></td>
</tr>
<tr>
<td>21 - 22 mm medium length</td>
<td>4.06</td>
<td>6.04</td>
<td></td>
</tr>
<tr>
<td>Cashmere droppings *</td>
<td>6.09</td>
<td>5.84</td>
<td></td>
</tr>
<tr>
<td>Coarse hair droppings #</td>
<td>1.62</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>Net cashmere yield %</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Excluding cashmere in droppings</td>
<td>26.1</td>
<td>23.8</td>
<td></td>
</tr>
<tr>
<td>Including cashmere in droppings</td>
<td>33.8</td>
<td>30.2</td>
<td></td>
</tr>
</tbody>
</table>

¹ The content of guard hair in the 21 to 40 mm long cashmere ranged from 0.17 to 0.29 %
* Calculated from cashmere droppings that contained 28 to 79 % cashmere,
# Calculated from coarse hair droppings that contained 1.3 to 3 % cashmere.

Only limited commercial processing of Australian worsted cashmere yarn has occurred and only a few samples of worsted spun cashmere knitwear were made by Dawson International (Smith 1987b). Dawson International regarded the cashmere from Australia as longer than that from existing supplies from China, Mongolia, Iran and Afghanistan but gave no details on the actual length (Smith 1985). Nesti (1989) believed that Australia had the potential to produce fine cashmere of 100 mm, which after dehairing could produce a top of mean length of 55 mm, a product that had not been seen before, but he did not provide any evidence to support his view. Steadman (1995) provided a brief report on the production of some samples of worsted spun 50% cashmere 50% wool samples.

Commercial processors of Australian cashmere aiming to produce worsted cashmere yarns report that far less than 50% of the dehaired cashmere is of sufficient length to be “suitable” for worsted processing. If this fibre is combed, the noils stored and the useable portion spun, the effective cost of the yarn is at least $360/kg. Such costs are prohibitive and the storage of dehaired noils is not a long term proposition as it ties up capital. Alternatively if such cashmere is spun on the worsted system, control of the short fibres during spinning will be poor and the resultant yarn will be excessively hairy, have significant thick and thin places, it will be weaker and resultant fabrics will pill.
excessively. It is clear that methods for processing such expensive dehaired cashmere into quality textiles need to be found.

Prior to and during this project, Australian cashmere processors have expressed strong interest in:
- the development of objective knowledge of the textile quality of raw cashmere fibre
- the blending of cashmere with other natural fibres
- improving the wear characteristics of pure and blend yarns
- the utilisation of short cashmere

as they believe markets are being missed because of their inability to properly develop new blends.

1.5 Changes in consumer markets

The traditional views held regarding cashmere and mohair fabrics also need to be challenged. For example cashmere, like wool, is regarded as a traditional warm textile for winter wear. Research by the International Wool Secretariat has shown that the future trends in the textile market include increasing market share for casual and sporting textiles and a declining market share for traditional clothing (IWS 1993). The IWS want to develop much more trans-seasonal uses for wool so that wool can be worn in autumn, winter and spring. Such approaches must include the development of lighter fabrics, and the development of blends with cotton and synthetic fibres. It is therefore critical that development research for both cashmere and mohair be undertaken on both the textile properties of the raw fibre and on the development of new products to exploit the natural advantages of cashmere and mohair.

1.6 Conclusion

For such an expensive textile raw material, surprisingly little objective information has been published on measurable attributes of cashmere in the form used by spinners. Much of the information that is available on Australian cashmere dates from the earliest years in the establishment of the Australian industry. Since that time the Australian cashmere industry has instigated strict quality control procedures that have now been in place for over a decade (Anon 1997c). In this climate of limited objective information on cashmere processing, lack of data about cashmere blend textiles and market failure for raw fibre this project was designed and undertaken.

This report provides selected results to demonstrate important outcomes from this project as there is insufficient space available in this report for all the results from this project. More specific details are available in McGregor (2001).
Chapter 2
Project Objectives and Methodology

2.1 Objectives

This RIRDC supported project DAV 98A was titled “Overcoming constraints to the development of high quality speciality fibre/wool blend textiles”. The objectives of this project were:
1. To improve the utilisation of short fibre length cashmere in textiles by determining the effect of blend ratio in blends of cashmere with wool or cotton on yarn and knitted fabric quality.
2. To determine the effects of using superior handling wool in cashmere/wool blend yarns on the textile properties of yarns and fabrics.
3. To identify preferred nutritional management practices for mohair and cashmere goats to optimise the textile properties of raw fibre, yarn and fabrics.

2.2 Methodology

2.2.1 Introduction

The following general process was outlined in the original submission and was carried out:
1. A review of literature pertaining to cashmere quality, cashmere processing and other aspects of this project was conducted using libraries, publication data bases etc. Parts of this review have been summarised in the introduction (Chapter 1) and it is published in McGregor (2001).
2. A survey was conducted of the quality and attributes of processed cashmere textiles available for spinners.
3. Australian cashmere was purchased, characterised and processed into top, blended with different Australian superfine wool, spun and knitted.
4. Short fibre by-products from the cashmere processing were blended with Australian cotton and processed into experimental yarns.
5. Extensive testing of the yarns and fabrics was completed.
6. Testing of cashmere and mohair fibre derived from various known sources and historic experimental samples.

2.2.2 Survey of processed cashmere textiles available for spinners

Justification for work

For cashmere production and manufacturing to prosper in Australia it is essential for these industries to obtain a much greater understanding of the physical quality attributes of its products as textile raw materials. It is also paramount that these industries understand the quality attributes of cashmere from other origins of production in order to form sound judgements about cashmere quality. This information may also provide suitable benchmarks for quality improvement programs for cashmere supplied to Australian manufacturers by the Australian cashmere growers and for manufacturers to design better processing systems and better textile products. These activities will provide realistic measures for quality improvement and will assist in reducing waste and costs.

Careful use of comparative data on the commercial attributes of cashmere could be used to help market Australian cashmere. Given the necessity for the Australian cashmere industry to establish superior quality traits in order to obtain and retain premium prices and to differentiate its product in the world market, objective data are required. It is also clear that proper definition of cashmere requires a substantial amount of new objective information on cashmere from all origins of production.
This work is also required in order to evaluate the experimental research that follows. An assumption underlying part of this research is that Australian cashmere contains excessive amounts of short fibre. To evaluate the cashmere purchased for the experimental work it is essential that appropriate comparative data are available.

**Materials and Method**

**Cashmere Samples**

Samples of commercial lots of dehaired cashmere (n = 117) and cashmere tops (n = 25) were provided by manufacturers in Europe, Iran, China, Australia, New Zealand and the USA. Samples of fibre classed as cashgora by cashmere marketing agencies in Australia, New Zealand and the USA have also been taken. The following samples were obtained from The Australian Cashmere Marketing Corporation (ACMC): core samples taken by the Australian Wool Testing Authority from the 1996 G Pool bales of raw Australian cashmere covering the range of colours, fibre types and fibre diameter and core samples from the vegetable matter contaminated CV bales from Pool G and the 1997 Pool H. The ACMC also provided 24 samples of raw cashmere from individual fleeces. These samples were chosen to represent the extremes seen in the pool with regard to fibre crimp style and frequency, cashmere and guard hair fibre length, cashmere yield and vegetable matter contamination.

**Testing Procedures**

Mean fibre diameter (MFD) and diameter distribution (coefficient of variation (CV(D)) and %&gt;30 µm), fibre curvature (/mm), medullated fibre incidence (%w/w) and medullated fibre diameter (white samples only, n = 47) were determined by mini coring dehaired cashmere samples or guillotining tops. Measurements were made using the OFDA following aqueous scouring. Fibre colour was determined using The Colour Machine (B.Y.K. Gardner Inc.) and resistance to compression (Rc) were determined after samples had been passed through a Shirley Analyser and conditioned for 24 hours. Fibre length was measured by Almeter on tops and on dehaired cashmere after a modified Length After Carding procedure (LAC). Not all samples were measured for LAC or colour. Samples of top and of dehaired fibre slivers stored in hank form following the LAC, were measured for bundle tenacity and bundle extension using the Sirolan-Tensor. Vegetable matter, soil contamination (ash), wool wax and suint (sweat) levels were determined using standard test procedures used for evaluating Australian wool.

**Statistical Analyses**

For the main analysis of the effect of origin on the attributes of processed cashmere, data is first presented as box plots, showing the median, upper and lower quartiles with outliers, plotted in country or origin groups. For some Countries there were too few samples for separate plotting. MFD, Rc and fibre curvature of dehaired cashmere were modelled as a function of geographical origin and processor using multiple regression with factors. For these attributes there was no evidence of interaction between origin and processor. Scatter plots between these measurements were created with the data adjusted for processor.

The initial geographical origins could be sensibly grouped into broader regions without losing any explanatory power of the model. The final origins were: West Asia (Iran, Turkey, Afghanistan), Eastern Asia (China including Inner Mongolia but excluding Xinjiang Autonomous Region), Central Asia (Western Mongolia, Xinjiang Autonomous Region of China), New (Australia, representing 85% of New samples, New Zealand, USA) and cashgora. For fibre curvature, Iran was a separate origin.

Models for other attributes of dehaired cashmere were also developed, some including interactions between origin and processor and can be seen elsewhere (McGregor 2001).

2.2.3 Worsted processing of Australian cashmere into textiles
Justification for work

This component was necessary to answer Objectives 1 and 2.

Hypotheses tested in experiment

The hypotheses that were tested in this experiment were:
1. That it is feasible to comb dehaired Australian cashmere and worsted spin the top.
2. That both blend ratio and wool type will affect the performance attributes of cashmere/wool blend textiles when soft handling wool is included in blends compared to when standard high crimp wool is blended (fibres having similar MFD).
3. That the performance attributes of pure cashmere fabrics cannot be obtained with either 100% soft handling low crimp wool of similar fibre diameter or when a large percentage of such wool is blended with cashmere.

Materials and Method

Design of worsted cashmere processing experiment
The main experiment had nine treatments. The design was:
Blend / (WT * BR) x 3 replicates.

Blend was analysed as:
Control: the Control base material specified as 100% Australian cashmere (100%CM) that had been dehaired and combed ideally with a hauteur > 30 mm (MFD 16.9 µm);
Other: blends of cashmere with wool and the pure wool treatments.

WT referred to Wool Type and had two levels specified as:
SW: standard commercial superfine wool tops (MFD 16.9 µm);
LCW: soft handling low crimp superfine wool tops (MFD 16.9 µm).

BR referred to Blend Ratio and had four levels specified as:
75: 75% CM, 25% either SW or LCW;
50: 50% CM, 50% either SW or LCW;
25: 25% CM, 75% either SW or LCW;
0: 0% CM, 100% either SW or LCW.

Note. In the graphical presentation of results 100BR refers to the control 100%CM.

For each treatment three yarns were produced, 2/18 tex, R24 tex/2 and singles 30 tex. For the 2/18 and R24 tex/2yarns three fabrics of different loop length or cover factors (CF) were knitted in plain jersey. For the 30 tex yarn only samples of one CF were knitted. For brevity results are presented for 18 tex yarn and fabric at one CF and for 30 tex yarn.

Australian cashmere
The purchase of cashmere from ACMC included the following conditions/guidelines:
1. the cashmere was to represent average fibre from Australian growing conditions
2. general specifications were mean fibre diameter of 16.9 µm, cashmere yield in the range 30 to 35% and fibre length > 45 mm
3. to provide the greatest choice of cashmere, fibre from the WC colour line was specified (white cashmere with coloured guard hair)
4. given that about one third of the main cashmere lines are grower tested lines it was clear that some of this fibre should be included in the order to enable it to fully represent the average fibre sold through the ACMC. This also enabled the matching of the mean fibre diameter specification, as closely as possible.

5. details of the AWTA tests on the classed bales and grower lines purchased were to be provided.

Wool
The LCW fibre was sourced directly from two farms that were known to produce the required wool type (< 4 crimps/cm, fibre curvature < 75°/mm). About 4 weeks prior to shearing, midside wool samples were taken from approximately 1000 sheep from 3 different mobs grazed in north-eastern Victoria and measured for fibre diameter, fibre crimp and staple length. Suitable sheep were identified and at shearing their fleece wool (not skirtings or other oddments) were separately bagged and identified. SW was sourced from the Elders fine wool sale held at Newcastle, New South Wales. Using the sale catalogue test information, lot grab samples of fleece wools were inspected for suitability and 12 different grab samples were purchased. In this way wool representing numerous commercial sources with known characteristics (> 7 crimps/cm, fibre curvature > 105°/mm) from properties in the New England region of NSW was purchased.

Additional fibre testing
All purchased fibre was extensively re-sampled prior to further processing. Samples were measured for mean fibre diameter attributes, fibre crimp frequency, fibre curvature, resistance to compression, fibre length, staple strength (wool only) and contaminants.

Processing of the cashmere into tops
The cashmere was shipped to Cashmere Processors Ltd, Auckland, New Zealand, who had been dehairing cashmere for over 10 years using their novel process. Following scouring and dehairing the bulk of the cashmere was carded, gilled three times and the slivers and second grade short cashmere shipped. Combing was undertaken on a PB25L worsted combing machine designed for fine and short wools of 21 µm and finer (N. Schlumberger et Cie, Guebwiller, Haut-Rhin, France) following adjustments.

To avoid entanglement of fibres on the edge, guide bars were installed, humidity was maintained at approximately 84% RH. The normal operating speed was 128 nips/minute at a feed output of 8.9 m/minute but the machine had been modified by the addition of a Zener MSC variable motor speed controller (Wang et al. 1999) to allow easy adjustment of the comb speed. The MSC speed was set at 26 giving 23 nips/minute. The feed length was set to 24 teeth (feed ratchet), the overlap was set to the extreme level (overlap = 6) and the gill feed set at 4.25. The brush was adjusted forward to 16.5. Trials were conducted by adjusting the distance from nipper to drawing-off rollers with the setting altered from the minimum of 23 to 42.5 mm. For the experiment the setting was set at 25 mm. To maintain combed sliver cohesion it was necessary to apply twist at a rate of 4 tpm using the sliver twister designed by Wang et al. (1999). The noil was collected and weighed.

For each replicate 21.5 kg of combed cashmere was randomly allotted as described. Prior to processing each bag of combed fibre was opened and refreshed by hand spraying tap water at a rate of approximately 1% (100 ml for 10 kg) and allowed to stand overnight. The slivers were gilled using a Prince-Smith & Stells Ltd. (Keighley, England) gill. The second gilling occurred 2 day after the first. The third gilling on a Raper Autolever (Prince-Smith & Stells Ltd., Keighley, England) occurred 2 days after the second gilling. Twist was applied to all outputs using the sliver twister and a twist factor of approximately 450 providing 4 tpm. Any greater twist broke the sliver, and any less twist did not provide cohesion. Spin oil (Bevaloid 4107, Rhone-Poulenc Chemicals Pty. Ltd., South Melbourne) was added at a rate of 0.75% w/w by hand spraying the output of the first gilling. During the third gilling, the autoleveler was run for approximately 160 m providing 2.5 kg of top. Output top was measured for length (m) and the lot weight was measured to the nearest 50 g. Almeter samples
were given 36 turns of twist within 10 minutes, tied and stored in air tight bags with identifying
labels.

**Processing the wool into tops**
The wool was hand blended following a procedure similar to that recommended by Haigh (1996a).
Wool was scoured in a standard four-bowl sample scour. Following spinning for 3 minutes, the wool
was dried for 4 hours at 80°C. Spin oil Bevaloid 4107 (Rhone-Poulenc) at 0.75% of active
component in solution was added by hand spraying each lot of the reconditioned scoured wool.
Sufficient water was added to bring the regain to 23%. The wool was carded using a G368 24 inch
card (Wm Tatham Ltd., Rochdale, England) and the lap was removed and stacked.

The wool was then gilled three times using the gill used for the cashmere. For combing the PB25L
comb was used with the feed wheel ratchet set at 23 teeth, the gill feed set at 3 and 9 to 11 input
slivers. The MSC speed was set at 30 giving 45 nips/minute. The sliver twister was not used. Noil
was weighed. Otherwise the operation was the same as for the cashmere combing.

Gilling used the same equipment as for the cashmere. For each wool type within each replicate 10.6
kg of wool was processed. The procedure used for cashmere was followed but without the sliver
twister.

