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Effect of divergent selection for wool bulk on live weight and wool characteristics in Perendale sheep

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ABSTRACT

A sixteen year selection trial in a flock of Perendale sheep selected for either increased (H line) or decreased (L line) wool bulk at yearling (hogget) shearing, was undertaken at Whatawhata, and later Winchmore Research Stations. A total of 2,620 progeny sired by 172 rams joined in single sire matings were measured, with data from an additional 664 fleeces providing direct information on base flock characteristics. A restricted maximum likelihood (REML) animal model adjusting for fixed effects of year, sex, birth date and birth/weaning rank was fitted to the data. Heritability estimates ± standard errors for each of the measured characteristics were; core wool bulk (0.57 ± 0.03), pre-shear live weight (0.35 ± 0.04), greasy fleece weight (0.44 ± 0.04), washing yield (0.42 ± 0.03), clean fleece weight (0.45 ± 0.03), staple length (0.54 ± 0.03), total crimps (0.38 ± 0.03), crimp frequency (0.46 ± 0.03), mean fibre diameter (0.62 ± 0.04), fibre diameter variation (0.58 ± 0.04) and mean fibre curvature (0.67 ± 0.04). At the end of the trial, line divergence (H – L) in core wool bulk and fibre curvature amounted to 2.5 phenotypic standard deviation units. It was associated with a positive divergence in crimp frequency and a negative divergence in staple length, washing yield and clean fleece weight of +2.1, -1.7, -1.4 and –0.8 standard deviation units respectively, and lesser changes in other traits.

Keywords: Perendale sheep; divergent selection; wool bulk; live weight; wool characteristics.

INTRODUCTION

Wool bulk, defined as the specific volume of a known weight of clean fibre under a set load expressed as cm^3/g, is an important characteristic associated with superior performance for many products produced from Romcross or "crossbred" type wool (Sumner *et al*., 1991). The compressed fibre mass may be in either an unprocessed form, as a yarn or as an end-product, such as carpet, with the bulk values in each form being highly correlated (Elliott *et al*., 1986). Bulk is of particular importance to carpet yarn, imparting increased wearability and improved appearance retention (Sumner *et al*., 1991). As much of the coarser type wool grown in New Zealand tends to have a relatively low bulk (Carnaby & Elliott, 1980), increasing wool bulk is a high priority for the New Zealand carpet wool industry. While bulk was initially measured using a scoured, carded, full length sample of wool (Dunlop *et al*., 1974), the standard test method now in current use (Standards Association of New Zealand NZS 8716:1994), is based on a scoured, carded sample obtained using a core boring tube with an internal diameter of approximately 18 mm (Burling-Claridge, 1994). Trials undertaken by Sanderson & Burling-Claridge (1991) and Sumner *et al*. (1995) have shown a linear relationship between loose wool bulk and core bulk, allowing conversion of data between the two measurement methods.

Short term trials have shown wool bulk to be strongly inherited (Sumner *et al*., 1989) with the Perendale (interbred Cheviot x Romney) having the bulkiest wool of the common breeds producing crossbred type wool in New Zealand (Carnaby & Elliott, 1980). However there is a genetic antagonism between wool bulk and fleece weight which may vary across breeds. This paper reports the effects of direct selection on wool bulk achieved in lines of Perendale sheep subjected to divergent selection for wool bulk of their yearling (hogget) fleece. Correlated responses in live weight, fleece weight and other objective fleece characteristics related to wool bulk are also reported.

MATERIALS AND METHODS

Breeding policy

A flock of approximately 200 Perendale breeding ewes, aged 2 to 5 years, was maintained at Whatawhata Research Centre from 1970 and relocated to the Winchmore Research Station in 1997. Between 1970 and 1986 the breeding ewes were joined for six weeks in the autumn with a group of five Perendale rams sourced from five different breeders invited to submit rams each year. This flock was therefore considered representative of the New Zealand Perendale breed. Replacement yearling ewes were selected at random from within the flock.

