Improving Knowledge, Fibre and Textile Quality, and Communications

by B.A. McGregor

June 2013

RIRDC Publication No. 12/137
RIRDC Project No. 005944
Foreword

As the rare natural animal fibres industries develop 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 three main issues:

i) To assist the local rare animal fibre industries in the key areas of efficient fibre production, improved fibre quality, cost-effective fibre processing and textile product development;

ii) To improve knowledge outputs and the knowledge base of industries using past RIRDC investments; and

iii) To improve communication and collaboration using expertise at the Institute for Frontier Materials for the Australian industries.

This project was funded for one year by the RIRDC Rare Natural Animal Fibres program. Industry co-investment was provided by farmers, processors and exporters who assisted the project by providing input and feedback based on their experience, business plans and networks.

This report, an addition to RIRDC’s diverse range of over 2000 research publications, forms part of our Rare Natural Animal Fibres R&D program, which aims to identify constraints and solutions hindering mohair, cashmere, and alpaca production. Most of RIRDC’s publications are available for viewing, free downloading or purchasing online at www.rirdc.gov.au. Purchases can also be made by phoning 1300 634 313.

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About the Author

As a Senior Research Fellow, Dr. Bruce McGregor B.Agr.Sc.(Hons), Ph.D., Advanced Cert. Textile Technology, has focussed on improving the production, quality, marketing and processing of mohair, cashmere, alpaca and superfine wool. This led to Ph.D. studies on the quality of cashmere, and its influence on textile materials produced from cashmere and blends with superfine wool. His scientific interests include animal growth and development, animal nutrition and grazing management, fibre production and quality, textile quality, farmer training and new industry development. He is also a Project Leader with the Cooperative Research Centre for Sheep Industry Innovation focusing on improving the next-to-skin comfort of wool textiles. 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 RIRDC reports that are available on the RIRDC website.

Acknowledgments

This project would not have been possible without the support of Professor Xungai Wang of Deakin University and the Rare Natural Animal Fibres Advisory Committee. Staff at Deakin University are thanked for their assistance, particularly Mrs Zhu Hui (Julie) Zhang.

Former colleagues at the Victorian Department of Primary Industries are thanked for support with relevant projects summarised in this report. Particulars are provided in each published research report. Also thanked are my co-authors in bringing to publication valuable RIRDC supported research.
# Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreword</td>
<td>iii</td>
</tr>
<tr>
<td>About the Author</td>
<td>iv</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>iv</td>
</tr>
<tr>
<td>Executive Summary</td>
<td>vii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Objectives</td>
<td>1</td>
</tr>
<tr>
<td>Methodology</td>
<td>3</td>
</tr>
<tr>
<td>New research</td>
<td>4</td>
</tr>
<tr>
<td>Colour properties of white Australian mohair and cashmere</td>
<td>6</td>
</tr>
<tr>
<td>Fundamental properties of rare natural fibres</td>
<td>9</td>
</tr>
<tr>
<td>Documenting and communicating research</td>
<td>13</td>
</tr>
<tr>
<td>Mohair</td>
<td>13</td>
</tr>
<tr>
<td>Alpaca</td>
<td>17</td>
</tr>
<tr>
<td>Cashmere</td>
<td>18</td>
</tr>
<tr>
<td>All industries</td>
<td>19</td>
</tr>
<tr>
<td>Bibliography of publications</td>
<td>20</td>
</tr>
<tr>
<td>International collaboration</td>
<td>22</td>
</tr>
<tr>
<td>Implications</td>
<td>23</td>
</tr>
<tr>
<td>New research into rare animal fibres</td>
<td>23</td>
</tr>
<tr>
<td>Documenting and communicating research</td>
<td>23</td>
</tr>
<tr>
<td>International collaboration</td>
<td>23</td>
</tr>
<tr>
<td>Recommendations</td>
<td>24</td>
</tr>
<tr>
<td>References</td>
<td>25</td>
</tr>
</tbody>
</table>
Tables

Table 1. Mean values weighted using sale lot weight, standard deviation (SD) and range in measured attributes of 520 commercial mohair lots from the years 2001-2009. .......................... 9

Table 2. Regression coefficients and their standard error for the relationships between alpaca cuticle scale frequency and the age of alpaca (years), mean fibre diameter (µm), section of fibre and greasy fleece weight (kg), n = 282. ................................................................. 11

Figures

Figure 1. Wool ComfortMeter assessment of fabrics made from R36 tex/2 yarn for two different superfine wool types and different cashmere/wool blend ratios knitted into three tightness factors (TF). ................................................................. 5

Figure 2. The surface of alpaca fibres showing the cuticle scales.............................................. 10

Figure 3. The predicted main effects of alpaca age, greasy fleece weight and mean fibre diameter on the frequency of cuticle scales on Peruvian alpaca..................................................... 11
Executive Summary

What the report is about

This is a technical report summarising activities to improve the knowledge about rare natural animal fibres in Australia, including aspects of their production, fibre quality, and textiles made from these fibres. It summarises results of Australian investment on these subjects, and makes recommendations about future investment. This is important, as there is limited scientific understanding of how to improve productivity, quality and financial returns from these industries in Australia.

Who is the report targeted at?

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

Where are the relevant industries located in Australia?

Industries are located in all states, but mainly in the wheat-sheep and high rainfall zones of southern, eastern and south-western Australia. Generally, producers are located within 200 km of major towns. There are approximately 400 mohair holdings, 4000 alpaca holdings and 75 cashmere producers. Most rare natural animal fibres are exported in the raw form, but local manufacturing does occur in regional centres, and a number of farm-based industries also provide local employment. Australian mohair productivity is amongst the highest in the world, whilst alpaca and cashmere industries have innovative genetic improvement programs. This research aims to benefit producers, processors and decision makers.

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
- producing textiles desired by the consumers.

Aims/objectives

The project had three main objectives:

1. to assist the local rare animal fibre industries in the key areas of efficient fibre production, improved fibre quality, cost-effective fibre processing and textile product development
2. to improve knowledge outputs and the knowledge base of industries using past RIRDC investments
3. to improve communication and collaboration using expertise at the Institute for Frontier Materials for the Australian industries.

Methods used

New investigations were completed into the comfort properties of textiles made with a range of rare natural animal fibres, and factors affecting the colour properties of white commercial mohair. New investigations also involved a study of the variation within alpaca fibre fleeces and fundamental fibre properties, and production of alpaca and mohair.

Data from RIRDC supported and completed research has been prepared for scientific publication. This involved data management, statistical analysis, preparation of manuscripts and art work, submission, and management through the publication processes. In many cases, collaboration with other scientists,
including overseas scientists, was involved. Findings of recent research were also communicated to industry via industry newsletters and conferences.

**Results/key findings**

New findings have been made regarding factors affecting the production and fibre quality of mohair and alpaca. It has been shown for the first time that both the amount of fleece, and the diameter of the fibres, change in proportion to changes in the body size (weight) of Angora goats.

Adding cashmere to a range of superfine wool knitwear improved the assessed comfort properties of the knitwear. Tighter fabrics were less comfortable. The research was able to detect comfort differences between fabrics which have similar constituent fibre diameter attributes but differ in other fundamental fibre properties. There was a large range in the comfort properties of other textiles made for next-to-skin wear using a variety of rare natural animal fibres.

The colour attributes of white Australian mohair were affected by differences between seasons and years, but these were not large and are unlikely to be of commercial importance. However, the extent of the differences in colour attributes of white mohair between farms, and variations in mean fibre diameter and the incidence of impurity medullated fibres, were large enough to be of commercial importance. A number of other factors which affect mohair colour and which can be manipulated by farmers were identified.

This project achieved publication in 10 science journal articles, one book chapter and six industry advisory articles. A further six science papers were accepted for publication at an international science conference, and a further seven science papers have been submitted as manuscripts but not yet accepted for publication. The research related to mohair, cashmere and alpaca production, quality and textiles. Key findings are being used in advisory articles.