**Random allocation of fibre to treatment and blending of tops**
Once the autoleveling was completed the individual lots of fibre were initially identified by a letter
given in the order of its processing sequence. Within each fibre type replicate, these lots of fibre were
then randomly allocated to treatment. The assignment of the subsequent processing number was
based on the random allocation of treatment within the cashmere replicates. Ends were fed into the
gill box used in the earlier processing in a sandwich arrangement with the cashmere in the middle or
on the top of the layers. The net amount of wool and cashmere used was calculated to determine the
actual blend ratio. The second blending run used the same gill box. The final blending was done in
producing the rovings.

**Production of rovings**
Fully blended tops ready for roving production were produced using a NSC GV11 Vertical Finisher
Gillbox (N.Schlumber et Cie, Guebwiller, France). The blended tops were refreshed with a 2% w/v
solution of antistatic/water mixture by hand spraying the antistatic Slebana 2001A before being
passed through the GV11 three times. The final 2 gillings of the 100%CM were made on the gill box
previously used and not on the GV11. Roving was produced on a rub rover (SFC Cognetex
Automatic Fast Finisher, Imola, Selice, Italy). Trial processing of 100% cashmere produced a roving
that was too weak to withstand the forces involved in spinning, as the roving would disintegrate and
not feed correctly. It was determined that the other blends of fibre could be satisfactorily produced
on the rub rover. The rover was set initially to produce packages consisting of 2 ends each of 2500 m
of 290 to 300 tex but for the second and third replicates this was reduced to packages of 1000 m. The
machine was operated at 25 m/minute and only one head was used for the entire operation. To
correctly set the appropriate draft, test lengths of 50 m of roving were measured until a satisfactory
draft was determined (range used 12 to 16). Each lot produced 5 to 8 packages.

Twisted cashmere roving was produced using a Cognetex SRB41 (Imola, Selice, Italy) modified to
operate as a flyer rover. The manual recommended a input sliver linear density of 8-9 g/m for Merino
with a draft gauge setting 5 mm greater than the highest Almeter reading and a humidity of 75 to
80% and temperature of 20 to 22°C. Following trials it was determined that an input sliver of 4.4
ktx was optimal and that a twist factor of 1146 was need to provide sufficient cohesion to the roving
while enabling satisfactory spinning. Twist factors of 592 and 842 (31.6 and 45 tpm respectively) did
not provide sufficient cohesion.
Roving packages were visually assessed for hairiness and ranked from least hairy to most hairy. The packages were gently handled to assess firmness and rated from softest to firmest.

**Spinning**
Test spinning of 18 tex cashmere yarn was conducted on a laboratory 6 bobbin machine to determine the most appropriate TF. TFs 2700, 2950 and 3100 were unsatisfactory (636, 695, 731 tpm respectively), a TF of 3335 (786 tpm) was marginal while a TF of 3487 (822 tpm) produced a strong yarn. Test spinning using the TF of 3487 produced satisfactory 12 tex yarn (1003 tpm) and 36 tex yarn (581 tpm) yarn.

Experimental yarn was spun on a Zinser RM 421E1 spinning frame with a SKF drafting set and a 48 mm diameter ring. Delivery speeds for 18 tex up to 13.5 m/minute were achieved but were not used in practice owing to difficulties experienced with two lots. Yarns were autoclaved after spinning. A Calvani Fancy Jet 6SP (Calvani, Milano, Italy) was used to two fold the yarns (18 tex yarn two folded at 392 tpm, 12 tex yarn two folded at 555 tpm). Following two folding the bobbins were autoclaved again. The autoclaved two folded yarns were waxed and wound on a Fadis Tuan/DE winder (Fadis spa, Varese, Italy). The winder operated at a speed of 300 m/minute with a ramp of 90 seconds. For each experimental lot two cones were produced.

**Knitting**
Knitting was completed on a FAK-10-3 (Lawson Hemphill Inc., Rhode Island, USA) circular knitting machine. This machine had interchangeable cylinders, a diameter of 10 inches and was operated with one positive feed input. All the experimental yarns were knitted on the 24 gauge cylinder with 732 needles.

Other test samples were knitted on the FAK-10-3 with an 18 gauge cylinder and R24 tex/2 yarn was knitted on a FAK-3-3 machine (3 inch diameter) with a 29 gauge cylinder.

**Processed fibre, top and yarn testing**
Blended treatment tops; fibre diameter testing as described earlier, fibre length measurements on the Almeter, four 50 g samples were taken for nep and VM content determination. Neps and VM were classified visually by two independent operators into size grades per 100 g as follows: Nep A ≥ 0.5 to < 1 mm, Nep B 1 to < 2.5 mm, Nep C 2.5 to 4 mm, Nep D > 4 mm; VM A < 3 mm, VM B 3 to < 10 mm, VM C 10 to < 20 mm, VM D ≥ 20 mm. Total Neps and Total VM faults were the sum of the different size grades.

Short droppings and cashmere noils; fibre length after carding using the LAC procedure and the fibre diameter measurements as described earlier.

The following procedure was followed for yarn testing:
1. Bobbins were randomly selected and dried in an oven at 50°C for 4 hours and then allowed to recondition for 24 hours (worsted yarns 6 bobbins, cotton 2 bobbins).
2. Linear density was determined.
3. Yarn evenness (CVm), yarn thick places (+50%), yarn thin places (-50%), neps (+200%) and hairiness and hairiness SD were measured using the Uster Tester 3 v2.50.
4. Yarn breaking force, elongation and tenacity (worsted yarns only) were determined using a Uster Tensorapid 3 v6.1.
5. The coefficient of friction of yarns was determined using a Yarn Friction Hairiness Tester SDL 096/98 (Shirley Developments Ltd, Stockport England).
**Fabric testing using Kawabatas Evaluation System for Fabrics (KESF)**

Two randomly taken samples were tested in the following order:

1) Compression Properties of Fabrics. The deformation properties were measured using the Compression Tester (KES FB 3, Kato Tekko Co. Ltd., Kyoto, Japan), following the standard method. The following parameters were determined:

   - the compression work (WC, gf.cm/cm²), the recovery work (WC', gf.cm/cm²), fabric thickness \( T_0 \) (cm, when the pressure = 0.5 gf/cm²), fabric thickness \( T_m \) (cm, at maximum pressure of 50 gf/cm²), and fabric thickness \( T_{10} \) (cm, at initial compression pressure = 10 gf/cm²). WC and WC' were converted to N.m/m².

   The following parameters were calculated:
   - compressional resilience \( RC = (WC'/WC) \), converted to %,
   - compressional linearity \( LC = WC/((T_0-T_m)50/2) \).

2) Surface friction and surface roughness of fabrics. The surface friction and surface roughness coefficients and variation were measured using the Surface Tester (KES FB 4, Kato Tekko Co. Ltd., Kyoto, Japan), following the standard method. The following parameters were determined in this order: the forward and backward direction for the face followed by the back of the fabric; friction coefficient \( \mu \), MIU; mean deviation of \( \mu \), MMD; surface roughness, SMD (\( \mu m \)).

3) Bending Properties of Fabrics. The bending properties were measured using the Pure Bending Tester (KES FB 2, Kato Tekko Co. Ltd., Kyoto, Japan), following the standard method. The following parameters were determined:

   - fabric bending rigidity (B, gf.cm²/cm), converted to \( \mu N.m^2/m \),
   - fabric bending hysteresis (2HB, gf.cm/cm), converted to Nm/m.

4) Shear properties of fabrics. The shear properties were measured using the Tensile and Shearing Tester (KES FB 1, Kato Tekko Co. Ltd., Kyoto, Japan), following the standard method in the direction of the wales. One measurement was taken on each fabric sample. The following parameters were determined:

   - fabric shear rigidity (G, gf/cm.degree), converted to N/m.radian,
   - fabric shear hysteresis at 0.5 degree (2HG, gf/cm), converted to N/m,
   - fabric shear hysteresis at 5.0 degrees (2HG5, gf/cm), converted to N/m.

5) Tensile properties of fabrics. The tensile properties were measured using the Tensile and Shearing Tester (KES FB 1, Kato Tekko Co. Ltd., Kyoto, Japan), following the standard method except that the maximum force \( F \) was set at 200 g/cm. Fabrics with a cover factor of 1.2 were too extensible and were not tested. One measurement was taken on one sample. The following parameters were determined:

   - the extension work (TW, gf.cm/cm²), the recovery work (TW', gf.cm/cm²) and maximum tensile strain (\( \varepsilon_m \)) recorded as a fraction. TW and TW' were converted to N.m/m².

   The following parameters were calculated:
   - tensile resilience, \( RT = (TW'/TW) \), converted to %,
   - tensile linearity, \( LT = TW/(\varepsilon_m)(200/2) \).

6) Thermal insulation of textile material. The thermal conductivity of the knitted fabrics simulating actual wear was measured using the Thermolabo II instrument. The energy required to maintain the temperature of a covered surface was measured with wet contact. The BT-Box temperature was set at the conditioned laboratory temperature and \( \Delta t_o \) set at 10°C. A wind tunnel was used to simulate the effect of air moving across the outer fabric surface (air speed 1m/sec). The following parameters were calculated:

   - heat loss, \( W = \sigma/(\Delta t_o \times A) \) (W/m² °C), where \( A \) is the area of contact with the heat plate,
   - thermal insulation value, \( TIV\alpha = (\sigma_o-\sigma)/\sigma_o \times 100 \) (%)

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Other fabric tests
The following fabric tests were undertaken in standard conditions using Standard Methods:
1. Mass per unit area.
2. Fabric width.
3. Air permeability.
4. Relaxation shrinkage and hygral expansion.
5. Dimensional stability during laundering using a gentle hand wash cycle of 20 minutes duration. Fabrics were dried flat. All samples were washed twice and fabrics made from the R36 tex/2yarns were washed 8 times.
6. Pilling resistance using the random tumble method was determined only on Replicate 1 using a 30 minute test. It was regarded as unsuitable as it did not differentiate between treatments.
7. Resistance to pilling and change in appearance (ICI Pill Box Method). The change in appearance was assessed using the standard SM 54 Botany photographs for knitted fabrics. An independent observer was used to assess the fabrics after the test. Only fabrics made from R36 tex/2yarn were tested. Weight loss was determined by drying and reconditioning samples before and after the test using standard procedures.
8. Spirality was measured on the single 30 tex fabrics.

Statistical analyses
Where the results relate to the replicated experiment the data has been analysed using Genstat 5.4.1 for Windows (Anon 1998b). Results given in the text include the standard error of difference between means (sed). Most results have been graphed. Plotted with the control 100%CM treatment are error bars indicating the effective standard error (ese) for the comparison of any two means using the sed for the Blend.WT.BR interaction (Anon 1998b). The ese = sed/√2. During analysis the data was tested for linearity and curvature. Depending on the significance of these tests the plotted graphs have been fitted with either:
1. a constant line; indicating that there was no significant effect of WT or BR.
2. one straight line; indicating an effect of BR but no effect of WT.
3. two straight lines; indicating an effect of WT and an effect of BR. If these lines are parallel then the effect of BR was the same for each WT but if the lines have different slopes then there was an interaction of Blend.BR.WT.
4. one curve; indicating a quadratic effect of BR but no effect of WT.
5. separate curves; indicating a quadratic effect of BR and an effect of WT. If these lines are parallel then the effect of BR was the same for each WT but if the lines have different slopes then there was an interaction of Blend.BR.WT.

Otherwise the results are presented as means ± S.D., graphed where appropriate with original values, presented as box plots showing the median, upper and lower quartiles and outliers, analysed using linear regression analysis (Anon 1998b) or analysed by one-way ANOVA (Anon 1998b).
2.2.4 Processing of short Australian cashmere by-products into textiles

Justification for work

This component was necessary to answer Objective 1.

Hypothesis tested in experiment

The hypothesis that was tested in this experiment was:
1. That it is feasible to spin short cashmere by-products via a cotton spinning process and that the blend ratio will affect the performance attributes of cashmere/cotton blend textiles.

Materials and Method

Design of short cashmere by-product processing experiment.

This experiment had 11 treatments. The design was:
   FT*BR + Control x 1 replicate.

The control base material was specified as 100% Australian cotton (CT)

FT referred to Fibre Type and had two levels specified as types of Australian cashmere:
SGCM: dehaired second grade cashmere;
NCM: cashmere noil.

BR referred to Blend Ratio had five levels specified as:
15: 15% cashmere 85% cotton;
30: 30% cashmere 70% cotton;
45: 45% cashmere 55% cotton;
60: 60% cashmere 40% cotton;
75: 75% cashmere 25% cotton.

Note. In the graphical presentation of results 0% BR refers to the control CT.

Material preparation and spinning

Australian cotton lap fibre was carded and drawn three times using a Shirley Miniature Spinning Plant (Platt Bros., Oldham, England). The roller settings were based on an effective fibre length of 1 1/8 inch and were; 1" roller, 1 6/16 inch; 2" roller, 2 11/16 inch, Back roller, 4 7/16 inch. The processing sequence resulted in 18 doublings and a final sliver linear density of 2 g/m.

Test samples of yarn were spun on a Suessa Rotor Spinner operating at a draft of 65 and delivery speed of 35 m/minute. For 30 tex yarn and a TF of 5240 the desired twist was 957 tpm. The settings used were a beater speed of 5000 rpm and a rotor speed of 33485 rpm. Some samples of 50 tex yarn were produced using a draft of 60, with a twist of 741 tpm and a rotor speed of 25935 tpm.

Experimental yarns were spun on a Schlafhorst Autocoro ACO288 (W.Schlafhorst AG & Co., Mönchengladbach, Germany) an open-end rotor spinning machine with automatic piecing. A 46 mm rotor with a B174 opening was used, two input slivers had to be used and yarn output was waxed. Two different twists were spun (796 and 960 tpm).

Statistical analyses

For the cotton blend yarns, regression analysis has been used for each FT.
2.2.5 The effect of management practices on some cashmere and mohair textile properties

Justification for work
This was necessary to evaluate Objective 3. The scope of this work was restricted to a few attributes.

Hypothesis tested
1. That nutritional management of mohair and cashmere goats influences the textile attributes, other than mean fibre diameter, of the raw fibre.

Materials and Method
Cashmere was obtained from:
1. A replicated experiment designed to assess the effect of nutrition on fibre quality and production of Australian cashmere goats (McGregor 1988).
2. Samples of cashmere from individual goats that had been evaluated by Madeley (1994) for length after dehauling and carding.

Mohair was obtained from:
1. A replicated experiment designed to assess the effect of grazing management on mohair quality and production on Australian mohair goats (McGregor 1985).
2. A mohair stud that had a range of new mohair genetics and had some measurements on their mohair. The samples provided (n = 38) came from the winter shearing with ages at shearing ranging from 1 to 4 years of age. The median genetic background was 75% Texan 25% Australian with a range from 25 to 100% Texan.

Measurements and analyses
These samples were measured for characteristics that may affect textile properties relevant to the scope of this project, namely fibre curvature, resistance to compression and staple fibre length using the methods previously described in this report. For the experiments, where some information had been published, midside samples were measured for the attributes that had not been published.

Results were analysed using analysis of variance and linear regression analysis (Anon 1998b).
Chapter 3
Results

3.1 Survey of processed cashmere textiles available for spinners

3.1.1 Dehaired cashmere and cashmere tops
The quality of dehaired cashmere was significantly affected by the origin of the cashmere and the processor of the cashmere. The attributes affected included the mean fibre diameter, CV(D), fibre curvature, length after carding and colour of white cashmere. Some results are presented in Figure 1. Further data are available in McGregor (2000b) and full details of the survey are available in McGregor (2001). The results are discussed in detail.

3.1.2 Extremes in fibre attributes of Australian cashmere and cashgora
The results of the assessment of extreme samples of Australian grown down supplied by the ACMC are shown in Table 2. The ranges in various attributes were as follows: MFD, 13.8 to 20.9 µm; length of cashmere, 35 to 113 mm; fibre crimp frequency, 1.5 to 6.0 crimps/cm; fibre curvature, 27 to 59 °/mm; Rc, 4.7 to 6.7 kPa; cashmere length/MFD², 0.18 to 0.43.

3.1.3 Vegetable matter and soil contamination
The level of vegetable matter (VM), ash and washing yield and the calculated wool base for Australian cashmere are shown in Table 3. Further data on these attributes are provided for the research samples in Table 6. Typically the main line cashmere bales contained less than 1% VM and 2% ash. The bales classed as vegetable matter contaminated contained 12% VM and 3% ash but levels of contamination as high as 41% VM and 16% ash are possible in extreme samples (which were normally discarded).

