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Author:	Hatcher, S.; Preston, J.W.V.
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Staple strength – What have we learnt from the Sheep CRC's Information Nucleus?

S. Hatcher[A,B] *and J.W.V. Preston*[A,B]

[A]*CRC for Sheep Industry Innovation, Homestead Building, UNE, Armidale N.S.W. 2350*
[B]*NSW DPI, Orange Agricultural Institute, Forest Road ORANGE N.S.W. 2800*
sue.hatcher@dpi.nsw.gov.au

Summary

The measurement of staple strength does not have a single, simple biological basis as it was developed as a physical measure primarily to predict the efficiency of early stage processing. This fact is a likely contributor to the large differences in phenotypic expression of SS both within and between flocks, which in turn makes on-farm management of SS complicated. Genetic improvement of SS can produce long term improvements as the yearling and adult expressions of the trait are both highly heritable and highly genetically correlated. The considerable variation in ASBVs for yearling and adult SS provides an opportunity for commercial sheep producers to identify sires with superior genetics for SS when deciding which rams to purchase for use in their flocks. While a genotype x environment interaction was identified between the IN sites, it is likely to be of little commercial relevance as the correlation between sire EBVs was high. Fibre diameter was the only key wool production and quality trait to have an unfavourable genetic relationship with SS such that selection for increased SS will lead to broader fibre diameter. However, the genetic variation between sires means that there are sires out in industry that combine high ASBVs for SS with low ASBVs for fibre diameter. The coefficient of variation in fibre diameter (CVFD) is an effective alternate selection criteria for SS on a within flock basis when selecting replacement animals to remain in the flock however, more research is required to quantify the value of CVFD for between flock selection.

Introduction

Staple strength (SS) is a physical measurement of a material property. It is the peak force (measured in Newtons, where 1 kg = 9.81N) required to break a staple of a given linear density (measured in kilotex, which is the weight in grams of 1 kilometre of staple):

$$\text{Staple strength (N/ktex)} = \frac{\text{Force (Newtons)}}{\text{Clean weight (g) / Staple length (mm)}}$$

The Automatic Tester of Length and Strength (ATLAS) machine was developed in the early 1980s to provide an objective measure of both the length and strength of sale lots replacing visual appraisal of staple length and the 'flick-test' for SS. Only staples longer than 50mm are measured for SS as 25mm of each staple is held in the tip and base jaws of the ATLAS and cannot be tested and therefore not broken (Australian Wool Testing Authority Ltd 2000). In 1988, the TEAM Project (Trials Evaluating Additional Measurements) established that key early stage processing performance parameters: i. Hauteur or the average fibre length of top; ii. CVH a measure of the variation in hauteur; and iii. Romaine a measure of the efficiency of the topmaking process – which is the proportion of noil, short fibre, generated during topmaking (relative to the total weight of top and noil produced) can be predicted using the staple measurements provided by the ATLAS together with the standard core test results (Anonymous 1988). The use of the TEAM formulae as a benchmark has enabled individual mills to significantly improve their processing performance (TEAM-3 Steering Committee 2004).

Staple length and strength measurements first appeared in wool sale catalogues in the 1985-86 wool selling season (Adams and Kelly 2000) and in 1991 IWTO-30 "*Determination of Staple Length and Strength*" was adopted by the International Wool Textile Organisation (IWTO) as a full test method. This facilitated the calculation of premiums and discounts for staple length and strength based on the auction prices paid for individual sale lots. Given the significant impact of SS on hauteur, CVH and romaine it is not surprising that SS is consistently second only to fibre diameter as a key determinant of the value of raw wool (Australian Wool Innovation and Meat & Livestock Australia 2008). Wool measuring 35N/ktex is considered 'sound' and is used as the benchmark for reporting premiums and discounts for wools of varying SS. The premiums paid for high SS sale lots and the discounts applied to sale lots with low SS are both considerably greater for fine wools compared to medium wools (Figure 1). The range in price paid for wool varying in SS from 14N/ktex to 40N/ktex in fine wool is commonly 250c/kg clean, while the same range in medium wools is 100c/kg clean. Given these clear price signals, it is not surprising that increasing the SS of their wool clip continues to be a major goal for many Australian Merino producers, particularly those producing fine wool.