**Implications for relevant stakeholders**

This work identified that new technology can be applied to textiles composed of rare natural animal fibres, to identify improved comfort properties of knitwear and methods to improve manufacturing of knitwear.

Variation in the colour reflectance properties of mohair and cashmere provide the first base line measurements which can be used to monitor changes in whiteness over time. The results reinforce the recommendations that fibre producers focus on finer fibre production, which is where the superior white fibres were identified.

The discovery that fundamental aspects of the surface structure of rare natural animal fibres can be manipulated has consequences for selecting fibre for improved textile attributes.

A major contribution has been made to documenting and communicating important research into rare natural animal fibres. A large number of important discoveries have been made which impact upon fibre production, fibre processing and textile quality. Of greatest significance is a fundamental change in understanding how fibre diameter and fibre production change in proportion to changes in the size (live weight) of animals. The change in alpaca fibre diameter with changes in skin follicle density is an advance in knowledge with important implications. For grazing goats, several findings relating to incisor teeth eruption and wear have important implications for animal management and culling. For alpacas, the documentation of blood vitamin and mineral levels has long-term implications for advisory animal health work with alpacas.

The findings provide directions for more efficient animal management, nutritional management and animal selection, fibre production, and fibre selection. All the research outcomes provide new information for use in scientific education and farmer training materials.
Important connections with overseas scientists have been built upon, and such collaborations are resulting in research partnerships and outputs. This is a cost effective method of increasing scientific knowledge and sharing scientific skills.

Recommendations

The following steps need to be considered to further develop, disseminate and exploit commercially the results of the project:

- Publish and extend the findings of this review
- Focus research and industry training on fibre attributes, which are the major drivers of industry profitability and consumer market acceptance. These include finer and whiter fibres, long and strong fibres, soft, comfortable and lustrous fibres
- Support international collaborations in areas of rare natural animal fibre production and science
- Support industry groups to extend the findings of research and development via conferences, field days and publications
- Provide financial and in-kind support for the implementation of the recommendations.
Introduction

Background

This project arises from:

- the focus by RIRDC to improve the knowledge base and outputs of their research
- changes in funding arrangements for research and development in Australian agriculture
- the availability of new equipment to assess textile properties of rare natural fibres in both the raw and processed state.

The main changes in industry conditions reflected in this project were:

a) the national and international focus on improving the comfort properties of next-to-skin knitwear, as this is an area where rare animal fibres should excel. This focus is demonstrated by the activities of the Australian Co-operative Research Centre (CRC) for Sheep Industries Innovation, which includes a program on comfort properties of knitwear. Deakin University became a member of the CRC for Sheep Industries Innovation in early 2010 and is leading the work in evaluating comfort properties of next-to-skin wool knitwear.

b) the National New and Emerging Industries RD&E Strategy suggested the establishment of centres of excellence to lead various aspects of new and emerging industry RD&E. The area of relevance to Deakin University is to lead the rare natural fibres and textiles area.

Scientific review of rare natural animal fibres

A comprehensive literature review, “Properties and performance of rare animal fibres: A review and interpretation of existing research results”, was undertaken in 2010 (McGregor, 2012). This provides the outcomes of RIRDC contributions based on investments since 1992; the latest information on recent developments in the field from Australian and overseas research; and suggests future investment priorities. The review highlights the limitations of current knowledge, and where further gains can be made. The present project has investigated some of the issues identified in that review.

Scope of this report

Various components of this project have been completed and the results published elsewhere. This report summarises the main outcomes of such work.

Objectives

The project had three main objectives:

1. to assist the local rare animal fibre industries in the key areas of efficient fibre production, improved fibre quality, cost-effective fibre processing and textile product development
2. to improve knowledge outputs and the knowledge base of industries using past RIRDC investments
3. to improve communication and collaboration using expertise at the Institute for Frontier Materials for the Australian industries.

**Term of project**

The original project submission was for a three year period of investigation. Funding was approved for a 12 month period. Consequently this report summarises outcomes of work for the 12 month period from 1 October 2011. Given the shortened period, the original work schedule was modified to enable a selection of the proposed investigations to be completed in the available timeframe.
Methodology

1. Targeted new research undertaken at Deakin University into properties of rare natural animal fibres, based on the outcomes of the review of properties and performance of rare natural animal fibres. Specific research tasks included:
   
   a) Evaluating comfort properties of knitwear made with Australian rare natural animal fibres and in blends with wool, and communicating findings
   
   b) Evaluating fibre quality of RNF produced in Australia, particularly whiteness and yellowness properties of mohair.

2. Knowledge outputs and the knowledge base of industries improved using past RIRDC investments, by analysing and documenting research data collected during RNF projects that aimed to improve production efficiency, fibre quality and value-adding of RNF. This was done by documenting and communicating research findings from existing data.

   Articles produced from data already collected by Dr McGregor during rare natural animal fibre projects that aimed to improve production efficiency, quality and value-adding. This involved statistical analysis of data, interpretation of results, preparation of manuscripts, reviewing existing published material for inclusion in manuscripts, and managing the manuscripts thought the scientific review and publication processes.

   Research results were also summarised and prepared for industry journals published by producer associations.

3. Research findings communicated to industry associations.

4. Collaborations with overseas RNF scientists undertaken. Where possible, collaborations with overseas scientists working with alpaca, cashmere and mohair were established and/or continued. This included:

   i) hosting visits by overseas scientists to Deakin University
   
   ii) undertaking scientific collaborations
   
   iii) collaborating with international efforts to document production, quality and other attributes of RNF
   
   iv) attending overseas conferences, including the International Goat Conference.
New research

Comfort properties of knitwear made with rare natural fibres

In recent years, the wool textile industry has increasingly focused its attention on consumer trends in clothing, particularly the comfort properties of wool apparel. Reviewing these trends showed that sensory comfort had three dimensions: tactile, thermal-wet and body-fit comfort. The relative importance of these three sensory factors changes under different wearing situations.

Until recently, the lack of robust, repeatable and cheaply operated laboratory equipment resulted in the assessment of the tactile comfort properties of knitwear using lengthy and expensive wearer trials. In recent years, new instruments have been developed to assess the tactile comfort properties of knitted fabric. A novel instrument, the “Wool ComfortMeter” (WCM), has been developed as a rapid laboratory method to quantify knitted fabric tactile comfort ratings (Tester, 2010). The evaluation and detection of the surface properties of fabrics is based on stimulating the WCM measurement string as the scanning head is passed over the surface of the fabric. This gives a value that is related to the number and density of coarse fibres protruding from the fabric.

The WCM readings are strongly correlated with average prickle ratings assigned by wearers of the garments. As average wool fibre diameter and fabric knit structure are changed in the fabrics used in the wearer trials, the relationship between the WCM value and the wearer prickle rating of fabrics remains highly correlated (McGregor et al., 2012).

In relation to tactile comfort of wool fabrics, attention has also been focused on understanding the relationship between attributes of wool fibre diameter distribution, and perceived fabric-evoked discomfort of next-to-skin knitwear. Coarser fibres (greater than about 30µm) in the fibre diameter distribution have been associated with the neural basis and detection of fabric-evoked prickle (Garnsworthy et al., 1988). Other attributes of single jersey knitted fabrics are also implicated in the detection of prickle sensations.

Effect of fibre, yarn and knitted fabric attributes associated with comfort properties

We aimed to identify and quantify the effects of constituent fibre and yarn properties, and the physical and mechanical properties of single jersey fabrics made with blends of cashmere and low or high crimp superfine wool (17µm), upon the fabric comfort properties as determined by the WCM.

The experiment used 81 fabrics and yarns which were constructed during earlier research funded by RIRDC (McGregor 2002, McGregor and Postle 2004, 2007, 2008, 2009). Briefly, the experiment had nine treatments each with three replicates, and used pure 17µm Australian cashmere and two types of superfine wool with different fibre crimping (fibre curvature). The wools and cashmere were also blended into three blends ratios. These fabrics were evaluated using the Wool ComfortMeter, which has been calibrated using wearer trials of wool knitwear. General linear modelling determined the best prediction models for log10 transformed fabric WCM values using 27 fibre, 16 yarn and 30 fabric attributes.