Other fibre attributes of the CV bales compared to the main line bales are shown in Table 4.
Figure 1a. Box plots of measurement data for the properties of dehaired cashmere and dehaired cashgora (CG) from different origins showing the median, upper and lower quartiles and outliers (IR = Iran, WA = Western Asia, CH = China, CA = Central Asia, AU = Australia, US = United States of America)

Figure 1b. The distribution of resistance to compression and fibre curvature attributes of dehaired cashmere and cashgora by origin after adjustment for processor effects
Table 2. The mean attributes of samples of raw cashmere selected to exhibit extreme forms of fibre style, fibre length or fibre diameter from the ACMC. The calculated cashmere length divided by the mean diameter^2 is shown as the l/d^2 ratio

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Description</th>
<th>MFD µm</th>
<th>CV(D) %</th>
<th>CY % w/w</th>
<th>Med MFD µm</th>
<th>Length cashmere mm</th>
<th>Length hair mm</th>
<th>Cashmere crimps/cm</th>
<th>FC °/mm</th>
<th>Rc kPa</th>
<th>l/d^2 mm/µm^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACMC 2</td>
<td>Very fine</td>
<td>15.1</td>
<td>23.3</td>
<td>61.1</td>
<td>43.4</td>
<td>93</td>
<td>58</td>
<td>3.5</td>
<td>48.5</td>
<td>5.8</td>
<td>0.41</td>
</tr>
<tr>
<td>ACMC 3</td>
<td>Fine, long, high yield</td>
<td>15.5</td>
<td>19.3</td>
<td>36.3</td>
<td>77.1</td>
<td>98</td>
<td>63</td>
<td>3.0</td>
<td>53.0</td>
<td>5.2</td>
<td>0.41</td>
</tr>
<tr>
<td>ACMC 4</td>
<td>Medium high yield, plain style</td>
<td>18.8</td>
<td>18.4</td>
<td>46.8</td>
<td>88.2</td>
<td>104</td>
<td>61</td>
<td>2.5</td>
<td>38.2</td>
<td>5.5</td>
<td>0.29</td>
</tr>
<tr>
<td>ACMC 5</td>
<td>Very short, plain style</td>
<td>16.9</td>
<td>23.1</td>
<td>39.1</td>
<td>64.7</td>
<td>56</td>
<td>53</td>
<td>2.0</td>
<td>36.5</td>
<td>5.4</td>
<td>0.19</td>
</tr>
<tr>
<td>ACMC 6</td>
<td>Short, fine very, plain style</td>
<td>13.8</td>
<td>23.4</td>
<td>23.4</td>
<td>51.9</td>
<td>35</td>
<td>91</td>
<td>2.0</td>
<td>31.2</td>
<td>6.7</td>
<td>0.18</td>
</tr>
<tr>
<td>ACMC 7</td>
<td>Long, high yield</td>
<td>14.6</td>
<td>16.4</td>
<td>47.9</td>
<td>74.1</td>
<td>91</td>
<td>75</td>
<td>4.5</td>
<td>49.5</td>
<td>4.9</td>
<td>0.43</td>
</tr>
<tr>
<td>ACMC 8</td>
<td>Ringlet style, straight tips</td>
<td>19.4</td>
<td>22.9</td>
<td>44.0</td>
<td>81.8</td>
<td>88</td>
<td>55</td>
<td>1.5</td>
<td>26.9</td>
<td>4.7</td>
<td>0.24</td>
</tr>
<tr>
<td>ACMC 9</td>
<td>Ringlet style, straight tips</td>
<td>16.8</td>
<td>22.8</td>
<td>45.9</td>
<td>78.5</td>
<td>83</td>
<td>49</td>
<td>2.0</td>
<td>37.6</td>
<td>4.7</td>
<td>0.29</td>
</tr>
<tr>
<td>ACMC 10</td>
<td>Very short</td>
<td>16.0</td>
<td>24.4</td>
<td>32.1</td>
<td>66.1</td>
<td>54</td>
<td>39</td>
<td>3.0</td>
<td>51.5</td>
<td>5.7</td>
<td>0.21</td>
</tr>
<tr>
<td>ACMC 11</td>
<td>Short, very low yield</td>
<td>15.0</td>
<td>21.3</td>
<td>24.3</td>
<td>92.8</td>
<td>55</td>
<td>51</td>
<td>2.0</td>
<td>57.5</td>
<td>5.8</td>
<td>0.24</td>
</tr>
<tr>
<td>ACMC 12</td>
<td>Long guard hair, low yield</td>
<td>18.4</td>
<td>19.2</td>
<td>39.4</td>
<td>118.7</td>
<td>113</td>
<td>139</td>
<td>4.0</td>
<td>52.8</td>
<td>5.4</td>
<td>0.34</td>
</tr>
<tr>
<td>ACMC 14</td>
<td>Boer goat XB, high yield</td>
<td>15.0</td>
<td>20.7</td>
<td>23.1</td>
<td>79.0</td>
<td>71</td>
<td>60</td>
<td>3.5</td>
<td>49.2</td>
<td>5.1</td>
<td>0.32</td>
</tr>
<tr>
<td>ACMC 15</td>
<td>Boer goat XB, short, low yield</td>
<td>16.4</td>
<td>23.4</td>
<td>20.1</td>
<td>90.2</td>
<td>54</td>
<td>85</td>
<td>6.0</td>
<td>48.7</td>
<td>5.4</td>
<td>0.20</td>
</tr>
<tr>
<td>ACMC 16</td>
<td>Boer goat XB kid</td>
<td>16.6</td>
<td>21.6</td>
<td>41.9</td>
<td>67.5</td>
<td>85</td>
<td>47</td>
<td>3.0</td>
<td>48.7</td>
<td>5.7</td>
<td>0.31</td>
</tr>
<tr>
<td>ACMC 17</td>
<td>Boer goat XB, plain style</td>
<td>17.1</td>
<td>18.5</td>
<td>61.7</td>
<td>79.0</td>
<td>94</td>
<td>31</td>
<td>2.0</td>
<td>40.1</td>
<td>5.3</td>
<td>0.32</td>
</tr>
<tr>
<td>ACMC 18</td>
<td>Very fine</td>
<td>14.8</td>
<td>19.7</td>
<td>43.0</td>
<td>68.3</td>
<td>75</td>
<td>54</td>
<td>5.0</td>
<td>59.6</td>
<td>5.3</td>
<td>0.34</td>
</tr>
<tr>
<td>ACMC 20</td>
<td>Plain flat lock style</td>
<td>20.9</td>
<td>21.1</td>
<td>22.0</td>
<td>92.1</td>
<td>79</td>
<td>107</td>
<td>3.5</td>
<td>38.8</td>
<td>5.6</td>
<td>0.18</td>
</tr>
<tr>
<td>ACMC 21</td>
<td>Plain flat lock style</td>
<td>17.5</td>
<td>18.3</td>
<td>36.0</td>
<td>50.9</td>
<td>71</td>
<td>55</td>
<td>4.0</td>
<td>41.0</td>
<td>5.6</td>
<td>0.23</td>
</tr>
<tr>
<td>ACMC 22</td>
<td>Very long, plain flat lock style</td>
<td>17.3</td>
<td>21.3</td>
<td>48.0</td>
<td>55.8</td>
<td>109</td>
<td>84</td>
<td>2.5</td>
<td>43.1</td>
<td>4.9</td>
<td>0.36</td>
</tr>
</tbody>
</table>

1 VM, vegetable matter contamination; XB, cross bred with cashmere doe.
Table 3. The vegetable matter (VM) and ash content, clean washing yield (CWY), and wool base for normal and extreme samples provided by the ACMC

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Description</th>
<th>Description of VM</th>
<th>CWY %</th>
<th>VM %</th>
<th>VM base %</th>
<th>Wool base %</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACMC ML</td>
<td>Main line cashmere&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td>96.4</td>
<td>0.8</td>
<td>0.7</td>
<td>80.4</td>
<td>1.9</td>
</tr>
<tr>
<td>ACMC CV</td>
<td>CV bales&lt;sup&gt;2&lt;/sup&gt;</td>
<td></td>
<td>94.2</td>
<td>12.4</td>
<td>10.0</td>
<td>69.3</td>
<td>3.2</td>
</tr>
<tr>
<td>ACMC 25</td>
<td>Composite&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Odd grass seed</td>
<td>98.3</td>
<td>1.67</td>
<td>1.40</td>
<td>81.37</td>
<td>2.75</td>
</tr>
<tr>
<td>ACMC 26</td>
<td>Composite&lt;sup&gt;4&lt;/sup&gt;</td>
<td>Seeds and herbage</td>
<td>95.8</td>
<td>0.87</td>
<td>0.71</td>
<td>79.97</td>
<td>1.70</td>
</tr>
<tr>
<td>ACMC 13</td>
<td>Cotted, high VM</td>
<td>Grass seeds, burr, dags</td>
<td>88.9</td>
<td>2.52</td>
<td>1.91</td>
<td>72.93</td>
<td>4.59</td>
</tr>
<tr>
<td>ACMC 23</td>
<td>Very fine, high VM</td>
<td>8 mm grass seeds/shive</td>
<td>95.2</td>
<td>3.58</td>
<td>2.91</td>
<td>77.27</td>
<td>1.19</td>
</tr>
<tr>
<td>ACMC 24</td>
<td>VM fault, slightly cotted</td>
<td>Noogoora and medic burr</td>
<td>86.6</td>
<td>20.84</td>
<td>15.42</td>
<td>57.47</td>
<td>16.06</td>
</tr>
</tbody>
</table>

1 The mean values from 12 main line randomly selected bales from ACMC Pool G
2 The mean values from 10 vegetable matter contaminated bales from ACMC Pools G and H
3 ACMC 25 sample from 12 fleeces, no VM feel, only odd grass seed
4 ACMC 26 sample from 5 fleeces, easy to see and feel seeds and herbage, when opened fine litter fell out

Table 4. Fibre quality attributes of Australian cashmere in CV bales and a random selection of main line cashmere bales (with SD)

<table>
<thead>
<tr>
<th>Identifier</th>
<th>MFD µm</th>
<th>CV(D) %</th>
<th>CM yield %</th>
<th>Relative CM yield %</th>
<th>FC °/mm</th>
<th>Rc kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACMC ML</td>
<td>17.02</td>
<td>20.8</td>
<td>33.3</td>
<td>41.4</td>
<td>51</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>(0.78)</td>
<td>(0.8)</td>
<td>(1.8)</td>
<td>(2.4)</td>
<td>(4)</td>
<td>(0.3)</td>
</tr>
<tr>
<td>ACMC CV</td>
<td>17.41</td>
<td>21.6</td>
<td>28.7</td>
<td>41.6</td>
<td>52</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>(0.34)</td>
<td>(0.7)</td>
<td>(2.9)</td>
<td>(4.6)</td>
<td>(3)</td>
<td>(0.3)</td>
</tr>
</tbody>
</table>
Table 5. The mean fibre diameter attributes and fibre curvature of the raw cashmere purchased from the ACMC. The test results supplied by the AWTA based on dehaired cashmere obtained from the bale or lot core samples and the results from testing the dehaired cashmere on the OFDA are indicated. The results for the layers in bale F were based on dehaired cashmere obtained by the AWTA using the bulk grid samples

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Bale/Lot</th>
<th>MFD µm</th>
<th>CV(D) %</th>
<th>F&gt; 30 µm %</th>
<th>CY %w/w</th>
<th>MFD µm</th>
<th>MFD CV %</th>
<th>FC °/mm</th>
<th>Cashmere weight kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>AWTA</td>
<td>AWTA</td>
<td>AWTA</td>
<td>OFDA</td>
<td>OFDA</td>
<td>OFDA</td>
<td>AWTA</td>
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<tr>
<td>A</td>
<td>Lot</td>
<td>16.9</td>
<td>23.1</td>
<td>0.8</td>
<td>30.3</td>
<td>16.6</td>
<td>22.6</td>
<td>47.9</td>
<td>15.18</td>
</tr>
<tr>
<td>C</td>
<td>Lot</td>
<td>16.9</td>
<td>20.1</td>
<td>0.5</td>
<td>34.0</td>
<td>16.1</td>
<td>20.4</td>
<td>51.4</td>
<td>14.19</td>
</tr>
<tr>
<td>D</td>
<td>Lot</td>
<td>16.7</td>
<td>19.2</td>
<td>0.2</td>
<td>32.5</td>
<td>16.2</td>
<td>19.9</td>
<td>56.8</td>
<td>3.61</td>
</tr>
<tr>
<td>E</td>
<td>Lot</td>
<td>16.9</td>
<td>20.1</td>
<td>0.2</td>
<td>34.6</td>
<td>16.5</td>
<td>20.5</td>
<td>54.5</td>
<td>2.49</td>
</tr>
<tr>
<td>1HB2 - F</td>
<td>Bale</td>
<td>16.7</td>
<td>19.8</td>
<td>0.2</td>
<td>36.6</td>
<td>16.2</td>
<td>21.5</td>
<td>52.5</td>
<td>44.68</td>
</tr>
<tr>
<td>1HB2 - F1</td>
<td>Layer 1</td>
<td>17.1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1HB2 - F2</td>
<td>Layer 2</td>
<td>15.2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1HB2 - F3</td>
<td>Layer 3</td>
<td>16.4</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1HB2 - F4</td>
<td>Layer 4</td>
<td>15.3</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1HB2 - F5</td>
<td>Layer 5</td>
<td>16.5</td>
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<tr>
<td>1HB2 - F6</td>
<td>Layer 6</td>
<td>17.8</td>
<td></td>
<td></td>
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<td>1HB2 - F7</td>
<td>Layer 7</td>
<td>17.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1H1 - G</td>
<td>Bale</td>
<td>17.0</td>
<td>20.6</td>
<td>0.5</td>
<td>32.3</td>
<td>16.6</td>
<td>20.1</td>
<td>51.4</td>
<td>46.44</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td>16.85</td>
<td>20.5</td>
<td>0.4</td>
<td>33.4</td>
<td>16.43</td>
<td>21.5</td>
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</tr>
<tr>
<td>SD</td>
<td>0.12</td>
<td>1.4</td>
<td>0.2</td>
<td>2.18</td>
<td>0.68</td>
<td>1.3</td>
<td>5.7</td>
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<tr>
<td>Weighted mean</td>
<td>16.86</td>
<td>20.5</td>
<td>0.4</td>
<td>33.6</td>
<td>16.38</td>
<td>20.9</td>
<td>51.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Bale F SD</td>
<td>0.9</td>
<td>1.4</td>
<td>6.1</td>
<td></td>
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</table>

1 The weighted mean is based on the purchased lots in proportion to the weight of cashmere
Table 6. The additional measurements taken on core and grab samples (for the layers in bale F) and on dehaired cashmere for resistance to compression (Rc)