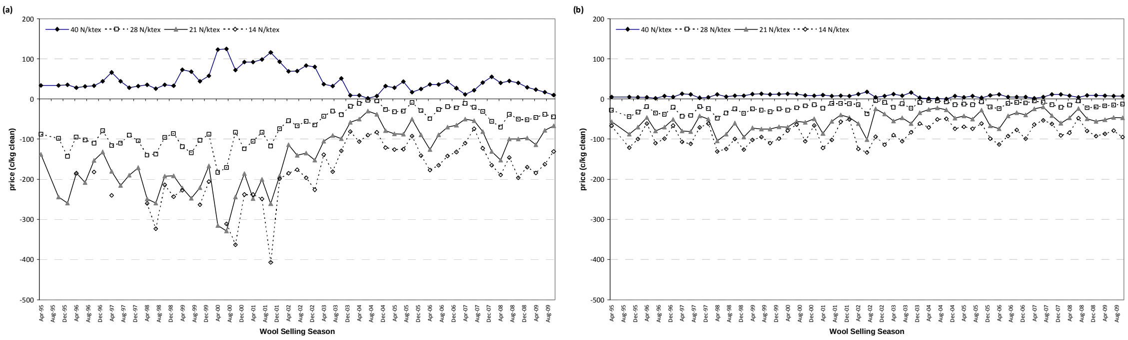

Figure 1. Premiums and discounts (c/kg clean) applied to various staple strength (relative to 35N/ktex) at auction for (a) fine (17.5 – 19.5 µm) and (b) medium (19.5 – 21.5 µm) wool from Apr 1995 to Oct 2009 (Source: http://www.wool.com/Fibre-Selection_Woolcheque_Wool-characteristics_Price-schedules.htm 30Apr13)

SS – a material property not a biological phenomenon

As detailed above, SS measurement was developed to measure a material property and does not directly relate to a single biological phenomenon (Adams *et al.* 2000). For uniform single wool fibres, N/ktex is a measure of the intrinsic strength or tenacity of the fibre because the linear density (weight/length) is an estimate of the fibre's cross-sectional area (Hynd and Schlink 1993). However staples consist of many hundreds of single wool fibres and the measured strength in N/ktex *does not* solely relate to the intrinsic strength of the proteins that make up the fibre. Other key staple components including variation in fibre diameter (FD) along fibres; variation between fibres and follicle shutdown *together* with intrinsic fibre strength reduce SS from a theoretical maximum of 150 – 160 N/ktex (Schlink *et al.* 2000; Thompson and Hynd 2009). While these four biological components interact to influence both the tex component of SS and the force required to break the fibres, it is the impact of these components on the tex of the staple that is the most important factor influencing SS. Intrinsic fibre strength has been shown to play only a minor role in determining the SS of wool staples (Thompson and Hynd 2009), while fibre shedding and follicle shutdown are not usually important contributors to variation between animals or flocks in SS (Adams and Kelly 2000). The tex of a staple and its SS is therefore predominantly influenced by those factors that alter the FD along a wool fibre and variation in FD between fibres comprising the staple. As a result, it is not surprising that the SS of an individual sheep is a complex interaction between the environment in which it lives (including seasonal conditions, the nutritional environment as well as rumen microbial effects), the animal's physiological state, disease status and its genotype (Hynd and Schlink 1993), as each of these factors can have a significant impact on FD both along and between fibres.

Environmental differences in SS

The genetic diversity and geographical location of the 8 flocks that comprise the Cooperative Research Centre for Sheep Industry Innovation's (Sheep CRC) Information Nucleus (IN) provides a current snap shot of variation in SS across Australia. The average SS of the yearling (shorn at approximately 11 months of age) Merino progeny born between 2007 and 2010 was 32.6N/kex while that of the adult animals (shorn at approximately 23 months of age) was 35.0N/ktex. However, there was considerable variation between sites for both yearling and adult SS (Figure 2 a&b).

