Scouring and Dehairing
Australian Cashmere

by B.A. McGregor
February 2018
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Foreword

Australia’s rural industries make a fundamental contribution to the Australian economy and way of life. In addition to the major industries, numerous new and emerging rural industries bring opportunity, diversity and resilience to rural Australia.

The long-term sustainability of the rare natural animal fibre industries is of considerable importance both to the production industries and for economic and social benefits generated by value-adding processing of rare animal fibres in Australia. As these are new industries in Australia, there is substantial scope to improve production efficiency, fibre quality and value adding of these fibres.

To assist the development of these new industries this project focussed on two main issues:

1. To assist the local rare animal fibre industries in the key area of efficient cost-effective fibre processing; and

2. To improve knowledge outputs and the knowledge base of industries.

This report is an addition to AgriFutures Australia’s diverse range of over 2000 research publications and it forms part of our Emerging Industries arena. Most of AgriFutures Australia’s publications are available for viewing, free downloading or purchasing online at www.agrifutures.com.au.

John Harvey
Managing Director
AgriFutures Australia
About the Author

As a Research Scientist, Dr. Bruce McGregor B.Agr.Sc. (Hons), Ph.D., Advanced Cert. Textile Technology, has focussed on improving the production, fibre quality, processing and comfort properties of rare natural animal fibres including superfine wool, cashmere, mohair and alpaca. This led to Ph.D. studies on the quality of cashmere and its influence on textile materials produced from cashmere and blends with different qualities of superfine wool. Recently he was Program Leader of the Wool Comfort research conducted by the CRC for Sheep Industry Innovation. He has published over 150 scientific research papers plus numerous technical bulletins and advisory publications. Bruce has travelled widely to countries that produce rare natural animal fibres so he could understand the environmental, social and technological conditions in these regions. He has published a number of other reports that are available on the AgriFutures website.

Acknowledgments

This project would not have been possible without the financial support of the Australian Cashmere Growers Association. Participating farmers are thanked for contributing their cashmere to this project. The dedicated support of staff of Cashmere Connections Pty Ltd, particularly Ms. Trisha Esson and Ms Debbie Whittaker, is gratefully acknowledged. Fibre testing was undertaken by the Australian Wool Testing Authority and Micron Man (Bibra Lakes, WA). Mr Stuart McPherson is thanked for providing processed fibre length measurements.

Cover photos

Left photo shows how the bales of Australian cashmere were core sampled at an accredited wool sampling broker under the supervision of Australian Wool Testing Authority staff.

Right photo shows Australian cashmere following scouring and before entering the drier and prior to dehairing.
Abbreviations and definitions

AWTA: Australian Wool Testing Authority

Baer diagram: a hand drawn fibre array to determine fibre length measurements

Carding: the mechanical process that disentangles, cleans and mixes fibres to produce a continuous web or sliver suitable for subsequent processing

Cashmere: the fine valuable undercoat which grows on cashmere goats

Cashmere yield: the percentage by weight of cashmere fibres in the total fleece (% w/w)

Clean washing yield: the percentage by weight of clean fleece in a raw greasy fleece (% w/w)

Dehairing: a textile process that removes the coarse outer guard hairs from the finer valuable fibres

FC: fibre curvature (°/mm) is an objective measure of fibre crimp frequency

Guard hairs: the coarse hairs which grow as the outer coat on cashmere goats which are most commonly referred to as hair

IWTO: International Wool Textile Organisation which sets the international rules regarding fibre measurement methods and trading rules

LAC: mean fibre length after carding, measured using an Almeter. The Almeter is the IWTO accepted instrument for the measurement of fibre length properties

Medullated fibres: fibres which have a hollow or a partially-filled central canal running either as a continuous or in a fragmented form along their length. Most medullated fibres present in cashmere are guard hairs which are removed by dehairing.

MFD: mean fibre diameter (μm)

n: number of observations or records

OFDA: Optical fibre diameter analyser is a computer-based laboratory measuring instrument

P-value: the statistical probability. Values less than 0.05 indicate that there is less than a 5% chance that there is no effect. In other words, the test suggests that the observed data is inconsistent with a null hypothesis

r: correlation coefficient

r²: indicate the variance accounted for by the regression (values adjusted)

RSD: the residual standard deviation for regression equations

s.d.: standard deviation

s.e.: standard error of estimate

μm: a unit of length called micrometre equal to one thousandth of a mm (often referred to as micron)
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Executive Summary

What the report is about

This report provides objective information on the processing of white Australian cashmere. The report documents objective testing of raw fibre through various stages of textile processing to cashmere ready for use by commercial spinners. This is important as there is limited scientific understanding of dehairing and the effects of raw cashmere quality on the quality of dehaired cashmere.

Who is the report targeted at?

The report is aimed at producers, processors and industry organisations.

Where are the relevant industries located in Australia?

Generally, producers are located within 200 km of major towns in southern, eastern and south-western Australia. Local manufacturing occurs in regional centres of Victoria. A number of farm-based industries using cashmere textiles also provide local employment.

Background

A knowledge and understanding of the properties of rare animal fibres is essential for: providing the producer with a clear understanding of the requirements of the textile industry; the effective utilisation of fibre in processing to garments; and producing textiles desired by the consumers. This project arises from the need for cashmere producers and processors to have confidence that dehaired Australian cashmere products can meet international standards and to understand the current dehairing process as the method to extract value for Australian cashmere producers.

Aims/objectives

The project had two main objectives:

1. to quantify the physical quality and processing efficiencies of white Australian cashmere; and
2. to document the processing performance of white Australian cashmere during dehairing.

Methods used

1. Seven cashmere producers consigned bales of their fibre to Cashmere Connections.
2. Objective sampling and testing of the cashmere bales was undertaken.
3. Cashmere was commercially scoured in Melbourne and the process was monitored.
4. In collaboration with Cashmere Connections, the fibre was monitored and sampled during all stages of fibre preparation and dehairing. At every step of the processing all residual and main product fibre was weighed, sampled and tested.
5. Staff at Cashmere Connections determined the technical requirements for processing such as machine settings, humidity requirements and the speed of processing.
6. The mass transfer through the dehairing was calculated for all lots and for each step.
7. Data were analysed to determine important processing outcomes and the influence of physical properties upon processing efficiency using correlation and regression analysis.
8. Key data were compared with a database of measurements from cashmere dehaired overseas.
Results/key findings

While the fibre generally accorded with the fibre preparation standards of the Australian Cashmere Growers Association, several lots contained unacceptable fibre. All faulted fibre should be removed at shearing as it caused multiple problems during processing.

The mass transfer monitoring demonstrated that the processes in place adequately measured and tracked the consigned fibre. The cashmere bales had higher levels of material removed by scouring than earlier studies, most probably because of lower wool base related to greater vegetable matter content and most probably greater soil content.

The dehairing process is complex and time consuming, and includes opening, humidifying and at least three dehairing passes. Different factors affected the efficiency and effectiveness of dehairing as the fibre progressed through the various processes. Two lots required four dehairing passes. Hair removal is not perfect as some cashmere is also removed. On average, 63.3% of the cashmere content estimated in the consigned bales was present as the final dehaired product. At every stage of dehairing the cashmere content of the removed fibre was less than the cashmere content of the processed sliver. However, the ability of the dehairing process to differentiate between hair and cashmere declined as dehairing proceeded, as the remaining guard hairs are finer than the average at the beginning. The fibre diameter of cashmere in the main product of dehairing did not change appreciably as the dehairing proceeds. Longer cashmere was associated with better dehairing outcomes. A lower ratio of cashmere hair length was associated with poorer processing outcomes.

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The physical properties of the dehaired cashmere were within the international range. Fibre length attributes were at the higher end of expectations based on international benchmarking indicating that top making should provide a high value product.

Implications for relevant stakeholders

All faulted fibre should be removed at shearing as contaminated fibre required more processing and caused multiple problems. Cashmere growers should not be concerned about losing cashmere fibre in processing. They should focus on growing and preparing cashmere of high quality which will be easy to dehair and not require additional dehairing to remove contaminants. The fibre diameter of cashmere in the main product of dehairing does not change appreciably as the dehairing proceeds.

The effects of and the ability to eliminate, in both raw and semi-processed fibre, the finer medullated hairs needs further investigation given the lack of scientific information.

The quality of the final dehaired cashmere easily fits into the known range of the physical properties of internationally traded dehaired cashmere and the length attributes were at the high end of known products.

Recommendations

To further develop, understand and exploit commercially the results of the project:

- Publish and extend to cashmere producers the findings of this investigation.
- Focus industry training on fibre preparation, reducing vegetable matter, coloured fibre and cott contamination, and the production of long cashmere and coarse guard hairs.
- When necessary, to use existing wool industry testing methods to quantify raw and processed fibre attributes.
- Investigate further the medullated fibre attributes of dehaired cashmere and the hair properties of existing samples of Australian cashmere.
Introduction

Background

This report provides objective information on the processing of white Australian cashmere for key industry collaborators. The author was tasked with documenting objective testing of raw fibre through various stages of textile processing to cashmere ready for use by commercial spinners.

Before cashmere can be spun into yarns, raw cashmere requires a special processing stage called dehairing, which is not required for wool processing. Dehairing is an expensive textile process that removes the coarse outer guard hairs from the finer valuable fibres. There is little objective information published on the dehairing of cashmere compared with published information available on the processing of wool, mohair or other fibres, because such information is regarded as commercial in confidence. Dehairing is essential for raw cashmere and has been commercially used for alpaca, llama, camel and yak. Further information is available elsewhere (McGregor, 2012).

With commercially available dehaired cashmere textile products, the quality of the dehairing is assessed by the content of the remaining impurity residual guard hairs and the length properties of the dehaired fibre. Comparisons between dehaired products can be made by referencing published survey data on the residual guard hairs in internationally traded cashmere products in addition to the fibre length characteristics. The mean values for residual guard hairs are (mean ± s.d and range): dehaired cashmere 0.5, 0.7, 0 to 3.7 %w/w; cashmere tops 0.4, 0.5, 0.1 to 1.5 %w/w (McGregor, 2001; McGregor and Postle, 2004a). The incidence of residual guard hair in dehaired cashmere was best predicted by origin of cashmere, mean fibre diameter, and coefficient of variation of fibre diameter (McGregor, 2000). The ranges in residual guard hairs partly reflect differences in the ability of commercial dehairers to remove guard hairs from raw cashmere, and also differences in the physical attributes of the raw fibre which affect the efficiency of the dehairing process (McGregor, 2006; McGregor and Butler, 2008). The dehairing process has to be repeated numerous times to reduce the residual guard hair to < 0.5 % w/w.

