BREEDING FOR WOOL QUALITY IN APPAREL WOOL SHEEP

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INTRODUCTION

Quality considerations are vitally important determinants of returns in all livestock production systems. For apparel wool, quality has a major impact on the end-use and on the efficiency with which a package of raw wool is converted into a finished garment.

In a review focussed on genetic improvement of wool production, Atkins (1997) argued that the important features of genetic improvement programs for wool sheep are to increase production of fibre from a fixed resource (usually land) in order to gain a greater economic return per hectare, and to improve the quality of fibre so that it can be processed into superior end-product, thus attracting a higher unit value for the wool produced. Previously, Ponzoni (1990) specified a list of raw wool characteristics that influenced quality, commented on the clarity of price signals for each trait and discussed prospects for genetic improvement.

In this paper we will focus on those traits for which there have been technological developments in the last decade, for which new price signals have emerged, or which show promise as new goals for breeding programs for apparel wool sheep. We present a largely Australian perspective as this country produces more than 70 % of the world apparel wool.

DEVELOPMENTS IN PRODUCTION OF APPAREL WOOL

In the last two decades there have been dramatic changes in the volume and make-up of apparel wool production in the major producing countries, as typified by Australian statistics, which are presented in table 1. These clearly show an increase in the production of wools finer than 19 microns, whilst premiums for the finer categories have been maintained.

Table 1. Production (kg clean) and price (c/kg clean) received for Australian apparel wool (16-24 micron categories) over the past 3 decades

		Mean Fibre Diameter (μm)								
	Decade	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Production (tonnes)	1971-1980	20	191	4145	15117	32570	56313	69747	51908	42003
	1980-1990	88	993	6531	21464	47387	70274	81123	72226	45494
	1990-2000	414	3033	13614	31623	54070	68517	67156	53844	31142
Price (0.01$)	1971-1980	832	424	168	141	120	107	105	105	94
	1980-1990	1766	1489	943	716	592	522	489	461	423
	1990-2000	1982	1330	959	762	618	566	519	495	472

Source : Merino Ratings Pty Ltd

DEVELOPMENTS RELATING TO INDIVIDUAL WOOL QUALITY TRAITS

Mean fibre diameter. In recent years the widespread adoption of fleece testing has been a dramatic development and has been stimulated by the existence of substantial premiums for finer wool (table 1). The cost of fleece testing has gradually reduced over the last decade and new methods of measurement have emerged to replace the airflow method first introduced in the 1950's. Two new technologies, Laserscan (Dabbs and Glass, 1992) and OFDA (Brims *et al*., 1999), also supply measures of the distribution of fibre diameter, and more recently of fibre curvature.

A recent development in Australia has been the widespread adoption of mobile fleece sampling and diameter measurement devices that have evolved from the Laserscan and OFDA technologies. Whilst the primary stimulus for most woolgrowers has been the use of measurement to aid fleece classing into micron groups, woolgrowers and ram breeders are also using the information for selection and culling purposes. Together with the price premiums associated with finer apparel wools, these developments have had the effect of increasing the proportion of the Australia wool clip falling into the less than 19.5-micron category.

A major challenge for ram breeders has been to deal with these market developments whilst taking account of the antagonistic genetic association between mean fibre diameter (MFD) and clean fleece weight (CFW); the latter being the other major determinant of fleece value. The current MFD of their own flocks and of their ram buying clients influences the relative emphasis that breeders place on reducing MFD relative to increasing CFW per head.

Breeders have also had available increasing information on differences between bloodlines. Studies have shown that at the finer end of the distribution of bloodlines, changing ram source to a finer bloodline is on average associated with lower fleece weight (Atkins and Casey, 2000). For such an option to be economically attractive, the maintenance of relatively high premiums is necessary. At the ultra-fine end of the bloodline distribution there is very little choice in bloodline availability, despite the existence of extremely high micron premiums.

In the last decade estimation of genetic parameters for fibre diameter traits has routinely used REML algorithms, and as computing power has increased the animal model has become the preferred option. Prior to this, heritability estimates of MFD based on sire models had averaged around 0.5 (Atkins, 1997). The more recent estimates based on full pedigree information in the animal model have tended to be higher, in the range 0.6 to 0.65. (Swan *et al*., 1997 ; Taylor *et al*., 1999). Whether these differences are due to improvements in statistical models or in measurement technology is not clear. However, for genetic improvement programs the important issue is that the most appropriate parameter values are used, and that across program evaluations are based on a common parameter set.