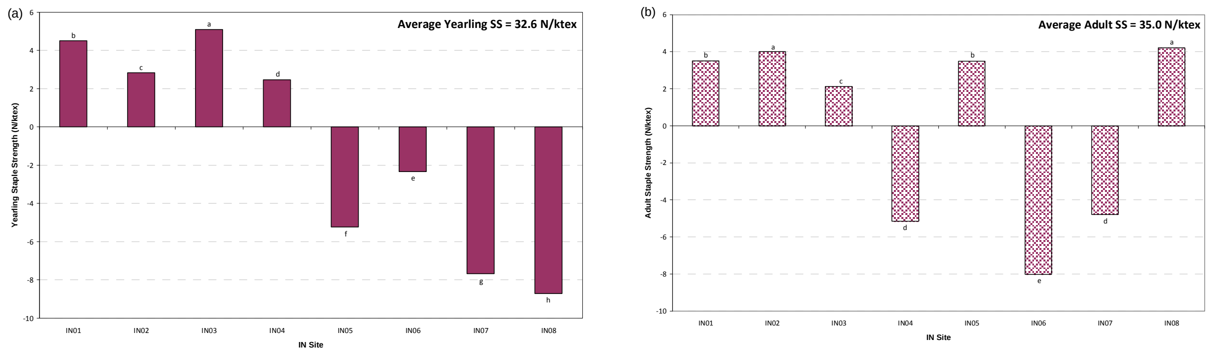

Figure 2. Yearling (a) and adult (b) staple strength of each Sheep CRC IN flock. Data are presented as the deviation from the average yearling (32.6N/ktex) or adult (35.0N/ktex) staple strength

In addition to differences in the environment between the eight IN sites, including rainfall; seasonality of pasture growth; time of shearing relative to the weakest part of the staple; and time of lambing relative to shearing (for the adult ewes), variation in the base ewe population between sites contributed to the significant differences between the sites in SS. For yearling SS each of the sites was different from the others (P<0.001, Figure 2a), IN01 (Kirby), IN02 (Trangie), IN03 (Cowra) and IN04 (Rutherglen) each had above average SS (37.1, 35.4, 37.7 and 35.1 N/ktex respectively) with IN05 (Hamilton), IN06 (Struan), IN07 (Turretfield) IN08 (Katanning) having lower than average SS (27.4, 30.3, 24.9 and 23.0 N/ktex respectively). In general those sites with a Mediterranean climate (i.e. IN06, IN07 & IN08) had the weakest wool (i.e. lowest SS). Interestingly, while the average SS of the adult Merinos was higher than that of the yearlings, the difference was not consistent between flocks (Figure 2b). The variable sensitivity in SS of individual ewes to reproduction (Robertson *et al.* 2000; Thornberry *et al.* 1988), is the most likely explanation for the inconsistency. Variation between IN sites is not likely to be the cause as the time of shearing relative to the time of lambing as shearing at most IN sites occurred within 2 months of lambing, meaning the weakest point was likely to be at either the tip or base of the staple not the midpoint.

There were significant differences between drops in both yearling & adult SS (P<0.001). Note that for the analyses of the IN wool data, drop (i.e. the year an animal was born) is fitted as a fixed effect to separate the different cohorts of IN progeny. Therefore, differences between drops may represent both the environment experienced by the animal's dam during pregnancy and lactation as well as the differences in the wool growing season experiences by the animal itself. For these analyses yearling SS was highest for the cohort of progeny born in 2007 and decreased with each subsequent drop with all drops significantly different from each other (32.1, 30.6, 29.9 and 29.3 N/ktex for 2007, 2008, 2009 and 2010 drop animals respectively). Adult SS was highest for progeny born in 2009 (35.6 N/ktex), followed by 2007 (35.4 N/ktex) and then 2008 (34.6 N/ktex) with all drops again significantly different from each other. There was a highly significant interaction between drop and IN site (P<0.001) for both yearling and SS, which highlights the large influence of the environment on SS. Ewes had lower SS than wethers as yearlings (P = 0.005), but higher SS as adults (P = 0.005). However, the small differences were significant (<0.5N/ktex as yearlings and 1.5 N/ktex as adults). There was no significant difference in either yearling or adult SS due to the MERINOSELECT Wool Type (i.e. ultrafine/superfine, fine/fine-medium or medium/strong), birth rearing rank or age of dam.