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Bale/Lot</th>
<th>FL mm</th>
<th>Crimp/cm</th>
<th>CWY %</th>
<th>VM %</th>
<th>Ash % w/w</th>
<th>Wool base % w/w</th>
<th>Wax %</th>
<th>Suint %</th>
<th>Wax:Suint Ratio</th>
<th>Rc kPa</th>
<th>Origin in Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Lot</td>
<td>55.8</td>
<td>3.1</td>
<td>96.40</td>
<td>0.97</td>
<td>1.63</td>
<td>80.18</td>
<td>2.7</td>
<td>3.2</td>
<td>0.84</td>
<td>5.78</td>
<td>Western Australia</td>
</tr>
<tr>
<td>C</td>
<td>Lot</td>
<td>68.4</td>
<td>3.2</td>
<td>93.57</td>
<td>0.35</td>
<td>4.48</td>
<td>78.42</td>
<td>3.5</td>
<td>4.5</td>
<td>0.78</td>
<td>5.88</td>
<td>Queensland</td>
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<tr>
<td>D</td>
<td>Lot</td>
<td>62.3</td>
<td>3.4</td>
<td>96.26</td>
<td>0.09</td>
<td>2.18</td>
<td>80.95</td>
<td>4.5</td>
<td>4.3</td>
<td>1.05</td>
<td>5.98</td>
<td>NSW, central</td>
</tr>
<tr>
<td>E</td>
<td>Lot</td>
<td>79.9</td>
<td>3.1</td>
<td>97.43</td>
<td>0.30</td>
<td>1.68</td>
<td>81.73</td>
<td>2.5</td>
<td>3.2</td>
<td>0.78</td>
<td>5.64</td>
<td>NSW, southern</td>
</tr>
<tr>
<td>1HB2 - F</td>
<td>Bale</td>
<td>77.6</td>
<td>3.2</td>
<td>96.91</td>
<td>1.82</td>
<td>2.41</td>
<td>79.77</td>
<td>2.9</td>
<td>4.6</td>
<td>0.63</td>
<td>5.59</td>
<td>Multi-State</td>
</tr>
<tr>
<td>1HB2 - F1</td>
<td>Layer 1</td>
<td>78.8</td>
<td>3.1</td>
<td>84.23</td>
<td>1.44</td>
<td>1.49</td>
<td>69.47</td>
<td>4.80</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1HB2 - F2</td>
<td>Layer 2</td>
<td>72.2</td>
<td>3.1</td>
<td>95.16</td>
<td>1.15</td>
<td>1.14</td>
<td>78.96</td>
<td>4.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1HB2 - F3</td>
<td>Layer 3</td>
<td>78.5</td>
<td>3.3</td>
<td>96.58</td>
<td>0.89</td>
<td>0.73</td>
<td>80.42</td>
<td>4.66</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1HB2 - F4</td>
<td>Layer 4</td>
<td>74.5</td>
<td>3.5</td>
<td>1</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>5.29</td>
<td></td>
</tr>
<tr>
<td>1HB2 - F5</td>
<td>Layer 5</td>
<td>73.6</td>
<td>3.2</td>
<td>96.97</td>
<td>0.34</td>
<td>1.54</td>
<td>81.29</td>
<td>5.29</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1HB2 - F6</td>
<td>Layer 6</td>
<td>3.0</td>
<td></td>
<td></td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>i</td>
<td>5.00</td>
<td></td>
</tr>
<tr>
<td>1HB2 - F7</td>
<td>Layer 7</td>
<td>88.2</td>
<td>3.5</td>
<td>96.06 (2)</td>
<td>3.87 (2)</td>
<td>1.66 (2)</td>
<td>77.00 (2)</td>
<td>4.80</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1H1 - G</td>
<td>Bale</td>
<td>84.3</td>
<td>3.2</td>
<td>97.23</td>
<td>0.47</td>
<td>1.59</td>
<td>81.38</td>
<td>2.9</td>
<td>4.2</td>
<td>0.69</td>
<td>5.88</td>
<td>NSW, southern</td>
</tr>
<tr>
<td>Arithmetic mean</td>
<td></td>
<td>74.5</td>
<td>3.2</td>
<td>95.16</td>
<td>1.06</td>
<td>1.87</td>
<td>79.05</td>
<td>3.2</td>
<td>4.0</td>
<td>0.80</td>
<td>5.34</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>9.0</td>
<td>0.2</td>
<td>3.79</td>
<td>1.07</td>
<td>0.98</td>
<td>3.48</td>
<td>0.7</td>
<td>0.6</td>
<td>0.14</td>
<td>0.48</td>
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</tr>
<tr>
<td>Weighted mean</td>
<td></td>
<td>76.0</td>
<td>3.2</td>
<td>96.57</td>
<td>0.98</td>
<td>2.23</td>
<td>80.32</td>
<td>3.0</td>
<td>4.2</td>
<td>0.71</td>
<td>5.76</td>
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</tr>
<tr>
<td>Within Bale F SD</td>
<td></td>
<td>5.8</td>
<td>0.2</td>
<td>5.4</td>
<td>1.4</td>
<td>0.4</td>
<td>4.7</td>
<td></td>
<td></td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 There was insufficient sample available for this layer
2 Samples for F6 and F7 mixed together in proportion to their lot weight
3 The weighted mean is based on the purchased lots in proportion to the weight of cashmere
Table 7. The mean raw wool attributes of the purchased fibre. Measurements were taken before shearing with the low crimp wool on midside samples (MS) and for the standard wool measurement values obtained from the sale catalogue (SC) and those taken after purchase on grid samples are indicated.

<table>
<thead>
<tr>
<th>Identifier</th>
<th>MFD $\mu$m</th>
<th>MFD $\mu$m</th>
<th>CV(D) %</th>
<th>F&gt; 30 $\mu$m %</th>
<th>SL $^2$ mm</th>
<th>SS $^3$ N/ktex</th>
<th>MOB $^4$ %</th>
<th>CWY $^5$ % w/w</th>
<th>FC $^6$ %/mm</th>
<th>Crimps /cm</th>
<th>Re $^8$ kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low crimp wool$^{1a}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>16.9</td>
<td>17.4</td>
<td>19.9</td>
<td>0.4</td>
<td>94</td>
<td>24</td>
<td>54</td>
<td>74.4</td>
<td>74.4</td>
<td>3.8</td>
<td>7.4</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.4</td>
<td>0.4</td>
<td>1.9</td>
<td>0.2</td>
<td>7</td>
<td>6</td>
<td>44</td>
<td>2.0</td>
<td>3.4</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Standard wool$^{1b}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>17.0</td>
<td>17.2</td>
<td>18.3</td>
<td>0.2</td>
<td>82</td>
<td>39</td>
<td>45</td>
<td>76.4</td>
<td>114.1</td>
<td>7.2</td>
<td>10.4</td>
</tr>
<tr>
<td>S.D.</td>
<td>0.2</td>
<td>0.6</td>
<td>1.4</td>
<td>0.2</td>
<td>5</td>
<td>5</td>
<td>27</td>
<td>1.6</td>
<td>12.6</td>
<td>0.9</td>
<td>1.1</td>
</tr>
</tbody>
</table>

$^{1a}$ wool sold from the same flocks of sheep had a vegetable matter content of 0.1%; $^{1b}$ the vegetable matter content ranged from 0.1 to 2.2% averaging 1.0%;

$^2$ staple length; $^3$ staple strength; $^4$ % of staples with a midpoint of break; $^5$ clean washing yield; $^6$ resistance to compression;
3.2 Worsted processing of Australian cashmere into textiles

3.2.1 Raw fibre attributes

Cashmere

The test data provided by the ACMC are given in Table 5 along with the additional test data from the OFDA testing of the remaining core keeper sample. The additional testing undertaken on the bale and grower lot core samples and on the grab samples taken from the layers in Bale 1HB2 are given in Table 6.

The crimp frequency and raw fibre length measurements are summarised in Figure 2. The mean crimp frequency was $3.2 \pm 0.9$ crimps/cm, cashmere length $75.3 \pm 20.4$ mm and the guard hair length $63.3 \pm 27.0$ mm. Over 90% of the fibres examined had 2 dimensional crimp form (see McGregor 2001 for details). Most of the remainder had simple 3 dimensional crimp forms. Only a few fibres had more than one helical type crimp form.

Evidence of lice was seen in 3% of samples, representing very light contamination in 3 different lots or layers. Skin or scurf was seen in 8% of samples, all originating from one lot.

Wool

Results of fibre testing in the sale by sample catalogue for purchased SW and for the midside samples taken before shearing of the LCW and grid samples taken after purchase on all wool are summarised in Table 7.

Relative fibre attributes

The relative raw fibre attributes are presented as box plots in Figure 3. There were no differences in MFD. There were significant differences in fibre curvature, $R_c$ and crimp frequency between each of CM, LCW and SW.

3.2.2 Early stage processing

Scouring, dehairing and carded sliver production

The reconciliation of the cashmere fibre is shown in Table 8. Some of the weights shown have not been corrected for moisture content as samples were not available. Care needs to be exercised in interpreting these values. The actual cashmere reported as dehaired was 127.28 kg. This value was greater than expected but the value has not been adjusted to a regain of 16%. For the dehaired cashmere, 8.4% was of inferior length grades, of which nearly 5% was discarded as short fibre machine droppings. The actual amount of dehaired cashmere received (113.53 kg) represented 90.58% of the AWTA estimated down content (125.33 kg).

Fibre attributes of the gilled sliver and the second grade cashmere droppings are in Table 8. Visual inspection of the gilled sliver revealed that the guard hair present was mostly long white fibre with the occasional short black hair fibre. The gilled sliver also contained a small number of VM faults that were circular pieces of burr medic. Measurements of VM in the cashmere top are provided later in this Chapter.

Combing

The amount of cashmere noil was $15.99 \pm 0.31\%$ (n = 81). Results of the comb setting adjustment trial for cashmere are given in Figure 4. Increasing the comb setting significantly increased the hauteur of the combed cashmere and the production of noil. Details of top and noil fibre attributes are in Table 9.

The wools produced significantly different amounts of noil with noil production for the low crimp wool of $14.52 \pm 0.63\%$ (n = 40) and for the standard wool $16.69 \pm 0.82\%$ (n = 33).
Figure 2. Histograms showing the distribution of unprocessed cashmere fibre length and individual fibre crimp in Australian cashmere used in the experiment.
Figure 3. Raw fibre attributes of experimental low crimp (LCW) and standard (SW) Merino wool and cashmere (CM) presented as box plots showing median, upper and lower quartiles and outliers. (The means for cashmere staple length and crimp frequency refer to fibre length and fibre crimp but for wool refer to staple length and staple crimp)
Table 8. Reconciliation of cashmere fibre weight during purchase, sampling and processing

<table>
<thead>
<tr>
<th>Processing step</th>
<th>Weight (kg)</th>
<th>Proportion of dehaired cashmere %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reconciliation of raw fibre</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total raw weight of cashmere purchased (AWTA tests)</td>
<td>376.24 *</td>
<td></td>
</tr>
<tr>
<td>Less weight of samples taken adjusted for moisture loss</td>
<td>3.35 *</td>
<td></td>
</tr>
<tr>
<td>Net raw fibre sent to NZ allowing for moisture content</td>
<td>372.89 *</td>
<td></td>
</tr>
<tr>
<td>Net wt of raw fibre following grid sampling and rebaling</td>
<td>369.8</td>
<td></td>
</tr>
<tr>
<td>Weight of fibre received from scour at dehairer in NZ ¹</td>
<td>369 ²</td>
<td></td>
</tr>
<tr>
<td><strong>Reconciliation of cashmere</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total down purchased (AWTA tests)</td>
<td>126.599 *</td>
<td></td>
</tr>
<tr>
<td>Down removed during sampling at ACGA by author</td>
<td>1.127 *</td>
<td></td>
</tr>
<tr>
<td>Weight of down in samples taken in NZ</td>
<td>0.142</td>
<td></td>
</tr>
<tr>
<td>Net down available for processing</td>
<td>125.33 *</td>
<td></td>
</tr>
<tr>
<td>Weight of dehaired cashmere at end of dehairing ¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cashmere</td>
<td>116.58</td>
<td>91.6</td>
</tr>
<tr>
<td>Second grade cashmere</td>
<td>4.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Short fibre machine droppings</td>
<td>6.0</td>
<td>4.7</td>
</tr>
<tr>
<td>Total</td>
<td>127.28</td>
<td>100.0</td>
</tr>
<tr>
<td>Weight of cashmere delivered to Sydney</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gilled slivers</td>
<td>104.1 *</td>
<td></td>
</tr>
<tr>
<td>Sliver waste</td>
<td>4.75 *</td>
<td></td>
</tr>
<tr>
<td>Cashmere short droppings</td>
<td>4.68 *</td>
<td></td>
</tr>
<tr>
<td>Total delivered</td>
<td>113.53 *</td>
<td></td>
</tr>
</tbody>
</table>

* Values adjusted for moisture content
¹ values provided by dehairer
² the average yield reported by the scour was 94.85%. This figure includes other Australian cashmere that was scoured on the same day.
Figure 4. The relationship between the comb setting, fibre length of the combed sliver and noil production for the experimental dehaired cashmere
Table 9. The mean fibre attributes of the cashmere throughout processing and for the wool tops and noils. The number of measurements is shown in brackets. All fibre length measurements on fibre other than top was following the modified length after carding procedure.

<table>
<thead>
<tr>
<th>Identifier</th>
<th>H-mm</th>
<th>CV(H)-%</th>
<th>%&lt;25-mm</th>
<th>HL-5%</th>
<th>HL-1%</th>
<th>B-mm</th>
<th>CV(B)-%</th>
<th>%&lt;25-mm</th>
<th>BL-5%</th>
<th>BL-1%</th>
<th>MFD-μm</th>
<th>MFD-CV-%</th>
<th>Med-%w/w</th>
<th>FC-%/mm</th>
<th>Re-kPa</th>
<th>Ten-cN/ktx</th>
<th>Extn-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cashmere</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carded and gilled (10)</td>
<td>28.8</td>
<td>69.3</td>
<td>50.6</td>
<td>66.8</td>
<td>82.8</td>
<td>42.5</td>
<td>48.5</td>
<td>22.4</td>
<td>77.9</td>
<td>90.7</td>
<td>16.2</td>
<td>21.3</td>
<td>0.19</td>
<td>52.7</td>
<td>4.7</td>
<td>10.5</td>
<td>46.0</td>
</tr>
<tr>
<td>Second grade droppings (10)</td>
<td>23.4</td>
<td>73.1</td>
<td>62.9</td>
<td>57.4</td>
<td>72.6</td>
<td>35.8</td>
<td>55.7</td>
<td>33.7</td>
<td>69.3</td>
<td>81.6</td>
<td>17.2</td>
<td>22.4</td>
<td>0.25</td>
<td>48.3</td>
<td>10.2</td>
<td>45.1</td>
<td></td>
</tr>
<tr>
<td>Tops after autoleveler (21)</td>
<td>41.8</td>
<td>45.0</td>
<td>20.1</td>
<td>76.4</td>
<td>92.9</td>
<td>50.2</td>
<td>38.8</td>
<td>9.0</td>
<td>85.0</td>
<td>99.5</td>
<td>16.6</td>
<td>20.6</td>
<td>0.12</td>
<td>48.4</td>
<td>3.7</td>
<td>11.2</td>
<td>50.0</td>
</tr>
<tr>
<td>Tops after 5 gillings (12)</td>
<td>40.8</td>
<td>45.6</td>
<td>21.8</td>
<td>74.5</td>
<td>92.0</td>
<td>49.1</td>
<td>39.4</td>
<td>9.9</td>
<td>83.3</td>
<td>101.2</td>
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<tr>
<td>Noils (14)</td>
<td>13.5</td>
<td>53.4</td>
<td>92.3</td>
<td>28.0</td>
<td>38.15</td>
<td>17.3</td>
<td>51.0</td>
<td>82.2</td>
<td>35.1</td>
<td>43.1</td>
<td>14.96</td>
<td>20.8</td>
<td>0.08</td>
<td>61.6</td>
<td>5.2</td>
<td>7.0</td>
<td>40.9</td>
</tr>
<tr>
<td>Wool</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lcw top</td>
<td>49.2</td>
<td>55.3</td>
<td>18.7</td>
<td>105.9</td>
<td>128.1</td>
<td>64.2</td>
<td>46.8</td>
<td>6.8</td>
<td>121.1</td>
<td>135.8</td>
<td>17.6</td>
<td>19.9</td>
<td>0.1</td>
<td>71.6</td>
<td>4.9</td>
<td>10.2</td>
<td>45.8</td>
</tr>
<tr>
<td>Sw top</td>
<td>51.8</td>
<td>52.2</td>
<td>17.8</td>
<td>101.2</td>
<td>118.3</td>
<td>65.8</td>
<td>41.3</td>
<td>6.4</td>
<td>110.6</td>
<td>125.0</td>
<td>17.2</td>
<td>18.7</td>
<td>0.1</td>
<td>107.3</td>
<td>6.2</td>
<td>10.0</td>
<td>44.1</td>
</tr>
<tr>
<td>Lcw noil (9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sw noil (7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
**Blending**

As expected, the fibre curvature of the blended tops was affected by Blend, WT and BR. The FC values for the blended tops before aqueous scouring of the pure blends were; CM 31.2, LCW 61.2, SW 83.2 %; sed_CM-WT 4.95, sed_WT 3.13; P<0.001).

Increasing BR reduced hauteur, barbe, and CV(H). The % fibres <25 mm for hauteur was not affected but for % fibres < 10 mm and < 15 mm increasing BR produced small but significant declines (P<0.05). For % fibres < 25 mm for barbe there was a linear increase with increasing BR.

**Neps and VM contaminants in the tops**

There were significant differences in the level of faults in the tops (Figure 5). Cashmere tops had the least faults and as BR increased the level of faults decreased. SW had significantly more nep faults and significantly less VM faults than LCW (P< 0.01). The VM faults in the SW were primarily parts of thistle plants and shive and in the LCW oat grain and burr.

