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Rural Industries Research and Development Corporation

Improving Production Efficiency, Quality and Value-Adding of Rare Natural Animal Fibres

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by B.A. McGregor

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Foreword

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 new enterprises 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 document current knowledge of the properties and processing of rare natural animal fibres by revising and expanding the 1992 RIRDC supported review of these fibres. This will provide an essential reference guide for students, industries, scientists and research managers.

ii) To investigate the application of new production technology and organic supply chains; and

iii) To document and communicate research findings from existing data and new research into rare natural animal fibres. This included production of scientific and industry targeted publications.

This project was funded by direct grants from the RIRDC Rare Natural 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 2100 research publications, forms part of our Rare Natural Fibres R&D program, which aims to identify constraints and solutions hindering increasing 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.

Craig Burns
Managing Director
Rural Industries Research and Development Corporation

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, genetic improvement, animal health and welfare, farmer training and new industry development. 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 internet site.

Acknowledgments

The project would not have been possible without the support of Professor Xungai Wang of Deakin University and Dr Peter McInnes, formerly of RIRDC and the Rare Natural Animal Fibres Advisory Committee. Staff and students at Deakin University are thanked for their assistance particularly: Mrs Zhu Hui (Julie) Zhang, Mrs Hua Zhou, Dr Xin Liu, Ms Christine Rimmer, Mr Graham Keating, and Mr Barry Tucker (the Librarian).

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, many of whom had retired from active research, but who were willing to provide their expertise in order to assist in bringing to publication valuable RIRDC supported research.

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Executive Summary

What the report is about

This is a technical report on the production, quality, processing and performance of rare natural animal 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 for 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 500 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. Mohair productivity is amongst the highest in the world, while 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:

1. providing the producer with a clear understanding of the requirements of the textile industry
2. the effective utilisation of fibre in processing to garments
3. producing textiles desired by the consumers.

This project arose from several developments:

1. The fading impact of a major scientific review of research relevant to these industries. In 1991, RIRDC sponsored a review of the existing research on raw-fibre-to-end-product properties and performance of goat fibres. This provided a benchmark for RIRDC supported R&D projects between 1992 and 2007. It was an essential reference for a generation of Australian textile processors, fibre producers, students and scientists studying rare natural animal fibres. The review was outdated
2. Development of new technology for the production and processing industries including organic fibre production. The world organic textile market is valued at over $5 billion and is growing at 20% compound annually. Australian farmers, processors and exporters do not have access to information on pathways for organic rare animal fibre production
3. Restructure of state and federal funding for these industries. This led to a body of research data on rare animal fibres obtained with government and industry investment which had not been published in international scientific journals and was therefore not available to producers processors, other scientists and research investment decision makers
4. Developments at Deakin University to focus on the application of new technologies for fibre industries
5. The availability of a leading researcher in rare animal fibres.

Aims/objectives

1. To document current knowledge of the properties and processing of rare natural animal fibres
2. to investigate new production technology and organic supply chains
3. to document and communicate research from existing data
4. to undertake selected new research.

Methods used

Deakin University employed Dr. Bruce McGregor, who had 30 years experience in production and processing of rare animal fibres and in extension of research findings to industry. The original scientific review into fibre properties was extensively revised, with the latest information on developments obtained from literature searches, libraries and other sources. New sections, figures and photographs were added, layout edited and most sections expanded. Findings of RIRDC sponsored research since 1992 were included. References were considerably expanded. Several new investigations into properties of rare animal fibres were undertaken, based on issues indentified in the scientific review.

The report into organic supply chains involved desk, literature and internet searches and communication with industry. The study investigated the international interest in, and progress related to, the marketing and processing of organic wool and rare animal fibres. The process for Australian farmers to become certified organic producers was investigated and summarised. Local and international case study examples of producers who have sold organic wool and similar fibres were explored and summarised.

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 was involved and for some investigations involved former colleagues who had retired.

Results/key findings

A substantial reference manual was prepared documenting important issues for the supply chain of rare animal fibres. These fibres have special properties of softness, smoothness and lustre, when compared with wool. Generally, knowledge about these fibres is limited and research effort small. There are problems for manufacturers and industry with identifying rare animal fibres when goods are traded or fibres are blended. Prickle discomfort in next-to-skin wear is a major concern for consumers and manufacturers. Natural colours, whiteness and yellowness of rare animal fibres are important attributes, with raw fibre having both positive and negative colour attributes. RIRDC investments have made gains about fundamental and applied areas of knowledge on the production, properties, testing and processing of rare animal fibres. Priorities for investment include production of finer whiter fibre, fundamental fibre properties, identification of fibre type and improved processing for more comfortable textiles.

There are seven organisations in Australia that provide organic certification. Australia wool producers have exported organic wool, but the premiums are low and only large scale producers are viable. There are a variety of certified organic textile products available world-wide that use a range of differing standards. Many local rare animal fibre producers are not satisfied with current certifying requirements and seek more producer friendly and environmentally relevant standards. Seven issues need addressing by producer industries and supply chain partners if they are to develop organically certified products.

This project achieved publication of 23 science journal articles, 19 industry advisory articles and 7 technical reports. The research related to mohair, cashmere and alpaca production, quality and textiles. Key findings are being used in advisory articles. Experiments identified effects of management and origin of fibres on fundamental fibre properties with implications for processing and textile quality. One method was not suitable for reliably differentiating between fibre types. A new method of measuring fibre length has considerable promise for improvements in fibre length measurement.

Implications for relevant stakeholders

Given the size of rare natural fibre enterprises, the impact of cost structures in auditing organic supply chains and the importance of scale in producing organic fibres it will be difficult to develop profitable organic supply chains. To assist in developing these industries, critical issues in the production of these fibres needs to be overcome, including developing a low-cost certification system.

The review of rare animal fibres provides producers and levy contributors a summary of the contributions to knowledge and practices which have flowed from RIRDC investments. For producers and processors, the review documents which fibre attributes are important, and why. For processors, the review provides a summary of best practice information on the processing of rare animal fibres. For RIRDC, the outcomes of past research investment, and the suggestions for future R&D investment, provide a guide to help direct future investments. For researchers and students, the review provides the latest information and references to guide the design and conduct of future investigations.

A major contribution was made in documenting and communicating research into rare animal fibres. It is unlikely that this research will be repeated, so it is timely and cost-effective to ensure its publication. A large number of important discoveries have been made which impact upon fibre production, fibre processing and textile quality. Given the complexity of some outcomes, it will take some time to fully communicate all these findings with industry. However, the findings provide directions for more efficient land and pasture management, animal management, nutritional management and animal selection, fibre production, fibre selection for processing, and enterprise financial planning and management. Research has also identified improved experimental design for cashmere nutrition experiments.

All the research outcomes provide new information for use in scientific education and farmer training.

The discovery that nutritional management alters fundamental aspects of rare natural animal fibres provides opportunities to manipulate fibre properties 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
- different felting and wear properties of textiles. There are also important consequences upon the determination of cashmere origin.

While FTIR spectra can distinguish between various fibres, there was considerable overlap between the spectra of cashmere and wool. At this stage in the research, it does not seem likely that FTIR spectra offer a reliable method to distinguish between cashmere and wool for diagnostic tests to determine the fibre composition of finished textiles. However, the OFDA4000 proved to be a rapid and direct method of measuring fibre length in tops and slivers, particularly for textiles which contain many short fibres.

Recommendations

The following steps need to be considered by RIRDC and the rare natural animal fibre industries and supply chain partners to further develop, disseminate and exploit commercially the results of the project:

- Publish and extend the findings of the updated scientific review.
- Assist industries develop low-cost “organic” or “eco-friendly” certification systems for rare natural animal fibres, and develop case studies of successful supply chains.

- Focus research and training on fibre attributes which are the major drivers of profitability and consumer acceptance including finer, whiter, longer, stronger, softer and more lustrous fibres.
- Support textile research on the production and evaluation of light weight, high value fabrics which are comfortable for next-to-skin wear.
- Continue to support scientific documentation and communication of research into rare natural animal fibres using existing data.
- Support research on fundamental properties of rare natural animal fibres related to market access, price premiums or textile performance which link production systems with research investigations.
- Support industry to extend the findings of this research via conferences, field days and publications.
- Provide financial and in-kind support for the implementation of the recommendations.

1. Introduction

1.1 Background

The long-term sustainability of the rare natural animal fibre industries is of considerable importance to both the producers of the fibres and for the economic and social benefits generated by value-adding processing of the rare animal fibres in Australia. This project arose from three developments within the Australian rare natural animal fibre industries:

1. The fading impact of a major scientific review of research findings relevant to these industries;
2. Development of new technologies for the production, processing and communications industries; and
3. The availability of a leading researcher in rare natural fibres.

Scientific review of rare natural animal fibres

The RIRDC sponsored scientific review of the properties and performance of goat fibres (Leeder et al. 1992, 1998) covered a range of fibres now included under the RNF program. The review provided a valuable benchmark for a range of RIRDC supported R&D projects between 1993 and 2002 and was essential reference material for a generation of students and scientists studying rare natural animal fibres at the University of New South Wales, Deakin University, University of New England, Lincoln University and Melbourne Institute of Textiles. The review was uploaded onto the RIRDC website in 1998 but this version lacked diagrams and graphics. There has been an urgent need to update the review to include research conducted since 1992 in Australia and overseas, not only to steer future RIRDC research, but to demonstrate to levy payers and industry supply-chain partners that RIRDC research provides valuable and useful outcomes based on focussed and innovative research.

The initial review identified a range of areas where research was required to improve textile attributes both in the raw material and during processing. Some of these research areas have been studied. The current project aimed to highlight areas where progress is needed.

New technologies and organic supply chains

There have also been significant developments in new production and processing technologies in recent years. For processing this includes nanotechnology and plasma surface treatment. Other natural fibre sectors have started to examine the potential implications of these new technologies. For instance, CRDC is currently conducting a review on the implications of nanotechnology for the Australian cotton fibre industry. Their implications for rare natural animal fibres needed to be summarised.

Australian research has also identified new production and processing technologies but following the upheavals of R&D providing organisations during the past 15 years, many valuable scientific discoveries have not been properly documented for current and future generations of RNF producers and scientists. It is very opportune to properly document this research as the costs of repeating this work are prohibitive.

New production, processing and marketing developments have arisen for organic textiles and the potential supply chains for organic production of rare natural animal fibres in Australia are a priority area for investigation.

The development of new communication technologies based on computer applications and the internet provide improved and cheaper methods of documenting and communicating research findings.

Availability of leading researcher

The Centre for Material and Fibre Innovation at Deakin University has provided a focus on the application of new technologies to fibre processing. However a strategic skills gap has been the lack of detailed knowledge in the production of rare natural animal fibres. This project allowed the appointment of Dr Bruce McGregor, who has over 30 years experience in the production and processing of mohair, cashmere, alpaca and superfine wool in research, development and communications roles. Such an appointment will aid RIRDC to implement its 5 year R&D Plan. Deakin University has developed an outstanding Centre for coordinating a range of relevant R&D that could have application in new developments for Australian rare natural animal fibres. As part of Deakin's role in coordinating R&D in material science it has established the Australian Future Fibre Research and Innovation Centre (AFFRIC). AFFRIC is a collaborative relationship between Deakin University, CSIRO and the Victorian Centre for Advanced Materials Manufacturing.

Scope of this report

Various components of this project have been completed and the results published elsewhere by RIRDC or other organisations. This report highlights the main outcomes of such work.

1.2 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 new product development; and to
2. retain and further grow the pool of expertise in the rare natural animal fibre area for the long term benefit of the rare animal fibre industries; by
3. funding Dr. Bruce McGregor's continued R&D for the Australian rare natural animal fibre industries.

Specifically, this project will help maintain and significantly enhance the R&D capacity in Australian rare natural animal fibre industries, through strategic support for the Centre for Material and Fibre Innovation at Deakin University, including funding for the Centre to appoint Dr Bruce McGregor as a Senior Research Fellow to continue and grow his research into rare natural animal fibres, in collaboration with Professor Xungai Wang.

1.3 Methodology

1. Dr. Bruce McGregor was appointed as a Senior Research Fellow (half-time i.e. 50%) at Deakin University commencing work in October 2008. The original proposal and work schedule was for a 5 year project initially funded for 3 years. A mid-project review was to be undertaken in mid 2010. In mid 2010, program management changes at RIRDC, indicated that an extension would not be appropriate and an application for a new 3 year project was prepared and submitted.

2. Details of supply chain pathways for the potential marketing of Australian organic rare natural animal fibre and the requirements for establishing credence values and certification was documented. Information has been sourced directly from supply chains involved with rare natural fibre marketing, from the world-wide web sources and by discussion with certifying agencies and interested farmers. Published articles have been sought in data base searches and libraries.

3. A revision and expansion of the review 'Properties and performance of goat fibres' prepared in 1992 and published by RIRDC in 1998 was completed. The scope of the revision was expanded to include camelid fibres (alpaca, llama and camel), outcomes of research completed

in Australia and overseas since 1992, to scope R&D needs for the rare natural animal fibre industries by identify areas where progress is needed and to assess the implications for enhancing the competitiveness of rare natural animal fibres of new technology including nanotechnology, plasma surface functionalisation and fibre powdering. The revised review was to be produced so that it includes relevant illustrations and photographs of the original 1992 version which were omitted in the 1998 RIRDC publication.

4. Documenting and communicating research findings from existing data. Production of articles 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 and associated figures, reviewing existing published material for inclusion in manuscripts and managing the manuscripts thought the scientific review and publication processes. For many manuscripts, where collaboration in the research phase was undertaken with other scientists, changes in the employment status of collaborators disrupted the scientific reporting processes. Results of research were also summarised and prepared for industry journals published by producer associations.