Coefficient of variation of fibre diameter. Evidence that the coefficient of variation of fibre diameter (CVFD) is strongly correlated with staple strength (SS) (Greeff *et al*., 1995), and the availability of CVFD as a routine measurement from fleece testing laboratories and in-shed testing has increased breeder use of this trait in Merino breeding programs. Breeders are using CVFD in indexes as an indirect selection criterion for influencing genetic change in SS (Swan

et al., 2000) and there is also independent culling of animals with high CVFD on the basis of supposed genetic associations with the increase in MFD with age (micron blow-out), and susceptibility to fleece rot and fly strike.
Two issues remain with respect to CVFD that need clarification in order that breeders can be confident of applying the appropriate selection pressure to this trait in their breeding programs. Firstly, the incorporation of CVFD into selection indices has been simply as a selection criterion or as a trait in the breeding objective with the economic value based on its relationship with MFD and the effect on spinning efficiency (5 % difference in CVFD equivalent to the effect of 1 micron difference ; Lamb and Yang, 1998). The advent of CVFD measurements in auction sale catalogues from July 2001 will see relative economic values calculated from data that reflects the relative importance that buyers and their processor clients attach to variation in this trait.
The second issue is that the OFDA 2000 technology has stimulated interest in the potential value of the "diameter profile" as a measure of diameter variability from which the along-fibre variation could be separated from between-fibre variation. Brown *et al.* (1999) reported genetic differences at the within-flock and bloodline level in a range of characteristics of fibre diameter profiles. Greeff (2001) has shown that in Western Australian Merinos, the along-fibre component is only half as heritable as the between-fibre measure (0.2 vs. 0.4) and neither is as heritable as the CVFD determined from a cored sample of fleece (0.67). He also established that the along-fibre component is only moderately related genetically to SS (-0.2), whilst the between-fibre component is strongly related (-0.67). Similar results have been found by Yamin *et al*. (1999) in a study of South Australian Merinos.
The current equations used to predict hauteur and noil on commercial sale lots incorporate measurements of MFD, staple length (SL), SS, CVFD, and percentage of mid–breaks (PMB). Further studies are required to establish whether characteristics calculated from fibre diameter profiles can improve the accuracy of these prediction equations.

Staple Strength. Greeff *et al*. (1995) have shown that the heritability of SS is robust across Merino genotypes and across vastly different environments. Whilst the heritability in adults and the genetic relationship between ages is important, the major challenge for woolgrowers in terms of relative economic penalties lies with improving SS of the animal's first fleece. This is because of the fineness of the hogget fleece and the fact that price discounts for lower strength increase as the fibre diameter of the sale lot decreases (Swan *et al.,* 2000). Whilst price discounts are consistent across staple strength groupings, there are quite severe fluctuations in discounts that appear to be related to the supply/demand nexus. The interaction between SS and PMB is complex with the latter trait influenced by environmental and animal husbandry considerations.

Staple length and fibre length. In his review of genetic improvement of wool production, Ponzoni (1990) cautioned against the routine adoption of a goal of increasing SL, without consideration of the economic value of changing SL in a particular production system. Measurement of SL in auction sale lots was introduced in Australia in 1985, and is now a routine feature. Analysis of sale lots by Atkins (1997) identified a critical length of 90 - 95 mm, depending on diameter, below which significant discounts were applied. A recent analysis by Swan *et al*. (2000), which focussed on fine/superfine production, revealed there is an intermediate optimum length for wools in the 16 - 19 micron range, and that penalties for long and short SL were highest in the finest micron categories (16 - 18 microns). Lamb (2000) has argued that the current market situation where wools are penalised in price where they are "over-long" and with low crimp relative to the MFD of the sale lot is unlikely to persist.

Style. Analyses of auction sale data have shown that assessed style grade (incorporating crimp definition and frequency, staple tip weathering, colour, and dust penetration) makes only a modest contribution to variation in price (eg Atkins, 1997). More recently Swan *et al*. (2000) have reported that style has increased importance in the finest micron categories (16-18 microns) and suggest that the higher premiums for the finest wools reflect the experience of processors whereby wools of better style process more predictably and the higher premiums are a component of their risk management strategies.
Assessed style is moderately heritable (Taylor *et al.,* 1997 ; Swan *et al.,* 1997) and as shown later in this paper the genetic association with the other traits that contribute to fleece value are such that most modern improvement programs will deliver small but positive changes in style grade.