In 1987 the adult breeding ewes were divided into two selection lines based on the bulk of a mid-side fleece sample (Bedford *et al.,* 1977) taken at hogget shearing in the spring after previously being shorn as lambs at 4 months of age. Those with a wool bulk higher than the group mean became the foundation dams for a line selected for increased wool bulk (H line) and those with a wool bulk lower than the group mean became the foundation dams for a line selected for decreased wool bulk (L line). Between 1987 and 2002 five rams were joined as single sire matings within each selection line.

The selected rams used in 1987 included three high wool bulk and three low wool bulk, half-sib pairs from three industry flocks, and two half-sib pairs of rams born in the Whatawhata flock but whose sires represented different industry flocks (Sumner *et al.,* 1989). The sires, their sons and their progeny were selected on the basis of the wool bulk of a mid-side fleece sample (Bedford *et al.,* 1977) taken at their hogget shearing.

From 1988 onwards, one ram with the highest wool bulk from within each of the five sire groups in the H line and one ram with the lowest wool bulk within each of the five sire groups in the L line were used. On eight occasions, when there were insufficient rams available in a particular sire line, the ram used the previous year was used again. A total of 172 selected rams were used between 1987 and 2002. No outside sheep were introduced into the flock from 1988 onwards.

When surplus ewe hoggets were available to enter the flock those with the highest and lowest wool bulk within the H and L lines respectively were retained for breeding.

Beginning in 1996 a portion of the ewes in the H and L lines were joined with rams from the other line to create "½H½L" progeny. The ewes within each selection line were re-randomised each year for joining with either a H line or a L line ram. All ½H½L females born from these crossings were retained while all males were culled after being shorn as a hogget. Beginning in 1998 the ½H½L ewes were re-randomised annually to be joined with one of the five H line or one of the five L line rams to create "¾H¼L" and "¼H¾L" backcross progeny, none of which were retained after being shorn as a hogget.

Management policy

Both selection lines were treated similarly at all times except over mating and lambing. The ewes were single-sire joined for two cycles after oestrus synchronisation. Ewes within each selection line were re-randomised to mating groups annually while avoiding half-sib or dam-offspring matings. To prevent errors in "mothering-up" across selection lines at lambing, ewes in the two selection lines were lambed in groups based on the genotype of their progeny. Lambs were individually identified at birth.

Lambs were weaned and shorn in December, and weighed and shorn as hoggets in the following spring. While at Whatawhata the ram hoggets were shorn in late August and the ewe hoggets shorn in mid-October. After the flock was transferred to Winchmore all hoggets were shorn on the same date in mid-October.

Measurement methods

Individual live weight was recorded prior to shearing. Greasy fleece weight was recorded at hogget shearing and a mid-side fleece sample taken for measurement of washing yield at 16% regain, staple length, total number of crimps along the staple, wool bulk, mean fibre diameter, fibre diameter variation and mean fibre curvature. Between 1982 and 1995 wool bulk was measured with the wool prepared as a carded batt of full-length fibres, termed loose wool bulk, using a WRONZ bulkometer (Bedford *et al.,* 1977). From 1995 bulk was measured as core bulk according to the Standards Association of New Zealand NZS 8716:1994 test method where the staples of wool were cut to simulate a core bore sample, mechanically blended and carded before their compressibility was measured. The earlier derived loose wool bulk measurements were converted to a core bulk measurement by the prediction equations developed for samples measured within the Whatawhata wool measurement laboratory (Sumner *et al.,* 1995). Prior to 1994, mean fibre diameter was measured using a fibre fineness distribution analyser (FFDA) (CSIRO, Australia) (Lynch & Michie, 1976). Beginning in 1995 an optical fibre diameter analyser (OFDA 100) (BSC Electronics Pty. Ltd., Australia) was used to measure fibre diameter. The instrument had the capacity to also measure fibre curvature simultaneously (Edmunds, 1995). Clean fleece weight was calculated as greasy fleece weight multiplied by the washing yield of the midside sample and crimp frequency was calculated as the total number of crimps along the staple divided by the staple length.