The impact of pregnancy status on staple strength

Pregnancy and lactation can have a significant impact on SS with reductions of up to 45% reported for ewes raising twins compared to dry sheep (Thornberry *et al.* 1988). Among all the IN ewes, dry ewes had the highest SS, followed by single bearing ewes, while twin bearing and lambed and lost ewes were not different to each other (P<0.05 Table 1). Lee *et al.* (2003) and Masters and Mata (1998) both reported a similar trend, albeit with larger differences in SS between the various pregnancy status groups. However, when the three MERINOSELECT Wool Types in the IN were analysed separately, the negative impact of reproductive performance on SS was greatest for ultrafine/superfine ewes that conceived and raised twins (Table 1).

Table 1 Deviations from the mean (± s.e.) SS due to reproductive performance of adult Merino ewes from the Sheep CRC's IN

	Mean		Pregnancy Status		
	(N/ktex)	Dry	Single	Twin	Lambed & Lost
All IN ewes	35.0	1.7 ± 0.5 [a]	0.7 ± 0.4 [b]	-0.3 ± 0.6 [c]	-0.4 ± 0.6 [c]
Ultrafine/Superfine	36.1	0.6 ± 1.1 [a]	-0.1 ± 1.0 [a]	-5.0 ± 1.7 [b]	0.5 ± 1.4 [a]
Fine/Fine-Medium	36.0	0.9 ± 0.7 [a]	-0.1 ± 0.6 [b]	1.0 ± 0.9 [a]	-1.3 ± 0.8 [c]
Medium Strong	34.2	2.2 ± 0.9 [a]	1.2 ± 0.8 [b]	-0.7 ± 1.0 [c]	-1.0 ± 1.1 [c]

Managing the environmental differences in SS

On farm management of staple strength was the focus of much work in the late 1990s with the CRC for Premium Quality Wool developing strategies to manage the FD profile (Figure 3) to produce wool fibres that were more uniform in diameter along their length and higher SS (Peterson *et al.* 2000).

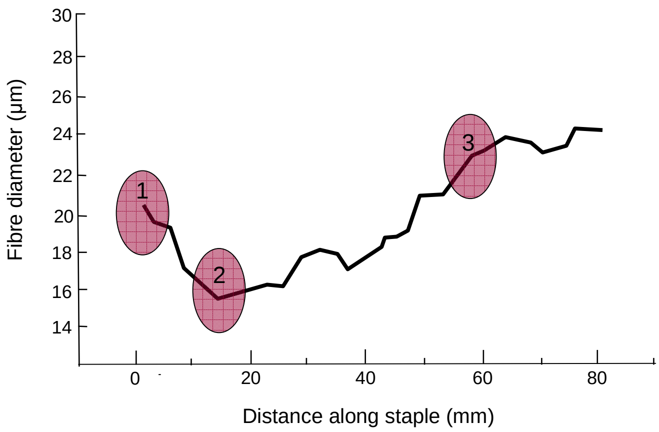

Figure 3. Staple fibre diameter profile of a spring-shorn hogget from south-western Australia. The circles denote regions in the profile that may be altered by specific management. Source: Peterson *et al.* (2000)

One of the main findings from that body of work was that liveweight can be used as a proxy for changes in the FD profile, therefore minimising liveweight variation over a full year should reduce variability in wool growth, FD variability and hence SS (Peterson *et al.* 2000). The key windows for managing SS were to increase the initial liveweight (Figure 3, circle 1) or minimise the decline in liveweight over summer-autumn (Figure 3, circle 2) using targeted supplementary feeding or grazing management specifically to control intake on green feed to limit FD increases after the break of the season (Figure 3, circle 3) (Peterson *et al.* 2000). However, these strategies are not always effective with results varying between autumn and spring shorn wools, the age of the animal, sex and pregnancy status (Peterson *et al.* 2000). Furthermore, some of these strategies may compromise fleece value through higher FD from increasing the minimum FD, decreasing clean fleece weight per head through increasing stocking rate to limit intake of green feed or negatively impact on the performance of breeding ewes by restricting liveweight gain during pregnancy. Therefore, any management strategy to increase SS must be both carefully considered and executed. Moving lambing or shearing times can lead to significant increases in SS but can also have negative consequences. Moving lambing later in the year can lower weaning weights as weaning will occur when pasture quality and quantity are in decline which can compromise weaner survival, while changing the time of shearing has the potential to increase vegetable matter content (Peterson *et al.* 2000).