Tighter fabrics were less comfortable as they had higher assessed Wool ComfortMeter readings (Figure 1). Adding cashmere to fabrics at each tightness factor improved comfort assessment, as the Wool ComfortMeter readings were reduced (Figure 1).
Figure 1. Wool ComfortMeter assessment of fabrics made from R36 tex/2 yarn for two different superfine wool types, and different cashmere/wool blend ratios, knitted into three tightness factors (TF).

Lower Wool ComfortMeter values correspond with more comfortable wearer assessment. The effective standard error is plotted at blend ratio 100% (pure cashmere). Fibre type symbols: for TF 15.5, □ low curvature wool; ▲ standard high curvature wool; ● pure cashmere; for TF 14.0, open symbols; for TF 17.0, cross-hatched symbols (McGregor and Naebe, 2012).

The Wool ComfortMeter was able to detect differences between fabrics which were more supple and springy, thinner and lighter, and were composed of more elastic, uniform and stronger yarns. Together these attributes explained 82% of the variance in Wool ComfortMeter value. Thus, it is clear that the Wool ComfortMeter is able to detect the differences between fabrics which have similar constituent fibre diameter attributes, but differ in fibre curvature and fundamental fabric mechanical properties.

These results have been submitted for publication.

**Preliminary survey of Wool ComfortMeter assessment of textiles made from rare natural animal fibres**

A selection of commercially available and experimental commercial garments made with rare natural animal fibres were evaluated on the Wool ComfortMeter (WCM). The garments were classified according to their construction (knitted single jersey, rib knit, other knit, woven), fibre (alpaca, cashgora, cashmere, merino wool, mohair, manmade fibres, wool from heritage breeds), finishing method (brushed, other) and prior use (none, limited, heavy). The WCM values were analysed using these attributes in a regression analysis, which accounted for 90.2% of the variation in WCM values.

The mean findings showed that the mean WCM values for these attributes were:

- Fibre type: wool from heritage breeds had higher WCM values than merino types, and so would be more likely to cause prickle discomfort
- Construction: Other knitting constructions (mainly cables) had higher WCM values than single jersey, with woven garments intermediate
• Finishing: brushed mohair had lower WCM values than other mohair finishing; other finishing of cashmere (mainly washing) had lower WCM values than brushed cashmere finishing. Low WCM values are associated with improved wearer comfort.
• Prior use: heavy prior use had higher WCM values than limited or no garment use. This suggests that older garments with greater wear are likely to be less comfortable.

Colour properties of white Australian mohair and cashmere

White animal fibres are preferred by processors, as they can be dyed to a greater range of colours. Exposure to UV light present in sunlight causes photo-bleaching, followed by progressive photo-yellowing. After a few months, the wool undergoes photo-tendering, characterized by reduced tensile strength. Millington (2006a, b) provides comprehensive reviews of factors affecting photodegradation of wool; factors which are likely to affect mohair, cashmere and alpaca.

The reflectance properties of animal fibres, particularly wool, are assessed prior to sales using international standards (IWTO-14). These methods describe the colour of an object in terms of tristimulus values (T units), where X refers to reflected red light, Y refers to reflected green light and Z refers to reflected blue light. Higher Y values indicate greater brightness (or lightness). Lower differences between the Y and Z values (Y-Z) indicate greater whiteness; higher differences indicate greater yellowness. Perfectly white fibre would have Y=100 and a Y-Z=0.

Two new investigations were undertaken into the natural fibre colour variation in white mohair produced on Australian farms, and an earlier investigation into white Australian cashmere was published.

Variation in the whiteness and brightness of mohair associated with farm, season, and mohair attributes

This work aimed to quantify factors affecting the reflectance attributes of Australian white mohair sourced from five different farms, and to evaluate the effect of season and year on mohair grown by goats of known genetic origin in a carefully managed, controlled study.

All goats and their fleeces were weighed. Mid-side samples were tested for mean fibre diameter and other fibre diameter attributes, clean washing yield (CWY), staple length (SL). For tristimulus values, X, Y (brightness), Z, and Y-Z (yellowness) was determined.

For the farm study, the samples originated from a mohair farm benchmark study (McGregor, 2010; n=196). The variation accounted for by farm alone was: X, 22%; Y, 24%; Z, 12%; Y-Z, 30%. Once farm had been taken into account, the regression models for X, Y and Z had similar significant terms: mean fibre diameter, CWY, SL and fibre diameter CV (CVD); and correlation coefficients (0.57-0.65). For Y-Z, in addition to farm, only mean fibre diameter was significant. While X, Y, Z and Y-Z were significantly associated with clean fleece weight, clean fleece weight was not significant in any final model.

For the season study, the mohair was harvested every three months for two years using goats which were part of earlier RIRDC funded projects (McGregor 2007; McGregor and Butler 2008). Season affected mohair Y, Z and Y-Z. Autumn grown mohair had higher Y and Z, and summer grown mohair had lower Z than mohair grown in other seasons. This resulted in summer grown mohair having the highest Y-Z, and winter grown mohair having the lowest Y-Z. The differences between years in Y, Z and Y-Z were statistically significant, but not large.

When Y, Z and Y-Z were modelled with season and other mohair attributes, mean fibre diameter, clean washing yield, clean fleece weight, incidence of medullated fibre (Med) and sire were also significant terms. The model for Y-Z accounted for 62.1% of the variance. Over the range of Med (0.3-4.2%), Y-Z increased by 11 T units. Increasing clean fleece weight by 0.5 kg was associated with
a decline in Y-Z of 7.5 T units. The variation in Y, Z and Y-Z associated with sire effects were 2.66, 3.77 and 1.04 T units respectively.

In both the farm and the season studies, increasing mean fibre diameter was associated with lower Y and Z and higher Y-Z. The extent of the differences in tristimulus values between seasons and years were unlikely to be of commercial importance. The extent of the differences between farms, and to variations in mean fibre diameter and Med, were large enough to be of commercial importance.

As found for Australian cashmere, variation between farms in the reflectance attributes of Australian mohair may reflect differences between farms in: geographic and climatic factors; productivity of the goats; consumption by goats of different nutrients and plants; and differences in genetic background.

It is likely that the farms which supplied the mohair experienced different levels of solar radiation, given the differences in latitude, altitude and climate of the farms. Differences in the ambient temperatures between farms may also alter sweating (suint production) which is also associated with yellowing of wool.

One mechanism for differences in Y and Y-Z between farms could be differences in the relative dilution of natural chromophores within the fleece, consequent upon differences in rates of mohair growth and the pastures eaten. This would imply that more productive Angora goats produce brighter (higher Y) and whiter (lower Y-Z) mohair. In the between farm study, while there were general associations between Y, Z and Y-Z and mohair production, clean fleece weight was not significant when farm was included in the models. Perhaps, the specific effect of clean fleece weight on Y, Z and Y-Z was included within the farm effect. However, in the controlled effect of season study, increasing clean fleece weight was associated with significant reductions in Y-Z, suggesting that there was a dilution effect on natural chromophores.

An important fibre quality measurement related to evaluating the productivity of Angora goats, and the value of mohair, is the mean fibre diameter of mohair. In both the farm and the season studies, increasing mean fibre diameter was associated with lower Y and Z and higher Y-Z, while in the farm study increasing CVD was associated with higher Y.

SL was significantly associated with Y and Z of mohair in the farm study but not in the season study. The magnitude of the effect of SL on Y and Z was the same, so the net effect on Y-Z was zero. It is interesting that increasing SL was associated with a reduction of Y and Z in the farm study, as it might have been considered that longer SL would provide some protective (shading) advantages to mohair which grew closer to the skin, as is observed with Merino wool.

For mohair there are two possible reasons why this effect may not have been detected. Firstly, the mohair fleece has a more open staple structure compared with the Merino fleece, which may allow greater UV light penetration. The more open staple structure when compared with Merino wool is based on a lower skin follicle density, and a reduced number of cross fibres. Secondly, in the season study the mohair fleece was shorn every three months rather than annually, as practiced with Merino sheep. Clearly, the short shearing interval is likely to have precluded SL developing to the extent that any protective effect from shading may become significant.