![Figure 5. Nep and vegetable matter faults in treatment tops.](image)

*Symbols: ■ Low crimp wool; ▲ Standard wool; ◆ pure Cashmere*
3.2.3 Worsted yarn production

**Roving production - cashmere**

The 100% cashmere rubbed roving was too weak for spinning as it was unable to withstand the forces required to unwind the package. To minimise the production of slubs and other faults in the twisted rovings the following modifications were made to the flyer rover processing:

1. untwisted top was supplied rather than twisted top
2. the first and second sliver guide condensers were changed to ceramic annulus of 25 mm diameter rather than the fitted narrow oblong metal condensers
3. pressure was maintained at a high level on the rollers
4. the spacer between the rollers was increased
5. top was supplied to minimise vertical lift to prevent self drafting
6. adjustments were made to the automatic bobbin diameter mechanism to avoid unnecessary entanglement of the roving before it was wound.

**Roving packages and roving**

There was a noticeable range in the firmness of the roving packages (Table 10). After storage of three weeks the softest packages (first replicate) tended to lose their shape.

### Table 10. The subjective firmness rating of the roving packages

<table>
<thead>
<tr>
<th>Firmness grade</th>
<th>Softest</th>
<th>Soft</th>
<th>Medium</th>
<th>Firm</th>
<th>Firmest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>25LCW</td>
<td>50LCW</td>
<td>75LCW</td>
<td>50SW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>25SW</td>
<td></td>
<td></td>
<td>75SW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100LCW</td>
<td></td>
</tr>
</tbody>
</table>

The roving packages also exhibited a noticeable range in visual hairiness (Table 11).

### Table 11. The subjective hairiness ranking of the roving packages

<table>
<thead>
<tr>
<th>Hairiness</th>
<th>Most</th>
<th>Least</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>25LCW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>50LCW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>25SW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>75LCW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>50SW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>75SW</td>
<td>100SW</td>
</tr>
<tr>
<td></td>
<td>100LCW</td>
<td>100SW</td>
</tr>
</tbody>
</table>

Two lots that had a high cashmere content had some degree of felting inside the roving packages. It was determined that the problem was related to the large roving package. The size of the package was reduced to 1000 m.

There was a significant difference in the roving CVm between pure CM and the other treatments but no difference between any other treatment or WT and likewise with roving irregularity

**Yarn quality**

**18 tex yarns**

Analyses of the test results for 18 tex yarn are shown in Figure 6. There was no effect of treatment on CVm. The neps in CM was less than other treatments (P<0.05) and the difference between WT was significant at P = 0.052. Yarn hairiness of CM was higher than Blends (P< 0.001), the WT were different (P<0.001) and hairiness increased linearly with BR (P<0.001).

Yarn tenacity of CM was lower than the Blends and the tenacity was affected by WT (P<0.01) and declined as BR increased (P<0.01). Yarn elongation showed similar effects to that of tenacity (P<0.001) and BR (P<0.001).
30 tex yarns
There was no affect of treatment on CVm or yarn faults. Hairiness increased as BR increased and SW had lower hairiness values than LCW. Yarn friction values averaged 0.273 ± 0.006 and the cashmere yarn had a significantly higher friction coefficient than other yarns (P<0.01). The tenacity of the pure CM 30 tex low twist yarn was 5.57 ± 1.54 cN/tex and the elongation was 7.75 ± 4.53%.

3.2.4 Fabric
KESF fundamental fabric properties
Compression properties of fabrics
Fabric thickness of CM was significantly lower than the Blends. \( T_m \) was affected by WT with LCW fabrics having a lower \( T_m \) than SW fabrics and \( T_m \) declined as BR increased (Figure 7). A similar result was found in 30 tex single yarn fabrics.

At CF 1.32 and 1.2 there were no significant effects on compressional resilience but at CF 1.45 CM had a lower compressional resilience than Blends. Compressional linearity showed few effects of treatment. At CF 1.45 CM had a lower compressional linearity than blends and at CF 1.45 and 1.32 increasing BR resulted in a decline in compressional linearity (Figure 7).

Surface friction and surface roughness of fabrics
There were few significant treatment effects on surface friction properties. When the data for the face and back were meaned for the fabric CF 1.45, CM had a lower MIU than blends and a lower MMD. When the data for all CFs (both face and back) were meaned WT was significant with CM and LCW having a lower MIU than SW.

For surface roughness SMD, when the data for the face and back was meaned CM had a lower SMD than Blends at CF 1.45 and at CF 1.20.

Bending Properties of Fabrics
Fabric bending rigidity of the fabric face declined with increasing BR in CF 1.45 and 1.32 (Figure 7). At CF 1.20 CM had a lower bending rigidity than Blends. For the fabric back bending rigidity of CF 1.45 and 1.32 was affected by Blends and declined as BR increased but there was no affect at CF 1.20.

Fabric bending hysteresis for the face of fabrics CF 1.45 and 1.32 declined as BR increased and for CF 1.20 was affected by WT but not BR (Figure 7).

Shear properties of fabrics
The fabric shear rigidity of all fabrics declined significantly with increasing BR and CM had lower shear rigidity than Blends for CF 1.32 and 1.20. The shear hysteresis values 2HG and 2HG5 both showed the same response as shear rigidity and at greater significance for all CFs (Figure 7).

Tensile properties of fabrics
Most of the tensile parameters showed a WT or a WT.BR effect and most of the LCW.BR interactions were best described by a constant and the SW.BR interactions were best described by a straight line regression.

Generally the extension work of CM was lower or equal to LCW that was in turn lower than SW. The maximum tensile strain in CF 1.45 was affected by an interaction between WT and BR. The maximum tensile strain of SW declined significantly as BR increased. The maximum tensile strain of 100SW was significantly greater than that of 100LCW.

Tensile resilience of CM was higher than that of Blends in fabrics CF 1.32 and 1.20. Increasing BR increased mean tensile resilience of Blends at CF 1.20. Tensile linearity was affected by WT.BR interactions at each CF as increasing BR reduced tensile linearity of SW but had no affect on LCW.
Figure 6. Various properties of 18 tex yarn.
Symbols: ■ Low crimp wool; ▲ Standard wool; ● pure Cashmere
Figure 7. Selected fabric mechanical properties of fabric knitted with a cover factor of 1.32 made from R36 tex/2 yarns of different wool types and blend ratios with cashmere. Symbols: ■ Low crimp wool; ▲ Standard wool; ● pure Cashmere
at each CF. The effect of Blend was significant at each CF with CM having lower tensile linearity than Blends. The effect of WT was significant at CF 1.45 and CF 1.20 with LCW having lower tensile linearity than SW.

**Thermal insulation of textile material**
There was no effect of Blend, WT or BR detected on the thermal insulation value for any CF.

**Other fabric properties**

**Mass per unit area and fabric width**
Fabric mass per unit area of pure CM was lighter than Blends at CF 1.32 and CF 1.20. WT was significant as LCW produced lighter fabrics than SW at CF 1.45 and 1.32 and at CF 1.2 both pure CM and LCW had lighter fabrics than SW. Fabric mass per unit area declined significantly as BR increased and the significance of this response increased as CF declined.

The effects of Treatment on fabric width changed from no effect at CF 1.45 to small effects at CF 1.32 and highly significant effects at CF 1.20.

**Air permeability**
The effects of Blend, WT and BR were highly significant at all CFs and showed similar trends. Pure CM was more permeable than SW at all CFs and was more permeable than LCW at CF 1.32 (Figure 8) and 1.20. LCW fabrics were more permeable than SW fabrics at all CFs. As BR increased the fabrics became more permeable.

Increasing the CF (reducing stitch length) reduced air permeability.

**Resistance to pilling and change in appearance**
WT affected pill score with LCW having higher resistance to pilling scores than SW. The effect of WT declined as CF declined from CF 1.45 to CF 1.20. Increasing BR increased resistance to pilling score at all CF (Figure 8).

The high pill scores, indicating low incidence of pills present during assessment, were associated with higher fabric weight loss (Table 12).

Increasing the CF (reducing stitch length) increased resistance to pilling score.

**Table 12. The mean loss of weight during ICI Resistance to Pilling testing and the treatment mean resistance to pilling score for knitted fabrics (CF 1.32) made from 100% cashmere (CM), 100% low crimp wool (LCW) and 100% standard wool (SW)**

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Mean weight loss (%) ± (SD)</th>
<th>Treatment Mean resistance to pilling score</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM</td>
<td>1.25 (0.28)</td>
<td>3.75</td>
</tr>
<tr>
<td>LCW</td>
<td>0.86 (0.19)</td>
<td>2.58</td>
</tr>
<tr>
<td>SW</td>
<td>0.67 (0.23)</td>
<td>1.92</td>
</tr>
</tbody>
</table>

**Relaxation shrinkage and hygral expansion**

**Relaxation shrinkage**
In the course (width) direction CM had less shrinkage than Blends, LCW had less shrinkage than SW and shrinkage declined as BR increased at each CF. In the wale (length) direction WT was highly significant at all CFs with CM having greater shrinkage than LCW which in turn had greater shrinkage than SW (Figure 8).
Hygral expansion
SW had significantly greater hygral expansion in the course direction than LCW, which in turn had
greater hygral expansion than CM, and hygral expansion declined as BR increased. In the wale

Figure 8. Various properties of fabrics knitted with a cover factor of 1.32 made from
R36 tex/2 yarns of different wool types and blend ratios with cashmere.
Symbols: ■ Low crimp wool; ▲ Standard wool; ● pure Cashmere
direction there were few effects other than at CF 1.20 were CM had less hygral expansion than Blends and LCW had less hygral expansion than SW (Figure 8).

**Dimensional stability during laundering**

There were significant effects of Blend, WT and BR and some interactions between the WT.BR for changes in length, width and area shrinkage measurements after each wash cycle and for each CF.

The direction of the effects for CF 1.32 were:
Shrinkage in course direction. With 1 to 8 washes increasing BR reduced shrinkage in SW but BR had no effect on LCW.
Shrinkage wale direction. After 1 wash LCW was unaffected by BR but SW had less shrinkage as BR increased. With 2 to 8 washes LCW was unaffected by BR and there was more shrinkage as BR increased.
Area shrinkage. After washes 1 and 2 there was no effect of BR or WT. After 4 and 8 washes increasing BR reduced shrinkage in SW but had no effect on LCW.

**30 tex single yarn fabric**

The fabric mass per unit area of the high twist yarn fabric was significantly heavier than that of the lower twist yarn fabric. Fabric mass per unit area was significantly affected by Blend, WT and BR. Pure CM produced lighter fabric weight than Blends, and fabric mass per unit area declined as BR increased.

Increasing yarn twist reduced the air permeability of the fabric. The spirality of the higher twist yarn fabric was greater than that of the lower twist yarn fabric. Blend, WT and BR significantly affected spirality with spirality increasing as BR increased. Results are summarised in Table 13.

**Table 13. The effect of yarn twist on properties of fabrics knitted with a cover factor of 1.32 from 30 tex worsted spun single yarns made from cashmere and blends with superfine wool**

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Low twist</th>
<th>High twist</th>
<th>T-statistic</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric mass per unit area, g/m²</td>
<td>175.3</td>
<td>186.1</td>
<td>6.23</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Spirality, degree</td>
<td>16</td>
<td>21</td>
<td>8.41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Air permeability, cm³/cm².sec</td>
<td>156</td>
<td>143</td>
<td>3.01</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Fabric thickness Tₘ, cm</td>
<td>0.266</td>
<td>0.290</td>
<td>10.31</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Thermal insulation value, %</td>
<td>53.4</td>
<td>51.3</td>
<td>2.20</td>
<td>0.06</td>
</tr>
</tbody>
</table>

**3.3 Processing of short Australian cashmere by-products**

**3.3.1 Cotton cashmere blend yarns**

*Processing and spinning*

The high twist yarns were spun first and significant difficulties were experienced as BR increased. The CT and BR 15 yarns spun well and so did NCM 30 but SGCM 30 was difficult to spin and only a small quantity of BR 45 was produced. No BR 60 or BR 75 could be spun. These yarns broke frequently and the automatic piecing did not rejoin and the rotor had to be cleaned frequently. When the twist and the machine speed were reduced all the yarns could be spun but similar difficulties occurred at a higher BR. At the lower speeds CT and BR 15, 30 and NCM 45 spun relatively well. SGCM 45 and 60 spun with lots of hand piecing often needing to use 100% cotton to complete a piecing. NCM 60, NCM 75 and SGCM 75 yarn would only piece up with great persistence as the yarn had little strength. An attempt was made to spin NCM 75 using a smaller rotor but this failed.
**Sliver and yarn attributes**

The test results obtained on the slivers and yarns are shown in Figure 9. The mean (± SD) yarn count obtained was 33.0 ± 3.8 tex with the CT 36.0 tex, noil yarns 34.3 and SGCM 31.1 tex. The higher the BR the lower the yarn count. The effect of progressively increasing the BR of NCM was to reduce hauteur and barbe, increase CV(H), CV(B), MFD, reduce CV(D), fibre curvature and yarn faults such as neps. Progressively increasing the BR of SGCM increased hauteur, barbe, CV(H), CV(B), MFD and to reduce CV(D), fibre curvature and yarn faults such as neps. The effect of increasing BR on yarn friction was curvilinear. At any BR most attributes of SGCM were greater than those of NCM except for fibre curvature and neps where they were less.

As BR increased the yarns were softer to touch and visibly hairier. The yarns with noil were softer than the SGCM yarns.

### 3.3.2 Other products

Attempts made to process SGCM and NCM using other methods were unproductive and have not yet led to products.

![Graphs showing the affect of increasing blend ratio of second grade cashmere (▲) and cashmere noil (■) on various attributes.](image)

**Figure 9.** The fibre length, fibre diameter and yarn friction properties of cashmere cotton blends showing the affect of increasing blend ratio of second grade cashmere (▲) and cashmere noil (■).
3.4 The effect of management practices on some cashmere and mohair textile properties

3.4.1 Cashmere

Effect of nutrition on fibre curvature, Rc and cashmere length

Increasing nutrition during the cashmere growing period increased cashmere production (McGregor 1988). The testing in the present work showed that nutrition treatment significantly affected fibre curvature (P<0.05). When the data for nutritional treatment are plotted as cashmere weight related to cashmere fibre curvature, a very strong linear regression was observed (Figure 10). Increasing cashmere length was highly correlated with a reduction in cashmere fibre curvature. Rc of cashmere was increased slightly as fibre curvature increased. The following linear regressions were calculated:

- Fibre curvature = 89.42 – 0.19 (0.005) Cashmere weight; RSD 0.39; r = 0.99; P<0.001.
- Fibre curvature = 142.9 – 0.93 (0.23) Cashmere length; RSD 3.47; r = 0.89; P<0.05.
- Rc = 4.81 + 0.015 (0.003) FC; RSD 0.05; r = 0.92; P<0.05.

![Figure 10. The relationships between nutritional treatment group cashmere production, cashmere fibre length, cashmere mean fibre diameter and cashmere fibre curvature](image)
Fibre length and curvature of processed Australian cashmere
The new measurements of Rc, and OFDA determined MFD and fibre curvature were analysed with the dehaired and carded cashmere lengths reported by Madeley (1994). The following linear regressions were calculated using treatment means (Figure 11):

Length after processing = -10.85 + 2.273 (0.249) MFD; RSD 2.00; r = 0.89; P<0.001.
Fibre curvature = 81.42 – 1.31 (0.226) Length after processing; RSD 4.61; r = 0.78; P<0.001.
Fibre curvature = 110.4 – 3.80 (0.39) MFD; RSD 3.16; r = 0.90; P<0.001.

The fibre curvature of these samples declined to a much lower value than that found in the nutrition study (Figure 11).

Figure 11. The relationships between dehaired and carded cashmere length (LAC, from Madeley 1994) and measurements of cashmere mean fibre diameter and cashmere fibre curvature measured on the OFDA

3.4.2 Mohair
Effect of stocking rate
The mohair grown at high stocking rates during winter had a higher fibre curvature than mohair grown at lower stocking rates. The change in fibre curvature did not affect resistance to compression measurements (Table 14). There was no linear relationship between the resistance to compression and the fibre curvature measurements when analysed using the individual replicate data.
Table 14. The effect of stocking rate of mohair goats during summer and winter on the fibre curvature and Rc properties of mohair

<table>
<thead>
<tr>
<th>Stocking rate /ha</th>
<th>Fibre curvature (°/mm)</th>
<th>Rc (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>March</td>
<td>September</td>
</tr>
<tr>
<td>7.5</td>
<td>21.0</td>
<td>18.8</td>
</tr>
<tr>
<td>10</td>
<td>22.1</td>
<td>21.6</td>
</tr>
<tr>
<td>12.5</td>
<td>20.7</td>
<td>27.4</td>
</tr>
<tr>
<td>Sed</td>
<td>0.97</td>
<td>3.61</td>
</tr>
<tr>
<td>P</td>
<td>NS</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Effect of newer genetics

The fibre samples came from a range of genotypes with a range in fibre attributes (Table 15).