5. Undertaking targeted new research 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. Progress in this area has been curtailed given the reduction in length of the project from the initial 5-year program to a 3-year project. Appropriate areas for investigation have been included in the new project proposal supported by RIRDC.

2. Organic pathways

2.1 Background

While all animal fibres can claim to be natural, biodegradable and sustainable only those whose production system has been accredited as being organic can claim to produce organic fibre. There has been relatively little documentation or review of organic animal fibre production as most of the focus has been on food production or cotton. This report investigated the issues associated with the development of pathways for new supply chains for organic production of rare natural animal fibres in Australia. There are two specific markets being targeted:

1. The world rare natural fibre market for mohair, alpaca and cashmere valued at over $1 billion.

2. The world organic textile market currently valued at over $5 billion and growing at 20% annually.

For other natural animal fibres such as Australian Merino wool, regulators and markets are placing pressure on wool producers to improve the ethical aspects (e.g. traceability, sustainability, safety, animal welfare) of their enterprises, and this will increase with time (Pahl, 2007). Australian wool growers could embrace continual improvement in ethical performance and wool quality as a means of differentiating themselves from their competitors, and improve their competitive position in higher value markets (Pahl, 2007).

The report is not about the on-farm or in-factory details of how to produce organic fibre. Rather it is about how farmers and supply chain partners can participate in the rapidly growing organic fibre market. The report summarises recent developments in European regulations for organic textile accreditation. The review describes the international interest in and progress related to the marketing and processing of organic wool and rare natural fibres. The process for Australian farmers to become certified organic producers has been summarised. Local and international case study examples of producers who have sold organic wool and similar fibres are provided.

2.2 Road map for future development of organic pathways

Seven critical issues were identified that need addressing by the Australian rare natural fibres industries and supply chain partners if they are to develop organically certified products:

- Development and adoption of a simplified and low-cost “organic” or “eco-friendly” certification system for rare natural animal fibre producers and supply chain participants.
- Investigation of critical production issues for organic or eco-friendly rare natural animal fibre production including: animal health especially internal parasitism; animal welfare issues; castration; development a critical mass of fibre; record keeping.
- Alignment of research and development priorities within the RIRDC organic program, with the Australian Wool Innovation and other support agencies.
- Increasing the flow of information to producers regarding organic fibre production including involvement of appropriate organic certification organisations at industry events.
- Working with larger rare natural animal fibre producers to develop successful case studies and training opportunities including field days.
- Clear identification of market opportunities and supply chains for organic rare animal fibres.
- Development of direct marketing pathways for organic animal fibre to enable higher selling costs to help overcome the high costs for compliance.

Ramifications and critical issues for an organic animal fibre supply chain are summarised in Figure 2.1.

Supply Chain	Organic Ramifications	Critical issues
Producer	Can a simplified certification system be agreed upon by industry? Will the cost of certification be sufficiently rewarded by the selling price? Who will audit the certification?	Animal welfare, "normal" farm practices. Enterprise size, cost of auditing, consumer attitudes.
Fibre Buyer	Will there be sufficient quantity to attract raw fibre buyers? Will the buyer pay a premium?	Size of orders and specifications. Cost of production and cost of certification.
Processor	Will there be sufficient fibre in one lot to process a 100% organic product? Who will audit the certification?	Availability of smaller scale processors. Costs of processing.
Garment Manufacturer	Traceability of certified fibre. Who will audit the certification?	Fibre quality and textiles that meet specifications.
Retailer	Will retailers accept a simplified organic certification system? Will they prominently display textiles?	Will they pay a premium? Profit margin.
Consumer	Will consumers accept a simplified organic certification system?	Will consumers pay a premium?

Figure 2.1. The ramifications and critical issues relevant to the development of an organic animal fibre supply chain.

RIRDC has published the full report which is available at:

McGregor, B.A. (2010). Pathways for the Development of Organic Rare Natural Animal Fibre Production. RIRDC Research Report 09/163 pp.25 + ix. (RIRDC: Barton, ACT), https://rirdc.infoservices.com.au/items/09-163

Figure 2.2. Many indigenous cultures have been able to combine their cultural heritage with organic textile production.

This example shows a range of traditionally designed rugs using wool organically dyed with plant extracts and cochineal from the Oaxaca region, Mexico. (Photos by the author).

3. Review of rare natural fibres

The original review has been revised, expanded to over 100 pages and the latest information on recent developments has been included. Issues no longer of importance and some sections dealing with historical developments have been omitted. There are a number of new sections, layout has been edited and most sections have been expanded. New figures and photographs have been added. Findings of RIRDC sponsored research since 1992 have been included. References have been considerably increased.

The result is a substantial up-to-date reference manual which documents important issues for producers and processors of rare natural animal fibres. Important issues are highlighted and references to source material are supplied. New developments in testing and in textile processing have been summarised. The direction and scope of future research and development investment are summarised in the following sections.

3.1 Summary of findings

Compared with wool rare natural animal fibres generally have fewer and less-prominent cuticle scales which provide lower cohesion in processing, reduce processing speeds, provide slower felting and fabric shrinkage, higher lustre and smoother finishes. Rare natural animal fibres also have a greater incidence of medullated fibres compared with Merino wool, which negatively affect processing, fabric appearance and wearer comfort. A high incidence of medullated fibres (guard hairs) result in extra processing costs of cashmere, alpaca, llama, camel and other fibres. Prickle discomfort in mohair, alpaca and other rare natural animal fibres is a major concern for consumers and textile manufacturers. Natural colours and whiteness of rare natural animal fibres are important fibre attributes for dyers and consumers.

The main advantage of cashmere is its fineness and related softness. Its main drawbacks are short mean fibre length, although Australian cashmere is longer than Chinese cashmere, and the need for dehairing. The increased length of Australian cashmere should have advantages in worsted-type processing. The mean fibre diameter of the Australian wool clip is reducing as farmers use genetics to select finer sires and nutritional management of pregnant and lactating ewes to improve lamb development and growth. For Australian mohair and alpaca there is little evidence of a focus on finer fibre production although research on these topics remains unpublished.

3.2 Fundamental fibre properties

The review highlighted the fragmentary nature of research and resultant knowledge on the fundamental chemical and histological structure of rare natural animal fibres. Researchers in Australia and at the DWI (Germany Wool Laboratories) have applied their experience in wool research to rare natural animal fibres. Many examples of the value of this approach to the wool industry have been documented. For example, research at Deakin on alpaca processing, supported by RIRDC, has led to a unique alpaca dehairing process, now adopted for commercial processing by Cashmere Connections P/L. Studies of surface structure have led to new approaches to comfort, washability, wettability and printing. Increased knowledge of internal structure, and in particular the "cell membrane complex" has directly resulted in new approaches to dyeing, low-damage chemical finishing and wear-life. However, the obvious next step has not yet been taken, the application of this knowledge to relate fundamental fibre properties to end-use performance of rare natural animal fibres.

The fundamental studies undertaken indicate that there are differences in surface and internal structure between wool and rare natural animal fibres. This research should be extended. In particular preserving and enhancing the surface lustre and softness of these fibres during mechanical processing and chemical finishing is a priority. Many anomalies, inconsistencies and gaps in our knowledge of fibre properties have become apparent during this review. These include: correlation of single-fibre stiffness with diameter of each fibre type; role of scale height and shape in specular reflection, hence definition of lustre in fabrics; role of fibre diameter, fibre length and fibre stiffness in sliver cohesion; the factors affecting the softness of mohair, cashmere and alpaca at the fibre structural level. It is important to define differences from rather than similarities to wool and to maximise advantageous properties of rare natural animal fibres and to overcome deficiencies.

Single fibre profile effects on fibre tensile strength and elongation and the impact on processed fibre length have been investigated for wool but little undertaken on mohair, cashmere or alpaca. Very little has been published on the cell membrane complex (CMC) in rare natural animal fibres. There is a need for a study of the practical consequence of any differences between the CMC - epicuticle components of mohair, cashmere, alpaca and wool.

A major issue with much published textile and fundamental fibre research is that researchers have not defined the origin or production attributes of the fibres that they have used, often taking samples from a visit to a textile processor. There are no clear connections between the reported science and any known production system or animal science. For example, does animal fibre growth rate affect cuticle and cortical cell properties and if so is this related to seasonal nutritional conditions, photoperiod, live weight, fibre diameter or other biological influence? Unlike other textile fibres, the production factory for rare natural animal fibres is a biological system and so a clear and controlled knowledge of production attributes is necessary to inform farm practice and future areas for scientific investigation. Future research into fundamental fibre properties must be strongly linked to known sources of fibre.

3.3 Testing

Definition and measurement of fibre length and length uniformity (distribution) is becoming of increasing importance in defining processing performance and end usage. There is a need for greater understanding of factors affecting the fibre strength of rare natural animal fibres. New equipment is available but controlled studies are required.

There is a requirement for reliable laboratory test methods to identify the animal species origin of fibres. The effects of animal and environmental variables on fibre properties such as cuticle scale attributes need to be quantified to enable appropriate interpretation of test results. New methods need to be further evaluated including methods for chemical fingerprints of rare natural animal fibres.

Lightness of rare natural animal fibres is a very desirable attribute as it increases the potential range of pastel shades available in dyeing. Little is known about factors affecting the colour of naturally coloured and white rare natural animal fibres, both during production systems and from changes induced during processing. This aspect has been examined for wool only through a project funded by the CRC for Sheep Industry Innovation. Clearly there is a need to investigate the formation of cysteic acid (formed from the photochemical oxidation of the amino acid cystine present in fibres) during fibre growth and to ascertain the role (if any) that guard hairs may play in providing protection for cashmere fibres against ultraviolet light. If guard hairs are not required can they be bred out so as to avoid the costly dehairing process?

There is a need for future work, aimed at characterising those medullated fibres which show up differently after dyeing and incorporating this into rapid methods of measuring medullation in animal fibres. The potential for medullated fibres to improve insulation properties of textile fibres such as alpaca appears not to have been quantified.

3.4 Process development

The majority of published information on the processing of mohair has emanated from the South African Wool & Textile Research Institute (SAWTRI) which ceased active research in this area nearly two decades ago. It is obvious that undisclosed knowledge is available within European and Chinese processing mills, but this knowledge is not available to Australian processors, so there is an urgent need for process development. For cashmere and to a lesser extent alpaca, there is enormous scope for improving the mechanical and physico-chemical aspects of dehairing e.g. improved opening, fibre lubrication specification and control of humidity, innovative approaches to separation, minimisation of fibre breakage, increased speed of processing, measurement and control of surface damage. Recent research in Australia has overcome some of these deficiencies but further development is required.

Given the commercial importance of dyeing more investigations are required regarding the dyeability of rare natural animal fibres and to identify production systems which improve or detract from dyeability. In other words, the colour properties of lightness and yellowness of mohair, cashmere and alpaca need to be investigated from the production system to the end product.

Rare natural animal fibres are smoother and more slippery than wool, and this creates problems in early stage processing, particularly carding and combing. Methods to control fibre properties by surface modification without detracting from the surface properties of rare natural animal fibres are needed.

Consumers are demonstrating increasing desire for ecologically friendly products which demand lower energy, less polluting green processing technologies. There are opportunities to improve scouring of rare natural animal fibres, which have lower levels of wax and suint compared with Australian wool, by new approaches including ultrasonic processing and perhaps powder scouring.

3.5 Product Development

There is no doubt that alpaca, cashmere and mohair have many characteristics which make them highly desirable and valued by consumers all over the world. These include lustre, durability, resilience and comfort, their ability to be dyed to bright colours and low felting propensity. However, it should be stressed that, in this modern high-technology age in which the technologies keep advancing and changing, it is essential that research on these fibres and their processing is carried out on an on-going basis to enable these fibres to maintain prestige, image and place in the textile world. Objective measurements on blends of rare natural animal fibres with other fibres are needed to define optimum blend ratios for various products. For example, can blends of wool and mohair or alpaca be created to give washable knitwear? What are the best areas to exploit softness and lustre?

Evaluation for wearer detected prickle discomfort of knitted and woven garments made with rare natural animal fibres would be a very valuable aid to textile manufactures, fibre producers and others in the fibre marketing chain in helping to avoiding marketing garments which adversely affect consumer sentiment. Recent developments now provide a low cost method of detecting the “comfort” properties of light-weight fabrics, which is the fastest growing segment of the retail market, and the technology should be applied to rare natural animal fibres.

Higher quality products are becoming available e.g. fine hoisery, light-weight woven worsteds, by developing special processing techniques. There is scope for a much wider range of rare natural animal fibre products by extending process development studies undertaken on other fibres. The development of fine and low-twist mohair yarn technology has created the possibility for further mohair product development and further efforts can be made in terms of making very fine pure mohair yarns and fabrics.

Developing these new products: high comfort fabrics, fine light-weight fabrics, fine low-twist yarns; will achieve little if there is not an increased supply of fine mohair and fine alpaca to enable textile manufacturers to supply sufficient products to create viable new markets.

4. 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. For most of these science reports industry and RIRDC have been previously advised of the main project outcomes in the form of technical and advisory reports. For some projects the additional findings were only discovered during further scientific examination of data collected. As RIRDC is encouraging international collaboration in the area of rare natural animal fibres, research which has arisen from collaboration is also documented.

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 which may stimulate further work and advances in knowledge. Each of these aspects is of advantage to the Australian rare natural fibre industries as it leads 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 and 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: 23 refereed science journal articles; 19 advisory articles in industry publications; and 7 technical and conference reports. The full reference details are provided in Section 4.5 of this report. The abstracts from each of the 23 science papers are provided under the industry to which they are most relevant. Some papers are relevant to more than one industry. One paper was a scientific review prepared to assist the analysis and publication of research data currently being prepared for publication. A number of other manuscripts have also been prepared and submitted but details are withheld as these manuscripts have not been published. Publications are for the period October 2008 until August 2011.