Part of the farm effect is likely to be related to goats grazing on farms located in different geographic and climatic regions, where pastures are composed of different plant communities and grow on different soil types. Thus, it is likely that goats on different farms will ingest different nutrients and plant chromophores. Both the quantity and quality of plant food consumed by goats has been shown to affect the Y, Y-Z of white cashmere changes. This is most likely mediated via changes in the amino acid content of the fibre, and perhaps the trace metal content of the fibre (McGregor and Tucker, 2010). Variation in soil type also causes variations in the trace metal content of wool.

In both the farm and season studies, CWY affected Y and Z of mohair but not the Y-Z. As discussed for SL, the magnitude of the effect of CWY on Y and Z was similar, and so the net effect on Y-Z was
The mechanism of action of CWY is a likely consequence of changes in the content of suint and wax in the greasy fleece, as increased CWY indicates less natural contaminants. Increasing quantities of wax and suint in raw cashmere have been associated with changed tristimulus values for raw and processed cashmere and raw and processed wools (McGregor and Tucker, 2010).

Fibres which have a hollow or partially filled central canal, running either as a continuous or fragmented form along their length are known as medullated fibres. Medullated fibres affect numerous properties of mohair textiles. Because medullated fibres (particularly kemp) tend to lie on the surface of the yarn and fabric, and are generally much thicker than the surrounding fibres, the visual and other effects they produce can be out of proportion to the actual quantity present. Furthermore, dyed medullated fibres generally appear much lighter than the surrounding dyed non-medullated fibres, and show up prominently in the fabric. This occurs as the medulla affects the optical properties of light passing through the fibre by diffraction, not from differences in dye uptake by the keratin of the fibre.

After accounting for other effects, including mean fibre diameter in the prediction models for the season study, increasing the incidence of Med increased Y to a greater extent than Z, resulting in a significant increase in Y-Z. Over the range of Med in the samples of 0.3-4.2%, Y-Z increased by around 11 T units. Previous reports on the effect of medullated fibres on tristimulus values of mohair or wool have not been located. This effect may be mediated by the reflection and scattering of light from interface between the keratin cells and the medulla within the mohair fibres.

These findings reinforce the view that mohair producers will maximize their financial rewards by maintaining a focus on the production of finer mohair with low levels of medullated fibre, as any potential price reduction on the basis of tristimulus values would penalise the coarser and more medullated mohair.

Season affected mohair tristimulus values Y, Z and Y-Z. Autumn grown mohair had higher Y and Z and summer grown mohair had lower Z than mohair grown in other seasons. This resulted in summer grown mohair having the highest Y-Z and winter grown mohair having the lowest Y-Z. The differences between years in Y, Z and Y-Z were not large. The differences detected between seasons are most likely to be related to the natural variation in solar radiation given the seasonal change in the altitude of the sun. However, variation in the intake of natural plant chromophores, and perhaps mineral intake, may modify the effect of the natural rhythm of solar radiation on tristimulus values to varying extents. These variations would be mediated by differences in rainfall affecting pasture growth and variations in cloud cover influencing solar radiation and together, may explain the small differences detected in the tristimulus values between years.

In the season study, knowledge of the genetic origin of the goats was a significant determinant of the Y, Z and Y-Z of mohair. This appears to be a new finding, as no other report of a genetic effect on mohair reflectance traits has been located. Such an effect is not surprising as variation in genetic origin affects the Y and Y-Z of wool and both attributes are moderately heritable.

Factors affecting the variation in the brightness and yellowness of commercial lots of Australian mohair

This study was undertaken in collaboration with Dr Douglas Stapleton, using data from 520 sale lots of commercial mohair sold by the National Mohair Pools Pty Ltd. Data for mohair sale lots was assembled for the years 2001-2009 representing over 500,000 kg mohair. Over 97% of this mohair had all the tristimulus test data available from the Australian Wool Testing Authority. For the remainder of the mohair, only the Y-Z test values could be located. At the time of preparing this report the analysis is being completed and prepared for publication.

The mean (weighted using lot weights), minimum, maximum, and standard deviation of some important attributes of the sale lots are provided in Table 1.
Table 1. Mean values weighted using sale lot weight, standard deviation (SD) and range in measured attributes of 520 commercial mohair lots from the years 2001-2009.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Mean</th>
<th>SD</th>
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</thead>
<tbody>
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<td>Vegetable matter content (% w/w)</td>
<td>1.0</td>
<td>1.0</td>
<td>0.2</td>
<td>17.9</td>
</tr>
<tr>
<td>IWTO yield (% w/w)</td>
<td>85.3</td>
<td>2.7</td>
<td>62.3</td>
<td>98.3</td>
</tr>
<tr>
<td>Y (T units)</td>
<td>68.4</td>
<td>3.08</td>
<td>43.7</td>
<td>73.5</td>
</tr>
<tr>
<td>Y-Z (T units)</td>
<td>10.4</td>
<td>0.65</td>
<td>8.7</td>
<td>12.6</td>
</tr>
</tbody>
</table>

For the brightness (Y) of commercial lots of mohair, over 91% of the variation in Y was accounted for by the following attributes and interactions between these attributes: year; selling season; mean fibre diameter; mohair staple length; presence of kemp, stained mohair and cotts; level of vegetable matter contamination.

Further details will be provided to industry when the final report has been accepted for scientific publication.

**Variation in the whiteness and brightness of white cashmere associated with farm of origin and fibre attributes**

While white cashmere is preferred by processors, its whiteness and brightness is affected by country of origin, amino acid composition, nutrition and cashmere production of goats (McGregor, 2002; McGregor and Tucker, 2010). This work aimed to quantify the factors which affect the whiteness and brightness of 36 batches of processed Australian white cashmere, sourced from nine different farms. This cashmere was assembled as part of an earlier RIRDC supported farm benchmarking and processing project, and some results were reported then (McGregor, 2006). The main activity for this study was to ensure the findings were made available in scientific journals.

The cashmere was tested for tristimulus values brightness (Y) and whiteness, as measured by yellowness (Y-Z). Linear models relating Y and Y-Z were fitted to farm of origin and other objective measurements. Mean attributes (range) were: mean fibre diameter, 16.9 µm (13.9-20.4 µm); fibre curvature (FC), 45 °/mm (31-59 °/mm); clean washing yield (CWY), 91.3% (79.5 – 97.3%); Y, 78.7 (74.7-82.2); Y-Z, 11.9 (10.3-13.6).

Farm alone accounted for 72% of the variation in Y and 65% of the variation in Y-Z. Once farm had been taken into account, only FC was significant in predicting Y and only CWY affected Y-Z. For each 10°/mm increase in FC, Y increased 1.3 units. Neither the proportion of the fleece present as guard hair (clean cashmere yield), nor cashmere staple length, were significant determinants of Y or Y-Z. For each 10% increase in CWY, Y-Z declined 0.9 units. Variations in Y and Y-Z among farms were probably related to differences in geographic and climatic conditions and were significantly correlated to cashmere production. The effect of CWY was probably related to reduced suint content. Full details are published elsewhere (McGregor, 2012).

**Fundamental properties of rare natural fibres**

**Cuticle cell frequency of alpaca**

This study was undertaken in collaboration with colleagues in Peru. White alpaca was grown at the Research and Development Centre of South American Camelidaes, Lachhoc, of the National University of Huancavelica. The site is located at an altitude of 4600m. Adult female white Huacaya alpaca aged between one and six years (n = 24) from the Lachhoc herd were randomly selected to cover the range of fleece weights and ages. Fleeces were weighted to the nearest 5g and sampled prior
to shearing in May 2009 from the mid-side site. Mean fleece weight was 2.26kg (SD 1.29kg, range 1.16 to 6.23kg).