Statistical analysis

A residual maximum likelihood (REML) animal model was run using ASReml (Gilmour *et al*., 2006). Additional fixed effects associated with year of birth x sex, birth/weaning rank and birth date were included in the model. Triplets were combined with twins. A multivariate analysis was run for the 11 measured traits to estimate the heritability of each trait and the phenotypic and genetic correlations between each pair of characteristics. All available data were analysed. This included data from the screened females born between 1982 and 1986 that were used as foundation dams for the selection lines. Breeding value solutions for each selection line were averaged by year of birth to provide plots of genetic trends between 1987 and 2002. The breeding value of the foundation dams was averaged by their contribution to each line and the average figure for each line deemed the baseline value for the line. The different values for each line reflected the effect of pre-selection screening of the foundation dams.

RESULTS

During the period 1982 to 1985 a total of 374 ewe hoggets were fleece sampled at hogget shearing. In 1986, during the early studies on the inheritance of wool bulk (Sumner *et al.,* 1989), a total of 216 ram and ewe hoggets were fleece sampled at hogget shearing. The numbers of hoggets born within the respective “genotype” groups between 1987 and 2002 that were later fleece sampled at hogget shearing are shown in Table 1.

Adjusted line means and phenotypic standard deviations over the period 1982 to 2002, are presented in Table 2.

Estimates of heritability and phenotypic and genetic correlations are presented in Table 3. The order of decreasing heritability estimates for this flock was mean fibre curvature (0.67), mean fibre diameter (0.62), fibre diameter variation (0.58), core bulk (0.57), staple length (0.54), crimp frequency (0.46), clean fleece weight (0.45), greasy fleece weight (0.44), washing yield (0.42), total crimps (0.37) and live weight (0.35).

Other than being positively related to greasy fleece weight (0.36) and clean fleece weight (0.32), liveweight was not closely related genetically to other wool characteristics. The strongest genetic correlation (0.95) was between greasy and clean fleece weight. Washing yield was moderately genetically correlated with fibre curvature (-0.64), core bulk (-0.62), crimp frequency (-0.60) and staple length (0.56). Its association with total crimps was lower (-0.35) and non-significant for fibre diameter. Clean fleece weight showed moderate genetic associations with staple length (0.56), fibre curvature (-0.55), lower genetic association with fibre diameter (0.32), and no significant association with total crimps. Wool bulk was closely associated with fibre curvature (0.80), crimp frequency (0.80) and staple length (-0.73) with its genetic association being lower for total crimps (0.46) and clean fleece weight (-0.34). The magnitudes of these genetic associations with core bulk were all greater than the corresponding phenotypic associations.

Figure 1 shows a plot of the average breeding values for core bulk of each genotypic group born between 1987 and 2002. The difference between the lines plotted in 1986 is the average difference present in the foundation dams due to the initial selection applied based on the core bulk of their own fleece. Divergent selection for wool bulk resulted in an increasing divergence in the average breeding value of successive crops of lambs born within each selection line. Progeny with a ½H½L genotype closely followed the zero baseline while the ¾H¼L and ¼H¾L lines were intermediate between the baseline and the H and L wool bulk lines respectively.

The average breeding values of the hoggets of each genotype born between 1998 and 2002 are included in Table 2. Line divergence (H – L) in wool bulk and fibre curvature amounted to +2.5 phenotypic standard deviation units. It was associated with a negative divergence in staple length, washing yield and clean fleece weight of -1.7, -1.4 and -0.8 units respectively, and a positive divergence in crimp frequency of +2.1 phenotypic standard deviation units. Associated changes in other traits were of lesser magnitude.

DISCUSSION

Parameter estimates for the traits generally fell within the previously reported range for other breeds of sheep (Safari *et al*., 2005; Sumner & Bigham, 1993; Sumner *et al*., 1998). However, the genetic correlation between washing yield and staple length in this study of 0.56 was significantly greater than the 95% confidence interval of 0.11 – 0.38 reported by Safari *et al.* (2005) and the range of 0.2 – 0.4 reported by Sumner & Bigham (1993). This may indicate a stronger relationship for these characteristics within the Perendale breed, associated with the wide range in wool bulk and the strong genetic relationship between washing yield and staple length with wool bulk. In addition, the genetic antagonism of core bulk with clean fleece weight was somewhat lower than previously reported for crosses of Poll Dorsets and Texels with Romneys (Clarke *et al.,* 1999).