4.1 Mohair

Variation of staple length across mohair fleeces: implications for animal selection and fleece evaluation (McGregor and Butler, 2009)

The work aimed to determine how the average mohair staple length (SL) differences between nine sampling sites vary between sex and flock, to identify differences in SL variability between sampling sites as a result of between animal and between sire variability and to determine SL correlations between sampling sites in between animal and between sire variability. Australian Angora goats (*n*=301) from two farms in southern Australia were sampled at 12 and 18 months of age at nine sites (mid side, belly, brisket, hind flank, hip, hock, mid back, neck, shoulder). Staples were taken prior to shearing at skin level and stretched staple length determined. For each shearing, differences in SL between sampling sites, how these differences were affected by farm, sex, and sire, and the covariance between sites for sire and individual animal effects were investigated by restricted maximum likelihood (REML) analyses. The median mid side SL at 12 and 18 months of age was 110 and 130 mm respectively, but the actual range in mid side SL was 65 – 165 mm. There was an anterior-posterior decline in SL with the hock being particularly short. There was no evidence that the between site correlation of the sire effects differed from 1, indicating that genetic selection for SL at one site will be reflected in SL over the whole fleece. However, low heritabilities of SL at the hock, belly and brisket or at any site at 12 months of age were obtained. There was more variability between sites than between sires, but the between animal variation was greater. The hip and mid back sites can be recommended for within flock (culling) and genetic selection for SL due to their low sampling variability, moderate heritability and ease of location.

Variation of fibre diameter coefficient of variation and fibre curvature across mohair fleeces: implications for within flock animal selection, genetic selection, fleece evaluation (McGregor and Butler, 2009)

The work aimed to determine how the average fibre diameter coefficient of variation (CVD) and fibre curvature (FC) differences between nine sampling sites vary between sex and flock, to identify differences in variability between sampling sites as a result of between animal and between sire variability and to determine correlations between sampling sites in between animal and between sire variability. Australian Angoras (n=313) from two farms in southern Australia were sampled at 12 and 18 months of age at nine sites (mid side, belly, brisket, hind flank, hip, hock, mid back, neck, shoulder). Staples were taken prior to shearing at skin level and CVD and FC determined. For each shearing, differences in CVD and FC between sampling sites, how these differences were affected by farm, sex, and sire, and the covariance between sites for sire and individual animal effects were investigated by restricted maximum likelihood (REML) analyses. The median mid side CVD at 12 and 18 months of age ranged from 23.6 to 25.1% but the actual range was 16.8 to 34.2%. The median mid side FC at 12 and 18 months of age ranged from 14.4 to 18.6 °/mm but the actual range was 10.5 to 26.3 °/mm. The general pattern for CVD was for the mid back, hip and neck sites to have similar CVD, the brisket, hind flank and hock sites to have larger CVD and the belly to have smaller CVD than the mid side site. The between animal variation for CVD was lowest at the mid back site. This implies that the mid back would be the most effective site for between animal selection for CVD. Heritabilities for CVD (range at 18 months 0.18-0.30) were only about half the heritabilities for mean fibre diameter in the same study. There was a marked anterior – posterior increase in FC at both farms and with both ages. The results give no clear indication of the best site for between animal selection for FC, other than that the hock should be avoided. Heritabilities for FC are moderate to high (range at 18 months 0.44-0.77) and the genetic correlations are high except for the hock. Thus genetic selection for FC at any site, other than the hock, should be effective for changing FC over the entire fleece. There was more variability between animals than between sites and sires. These results are put into context with associated research on variation in mean fibre diameter and staple length.

Development of strategies to increase commercial production of mohair and cashmere in Australia (McGregor and Chaffey, 2009)

We aimed to identify impediments to investing into mohair and cashmere production and to suggest programs and strategies to attract investors. Targeted interviews of people focussed on attributes of an investment opportunity. Analysis differentiated views of small and large-scale producers and those not involved in these industries. Potential investors into mohair and cashmere make decisions based on the compatibility of the enterprise to their farm system, the technical, financial and market feasibility of the enterprise and its comparative advantage with other possible courses of action. They are sceptical of information coming from within these industries that is not sufficiently supported by fact. There are many implications from these findings including the need for the industries to: understand the investment decision process; provide objective financial and benchmarking data; make information more accessible; overcome resistance to these industries; and increase the visibility of the industries.

Using benchmarking to improve the financial and social sustainability of commercial goat meat, cashmere and mohair farms in Australia (McGregor, 2009)

Production and financial benchmarking was undertaken with commercially motivated mohair, cashmere and goat meat farmers in Australia. There were large differences in animal and fleece production and financial returns between the best and worst performing farms. Farmers and industry groups reported that the process and results were helpful and resulted in them changing management practices. Benchmarking demonstrated that there is substantial scope to increase productivity and profitability through improved genetic selection and improved management of pastures, breeding flocks and in kid survival and growth.

Meeting the challenge of establishing commercial mohair enterprises by building an interactive enterprise management and financial model (Chaffey and McGregor, 2009)

To assist in attracting investors into mohair production in Australia, a production and financial model was built as a learning and support tool. The work aimed to reduce search time and thinking costs about the impact of management strategies on financial feasibility. Various management strategies and assumptions applied to a case study with 300 breeding Angora does and eight variations. The results showed an internal rate of return for mohair ranging from 9.3% to 21.2% over 12 years, a median gross margin per effective hectare ranging from $82 to $167, cash at bank in year 12 ranging from $8,700 to $56,800 and net enterprise assets ranging from $69,900 to $155,700. A key benefit of the model was its ability to allow new farmers to explore potential management strategies and their assumptions about a future enterprise before investing.

Gross margins in Australian mohair enterprises and relationships with farm inputs, productivity and mohair quality (McGregor and English, 2010)

In the absence of financial information on Australian mohair enterprises we aimed to determine the gross margins (per dry sheep equivalent, DSE) and their relationships with farm inputs, productivity and mohair quality in Australian mohair enterprises. Using established Victorian Farm and Sheep Monitor Project protocols we collected data for the financial years 2004-05, 2005-06 and 2006-07 from farmers in south-eastern Australia and made comparisons with data from wool enterprises of similar farm area. Over 3 years the financial returns from mohair exceeded that from wool in terms of $/DSE ($23.0 versus 11.3) and $/ha ($132 versus $116). This result was achieved despite the mohair enterprises grazing their goats far less intensively compared with the grazing intensity of sheep (5.9 versus 10.3-11.1 DSE/ha) and by using far less phosphate fertilizer than used in the wool enterprises (2.2 versus 4.6-6.1 kg P/ha). These differences were counterbalanced by higher prices for mohair compared with fine wool ($13.15/kg versus $8.35/kg clean fibre). Gross margin for the mohair enterprise did not increase as stocking rate increased. Income from mohair sales declined as the proportion of does in the flock increased. Increasing the proportion of does in the flock was associated with a decline in the average price of mohair ($16/kg greasy at 42% does to $8/kg greasy at 83% does in the flock). This decline was closely associated with the increasing proportion of the total amount of mohair coarser than 34.0 µm (either fine hair or hair) plus stained mohair. The variation in profitability between farms indicates significant scope for many mohair enterprises to increase profit. A focus on producing finer quality mohair will increase mohair profitability.

The influence of stocking rate and mixed grazing of Angora goats and Merino sheep on animal and pasture production in southern Australia. 1. Botanical composition, sward characteristics and availability of components of annual temperature pastures (McGregor, 2010)

The effects of animal species (AS, Angora goats, Merino sheep or goats and sheep mixed-grazed together at ratio 1:1) and stocking rate (SR, 7.5, 10 and 12.5 animals/ha) on the availability, botanical composition and sward characteristics of annual temperature pastures under continuous grazing were determined in a replicated experiment from 1981 to 1984. AS and SR had significant effects on pasture availability and composition and many AS × SR interactions were detected. The pastures grazed by sheep had significantly reduced content and proportion of subterranean clover and more undesirable grasses compared with those grazed by goats. There were no differences in dry matter availabilities between goat and sheep grazed pastures at 7.5/ha, but at 10 and 12.5/ha goat pastures had significantly increased availabilities of green grass, dead and green clover and less weeds compared with sheep pastures. There was a significant AS×SR interaction for the density of seedlings in May following pasture germination. Between July and January, the height of pastures was greater under goats than sheep but from January to March pasture height declined more on goat than on sheep grazed pastures. There was an AS×SR interaction for incidence of bare ground. Increasing the stocking rate increased bare ground in pastures grazed by sheep but no change occurred on pastures grazed by goats. Changes in pasture characteristics due to increased SR were minimised on pastures grazed by goats but the grazing of sheep caused larger and faster changes and the pastures were damaged at the highest stocking rate. Goats did not always select the same herbage material as sheep, changed their selection between seasons and were not less selective than sheep. Angora goats were flexible glazers and continually adapted their grazing behaviour to changing herbage conditions. Goat grazing led to an increase in subterranean clover, an accumulation of dead herbage at the base of the sward, reduced bare ground, taller pastures in spring and a more stable botanical composition. Mixed-grazed pasture characteristics were altered with SR. With careful management Angora goats on sheep farms may be used to manipulate pasture composition, to speed up establishment of subterranean clover, to decrease soil erosion and to reduce weed invasion.

The influence of stocking rate and mixed grazing of Angora goats and Merino sheep on animal and pasture production in southern Australia. 2. Live weight, body condition, carcass yield and mortality (McGregor, 2010)

The effects of animal species (AS, Angora goats, Merino sheep, mixed-grazed goats and sheep at the ratio of 1:1) and stocking rate (SR, 7.5, 10 and 12.5 animals/ha) on the live weight, body condition score, carcass yield and mortality of goats and sheep were determined in a replicated experiment on improved annual temperate pastures in southern Australia from 1981-1984. The pattern of live weight change was similar for both species with growth from pasture germination in autumn until maturation in late spring followed by weight loss. In winter, sheep grew faster than goats (65 v. 10 g/d, $P<0.05$). In mixed-grazed treatments between November and December goats either grew when sheep were losing weight or goats lost less weight than sheep ($P<0.01$). Both AS ($P<0.001$) and SR ($P<0.001$) affected live weight of sheep and an AS × SR interaction ($P<0.05$) affected live weight of goats. Mixed-grazed sheep were heavier than separately grazed sheep at all stocking rates with a mean difference at 10/ha and 12.5/ha of 4.6 kg. Mixed-grazed goats at 10/ha were heavier than separately grazed goats from the end of the second year of the experiment, but at 12.5/ha, separately grazed goats maintained an advantage over mixed-grazed goats, with a 9.4 kg mean difference in December ($P<0.05$). Body condition scores of goats and sheep declined with increasing stocking rate; they were highest in late spring and were highly correlated with live weight ($r^2 > 0.8$). Both AS and SR affected ($P<0.001$) carcass weight and GR tissue depth as a direct result of differences in live weight. Adjusting for differences in carcass weight negated AS effects on GR tissue depth. Carcass weights of sheep and goats increased by similar amounts for each 1 kg increase in live weight. Mortality of sheep (3.1% pa) was unaffected by AS or SR. An AS × SR interaction indicated mortality of separately grazed goats at 12.5/ha and mixed-grazed goats at 10 and 12.5/ha were higher ($P<0.05$) than all other goat (29 v. 9%) and sheep treatments, primarily because of increased susceptibility to cold stress. Disease prevalence differed between sheep and goats. Mixed-grazing of Merino sheep and Angora goats produced complimentary and competitive effects depending upon the stocking rate. Goats used summer pasture better but winter pasture less well for live weight gain than sheep. Angora goats should not be grazed alone or mixed-grazed with sheep on annual temperate pastures at stocking rates greater than that recommended for Merino sheep and the evidence indicates a lower stocking rate will reduce risks associated with mortality.

The influence of stocking rate and mixed grazing of Angora goats and Merino sheep on animal and pasture production in southern Australia. 3. Mohair and wool production and quality (McGregor, 2010)

The effects of animal species (AS, Angora goats, Merino sheep, mixed-grazed goats and sheep at the ratio of 1:1) and stocking rate (SR, 7.5, 10 and 12.5 animals/ha) on the fibre production and quality were determined in a replicated experiment on improved annual temperate pastures in southern Australia from 1981-1984. Separately-grazed sheep produced the most total clean fibre/ha at each SR. Mixed-grazed treatments produced amounts of clean fibre/ha similar to the arithmetic mean of sheep and goat treatments at 7.5/ha (21.9 *v.* 21.3 kg/ha), 10% more at 10/ha (28.3 *v.* 25.3 kg/ha, $P<0.05$) and 7% more at 12.5/ha (31.6 *v.* 29.6 kg/ha, $P<0.10$). Clean wool production/head was affected by AS and SR but not year. Clean mohair production was affected by SR and year but not AS. Variation in mean fibre diameter (MFD) accounted for 67% and 71% respectively of the variation in clean wool and clean mohair production/head. There was an AS × SR interaction for clean fibre production/t pasture. Growth rate of mohair was highest in autumn and least in summer. In each season, an increase in the SR reduced clean mohair growth rate. Growth rate of wool was highest in spring and least in summer. Wool and mohair MFD were affected by an AS × SR interaction. Mohair MFD was also affected by year and season. At 10/ha, wool from mixed-grazed sheep had a greater MFD than wool from separately-grazed sheep (20.2 *v.* 18.9 µm) and mixed-grazed goats grew mohair 1 µm coarser than separately-grazed goats. At 12.5/ha mixed-grazed goats grew mohair 1.9 µm finer than separately-grazed goats. Mohair MFD was predicted by a multiple regression that included average liveweight for the period of fleece growth, season of growth (summer 1 µm finer than winter) and year (range 1.27 µm). Mohair MFD increased 4.7 µm/10 kg increase in average fleece-free liveweight (FFLW, $P = 6.4 \times 10^{-14}$). FFLW alone accounted for 76.4% of the variation in mohair MFD. There was an AS × SR interaction for the incidence of kemp and medullated fibres; under severe grazing pressure their incidence was suppressed. This experiment indicated that the principles associated with the effects of SR on wool production on annual temperate pastures apply to mohair production. Mixed-grazing of Merino sheep and Angora goats produced complimentary and competitive effects depending upon the stocking rate. Angora goats should not be grazed alone or mixed-grazed with sheep on annual temperate pastures at stocking rates greater than that recommended for Merino sheep.