Scope of this report

This report summarises the main outcomes of the project work.

While every attempt has been made to fully and accurately document all aspects of the fibre sampling and processing it is not possible to guarantee that the information provided is without errors, and so users of this document need to seek advice regarding the application of the information for their own situation.
Objectives
The project had two main objectives:
1. to quantify the physical quality and processing efficiencies of white Australian cashmere; and
2. to document the processing performance of white Australian cashmere during dehairing.

Methodology

- In September 2015 seven cashmere producers (referred to as Lots 1 to 7) consigned bales of their fibre to Cashmere Connections Pty. Ltd. For all subsequent steps of the sampling and processing, fibre from each Lot was kept separate.

- Objective sampling of the cashmere bales was organised through an Australian Wool Testing Authority (AWTA) certified wool sampling broker (Photo 1). Subsequently objective testing was completed on these fibre samples with the AWTA.

- The cashmere bales were commercially scoured in Melbourne and the process was monitored. Immediately prior to scouring fibre was randomly sampled and cashmere and guard hair length measurements were undertaken (average measurements per bale = 54). During fibre sampling some fibre was removed as it failed to meet industry classing requirements. The scoured cashmere was dried, baled and transported to the dehairer.

- In collaboration with Cashmere Connections, dehairing processors, the fibre was monitored and sampled during all stages of fibre preparation and dehairing. The fibre was opened, humidified and dehaired. Some raw fibre was removed prior to dehairing as it was heavily cotted and would not process. At every step of the processing all residual and main product fibre was collected, weighed and the moisture content was determined. Fibre samples were also kept of all residual and main product fibre for each step of the processing.

- Staff at Cashmere Connections determined the technical requirements for processing such as machine settings, humidity requirements and the machine speed of processing. They also determined the number of dehairing stages required. For five lots only three dehairing stages were required. Two lots required a fourth dehairing to achieve the required standard.

- Fibre samples taken during processing were tested for physical properties including length.

- The mass transfer through the various stages of the dehairing process was calculated for all lots and for each stage by adjusting the moisture content to a standard 17% regain.

- Data were analysed to determine important processing outcomes and the influence of physical properties upon processing efficiency using correlation and regression analysis.

- Results were summarised.
Results

Physical properties of raw cashmere

A total of 18 bales of cashmere containing 2085 kg of fibre were delivered for processing. During inspections prior to scouring some raw fibre was removed for the following reasons (Photos 2, 3, 4):

1. black or brown fibre was found at the bottom of several bales;
2. presence of heavily cotted and vegetable matter contaminated fibre;
3. bacterial staining (blue/green) of some white fibre.

The mean physical properties of the raw fibre are summarised in Table 1. Mean lot cashmere fibre staple length varied from 7.4 to 9.5 cm, mean lot guard hair length varied from 4.3 to 8.1 cm and the ratio of cashmere to hair length varied from 1.12 to 1.97. The wool base varied from 74.3 to 78.6% and the vegetable matter base (VM) varied from 0.3 to 2.5%. The IWTO washing yield averaged 92.9%, with a range of 91.9 to 94.1%. Estimated cashmere mean fibre diameter ranged from 15.7 to 18.0 μm. The theoretical cashmere yield varied from 37.9 to 55.0%. The estimated amount of cashmere present in the raw fibre, which was actually dehaired, totalled 1149 kg.

Increased cashmere staple length was associated with reduced vegetable matter content ($r = -0.81$, $P = 0.027$) but hair length and the ratio of cashmere : hair length were not associated with vegetable matter content (respectively: $r = 0.26$, $P = 0.58$: $r = -0.40$, $P = 0.38$).
Photo 1. Core sampling a bale of Australian cashmere at an AWTA accredited wool sampling broker under the supervision of AWTA staff.

Photo 2. A sample of cashmere showing characteristic blue/green discoloration caused by bacterial action and also vegetable matter contamination.

Photo 3. Cashmere showing vegetable matter contamination with burr.

Photo 4. Cashmere showing grass seed vegetable matter contamination.
Table 1.  Physical properties of raw cashmere from 7 Australian farms based on testing before processing.

Please read the footnotes under the table for an explanation of the measurements.

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<th>Cashmere staple length (cm)</th>
<th>Hair length (cm)</th>
<th>Ratio cashmere : hair length Mean</th>
<th>Wool base B</th>
<th>VM base C</th>
<th>IWTO yield D</th>
<th>Cashmere MFD E</th>
<th>Cashmere yield F</th>
<th>Coarse hairs G</th>
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<th>Cashmere in fibre dehaired J</th>
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<td>Mean  s.d.</td>
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A Total net weight of bales at core testing.
B The percentage of clean fibre, both cashmere and hair, in the greasy cashmere.
C The percentage of vegetable matter in the greasy cashmere.
E Estimated mean fibre diameter of the cashmere using the fibre diameter distribution data including all fibres up to 30 μm. Some of the fibres less than 30 μm may be fine medullated fibres.
F The estimated percentage of cashmere in the greasy cashmere determined using the wool base and the fibre diameter distribution data.
G The incidence by number of fibres coarser than 30 μm determined from the fibre diameter distribution measured by the OFDA100.
H The estimated amount of cashmere in the consigned bales.
J Some raw fibre was removed at scouring and before dehairing (see Table 2) and this is the estimated amount of cashmere in fibre which was actually dehaired.
Mass transfer and main products during processing

The main products of processing and the mass transfer during processing are summarised in Figure 1 and Table 2. As shown in Figure 1, there were many processing steps, most involving mechanical action with revolving equipment to open the fibres and/or to separate the guard hairs from the cashmere fibre. The actual number of interactions between fibre and mechanical rollers is greater than shown in Figure 1. Values shown in Figure 1 omit data from Lot 6 which was not regarded as typical Australian cashmere as will be discussed later in this report. Data for Lot 6 is shown in Table 2. Please note that the scouring and dehairing of the lots were not undertaken in the order shown in the tables.

Moisture, scouring and humidifying

Another feature of the processing of cashmere is the addition of water at several stages of processing. During scouring, prior to dehairing and during dehairing water is directly added to the fibre or the atmosphere to assist in the efficient operation of equipment and separation of hairs and cashmere. Cashmere, like other animal fibres, can absorb up to 30% of its mass with water before becoming wet to touch. Variations in the water content of cashmere occurs during processing, between processing lots and between different days of processing, so accurate monitoring of the water content is essential. It is a standard requirement to adjust the moisture content of cashmere to 17% to enable objective measurements of mass. During the present study over 190 moisture tests were undertaken and the mass of different processing products have been adjusted to a standard 17% moisture content.

Scouring is designed to remove natural fibre contaminants known as wool grease and soil which adheres to the fibre. Wool grease consists of wax and suint (dried sweat) which are produced by different glands in the skin. The content of wax and suint in Australian cashmere is less than that reported for Chinese cashmere and Merino wool. Two methods were used to estimate the weight loss expected at scouring. The mean IWTO washing yield of 92.9% (Table 1) indicates that 7.1% of the mass would be expected to be removed during scouring. Alternatively, if the Wool base measurement (Table 1) is used with a 17% moisture regain, then a mean washing yield of 89.7% would be expected if all non-fibre contaminants were removed. This value implies an average expected loss of mass of 10.3% during scouring. Data for mass loss during the scouring operation include fibre also lost during opening and drying which cannot be separated from the mass loss solely due to scouring. Measurements showed that an average of 8.7% of the original total mass was lost during opening, scouring and drying with a range for lots of 7.1 to 9.1% (Table 2, Figure 1).

Approximately 1% of the fibre mass was removed by inspections prior to scouring or following opening and prior to dehairing as discussed earlier (Figure 1). In addition, during opening, approximately 1% of the fibre mass was recovered at cleaning of the equipment and the floor. This material was predominantly hair, dust and skin pieces (sometimes called scurf or dandruff). Such material is sometimes referred to as “fly” and “machine sinkage”.

The humidifying step shown in Figure 1 is partially automated to ensure a high moisture content prior to dehairing, but without the fibre becoming too wet i.e. a moisture content no greater than 30%. It was found that in several lots with cotted fibre that at both the drying after scouring stage and at the humidifying step after opening that cotted fibre retained more moisture than 30%. Lots with cotted fibre were difficult to:

1. dry after scouring as the cotts formed thick mats which were not dried properly;
2. accurately humidify as they contained more water in some places within the bales, particularly the lower sections of bales which had cotted fibre;
3. dehair the fibre as the wet cotted fibre stuck to equipment or fell off the feed rollers; and
4. determine accurately the moisture content as it was difficult to both sample the bales and to dry the samples accurately.

![Diagram of fiber processing steps](image)

**Figure 1.** Schematic illustration of the major steps in the processing of raw fibre.

At each major step the typical average mass loss from the consigned fibre is shown by the down arrows (data from Lot 6 was omitted). Data for DH3 and DH4 have been combined. Symbols: DH, dehairing steps; ⊗, indicates that the fibre underwent carding and or mixing action in revolving machinery; c, indicates that a final carding converted the fibre into webs for further processing.
Table 2. Main products following the scouring and dehairing of Australian cashmere from 7 farms. All fibre values have been adjusted to 17% regain. Most weights are rounded to nearest whole number. The footnotes provide an explanation of the measurements.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Raw fibre kg</th>
<th>Scour loss A kg</th>
<th>Scour loss %</th>
<th>Dehairing droppings B kg</th>
<th>Final cashmere product C kg</th>
<th>Final cashmere product as % of raw cashmere consigned D</th>
<th>Final cashmere yield as % of consigned raw fibre E kg</th>
<th>Mass recovery at finish F kg</th>
<th>Mass recovery at finish % G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>575</td>
<td>52</td>
<td>9.1</td>
<td>336</td>
<td>201.6</td>
<td>62.3</td>
<td>35.1</td>
<td>591</td>
<td>102.8</td>
</tr>
<tr>
<td>2</td>
<td>103</td>
<td>8</td>
<td>7.3</td>
<td>57</td>
<td>38.0</td>
<td>61.1</td>
<td>36.9</td>
<td>103</td>
<td>99.9</td>
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<tr>
<td>3</td>
<td>197</td>
<td>18</td>
<td>9.1</td>
<td>109</td>
<td>68.2</td>
<td>65.6</td>
<td>34.6</td>
<td>195</td>
<td>99.1</td>
</tr>
<tr>
<td>4</td>
<td>108</td>
<td>9</td>
<td>8.0</td>
<td>50</td>
<td>45.0</td>
<td>73.4</td>
<td>41.6</td>
<td>106</td>
<td>97.9</td>
</tr>
<tr>
<td>5</td>
<td>290</td>
<td>21</td>
<td>7.3</td>
<td>161</td>
<td>105.7</td>
<td>57.3</td>
<td>36.5</td>
<td>288</td>
<td>99.3</td>
</tr>
<tr>
<td>6</td>
<td>451</td>
<td>40</td>
<td>9.4</td>
<td>329</td>
<td>77.6</td>
<td>40.3</td>
<td>17.2</td>
<td>447</td>
<td>99.2</td>
</tr>
<tr>
<td>7</td>
<td>361</td>
<td>26</td>
<td>7.1</td>
<td>199</td>
<td>133.0</td>
<td>60.1</td>
<td>36.8</td>
<td>358</td>
<td>99.1</td>
</tr>
</tbody>
</table>

A The loss of material during pre-scouring opening, scouring, and drying. Most material loss would be wool grease, suint and soil during scouring. Small amounts of fibre are likely to have been lost during opening, scouring and subsequent drying.