The cuticle cells of alpaca fibres were examined using the scanning electron microscope (SEM). Four fibres were carefully selected to enable the tip of the fibre (summer growth), the mid-point, and the base of the same fibre (autumn/winter growth) to be examined by the SEM. For each section of fibre, four measurements of the cuticle scale frequency were made. The fibre diameter along the length of the fibre where each cuticle scale measurement was made was measured in four places.

The data for each section of each fibre was meaned. The data for each section of each fibre was treated as a separate replicate for analysis. This provided a potential 24 (animals) × 3 (sites along each fibre) × 4 (separate fibres) = 288 degrees of freedom for the analyses. Five fibre sections were lost and one mean value was identified as an outlier. Data were analysed using regression analysis with factors for age of alpaca, fleece weight, fibre diameter and section of the fibre.

Mean fibre diameter was 22.2µm (SD 7.01µm, range 12.9 to 61.4µm). Mean cuticle scale frequency was 9.9/100µm (SD 1.14) with a range of 7.0 – 14.7/100µm. Examples of two SEM micrographs are shown in Figure 2.

Cuticle scale frequency was affected by four parameters: age of alpaca ($P = 1.2 \times 10^{-14}$); fleece growth ($P = 3.4 \times 10^{-11}$); season of growth (section of fibre, $P = 0.00072$); and mean fibre diameter ($P = 0.0039$). The model accounted for 40.7% of the variance with a residual SD of 0.88. The effects of variation in the significant terms in the model are shown in Table 2.

Compared with age 1 and 2, increasing age of alpacas resulted in an increase in cuticle scale frequency. Increasing greasy fleece weight resulted in a decline in cuticle scale frequency, while increasing mean fibre diameter was associated with an increased cuticle scale frequency. The effects of changes in alpaca age, greasy fleece weight and alpaca fibre mean diameter are illustrated in Figure 3 using the mean value for each age for the mean fibre diameter, or greasy fleece weight. After adjustment for other factors in the model, the root end of the fibre had 0.49 more cuticle scales /100 µm compared with the tip end, with the mid section being intermediate.
Table 2. Regression coefficients and their standard error for the relationships between alpaca cuticle scale frequency and the age of alpaca (years), mean fibre diameter (µm), section of fibre and greasy fleece weight (kg), n = 282.

The regression constant is for the mid section of the fibre in 1 year-old alpacas.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Regression constant</th>
<th>Coefficient estimate</th>
<th>s.e.</th>
<th>t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>10.06</td>
<td>0.266</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Total fleece weight</td>
<td>-0.444</td>
<td>0.0643</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Mean fibre diameter</td>
<td>0.0288</td>
<td>0.00990</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>Section Tip</td>
<td>-0.36</td>
<td>0.130</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>Section Root</td>
<td>0.13</td>
<td>0.128</td>
<td>0.33</td>
<td></td>
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<tr>
<td>Age 2</td>
<td>-0.32</td>
<td>0.168</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>Age 3</td>
<td>0.57</td>
<td>0.223</td>
<td>0.011</td>
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<tr>
<td>Age 4</td>
<td>0.56</td>
<td>0.221</td>
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<td></td>
</tr>
<tr>
<td>Age 5</td>
<td>1.63</td>
<td>0.311</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Age 6</td>
<td>2.28</td>
<td>0.276</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. The predicted main effects of alpaca age, greasy fleece weight and mean fibre diameter on the frequency of cuticle scales on Peruvian alpaca.

The mean scale frequency values are shown for the mid-section of fibres at ages: 2 years (◇, ◇); 4 years (□, □); and 6 years (△, △) for:

- Variations in the greasy fleece weight when the mean fibre diameter is kept at the average value in the data set, being 20.9, 24.2 and 33.6 for ages 2 (grey line), 4 (red line) and 6 (purple line) respectively.
- Variations in mean fibre diameter when the greasy fleece weight is kept at the average value in the data set, being 1.96, 3.25 and 2.66 kg for ages 2 (blue line), 4 (brown line) and 6 (green line) respectively.

Data are shown for the range observed during measurement.

These results challenge the currently accepted view that the cuticle scale frequency of alpaca is a fixed characteristic, which is diagnostic of alpaca fibres. There are potentially important implications upon
the determination of alpaca fibre origin and in explaining the superior textile qualities of “baby alpaca”.

Clearly, alpaca cuticle scale frequency varies along the fibre, and is therefore influenced by seasonal conditions, possibly both nutritional variation and photoperiod effects. Variation in nutritional conditions also affects cuticle scale frequency as indicated by the large effect of variation in fleece weight. The effect of fibre diameter upon cuticle scale frequency may relate to variations in nutritional status. It also indicates that larger fibres grown in primary skin follicles will differ from finer fibres grown in secondary skin follicles, and that fibres grown in areas of the skin with lower skin follicle densities will have different cuticle scale frequencies compared with fibres grown in areas of higher skin follicle densities.

The results suggest that fibre biosynthesis, as shown by differences in fibre surface structure (cuticle scale frequency), is not only affected by the rate of fleece growth but also by the age of the alpaca. It may be easier to explain the effect of increasing greasy fleece weight as a result of greater fibre length growth per unit time, thus cuticle scale frequency declines with increasing greasy fleece weight.

The increase in cuticle scale frequency as alpaca’s age is less easy to explain. The effect of age may be related to the general tendency for older alpacas to produce coarser fibres on average (McGregor and Butler 2004), although the differences between the ages were large: between 20 and 30µm (Figure 3b). However, it could be that other effects are occurring in the skin follicle such that the skin follicle bulb is only able to produce a certain amount of keratin material per unit of time for the fibre shaft. Thus, as the fibre diameter increases, the length growth rate is proportionally reduced. Such an effect on length growth would lead to an increase in cuticle scale frequency, imitating the effect of reducing greasy fleece weight.

The consequences of these variations in cuticle scale frequency, and therefore cuticle scale size, will be variation in: surface friction characteristics; surface lustre attributes; differences in fibre cohesion during processing; and different felting and wear properties of textiles made from alpaca. The superior textile properties of baby alpaca may be related to the differences in cuticle scale frequencies identified in this study.
Documenting and communicating research

A major aim of this project was the documentation and communication of research previously conducted on rare natural animal fibres, and the animals and production systems which support these industries. This research was primarily conducted while the author was employed by the Victorian Department of Primary Industries. Generally, RIRDC provided essential operating funding for these projects and RIRDC have been previously advised of the main project outcomes, in the form of technical and advisory reports. For some projects, additional findings were only made during further scientific examination of data collected.

There are a number of benefits obtained from fully publishing the results of research in science journals. Scientific publication ensures future access to the results of research by industry and scientists, as the scientific publication makes the work accessible in scientific databases around the world. The scientific publication process also places the results of the research into the existing body of scientific knowledge, and publication draws attention of other scientists to the work and its findings; this may stimulate further work and advances in knowledge. Each of these aspects is advantageous to the Australian rare natural fibre industries, as they lead to improved communication, improved knowledge, future collaborations and a greater understanding of methods to improve production systems, product quality and economic benefits. Furthermore, it is unlikely that the financial support previously provided by the Victorian Department of Primary Industries will be found elsewhere in future, so the science which has been undertaken needs to be fully investigated and published in order to obtain the full benefits of this investment.

During this project, the following research has been prepared for analysis, statistically analysed, manuscripts and art work prepared, submitted, revised and published: 10 refereed science journal articles, one book chapter and six advisory articles in industry publications. A further six science papers were accepted for publication at an international conference. Another seven science journal articles were prepared and submitted to journals but have yet to be accepted, so details of the abstract have been withheld.

The full reference details are provided in Section 3.5 of this report. The abstracts from each of the 10 science papers and the book chapter are provided under the industry to which they are most relevant. Some papers are relevant to more than one industry.

Publications are for the period September 2011 to September 2012.