The genetics of staple strength

Given the large impact of the environment and the variable responses to on-farm strategies to manage SS, genetic improvement of the trait becomes an important approach to produce long term improvements in SS. The rate of genetic improvement possible for a particular trait is a combination of:

i. the heritability;
ii. the variability; and
iii. the ability to reliably quantify the genetic differences between sheep.

Heritability, variability and reliably selecting superior sires for high SS

The heritability of yearling SS was 0.33 while that of adult SS was 0.36 (Table 2), both would be classified as highly heritable traits (i.e. >0.3). The CV of yearling and adult SS were 28.4 and 26.5% respectively. Both the heritability and CV of SS estimated from the IN are similar to the average heritability of 0.34 with a CV of 29.2% reported by Safari *et al.* (2005). This indicates that SS will respond to selection and the variation between animals will increase the rate of genetic improvement.

Table 2 The average, CV and heritability of yearling and adult SS from the Sheep CRC IN

	Average (N/ktex)	CV (%)	Heritability
Yearling SS	32.6	28.4	0.33 ± 0.06
Adult SS	35.0	26.5	0.36 ± 0.06

With respect to reliably quantifying the genetic differences between sheep, there is considerable variation in ASBVs for SS among the sires used in the IN (Figure 4). The average ASBV for yearling SS was -0.2, however there was a range of 18.6N/ktex between the highest and lowest ASBV (-11.1 to 7.5 N/ktex). The range in ASBVs for adult SS was slightly greater, being 20.09 (-9.53 to 10.56 N/ktex). The current range of SS ASBVs in MERINOSELECT is 25.3 N/ktex [1]. ASBVs therefore, provide a reliable means of ranking sires based on SS and can be used to identify sires with superior genes for SS when making ram purchasing decisions.

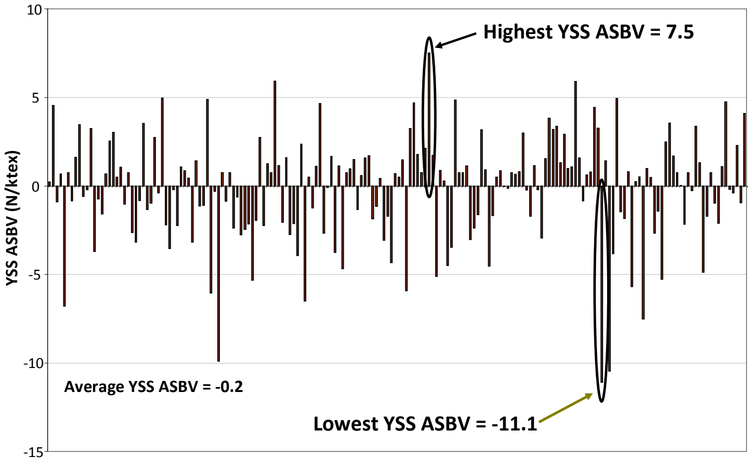

Figure 4. There was an 18.6N/ktex range between sires used in the IN for yearling SS

What about genotype x environment interactions?

The presence of a genotype x environment interaction (GxE) can change the ranking of a sire from one environment to another. Therefore, selection of a sire based on his progeny's performance in one environment may not translate into superior performance in a different environment. Within the IN there was evidence of a GxE for both yearling and adult SS. A sire x flock effect included in the modelling of these two traits accounted for 2.8% and 3.7% respectively of the phenotypic variation. Dominik *et al.* (1999) identified a GxE for SS between 2 management groups (that mimicked typical 'stud' and 'commercial' nutritional management levels) but concluded that it was not likely to be of

[1] Sheep Genetics ASBV and Index Percentile Band Table Run date 21-Jan-13

practical significance as the genetic correlation between the two environments was greater than 0.8 (correlations below 0.8 indicate the presence of a GxE of agricultural importance (Robertson 1959). To examine this we compared the performance of sires at Armidale (IN01) and Katanning (IN08) as these sites had the most diverse environments and all IN sires were used at each. For both yearling and adult SS, the correlation between sire EBVs in both environments was greater than 0.8 (Figure 5a&b) indicating that, while present, the GxE for SS is likely to be of little commercial relevance.