B Machine droppings is material removed by the dehairing machine, including hair, vegetable matter, cashmere and some soil and skin pieces.

C The amount of dehaired cashmere fibre which was produced after the final dehairing pass.

D The weight of the final dehaired cashmere product expressed as a percentage of the weight of cashmere measured in the raw fibre.

E The weight of the final dehaired cashmere product expressed as a percentage of the weight of raw fibre consigned for processing.

F Mass recovery is a measurement which tracks the quantity of all fibre from weighing at bale coring through scouring and dehairing. Bale cores weighed 0.30 kg per lot. Water was added to the fibre during scouring and before and at times during dehairing. So water content measurement is essential but difficult. Over 190 moisture measurements were taken. It is important to note that no cashmere was transferred between lots during dehairing, as all machines were carefully cleaned between lots. The mass recovery value includes scour loss, dehairing droppings, final product and material lost during opening and caught in machine parts which was collected when machines were cleaned and the floor swept. For some lots this value includes cotted and stained raw fibre which was removed before scouring or before dehairing.

G Mass recovery expressed as a percentage of the raw fibre mass. Mass recovery values within 2% show that we had good accounting for all the material (within the limits of measurement). Lot 1 contained much cotted fibre which retained a lot of water after scouring and opening, and the water content of the cotted fibre was difficult to measure.
Dehairing

During the dehairing stages, an average mass loss of 36.8%, 14.0% and 2.3% occurred at the first, second and final (third and if required fourth) dehairing stages (Figure 1). Table 1 shows the total dehauling machine droppings, which is the total of both hair and cashmere removed, for each lot. Final machine cleaning amounted to a mass loss of approximately 0.9% (Figure 1). For the typical Australian cashmere consigned for processing, 36.0% was extracted as dehaired cashmere.

The production of the final dehaired cashmere product is quantified in Table 2. For all lots with the omission of Lot 6, the average recovery of cashmere from the estimated amounts in the consigned raw fibre averaged 63.3%, with a range of 57.3 to 73.4%. Lot 6 recovered only 40.3% of the raw cashmere in the final dehaired product. The final cashmere yield based on the fibre consigned for all lots with the omission of Lot 6, averaged 36.0%, with a range of 34.6 to 41.6%. Lot 6 had a cashmere yield of 17.2%.

Mass recovery

The total mass recovery at the finish of processing is shown in Table 2. This value is the sum of all the fibre removed and measured at every stage of scouring and processing including waste products, amounts cleaned from machines plus the final dehaired cashmere product. All values have been adjusted to a moisture content of 17%. Table 2 also shows the mass recovery as a percentage of the initial raw fibre mass, with values for lots ranging from 97.9 to 102.8%, and a mean value of 100.2%. For five lots the mass recovery was in the range 99.1 to 99.9%.

The mass recovery values are considered to show that the fibre consigned for processing can be accounted for based on the following considerations:

1. Accurate accounting for moisture balance is difficult given the numerous waste products which need to be weighed, sampled and dried. Doing all these activities in a busy noisy factory, where interruptions occur, is not without difficulties. Values within 2% are considered acceptable. For example, it is likely that for some lots, the weight of samples taken were not included in the final weight of machine droppings.

2. It is not possible to collect and weigh all the dust and fibre which is produced as fly and either settles outside the area of processing and cleaning or is extracted by fans and lost in airflow. Similarly it is also not possible to collect and weigh all the fibre which remains within machines. While every reasonable effort was made to collect material in machines during cleaning after the processing of lots, the fact remains that some material will remain inaccessible. Thus the mass recovery for the five lots with values of 99.1 to 99.9% probably indicates that the weights are as accurate as could be expected given small losses which cannot be measured.

3. Mass recovery for Lot 1 indicates a gain of 2.8% representing approximately 16 kg. This is the lot which had a large quantity of cotted and vegetable contaminated fibre. The apparent gain in mass was most probably related to poor drying after scouring. Poor drying became apparent following delivery of the scoured bales to Cashmere Connections. Two bales had free water in the lower half of the bales, a result of gravity as the water drained downwards, making it impossible to obtain accurate samples for determining the water content. It was also difficult to determine the water content of the samples when the water content exceeded 30%. While extra labour could have overcome these difficulties, it was not available when the problem became apparent.

4. Mass recovery for Lot 4 was 97.9%, representing a loss of 2.1% equivalent to 2 kg. It is not know why the mass recovery for Lot 4 is the lowest amongst the lots. Lot 4 had the longest cashmere and the lowest vegetable matter content (Table 1). Lot 4 also had the
highest recovery of cashmere from the raw fibre (73.4%; Table 2) and the highest processed cashmere yield (41.6%; Table 2). Given that Lot 4 was one of the smallest lots to be processed it could be that a small amount of waste product, such as machine cleanings or droppings, were not recorded at one point in the processing sequence.

**Fibre separation and removal during dehairing**

The dehairing process is designed to separate and remove all the hair and other impurities, such as skin pieces and vegetable matter, and produce pure cashmere. An undesirable consequence of the mechanical separation and removal of hair is the associated removal of some cashmere. The removal of hair and cashmere at each stage of the dehairing process is summarised in Table 3. Table 3 shows the percentage of the total amount of hair and cashmere which were removed from each lot. We will discuss hair removal first as dehairing was undertaken until basically 99.5% of the hair was removed. Examples of various products and by-products of each dehairing stage are shown in Photos 5 to 9.

**Hair removal**

During the opening and cleaning an average of 3.3% of the total hair was removed (range for lots was 1.3 to 6.2%; Table 3). The major removal of hair occurred during the first dehairing with an average of 74% removed (range 65 to 81%). During the second dehairing an average of 21% of the hair was removed (range 11 to 30%). The third dehairing removed 1.4% of the hair (range 0.6 to 2.3%). For two lots, where hair removal during the third pass was low (Lots 1 and 6), a fourth dehairing was required which removed a further 0.35% of hair in those lots. Combining dehairing 3 and 4 resulted in the average removal of 1.45% of the hair.

**Cashmere removal**

As indicated earlier and in Table 2, an average of 60% of the cashmere consigned for processing (range for lots 40.3 to 73.4%) was separated from the raw fibre and produced in the final dehaired product. This means that 40% of the cashmere was not separated from the hair and was removed with the hair. Table 3 indicates the contribution made to that loss for each stage in the processing.

During the opening and cleaning an average of 8.3% of the cashmere loss occurred (range for lots was 4.5 to 11.0%; Table 3). An average of 31% of cashmere loss occurred during the first dehairing (range 11 to 45%). During the second dehairing, cashmere loss averaged 47% of the total cashmere removed (range 33 to 68%). An average of 11% of the cashmere loss occurred during the third dehairing (range 2.4 to 18.1%). During the fourth dehairing of Lots 1 and 6, cashmere loss averaged 9% of the total cashmere removed in those lots. Combining dehairing 3 and 4 contributed an average 13.6% to cashmere removal.

**The fourth dehairing**

The fourth dehairing was required for part of Lot 1 and all of Lot 6 (Photo 9). The fourth dehairing removed only a tiny proportion of the original hair (average 0.35%) but removed an average of 9% of the cashmere which was removed. For Lot 1, this equated to 2.7% of the consigned cashmere [determined as: \[100-62.3 \text{ (see Table 2)} \times 0.073 \text{ (from Table 3)}\]]. For Lot 6, this equated to 6.2% of the consigned cashmere. For these lots, more of the cashmere was lost during the fourth dehairing than during the third dehairing.

The fourth dehairing was required for the raw fibre with the highest vegetable matter contamination. Lot 1 also had the greatest amount of cotted fibre.
Table 3.  The removal of cashmere and hair at different stages of processing.

The values shown are a percentage of the total amount of cashmere or hair removed from each lot. All values have been determined following adjustment of weights to 17% moisture regain.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Opening and cleaning $^A$</th>
<th>Dehairing pass 1</th>
<th>Dehairing pass 2</th>
<th>Dehairing pass 3</th>
<th>Dehairing pass 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cashmere</td>
<td>Hair</td>
<td>Cashmere</td>
<td>Hair</td>
<td>Cashmere</td>
</tr>
<tr>
<td>1</td>
<td>8.4</td>
<td>5.6</td>
<td>45.6</td>
<td>76.1</td>
<td>32.8</td>
</tr>
<tr>
<td>2</td>
<td>8.6</td>
<td>2.3</td>
<td>19.7</td>
<td>70.1</td>
<td>60.0</td>
</tr>
<tr>
<td>3</td>
<td>10.4</td>
<td>1.3</td>
<td>28.5</td>
<td>69.9</td>
<td>43.0</td>
</tr>
<tr>
<td>4</td>
<td>5.3</td>
<td>2.5</td>
<td>33.9</td>
<td>65.3</td>
<td>46.6</td>
</tr>
<tr>
<td>5</td>
<td>10.0</td>
<td>2.3</td>
<td>11.2</td>
<td>77.8</td>
<td>67.7</td>
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<tr>
<td>6</td>
<td>11.0</td>
<td>6.2</td>
<td>43.4</td>
<td>81.4</td>
<td>32.8</td>
</tr>
<tr>
<td>7</td>
<td>4.5</td>
<td>3.2</td>
<td>35.5</td>
<td>77.3</td>
<td>45.7</td>
</tr>
<tr>
<td></td>
<td>Mean 8.3</td>
<td>3.3</td>
<td>31.1</td>
<td>74.0</td>
<td>46.9</td>
</tr>
</tbody>
</table>

$^A$ Opening and cleaning: includes all fibre collected in the cleaning of the equipment and floor during the entire processing sequence but excluding scouring

$^B$ For Lot 1, three of the five bales required a fourth dehairing pass.