Mohair

The allometric relationship between mean fibre diameter of mohair and the fleece-free live weight of Angora goats over their lifetime (McGregor, Butler and Ferguson, 2012)

As mean fibre diameter (MFD) is the primary determinant of mohair price, we aimed to quantify the lifetime changes in mohair MFD as Angora goats aged and grew. Measurements were made over 12 shearing periods on a population of Angora goats representing the current range and diversity of genetic origins, including South African, Texan and interbred admixtures of these and Australian sources. Records of sire, dam, birth weight, birth parity, live weight, fleece growth and fleece quality were taken for does and castrated males (wethers) (n=267 animals). Fleece-free live weights (FFLwt) were determined for each goat at shearing time by subtracting the greasy fleece weight from the live weight recorded immediately prior to shearing. A restricted maximum likelihood (REML) growth curve model was developed for relating MFD to FFLwt, age and other measurements.

A simple way of describing the results is: $MFD = \kappa (FFLwt)^\beta E$; where $\kappa$ is a parameter that can vary in a systematic way with shearing (age), breed, weaning weight, sire, dam and individual; $\beta$ is a parameter that is the same for nearly the whole study; and $E$ are independent errors from a log-normal
distribution. The analysis shows that $\beta = 0.34$, with s.e. ( $\beta$ ) = 0.021. Thus, mohair MFD was allometrically related to the cube root of FFLwt over the lifetime of Angora goats.

However, the allometric proportionality constant differed in a systematic way with age at shearing, genetic strain, weaning weight, sire, dam and individual. For Texan-breed goats, MFD decreased as weaning weight increased. The findings indicate that management factors which affect live weight and weaning weight have lifetime effects on mohair fibre diameter and therefore the value of mohair, and the profitability of the mohair enterprise.

The allometric relationship between clean mohair fleece weight and the fleece-free liveweight of Angora goats over their lifetime varies with season and liveweight change (McGregor, Butler and Ferguson, 2012)

Clean fleece weight (CFWt) is affected by live weight and change in live weight in Merino sheep, Angora and cashmere goats. However, how these relationships progress as animals age has not been elucidated.

Measurements were made over 12 shearing periods on a population of Angora goats representing the current range and diversity of genetic origins including South African, Texan and interbred admixtures of these and Australian sources. Records of breed, sire, dam, date of birth, dam age, birth weight, birth parity, weaning weight, live weight, fleece growth and fleece quality were taken for does and castrated males (wethers) ($n$=267 animals). Fleece-free live weights (FFLwt) were determined for each goat at shearing time by subtracting the greasy fleece weight from the live weight recorded immediately prior to shearing. The average of the FFLwt at the start of the period and the FFLwt at the end of the period was calculated (AvFFLwt). Live weight change (LwtCh) was the change in FFLwt over the period between shearings. A restricted maximum likelihood (REML) model was developed for CFWt, after log10 transformation, which allowed the observations of the same animal at different ages to be correlated in an unstructured manner.

A simple way of describing the results is: CFWt = $\kappa$(AvFFLwt)$^\beta$, where $\kappa$ is a parameter that can vary in a systematic way with shearing age, shearing treatment and LwtCh; and $\beta$ is an allometric coefficient that only varies with LwtCh. CFWt was proportional to FFLwt$^{0.67}$, but only when live weight was lost at the rate of 5 to 10 kg during a shearing interval of six months. The allometric coefficient declined to 0.3 as LwtCh increased from 10 kg loss to 20 kg gain during a shearing interval. A consequence is that, within an age group of Angora goats, the largest animals will be the least efficient in converting improved nutrition to mohair.

Variation in the whiteness and brightness of mohair associated with farm, season, and mohair attributes (McGregor, 2012)

This work aimed to quantify factors affecting the reflectance attributes of Australian white mohair sourced from five different farms, and to evaluate the effect of season and year on mohair grown by goats of known genetic origin in a replicated study. For the season study, the mohair was harvested every three months for two years. All goats and their fleeces were weighed. Mid-side samples were tested for fibre diameter attributes, clean washing yield (CWY), staple length (SL) and for tristimulus values X, Y (brightness), Z and Y-Z (yellowness). For the farm study ($n$=196), linear models relating Y, Z and Y-Z were fitted to farm of origin and other objective measurements. For the season and year study ($n$=176), data were analysed by ANOVA and then by linear analysis.

The variation accounted for by farm alone was: X, 22%; Y, 24%; Z, 12%; Y-Z, 30%. Once farm had been taken into account, the regression models for X, Y and Z had similar significant terms: mean fibre diameter (MFD), CWY, SL and fibre diameter CV; and correlation coefficients (057-0.65). For Y-Z, only MFD was significant in addition to farm. While X, Y, Z and Y-Z were significantly for clean fleece weight (CFwt), CFwt was not significant in any final model. Season affected mohair Y, Z and Y-Z. Autumn grown mohair had higher Y and Z, and summer grown mohair had lower Z than
mohair grown in other seasons. This resulted in summer grown mohair having the highest Y-Z, and winter grown mohair having the lowest Y-Z.

The differences between years in Y, Z and Y-Z were significant but not large. When Y, Z and Y-Z were modelled with season and other mohair attributes, MFD, CWY, CFwt, incidence of medullated fibre (Med) and sire were also significant terms. This model accounted for 62.1% of the variance. Over the range of Med (0.3-4.2%), Y-Z increased by 11 T units. Increasing CFwt 0.5 kg was associated with a decline in Y-Z of 7.5 T units. The variation in Y, Z and Y-Z associated with sire effects were respectively 2.66, 3.77 and 1.04 T units. In the farm and the season studies, increasing MFD was associated with lower Y and Z and higher Y-Z.

The extent of the differences in tristimulus values between seasons and years, were unlikely to be of commercial importance. The extent of the differences between farms, and to variations in MFD and Med, were large enough to be of commercial importance. Clean mohair colour was artefactually biased by MFD.

The relationship between permanent incisor wear and mohair production (McGregor and Butler, 2011)

We aimed to quantify if and to what extent permanent incisor wear affected mohair production in adult Angora castrate goats. The goats were grazed on annual temperate pastures for 6 years. During their sixth year mohair was harvested every six months and live weight measured. Incisors were inspected at ages five and six years and the amount and pattern of wear quantified. Restricted maximum likelihood (REML) base models were developed to account for background sources of variation. Once a base model had been selected for each fleece attribute, an extra term for the linear effect of the first and other permanent incisor wear were added to the model. During the year, mean live weight, greasy mohair production, clean mohair production and mean fibre diameter were (SD): 55.6 (5.85) kg, 4.97 (1.00) kg, 4.16 (0.87) kg, 34.8 (4.02) µm. Mean wear on permanent first incisors was 9% (range 0-30%). There was little wear on other permanent incisors. Greasy fleece weight, clean fleece weight, staple length and fleece entanglement were reduced significantly with increased wear of first permanent incisors. There were no significant effects of incisor wear detected for nine other fleece attributes or live weight.

The results indicate that 30% wear of the permanent first incisors reduced greasy fleece production by 20% and reduced clean fleece production by 30%. Given the magnitude of the effects detected, it is clear that relatively small amounts of wear of permanent incisors in adult Angora goats reduce production of mohair and, consequently, will reduce financial returns from mohair sales. The clear implication is that managers of mohair producing enterprises should assess the incisors of adult Angora goats, and use this information in determining which animals to cull from their flocks.

Determinants of permanent first incisor eruption in grazing Australian Angora goats (McGregor and Butler, 2011)

We aimed to investigate the effects of live weight, sex and other factors upon deciduous first incisor loss and permanent first incisor development in Angora goats. Goats were part of a pen study of the effects of energy intake of Angora does during pregnancy, and lactation on kid growth and development. The design was three levels of nutrition in mid-pregnancy by two levels of postnatal nutrition in 17 randomised blocks. Artificial insemination, ultrasound examination 43 days after insemination and feeding does in pens different amounts of a formulated diet enabled accurate conduct of the study. After weaning, goats were grazed in sex groups. Deciduous first incisor loss and permanent first incisor development were recorded at 11 weighings from 14 to 20 months of age.

For each sex, the time for permanent first incisor visible eruption and full development declined linearly with increases in live weight by 5.9 and 5.4 days/kg live weight respectively. The time to reach similar development stages for first permanent incisors eruption was three months longer for the lightest animals compared with the heaviest animals. Date of birth, birth weight, doe age, growth rates,
mid-pregnancy and postnatal nutrition, parity, day of weaning and weaning weight had no detectable effect.

