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Variation of wool between and across the fleeces of composite-breed strong-wool sheep in New Zealand

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ABSTRACT

Many farmers in New Zealand have moved towards using composite-breed sheep flocks to increase the meat production and fecundity of their stock. We aimed to determine whether flocks with a wider genetic base had greater between and within-fleece variation than single-breed flocks. Wool from seventeen body sites of sheep from five flocks of diverse genetic background (Romney, Coopworth, and crosses with Texel, Finnish Landrace and East Friesian breed lines) were compared. Both mean fibre diameter and mean fibre curvature differed between flocks ($P < 0.001$), and across the body ($P < 0.01$). While fibre diameter was more consistent, fibre curvature was more variable across the finer fleeces of flocks with some Finnish Landrace influence. Wool was shorter in Texel crosses, resulting in more consistent length across body sites. Our data suggests that composite-breed sheep exhibit increased within-fleece variation of some wool traits and decreased variation of others. Of most significance was that the extent of wool variation across body sites varied considerably between sheep, regardless of their genotype. In general, there was little association between wool traits with respect to this across-fleece uniformity. Fleece uniformity can be assessed by sampling across the anterior-posterior axis. Selection of stock with more uniform fleeces for specific traits may aid the production of wool better specified to satisfy differentiated niche markets.

Keywords: topobiology; staple length; fibre diameter; curvature.

INTRODUCTION

The intrinsic properties of wool are defined by the breed choices of the wool producer. As such, the New Zealand wool clip has changed due to increased emphasis on meat production. To achieve the goals of higher fecundity and increased lamb carcass weights, many New Zealand farmers have moved towards using composite-breed sheep flocks. As production costs have increased at a faster rate than farm prices for lamb and wool, sheep producers have been forced to improve animal efficiency to remain profitable. As 85% of on-farm profit has been obtained from carcass production rather than harvested wool (Meat and Wool New Zealand Economic Service, 2006), farming practices and stock selection have aligned to meat production. The importance of Finnish Landrace (Finn) in increasing reproductive rate, East Friesian (EF) in increasing milk yield and the Texel and Suffolk breeds in increasing lean muscle growth have all been acknowledged worldwide (Rasali *et al.*, 2006). These breeds have been deliberately incorporated into both dual purpose and terminal sire flocks in New Zealand. These recent trends in sheep production have been associated with changes in the wool clip with decreased fleece weights, increased black fibre content and with shearing policies based on efficient meat production rather than wool quality.

We hypothesised that in addition to increased variation between sheep within these composite-breed flocks, greater within-fleece variation may also occur as genetic diversity increased. We undertook this study to determine whether flocks with a wider genetic base had greater between and across-fleece variation than traditional single-breed flocks. Here, we compare wool characters in five flocks of differing genetic composition from within the Waikato region. The ultimate aim of these studies is to develop protocols enabling identification and production of wools that could target markets requiring a uniform raw product, and more precise specification. To assess uniformity within a fleece with respect to these characters we have measured fibre diameter and its variation between fibres both within and along the staple, and between staples from seventeen body sites across the animal. Variation across body sites is referred to in this paper as across-fleece variation to distinguish it from within-fleece variation which also includes the variation between and within fibres, within a staple. Similarly mean fibre diameter and mean fibre are together an indicator of wool bulk (Edmonds & Sumner, 1996), which was estimated both within and between body sites. Finally, we have devised a protocol for efficiently assessing fleece uniformity. This may prove a useful tool for selection of breeding stock.

TABLE 1: Flocks characterised within this study.

Flock	Proportion	Location	Number of sheep sampled
Romney	1	Ruakura	25
Coopworth	1	Whatawhata	25
RxT	1 : 1	Whatawhata	20
RxTxF	2 : 1 : 1	Whatawhata	25
CxTxFxEF	6 : 2 : 1 : 1	Whitehall	25

TABLE 2: Comparison in wool characteristics of five sheep flocks. The mean data ± standard error of mean between sheep within each flock for wool from 17 body sites of each sheep was included in the analyses. SD = Standard deviation, R = Romney, T = Texel, C = Coopworth, F = Finn, EF = East Friesian, LSD = Least significant difference at P = 0.05.