$^C$ For Lot 6, all bales required a fourth dehairing pass.
Photos 5, 6, 7 and 8. Products of various stages of the opening and dehairing processes for two farm lots with differing vegetable matter content.
Photo 9. Products of the final stages of dehairing for lots 3 and 6. Lot 3 required three dehairing passes to obtain a suitable end product.

For Lot 6, the end product after three dehairing passes required a fourth dehairing pass in order to achieve a suitable final end product. See tables for details of objective test measurements.

Where cashmere fibre removal occurred and the efficiency of dehairing

As it is not in anyone’s interest to have cashmere removed with guard hair some further data is provided to help understand where and how this occurred. Table 4 shows the proportion of cashmere in the fibre removed during the opening and dehaiering stages. In Table 4 there are details for each dehairing pass and each of the three “bins” where fibre accumulates after being removed. It is from each of these bins that the fibre was weighed, sampled and tested.

As dehairing proceeds the proportion of cashmere in the fibre which is removed in each dehairing pass increases (Table 4). In the opening and waste fibre on average 13% is cashmere. For dehairing pass 1, at the first bin about 14.5% is cashmere, much of which was cotted fibre rejected by the machinery. For bins 2 and 3 only about 5% of the fibre is cashmere. For dehairing pass 2 the removed fibre averaged 38 to 42% cashmere. For dehairing pass 3 the removed fibre averaged 65 to 70% cashmere and dehairing pass 4 averaged 85 to 88% cashmere.

The cashmere content of the raw fibre and the main product of each dehairing stage are shown in Table 5. The raw fibre contained an average of 48.9% cashmere. As dehairing progresses the sliver after dehairing passes 1, 2, 3 and 4 contained an average of 76.7, 96.4,
98.7 and 99.1% cashmere respectively (Table 5). So at every stage the cashmere content of the removed fibre was less than the cashmere content of the processed sliver.

To express the dehairing "efficiency" a processing differential has been calculated for different stages of the processing. This differential or ratio was determined by dividing the cashmere content of the main fibre mass by the cashmere content of the fibre removed at different stages and bins. For bin 1 the cashmere content of the raw fibre (pass 1) or of the main product of the previous pass was used. For bin 3 the main product of that pass was used. For example, for Lot 1, pass 2 bin 1, the cashmere content of the main product of pass 1 (Table 5) was divided by the cashmere content of the fibre removed by pass 2 bin 1 (Table 4), that is: 79.6/38.0 = 2.1. These processing differential values are shown in Table 5.

There are three findings for the processing differential results:

- Generally they declined as processing advanced. For example for bin 1, for pass 1 the processing differential averaged 6.7, or if lot 5 is omitted, 3.0; for pass 2 the processing differential averaged 2.0, for pass 3 1.4, and for pass 4, 1.15.
- Processing differentials were higher for bin 3 than for bin 1. This was especially important in pass 1, where most of the hair was removed.
- There was a lot of variation between Lots. For the two lots which required four dehairing passes, their processing differential for pass 1 bin 3 were 14.7 and 6.4, whereas the other lots ranged from 16.8 to 30.2.

These numbers make sense as the amount of hair is being progressively reduced and it becomes harder for the machines to remove a small amount of hair which is contained in a sliver of predominantly fine cashmere fibres.

**Fibre diameter of fibre removed and fibre retained**

The mean fibre diameter of cashmere in the raw fibre and in the fibre removed during the opening and dehairing stages are given in Table 6. Table 6 has details for each dehairing pass and each of the three “bins” where fibre accumulates after being removed. The mean fibre diameter of cashmere in the main product after each dehairing pass is given in Table 7. The fibre diameter of cashmere in the main product of dehairing does not change appreciably from the raw fibre as the dehairing proceeds and may be slightly finer for reasons discussed below. For Lot 5, the cashmere mean fibre diameter after pass 1 appears to be lower than those for the raw fibre, which may be due to sampling error, as the fibre diameter values for the main product after passes 2 and 3 are close to the mean of the raw fibre. For Lot 2, the cashmere mean fibre diameter appears to be reduced after dehairing compared with the raw fibre, perhaps for the reasons discussed below regarding the diameter of the hair fibres.
Table 4. The proportion of cashmere in the dehairing droppings for each dehairing pass and for each bin.

All values shown are a proportion of the mass after adjustment to 17% regain. Values rounded. The mean proportion of cashmere in the cleanings from under the final card, floor sweepings and vacuuming after each dehairing pass is given in the footnote A.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Opening</th>
<th>Dehairing Pass 1</th>
<th>Dehairing Pass 2</th>
<th>Dehairing Pass 3</th>
<th>Dehairing Pass 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>waste</td>
<td>Bin 1 Bin 2 Bin 3</td>
<td>Bin 1 Bin 2 Bin 3</td>
<td>Bin 1 Bin 2 Bin 3</td>
<td>Bin 1 Bin 2 Bin 3</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>0.078 0.207 0.062</td>
<td>0.054 0.380 0.327</td>
<td>0.452 0.726 0.598</td>
<td>0.537 0.895 0.858</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>0.131 0.156 0.024</td>
<td>0.029 0.497 0.402</td>
<td>0.371 0.544 0.673</td>
<td>0.768</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>0.238 0.123 0.061</td>
<td>0.041 0.294 0.251</td>
<td>0.274 0.526 0.820</td>
<td>0.620</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>0.131 0.235 0.076</td>
<td>0.025 0.422 0.200</td>
<td>0.238 0.856 0.685</td>
<td>0.713</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>0.051 0.019 0.036</td>
<td>0.047 0.344 0.678</td>
<td>0.428 0.757 0.645</td>
<td>0.809</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>0.163 0.139 0.092</td>
<td>0.117 0.393 0.523</td>
<td>0.571 0.677 0.438</td>
<td>0.432 0.804 0.912</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>0.116 0.133 0.058</td>
<td>0.039 0.366 0.293</td>
<td>0.598 0.823 0.689</td>
<td>0.823</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.130 0.145 0.058</td>
<td>0.050 0.385 0.382</td>
<td>0.419 0.701 0.650</td>
<td>0.672 0.850 0.885</td>
</tr>
</tbody>
</table>

A The mean proportion of cashmere in the fibre collected during the cleaning of the final card, floor sweeping and vacuuming after the dehauling of each lot: pass 1, 0.445; pass 2, 0.889; pass 3, 0.960; pass 4, 0.983.

Table 5. The percentage of cashmere in the raw fibre and in the main product at the end of each dehairing pass, and the processing differential for all dehairing passes for bins 1 and 3.

The processing differential is the cashmere content of the main product divided by the cashmere content of fibre removed at a bin.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Percentage of cashmere (%) w/w</th>
<th>Processing differential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49.5 79.6 96.9 99.0 99.2 2.4 14.7 2.1 2.1 1.3 1.8 1.1 1.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>52.1 75.6 97.6 99.5 3.3 26.1 1.5 2.6 1.8 1.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>45.4 69.0 94.0 99.2 3.7 16.8 2.3 3.4 1.8 1.6</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>49.4 75.4 95.0 99.6 2.1 30.2 1.8 4.0 1.1 1.4</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>55.0 82.6 95.8 97.7 28.9 17.6 2.4 2.2 1.3 1.2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>37.9 74.7 97.3 96.3 98.9 2.7 6.4 1.9 1.7 1.4 2.2 1.2 1.1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>53.0 80.2 97.9 99.7 4.0 20.6 2.2 1.6 1.2 1.2</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>48.9 76.7 96.4 98.7 99.1 6.74 18.90 2.03 2.54 1.42 1.54 1.15 1.14</td>
<td></td>
</tr>
</tbody>
</table>
The measurements in Table 6 indicate that the diameter of cashmere fibre measured for each dehairing pass tends to increase in successive bins and is greater than the cashmere fibre diameter of the main product of each dehairing pass (Table 7).

The diameter of the hair fibres in the raw cashmere and the main product after each dehairing pass is shown in Table 7. The mean diameter of the coarse hairs in the raw fibre was 53 μm with a lot mean range of 50 to 55 μm. After the second dehairing pass, the mean diameter of hairs in the main product had been reduced to 39 μm, and after the third pass was reduced further to 27 μm. There was a large range in the lot mean medullated fibre diameter after the third pass, varying from 21 to 39 μm (Table 7) although the incidence of these fibres was generally less than 1% in the lots not processed a fourth time (see the percentage cashmere columns in Table 5). Clearly the dehairing process removes the coarser hairs and the hairs remaining tend to be the finer medullated fibres.

Some of the medullated fibres have a measured diameter less than 30 μm. It is well known that some of these medullated fibres are not circular but have a very elliptical cross section. This means that one axis is much longer than the other. In other words, a fibre could be measured at say 50 μm on one axis and 29 μm on another axis. Some medullated fibres have thick and thin places, which means the mean diameter may be 55 μm at one place and 30 μm at another place. Hair fibres can also have split ends which may measure below 30 μm and not show as medullated fibres. Some hair fibres are only partially medullated, which means that in some sections they do not have a medulla but at other places they have a medulla. These known effects have several implications regarding how the measurements are interpreted:

1. The testing for fibre diameter measures sections of fibre which are no longer than 2 mm. These short fibres can orientate on their wider flatter side (axis) and so we undermeasure the finer narrower side (axis).

2. In estimating the mean fibre diameter, it was assumed that all fibres less than or equal to 30 μm are cashmere but some of these fibres could be fine hair fibres, such as thin places or split ends.

3. When we measure the incidence of medullated fibres we do not detect coarse hair fibres which do not have medullas.

4. It is assumed that these generally small effects cancel each other out, that is we include a few fine hairs but omit a few coarse hairs. It is likely that sampling errors are more important than measurement errors.

5. As dehairing progresses the machinery removes long guard hairs. Thus, any small errors in determining the fibre diameter of the dehaired product caused by measuring split ends, non-medullated sections of coarse hairs and fine sections in coarser hairs are reduced as the incidence of hairs declines to less than 4% by the end of the second dehairing pass (Table 5). In the final product the incidence of medullated fibres is less than 1% of all measured fibres.