Table 15. The genetic background, fibre production and fibre attributes of mohair goats used in the study

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Mean</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical Texan proportion, %</td>
<td>67</td>
<td>25</td>
<td>100</td>
</tr>
<tr>
<td>Greasy fleece weight, kg</td>
<td>3.01</td>
<td>1.86</td>
<td>4.22</td>
</tr>
<tr>
<td>Staple length, cm</td>
<td>13.1</td>
<td>7.8</td>
<td>16.5</td>
</tr>
<tr>
<td>MFD, µm</td>
<td>32.5</td>
<td>25.8</td>
<td>40.9</td>
</tr>
<tr>
<td>CV(D), %</td>
<td>22.2</td>
<td>16.1</td>
<td>27.0</td>
</tr>
<tr>
<td>Fibre curvature</td>
<td>12.0</td>
<td>7.6</td>
<td>18.1</td>
</tr>
<tr>
<td>Rc, kPa</td>
<td>4.28</td>
<td>3.78</td>
<td>4.90</td>
</tr>
<tr>
<td>Medullation, % by number</td>
<td>1.77</td>
<td>0.80</td>
<td>3.60</td>
</tr>
</tbody>
</table>

Regression modelling indicated that the best predictor of fibre curvature and Rc was MFD with Texan% only being significant if it was reduced to 6 levels (AdjTexan%). No other attribute including staple length and the variate (MFD*fibre curvature) was significant (Figure 12). These regression equations were weak predictors as shown by the low correlation coefficients (r):
Fibre curvature = 20.34 - 0.26 (0.08) MFD; RSD = 1.88; r = 0.43; P<0.005.
Fibre curvature = 16.83 - 0.16 (0.08) MFD + ^AdjTexan%; RSD 1.70; r = 0.59; P<0.005.
(^ various coefficients depending on proportion of Texan breeding).
Rc = 3.43 + 0.026 (0.010) MFD; RSD = 0.22; r = 0.38; P=0.01.

Figure 12. The relationships between mohair mean fibre diameter and fibre curvature and staple length and fibre curvature
Chapter 4
Discussion

4.1 Survey of processed cashmere textiles available for spinners

This investigation has demonstrated for the first time by using objective testing that cashmere from different origins has distinctive properties.

4.1.1 Fibre diameter and fibre diameter variability

Mean fibre diameter (MFD) of dehaired cashmere samples ranged from 13.6 to 19.2 μm and that of cashgora samples from 17.8 to 22.7 μm. The box plots and the LSIs indicate that the Chinese samples were finer than those from other origins and that cashmere from Australia was finer than that from Iran. Cashgora was significantly coarser than all the cashmere.

The mean CV(D) of the dehaired cashmere samples was 22.0%. Some fibre from Iran and some cashgora had CV(D)s greater than 24% as a result of a high content of residual guard hairs. The fitted models indicated that processors vary significantly in their ability to remove guard hairs. The commercial significance for spinning performance of increasing the amount of residual guard hair in dehaired cashmere from the median value of 0.25%/w/w to 1%/w/w would be an increase of 2.25% in CV(D) which is equivalent to a change of approximately 0.5 μm in mean fibre diameter (Butler and Dolling 1995).

As the MFD of dehaired cashmere increased, an associated increase in the incidence of residual guard hairs occurred, along with a decline in the mean fibre diameter of those residual guard hairs. These observations indicate the difficulties that processors have in separating cashmere from the guard hair contained in raw cashmere. Clearly as the MFD of cashmere increases there is an increasing tendency for the fibre diameter distributions of cashmere and guard hair to overlap. Processors must balance the desire to remove the relatively coarse guard hairs from the cashmere to maintain softness and maintain spinning performance by maintaining a low CV(D) against the penalty of reduced length after carding as a consequence of subjecting cashmere to repeated dehairing operations.

This data indicated the % of fibres coarser than 30 μm rose from 0% to 1.2% as the MFD of cashmere increased from 15 to 19 μm. This analysis provided no evidence that the incidence of guard hairs in dehaired cashmere was related to cashmere length after carding. It is fibre breakage during carding that is possibly the greatest issue during processing.

4.1.2 Fibre curvature and resistance to compression

After adjustment for Processor effect, cashmere from New Origins had lower fibre curvature than that from Iran, East and Western Asia. Cashgora samples had the lowest mean fibre curvature of 35.8°/mm ranging from 24 to 46°/mm. Following adjustment for Processor there was no overlap in the range of fibre curvature between cashgora and cashmere.

After adjustment for Processor effect the LSIs indicate that New Origin cashmere had the lowest resistance to compression (Rc) values recorded for cashmere. Cashgora had significantly lower Rc compared to New Origin cashmere.

This analysis has differentiated the cashmere produced in different regions of the world on the basis of the cashmere fibre attributes. By plotting any two of mean fibre diameter, fibre curvature and Rc, cashmere from different producing regions segregate into distinct groupings. Cashgora is also segregated from cashmere even though the finest cashgora has a similar fibre diameter to that of
Iranian cashmere, as cashgora had a fibre curvature of less than 45 °/mm and cashmere had fibre curvatures greater than 45 °/mm.

The plot of Rc against fibre curvature (Figure 1) suggests that a general relationship exists for cashmere where increasing fibre curvature is correlated (r = 0.85) with increasing Rc. In 1946 van Wyk demonstrated that the Rc of sheeps wool was linearly related to the product of the MFD and the staple crimp frequency of the wool. When a similar comparison is made using the MFD and fibre curvature (approximating single fibre crimp) measurements for cashmere the correlation is increased only marginally (r = 0.88). This implies that the important information in predicting Rc for cashmere is associated with fibre curvature. Once the data had been corrected for Processor effect, origin and fibre curvature essentially become the one parameter.

The findings of this study have provided the first objective data that cashmere from New Origins of production has lower Rc than cashmere produced elsewhere. If the experience of the wool industry is applicable (Madeley et al. 1995, Stevens 1994, Stevens and Mahar 1995, Wuliji et al. 1995) then reducing Rc of raw cashmere will lead to softer handle in cashmere textiles. On this basis it is likely that cashmere from New Origins will have softer handle than cashmere from traditional origins. It is yet to be shown what properties cashmere from New Origins of production has in textiles and this issue has been addressed in this project.

### 4.1.3 Fibre length and colour

The length after carding (LAC) of dehaired cashmere and the hauteur of cashmere tops was affected by origin. The data show that dehaired cashmere from New Origins had LACs up to 20% longer than that from traditional origins. The data and model also show that increasing MFD was correlated with increasing LAC of dehaired cashmere. These observations were magnified in cashmere tops although the database is limited.

It is clear why most cashmere is processed on the woollen system as the short LAC of dehaired cashmere is unsuitable for worsted processing. Worsted processors have traditionally used longer cashmere from Iran and Mongolia. These data indicate that dehaired cashmere from New Origins is longer and finer than cashmere from the origins traditionally used for worsted processing.

The range in lightness of white samples between origins was similar except that Iran had the lowest values and the greatest range. Only China and Australia had cashmere with yellowness values less than -0.5. The lowest yellowness values for Chinese cashmere was found in the samples of 28 mm or less. The within origin range in lightness and yellowness of “white” commercial lots was of commercial significance.

### 4.1.4 The effect of Processor on cashmere fibre attributes

This analysis reports significant effects of Processor on cashmere fibre attributes. The effect of Processor includes:

1. the differences due to fibre processed as a result of selection or purchase decisions and
2. differences in processing between processors.

This analysis is not able to differentiate between these causes. For example, Processor affected the yellowness and lightness of commercial lots of cashmere. This may suggest that processing treatments such as scouring and drying conditions or the actual origin of cashmere purchased may be affecting measured colour. The affect of Processor on length after carding of dehaired cashmere may be due to differences in machinery, machinery operation, processing operations etc and/or the quality of cashmere processed. As the length of dehaired cashmere affects the price of cashmere (McGregor 2000a, 2001) it is in the interests of those aiming to produce cashmere with the highest LAC to determine which processors can maximise the LAC of the final dehaired cashmere.
4.1.5 Cashmere classification, fibre curvature and fibre length

This study indicates that cashmere from Australia and from other New Origins of production has many properties equal to and superior to that found for cashmere from traditional origins including:

- mean fibre diameter and fibre diameter variability
- length after carding
- softness as measured by resistance to compression
- colour of white cashmere

All of these superior attributes place New Origin cashmere in the premium position for worsted yarn production. As the MFD of cashmere tops in this survey was 17.3 \( \mu \text{m} \) with a range up to 19.3 \( \mu \text{m} \) (McGregor 2001) there should be no problems in processing New Origin cashmere into worsted yarn.

One attribute where New Origin cashmere is significantly different to traditional cashmere is in having lower fibre curvature. As this attribute can be easily observed by a trained fibre merchant it may be a major factor contributing to the assertion that New Origin cashmere comes from a cross breeding of cashmere goats with Angora type goats. Currently there are no data available to determine if other factors associated with origin could explain the differences in cashmere fibre curvature. This issue has been addressed in this report in Sections 3.4 and 4.4.

4.1.6 Towards a better definition of Cashgora

“Cashgora” has been recognised by the IWTO since 1988 (Anon 1997a) and a review of the textile attributes of cashgora has been included in a recent Australian study (McGregor 1997a). There are numerous definitions of “cashgora” dating back to 1972 (Moylan and McGregor 1991, McGregor 2000a). In Australia, strict fibre preparation standards over the past 15 years have reinforced perceived differences between cashmere and cashgora (Anon 1997c). The findings reported here show that the fibre characteristics of cashgora are distinct from those of cashmere produced in New Origins such as Australia. These new findings need to be incorporated into clearer definitions of cashmere and cashgora.

The proposal by Phan et al. (1996) to classify 19 \( \mu \text{m} \) cashmere as cashgora will pose problems for those producers and processors of traditional cashmere tops currently in the 19 \( \mu \text{m} \) range. The analyses in this project have shown that 19 \( \mu \text{m} \) cashmere and cashgora have distinct properties. It is unlikely that traditional producers of 19 \( \mu \text{m} \) cashmere will agree to the reclassification of their cashmere to cashgora on the basis of difficulty in SEM differentiation.

4.1.7 Extremes in fibre attributes of Australian cashmere

Cashmere as fine as 13.8 \( \mu \text{m} \) is produced in Australia (Table 1). This fibre does not necessarily have the fibre curvature seen in traditional Chinese cashmere. The finest sample in this study had only 2 crimps/cm and a fibre curvature of 31 °/mm, clearly placing it in the cashgora definition if a fibre curvature of 45 °/mm was used as an arbitrary cut off. The two samples with the highest fibre curvature of 57 to 60 °/mm were 14.8 to 15.0 \( \mu \text{m} \). These samples had similar attributes to the fine bales from New Origins tested in the dehaired cashmere survey and have fibre curvatures much lower than Chinese cashmere. Some other fibre attributes correlated with low fibre curvature are discussed in Section 3.4 and 4.4.

The samples included three examples of cashmere of 14.6 to 15.5 \( \mu \text{m} \) cashmere with lengths of 91 to 98 mm and fibre curvatures of 48 to 53 °/mm. This fine and very long cashmere is clearly a premium product. The ratio \( l/d^2 \) for these three fine long samples of 0.41 – 0.43 is 130% greater than the lowest values recorded in the study and almost 50% greater than the mean value for these samples of 0.29. Clearly potential exists to select these animals for genetic improvement programs.

The two longest samples, with down lengths of 104 and 113 mm displayed very different guard hair and fibre crimp attributes but both had coarse MFD and about average \( l/d^2 \) ratios.
4.1.8 Vegetable contamination and classing practice
The mean VM base for the main line fleece bales tested from Pool G (Table 2) was very low. With the mean washing yields at over 96% and soil levels (ash) less than 2% these data clearly show that Australian cashmere is very clean compared with Chinese cashmere. The bales classed as CV (contamination vegetable) had significantly more contamination. However in other respects the quality of the cashmere in CV bales was no different to that of the cashmere in the random selection of 12 bales of main line cashmere (Table 3). When allowance was made for the different wool base in CV bales (caused by the greater VM content, scourable matter and higher soil content) the relative cashmere yield was no different to the cashmere yield of main line cashmere bales (Table 3).

The vegetable matter contamination of the extreme samples was very high. These samples also had very high soil contamination as seen by the relatively low washing yields and very high ash determinations. The resultant low wool base when combined with a cashmere yield of 35% would provide cashmere yields of less than 20%. Such fibre has reduced commercial value. Growers should be advised not to consign such fibre to the Pool. Any fibre of this type received by the ACMC is discarded in the NCV line.

The results of the processing of experimental cashmere show that some burr does remain after dehairing. This means that greater vigilance is needed to remove any pockets of burr in bales of cashmere to minimise the chance of residual burr in dehaired cashmere.

These results show that the classing procedures at the ACMC are an effective method of removing the burr, twigs, seed and shive from Australian cashmere.

4.1.9 Conclusions
Cashmere from different origins shows commercially important variations in fibre attributes. While origin of cashmere is the major determinant of cashmere fibre attributes, Processor effects are also important. Cashmere from Australia and other New Origins of production had longer fibre length after carding, lower resistance to compression, lower fibre curvature and is likely to have a softer handle than traditional cashmere. Dehaired cashmere from different origins and cashgora can be differentiated using the fibre attributes of mean fibre diameter, fibre curvature and resistance to compression. Australian cashmere has low levels of VM and soil contamination. The practices in the ACMC are effective in removing VM from main line cashmere. A study of some extreme samples of Australian cashmere demonstrates that long fine cashmere is being produced.

4.2 Worsted processing of Australian cashmere into textiles
4.2.1 Raw fibre attributes
Cashmere
The purchased commercial lots of Australian cashmere were clearly crimped with a mean crimp frequency of 3.2 and a range from 2 to 6 crimps/cm. The crimp form of Australian cashmere is primarily of uniplanar sinusoidal form with very few three dimensional helical structures. This form of crimping explains in part the low Rc (which ranged from 4.7 to 6.0 kPa) measured on the Australian cashmere as in Merino wool this form of fibre crimping is associated with a low Rc (van Wyk 1946, Balasubramaniam and Whiteley 1964). The ranges in cashmere fibre attributes are similar to the ranges seen in the extreme samples described earlier (Section 3.1.2).

The measurements of cashmere VM, ash, wax and suint content are the first for commercial lots of Australian cashmere.

The measurements of VM, ash and wax content provide evidence that Australian cashmere has low level of contaminants compared to the cashmere from the best producing regions in China (see Table
For example, Chinese cashmere has a mean grease (wax) content of 4.9% compared to the 3.2% reported here for Australian cashmere and for ash (soil) content Chinese cashmere averaged 6.1% and Australian cashmere 1.9%. The VM content of Australian and Chinese cashmere is similar and very low but the content of skin debris is high in the Chinese fibre at almost 9% but virtually unknown in Australian cashmere.

Table 16. The quality of white cashmere from the seven main producing regions in China (adapted from Ze 1989)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil, %</td>
<td>6.1</td>
<td>3.0</td>
<td>10.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Skin debris, %</td>
<td>8.9</td>
<td>5.6</td>
<td>20.4</td>
<td>3.1</td>
</tr>
<tr>
<td>Vegetable matter, %</td>
<td>0.7</td>
<td>0.3</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Kemp, %</td>
<td>5.0</td>
<td>3.5</td>
<td>10.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Bristle, %</td>
<td>2.6</td>
<td>3.2</td>
<td>9.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Fine bristle, %</td>
<td>1.6</td>
<td>2.3</td>
<td>6.8</td>
<td>0.1</td>
</tr>
<tr>
<td>Hair, %</td>
<td>4.3</td>
<td>4.5</td>
<td>10.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Grease content, %</td>
<td>4.9</td>
<td>1.5</td>
<td>6.8</td>
<td>3.1</td>
</tr>
<tr>
<td>Cashmere length, mm</td>
<td>48.9</td>
<td>3.0</td>
<td>52.0</td>
<td>44.0</td>
</tr>
<tr>
<td>Short cashmere content, %</td>
<td>5.5</td>
<td>3.9</td>
<td>14.0</td>
<td>2.7</td>
</tr>
<tr>
<td>Cashmere fibre diameter, µm</td>
<td>14.8</td>
<td>0.5</td>
<td>15.6</td>
<td>14.1</td>
</tr>
</tbody>
</table>

The raw Australian cashmere that was purchased had maximum fibre lengths ranging up to 110 mm but the mean maximum was 75 mm with a range in the lot means of 55 to 88 mm. This fibre length was much greater than that which the ACMC attempted to obtain in the early 1990s for their worsted cashmere trial.