Staple crimp and fibre curvature. Staple crimp (SC, crimps/cm) has always been a trait of great significance to Merino breeders. This is despite the fact that it is a trait of secondary importance in terms of processing efficiency and product qualities (Lamb, 2000). Interest in the trait has been maintained despite the knowledge that crimp frequency cannot be used to distinguish differences in MFD within flocks.
Smith *et al*. (2001) have shown that selection programs focussed on the major traits influencing fleece value are likely to cause only very modest correlated changes in staple crimp over a 10 year period. There remains the opportunity however, for breeders to focus on producing genotypes with a particular staple crimp/MFD/SL combination and this may provide niche-marketing opportunities for their woolgrower clients.

Wool faults and pigmentation. Fleece faults remain a target of breeding programs. Whilst recent studies shows that there is opportunity for reducing the incidence and severity of faults by genetic means (Li *et al*., 1999), there remains the problem of extremely variable incidence across years. Similarly, the problem of genetically determined, isolated dark fibre pigmentation, although currently of low incidence in Merino flocks, is extremely difficult to eliminate because of a lack of practical measurement techniques. In this regard, molecular technologies (see later) may offer new ways of dealing with these problems.

SELECTION PROGRAMS AND WOOL QUALITY

As is apparent from the preceding discussion, there are a number of wool quality traits, which affect price. Merino breeding programs based on index selection have traditionally included CFW and MFD as the only wool traits. More recently, CVFD has been added as a way of maintaining or improving SS. With price information from auction sale lots, it has been possible to calculate economic values for a number of additional wool quality traits. As the specification of wool improves it is possible that even more traits will be added to the list; for example, fibre curvature for crimp frequency. If, as has been observed for fleece weight and fibre diameter, the hogget and adult expressions of these traits have lower than unity genetic correlations, the number of traits in wool breeding objectives may grow significantly. There is a danger that breeders may try to overcomplicate selection decisions, losing focus on the important traits in their desire to improve or maintain traits of more marginal value. In addition, the lack of precision of genetic parameter estimates for new traits may lead to inaccurate selection decisions.

Table 2. Predicted in changes in hogget traits after 10 years of selection based on hogget measurements of clean fleece weight (CFW), mean fibre diameter (MFD), CV of fibre diameter (CVFD) and body weight - for three different wool quality breeding objectives

Price Premium (%)			10 year response			
MFD	SS [c]	Style [a]	CFW (Kg)	MFD (μm)	SS (N/Kt) [c]	Style [a]
8	-	-	0.1	-2.8	-7.6	-0.1
8	*2*	-	0.1	-1.7	2.4	-0.2
8	*2*	*5* [b]	0.1	-1.7	2.6	-0.3
20	-	-	0.0	-3.4	-7.2	-0.1
20	*4*	-	-0.1	-2.5	2.1	-0.1
20	*4*	*5* [b]	-0.1	-2.5	2.1	-0.2

[a] Style is assessed on a 1 – 7 scale (best to worst). A change in style of –0.1 units indicates an additional 10% of wool has moved into the next better category.
[b] Objectives that contain style also include the trait as a selection criterion.
[c] SS is staple strength.

In the CSIRO Fine Wool Project, data for a variety of wool quality traits were collected on a large pedigree breeding flock over a 10-year period in the 1990's. The estimates of genetic parameters obtained from this flock have been incorporated in a software package known as SelectGene (Swan *et al*., 2000), which enables prediction of selection responses for objectives with additional wool quality traits. Table 2 shows an example with two base breeding objectives, the first with a moderate emphasis on MFD (8 % price premium) and the second with a high emphasis on MFD (20 % price premium). Under these base breeding objectives, large reductions in MFD are obtained while improving or maintaining CFW. However, there is a large reduction in SS, due to an antagonistic genetic correlation between SS and MFD. This effect can be compensated for, by adding SS as a trait of the breeding objective, with 2 % and 4 % premiums for the 8 and 20 % micron premium objectives respectively. However, the antagonistic correlation means there is also a cost in MFD response.

The need to add Style as an objective trait or selection criterion is not so compelling. Due to the neutral to slightly favourable correlations for Style with MFD and CFW, we see improvements in Style, even when the trait is not included in the breeding program. The improvements are better when style is included, but the changes are not dramatic. Similar conclusions may be drawn for the trait crimp frequency, as discussed by Smith *et al*. (2002) in these proceedings.