6. The mean fibre diameter of medullated fibres in the final dehaired product was less than 30 μm in all but one of the lots (Table 7).
Ratio of hair : cashmere fibre diameter

The ratio of hair : cashmere mean fibre diameter can be determined from the values in Table 7 for raw fibre and for each of the main products after each dehairing pass. The mean ratios were: raw fibre, 3.13 (range 2.80-3.26); after pass 1, 3.49 (range 3.41-3.66); after pass 2, 2.37 (range 1.69-2.92); after pass 3, 1.61 (range 1.25-2.17); after pass 4, 1.48 (range 1.22-1.73). Thus the ratio of hair : cashmere fibre diameter initially increased after the first dehairing pass but then declined for each subsequent dehairing pass. None of these ratios exceeded 3.66 for an individual lot.
Table 6. The mean fibre diameter (MFD, μm) of cashmere fibre in the waste and droppings produced during the dehairing process.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Opening waste</th>
<th>Dehairing Pass 1</th>
<th>Dehairing Pass 2</th>
<th>Dehairing Pass 3</th>
<th>Dehairing Pass 4 A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bin 1</td>
<td>Bin 2</td>
<td>Bin 3</td>
<td>Bin 1</td>
<td>Bin 2</td>
</tr>
<tr>
<td>1</td>
<td>18.1</td>
<td>16.3</td>
<td>17.4</td>
<td>18.7</td>
<td>16.7</td>
</tr>
<tr>
<td>2</td>
<td>17.5</td>
<td>16.4</td>
<td>19.4</td>
<td>18.6</td>
<td>16.9</td>
</tr>
<tr>
<td>3</td>
<td>16.6</td>
<td>17.5</td>
<td>18.2</td>
<td>18.7</td>
<td>17.6</td>
</tr>
<tr>
<td>4</td>
<td>17.2</td>
<td>16.6</td>
<td>17.5</td>
<td>19.3</td>
<td>17.6</td>
</tr>
<tr>
<td>5</td>
<td>19.7</td>
<td>19.9</td>
<td>19.6</td>
<td>18.8</td>
<td>18.7</td>
</tr>
<tr>
<td>6</td>
<td>18.3</td>
<td>18.1</td>
<td>18.7</td>
<td>18.4</td>
<td>17.8</td>
</tr>
<tr>
<td>7</td>
<td>17.4</td>
<td>18.1</td>
<td>18.8</td>
<td>19.7</td>
<td>18.1</td>
</tr>
<tr>
<td>Mean</td>
<td>17.8</td>
<td>17.6</td>
<td>18.5</td>
<td>18.9</td>
<td>17.6</td>
</tr>
</tbody>
</table>

A For Lot 1, three of the five bales required a fourth dehairing pass.

Table 7. The mean fibre diameter (MFD, μm) of cashmere fibre and of medullated fibre in the main product at the end of each stage of the dehairing process.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Cashmere mean fibre diameter (μm)</th>
<th>Medullated fibre mean fibre diameter (μm)</th>
<th>Cashmere fibre diameter coefficient of variation (%) C</th>
<th>Fibre curvature (º/mm) C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.7</td>
<td>15.3</td>
<td>15.4</td>
<td>15.6</td>
</tr>
<tr>
<td>2</td>
<td>17.4</td>
<td>16.7</td>
<td>16.2</td>
<td>16.7</td>
</tr>
<tr>
<td>3</td>
<td>16.5</td>
<td>16.5</td>
<td>16.3</td>
<td>16.6</td>
</tr>
<tr>
<td>4</td>
<td>17.0</td>
<td>17.4</td>
<td>17.2</td>
<td>17.1</td>
</tr>
<tr>
<td>5</td>
<td>18.0</td>
<td>17.2</td>
<td>17.7</td>
<td>17.8</td>
</tr>
<tr>
<td>6</td>
<td>17.4</td>
<td>17.2</td>
<td>17.0</td>
<td>17.4</td>
</tr>
<tr>
<td>7</td>
<td>16.8</td>
<td>16.8</td>
<td>16.5</td>
<td>16.9</td>
</tr>
<tr>
<td>Mean</td>
<td>17.0</td>
<td>16.7</td>
<td>16.6</td>
<td>16.9</td>
</tr>
</tbody>
</table>

A From Table 1.
B Determined as mean of fibres coarser than 30 μm.
C Main product after final dehairing pass.
D For Lot 1, three of the five bales required a fourth dehairing pass.
Relationships between cashmere dehairing yield and recovery and physical properties of raw fibre

This section analyses the relationships between the cashmere dehairing yield and the recovery of cashmere in consignments with the physical properties of the raw fibre. The correlations between the physical properties and the cashmere dehairing yield and cashmere recovery are provided in Table 8 along with the statistical significance shown as the P-value. As there were only 7 lots in the study, it is more difficult to obtain statistical significance for correlations which may appear to differ from zero compared with having a larger sample of lots.

The analysis shows that there were five physical properties associated with significant correlations. Both the actual cashmere dehairing yield and the percentage recovery of cashmere in the consignment were significantly positively correlated with the ratio of cashmere length : hair length and significantly negatively correlated with the coefficient of variation of cashmere fibre diameter and the incidence of fibres greater than 30 μm in the fibre diameter distribution (Table 8). Hair fibre length was significantly negatively correlated and predicted cashmere yield significantly positively correlated with cashmere dehairing yield (Table 8). For these five physical properties the absolute value of the correlations and their statistical significance were greater for the actual cashmere dehairing yield.

Cashmere staple length was also positively correlated with cashmere dehairing yield and the recovery of cashmere, and although the P-value was only 0.053, the importance of cashmere staple length is emphasised in the significance of the ratio of cashmere length : hair length and in multiple regression analysis as discussed later in this section.

Table 8. The correlation coefficients (r) for the actual cashmere dehairing yield (% w/w) and the recovery of cashmere in consignments (%) with the physical properties of the raw fibre.

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Dehairing yield</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r</td>
<td>P-value</td>
</tr>
<tr>
<td>Cashmere staple length (cm)</td>
<td>0.74</td>
<td>0.058</td>
</tr>
<tr>
<td>Cashmere staple length standard deviation (cm)</td>
<td>-0.71</td>
<td>0.075</td>
</tr>
<tr>
<td>Hair fibre length (cm)</td>
<td>-0.77</td>
<td><strong>0.043</strong></td>
</tr>
<tr>
<td>Hair fibre length standard deviation (cm)</td>
<td>-0.65</td>
<td>0.11</td>
</tr>
<tr>
<td>Ratio cashmere length : hair length</td>
<td>0.87</td>
<td><strong>0.010</strong></td>
</tr>
<tr>
<td>Ratio cashmere length : hair length standard deviation</td>
<td>0.03</td>
<td>0.95</td>
</tr>
<tr>
<td>Cashmere mean fibre diameter (μm)</td>
<td>-0.15</td>
<td>0.74</td>
</tr>
<tr>
<td>Coefficient of variation of cashmere fibre diameter (%)</td>
<td>-0.84</td>
<td><strong>0.018</strong></td>
</tr>
<tr>
<td>Incidence of fibres greater than 30 μm in fibre diameter distribution (%)</td>
<td>-0.93</td>
<td><strong>0.003</strong></td>
</tr>
<tr>
<td>Hair mean fibre diameter (μm)</td>
<td>0.04</td>
<td>0.933</td>
</tr>
<tr>
<td>Ratio hair : cashmere fibre diameter (raw fibre)</td>
<td>0.16</td>
<td>0.74</td>
</tr>
<tr>
<td>IWTO yield (%w/w)</td>
<td>0.17</td>
<td>0.72</td>
</tr>
<tr>
<td>Wool base (%w/w)</td>
<td>0.51</td>
<td>0.25</td>
</tr>
<tr>
<td>Vegetable matter base (% w/w)</td>
<td>-0.64</td>
<td>0.12</td>
</tr>
<tr>
<td>Cashmere yield (%w/w)</td>
<td>0.83</td>
<td><strong>0.021</strong></td>
</tr>
<tr>
<td>Fibre curvature (%/mm)</td>
<td>0.49</td>
<td>0.27</td>
</tr>
</tbody>
</table>

P-values in bold are less than 0.05
The relationship between the variation in the ratio of cashmere length : hair length explained 71% of the variance in the actual cashmere dehairing yield (RSD 4.16%), with the slope of the relationship increasing by 23.6% (s.e. 5.89) for each 1 unit increase in the ratio (Figure 2). However, the relationship between the variation in the incidence of fibres coarser than 30 μm in the fibre diameter distribution explained 83% of the variance in the actual cashmere dehairing yield (RSD 3.24%), with the slope declining 4.15% (s.e. 0.761) for each 1% increase in fibres coarser than 30 μm in the fibre diameter distribution (Figure 3).

Figure 2.  The relationship between the actual cashmere dehairing yield and the ratio of cashmere staple length to hair fibre length.

Figure 3.  The relationship between the actual cashmere dehairing yield and the incidence of fibres coarser than 30 μm in the fibre diameter distribution of raw fibre.

Figure 4.  The relationship between the actual cashmere dehairing yield and cashmere staple length.

Figure 5.  The relationship between the actual cashmere dehairing yield and cashmere fibre curvature.
Multiple regression analysis was performed to identify if any additional physical properties could explain additional variance in the actual dehairing yields. The best predictive equation was the following (s.e. in brackets):

\[
\text{Cashmere dehairing yield} = 19.4 (9.25) - 3.3 (0.42) \times \text{incidence of fibres coarser than 30 \(\mu\)m} + 3.9 (0.93) \times \text{cashmere staple length}; \text{RSD 1.56; } P = 0.00072.
\]

This equation explained 96% of the variance. The marginal significance of including the incidence of fibres coarser than 30 \(\mu\)m was \(P = 0.0013\), and including cashmere staple length was \(P = 0.0139\). There was no statistical support for including other physical properties in this equation (cashmere staple length s.d., \(P = 0.15\); hair fibre length, \(P = 0.21\); ratio of cashmere length: hair length, \(P = 0.18\); cashmere mean fibre diameter, \(P = 0.20\); cashmere fibre diameter CV, \(P = 0.44\); IWTO yield, \(P = 0.35\); fibre curvature, \(P = 0.085\); vegetable matter base, \(P = 0.95\)). If the best of these physical properties was included, that is fibre curvature, the variance accounted for increased to 98.3%.

**Processing performance and physical properties of raw fibre**

Processing performance can be assessed using the following measurements: the removal of cashmere and hair during each dehairing pass as a percentage of the total amount removed from each lot (Table 3); the proportion of cashmere in the fibre removed during each dehairing pass and for each bin (Table 4); and the processing differential during dehairing (Table 5). The following physical raw fibre properties had significant effects on processing performance.

**Cashmere staple length**

Cashmere staple length was associated with the processing differential during dehairing pass 1 bin 3 \((r = 0.85, P = 0.015, \text{Figure 6})\) and during dehairing pass 2 bin 3 \((r = 0.82, P = 0.034)\). In other words, longer cashmere was associated with increased processing differential at these points. At both these points, cashmere staple length was associated with the percentage of cashmere in the droppings with less cashmere content associated with longer cashmere (respectively: \(r = -0.79, P = 0.034\); \(r = -0.83, P = 0.020\)). Cashmere staple length was also associated with opposite effects on the loss of hair as a proportion of total hair loss during dehairing passes 1, 2 and 3 (respectively: \(r = -0.86, P = 0.013\); \(r = 0.93, P = 0.002\); \(r = 0.74, P = 0.055\)). In other words, longer cashmere staples were associated with relatively less of the hair removed during dehairing pass 1 but with more hair removal for the remaining dehairing passes.