The assumptions underlying the initial protocols for this research project have proven to be incorrect. The survey of international cashmere available for spinners (Section 4.1) has shown that Australian cashmere is the longest available. The cashmere purchased for this experiment was at the longest end of Australian cashmere scale and contained cashmere that would have produced even longer dehaired fibre if it had been processed separately. The vision of the 1980s is being approached and should be deliberately pursued.

There is clearly potential with current Australian cashmere production to class lots of cashmere that have longer mean fibre lengths for worsted production. Recent improvements in on-farm nutritional management of cashmere goats also offer the potential to significantly increase cashmere fibre lengths (McGregor and Umar 2000).

The within bale variation in cashmere fibre quality parameters was determined from the data for the layers in bale F (see Table 6). While this bale may not be representative of all bales sold by the ACMC it is clear that significant variation was present in all parameters except ash content.

Wool
The selection of wool achieved the objective of obtaining wools with different crimp frequency, fibre curvature and resistance to compression properties. With the LCW there was a great ability to select the required fleeces as only 16 were required from nearly 1000 tested. Conversely it should not be taken for granted that the low level of fibre curvature (mean 75 °/mm) in the LCW at the MFD of 17 µm is currently the norm in those flocks that grow this type of wool. The SW selected exceeded the specified fibre curvature and the lots varied from 96 to 141 °/mm. The nature of commercial lots is that there is variation within a lot as well as between lots. Clearly it is possible to select wool with a higher mean fibre curvature than was done but a wider range of lots would be needed or individual
fleeces selected on farm as was done with the LCW. The purpose was to obtain SW that was typical of what is commercially available and this was achieved.

While the staple crimp rate of LCW was similar to the fibre crimp rate of the CM, the fibre curvature (CM range 39 to 58 °/mm, LCW range 70 to 82 °/mm) and the Rc of the LCW was greater than that of the CM. This is because staple crimp does not reflect the individual fibre crimp of wool. Thus while LCW more closely approaches these fibre attributes of CM than does SW, LCW still does not reach the low levels found in Australian cashmere.

The LCW used were at the extreme limit of what is possible. Based on an extensive survey of Australian Merino wool, Whiteley et al. (1986) reported that the mean and 95% confidence limits for wool lot staple crimp frequency and Rc for 18 to 18.5 µm wool was 7.3 ± 1.6 crimps/cm and 10.0 ± 2.7 kPa.

4.2.2 Cashmere processing

Cashmere dehairing, quality and yield
The dehairer was able to separate all the cashmere identified in the AWTA tests. The cashmere of suitable length for worsted processing was 91% of the weight obtained by dehairing. The very short machine droppings were discarded but could be useful for felting and stuffing etc while the second grade cashmere droppings had a LAC of 23 mm and is potentially suitable for certain woollen spinning applications such as blending with wool or cotton in high twist yarns.

The processing procedure could be altered to reflect some of the practices used in China. For example, it is possible to keep separate the longest cashmere that is dehaired during the first dehairing pass. This was deliberately not done in this experiment as it was desired to obtain all the suitable cashmere in one blended lot. If this practice was done then the remaining cashmere would have a shorter mean fibre length.

The recovery of all the cashmere identified by the AWTA tests implies that no cashmere was lost in the separated coarse hair. The visual inspection of the coarse hair confirmed this but the OFDA tests on the coarse hair that was fully dehaired suggest that perhaps up to 1.8% of fine fibres remained in the coarse hair reject. It is likely that this measurement reflects finer guard hairs, or finer parts of guard hairs, such as split ends, as shown by the measurements of medullated fibre in the processed cashmere.

The incidence of medullated fibres in the dehaired cashmere was < 0.4%w/w during the set up phase and < 0.2%w/w in the gilled cashmere. After topmaking the incidence of medullated fibres declined to < 0.15% and the MFD of those medullated fibres was 38 µm (Table 9). This level of medullated fibre compares very favourably with that reported in dehaired cashmere and cashmere tops from other producing countries (Section 4.1).

This level of medullated fibre in cashmere was similar to that measured in both the wool tops produced in this experiment and in other commercial fine wool tops that have been examined (McGregor 2001). It is possible that some of the “measured” medullated fibres were dark or black fibres contaminating the wool and cashmere. If this is assumed to be the only explanation then it provides evidence that Australian white cashmere that has coloured guard hairs (WC) can be successfully dehaired to the extent that tops made from the fibre has the same level of medullated and dark fibres as that obtained from commercial and experimental wool tops. On this basis there is little reason to separate WC cashmere from white cashmere that has white guard hair.

However, even a very low number of coloured (dark) fibres in a high quality white garment can lead to a down grade of quality. It is clearly important to be able to separately measure medullated and dark fibres and eliminate both from white cashmere.
A reconciliation of cashmere weight has been provided (Table 7). There are a number of potential sources for cashmere fibre weight variation including the following:

1. Loss of fibre during fumigation in New Zealand. Nothing is known of this process but it is unlikely that weight loss would be significant.

2. During scouring in New Zealand. Fibre could be lost during unpacking, blending, feeding, transfer to drying, during drying, during repacking and transport to the dehairer. The figures provided by the dehairer suggest that the weight of the delivered fibre from the scour was either in error or the scouring fibre had more than 16% regain.

3. During dehauling as cashmere fibre can be lost in hair waste. Visual examination of the majority of guard hair waste showed no cashmere fibre.

4. Residual guard hair was present in the dehaired cashmere but at a very low incidence.

5. During carding and gilling as card waste, fly and sinkage in the machine. Fibre can be damaged and spoilt by entanglement, oil contamination etc. The figures suggest that about 7.75 kg of cashmere (6.1%) was lost between dehauling and delivery of the fibre to Sydney. Along with the amount of sliver waste that was delivered, approximately 12.5 kg of cashmere was lost from the gilled sliver in this step. Some of this was expected as new gills were being commissioned. The gilled sliver waste that was received was suitable for recycling into the card or for woollen spinning.

**Combing**

The results indicate that it is possible to obtain a hauteur of 50 mm but that noil losses will approximate 50%. This may be commercially acceptable as Nesti (1989) reported that processors obtaining hauteurs of 33 to 38 mm lose 35 to 38% noil. The regression coefficients obtained in the comb setting test indicated that for every 5 mm increase the setting the following changes occurred in the resulting combed sliver, hauteur increased by 2.1 mm, CV(H) declined by 2.4%, noil increased by 8.6% and MFD increased by 0.13 µm.

The length properties of these cashmere tops place them at the middle to upper level of world cashmere tops. This is illustrated by summarising relevant data from the survey (Section 4.1). The experimental tops also considerably exceed the Hauteur measurements of the Australian cashmere top purchased by Steadman (1995), despite the top in this experiment being considerably finer. Relevant measurements provided by Steadman (1995) or conducted on samples of his top are given in Table 17. The top used by Steadman had a much lower elongation than the other tops and the samples tested by the OFDA had a MFD almost 1 µm finer than that reported by Steadman.

These observations on the large variations in the properties of Australian cashmere tops reinforces the conclusion reached that processor affects are of significant commercial importance in determining the processed length of cashmere.
Table 17. A comparison of the attributes of the experimental Australian cashmere top with attributes of international cashmere tops and of the Australian cashmere top purchased by Steadman (1995)

<table>
<thead>
<tr>
<th>Attribute of top</th>
<th>International tops</th>
<th>This experiment</th>
<th>Steadman (1995)²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Best</td>
<td></td>
</tr>
<tr>
<td>Hauteur, mm</td>
<td>39</td>
<td>45</td>
<td>42</td>
</tr>
<tr>
<td>CV(H), %</td>
<td>43</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>Hauteur &lt; 25 mm, %</td>
<td>21.3</td>
<td>6.9</td>
<td>20.1</td>
</tr>
<tr>
<td>Barbe, mm</td>
<td>47</td>
<td>54</td>
<td>50</td>
</tr>
<tr>
<td>Medullated fibres, % w/w</td>
<td>0.43</td>
<td>0.08</td>
<td>0.12</td>
</tr>
<tr>
<td>Tenacity, cN/ktex</td>
<td>10.25</td>
<td>11.96</td>
<td>11.21</td>
</tr>
<tr>
<td>Extension, %</td>
<td>38.8</td>
<td>50.0</td>
<td>50.0</td>
</tr>
</tbody>
</table>

¹ could not be measured as grey fibre ² OFDA measurements, MFD 17.8 µm, CV(D) 22.8%, fibre curvature 45.6 °/mm, Rc 3.68 kPa.

The relatively good performance of the experimental tops is despite the fact that not all variables in the processing were optimised in this experiment. The data indicate that improvements in hauteur are possible by better comb performance. For example, Almeter data indicates there are still about 20% of fibres by number and 10% by weight less than 25 mm. These values are higher than those obtained for the wool and measured on a random selection of commercial wool tops (McGregor 2001) and although just below the mean of the tops in the cashmere survey the value is 3 times that measured in the best cashmere top. Clearly best practice indicates that cashmere combing could be improved to the level seen in the commercial wool tops then hauteur would improve considerably and the noil would increase. One way to improve hauteur would be to apply the correct level of the appropriate lubricant. Lubrication has increased the hauteur of wool by up to 10 mm (Haigh 1996b).

Of interest is the change in the MFD of the cashmere as the processing proceeds. Widespread experience with wool (Haigh 1996a) and that observed in this experiment is that the MFD of the combed top is usually greater than the MFD of the raw wool. A similar change occurred with the cashmere when the testing is standardised to the OFDA. This physical change is a result of the removal of the shorter and finer noil. The relevant data is obtained in Tables 9. However the change was less than seen with the wool as the second grade short droppings that were not included in the gilled sliver had a higher MFD than that of both the raw cashmere and gilled sliver.

4.2.3 Wool tops and comparison with cashmere

The significant differences in the fibre curvature between the raw fibre was maintained in the top (SW 107, LCW 72, CM 48 °/mm) with the actual curvature values only reduced slightly by processing into top despite the removal of about 16% of the fibre as noil. The noils had fibre curvature values about 10 °/mm higher than the raw fibre measurements.

The level of nepes and VM in the cashmere was very low and significantly less than that of both SW and LCW tops. Blending the wool with the cashmere significantly increased the level of nepes and VM in the tops. SW had significantly more nepes entanglements than LCW, a finding similar to that reported in unreplicated trials (Prins and Robinson 1996). The level of nepes in this experiment was very similar to that reported by Prins and Robinson for single combed top. They found that recombining the top reduced the incidence of nepes by 80%. Recombining appears to be unnecessary in cashmere if the purpose is to remove nepes. Based on these findings the likely explanation for the very low level of nepes in cashmere is the low level of fibre curvature in cashmere tops.
Comparisons between this study and others can be based on the following reports. Noil yield is known to vary with staple crimp frequency and MFD of wool (Turpie 1977). At 20 µm increasing the staple crimp frequency for wool from 3 to 8 crimps/cm resulted in an increase in noil from about 2.0% up to 9.5% (Turpie 1977). Kurdo et al. (1986) reported that Rc affected the processing performance of Australian 18 µm Merino wool. They found that that high Rc wools (12.3 kPa) produced Hauteurs of 46 to 54 mm while low Rc wools (8.2 to 9.5 kPa) from the same flock produced significantly longer Hauteurs of 52 to 62 mm with a mean difference of 5 mm. The high Rc wool produced less top and more noil. They also reported a very strong relationship between the raw-wool-to-top MFD difference and staple strength. As staple strength (SS) declined the difference between the MFD of the (top - raw wool) increased linearly from zero at 55 N/ktx to 1.2 µm at 25 N/ktx. They concluded that these differences must be due to preferential breakage and subsequent loss of finer fibre during carding (and perhaps combing) not evident in stronger wool. As they confirmed in their experiment when the wool was sound (SS > 42 N/ktx) there was no difference in the MFD of the raw wool and tops with the noil 0.3 µm finer and card waste 0.4 µm coarser.

For a given Hauteur, the characteristics of the wool tops produced in this experiment were of similar quality to those produced by Kurdo et al. (1986) using worsted processing equipment at CSIRO.

4.2.4 Yarn
There were significant differences in roving production and quality between WT and between wool and cashmere. SW required higher drafting to produce the same roving tex indicating that higher fibre curvature is associated with increased withdrawal forces. LCW roving packages were softer and LCW rovings were hairier than SW. Increased hairiness was also measured in both 18 and 12 tex LCW yarns.

The production of the cashmere roving was more difficult than the production of the wool roving. The quality of CM roving and yarn was different and lower than those of wool and wool blend yarns. The higher CVm of 18 tex cashmere yarns was associated with both increased total yarn faults and increased hairiness and the reduced tenacity was associated with increased thick places. These differences were less apparent in 12 and 30 tex yarn. The reduced quality of the worsted cashmere yarns was most probably related to the method of roving production. The higher CVm value of the twisted cashmere roving is most probably related to the operation of the flyer rover, where tension varies during the pack building process. The existence of drafting waves associated with the high incidence of fibres < 25 mm is also a likely contributing cause to the high CVm values. Rub roving production is now the preferred method in the wool industry as rubbed roving production is faster, cheaper and the quality problems are less than flyer roving production. In a later trial it was possible to produce 75%CM rubbed rovings with a suitable cohesive agents. The addition of 25% wool clearly resulted in improved roving and yarn quality. Rubbed rovings with a high proportion of cashmere or cashmere and LCW blends should be produced in relatively small packages and handled with care as they are softer than SW and will deform with storage.

In the flyer roving production of the combed yarn, in the worsted yarn spinning and in the open ended spinning of the cashmere cotton yarns it was necessary to use the twist factor (TF) appropriate for 100% cotton spinning in order to obtain suitable roving and yarn rather than using the TF associated with the processing of wool. The use of the cotton TF is related to the shorter fibre length and the lower fibre curvature of the cashmere relative to wool. Only two previous reports can be found on this topic. Madeley (1994 and personal communication) used a cotton spinning system to produce 100% cashmere yarn of 43 tex, using a TF of 3082 and twist of 470 tpm. Steadman (1995) used ring spinning to produce 100% cashmere of 37 tex with a ply twist of 530 but the yarn was too weak to test. His cashmere wool 50%/50% blend yarn only required a ply twist of 364 and a blend of cashmere and micro-fibre needed only a ply twist of 297. Steadmans yarns were more even, had similar tenacity and strength to the yarns in this experiment but were hairier.
Commerciaally most yarns are spun at less than optimal twist level to achieve greater production as the amount of twist is lower in both spinning and during plying. This amounts to an easy method to achieve softer yarns as both spinning twist and ply twist are reduced. The reduced twist also reduces yarn twist liveliness.

The general responses in yarn quality were:
- yarns composed of wool and cashmere were more even (12 tex) and had fewer thin and thick (18 tex) faults and neps (12 tex) than pure cashmere yarns
- yarns composed of wool and cashmere had fewer thick places (18 and 12 tex), fewer thin places (12 tex), fewer neps and lower yarn friction (12 tex) than pure wool yarns
- low crimp wool yarns were hairier, weaker and had lower elongation (all yarns), had fewer neps (18 tex) and were more variable (12 and 30 tex) than standard wool yarns
- Increasing the proportion of cashmere increased yarn hairiness (all yarns), reduced yarn tenacity and yarn elongation (18 and 12 tex) had no effect on evenness (18 tex) and in low crimp wool yarns increased yarn friction (18 tex)

Generally the 18 tex yarns were of acceptable commercial quality. The level of unevenness was similar to industry specifications and yarn tenacity and elongation were acceptable. The blended yarns of 25, 50 and 75 % cashmere have acceptable thin places but the number of thick places and nep incidence were too high (Alexander 1995).

4.2.5 Fabric

Knitting process
The pure CM had to be knitted at slower speeds than the other yarns as the cashmere yarn had low tenacity and low elongation. It was not possible to knit the R36 tex/2pure CM yarn at CF 1.58 (stitch length 3.24 mm) but it was knitted at stitch lengths ranging from 3.33 to 4.62 mm and larger loop lengths were not tested. The R24 tex/2yarn was knitted with loop lengths of 2.88 to 3.50 mm with larger ranges not tested. Samples of all blends of R24 tex/2yarn were also knitted at 27 gauge. While such fine knitting is possible it is unlikely to be commercially feasible unless higher tenacity lower fault yarn can be spun.