NEW AND NOVEL WOOL QUALITY ATTRIBUTES

There is increasing realisation across the wool industry that in order for wool to improve its image as a clean, green product, the use of chemicals as part of the processing and finishing of wool needs to be eliminated. For example, treatment of wool by chlorination and addition of polymers is the current process to reduce the level of felting and resultant shrinkage in garments made from wool. This process damages the fibre, is an additional expense and poses problems in terms of residue disposal. Similarly, there is a challenge for the wool industry to compete more effectively in the development of yarns, fabrics, and garments that have new and novel attributes and can form the basis of a differentiated product.

Kenyon and Wickham (1999) found that yarn shrinkage is related to the diameter of a ball of wool created by scouring and tumbling. Subsequently, Greeff and Schlink (2001) have shown that this feltball diameter is heritable in Merino flocks (0.31) and genetic differences between bloodlines exist. Although the phenotypic variation in their study of medium and strong wool Merinos was small (4.6 %), further studies, particularly in fine wools, are needed to establish whether the development of flocks of extreme felting properties is practical.

As with feltability, natural variation in wool pigmentation, lustre, and crimp frequency also have the potential to be the focus of breeding programs where the objective is to develop flocks that can service the requirements of small niche markets.

Across the globe, the finest sale lots of wool are in the 13 - 14 micron category and the quantity of production is less than 5000 kg clean. Wuliji *et al.* (1995) and Purvis and Swan (2001) have reported selection programs in superfine flocks that aim to reduce the average diameter of the adult animals down towards the diameter of the finest sale lots that are currently produced. In both cases, the projects have strong commitments to forming alliances with downstream processors, a likely minimum requirement for all future projects aimed at producing novel products using wool.

MOLECULAR TECHNOLOGIES

As with most livestock species, there is an increasing body of research activity focussed on developing commercial applications from molecular technologies developed during the last decade. The identification and manipulation of genes of major effect for use in marker-assisted selection (MAS) programs is one focus of many of these research projects. Crawford (2001) has documented the major gene (QTL) detection experiments in sheep that are currently being undertaken around the world and several of the experiments have detection of genes influencing wool quality as a major objective. Wuliji *et al*. (1995) and Henry *et al*. (1998) did not find any QTL in a Merino Romney backcross flock. However, chromosome regions containing putative QTL with effects on wool quality traits have been reported by Ponz *et al.* (2001). These authors utilised segment mapping and identified regions of interest for MFD, CVFD and particularly for SL. A great deal of work and expense remains to either identify the actual genetic polymorphisms having the major effects on these traits, or to develop marker sets that effectively type animals for QTL status.

As indicated earlier, there are several wool quality traits that have attributes for which molecular tools may prove extremely effective in achieving genetic improvement. Several of the fleece faults are either variable in their expression (fleece rot, mycotic dermatitis, flystrike damage, low SS) or are difficult to measure (isolated pigmented fibre), and traits with these features are likely to be improved by MAS programs. However, markers may also be useful for

other wool quality traits such as MFD, SL and CF where an extreme variant is desired to be introduced from another population that has other unattractive attributes. Introgression into medium wool Merino flocks of genes associated with fineness in superfine flocks, whilst minimising the reduction in fleece weight normally associated with such a program, may be assisted by the use of markers associated with QTL for MFD (I. R. Franklin, *pers. comm*.).
Transgenesis also offers significant opportunities, particularly where the goal is to effect relatively dramatic changes to a particular quality attribute. Bawden *et al*. (2000) give an excellent example of how such a technology may be used to dramatically alter wool quality. It remains to develop efficient and repeatable transgenic tools and to develop research programs that have realistic time frames and which include evaluation of new genotypes for the processing sector.

CONCLUSION
Developments in the processing of apparel wool require greater and more targeted specification of raw wool. In addition, breeders and their ram buying clients are continually being challenged with new technologies such as on-farm raw wool measurements, DNA-based parentage testing and marker tests for genes of major effect. The challenge for scientists is to develop the capability to link these technologies together so that they become an integrated system using common technical language and focussed on commercial outcomes. Software packages such as SelectGene allow breeders to make rational decisions about whether or not to introduce a new wool quality trait to their breeding programs. As has been shown in this paper, it is important to include SS in wool breeding objectives, but other quality traits such as Style can be safely omitted.

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