There were no effects of cashmere staple length variation.

**Ratio of cashmere and hair length**

There were no significant effects of hair length or hair length variation. The ratio of cashmere: hair length was associated with increased processing differential and reduced cashmere in the droppings during dehairing pass 1 bin 3 (respectively: \(r = 0.76, P = 0.049\); \(r = -0.84, P = 0.017\)). The standard deviation of the ratio of cashmere: hair length was associated with reduced processing differential and increased cashmere in the droppings during dehairing pass 1 bin 1 (respectively: \(r = -0.87, P = 0.010\); \(r = 0.87, P = 0.010\)).

**Cashmere fibre diameter coefficient of variation**

There was no association between cashmere mean fibre diameter and any processing performance measurement in the present study. Cashmere fibre diameter coefficient of variation was positively associated with processing differential during dehairing pass 3 bin 3 \((r = 0.78, P = 0.038)\) meaning greater variation was associated with greater processing.
differential. Cashmere fibre diameter coefficient of variation was also associated with opposite effects on the loss of cashmere as a proportion of total cashmere loss during dehairing pass 1 bin 3 and pass 3 bin 2 (respectively: \( r = 0.85, P = 0.016; r = -0.88, P = 0.009 \)). Cashmere fibre diameter coefficient of variation was also associated with the loss of cashmere as a proportion of total cashmere loss during dehairing pass 3 (\( r = -0.84, P = 0.019 \)). These findings suggest that cashmere fibre diameter coefficient of variation had some limited effects during the last stage of dehairing where a greater variation was associated with greater processing differentiation, less cashmere in the droppings and less proportion of total cashmere loss. This can be interpreted as the operators ensuring that the final dehairing pass removed finer medullated fibres which were measured as part of the fibres less than 30 \( \mu m \).

Figure 6. The relationship between the processing differential during dehairing pass 1 at bin 3 and cashmere staple length. Figure 7. The relationship between the processing differential during dehairing pass 3 at bin 3 and vegetable matter base of raw cashmere.

Ratio of hair : cashmere fibre diameter

A higher ratio of hair : cashmere fibre diameter in raw fibre was associated with a poorer processing differential during dehairing pass 1 bin 1 (\( r = -0.90, P = 0.005 \)) and with a higher percentage of cashmere in the droppings during dehairing pass 1 bin 1 (\( r = 0.84, P = 0.019 \)). These results were entirely related to Lot 6 which was effectively an outlier in the data set. There were no other effects detected for the ratio of hair : cashmere fibre diameter in raw fibre or in any main product on subsequent processing, cashmere or hair loss.

Vegetable matter

Increasing vegetable matter content was associated with greater processing differential, less cashmere content in the droppings and a reduced loss of cashmere as a proportion of total cashmere loss during dehairing pass 3 bin 3 (respectively: \( r = 0.85, P = 0.014 \), Figure 7; \( r = -0.84, P = 0.019 \); \( r = -0.88, P = 0.009 \)). In other words, at the very end of dehairing the operators provided specific attention to ensure the removal of residual guard hairs.
Mass loss during scouring

The loss of mass during scouring was most strongly associated with wool base, with increasing wool base associated with less mass loss \((r = -0.87, P = 0.011, \text{Figure 8, Table 9})\). IWTO yield was not as strongly associated with mass loss during scouring compared with wool base \((r = -0.79, P = 0.035, \text{Table 9})\). Vegetable matter base was positively associated with mass loss during scouring \((r = 0.70, P = 0.079, \text{Figure 9, Table 9})\) suggesting a possible association between greater vegetable matter content and a greater presence of scourable material such as soil. The regression coefficients in Table 9 show that for each 1% increase in wool base the scour loss declined by 0.55%, and for each 1% increase in IWTO yield scour loss declined by 0.79%, for each 1% increase in vegetable matter base scour loss may increase by 0.7%.

No other physical fibre property was significantly associated with mass loss during scouring.

**Table 9.** Linear regressions relating scouring loss (% w/w) with either the wool base (% w/w), vegetable matter base (% w/w) or IWTO yield (% w/w) of Australian cashmere.

<table>
<thead>
<tr>
<th>Response variate</th>
<th>Regression Constant (± s.e.)</th>
<th>Dependent variate</th>
<th>Regression coefficient (± s.e.)</th>
<th>(r^2)</th>
<th>RSD</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scour loss</td>
<td>50.3 (10.7)</td>
<td>Wool base</td>
<td>-0.55 (0.139)</td>
<td>0.71</td>
<td>0.53</td>
<td>0.011</td>
</tr>
<tr>
<td>Scour loss</td>
<td>81.6 (25.6)</td>
<td>IWTO yield</td>
<td>-0.79 (0.276)</td>
<td>0.55</td>
<td>0.67</td>
<td>0.035</td>
</tr>
<tr>
<td>Scour loss</td>
<td>7.5 (0.41)</td>
<td>Vegetable matter base</td>
<td>+0.70 (0.320)</td>
<td>0.39</td>
<td>0.77</td>
<td>0.079</td>
</tr>
</tbody>
</table>
Dehaired fibre length

Representative samples of the final dehaired cashmere were assessed for fibre length. The samples were first carded on a laboratory scale benchtop card and then subject to a fibre draw or hand array length (Baer diagram), which is the traditional method used by textile companies. This method provides several length measurements including the mid length, 95% of maximum, and 5% of maximum length. In addition, the average of these three measurements was determined. For each lot, four replicate fibre draws were measured, and the mean values are shown in Table 10. The average mid length was 46.1 mm, with the longest mid length 48.8 mm and with 8 of the lots between 45.3 and 48.8 mm and two lots near 40 mm. Lots 2 to 5 had 95% maximum lengths of 81.8 to 84.0 mm and the average 95% maximum length was 78 mm. The 5% of maximum lengths varied from 15.3 to 19.3 mm. The average fibre length was generally within 1.5 mm of the mid length with the main exception being lot 3, where the average length was 6.1 mm longer.

Table 10. Dehaired cashmere length measurements determined from a Baer diagram fibre draw for all lots including different bale components of Lot 1, and the ratio of the 95% of maximum length and the mid length (MidL) to the raw fibre staple length.

<table>
<thead>
<tr>
<th>Lot</th>
<th>Mid length</th>
<th>95% of maximum</th>
<th>5% of maximum</th>
<th>Average</th>
<th>Ratio MidL : staple length</th>
<th>Ratio 95% : staple length</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>48.0</td>
<td>78.3</td>
<td>16.5</td>
<td>47.6</td>
<td>0.63</td>
<td>1.04</td>
</tr>
<tr>
<td>1b</td>
<td>40.0</td>
<td>72.3</td>
<td>16.0</td>
<td>42.8</td>
<td>0.64</td>
<td>1.02</td>
</tr>
<tr>
<td>1c</td>
<td>46.5</td>
<td>71.8</td>
<td>19.3</td>
<td>45.8</td>
<td>0.60</td>
<td>0.94</td>
</tr>
<tr>
<td>1d</td>
<td>48.8</td>
<td>77.5</td>
<td>18.8</td>
<td>48.3</td>
<td>0.50</td>
<td>0.84</td>
</tr>
<tr>
<td>2</td>
<td>47.8</td>
<td>81.8</td>
<td>18.8</td>
<td>49.4</td>
<td>0.49</td>
<td>0.81</td>
</tr>
<tr>
<td>3</td>
<td>40.8</td>
<td>83.0</td>
<td>16.8</td>
<td>46.8</td>
<td>0.56</td>
<td>0.83</td>
</tr>
<tr>
<td>4</td>
<td>47.8</td>
<td>84.0</td>
<td>15.8</td>
<td>49.2</td>
<td>0.48</td>
<td>0.79</td>
</tr>
<tr>
<td>5</td>
<td>47.3</td>
<td>82.5</td>
<td>15.3</td>
<td>48.3</td>
<td>0.55</td>
<td>0.91</td>
</tr>
<tr>
<td>6</td>
<td>48.5</td>
<td>77.0</td>
<td>16.3</td>
<td>47.3</td>
<td>0.54</td>
<td>0.87</td>
</tr>
<tr>
<td>7</td>
<td>45.3</td>
<td>74.3</td>
<td>15.8</td>
<td>45.1</td>
<td>0.50</td>
<td>0.84</td>
</tr>
</tbody>
</table>

The ratio of mid length to staple length varied from 0.48 to 0.64 for the different lots, with the average ratio being 0.55 (Table 10). The ratio of the 95% of maximum length to staple length varied from 0.79 to 1.04 for the different lots, with the average ratio being 0.89 (Table 10).

The correlation coefficients ($r$) determined between the dehaired length measurements and raw fibre length measurements are shown in Table 11. What these correlations show is that the raw cashmere staple length was the best predictor of the 95% maximum length with a positive coefficient of 0.76 ($P = 0.011$). This indicates that longer raw fibre was associated with longer 95% maximum dehaired lengths.

The next highest correlations were between the variation (s.d.) of the ratio of cashmere to hair length, which was negatively correlated with both mid length and the average length. This suggests that perhaps larger variation in cashmere to hair lengths is related to shorter mid length ($P = 0.056$) and shorter average length ($P = 0.062$).

The lack of significant relationships between dehaired mid length and raw fibre staple length is probably related to the small number of lots and the relatively similar and small range in mid length measurements, where 8 of the lots ranged in mid length between 45.3 and 48.8 mm.
Table 11. The correlation coefficients and significance of relationships between raw cashmere and hair fibre lengths and dehaired fibre lengths determined from a Baer diagram fibre array \( (n = 10) \).

<table>
<thead>
<tr>
<th>Baer diagram length</th>
<th>Raw fibre length</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cashmere staple length</td>
<td>Cashmere length s.d.</td>
</tr>
<tr>
<td>Mid length</td>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>95% maximum</td>
<td><strong>0.76</strong></td>
<td>0.46</td>
</tr>
<tr>
<td>5% maximum</td>
<td>-0.04</td>
<td>-0.14</td>
</tr>
<tr>
<td>Average length</td>
<td><strong>0.57</strong></td>
<td>0.33</td>
</tr>
</tbody>
</table>

P-values: < 0.05 are in bold; < 0.1 are in italics.