An apparent reduction in genetic gain from around 1995 may be either a reflection of both lines reaching a high level of homozygosity in the genes controlling the expression of wool bulk or a significant reduction in selection pressure due to

Table 1: Numbers of sheep born in each "genotype" group that were fleece sampled prior to being shorn as hoggets the following year. H = High wool bulk line, L = Low wool bulk line, R = Ram, E = Ewe.

	Genotype										
	H		¾H¼L		½H½L		¼H¾L		L		Total
Year born	R	E	R	E	R	E	R	E	R	E	
1987	31	35							41	39	146
1988	35	27							34	29	125
1989	39	31							27	29	126
1990	27	35							32	43	137
1991	21	30							28	28	107
1992	30	30							36	26	122
1993	36	32							19	42	129
1994	32	26							39	50	147
1995	23	26							37	34	120
1996	2	3			51	41			3	5	105
1997	11	11			57	53			12	10	154
1998	10	10	11	6	55	49	8	14	14	13	190
1999	12	15	15	21	27	38	19	25	9	9	190
2000	14	18	15	38	22	18	24	30	7	15	201
2001	8	16	47	34	19	23	33	36	12	8	236
2002	6	6	25	27	14	18	28	28	4	13	169
All years	337	351	113	126	245	240	112	133	354	393	2404

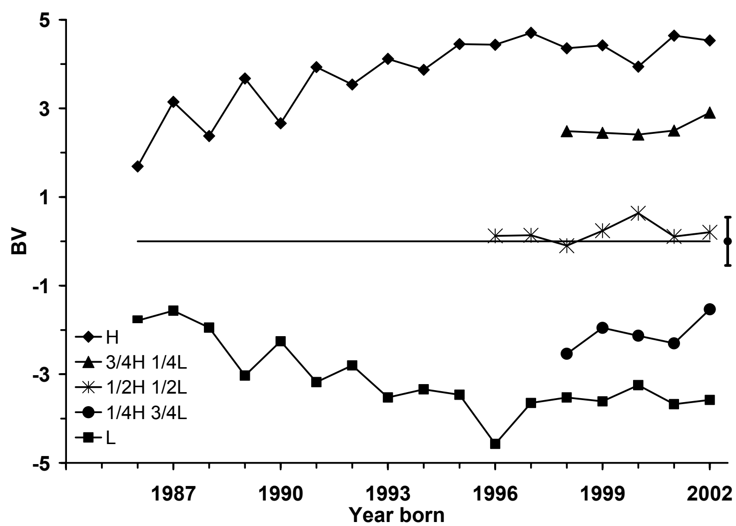
Table 2: Least squares mean ± standard deviation for the available measurements of pre-shear live weight and the measured wool characteristics over the period 1982 to 2002. The values were adjusted for year born x sex, birth date deviation from the year x sex mean and birth/weaning rank effects. The average breeding values for each characteristic are also listed for the hoggets of each genotype born between 1998 and 2002, where 0 is the average breeding value of the foundation dams born between 1982 and 1986.

Characteristic	Number of measurements	Mean ± standard deviation	Genotype				
			H	¾H¼L	½H½L	¼H¾L	L
Core bulk (cm^3/g)	2994	28.8 ± 3.1	4.3	2.6	0.2	-2.1	-3.5
Pre-shear live weight (kg)	2994	39.2 ± 4.8	0.84	0.88	0.92	0.76	0.76
Greasy fleece weight (kg)	2994	2.28 ± 0.41	-0.05	0.01	0.05	0.08	0.10
Washing yield (%)	2904	76.1 ± 4.4	-3.48	-1.98	0.18	1.67	2.83
Clean fleece weight (kg)	2904	1.74 ± 0.33	-0.10	-0.03	0.05	0.10	0.15
Staple length (mm)	2933	97 ± 15	-13.6	-7.5	1.3	8.6	13.5
Total crimps along staple	2933	17.1 ± 3.6	0.96	0.20	-0.80	-1.54	-1.43
Crimp frequency (number of crimps/cm)	2933	1.84 ± 0.47	0.48	0.26	-0.06	-0.32	-0.50
Mean fibre diameter (µm)	2626	31.3 ± 2.5	1.82	1.51	1.15	0.59	0.47
Fibre diameter variation (µm)	2626	7.3 ± 0.9	0.17	0.17	0.12	0.07	0.04
Mean fibre curvature (°/mm)	1365	64 ± 11	12.4	7.1	-1.0	-7.6	-12.1