Influence of grain supplements during winter on live weight, mohair growth and mohair quality of weaner Angora goats (McGregor, Harris and Denney, 2010)

To identify methods to improve growth and mohair production of weaned Angora goats (mean live weight 18-20 kg) during their first winter, 2 supplementary feeding experiments using whole grain barley and lupins were conducted on a farm in southern New South Wales, in a region where weaner illthrift had been reported. Experiment 1 was a 2 × 2 + 1 factorial with 16 replicates each of one goat; 2 feeding levels (115 or 230 g/d whole barley grain) × 2 periods of feeding (4 or 8 weeks) + Control (grazing only). Experiment 2 had 5 treatments ×13 replicates each of one goat; 3 treatments fed 230 g/d whole barley grain for periods of 2 or 3 months and 2 treatments fed a 50:50 mixture of lupin and barley grain at 350 g/d for 2 or 4 months. Goats were individually fed and then all returned together for grazing. There were no effects of feeding in Experiment 1 and variations of feeding 230 g/d of barley in Experiment 2 provided no benefit. Feeding lupin/barley for 4 months increased live weight (gain 59 g/d), mohair production, mohair fibre diameter and the incidence of medullated fibre. About 25% of this ration was not eaten by 8 goats, reducing treatment average intake to 295 g/d. By the end of spring there was no difference in treatment live weights. Regression constants indicated that: for each 1 µm increase in mean fibre diameter, greasy fleece weight increased 35 g and for each 1 kg increase in pre-shearing live weight greasy fleece weight increased 26 g. The results show that Angora weaner goats can grow during winter provided their energy and protein needs for growth are met. Improved pasture management and higher levels of supplementary feeding to weaned Angoras are indicated compared with current practices on farms in Australia.

4.2 Cashmere

A review of cashmere nutrition experiments and suggestions for the design and conduct of successful experiments (McGregor, 2009)

There has been continuing debate regarding the impact of nutritional management on cashmere production. If nutrition management is not important for cashmere production then it will follow that adverse welfare outcomes will result for grazing goats. A review of available published experiments and suitable methods of experimental conduct was conducted to identify the design and management features of cashmere nutrition experiments. Cashmere fibre production is an order of magnitude less than fibre production of Merino sheep or Angora goats and is more difficult to measure. Based on a comparison between cashmere experiments reporting responses to nutrition and those reporting no response, 13 design and management features were identified that are related to the ability of experiments to detect significant treatment affects. Allocation of animals to treatments must take into account live weight. Methods must be adopted to reduce the variance in cashmere production within treatments, by using sufficient animals per treatment, having enough replication to provide plenty of degrees of freedom to reduce error terms in analysis, and potentially using independent pre-experimental cashmere production attributes as co-variants in analysis of variance. It is recommended that cashmere production records from a previous full production year be taken for use as co-variants during statistical analyses, requiring that all potential experimental goats are managed within the one flock, without variations resulting from different grazing, reproduction or other management for a year prior to commencing the experiment. It is preferable to use more productive and older goats, and goats that are used to handling, and to the conditions and feed to be used. Nutrition treatments need to be sufficiently different from each other in order to produce different live weight growth curves and an appropriate control is needed such as live weight maintenance. Evidence of both nutrition intake and growth curves must be published with the cashmere production data so the claims made for the work can be verified by examination of the actual responses. As the raw cashmere fleece is composed primarily of hair and other contaminants, careful attention is required to measure, sample and test cashmere fleeces. It is difficult to measure cashmere production given the large errors associated with clean cashmere yield determinations. The use of mid side cashmere patches to determine cashmere growth and quality is seriously biased and must be avoided, preferably by shearing goats prior to and at the end of experiments. In order to obtain higher fleece growth responses and improve the ability of experiments to detect treatment effects it is preferable to start cashmere growth experiments by midsummer and conduct experiments for at least four and preferably six months. These requirements make it more difficult or impossible for many university students to plan, undertake and complete long-term cashmere nutrition experiments without considerable management support. It is a waste of resources to conduct experiments that are not sensitive enough to detect affects of experimental treatments. Claims that an experiment shows no responses to nutrition treatments should be subject to rigorous examination using the design and management features identified in this review. Resources should not be spent on cashmere nutrition experiments that are unable to apply the design and management features recommended in this review.

Wear properties of cashmere single jersey knitted fabrics blended with high and low crimp superfine Merino wool (McGregor and Postle, 2009)

In a replicated experiment, we investigated the impact of cashmere in blends with superfine wools on the wear attributes of single jersey knitted fabrics. We also investigated the relative performance of low crimp/low fibre curvature superfine wool when compared with cashmere and also when compared with traditional high crimp/high fibre curvature superfine wool in pure and blended knitted fabrics. Wool type, blend ratio and fabric structure affected fabric air permeability, resistance to pilling and change in appearance, relaxation shrinkage, hygral expansion, and dimensional stability during laundering. The responses to variation in fibre crimp were much greater than previously reported. The fabric properties of low crimp wool differed significantly from those made from high crimp wool and low crimp wool fabric properties differed significantly from, but were closer to, the fabric properties of cashmere, compared with high curvature wool.

Implications to fleece evaluation derived from sources of variation contributing to cashmere fibre curvature (McGregor and Butler, 2009)

Cashmere fibre curvature (crimp) has important impact on the softness and quality of cashmere textiles, the efficiency of cashmere processing and cashmere production. This work was aimed to quantify the magnitude and direction of factors affecting cashmere fibre curvature, with data collected from 11 Australian commercial cashmere farms, using general linear model analysis. Nineteen parameters were recorded for 1244 goats. Following log transformation the best model for fibre curvature included farm, age, clean washing yield, mean fibre diameter, cashmere yield, fibre diameter standard deviation, and liveweight and the interactions between these terms. The percentage variance accounted for was 71.7%. Mean fibre diameter alone accounted for 39% of the variation in fibre curvature and farm accounted for 49% of the variation. Cumulatively mean fibre diameter and farm accounted for 66.6% of the variation existing in fibre curvature. For the other terms, age added 2.2% and the other fibre measurements a further 2.9% to variation accounted for by the best model. Results suggest that within a farm, using cashmere fibre crimp frequency to estimate mean fibre diameter has a correlation of 0.72—provided the trained observers perform as well as the calibrated laboratory equipment. On the other hand, however, results indicate fibre curvature not to be a reasonable indicator of mean fibre diameter differences across farms. Farm-effects on fibre curvature are large and may explain the difficulties cashmere growers experience when they visit other farms to visually evaluate cashmere goats prior to purchase. This work indicated that heavier goats are likely to produce cashmere with a lower fibre curvature. As this relationship did not differ between farms, it is reasonable to conclude that all goats exhibit this phenotypic response. Using cashmere fibre curvature (crimp frequency) as a tool for changing mean fibre diameter or selecting homogenous batches of fibre for sale will be reasonably effective within a farm, but is not a reasonable indicator and predictor of mean fibre diameter differences between farms.

Phenotypic associations with fibre curvature standard deviation in cashmere (McGregor and Butler, 2010)

Cashmere fibre curvature (crimp) impacts on the softness and quality of cashmere textiles, the efficiency of cashmere processing and cashmere production. This study investigated the relationship between cashmere fibre curvature standard deviation (FCSD) and other fleece attributes, and how this relationship differs with animal and farm attributes, for 10 commercial cashmere flocks in Australia. Data was analysed using general linear model analysis. Nineteen parameters were recorded. Following log transformation, the best model for FCSD included farm, goat age, mean fibre diameter, fibre curvature, fibre diameter standard deviation, cashmere yield, cashmere staple length and live weight and the interactions between these terms. The percentage variance accounted for was 82%. Mean fibre diameter and fibre curvature accounted for 55% of the variation in FCSD and farm accounted for 41% of the variation. Cumulatively mean fibre diameter, fibre curvature and farm accounted for 75% of the variation existing in FCSD. For the other terms, age added 2% and the remaining measurements a further 5% to variation accounted for by the best model. Environmental (farm-effects) on FCSD are large and may explain the difficulties cashmere growers experience when they evaluate cashmere goats. Increasing the fibre curvature of cashmere was associated with an increase in cashmere FCSD, but for some combinations of farm and MFD the increase in FCSD was ≈ 35 °/mm while with other combinations the increase was ≈ 5 °/mm as fibre curvature increased. At a given fibre curvature the response of FCSD to mean fibre diameter differed substantially between farms, from strong negative to strong positive. Increasing cashmere yield from 20 to 55% was associated with decline in FCSD. Increasing fibre diameter SD from 3 to 5 µm increased FCSD by 6 °/mm, increasing staple length and live weight were associated with small declines in FCSD. There was strong evidence of an age effect that differed with farms, but there were few clear cut trends in FCSD with increasing age. The results suggest that farm based influences are affecting the point at which fibre keratinisation is completed and thus influencing the variation in FCSD. We conclude that, because the differences between farms in the relationship been fibre curvature standard deviation, mean fibre diameter and fibre curvature are great, it is unlikely that crimp rate and crimp definition will be good indicators of cashmere fineness across farms.

Affect of nutrition and origin on the amino acid, grease and suint composition and colour of cashmere and guard hairs (McGregor and Tucker, 2010)

Nutrition and environmental effects on the amino acid, wax and suint content and colour of raw cashmere were investigated. Cashmere was obtained from: goats fed with or without dietary protected protein; goats fed different levels of dietary energy and feeds; and Australia, China and Iran. Attributes determined included cashmere: production, diameter, length, fibre curvature, crimp, wax and suint content, amino acid composition, lightness and yellowness. The content of suint but not wax was affected by nutrition management. Amino acid composition of cashmere was affected by energy and protein nutrition, feed type and country of origin. The amino acid composition of cashmere was different to that of guard hair. Lightness and yellowness of cashmere was affected by nutrition treatment, grazing, cashmere production and the sum of (wax + suint) content of raw cashmere. The variation in amino acid composition of cashmere is likely to affect both the physical and chemical reactivity of cashmere. Nutrition manipulation of cashmere goats and the origin of goats have implications with regard to cashmere properties as changes to fibre cell biosynthesis can alter the amino acid composition of the fibre.

Associations of mature live weight of Australian cashmere goats with farm of origin and age (McGregor and Butler, 2010)

Differences in live weight and mature size associated with farm of origin, age and sex were quantified for commercial Australian cashmere goats. Goats from 11 farms in four Australian states, consisting of 1367 does and 98 wethers aged 1 to 13 year old were monitored between December and June (early summer to mid winter). We used the live weight for May, as this was present for all farms and was prior to pregnancy related increase in live weight. Individual live weight ranged from 9-69 kg. For does, at each farm, live weight increased substantially with age and approached the maximum value at about 5 years of age. Farms differed greatly in the adult live weight with some farms reaching about 46 kg and others only reaching about 30 kg. Nevertheless those farms that had the greatest mean live weight for young does generally had the greatest mean live weight as adults. With the exception of one farm, wethers and does of the same age had similar live weights. The differences due to farm were much larger than the effects of age and sex. This study demonstrates that there are large gains in mature live weight that can be achieved from Australian cashmere does.

Relationship of weaning weight to the mature live weight of cashmere does on Australian farms (McGregor and Butler, 2010)

Median weaning weight and its relationship with the median mature live weight of does was quantified for four commercial Australian cashmere farms in various parts of Australia. Individual live weights, of does of all ages at the time of weaning in December, ranged from 9 to 61 kg. Individual farm means of adult does (> 1 year old) ranged from 24.6 to 38.8 kg. The model for the logarithm of live weight was: $\log_{10}(\text{live weight}) = a + br^{(\text{Age} + 0.6)}$; where a, b and r are parameters that are different for each farm. The result that the r parameter differs with farm was statistically significant ($P = 9.4 \times 10^{-6}$). The percentage variance accounted for was 84.4% and the residual standard deviation was 0.042. Farms differed greatly in the median mature live weight with some farms reaching about 44 kg and others only 31 kg. Median weaning weight was 14.1 kg (range 11.4 to 16.8 kg). Median weaning weight as a percentage of median mature doe live weight on a particular farm varied from 32 to 42%. These weaning weights appear low in absolute and relative terms and thus are likely to incur production penalties.

Cashmere-producing goats in Central Asia and Afghanistan (Kerven, McGregor and Toigonbaev, 2009)

Indigenous goats of Central Asia and Afghanistan produce cashmere, the warm undercoat grown annually to protect them from cold winters. Cashmere is appreciated in luxury markets, but there are no efforts to conserve these goats. Commercial assessments of their fibre quality have recently been undertaken. Poorer villagers in the most climatically difficult remote desert and high altitude regions are particularly dependent on raising goats. Villagers in Kazakhstan, Kyrgyzstan and Tajikistan started selling raw cashmere mainly to Chinese traders in the 1990s. Afghan producers have been selling cashmere for a longer time. In comparison with China and Mongolia, Central Asian and Afghan producers sell their cashmere unsorted and at relatively low prices. Traders do not offer producers differentiated prices according to quality, but world commercial prices are highly sensitive to quality. Producers thus lose potential value. Summaries are given of tests on the quality of cashmere from samples of 1 592 goats in 67 districts and 221 villages from 2003 to 2008. There are cashmere goats in these sampled districts which produce the finest qualities of cashmere typical of Chinese and

Mongolian cashmere. There is impetus to increase the production, commercial value and income for producers from cashmere produced by Central Asian goats.