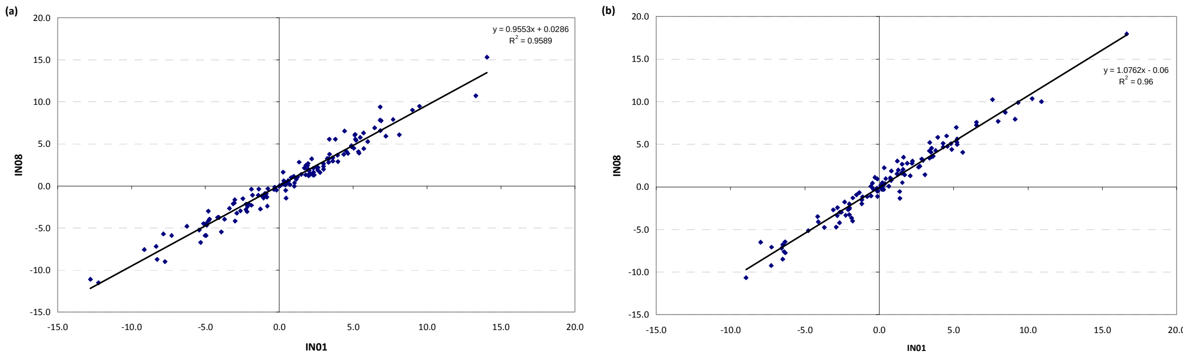

Figure 5. The correlation between IN sire ebvs at Armidale (IN01) and Katanning (IN08) were greater than 0.8 for both yearling (a) and adult (b) SS indicating a GxE of little commercial relevance

When is the time to select sires?

Within the IN, the genetic correlation between yearling and adult SS was high (0.85) indicating that the SS of wool grown at the yearling and adult stages are affected by the same genes. This means that selection for SS at the yearling age is highly genetically correlated with stronger staples as adults and yearling rams will retain that superiority as they get older.

What about genetic relationships with other wool production and quality traits?

SS is only one of a range of wool quality traits that impact on the price paid for wool, so selection decisions must be made on the range of traits that impact on enterprise profitability. It is therefore, important to take into account the genetic relationships with other traits including liveweight, wool production and both visual and measured wool quality. The genetic correlation between YSS and YFD was low (0.27), that between YSS and AFD negligible (0.16) but those between YFD and YSS (0.46) and AFD and ASS (0.43) were both moderate. These estimates are similar to those reported by (Safari *et al.* 2005) and are indicative of a unfavourable genetic relationship between SS and FD such that *genetic selection for increased staple strength will lead to broader fibre diameter*. The plot of the IN sires ASBVs for YSS and YFD provides a graphical representation of this genetic relationship, with the trend line clearly showing that *on average* sires with higher ASBVs for YSS will also have broader than average ASBVs for fibre diameter (Figure 6). However, the genetic variation occurring between sheep can be used to identify and select sires that ‘buck’ this trend, there are sires in the top left hand corner of the chart that combine high ASBVs for SS with low ASBVs for FD, that is their progeny grow fine fleeces with high SS.

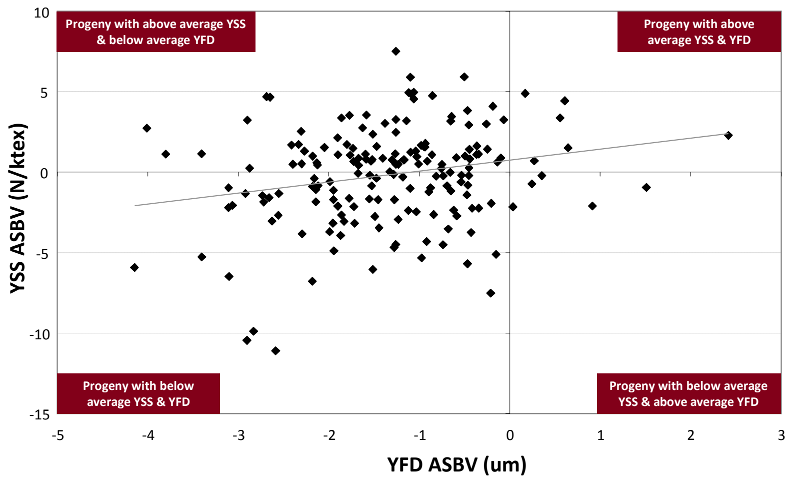

Figure 6. Although the genetic relationship between SS and FD is unfavourable, there are sires in industry that have the genes for fine fleeces with high SS