Clearly yarn composed of blends of cashmere had greater knitability as such yarn had greater strength and could be knitted to a wider range of loop lengths. The low evenness and higher hairiness of cashmere yarn also suggests that cashmere yarn would knit better at a coarser machine gauge than might be normally used for wool yarn of a similar linear density. In other words the use of a slightly longer stitch length could reduce the tension on the yarn and reduce the knitting friction.

KESF fundamental fabric properties
Cashmere fabrics were thinner than wool and wool cashmere blends. Blending cashmere with wool produced thinner fabrics. LCW fabrics were thinner than SW fabrics. Cashmere also had lower compressional resilience and lower compressional linearity than Blends although these effects were detected only at higher CFs. These observations may be explained by the greater resistance to compression (Rc) as a result of greater fibre crimp (increased fibre curvature) in the wool compared to the cashmere and in the SW compared to the LCW. Greater Rc of the unprocessed fibre is likely to result in fabrics being able to resist other compressional forces as the fibre curvature, while reduced slightly is not removed during processing. The differences between wool and cashmere are also likely to be greater than the differences in Rc as cashmere fibres have less prominent cuticle scales and fewer cuticle scales compared to wool fibres leading to reduced inter fibre friction and therefore easier compression. The measurement of the fabric surface friction and surface roughness
in this experiment support the view that cashmere has lower friction properties than wool. The measured differences in \( R_c \) on the unprocessed fibre directly correspond to the measured effects on \( T_m \), compressional resilience and compressional linearity in the knitted fabrics. There was no evidence that surface thickness of CM and LCW fabrics was increased as a result of the yarns being hairier.

Extension work and maximum tensile strain of cashmere and LCW were similar. Increasing BR of SW reduced these parameters so that at BR50 and BR75 there was no difference between pure CM, LCW and SW. The general response in LCW was that it performed in a “cashmere-like” way and was not affected by BR and therefore not affected by a decline in hauteur.

Given the similarity in fibre diameter, fibre composition, yarn linear density, knitting conditions and fabric thickness prior to compression testing it is not surprising that no affect on thermal insulation properties were detected. It has been known for many years that the thermal conductive resistance of ordinary clothing is determined primarily by the thickness of the layer as the relative difference in the porosity of individual layers of ordinary clothing is only moderate and the type of fibre is of little significance (Fanger 1972). It is therefore of more interest to examine the issue of porosity of the layer of fabric, a matter discussed under air permeability.

*Other fabric properties*
Pure cashmere yarns produced the lightest fabrics and adding cashmere to wool reduced fabric mass per unit area. There was also a marked difference between WT with LCW producing lighter fabrics than SW at most CFs. When stitch length was the greatest the addition of cashmere and of LCW increased fabric width.

There were very large and significant effects of fibre type on fabric air permeability. Adding cashmere increased the air permeability of all fabrics and LCW fabrics had significantly greater air permeability than SW fabrics. Reducing stitch length reduced air permeability. Reducing fabric mass per unit area increased fabric air permeability.

Increasing cashmere content improved resistance to pilling and using LCW instead of SW also improved resistance to pilling with this affect increasing as stitch length reduced. Fibre type was associated with differential fibre loss indicating that the increasing resistance to pilling as fibre type was changed and/or BR was increased was associated with loss of either the pills or fibre. This data therefore does not indicate the lack of pill formation.

CM and fabrics with increasing cashmere content had more dimensional stability. As a consequence there would be less stitch distortion and less fabric distortion. There were important differences between the two WT in the dimensional stability of the fabrics as LCW tended to behave in a “cashmere like” manner.

**4.3 Processing of short Australian cashmere by-products into textiles**

**4.3.1 Rotor spinning of cotton cashmere yarns**
It was feasible to rotor spin cashmere cotton blend yarns when the composition of cashmere is less than about 30%. It was not feasible to rotor spin high BR yarns. The problems for spinning high noil yarns were associated with reduced fibre length and too much bulk resulting in a lack of strength. Noil composition of any greater than 30% will present commercial difficulties. For SGCM greater problems were encountered with the increased fibre length, particularly the longest 5% of fibres greatly exceeding normal limits for efficient rotor operation and the greatly increased MFD as BR
increased led to a reduction in the number of fibres in the cross section. Thus it may be possible to spin higher BR yarns with SGCM but only at a greater yarn linear density. This approach is less likely to be commercially attractive as it is a questionable use for cashmere that can be used in woollen spinning.

The findings reported here are supported by both commercial and research experience using different fibres and processing techniques. Since this project commenced Todd & Duncan, Scotland have used 50 to 70% cotton with 15 to 25% silk and 15 to 25% cashmere in 36 to 60 tex ring spun yarns (Roberts 1996a). It is noticeable that the blend ratio of cashmere is low and yarn tex relatively high in order to produce a commercial yarn. The practicability and feasibility of spinning combed wool by the short staple system was described by Harry and Robinson (1977). They found that the practical spin limit of 100% wool of 40 mm length is 30 to 32 tex. They also reported that for poorer quality 40 mm wools at least 65 fibres are required in the yarn cross-section, although this may be reduced if higher percentages of synthetic are used or better quality wool is used. For a wool/cotton blend about 80 to 85 fibres in the yarn cross-section were needed for an acceptable spinning performance.

It is concluded that it is possible to spin cashmere in rotor spinning equipment provided the BR is no greater than 30% and that commercial yarn should be no less than 36 tex.

4.4 The effect of management practices on some cashmere and mohair textile properties

4.4.1 Cashmere
The data collected in this study showed that two quality attributes of cashmere of importance in textiles can be affected by management. Raw cashmere fibre length was strongly related to cashmere production, so practices that increased production can increase cashmere length. Increasing cashmere production and increasing cashmere length were related to a reduction in cashmere fibre curvature. With cashmere from goats of a completely different background, the length of the processed cashmere was highly correlated with cashmere MFD, and increasing MFD by 1 µm resulted in an increase in processed length by 2.2 mm. Increasing the length and the MFD of this processed cashmere resulted in a decline in cashmere fibre curvature.

These data from two widely different sources and with raw and processed cashmere indicates that the desire in Australia to produce longer cashmere is currently highly correlated with a decline in cashmere fibre curvature. Any decrease in fibre curvature has at least two implications: firstly decreasing fibre curvature will decrease Rc slightly and may marginally improve the softness characteristics of textile products; and secondly, people classifying such fibre may be tempted to classify cashmere with low fibre curvature as cashgora rather than cashmere.

In Merino sheep strains where length growth is high, the rate of fibre crimping is lowered (Nay and Williams 1969, Campbell et al. 1975). Experiments with Merino sheep also show that increased wool length is associated with increased mean fibre diameter (Reis 1992) and the same principle has been reported for Chinese and Australian cashmere (McGregor et al. 1991, McGregor and Umar 2000). More detailed studies with Chinese cashmere are reported elsewhere (McGregor 2001).

4.4.2 Mohair
Mohair fibre curvature is a lot lower than that of cashmere and cashgora. Mohair fibre curvature was affected by nutrition management during winter, with curvature increasing at higher stocking rates, presumably in response to reduced production and staple length. The increases measured here did not affect the Rc measurements of the Australian mohair. The fibre curvature of mohair from newer genotypes appears lower than the values reported here in the grazing study but they were higher than that reported for mohair from adult Australian reproducing does (8°/mm) and similar to the kid
Mohair studied (11 to 17 °/mm, McGregor 1995). Increasing the MFD of the modern Australian mohair reduced mohair fibre curvature but surprisingly appeared to increase Rc, albeit only slightly.

Fibre curvature in wool is likely to measure all the attributes correlated with fibre crimp. Mohair is usually described as having style, the number of curls or ringlets per cm, and character, the number of waves or crimp per cm. The measurement of fibre curvature of mohair is assumed here to provide a measure of these two mohair staple attributes. As such the effect of varying fibre curvature on mohair processing is likely to be similar to the reported effects of varying style and character on mohair processing as reviewed by McGregor (1997b). In this review, data from South African mohair goats indicates that increasing style and character by one grade was correlated with increases in top Hauteur of 6 mm, maximum spinning speed, and stronger yarns. However when other objective information is known, such as mean fibre diameter and Hauteur then there was no value in knowing the style and character of greasy mohair. Thus mohair fibre curvature is only a useful attribute to measure on raw fibre for breeding and selling purposes.

Given the low values of mohair Rc and the relatively low response of Rc to changes in other important fibre attributes it is unlikely that the use of Rc in fleece assessment is warranted.

4.5 Conclusions

4.5.1 Hypotheses tested in this project

The hypotheses that were tested in this experiment and the outcomes were:

1. That it is feasible to comb dehaired Australian cashmere and worsted spin the top.
   It was feasible to comb the dehaired Australian cashmere and to worsted spin 100% cashmere. Further work is required to fully commercialise the process.

2. That both blend ratio and wool type will affect the performance attributes of cashmere/wool blend textiles when soft handling wool is included in blends compared to when standard high crimp wool is blended (fibres having similar MFD).
   The evidence strongly supports this hypothesis.

3. That the performance attributes of pure cashmere fabrics cannot be obtained with either 100% soft handling low crimp wool of similar fibre diameter or when a large percentage of such wool is blended with cashmere.
   The evidence supports this hypothesis for some attributes of the fabrics but for other attributes there was no difference between the attributes of pure cashmere and the low crimp wool fabrics.

4. That it is feasible to spin cashmere by-products via a cotton spinning process and that the blend ratio will affect the performance attributes of cashmere/cotton blend textiles.
   It was feasible to spin cashmere by-products that have been blended with cotton on cotton spinning machinery and the blend ratio did affect performance attributes of yarns. Further work is required to commercialise the process.

5. That nutritional management of mohair and cashmere goats influences the textile attributes, other than mean fibre diameter, of the raw fibre.
   Evidence was obtained that demonstrates that nutritional management does affect the textile attributes of raw fibre, in particular cashmere fibre curvature and length.
Chapter 5
Implications

The outcomes that will have the greatest impact on industry in Australia are briefly discussed. It is not possible to give a cost benefit evaluation for these outcomes.

1. Demonstration of the fibre quality of Australian cashmere
The information on the quality of Australian cashmere compared to international cashmere provides a basis for improved marketing of Australian cashmere. The project has provided much more information on our competitors and the quality of their products. Improved marketing should improve prices and cash flow to producers. Information has been provided to industry to support this process.

2. Better definition and understanding of cashmere and cashgora
The information provided by this study will be used as a basis to challenge the suggestions that Australian cashmere is an inferior product compared to Oriental cashmere. The data will also help better define cashgora and to differentiate cashmere and cashgora. The demonstration of the influence of management during cashmere growth will also contribute to this debate.

3. Established the use of length after carding testing for defining product quality of Australian cashmere
The value of the length after carding testing procedure for cashmere, to companies trading Australian cashmere, has been demonstrated by its adoption by two companies. This use will reinforce the importance of length with the industry and should help exploit the length advantage of Australian cashmere during marketing.

4. Benchmarking the quality attributes of Australian cashmere
Benchmarks will become more valuable over time, as progress in processing cashmere and of improving the quality of raw fibre both evolve. The benchmarks have already alerted industry to the differences between processors in processing cashmere and have helped stimulate interest in alternative processing routes.

5. Assisted the selling of dehaired Australian cashmere rather than offering raw cashmere for sale and export
This project has provided considerable information about the quality of dehaired Australian cashmere and the processed tops. During the project other assistance has been provided to industry to assist them evaluate dehairing options for Australian cashmere. One example was the evaluation of unsold vegetable matter contaminated cashmere that demonstrated that the actual cashmere was of equal quality to the main line cashmere. This provided evidence that this unsaleable product could be processed into a premium product and not sold at low prices.

6. Clearer identification of processing options for Australian cashmere
The definition of the amount of short cashmere produced during worsted processing enables textile processors to objectively design textile projects. This will enable better costing of textile projects and the design of processing routes that can use the processed by-products. The project also indicated that the production of 12 tex pure cashmere yarns is unlikely to be feasible.

7. The project demonstrated that objective specification of Australian cashmere can provide long fibre length cashmere suitable for worsted processing
The project used objective data to purchase cashmere suitable for worsted processing. This was successful in providing appropriate material for worsted processing.
8. **New product development including blending cashmere with wool**
The project has evaluated a number of potential new cashmere products that can be produced in Australia. It is feasible to comb and worsted spin Australian cashmere and to process cashmere/cotton blends. Further, the benefits of blending cashmere with wool and on the actual specifications of that wool on textile quality have been highlighted. Interest has been shown in further developing some of these products by the active collaborators in Australia.

10. **Product development of low crimp wool textiles**
This project has demonstrated that soft low crimp fine wool has certain “cashmere like” attributes that differ from standard high crimp fine wool textiles. This information can be used to help provide the specialist producers of this rare Merino wool type a new differentiated market.

11. **Identification of further effects of management on the quality of cashmere**
The data analysed demonstrated that nutrition management and cashmere length do affect fibre curvature, that in turn may affect the way that the fibre is classified and the softness attributes of any textile. The effect of nutrition and cashmere length on fibre curvature may explain the large difference between Australian and traditional cashmere reported in the survey. These findings are important for the debate on the definition of cashmere, the marketing of Australian cashmere and the future prosperity of the Australian cashmere industry.
Chapter 6
Recommendations and Communication Strategy

6.1 Recommendations

On the basis of the findings of the project the following recommendations are made:

- That the Australian Cashmere industry actively promotes the demonstrated quality attributes of Australian cashmere to enhance the sale value of their product and to encourage new producers. This should include the demonstrated softness and length of the cashmere. The demonstrated potential to produce worsted yarns from existing Australian cashmere purchased from the industry also needs to be promoted.

- That the Australian Cashmere industry actively participates in the international debate on the definitions of cashmere and cashgora to ensure that Australian cashmere is not defined as "cross-bred cashmere" and devalued in the market. Further spread of the information from this project is required at an international level, including the International Wool Textile Organisation.

- That the Australian Cashmere industry focuses on improving cashmere length during production, in preparing cashmere for sale and during the processing of cashmere in Australia. This should include the adoption of length after carding measurements to describe dehaired cashmere.

- That the cashmere industry adopts Benchmarking practices to provide information on processed product quality and suitable processors. As part of benchmarking, a processing trial should be conducted by the Australian Cashmere industry that deliberately separates and processes very long fine Australian cashmere and independently verifies the outcomes, in order to demonstrate the existing potential of the industry.

- That the Australian Cashmere industry reviews the practices of separating pure white (WW) and white cashmere with coloured guard hair cashmere (WC) and of vegetable matter contaminated cashmere prior to sale and dehairing in order to ensure the most cost-effective fibre classing, lot building and processing procedures.

- That any processing trials to enhance worsted processing of cashmere in commercial works should focus on improved combing performance, the identification of appropriate lubricants and improving roving production in order to produce strong yarns suitable for commercial knitting.

- That new product development work should include a) the use of filament fibres to improve yarn strength and b) continued work to develop options for the processing of short fibre cashmere by-products.

- That the results of this project be extended to the cashmere industry and published.

- That during the development of any cashmere/wool blend textiles that the Australian Cashmere industry work with the producers and processors of soft fine wool in order to commercialise new products that exploit the natural attributes of their fibre.
6.2 Communications Strategy

On the basis of the recommendations of the project the following strategy is suggested:

- That educational and promotional material be prepared for dissemination of commercially important outcomes to cashmere growers and Australian processors.

- That reports on the outcomes of this project be prepared for international publication in wool trade magazines, for the International Wool Textile Organisation technical committees and where appropriate in textile and scientific journals.

- That further meetings be held with the Executive of the Australian Cashmere Growers Association to discuss the implications of this report and the implementation of its recommendations.

- As appropriate the Principal Investigator continue to assist in the commercial development of appropriate products with interested processors.

Publications to date

The following is a list of publications that have arisen during the conduct of this project:


Proposed future publications

The results from this project will be published in the following ways:

- As advisory articles in industry magazines and journals
- In internationally reviewed scientific papers in textile and animal science journals
- As a report published by RIRDC.

Presentations

Significant presentations not listed above include the following:

- Public seminar Department of Textile Technology, University of New South Wales, August 1997
- Australian Cashmere Growers Association National Meeting, Parramatta, 1999
- Australian Cashmere Growers Association Region Meetings, Victoria, 1999, 2000
- Australian Cashmere Growers Association Executive/Chairperson, numerous.

References


Ze, Li (1989). The technology of dehairing cashmere goats wool. (Australian National University: Canberra).