Sources of variation affecting cashmere grown in the Pamir mountain districts of Tajikistan and implications for industry development (McGregor, Kerven and Toigonbaev, 2011)

We aimed to quantify the sources of variation contributing to the main quality attributes of cashmere produced from goats in the Pamir mountain districts of Murghab, Shugnon and Vanj in Tajikistan. In early spring 2010, mid-side samples were taken from 194 adult females, 43 adult males and 20 castrates belonging to 58 farmers and pastoralists in 14 villages. For 57 goats, samples were also taken from the shoulder and hip sites. Mean fibre diameter (MFD), fibre curvature (FC) and cashmere staple length (SL) data were examined using a general linear model to determine the relationships between fleece attributes and other possible effects. For females, the mean (s.d.) for MFD, FC and SL were: 16.5 (1.70) µm; 46 (12.1) °/mm; 53 (22.9) mm. MFD was affected by District, SL and age of goat. SL was affected by District, MFD, gender, age of goat and village. FC was affected by District, MFD, shade of cashmere, age of goat and farmer. Cashmere from Vanj district was finer and shorter than cashmere from Murghab and Shugnon. Cashmere grown on the mid-side and hip sites was finer and had higher FC than cashmere grown on the shoulder. Cashmere grown on the hip was shorter than cashmere grown on the mid-side and shoulder. About 50% of the cashmere sampled was < 16.4 µm and potentially suitable for knitwear. Of this fine cashmere, 53% was 34 mm or longer. A further 37% of the cashmere was 16.4 to 18.5 µm, and suitable for weaving as 97% was longer than 36 mm. Almost 12% of samples were > 18.5 µm and may only be suitable for weaving or, if cashgora, will have little commercial value. Most of the cashmere was coloured. There are cashmere goats in the Murghab, Shugnon and Vanj districts of Tajikistan which produce the finest qualities of cashmere, comparable to premium grades of Chinese cashmere. There is substantial scope to increase the commercial value of cashmere produced by goats in Tajikistan, in particular increasing SL for fine cashmere, reducing MFD for the longest cashmere and ensuring cashmere has acceptable FC and white colour.

4.3 Alpaca

Factors associated with low vitamin D status of Australian alpacas (Judson, McGregor and Partington, 2008)

The objective of this work was to investigate factors associated with low vitamin D status of alpacas at pasture in southern Australia. The design was: a 2-year survey of alpacas from two farms in South Australia and three in Victoria. Blood samples were collected from 20 to 30 alpacas on each farm on five occasions each year. Breed, gender, age and fleece colour of animals were recorded. Blood samples were assayed for plasma 2.5-hydroxycholecalciferol (25-OH D_3) and plasma inorganic phosphorus (Pi). Data sets from 802 animal samples were analysed by multiple regression to determine variables associated with low vitamin D status of alpacas. The relationship between plasma 25-OH $D_3$and plasma Pi was also investigated. Vitamin D status was significantly affected by month of sampling, with low values in late winter and high values in summer. Plasma vitamin D concentrations increased with age, were higher in alpacas with light fleeces than in those with dark fleeces and were also higher in the Suri than in the Huacaya breed. Plasma Pi concentrations were generally lower in alpacas with plasma 25-OH D_3 values < 25 nmol/L. In conclusion, young alpacas with dark fleeces are most at risk from vitamin D insufficiency in late winter in southern Australia. The present study indicates that plasma Pi values are not a reliable indicator of vitamin D status of alpacas as assessed by plasma 25-OH D_3 concentrations.

Soil nutrient accumulation in alpaca latrine sites (McGregor and Brown, 2010)

Alpacas establish long-lasting communal latrine sites or dunghills. To quantify the extent of nutrient transfer and accumulation associated with alpaca latrine sites and to provide a three-dimensional assessment of a pasture paddock with 11-year-old latrine sites, three comparisons were made: a) centres of latrines were compared with non-latrine control sites 20 m away; b) surface soils (0-10 cm) were compared with subsurface soils (10-30 cm); and c) across cardinal compass directions and regular distances from latrine centres were compared. Accumulation of nutrients was clearly detected, with a significant surface build-up, relative to controls, observed in phosphorus (3 times), nitrate-nitrogen (3.8 times), potassium (3.2 times), sulphur (1.9 times), organic carbon (1.3 times) and electrical conductivity (2.4 times). Soil pH was also significantly decreased in the centre of the latrine sites (pHw 0.6-0.7 units). Across the main axes of the latrines there was a clear trend of decreasing electrical conductivity, organic carbon and nutrients (NO_3, P, K, Ca, Mg, Na and S) away from a peak concentration at or near the centre. Soil pH demonstrated the inverse with a decrease towards the centre. Under set stocking conditions large transfers in nutrients towards latrines could have long-term effects on pasture growth and composition. Some management options are discussed.

4.4 All industries

Fibre production by beef cows (McGregor and Graham, 2010)

Cattle grow and shed fibre which assists them adapt to seasonal changes in the environment. In the absence of cattle fibre production data for southern Australia, Angus, Hereford, Simmental and Limousin cows and crosses between these breeds grazing perennial pastures at Hamilton, Victoria were sampled in late winter. The fibre growing area on the sides of cattle was measured, fibre sampled at the mid-side site and the sampling area determined. Fibre was tested for fibre diameter distribution, clean washing yield and fibre length measured. Cows were 3-7 years of age, live weights were 412-712 kg and the mean fibre growing area was 2.2 m^2. This produced an average 682 g of total fibre (range 346-1175 g). The mean fibre diameter of all fibres was 51.7 µm (range 43-62 µm) and 18% of fibres were < 36 µm (range 6-39%). The clean washing yield was 92.4% (range 87.4-95.8%). Fibre length averaged 21 mm. Increasing the age, liveweight and condition score of cows and increasing weight of clean fibre were associated with significant increases in mean fibre diameter. Breed of cattle did not affect fibre production ($P>0.1$) but did affect mean fibre diameter ($P<0.05$). The quantity of fibre production indicates potential for low value textile production. The high level of total fibre production, twice that of an earlier report, and fibre shedding from cattle suggests that white fibre producing animals such as Merino sheep, Angora and cashmere goats and alpaca should avoid using cattle handling facilities, particularly in the month prior to shearing.

Incisor development, wear and loss in sheep and their impact on ewe production, longevity and economics: a review (McGregor, 2011)

The review investigates the use of permanent incisor wear and loss by farmers culling sheep from flocks, summarises investigations into incisor development, factors affecting incisor wear and loss, impacts on production and economics and practices designed to prolong incisor life and makes suggestions for future research. Periodontal disease is outside the scope of the review. Sheep farmers place considerable emphasis on the soundness of their ewes' mouths and cull sheep for a wide range of faults in their incisors. The length of the productive life in sheep is essentially determined by the state of their permanent incisors. It is normal for there to be a range in the number of incisors present at different ages probably related to maturity and live weight, but most reports fail to quantify these factors. Incisor wear and loss ("broken mouth") are affected by stocking rate, soil ingestion, farm of origin, breed and gender of sheep, pasture type, internal parasites, mineral nutrition, supplementary feeding and age at first mating of ewes. Incisor wear and loss affects feed intake of sheep, and in most studies reduces live weight gain, milk and wool production. Under certain conditions sheep are not affected by worn or lost incisors. Premature culling of sheep, as a result of incisor wear and loss, increases overhead and replacement costs and reduces lifetime productivity, genetic gain and income from sheep sales thus reducing profitability of sheep farming. A number of practices have the potential to increase longevity of ewes in flocks by reducing incisor wear and loss including: genetic selection; increasing dietary calcium intake during growth and lactation; and supplementary feeding during periods of short pasture. The evidence suggests the mechanical shortening of incisors provides no benefits. Incisor wear and loss in sheep has been accepted as an inevitable outcome of advancing age.

There has been little investigation of these issues during the past 20 years. Suggestions are made for future research including: quantification of economic benefit/cost ratio of different farm practices including mineral nutrition, on incisor condition and animal production; genetic selection to improved incisor retention and wear; and development of interactive economic models related to different culling strategies based on incisor condition. Suggestions are made on ways to improve the design and conduct of research in this field including adequate controls, size, duration and statistical power.

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5. New research

5.1 Structural properties of rare natural fibres

The outer surface of animal fibres consists of cuticle cells (scales) which overlap like tiles of a roof to give the well-known range of distinctive surface structures of wool and rare natural animal fibres (Figure 5.1). The cuticle of animal fibres is of great practical importance as it forms the interface between the fibre and the environment, including chemical processing media and the wearer of the product. Research with wool has shown that the cuticle constitutes 10 -20% of the weight of a fibre, and provides a tough protective layer for the 80 -90% bulk of the fibre, which is composed of long, spindle-shaped cortical cells, and medulla cells when these are present. However little is known about the structural composition of rare natural animal fibres.

Wildman (1954) published a frequency diagram which illustrates the distribution of cuticle scales/100 µm for two samples of commercial cashmere and 18 µm Merino wool. The two cashmere samples ranged from 4-10 scales/100 µm with mean values of 6.5/100 µm. The Merino wool ranged from 5.5 - 11 scales/100 µm with an average value of 8.5 - 9. Garner (1967) found that up to 20% of the Merino fibres he examined had the same scale frequency/unit length as cashmere. The shape of the cashmere scale is square shaped (Figure 5.1), whereas wool cuticle scales are strip-shaped.

Since this time the cuticle scale attributes have been used to identify cashmere from other animal fibres. The importance of cuticle scale measurements have received increased prominence in recent years in attempts by major exporting and importing business to eliminate fraud and misrepresentation in the rare animal fibre trade. This is particularly in relation to cashmere exports from China to USA and Europe which have been contaminated with wool, which includes wool chemically treated to remove or modify cuticle scales, and dehaired native wool, yak and other fibres which were blended with cashmere. There have also been some reports that concluded Australian cashmere differed from Chinese cashmere.

Given the importance of fraud in the cashmere fibre trade and the difficulties that arise in determining fibre types amongst various agencies, auditors and companies, the China National Cashmere Products Engineering and Technical Centre and the Inner Mongolian Erdos Cashmere Group have hosted five International Cashmere Determination Technique Seminars in 2001, 2003, 2005, 2008 and 2011. In response to the questioning of the validity of the commonly used measurement techniques for measuring cuticle scale size and height, that being the light microscope versus the scanning electron microscope, Chinese scientists have undertaken the largest analysis of cuticle scales of cashmere. A survey of raw cashmere from their main producing regions resulted in the measurement of the cuticle properties of over 9,000 fibres from 105 different cashmere samples (Yang et al., 2005; Zhang, 2005, 2008).

As little is known about the structural properties of Australian rare natural fibres, several studies were undertaken using cashmere from a highly controlled nutrition study of Australian cashmere where it was known that nutrition had altered the fibre properties or growth rate of fibre, and of other samples of known origin from different international producing regions.

Only the major findings are summarised in this report.

Impact of animal production system upon structural properties of animal fibres

The hypothesis for these studies is that nutritional management of cashmere goats will affect the structural properties of rare natural animal fibres. This is based upon the known differences in nutritional management between producing countries. Further, it is clear from a review of cashmere nutrition experiments that improving nutrition of cashmere goats alters the level of cashmere production and the fibre diameter, fibre length and fibre curvature properties of the cashmere (see Section 4.2). Thus it is speculated that other properties of cashmere are affected by nutritional manipulation or country of origin.

Studies of the impact of nutrition of cashmere goats on the cuticle and cortical cell properties of cashmere are summarised. The influence of nutrition and fibre type on fibre shape is also summarised.

Cuticle cell frequency of cashmere

White cashmere grown by Australian cashmere goats individually fed in a controlled nutrition experiment conducted indoors for 8 months was examined (McGregor, 1988; McGregor and Tucker, 2010). These goats were shorn at the start (3 December) and at the end (17 June) of the study so only cashmere grown during the nutrition study was tested. These goats were fed different quantities of the same basal diet of high quality hay to provide different levels of energy intake: 0.8M, sub maintenance live weight diet which resulted in live weight loss; M, maintenance of live weight diet; >M, above maintenance diet resulting in live weight gain. Nested within M were treatments to assess the influence of additional dietary protein: M, fed to maintain live weight with the base diet; M + 54 g FTC, fed to maintain live weight with 54 g/d of formaldehyde treated casein included in a pellet made with the hay and fed with the base diet. Nested within >M were three treatments of which some have been tested for this study: ADLIB, goats were fed the base diet *ad libitum*; 1.25M, goats fed M plus 25% of the difference in mean intake between M and ADLIB.

The cuticle cells of cashmere were examined using the scanning electron microscope (SEM). Fibre samples were taken of the entire growing period at the mid-side site in June. Cashmere fibres were carefully selected to enable the tip of the fibre (summer growth) and the base of the same fibre (autumn/winter growth) to be prepared and examined by the SEM. An example of two SEM micrographs is shown in Figure 5.1.