Genotype	Mean fibre diameter (μm)	Between fibre diameter SD (μm)	Within-fibre diameter SD (μm)	Staple length growth rate (mm/d)	Mean fibre curvature (°/mm)	Fibre curvature SD (°/mm)
Romney	35.9 ± 0.7	8.67 ± 0.2	1.87 ± 0.09	0.32 ± 0.01	33.8 ± 1.3	28.9 ± 1.0
Coopworth	37.1 ± 0.7	8.90 ± 0.2	1.55 ± 0.09	0.30 ± 0.01	25.5 ± 1.3	23.4 ± 1.0
RxT	34.7 ± 0.7	8.01 ± 0.2	1.22 ± 0.09	0.32 ± 0.01	31.3 ± 1.3	26.7 ± 1.0
RxTxF	32.8 ± 0.7	7.35 ± 0.2	1.22 ± 0.11	0.28 ± 0.01	35.9 ± 1.4	30.4 ± 1.1
CxTxFxEF	31.7 ± 0.7	7.31 ± 0.2	1.42 ± 0.09	0.26 ± 0.01	43.3 ± 1.3	34.9 ± 1.0
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
LSD	1.8	0.55	0.27	0.02	3.57	2.74

TABLE 3: Comparison of the variation in wool characteristics across 17 body sites. The mean data ± standard error of mean between sheep within each flock for wool from 17 body sites of each sheep was included in the analyses. SD = Standard deviation, R = Romney, T = Texel, C = Coopworth, F = Finn, EF = East Friesian, LSD = Least significant difference at P = 0.05.

Genotype	Mean fibre diameter (μm)	Between fibre diameter SD (μm)	Within-fibre diameter SD (μm)	Staple length growth rate (mm/d)	Mean fibre curvature (°/mm)	Fibre curvature SD (°/mm)
Romney	2.4 ± 0.1	1.01 ± 0.06	0.48 ± 0.03	0.039 ± 0.002	4.3 ± 0.4	3.6 ± 0.2
Coopworth	2.9 ± 0.1	1.27 ± 0.06	0.58 ± 0.03	0.047 ± 0.002	4.9 ± 0.4	4.0 ± 0.2
RxT	2.9 ± 0.1	1.10 ± 0.06	0.40 ± 0.03	0.043 ± 0.002	5.2 ± 0.4	4.1 ± 0.2
RxTxF	2.7 ± 0.1	0.97 ± 0.06	0.40 ± 0.04	0.039 ± 0.003	6.4 ± 0.4	4.5 ± 0.3
CxTxFxEF	2.7 ± 0.1	1.10 ± 0.07	0.50 ± 0.03	0.033 ± 0.002	6.5 ± 0.4	5.0 ± 0.2
P value	0.1	0.003	0.001	0.001	<0.001	0.002
LSD	0.4	0.16	0.09	0.01	1.0	0.7

TABLE 4: Relationship between across-fleece variations of wool traits expressed as the proportion of the variation explained by the regression (R^2) when across-fleece variations in each trait (standard deviation from 15 body sites across 120 fleeces) were plotted against each other trait. Belly and breech sites excluded. SD = Standard deviation.

Characteristic	Mean fibre diameter (μm)	Between fibre diameter SD (μm)	Within-fibre diameter SD (μm)	Staple length growth rate (mm/d)	Mean fibre curvature (°/mm)	Fibre curvature SD (°/mm)
Mean fibre diameter (μm)	1					
Between fibre diameter SD (μm)	0.4	1				
Within-fibre diameter SD (μm)	0.03	0.13	1			
Staple length growth rate (mm/d)	0.02	0.09	0.08	1		
Mean fibre curvature (°/mm)	0.16	0.06	0.001	0.001	1	
Fibre curvature SD (°/mm)	0.12	0.07	0.006	0.001	0.88	1