Predicted length after carding

Using the Baer diagram mid fibre length, and the prediction equations derived using dehaired cashmere samples and Almeter measurements (McGregor, 2007), estimates were made of the length after carding (LAC) and LAC “Barbe” measurements (Table 12). These predicted lengths are before top making (combing) and indicate LAC of 35-40 mm for eight of the ten lots, with the average LAC being 36 mm. The mean predicted 95% of maximum length (HL5) was 65 mm. The LAC “Barbe” measurement is similar to that used for Chinese length measurements and indicates that for eight of the ten lots that the LAC “Barbe” was 50-57 mm and the average of all lots was 52 mm.

Table 12. Predicted dehaired cashmere length after carding (LAC).

<table>
<thead>
<tr>
<th>Lot</th>
<th>Length after carding (mm)</th>
<th>95% of Maximum (mm)</th>
<th>LAC “Barbe” (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>38</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>1b</td>
<td>30</td>
<td>59</td>
<td>43</td>
</tr>
<tr>
<td>1c</td>
<td>37</td>
<td>58</td>
<td>52</td>
</tr>
<tr>
<td>1d</td>
<td>39</td>
<td>64</td>
<td>56</td>
</tr>
<tr>
<td>2</td>
<td>38</td>
<td>69</td>
<td>54</td>
</tr>
<tr>
<td>3</td>
<td>31</td>
<td>70</td>
<td>44</td>
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<td>4</td>
<td>38</td>
<td>71</td>
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<tr>
<td>5</td>
<td>37</td>
<td>70</td>
<td>53</td>
</tr>
<tr>
<td>6</td>
<td>39</td>
<td>64</td>
<td>55</td>
</tr>
<tr>
<td>7</td>
<td>35</td>
<td>61</td>
<td>51</td>
</tr>
</tbody>
</table>
Discussion and Implications

Mass transfer

The mass transfer monitoring demonstrated that the processes in place adequately measured and tracked the consigned fibre. The overall consignment deviation in mass was 0.2%, and with most lots the mass deviation was less than 1%. Given the large changes in moisture levels related to scouring in water, drying and then humidifying to nearly 30% moisture content, the measurement of mass change is difficult but clearly the results are more than adequate to say that fibre is not “lost” in the processing and is carefully supervised and legitimately accounted for. On this evidence, cashmere growers should not be concerned about “losing” cashmere in processing. They should focus on growing and preparing cashmere of high quality.

Raw fibre quality

While the fibre generally accorded with the fibre preparation standards previously published by the Australian Cashmere Growers Association (Anonymous, 1997), several lots contained unacceptable fibre. These faults included coloured fibre, heavily cotted and vegetable matter contaminated fibre and some bacterial staining (Photos 1-4). All this faulted fibre should be removed prior to consignment.

Cotted fibre is known to be associated with poorer dehairing efficiency and shorter dehaired cashmere (McGregor and Butler, 2008). Furthermore, cotted fibre caused problems in monitoring the mass transfer during dehairing and managing the correct moisture levels. Most cotted fibre was rejected at the first set of dehairing rollers and was deposited in the first dropping bin. Thus, cotted fibre increased costs of scouring, opening and dehairing for no financial return.

There was variation in cashmere and guard hair length. Longer cashmere was associated with better dehairing outcomes. A lower ratio of cashmere : hair length was associated with poorer processing outcomes. Ideally cashmere should have lengths greater than 8 cm and a ratio of cashmere : hair length greater than 1.6. There is no evidence that longer guard hairs protect the cashmere from the effects of weathering (McGregor, 2016) or vegetable matter contamination. Both weathering and vegetable matter contamination are more likely to be related to geographical issues and farm management practices.

Scouring

The results here add to previous reports of the scouring and clean washing yield of commercial bales of Australian cashmere. The IWTO yield range of 91.9 to 94.4% and mean of 92.9% is lower than earlier reports. The actual mass loss during scouring averaged 8.2% implying a scouring yield of 91.8%. The clean washing yield of commercial bales of 1997 pooled Australia cashmere was 96.6% and the reported scouring yield following commercial scouring was 94.9% (McGregor, 2002; McGregor and Postle, 2004a) with the difference probably due to loss of fibre at the commercial scour. For main line bales of commercial Australian cashmere, the clean washing yield was 96.5% and the vegetable matter content 0.8-1.1% (McGregor, 2003). In another study, for 48 smaller batches (mean weight 3.1 kg) of commercial Australian cashmere, from a range of Australian farms, the clean washing yield was 90.9% (range 79.5-97.3%) but the scour yield was 79% (range 68-88%). This lower scour yield probably reflecting small losses of fibre during processing (McGregor and Butler, 2008).
The present results indicate that the cashmere bales had higher levels of material removed by scouring than earlier studies of commercial cashmere, most probably because of the lower wool base related to greater vegetable matter content and most probably greater soil content (McGregor, 2003). In the present study, for each 1% increase in wool base scour loss declined by 0.55%, and for each 1% increase in IWTO yield scour loss declined by 0.79%.

Given the cost of dehairing and the low grease content in Australian cashmere compared with Merino wool, Wang et al. (2008) investigated dehairing one batch of greasy Australian cashmere compared with one similar batch of cashmere scoured before dehairing. The results suggest that scouring before dehairing may increase the incidence of fibre entanglements (neps), skin pieces, hair content and perhaps reduce dehaired length, as has been reported for the effect of scouring with Merino wool. However, fibre lapping on the rollers during dehairing of greasy fibre was a significant practical problem and the idea of dehairing greasy cashmere has not been pursued.

There were clearly problems with the drying of some batches of scoured fibre which lead to problems at the dehairer. Slow drying of crossbred goat fibre (cashgora type) has been noted during processing in New Zealand (Sanderson and Wilkinson, 1990). These experiences suggest that slowing the rate of passage of fibre through the dryer or improved monitoring of the drying process is necessary as a quality assurance procedure.

**Dehairing**

The dehairing process is complex and time consuming, and includes opening, humidifying and at least three dehairing passes. Two lots required four dehairing passes. The main issues in dehairing are removing the finer guard hairs and vegetable matter contamination. Basically, dehairing is required until 99.5% of the hair is removed and the more hair removed early in dehairing the better. Hair removal is not perfect and some of the cashmere is also removed. At every stage of dehairing the cashmere content of the removed fibre was less than the cashmere content of the processed sliver, so the process is clearly selecting hair.

The ability of the dehairing process to differentiate between hair and cashmere declines as dehairing proceeds as the remaining guard hairs are finer than the average guard hair at the beginning. As dehairing proceeds, the fibre diameter of cashmere in the main product of each dehairing stage does not change appreciably from the raw fibre, and may be slightly finer.

The evidence is that cashmere with longer staple length was associated with higher cashmere dehairing yields and better dehairing differentials during the first two dehairing stages. Furthermore, the ratio of cashmere length : hair length is important, with a ratio above 1.6 associated with higher dehairing yields compared with lower ratios nearer 1.2. More fibres coarser than 30 μm was associated with lower dehairing yields.

Several one-off effects were detected at different stages of dehairing, where one physical property affected the processing differential or cashmere loss. It is not possible to confidently say whether these are real effects and will occur with other processing and therefore reinforce the complexity of the dehairing process. In other words, many factors may affect dehairing but operate at different stages of dehairing. Alternatively, the data set may be too small and what effects that have been detected are really related to this particular set of lots, particularly Lot 6, which may have biased the analyses. A question which arises is why did Lot 6 required a fourth dehairing pass? Lot 6 had several physical attributes which were associated with poorer dehairing performance, these being the presence of higher VM contamination (Table 1), short cashmere of similar length to the guard hairs (Table 1), lower cashmere yield (Table 1) and a greater cashmere fibre diameter distribution compared (Table 7) with the other lots. For Lot 6, 54% of the cashmere removed during processing occurred...
during opening and dehairing pass 1, compared with an average of 37% for the remainder of
the lots (Table 3). Even during dehairing pass 2, Lot 6 had a higher proportion of cashmere in
the removed fibre than most other lots (Table 4). Lot 6 exhibited lower processing
differentials throughout dehairing (Table 5), indicating that there was considerable difficulty in
separating the hair and cashmere.

The literature on commercial dehairing is scant, because of trade secrecy so there are very
few reports which can be used for comparison with the present results. Smith et al. (1984), at
the time a senior executive of Dawson’s International Ltd., Bradford, which processed 60% of
the world’s cashmere, made two interesting comments about cashmere fibre for dehairing.
Firstly, Dawson’s did not want cashmere fibres > 27.9 µm. Dawson’s did not want either fine
guard hairs or coarse down fibres in the range 28 to 40 µm. The fine guard hairs are flexible
and almost impossible to remove during dehairing. The present results provide objective
evidence to support this contention that finer guard hairs require further dehairing to remove.

Secondly, Smith et al. (1984) observed that differential removal of coarse medullated fibres
occurs best where the diameter of the medullated fibres is about 3.5 to 4 times that of the
preferred cashmere fibres. At fibre diameter ratios less than 3.5, they reported that it was too
difficult to remove all the guard hairs owing to the differences in the elastic recovery and
rigidity between the finer fibres and guard hairs. Once these fibres become intimately mixed
and intermingled, then dehairing is more difficult (Townend et al., 1980; Frank et al., 2011)
with the implication that separation is required during the first passage through machinery. In
the present study, almost all the measurements of the ratio of hair to cashmere fibre diameter
were less than 3.5. Such a finding could suggest that: farmers should breed goats with
coarser guard hairs; equipment for dehairing Australian cashmere needs special design
criteria to remove fine guard hairs; or our methods for measuring hair and medullated fibres
need to be refined. It may also mean that the experience of dehairing combed Chinese
cashmere is not fully applicable to the dehairing of shorn fibre such as processed in the
present investigation.

In an earlier study of dehairing cashmere from 9 different commercial Australian cashmere
farms using 48 processing lots, McGregor and Butler (2008) demonstrated that white colour
compared with brown colour, longer raw cashmere, greater cashmere fibre curvature, lower
vegetable matter content, normal length guard hair compared with longer hair and the
absence of visible cotting were significantly associated with more efficient dehairing and or
the production of longer dehaired cashmere. Between 70 and 90% of the variation in
dehaired cashmere length and processing efficiency was explained by known attributes.
Despite the limitations in size of the present study, a number of these earlier findings were
supported by the present results.

The work of McGregor and Butler (2008) also identified that raw cashmere with a higher
cashmere content and higher mean fibre diameter processed less efficiently than raw
cashmere with a lower cashmere content and finer mean fibre diameter. The present study
was not able to detect any effects of mean fibre diameter, most probably related to
insufficient number of independent lots.