With the exception of FD and resistance to compression (RTOC), all of the significant genetic correlations between SS and other wool production and quality traits are favourable (Table 3). Selection for increased SS will generate:

i. little to no correlated improvements in greasy wool colour (i.e. whiter wool) and staple structure (i.e. finer staple bundles), off-shears liveweight, GFW, SL or Y-Z (i.e. clean colour);
ii. small improvements in fleece rot (i.e. decreased incidence of bacterial staining), character (i.e. better defined and more regular crimp frequency), dust (i.e. less penetration of dust into the staple), yield. CFW, FDSD and Y (i.e. brightness);
iii. moderate improvements in weathering (i.e. less visible weathering at the tip of the staple and deterioration of fibre structure) and the incidence of midbreaks; and
iv. large correlated improvements in CVFD.
v.

As discussed above, selection for increased SS will generate correlated increases in both FD and RTOC. This indicates that fleeces will become broader with increased compressional harshness which while good for upholstery and carpet end-uses is not suitable for next-to skin apparel.

Table 3 Genetic correlations* between SS, visual wool quality traits, off-shears liveweight & wool production and measured wool quality traits

Visual Wool Quality Scores	YSS	ASS	Liveweight & wool production	YSS	ASS	Measured wool quality	YSS	ASS
Colour	*-0.12*	*-0.11*	OSLWT	*-0.01*	*0.06*	FD	0.27	**0.46**
Character	-0.32✓	*-0.10*	GFW	*0.07*	*0.00*	FDSD	-0.34✓	-0.26
Dust	-0.39✓	*-0.15*	Yield	0.40✓	0.32✓	CVFD	**-0.62✓**	**-0.64✓**
Weathering	**-0.54✓**	**-0.43✓**	CFW	0.23✓	*0.11*	Curve	*0.11*	0.22✓
Fleece rot	-0.28✓	-0.24✓				RTOC	*0.13*	0.27
Staple structure	*-0.09*	*0.12*				SL	*0.10*	*0.05*
Handle	-0.31✓	*0.03*				MID	-0.23✓	**-0.44✓**
						Y	0.32✓	*0.18*
						Y-Z	*0.03*	*0.10*

* Negligible correlations (i.e. <0.2) are in *italics* text, low correlations (i.e. 0.2 – 0.4) are in normal text, medium correlations (i.e. 0.4 -0.6) are in bold text and high correlations (i.e. >0.6) are shaded. ✓ indicates a favourable genetic relationship.

It is important to note that breeding objectives that aim to improve the various visual wool quality traits, liveweight, wool production, fibre curvature, midbreaks and brightness will produce correlated increases in SS although of a relatively low magnitude. However, the high unfavourable genetic correlation between FD and SS means that breeding objectives that aim to reduce FD will lead to lower staple strength unless some selection pressure is placed on SS. For this reason it is recommended that commercial producers aiming to reduce the fibre diameter of their wool clip make ram purchase decisions based on an index that includes SS, such as the MERINOSELECT Fibre Production+ (FP+) index for predominantly wool production enterprises or Merino Production+ (MP+) index for enterprises with significant surplus sheep sales. After 10 years the use of these indexes can generate +2.8% fleece weight (FW), +1.1 kg liveweight (LWT), -1.3 um in FD and +4.6N/ktex in SS and +4.3% FW, +5.0 kg (LWT), -0.7 um in FD and +3.0N/ktex in SS for the FP+ and MP+ indexes respectively[2].

Selecting replacement ewes and wethers to retain in the flock

For commercial producers, genetic information is not readily available to assist with selecting replacement ewes and wethers to retain in the breeding flock or wool growing enterprise. ASBVs are not available for commercial ewes and the relatively high cost of SS measurement, currently $11.66 when done in conjunction with a yield test[3], means that it is necessary to identify replacement animals on the basis of a cheaper effective alternative selection criterion. When selecting replacement sheep from within the cohort of young animals born into the flock (i.e. within flock selection), it is necessary to consider the phenotypic correlations between SS and other wool production and quality traits as they are an indication of the relationships between traits in the current generation of animals.