MATERIALS AND METHODS

Animals and sampling

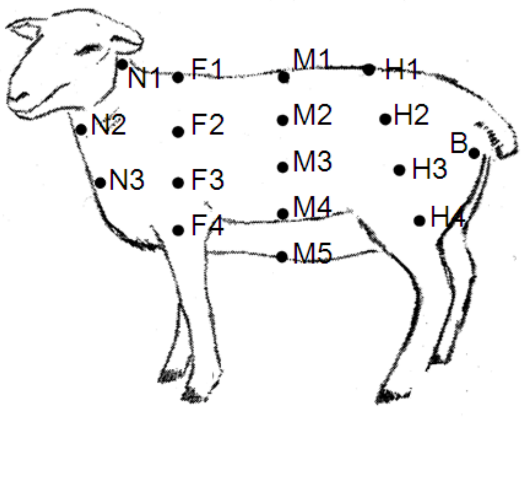
All animal experimental procedures were authorised by the AgResearch Ruakura Animal Ethics Committee. Wool was harvested from seventeen body sites of sheep from traditional dual purpose flocks (Romney and Coopworth), and three composite-breed flocks including Romney x Texel (RxT), a three way cross with Romney x Texel x Finn (RxTxF) and a four way cross with Coopworth x Texel x Finn x East Friesian (CxTxFxEF) (Table 1). Although care must be taken when directly comparing wool from sheep grazed under differing management and environments most analysis concerns growth within each fleece. While the Romney and CxTxFxEF flocks were farmed separately the Coopworth, RxT and RxTxF were grazed together as one mob.

In September 2008, full length fleece wool was removed from seventeen body sites (8 x 8 cm patches) on each sheep (Figure 1). An electric shearing handpiece fitted with a standard blades (Super Pacer comb and AAA cutter blade; Sunbeam Oster Stewart; Jarden Corporation, USA) was used. Mean fibre diameter (MFD), fibre diameter standard deviation (FDSD), staple length (adjusted to duration of growth), mean fibre curvature (MFC) and fibre curvature standard deviation (FCSD) were then assessed on one staple from each body site of each sheep by OFDA 2000 (SGS, Timaru).

Statistical analyses

For each wool trait, the differences between flocks and between body sites were assessed by analysis of variance. Overall mean values and standard error of the mean are reported. To identify two sites that best reflect across-fleece uniformity, we calculated the standard deviation (SD) across 15 body sites. The belly and breech were discarded as these parts of the fleece are usually separated from the body wool following crutching or shearing. For each combination of two sites the absolute difference was standardised by dividing it by the SD for each animal, and then subtracted from the square root of 2. The square of these differences was then summed for all animals. This calculation was performed for each trait. Optimal sampling sites contain low values for all traits and therefore represent sites that most closely describe the variation of multiple wool traits. These calculations were also compared to the average of the standardised deviations. These values would be about the square root of two (1.41) if the SD for any pair of sites approximates the SD for all fifteen body sites.

FIGURE 1: Sites on the body from wool was sampled comprising the Neck (N1; diagonally downward behind the ear; N2 throat covering jugular; N3 sternum); three dorso-ventral lines (spanning the Fore-leg (from the wither to fore-leg (F1 to F4)); Mid back to mid belly (M1 to M5); and Hind leg (from the rump to the hip (H1 H4)) and the Breech (5 cm laterally from the anus (B)).