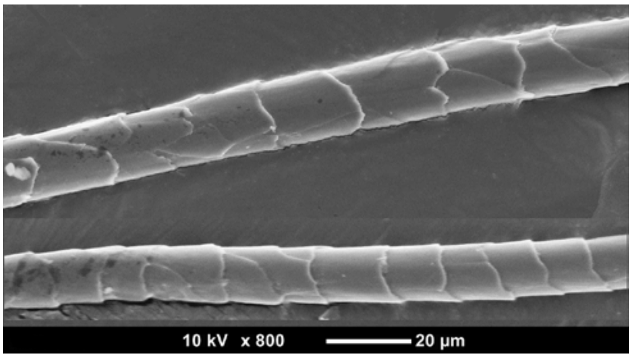


Figure 5.1 The surface of cashmere fibres showing the cuticle scales.

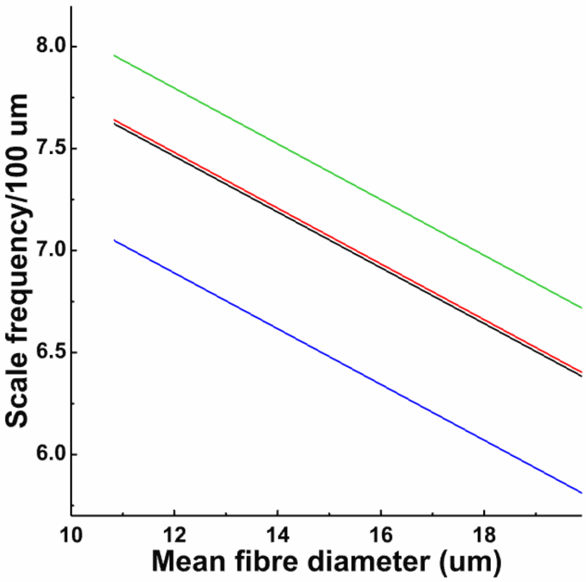
Top: Cashmere grown by a goat fed to maintain live weight from November to June which exhibits low scale frequency.

Bottom: Cashmere grown by a goat fed to lose live weight from November to April exhibiting high scale frequency.

Mean cuticle scale frequency based on 624 measurements of fibre ends was 6.6 (s.d. 0.92) with a range of 4.7 - 9.2/100 µm. Cuticle scale frequency was affected by four parameters: nutritional treatment ($P = 6.4 \times 10^{-10}$); season of growth (tip versus root of fibre, $P = 0.00079$); and the product of mean fibre diameter × cashmere length ($P = 0.005$). Increasing mean fibre diameter was associated with reduced cuticle scale frequency in all nutritional treatments as illustrated in Figure 5.2. The main statistical differences between nutritional treatments in cuticle scale frequency were: <M *v*. M, 0.45 ($P = 0.004$); <M *v*. M + 54 g FTC, 0.92 ($P < 0.001$); M *v*. M + 54 g FTC, 0.48 ($P = 0.002$). After adjustment for other factors in the model, the root end of the fibre had 0.35 more cuticle scales /100 µm compared with the tip end. Increasing cashmere length was associated with increased cuticle scale frequency.

Figure 5.2. The predicted main effects of nutritional treatment and mean fibre diameter on the frequency of cuticle scales on cashmere.

The mean scale frequency values are shown following adjustment for other effects in the linear model.
Symbols for nutritional treatments:
< M, green line;
M, black line;
1.25M, red line;
M + 54 g FTC; blue line.



Poorly fed goats and cashmere fibre grown during autumn and winter was more likely to have a higher cuticle scale frequency than cashmere grown by better fed goats and cashmere grown during the peak growing season in summer. Feeding additional protein resulted in cashmere with lower cuticle scale frequency compared with cashmere grown by goats fed the basal diet. These changes indicate that nutritional manipulation alters cell biosynthesis. As hypothesised in our study on the amino acid composition of cashmere (McGregor and Tucker, 2010), altered protein nutrition may not have significantly increased cell proliferation rate but it did affect cell biosynthesis as shown by altered amino acid composition and as shown in this study by the altered physical structure of the fibre surface.

These results challenge the currently accepted view that cashmere from certain origins will have certain fixed characteristics. Clearly cashmere cuticle scale frequency varies along the fibre and is influenced by season, nutritional manipulation and fibre diameter. 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 cashmere. There are also important consequences upon the determination of cashmere origin. It is not valid to conclude that cashmere fibres with a low cuticle scale frequency originate from a non-cashmere goat origin without understanding the nutritional and seasonal influences in which the cashmere was grown.

Cuticle cell thickness and fibre cross-sectional shape

Using cashmere from the same nutritional experiment and other sources of Australian cashmere the thickness of the cuticle cells was measured using the SEM. Figure 5.3 provides SEM images of the cross section of cashmere and mohair. The fibre contour (cross-shape shape) was determined by measuring the longest (major) and shortest (minor) axis of the fibres as shown in the cross-section images. For fibre contour studies, other rare natural animal fibres were examined. The fibre contour is expressed as the ratio of the fibre diameter: longest axis/shortest axis.

(a) **(b)**

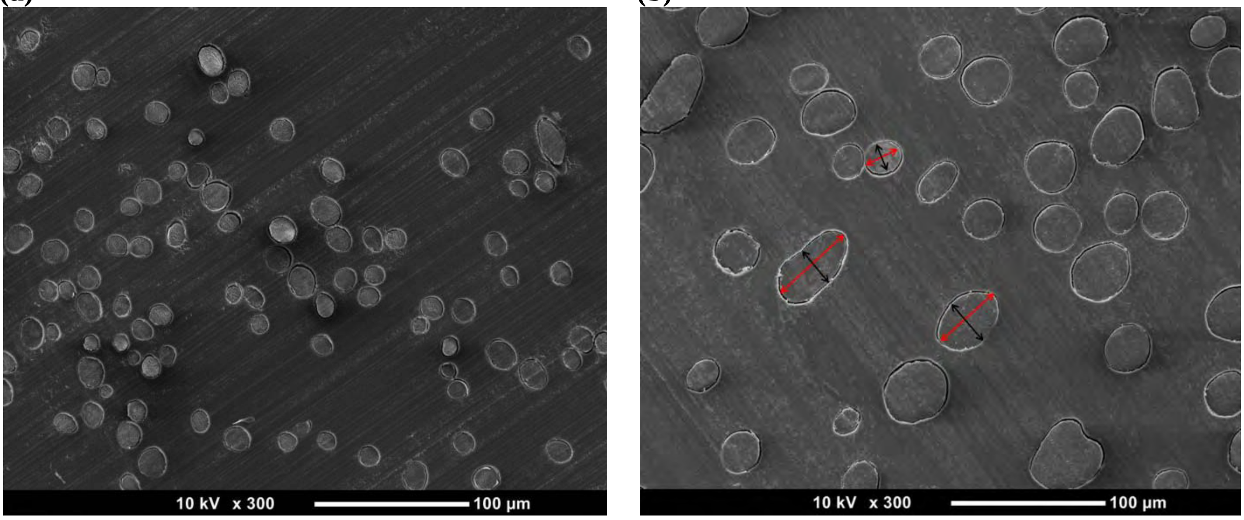


Figure 5.3. Scanning electron microscope images of the cross-section of (a) cashmere and (b) mohair fibres.

Examples of the longest (red arrow) and shortest (black arrow) axes of some mohair fibres are shown in (b).

The results indicate that different nutritional treatment of cashmere goats affected both the cuticle cell thickness and the fibre cross-sectional shape (Table 5.1). After taking into account other factors in the model, cuticle cell thickness increased 0.109 µm (s.e. 0.0648, $P < 0.001$) as the contour increased by one unit and cuticle cell thickness increased 0.071 µm (s.e. 0.0191, $P < 0.001$) for each 1 µm increase in mean fibre diameter. Treatment 1.25M grew more cashmere than the other treatments and had the thinnest cuticle cell thickness and the most circular contour compared with other treatments. The goats fed ADLIB had the thickest cuticle cells and the most elliptical contour.

Table 5.1. Cuticle scale thickness and the fibre cross-sectional shape expressed as the contour (ratio of fibre diameter: longest axis/shortest axis) (*P-values* shown).

Dietary treatment	Cuticle cell thickness (nm)	Statistical difference from restricted diet	Contour	Statistical difference from restricted diet
Restricted diets[a]	422	-	1.20	-
M+54 g FTC	415	-	1.16	0.033
1.25M	370	0.003	1.14	< 0.001
ADLIB	484	0.016	1.29	< 0.001

[a] restricted diets included < M, M and grazing animals experiencing live weight loss on natural grazing.

The samples of different rare animal fibres which were examined exhibited differences in their fibre contour (Table 5.2).

Table 5.2. Mean fibre cross-sectional shape expressed as the contour (ratio of fibre diameter: longest axis/shortest axis) for different animal fibres (*P-values* shown) (n = 1635).

Fibre	Contour	Statistical difference from Australian alpaca
Australian alpaca	1.28	-
Cashmere and mohair	1.20	< 0.001
Wool	1.37	0.006
Peruvian alpaca and vicuña	1.35	0.003

Cortical cell properties of cashmere

Cortical cells are spindle shaped and are aligned parallel to the fibre axis. Cortical cells consist of two main types: ortho and para with slightly different physical and chemical properties and the intermediate meso cells. There have been a number of studies of cortical cell type in wool, cashmere and mohair. The review of the properties of rare natural animal fibres conducted during this project found no information on cortical cell properties of rare animal fibres. Thus there are no systematic studies of factors which may affect the size of cortical cells of mohair, cashmere and alpaca.

For this report 29 different rare animal fibre samples were examined including mohair, alpaca and cashmere in both raw form and as processed tops. Cortical cells were mechanically extracted from 8 to 15 fibres per sample and were photographed under microscopic vision. For each field of view all cortical cells were measured for length and width. A total of nearly 18,000 cortical measurements were recorded. Measurements were only taken on cells which were undamaged. Data were analysed based on each fibre examined. Cortical cell volume was calculated as if the cortical cells were two cones joined at the widest and middle point: $\pi/3 \times (\text{width}/2)^2 \times$ length. The ratio of cortical cell length to cortical cell diameter was determined as: LD ratio = length/width.

The mean cortical cell length, diameter, volume and LD ratio for different fibres are summarised in Table 5.3.

Table 5.3. Cortical cell dimensions and ratio of length to diameter (LD ratio) for samples of alpaca, cashmere and mohair raw fibre and processed tops with s.d. in brackets.

Fibre	Mean length (µm)	Mean diameter (µm)	Mean volume (µm^3)	Mean LD ratio
Alpaca	51.9 (10.45)	4.9 (0.84)	346 (209.8)	10.3 (0.81)
Cashmere	47.5 (4.59)	4.5 (0.20)	254 (38.39)	10.5 (0.91)
Mohair	44.7 (2.55)	4.7 (0.21)	261 (29.61)	9.5 (0.63)

Cortical length was highly associated with cortical diameter ($P = 5.6 \times 10^{-32}$) and animal fibre type ($P = 7.5 \times 10^{-29}$). This relationship explained 59.6% of the variation in cortical cell length. Compared with alpaca and cashmere cortical cells, the samples of mohair cortical cells were significantly shorter ($P < 0.001$) relative to their diameter. However, the mean cortical cell volume of mohair was no different to that of cashmere, and both mohair and cashmere cortical cell volume was less than that of the alpaca samples tested ($P < 0.05$).

To examine the effect of nutrition on cortical cell dimensions samples of cashmere from the controlled nutrition study were measured. Nutritional treatment significantly affected cortical dimensions of all attributes measured ($P < 0.001$, Table 5.4).

Table 5.4. Cuticle dimensions of cashmere grown by goats subject to different nutritional regimens during the cashmere growing period between November and June. The ratio of length to diameter of cortical cell is shown as the LD ratio.

Dietary treatment[a]	**Cortical cell dimension**[b]			
	Length[c] **(μm)**	**Diameter (μm)**	**Volume**[c] **(μm^3)**	**LD ratio**[c]
Restricted grazing	34.46^{x}	4.14^{x}	170^{x}	8.39^{x}
Maintenance diets	47.50^{y}	4.48^{y}	245^{y}	10.59^{y}
Fed to grow	50.78^{z}	4.57^{y}	274^{z}	11.06^{z}
Statistical significance	1.6×10^{-11}	2.4×10^{-6}	1.5×10^{-12}	5.9×10^{-8}

[a] Dietary treatments: restricted grazing experienced live weight loss on natural grazing; maintenance fed goats maintained live weight; goats fed to grow gained 2 kg during cashmere growing period (diet 1.25M). [b] values in columns with different superscripts are different, $P < 0.05$. [c] values adjusted for differences in significant pre-treatment covariate (cashmere mean fibre diameter).

Summary

The studies have shown that both the cuticle and cortical cell dimensions of rare animal fibres were affected by nutritional management. There are important commercial implications which arise from these findings including variation in textile properties and in the identification of animal fibres, particularly cashmere.

5.2 Investigations into the identification of the origin of fibres

The accepted method of identifying the animal source of fibres is by inspecting the surface cuticle scales using the light microscope. However this method is now under intense scrutiny and has been the focus of five international conferences hosted by Chinese authorities. The controversy is in part related to the accidental contamination or the deliberate blending of various low value animal fibres, such as bleached yak wool, native sheep wool or chemically treated wool, into valuable fibres particularly cashmere. Part of the controversy relates to a lack of detailed knowledge of the natural variation of the cuticle properties of cashmere, as cashmere originates from hundreds of breeds of goats from a wide area in Asia (Turkey to eastern China).

This project investigated an alternative method of fibre identification by using Fourier Transform Infrared Spectroscopy (FTIR). All animal fibres consist of keratin proteins composed of various amino acids. These amino acids have different compositions and are bonded to form long polyamide chains. The different amino acids have side chains which contain differently charged chemical groups. FTIR examination provides a spectrum from which chemical bands for particular bonds can be clearly identified as peaks on the spectra (see Figure 5.4). The results show the attenuated total reflectance (ATR) indicating the incidence of the chemical bonds determined from the area under the spectra curve between particular wavelengths (Table 5.5).