The results explain much of the substantial range in reported first permanent incisor eruption dates for small ruminants, and have application in ageing of goats, marketing of kids for meat, selection of animals for breeding flocks and in education material.
Alpaca

Blood mineral, trace-element and vitamin concentrations in Huacaya alpaca and Merino sheep grazing the same pasture (Judson, McGregor and Howse, 2011)

We aimed to determine if the concentration of minerals and trace constituents in blood of Merino sheep and Huacaya alpacas grazing the same pasture differed with species and time of sampling. Blood samples and pasture samples were collected at frequent intervals over a period of two years for mineral and trace nutrient assay. The concentration of the minerals and trace nutrients in the grazed pasture usually met the dietary needs of sheep at maintenance, apart from potassium, sulphur, cobalt and vitamin E in occasional samples. Restricted maximum likelihood mixed model analysis indicated: a significant species × month × year interaction for all blood constituents assayed; a significant species × coat shade interaction for plasma vitamins D, E and B12; and a significant species × month × vitamin D interaction for plasma phosphorus concentrations.

In general, plasma calcium concentrations were greater in sheep than in alpacas, but plasma magnesium concentrations were greater in alpacas than in sheep. There was no consistent difference between the two species in plasma phosphorus concentrations, although low values were recorded in individual sheep and alpacas. Plasma vitamin D concentrations were more responsive to increasing hours of sunlight in alpacas than in sheep. Compared with alpacas, sheep had consistently higher concentrations of plasma copper, zinc and vitamin B12 and higher concentrations of blood selenium but lower concentrations of plasma selenium and vitamin A. No consistent difference was observed between the two species in plasma vitamin E concentrations.

Variation of fibre characteristics among sampling sites for High Andes Huacaya alpaca fleeces (McGregor, Ramos and Quispe Peña, 2012)

In the Huancavelica region of Peru, alpacas form the main and often only means of deriving an income for 3,300 poor families in 60 communities. Ninety percent of alpacas in the region are Huacaya which are grazed at altitudes 4,000 - 4,800 m. Little attention has been paid to alpacas grazed in the High Andes. We aimed to:

i) quantify the variation in alpaca mean fibre diameter (MFD), fibre diameter coefficient of variation (CVD), fibre curvature (FC) and staple length (SL) among 24 sampling sites
ii) quantify the difference between the mid-side sampling site and other fleece components for each fleece attribute
iii) identify the sampling site with the highest correlation to the fibre attributes of the fleece in general
iv) quantify the relationship between FC and MFD for alpaca.

Adult female alpacas (n=31, mean live weight 71 kg) were sampled and had their fleece weighed in 8 components. Total mean fleece weight was 3.35 kg (range 2.13-6.01). Staples were measured for length (mm) and tested on the OFDA2000 to determine MFD, CVD and FC. The effect of the site was determined using ANOVA analysis. Values for FC were log_{10} transformed. Correlations between sites and regression analysis between MFD and FC were performed.

The mean values for the mid-side site were: MFD 26.3 µm; CVD 20.2%; FC 34.9 °/mm; and SL 91 mm, which were finer and longer than other fleece components. The variation in MFD between the 24 sampling sites was 20.2 to 50.6 µm and between nine sampling sites in the main fleece saddle was 24.8 to 31.7 µm. Fleece attributes varied significantly between all fleece components and among fleece sites. Differences between the mid-side MFD and the MFD of other sites were affected by live weight. The general pattern was a marked dorso-ventral increase in MFD and decrease in FC and SL, and a decrease in SL on the neck. The MFD of the mid back site was more correlated with the MFD of the whole fleece than the MFD of the mid-side and the withers sites, and may be the preferred site for fleece sampling.
There was a significant relationship between log10FC with MFD and site accounting for 86.2% of the variance. This suggests that variation in FC (fibre crimp) can be used for selection of fleece components with different MFD but the slope of the regression (FC declined 1.0 °/mm for each 1 µm increase in MFD over the range of MFD 11-70 µm) indicates that this will only be detected by eye when there are large differences in MFD. The results indicate that care is needed in sampling alpaca fibre for testing, and that farmers should separate alpaca fibre carefully at harvest to keep separate fibre of vastly different commercial value.

**Relationships between skin follicle characteristics and fibre properties of adult Suri and Huacaya alpacas and Peppin Merino sheep (Ferguson, McGregor and Behrendt, 2012)**

We aimed to quantify the number, type and arrangement of skin follicles in Huacaya and Suri alpaca skin and correlate their follicle characteristics with fibre traits of harvested fibre. We then compared these relationships with those of Merino sheep.

Fibre and skin samples were collected from the mid-side of 12 Huacaya alpacas, 24 Suri alpacas and 10 Merino sheep. The mean fibre diameter (MFD ± s.e.) of the Huacaya and Suri were 35.5 ± 0.9 µm and 28.3 ± 1.0 µm respectively. The follicle groups found for alpacas were very different from the normal trio of primary follicles found in sheep and goats. The follicle group of the alpacas consisted of a single primary follicle surrounded by a variable number of secondary follicles. The mean ± s.e. primary follicle density was 3.1 ± 0.3 and 2.7 ± 0.1 follicles/mm² for Huacaya and Suri respectively. The mean ± s.e. secondary follicle density (SFD) was 13.7 ± 1.2 and 17.5 ± 0.6 follicles/mm² for Huacaya and Suri respectively. The mean ± s.e. ratio of secondary to primary follicles (S/P ratio) was 5.1 ± 0.5 for the Huacaya and 7.3 ± 0.2 for the Suri alpacas. The sheep had higher S/P ratios and SFD, lower MFD and produced significantly heavier fleeces. The key correlations found between traits in alpacas include a negative correlation between SFD and MFD (r = -0.71), and a negative correlation between S/P ratio and total follicle density (r = 0.38).

The study revealed that important relationships exist between alpaca skin follicle characteristics and fibre characteristics. It was the number of secondary follicles in a group that imparts density and a corresponding reduced MFD.

**Cashmere**

**Variation in the whiteness and brightness of white cashmere associated with farm of origin and fibre attributes (McGregor, 2012)**

While white cashmere is preferred by processors, its whiteness and brightness is affected by country of origin, amino acid composition, nutrition and cashmere production of goats. This work aimed to quantify the factors which affect the whiteness and brightness of 36 batches of processed Australian white cashmere sourced from nine different farms.

The cashmere was tested for tristimulus values brightness (Y) and whiteness, as measured by yellowness (Y-Z). Linear models, relating Y and Y-Z were fitted to farm of origin and other objective measurements. Mean attributes (range) were: mean fibre diameter, 16.9µm (13.9-20.4µm); fibre curvature (FC), 45°/mm (31-59°/mm); clean washing yield (CWY), 91.3% (79.5 – 97.3%); Y, 78.7 (74.7-82.2); and Y-Z, 11.9 (10.3-13.6). Farm alone accounted for 72% of the variation in Y and 65% of the variation in Y-Z. Once farm had been taken into account only FC was significant in predicting Y, and only CWY affected Y-Z. For each 10°/mm increase in FC, Y increased 1.3 units. Neither the proportion of the fleece present as guard hair (clean cashmere yield) nor cashmere staple length were significant determinants of Y or Y-Z. For each 10% increase in CWY, Y-Z declined 0.9 units. Variations in Y and Y-Z among farms were probably related to differences in geographic and climatic
conditions, and were significantly correlated to cashmere production. The effect of CWY was probably related to reduced suint content.

All industries

The role of objective and subjective evaluation in the production and marketing of goats for meat (McGregor, 2012)

Objective and subjective evaluations of goats for meat production are related to important determinants of production and profitability. The most important attributes in assessment of goats for market are: live weight; body condition score; and the age of goats. As goats grow, their carcass and body organs increase in weight, in proportion to the empty body weight. For farmers and field workers the linear regression approach for estimating carcass weight by measuring live weight is the most suitable, as it accounts for 88 to 97% of the variation in carcass, offal and boneless meat weight.