Within the IN, all of the phenotypic correlations with SS, with the exception of FD, FDSD and CVFD, were negligible (i.e. >0.20) (Table 4). CVFD had the strongest favourable phenotypic correlation (-0.40 and -0.34 for yearling and adult SS respectively), which indicates that within the current generation of a flock, those animals with lower CVFD will have higher SS. This means that CVFD, which received as part of the standard FD measurement, is the best trait to use as an alternative selection criteria for SS. The phenotypic correlations estimated in the IN agree with previous work (Swan *et al.* 2008; Greeff 1999). However, it must be noted that there is currently some conjecture within the industry about the value of using CVFD as an alternative selection criteria for SS across flocks as the relationship between CVFD and SS varies between bloodlines (Adams and Briegel 1998). Further analyses are currently underway to increase our understanding of within and between flock variation in CVFD and it relationship with SS.

Table 4 Phenotypic correlations* between SS, visual wool quality traits, off-shears liveweight & wool production and measured wool quality traits

Visual Wool Quality Scores	YSS	ASS	Liveweight & wool production	YSS	ASS	Measured wool quality	YSS	ASS
Colour	*-0.05*	*-0.05*	OSLWT	*0.06*	*0.05*	FD	0.22	0.25
Character	*-0.08*	*-0.03*	GFW	*0.11*	*0.01*	FDSD	-0.26✓	*-0.18*
Dust	*-0.10*	*0.00*	Yield	*0.18*	*0.15*	CVFD	-0.40✓	-0.34✓
Weathering	*-0.07*	*-0.05*	CFW	*0.17*	*0.07*	Curve	*0.03*	*0.06*
Fleece rot	*-0.06*	*-0.07*				RTOC	*0.07*	*0.09*
Staple structure	*-0.03*	*0.05*				SL	*0.02*	*0.10*
Handle						MID	*-0.08*	*-0.11*
						Y	*0.13*	*0.05*
						Y-Z	*0.02*	*0.03*

* Negligible correlations (i.e. <0.2) are in *italics* text, low correlations (i.e. 0.2 – 0.4) are in normal text, medium correlations (i.e. 0.4 -0.6) are in bold text and high correlations (i.e. >0.6) are shaded. ✓ indicates a favourable phenotypic relationship.

2 www.sheepgenetics.org.au/Getting-started/ASBVs-and-Indexes/MERINOSELECT-Indexes. Accessed 09May2013.
3 AWTA Raw Wool Testing Fees 2012/13

Is staple strength an indicator of 'robustness' or 'resilience'?

Thompson *et al.* (2006) reported that selection for SS resulted in a 30% difference in lamb mortality among flocks. Their study compared various biochemical profiles of neonatal lambs born in a flock selected for high SS (SS+) with those born lambs in a flock selected for low SS (SS-). SS+ lambs appeared to mature more rapidly, had a shorter gestation and were better able to adapt from foetal to postnatal metabolism (Thompson *et al.* 2006). An initial analysis of the genetic relationships between wool production and quality and lamb survival in the IN identified low positive genetic correlations between both yearling and adult SS and lamb survival. This indicates that selection for higher SS will lead to correlated increases in lamb survival – however, further work is required to quantify the magnitude of the response. There were also moderate to high negative genetic correlations between CVFD and lamb survival, particularly survival at birth, indicating the selection for low CVFD will lead to correlated increases in lamb survival. These findings make it reasonable to hypothesise that ewes with less variation in CVFD may be more robust or resilient and are better able to cope with variable feed availability during the reproductive cycle and may prove to have superior lifetime productivity. Further research is required in this area.

Conclusions

SS is a measurement of a material property and unlike other wool production and quality traits has no single, simple biological basis. This contributes to the large differences in phenotypic expression of the trait which makes on-farm management to improve SS problematic. Therefore genetic improvement of SS is an important means to produce long-term improvements in SS. For commercial producers, selection of sires using an index that includes SS can generate simultaneous decreases in FD and improvements in SS and overcome the high unfavourable genetic correlation between these two traits. CVFD can be reliably used as an alternative selection criterion for SS when selecting replacement animals to enter either the breeding flock or wool growing mob in a self-replacing Merino enterprise, however more research is required to quantify the value of CVFD for between flock selection.

Acknowledgements

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