Table 5.5. The wave lengths used to determine the area under particular spectra peaks for different chemical bonds.

Spectra peak	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**L1**	**L2**
Chemical bond	S-O	C-O	C-H	N-H	C=O	C-C(O)-OR	C-H	N-H
Wave length start	998	1210	1361	1500	1600	1720	2850	3010
Wave length end	1100	1290	1470	1572	1700	1750	3000	3500

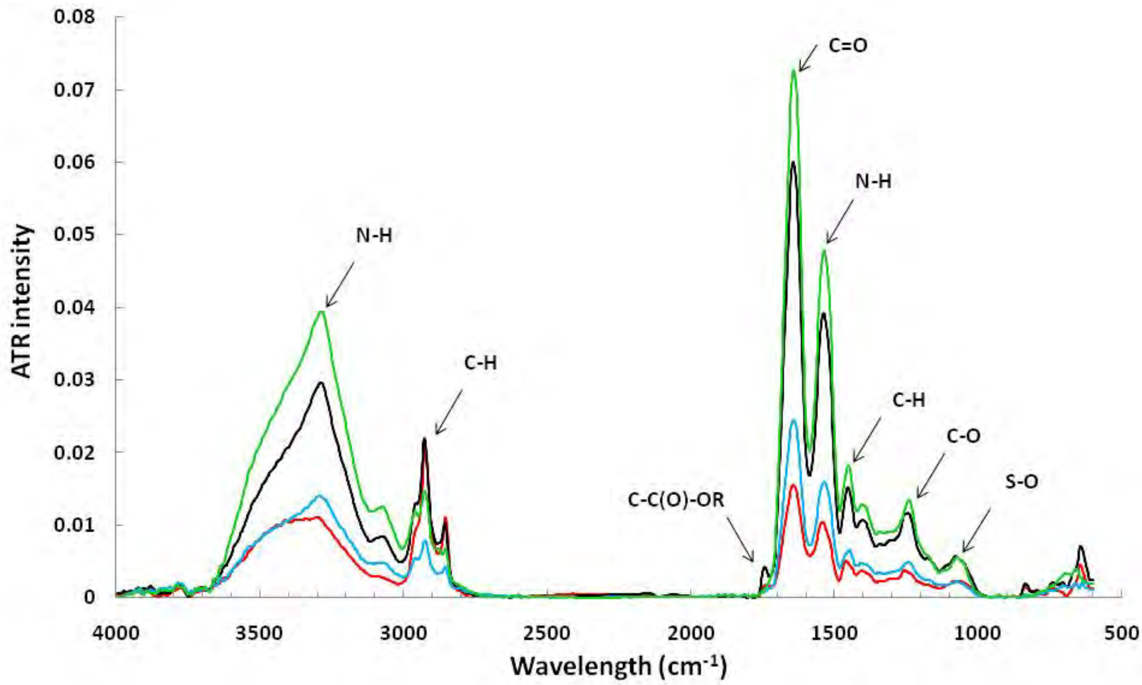


Figure 5.4. The FTIR spectra intensity for samples of Australian cashmere and the guard hair grown at the same time. Symbols: red line, cashmere and black line, hair from the same goat; blue line, cashmere and green line, hair from same goat.

The objective of this study was to investigate if FTIR: would enable the identification of different animal fibres; could differentiate between cashmere fibre from different origins; and could differentiate between cashmere from different production systems.

Cashmere, wool and other rare natural fibres from known sources (n = 93) was used including a set of Australian cashmere originating from intensive experiments where it was known that nutritional management had affected the amino acid content of the fibre (McGregor and Tucker, 2010). A full report of these investigations is being prepared for scientific publication. Collaboration with Chinese scientists and other staff at Deakin University is acknowledged. From China a collection of cashmere and native sheep wool provided fibres from a wide geographic and a range of nutritional backgrounds. Commercial cashmere and wool tops were also used.

Results

The FTIR method was able to differentiate between cashmere and guard hair. Goats which had cashmere with higher FTIR spectra also had hair which had higher FTIR spectra compared with goats with lower FTIR spectra (Figure 5.4).

The FTIR spectra appear to be affected by the nutritional treatment of the goats. Poorer fed goats had lower spectra intensity for both cashmere and hair compared with better fed goats. Figure 5.5 shows the FTIR spectra for cashmere from the controlled nutrition experiment and for some cashmere samples collected in extensive and degraded range lands in three different Central Asian regions. There are clear differences in the ATR intensity related to nutritional treatment which differ significantly in the area of particular chemical bonds ($P < 0.001$).

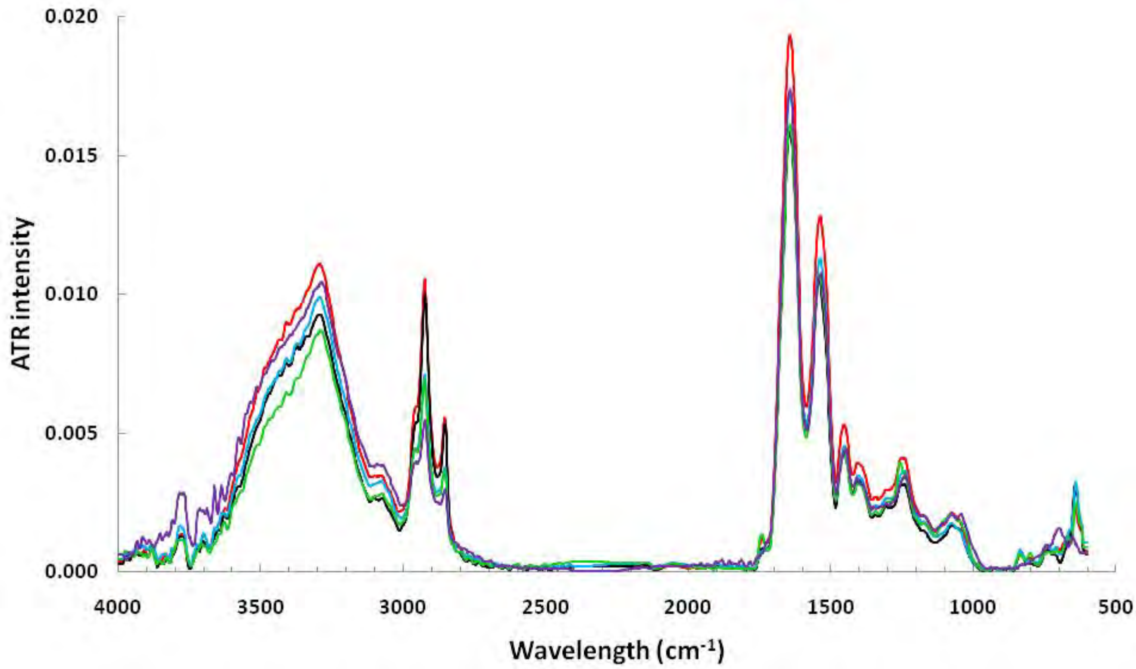


Figure 5.5. The FTIR spectra intensity for samples of Australian cashmere and cashmere from poor range in Central Asia (purple line). Symbols: red line, poor nutrition; blue, black and green lines, improved nutrition.

When FTIR spectra of Chinese native wool and Chinese cashmere are grouped according to their grazing conditions ATR intensity followed the opposite pattern as found in the controlled nutrition study. That is ATR intensity increased with improving nutrition. Further, the FTIR spectra of the wool and cashmere from different sources overlapped as illustrated in Figure 5.6.

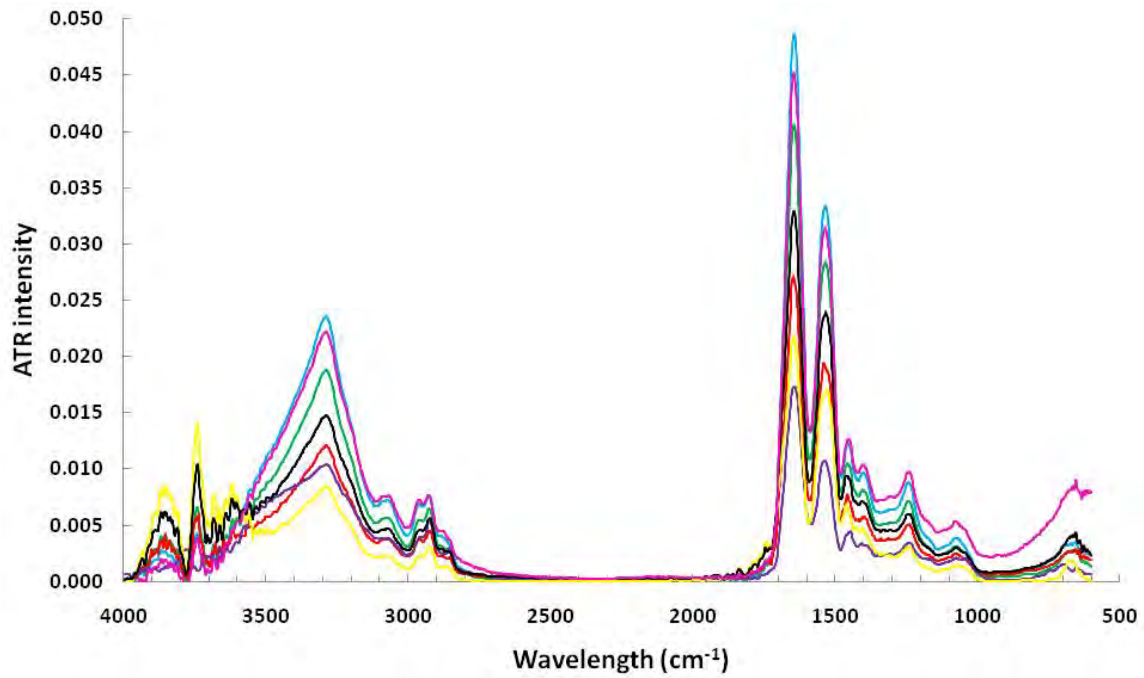


Figure 5.6. The FTIR spectra intensity for samples of Chinese wool and cashmere originating from different regions and grouped according to nutritional background. Symbols: wool, pink, black and yellow lines; cashmere, blue, green and red lines. The purple line is the same as in Figure 5.5.

Conclusions

FTIR spectra can distinguish between cashmere and guard hair. FTIR spectra of cashmere are affected by nutritional background of the goats. However the response to nutrition appears to differ between Australian and Chinese cashmere goats. While, the FTIR spectra of Chinese cashmere and Chinese wool are also affected by regional nutrition, the cashmere and wool spectra overlap. At this stage in the research it does not seem likely that FTIR spectra offer a reliable method to distinguish between cashmere and wool for diagnostic tests to determine the fibre composition of finished textiles.

5.3 Fibre length properties of rare natural animal fibres

The length of processed rare natural animal fibre is associated with premiums and discounts in the market as is the case with wool. About 90% of the worlds production of cashmere is used in woollen spinning as the length is too short for worsted spinning. One of the biggest problems with cashmere processing is gaining an accurate measurement of fibre length as the measurement of processed cashmere fibre length is notoriously difficult, in part owing to the large number of short fibres. There is also little public information on the fibre length of processed mohair and alpaca making it difficult for Australian producers to market commercial lots suitable for local processing for particular applications.

Over the past 44 years the Almeter, which measures fibre length indirectly by capacitance, has been the international standard for fibre length measurement (IWTO-17, 1967) in tops and slivers. The Almeter scans a prepared fibre array with a capacitance sensor to estimate the quantity of fibre at each point along the fibre array. The Almeter estimates the fibre length of tops, called the Hauteur, or the length after carding (LAC) of slivers as the mean length by number, Barbe (mean length by weight) and various other length measurements including the variability of length measurements.

There are a number of assumptions made when the Almeter is used to measure the length of processed fibres. With Hauteur, estimates assume that all fibres have the same importance with respect to their percentage in the cross-section, but in Barbe estimates the longer fibers have greater importance. However with blends of lots with large differences in mean diameter and mean length, large differences are seen between cumulative, numerical and cross-section biased diagrams (Anon, 1980). For example, this effect is greatest when cashmere is blended with wool.

The Almeter is an expensive piece of equipment and preparation of samples using the separate Fibroliner is time consuming and therefore costly. In some processing facilities hand drawn fibre length arrays are used to estimate fibre length. In textile laboratories separate equipment is also required to measure mean fibre diameter.

According to Anon (2005) the recently developed OFDA4000 incorporates features of the laboratory based OFDA100 with the along-the-fibre measurement features of the OFDA2000 adapted to measure processed fibres. The OFDA4000 directly measures fibre length (Figure 5.7). It is claimed that the OFDA4000 provides a range of other potential benefits including: labor cost savings due to easier sample preparation, no operator involvement in measurement phase, measures the actual length and diameter as well as Hauteur and Barbe simultaneously, determines automatically the fibre diameter versus fibre length profiles, and blends of different fibres can be measured accurately, which is not possible using capacitance based instruments.

Investigations of measuring commercial and experimental rare natural animal fibre tops and dehaired slivers of known origin and fibre content on the OFDA4000 and the relationships between OFDA4000 and Almeter measurements were conducted.

Materials and methods

Cashmere tops (*n* = 12), dehaired cashmere (*n* = 13), mohair tops (*n* = 17), dehaired llama (*n* = 1), yak wool (*n*=1), baby camel (*n*=1) were selected from a larger collection to cover the range in known Hauteur, measured mean fibre diameter and countries of origin. Countries of origin were China, Iran, Afghanistan, Mongolia, Turkey, Australia, Peru, Boliva, Mongolia and South Africa. Fibre samples were measured on the Almeter and the OFDA4000. The mean fibre diameter (MFD) of the fibre ends and the change in MFD along the fibre were determined. The change in fibre cross section area was calculated from the fibre diameter fibre length profile as: (MFD at fibre end + increase in MFD along fibre)^2 / (MFD at fibre end)^2.