RESULTS

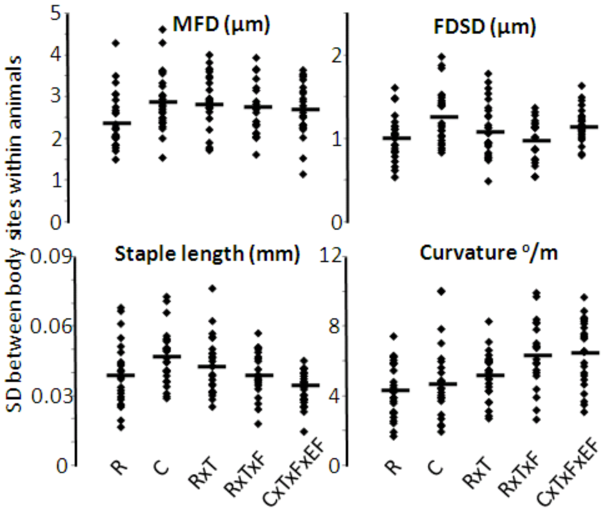
Wool variation between flocks

Differences between flocks were observed in all wool characters measured (Table 2). The coarsest wool was obtained from the Coopworth (37µm) and Romney (36 µm), while the composite flocks had finer wool (RxT, 34.7 µm; RxTxF, 32.8 µm; CxTxFxEF, 31.7 µm; $P < 0.01$). The variation between fibres within a staple followed a similar trend with lower coefficients of variation in the composite flocks with the finer wool (RxTxF and CxTxFxEF; $P < 0.05$) than in the Romney or Coopworth flocks. Diameter variation along fibres was greatest in Romney (SD = 1.9 µm) then Coopworth (SD = 1.6 µm) than in RxT and RxTxF (both SD = 1.2 µm). Staple length growth rate was greatest in Romney and RxT (0.32 mm/d) and least in RxTxF and CxTxFxEF (0.28 mm and 0.26 mm/d respectively; $P < 0.01$).

Wool variation across the body

The mean variation across the fleeces from each flock is presented in Table 3 as the flock mean and standard deviation of the body-site SD’s. Fibre diameter varied across the body of the sheep with an anterior-posterior and a dorso-ventral gradient present. These site-specific patterns in mean fibre diameter were generally similar in sheep of each flock. However, the within-staple FDSD across the fleece differed between flocks, with most uniformity in Romney and least in the Coopworth and CxTxFxEF (Coopworth based flocks; $P = 0.001$). Variations in diameter along the fibre also varied between flocks in a similar manner ($P < 0.001$) also with least variation on the neck. Staple length growth rate varied between body sites of each flock differently ($P < 0.001$) with most variation in Coopworth, and least in CxTxFxEF. Composite

FIGURE 2: Across-fleece variability of wool between sheep expressed as standard deviations of traits measured in Romney (R), Coopworth (C), and three composite flocks including Texel (T) Finnish Landrace (F) and East Friesian (EF) breed lines. The standard deviaiton of 15 sites across the fleece is shown for each sheep in each flock for four wool traits. The bars indicate within-flock means.



flocks RxTxF and CxTxFxEF had greater variation in MFC both between body sites (P <0.001), and within staples of different body sites (P <0.001) than their base breeds Romney and Coopworth.

Wool variation across the body within flocks

The magnitude of the across-fleece variation differed greatly between sheep of all flocks (Figure 2). For each wool trait, some individuals within each flock grew relatively uniform fleeces, while others were considerably more variable. However, with the exception of within-staple MFC and FCSD (R^2 = 0.88), and MFD and FDSD (R^2=0.40), there was little association between traits with respect to this across-fleece uniformity (Table 4). In order to assess fleece uniformity in the future we identified pairs of sampling sites that most efficiently reflect across-fleece variation in each trait. While some wool traits trended dorso-ventrally from site F1 to site H4 (MFD, FDSD) others trended ventro-dorsally from site F4 to site H1 (MFC, staple length growth rate). As a compromise, the ratio between wool harvested from F3 and H3 sites was identified as an optimal predictor of across-fleece variation in these multiple wool traits. Comparison of wool from these sites most accurately reflects the extent of uniformity within the entire fleece and sampling from these regions may be performed rather than the extensive regime undertaken in this study.

DISCUSSION

New Zealand farmers in general have little knowledge or control over what their wool will be used for. Nevertheless their choice in breeding stock defines the type of wool that enters the marketplace. The wider use of composite breed flocks has increased in recent years, coinciding with changes in the national wool clip (Meat and Wool New Zealand Economic Service, 2006). Containing a wider pool of genetic material these composite breeds could be selectively breed to optimise wool types for specific end-uses, as well as improved farm management systems (Scobie, 2008). As differentiated markets evolve under current wool industry restructuring initiatives, breeders and wool producers could target end uses of their wool and capitalise on particular niche markets (McDermott *et al*., 2006). By linking wool production to end users, growers could align more closely to processors and thus gain premiums for hitting targets in a vertically integrated supply chain. Value for the wool grower could be created, while efficiencies for the manufacturer are increased. In this way, the demand for New Zealand wool could be raised by offering a range of superior products, with more efficient on-farm production.