Live weight scales or heart girth tapes should be used and the risks and errors associated with these methods are summarized. The proportion of a live goat that is the carcass, known as dressing percentage, increases from 35% to about 50% as goats grow. The usefulness and errors associated with dressing percentage in field estimation are discussed. A valuable subjective method for estimating the nutritional status of goats is the use of body condition scoring as it accounts for 60 to 67% of the variation in live weight change, carcass weight and fat reserves of goats. A method for body condition scoring and a similar fat scoring system are explained. Body condition score is also associated with mortality risk and reproductive performance of goats. The number of permanent incisors in the lower jaw of goats is a method of estimating the age of goats, but is biased by differences in live weights of goats. The value and role of ultrasound scanning the carcasses of goats is summarized. For the marketing of kid meat, no permanent incisors should have erupted. Other useful practices for the successful marketing of goat meat are discussed including: knowing market specifications and chemical withholding periods; animal health; prevention of bruising; identification of goats; size of consignments; timeliness; provision of paperwork. A checklist is provided. The use of subjective and objective assessment techniques in evaluating goats for meat production will provide the best results. Where only subjective assessment techniques are available, they will provide satisfactory performance provided the skills have been learnt and are applied.

Production, properties and processing of American bison (Bison bison) wool grown in southern Australia (McGregor, 2012)

American Bison grow a thick coat of fibres which assists them to withstand severe climatic conditions. Bison fibre was traditionally used in textiles by native North Americans. This study aimed to quantify the production, fibre attributes and dehairing processing of bison fibre produced from bison grazed in north-eastern Victoria.

Three age/sex classes were sampled (n = 16) at seven body positions in spring. The fibre growing area was measured. Fibre was tested for diameter distribution, clean washing yield (CWY), proportion of fine fibres less than 36µm and fine fibre length, and processed by cashmere dehairing. Bison were one to two years of age, live weights 160-450kg and had mean fibre growing area of 1.4 m². They produced an average 1184g (range 530-1640g) of fine fibre with mean fibre diameter (MFD) 18.5µm, CWY 76.5%, wax content 9.8%, suint content 14.5%, clean fine fibre yield 56.4%, fine fibre length 37mm and fibre curvature (FC) was 93°/mm. Mid-side fibre had a crimp frequency of 6.5/cm and mean resistance to compression of 6.6 kPa. Fibre had a tenacity of 8.7 cN/tex and an extension of 39.3%. Restricted maximum likelihood (REML) mixed model analysis showed age/sex class and sampling site significantly affected all fibre attributes. Finer and longer fibre was produced in anterior sites and in younger bison. FC declined 5.3°/mm for each 1 µm increase in MFD. Dehaired fibre had a MFD of 17.8µm and mid-length of 28mm, suitable for woollen spinning. The production by bison of coats containing significant amounts of fibre indicates that careful harvesting of fibre could form an important source of income in bison enterprises.
Bibliography of publications

Science Papers


Manuscripts submitted but not yet accepted or published


McGregor, B.A. and Whiting, C.J. (2012). The effects of processing whole barley and oat grain and the amount and quality of roughage fed to Angora goats on whole gain excretion. Animal Feed Science and Technology


Advisory publications


International collaboration

Active collaborations continued with partners in South America, Asia and the EU. The main scientific collaboration with fibres involved the evaluation of alpaca fibre characteristics in Peruvian alpacas. This included studies of the fibre diameter, fibre curvature attributes, and fibre length growth in young alpaca. Once science paper was published as a result. Further collaborations with these partners will occur prior to the end of 2012.

Another collaboration with Professor O. Mahgoub, University of Oman, resulted in the publication of a chapter titled “The Role of Objective and Subjective Evaluation in the Production and Marketing of Goats for Meat” in the book on Goat Meat Production and Quality. Data used for this arose from numerous experiments undertaken during various RIRDC funded projects, dating between 1993 and 2009. The publication of this work will provide an international exposure to Australian science focussed on fibre goats used for meat production. Most of the writing was undertaken during the authors own time.

A highlight of the year was attendance at an International Fibre Forum, Sajama, Bolivia in early August 2012 hosted by the Comunidad Camélidos Project. Funding to attend this workshop was provided from a grant by the International Fund for Agricultural Development. This workshop provided networking opportunities with scientists, marketers and processors of mohair, cashmere and alpaca.

A number of invitations were received at the Bolivian forum and at the 11th International Conference on Goats, Spain to collaborate further in aspects of mohair, cashmere and camelid fibres with partners in South and Central America, Asia and Africa.

An invitation has been accepted from the organisers of the Sixth World Congress of South American Camelids to attend the congress in Chile in November 2012. It is anticipated that further discussions of projects and field work with scientists in Argentina, Bolivia and Peru will be undertaken at this time.

There will not be the opportunity to report the outcomes of future collaboration as the present RIRDC project was be finalised in September 2012.

Publications from international collaborations


Implications

New research into rare animal fibres

This work identified that the Wool ComfortMeter technology can be applied to textiles composed of rare natural animal fibres. The results indicate that blends of rare natural animal fibres can improve the comfort properties of knitwear.

Variation in the colour reflectance properties of mohair and cashmere indicated important differences between both farms and genetic effects. The results provide the first base line measurements which can be used to monitor changes in whiteness over time. The results reinforce the recommendations that fibre producers focus on finer fibre production, which is where the superior white fibres were identified.

The discovery that fundamental aspects of the surface structure of rare natural animal fibres can be manipulated has consequences for selecting fibre for improved textile attributes. The consequences of these variations in cuticle scale frequency will be variation in: surface friction characteristics; surface lustre attributes; differences in fibre cohesion during processing; and different wear properties of textiles.

Documenting and communicating research

A major contribution has been made to documenting and communicating important research into rare natural animal fibres. It is unlikely that this research will be repeated, so it is timely and cost-effective to ensure the information is published. A large number of important discoveries have been made which impact upon fibre production, fibre processing and textile quality. Of greatest significance is a fundamental change in understanding how fibre diameter and fibre production change in proportion to changes in the size (live weight) of animals. The change in alpaca fibre diameter with changes in skin follicle density is an advance in knowledge with important implications. For grazing goats, several findings relating to incisor teeth eruption and wear have important implications for animal management and culling. For alpacas, the documentation of blood vitamin and mineral levels has long-term implications for advisory animal health work with alpacas.

The findings provide directions for more efficient animal management, nutritional management and animal selection, fibre production and fibre selection. All the research outcomes provide new information for material for use in scientific education and farmer training.

International collaboration

Important connections with overseas scientists have been built upon, and such collaborations are resulting in research partnerships and outputs. This is a cost effective method of increasing scientific knowledge and sharing scientific skills.
Recommendations

The following steps need to be considered to further develop, disseminate and exploit commercially the results of the project:

- Publish and extend the findings of this review
- Focus research and industry training on fibre attributes which are the major drivers of industry profitability and consumer market acceptance. These include finer and whiter fibres, long and strong fibres, soft, comfortable and lustrous fibres
- Support international collaborations in areas of rare natural animal fibre production and science
- Support industry groups to extend the findings of research and development via conferences, field days and publications
- Provide financial and in-kind support for the implementation of the recommendations.
References


Improving Knowledge, Fibre and Textile Quality, and Communications

By B.A. McGregor

Pub. No. 12/137

This report outlines activities to improve the knowledge about rare natural animal fibres in Australia, including aspects of their production, fibre quality, and textiles made from these fibres. It summarises results of Australian investment on these subjects, and makes recommendations about future investment. This is important, as there is limited scientific understanding of how to improve productivity, quality and financial returns from these industries in Australia.

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

RIRDC is a partnership between government and industry to invest in R&D for more productive and sustainable rural industries. We invest in new and emerging rural industries, a suite of established rural industries and national rural issues.

Most of the information we produce can be downloaded for free or purchased from our website <www.rirdc.gov.au>.

RIRDC books can also be purchased by phoning 1300 634 313 for a local call fee.