Figure 5.7. The laboratory fibre measurement instrument the OFDA4000.

The Fibroliner4000 is shown on the left side of the instrument.

Means of replicate measurements were analysed by linear regression analysis of the form $y = a + bx$, where y is the response variate, a the regression constant, x the dependent variate and b the regression coefficient. Graphs have been prepared including a dashed line with the gradient of 1 or 0 depending on the comparison. As slivers made from yak, camel and llama were not identified as statistical outliers they have not been separately identified in the results.

Results and discussion

The mean and range in properties of alpaca, mohair and cashmere tops and slivers are provided in Table 5.6. For alpaca the range in mean fibre diameter and fibre length (Hauteur) were 20-33 µm and 70-74 mm, for mohair 23-35 µm and 66-99 mm and for cashmere 14.9 to 21.1 µm and 23 to 51 mm respectively.

The most interesting result was the fibre diameter profiles along the fibre (Table 5.6, Figure 5.8). The along fibre profiles of mean fibre diameter show that in all samples the mean fibre diameter increased from the beard end, with an average increase of 2.3 µm for cashmere, 4.3 µm for mohair and 6.3 µm for alpaca. For cashmere this increases equate to an average increase in fibre cross-section area of 27 to 30%, for mohair the increase was + 35% and for alpaca 55%. This indicates that the statement by the makers of the Almeter that "with normal processing lots of wool the percentage of fibres biased by cross-section area are approximately equivalent to the percentage of fibres by number" (Anon 1980) was incorrect for these commercial tops and slivers. It therefore seems reasonable to conclude that the Almeter estimates of fibre length contain biases. The greatest biases appear to be in estimating the incidence of short fibres.

There was good agreement between OFDA4000 fibre length and OFDA Hauteur but poorer agreement between OFDA4000 fibre length and Almeter Hauteur. The difference between the two measurement methods was greater in cashmere slivers than with cashmere tops. The differences in Hauteur for cashmere slivers was constant over the range of Hauteur measured (Figure 5.9) while for cashmere tops the differences were clustered around zero. This indicates that where differences between the OFDA4000 and the Almeter exist they relate to the measurement of the shorter fibres.

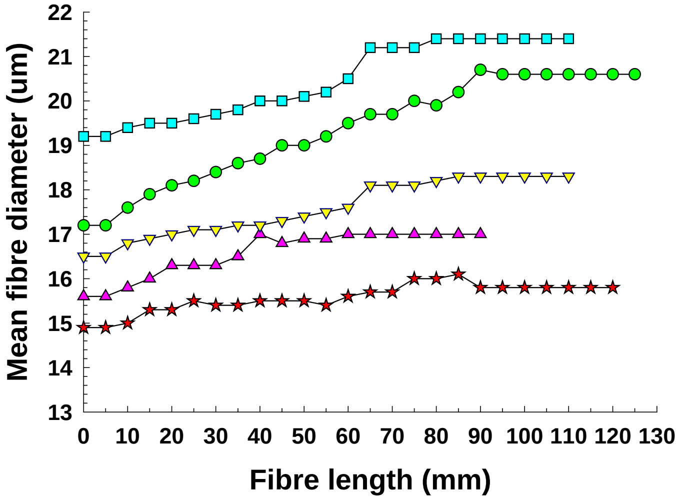
There were very high correlations between OFDA4000 measurement of the percentage of fibres shorter than 10 mm (L<10) and the OFDA4000 Almeter H%<10 mm (Figure 5.9) for tops and slivers, however there was no correlation for L<10 and the Almeter equivalent H%<10 mm for tops (Figure 5.9). This indicates that the Almeter was not reliably measuring the short fibres detected by the OFDA4000.

Table 5.6. The mean and range in attribute values for fibre diameter and fibre length determined by the OFDA4000 on tops and dehaired slivers.

	Alpaca tops			Mohair tops			Cashmere tops			Cashmere slivers		
Parameter	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**
Mean fibre diameter, µm	25.1	19.6	32.7	28.9	23.3	35.5	17.2	15.3	19.6	17.4	14.9	21.1
Fibre end diameter, µm	24.2	19.1	31.5	27.6	21.9	33.8	16.5	14.7	19.2	16.8	14.5	20.1
Increase in mean diameter along the fibres, µm	6.3	3.1	11.3	4.3	3.1	6.8	2.2	1.2	3.5	2.4	1.2	4.9
Change in cross-section area along the fibres, %	+54.9	+35.1	+84.6	+34.7	+19.2	+55.1	+27.5	+16.8	+44.8	+30.0	+16.9	+64.5
Mean fibre length, mm	65.9	64.8	67.4	78.5	60.3	93.4	36.0	27.4	41.9	27.1	19.4	43.2
CV length, %	53.6	50.9	57.8	48.7	39.9	63.6	45.3	32.3	56.9	61.0	52.9	67.9
% fibres < 10, mm	38.1	36.7	38.8	28.8	17.0	46.0	80.2	64.8	92.5	88.6	63.2	99.0
Longest 1% fibres, mm	161.1	146	179	164	142	212	77.9	66.9	86.2	73.1	49.9	117.4
Hauteur, mm	72	70	74	85	66	99	39.7	31.5	46.8	32.3	23.6	50.1
CVH, %	53.5	50.3	59.2	47.0	36.2	64.1	43.1	33.6	52.3	55.3	49.1	61.2
H% fibres <10 mm	33.8	31.9	35.3	24.3	11.6	41.5	74.9	59.2	87.5	83.0	56.7	96.8
HL1%, mm	161	146	179	164	142	212	86.8	75.4	96.4	84.0	58.2	133.0
Barbe, mm	92.9	88.5	99.7	104	86	117	47.1	38.8	54.3	42.3	29.5	66.8

Figure 5.8. The OFDA4000 along fibre profile of mean fibre diameter for examples of cashmere tops and slivers.

Symbols:
Star, Chinese white top;
Upright triangle, Australian white sliver;
Upside-down triangle, Australian white top;
Circle, Mongolian brown top;
Square, Iranian white top.



In undertaking these measurements the OFDA Fibroliner4000 significantly reduced labour compared with the operation of the Almeter. This allowed the author to complete other tasks while the automatic operation and adjustments built into the software enabled the Fibroliner4000 to efficiently process double layers of cashmere slivers or cashmere tops. The direct measurement of the length of 16000 fibres in 15 to 20 minutes by the OFDA4000 was an undertaking that would not have been considered possible with existing resources.

Conclusions

There were differences between the Almeter and the OFDA4000 measurement of Hauteur and fibre distribution and length measurements that may be associated with differences in the measurement of short and long fibres and in changes in mean fibre diameter along the fibre. The OFDA4000 proved to be a rapid and direct method of measuring cashmere fibre length in tops and slivers.

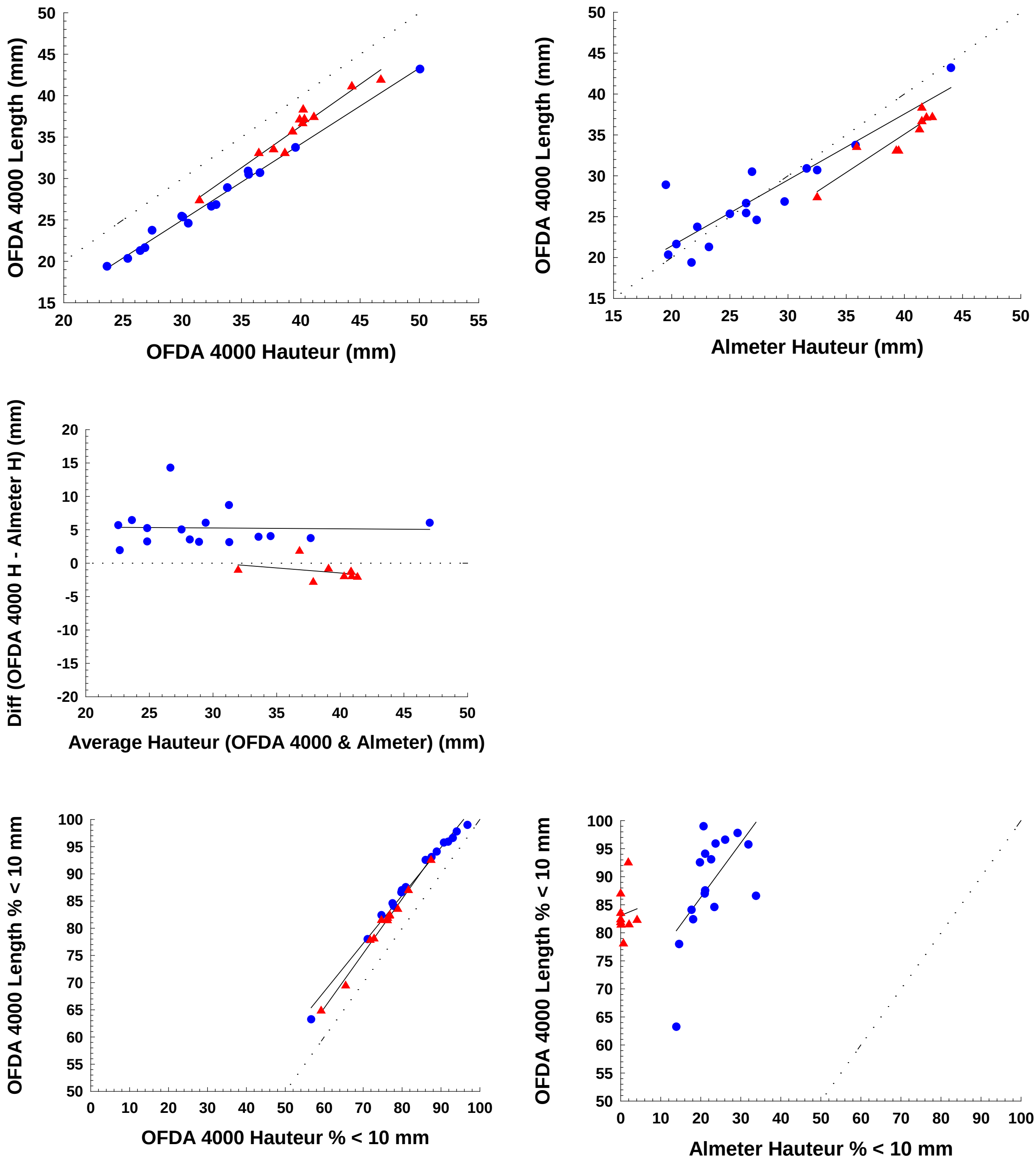


Figure 5.9. The relationship between OFDA4000 measurements and Almeter measurements of cashmere fibre length. Symbols: Cashmere tops ▲; Cashmere length after carding slivers ▲

6. Implications

6.1 Organic supply chains

Given the small size of rare natural fibre industries, the impact of cost structures in auditing organic supply chains and the importance of scale in producing organic fibres it will be difficult to develop profitable organic supply chains. To assist develop these industries critical issues in the production of these fibres need to be overcome including developing a low-cost certification system.

6.2 Review of rare natural fibres

The review provides producers and levy contributors a summary of the important contributions to knowledge and practices which have flowed from previous RIRDC investments. For producers and processors the review documents which fibre attributes are important and why. For processors the review provides a summary and references for best practice information on the processing of rare natural animal fibres. For RIRDC, the outcomes of past research investment and the suggestions for future R&D investment provide a guide to help direct future investments. For researchers and students the review provides the latest information and references to guide the design and conduct of future investigations.

6.3 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. Given the complexity of some outcomes it will take some time to fully communicate all these findings with industry. However the findings provide directions for more efficient land and pasture management, animal management, nutritional management and animal selection, fibre production, fibre selection for processing, and enterprise financial planning and management. Research has also identified improved experimental design for cashmere nutrition experiments.

All the research outcomes provide new information for material for use in scientific education and farmer training.

6.4 New research into rare animal fibres

The discovery that nutritional management alters fundamental aspects of rare natural animal fibres provides opportunities to manipulate fibre properties 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 felting and wear properties of textiles. There are also important consequences upon the determination of cashmere origin.

While FTIR spectra can distinguish between various fibres there was considerable overlap between the spectra of cashmere and wool. At this stage in the research it does not seem likely that FTIR spectra offer a reliable method to distinguish between cashmere and wool for diagnostic tests to determine the fibre composition of finished textiles. However the OFDA4000 proved to be a rapid and direct method of measuring fibre length in tops and slivers, particularly for textiles which contain many short fibres.

7. Recommendations

The following steps need to be considered by RIRDC and the Australian rare natural animal fibre industries and supply chain partners to further develop, disseminate and exploit commercially the results of the project:

- Publish and extend the findings of this review.
- Provide financial and in-kind support for the implementation of the recommendations.
- Assist industries develop low-cost “organic” or “eco-friendly” certification systems for rare natural animal fibres and develop case studies of successful supply chains.
- 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 textile research on the production and evaluation of light weight, high value fabrics which are comfortable for next-to-skin wear.
- Continue to support scientific documentation and communication of research into rare natural animal fibres using existing data.
- Support research on fundamental properties of Australian rare natural animal fibres related to market access, price premiums or textile performance which link production systems with research investigations.
- Support industry groups to extend the findings of research and development via conferences, field days and publications.

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Improving Production Efficiency, Quality and Value-Adding of Rare Natural Animal Fibres

by B.A. McGregor

Publication No. 11/155

This is a technical report on the production, quality, processing and performance of rare natural animal 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 for these industries in Australia.

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