The owner of flock CxTxFxEF is already gaining these niche market premiums by farming his stock organically, and marketing his meat through a direct supply agreement with a specialty meat processor targeting the end-product directly to the restaurant trade. In parallel, wool is targeted to also capitalise on its organic status to supply a niche market. With higher fibre curvature and finer fibre diameter, his wool clip has shifted from the base breed (Coopworth) enhancing its suitability for the handcraft market.

This study compared composite-breed flocks based on two common New Zealand strong-wool breeds of Romney and Coopworth. Coopworths had the greatest mean fibre diameter and the lowest mean fibre curvature, while the Romneys had the second coarsest wool. The composite-breed flocks were produced and farmed for commercial purposes under normal farm management on challenging hill country environments within the Waikato region. Flocks which included the Finn breed had finer fibre, increased uniformity between sheep, within staple, along fibres and less variation along the staple; with a limited effect on fibre curvature. Composites containing Texel genes had finer fibre diameter, within- and between-staple variation. Use of the Texel genotype tended to decrease staple length growth, and increase fibre curvature.

While many wool grower's primary breeding interest has been to 'select for vigour, resistance to parasites, fertility and the ability to lamb without assistance then feed the lambs well' (Michael

Oliver, Personal communication), the introduction of alternative breeds has also resulted in finer and bulkier wool. Our data suggests that some combinations of sheep breeds show increased within-fleece variation of some wool traits, such as mean fibre curvature, and decreased variation of others, such as uniformity of fibre diameter within individual staples. This illustrates that not only do traits vary across the fleece, but also that the degree of variation differs between flocks. Of most significance, however, is the difference in the extent of fleece variability between individual sheep within each flock. While some sheep exhibit considerable differences in wool growth, such as a two-fold variation in staple length across the fleece, others exhibit a near consistent length growth. Thus, our results support the previously accepted notion that the variation in wool types grown by individuals within a breed is greater than the variation between breeds. Selection of stock with more uniform fleeces may aid the production of wool better specified to satisfy differentiated markets requiring a uniform raw product.

These niche production goals are potentially achievable for wool without compromising meat production, by using genetic marker selection technology. Selection for stud stock is still largely carried out ‘by eye’, however a panel of genetic markers for wool traits might enable more rapid specialisation of wool types and could be used in conjunction with markers for other production traits. After the necessary research and development whole genome profiling technology may provide an integrated approach to improving wool quality in the future (McEwan, 2007).

It is somewhat surprising that across-fleece uniformity is so variable between individuals within a flock, and suggests it has not been subjected to selection pressure. Positive fleece selection pressures, if any in recent times, have likely been based on midside samples, but poor fibre quality on some regions such as the hip or belly, may confer a negative influence. In addition, longer or finer wool in anterior regions may have been welcomed as contributing to a finer fleece and increased total fleece weight while at the same time increasing across-fleece variation.

In this paper we have described the variation in wool traits across 15 body sites. While previous studies have described topographic patterns of wool growth (Craven *et al*., 2007; Craven *et al*., 2008; Sumner & Craven, 2000; Sumner & Revfeim, 1973; Young & Chapman, 1958), this is the first study to describe the variations in those patterns between flocks and within individuals. While patterns across the body differ for each trait, statistical analysis revealed that comparison of two sites lying at the middle of the anterior-posterior axis of the sheep at sites F3 and H3, reflect the across-fleece variation for important traits including fibre diameter, staple length and fibre curvature. This sampling method will allow efficient characterisation of fleece uniformity in the future. Fitting well with the developmental biology of pattern formation in mammalian skin (Widelitz *et. al.*, 2006), these sampling sites are reasonably likely to be applicable for other wool traits beyond those described here. The determination of heritability values for each wool trait will indicate the rate at which genetic improvement in fleece uniformity can be made (Morris *et al*., 1996).

While modern composite-breed sheep in New Zealand are bred predominantly for meat production they remain dual-purpose sheep. Our findings suggest that, at least in some instances, some co-incidental improvements in commercially relevant wool traits have occurred. These include finer and bulkier fleeces in flocks influenced by the Texel and Finn. However the fleece uniformity varies between animals, regardless of breed. Thus, variation among sheep within each flock precludes harvesting of wool with uniform quality. Strategies could be developed to further improve the intrinsic properties of the wool which affect post-farm suitability, processing efficiency, and manufacturing performance.

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