An important component of cashmere dehairing is the removal of vegetable matter
contamination. Vegetable matter contamination affects the efficiency of cashmere dehairing,
as increasing the vegetable matter base of raw cashmere reduces the proportion of
cashmere recovered as the final product (McGregor and Butler, 2008). In an earlier study of
Australia cashmere, for each 1% increase in the VM base, the predicted cashmere yield
decreased by 0.39%, and for each 1% increase in the wool base the predicted cashmere yield
increased by 0.35% (McGregor, 2003).
Vegetable matter contamination of cashmere may necessitate additional dehairing passes, as for two lots in the present study (Photo 9), or adjustment to equipment to remove more cashmere in the latter stages of dehairing. Increasing levels of vegetable matter in raw Merino wool are associated with greater losses of wool during carding, with 98% of the variation between processing lots for card loss being accounted for by differences in the VM base (Charlton et al., 1985). Of more concern in relation to efficient removal of vegetable matter are the findings of research with wool, which identified that optimal removal occurred near a moisture regain of less than 10% compared with a regain of 20% (Schmidt and Turpie, 1976; Townend and Russell, 1980). Put into a context of the desired regain of near 30% for the efficient removal of guard hairs then it can be seen that having a high level of vegetable matter in raw cashmere is very problematic for efficient dehairing. More information on the effects of vegetable matter contamination on wool processing losses and requirements can be found elsewhere (Bow et al., 1989; Atkinson, 1990; Haigh, 1996).

Residual hairs

The dehairing process is designed to cost effectively remove undesirable coarse hairs from the fine cashmere fibres. As this investigation indicates, the removal of the finer hairs is difficult and a residual remains in the final dehaired product. There is relatively little published information on the physical properties of residual hairs in cashmere textile products mostly because the focus has been on the cashmere mean fibre diameter and also the technology to easily measure residual hairs is relatively new. Data from a survey of the physical properties of dehaired cashmere undertaken between 1997 and 2000 are available (McGregor, 2001; McGregor and Postle, 2004b) and were used to benchmark the products from the present study (Table 13, Figures 10 and 11). The survey database was restricted to white dehaired cashmere with a mean fibre diameter less than 20 μm. The samples had been dehaired in Italy, Iran, China, UK, Mongolia, New Zealand and USA. What this comparison shows is that the present samples had a slightly higher mean fibre diameter and fibre diameter coefficient of variation, a higher average incidence of medullated fibres but the medullated fibres were finer. Generally, measurements were within the international range with the exception that several samples had finer medullated fibres remaining compared with the survey samples (Figure 11). This finding should be regarded as a good attribute.

It is possible to expand the benchmark data set by including more recent international samples and to investigate further the fibre testing data from recent investigations, such as on-farm sampling from Australian cashmere producers, to examine the physical properties and processing effects of hairs (e.g. McGregor, 2006; McGregor and Butler, 2008). In recent years there have been some investigations of the factors associated with the incidence of medullated fibre in mohair which may shed some light upon biological factors affecting hair properties in raw cashmere (McGregor et al., 2013a, b).
Figure 10. The relationship between the incidence of medullated fibre and a) mean fibre diameter, and b) fibre diameter coefficient of variation of dehaired cashmere. Plots are the observed values after model fitting. Symbols: ○, survey samples; △, present study.

Figure 11. The relationship between the mean fibre diameter of medullated fibre and a) mean fibre diameter of all fibres, and b) the incidence of fibres coarser than 30 µm in dehaired cashmere. Plots are the observed values after model fitting. Symbols: ○, survey samples; △, present study.
Table 13. Mean, s.d. and range of data for attributes of cashmere dehaired in various countries with a comparison to the attributes of dehaired fibre from the present investigation (n = 52).

Data derived from an international survey of dehaired cashmere (McGregor, 2001; McGregor and Postle, 2004b).

<table>
<thead>
<tr>
<th>Physical property</th>
<th>Mean</th>
<th>s.d.</th>
<th>Maximum</th>
<th>Minimum</th>
<th>Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean fibre diameter (MFD, µm)</td>
<td>16.0</td>
<td>1.56</td>
<td>19.3</td>
<td>13.5</td>
<td>16.9</td>
</tr>
<tr>
<td>FDCV (%)</td>
<td>21.9</td>
<td>1.30</td>
<td>27.1</td>
<td>19.8</td>
<td>23.5</td>
</tr>
<tr>
<td>Fibres &gt; 30 µm (%)</td>
<td>0.50</td>
<td>0.50</td>
<td>1.7</td>
<td>0.1</td>
<td>0.49</td>
</tr>
<tr>
<td>Fibre curvature (%/mm)</td>
<td>62.2</td>
<td>9.3</td>
<td>79.7</td>
<td>40.1</td>
<td>75.6</td>
</tr>
<tr>
<td>Incidence of medullated fibre (%)</td>
<td>0.12</td>
<td>0.10</td>
<td>0.4</td>
<td>0.0</td>
<td>0.23</td>
</tr>
<tr>
<td>Incidence of medullated fibre (% w/w)</td>
<td>0.4</td>
<td>0.46</td>
<td>2.0</td>
<td>0.0</td>
<td>0.9</td>
</tr>
<tr>
<td>Medullated fibre MFD (µm)</td>
<td>33.2</td>
<td>6.73</td>
<td>55.9</td>
<td>23.6</td>
<td>27.1</td>
</tr>
<tr>
<td>Ratio MedMFD : MFD</td>
<td>2.08</td>
<td>0.47</td>
<td>3.27</td>
<td>1.38</td>
<td>1.60</td>
</tr>
<tr>
<td>LAC (mm)</td>
<td>23.8</td>
<td>4.78</td>
<td>35.8</td>
<td>14.7</td>
<td>35^*</td>
</tr>
<tr>
<td>LAC (longest 5%, mm)</td>
<td>54.6</td>
<td>10.51</td>
<td>77.2</td>
<td>32.2</td>
<td>65^*</td>
</tr>
<tr>
<td>Inferred “Barbe” (mm)</td>
<td>34.3</td>
<td>7.11</td>
<td>50.1</td>
<td>19.4</td>
<td>50^*</td>
</tr>
</tbody>
</table>

* These values were predicted using the equations from McGregor (2007)

Dehaired fibre length

Processed wool and cashmere generally has reduced fibre length compared with measurements of staple or fibre length taken before processing. There are two main factors which are associated with the reduction in the measured length of processed fibre, the effects of weathering of the fibre and the repeated mechanical actions of processing equipment. In the present work, the average predicted fibre length after carding was 36 mm which compares with the results of the international survey mean of 23.8 mm and the maximum measurement of 35.8 mm (Table 13). Similarly, the predicted Barbe measurement of the present lots of 52 mm was well above the mean value of the survey samples of 34 mm. While less confidence can be placed on the estimates of the length of the long fibres, the data and predictions suggest that the present lots of dehaired fibre are above the average of the survey but less than the maximum length of the survey samples, respectively 65, 55 and 77 mm (Table 13). Thus, the results of the present work are at the high end of the length range observed in that survey.

Weathering refers to the degradation of animal fibres that occurs during growth from exposure of the fibres to sunlight, water and air. Weathering damages Merino wool fibre tips which become brittle. The brittle wool fibre tips are lost during early stage processing resulting in shorter processed wool fibre (Walls, 1963). Weathering damage also reduces the quantities of wool fibre that are harvested by 10-15% (Wheeler et al., 1977), reduces fibre length in raw wools, results in yellower wool and lowers the quality of dyeing. There are few reports on the extent of weathering damage of rare animal fibres despite their production in often harsh environments e.g. alpaca and vicuña from the high plateaus in South America, or cashmere produced in desert regions and higher altitudes in central Asia. A survey of 38 lots of commercial white dehaired cashmere and cashmere tops showed that the extent of weathering varied by up to six-times between these commercial lots. Increased weathering was associated with a reduction in cashmere fibre strength properties, increases in the yellowness and reduced brightness of white cashmere (McGregor, 2016). It is likely that weathering affected the length of the processed cashmere in the present investigation.
The effects of repeated mechanical actions during textile processing, particularly the opening and carding operations, are regarded as a major cause of fibre breakage. With cashmere, the effects of the additional dehairing operations to remove the guard hairs also results in additional fibre breakage compared with wool processing. Using small scale laboratory equipment, designed for cotton processing, for the dehairing of cashmere, resulted in the breakage of cashmere fibres (Couchman, 1989; Couchman and Holt, 1990), although the severity of fibre breakage may in part be related to the challenge of adapting the equipment for cashmere. Talebpour (2005) investigated the effects of dehairing on the length of a processing lot of 30 shorn Iranian cashmere fleeces (mean cashmere fibre diameter 19.2 μm) using a six-section modular commercial dehairing line. Mean cashmere fibre length was reduced from 60 mm in raw fibre to 48 mm after the first dehairing pass and then to 41 mm after the second dehairing pass, with the guard hair content declining respectively, from 34.9% to 0.7% and then 0.27%.

Using 48 lots of Australian cashmere, representing 418 shorn fleeces from 9 farms, and commercial dehairing equipment, the mean length of dehaired cashmere was substantially less than the staple length of raw cashmere (McGregor and Butler, 2008). Over the range of 3 to 13 cm in staple length, average dehaired cashmere length was positively linearly related to staple length, and quadratically related to fibre diameter. There were different relationships for white and coloured cashmere in the response to fibre diameter. Using the range in staple length of the present lots of 7.4-9.5 cm, and the relationship with average dehaired length, the earlier research would suggest an expected range in dehaired length of 30 to 38 mm and an average of about 35 mm, results which are about 10 mm less than those reported in Table 12 (40-48.8 mm).

**Objective testing**

Objective testing of cashmere bales before processing or sale is the best method to quantify the likely processing performance and properties of cashmere. This report identified certain objective tests as valuable predictors of important physical properties including: wool base, the incidence of fibres coarser than 30 μm, vegetable matter content, cashmere staple length and the ratio of cashmere : hair length. Commercial services can provide testing for all but the fibre length tests.

**Recommendations**

The following steps need to be considered by Australian cashmere producers and supply chain partners to further develop, understand and exploit commercially the results of the project:

- Publish and extend to cashmere producers and processors the findings of this investigation.
- Focus industry training on fibre preparation including reducing vegetable matter, coloured fibre and cott contamination, and the production of long cashmere, and coarse guard hairs.
- When necessary, to use existing wool industry testing methods to quantify raw and processed fibre attributes.
- Investigate further the medullated fibre attributes of dehaired cashmere and the hair properties of existing samples of Australian cashmere.
References


Scouring and Dehairing Australian Cashmere

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