Table 3: Estimates ± standard error of phenotypic correlations above the diagonal, heritability in bold along the diagonal and genetic correlations below the diagonal. CB = Core bulk (g/cm^3), LW = Pre-shear live weight (kg), GFW = Greasy fleece weight (kg), WY = Washing yield (%), CFW = Clean fleece weight (kg), SL = Staple length (mm), TC = Total number of crimps along staple, CF = Crimp frequency (number of crimps /cm), MFD = Mean fibre diameter (µm), FDSD = Fibre diameter variation (µm), MFC = Mean fibre curvature (°/mm).

Variate	CB	LW	GFW	WY	CFW	SL	TC	CF	MFD	FDSD	MFC
CB	**0.57 ± 0.03**	0.07 ± 0.02	-0.06 ± 0.02	-0.41 ± 0.02	-0.19 ± 0.02	-0.50 ± 0.02	0.36 ± 0.02	0.57 ± 0.01	0.17 ± 0.02	0.13 ± 0.02	0.68 ± 0.01
LW	0.01 ± 0.07	**0.35 ± 0.04**	0.50 ± 0.02	-0.04 ± 0.02	0.46 ± 0.02	0.17 ± 0.02	0.10 ± 0.02	-0.02 ± 0.02	0.24 ± 0.02	0.01 ± 0.02	-0.07 ± 0.02
GFW	-0.16 ± 0.06	0.36 ± 0.07	**0.44 ± 0.04**	0.01 ± 0.02	0.94 ± 0.01	0.36 ± 0.02	0.10 ± 0.02	-0.13 ± 0.02	0.39 ± 0.02	0.21 ± 0.02	-0.33 ± 0.02
WY	-0.62 ± 0.05	-0.07 ± 0.08	0.05 ± 0.07	**0.42 ±0.03**	0.33 ± 0.02	0.34 ± 0.02	-0.20 ± 0.02	-0.36 ± 0.02	0.10 ± 0.02	-0.03 ± 0.02	-0.44 ± 0.02
CFW	-0.34 ± 0.06	0.32 ± 0.07	0.95 ± 0.01	0.34 ± 0.06	**0.45 ± 0.03**	0.46± 0.02	0.03 ± 0.02	-0.23 ± 0.02	0.40 ± 0.02	0.18 ± 0.02	-0.45 ± 0.02
SL	-0.73 ± 0.04	0.15 ± 0.07	0.42 ± 0.05	0.56 ± 0.05	0.56 ± 0.05	**0.54 ± 0.03**	0.02 ± 0.02	-0.54 ± 0.01	0.18 ± 0.02	-0.04 ± 0.02	-0.60 ± 0.02
TC	0.46 ± 0.05	0.06 ± 0.08	0.10 ± 0.07	-0.35 ± 0.07	-0.02 ± 0.07	-0.11 ± 0.07	**0.37 ± 0.03**	0.77 ± 0.01	-0.10 ± 0.02	-0.25 ± 0.02	0.29 ± 0.02
CF	0.80 ± 0.03	-0.02 ± 0.07	-0.16 ± 0.07	-0.60 ± 0.05	-0.33 ± 0.06	-0.68 ± 0.04	0.76 ± 0.03	**0.46 ± 0.03**	-0.17 ± 0.02	-0.17 ± 0.02	0.61 ± 0.02
MFD	0.15 ± 0.06	0.16 ± 0.07	0.32 ± 0.06	0.08 ± 0.06	0.32 ± 0.06	0.07 ± 0.06	-0.40 ± 0.06	-0.28 ± 0.06	**0.62 ± 0.04**	0.40 ± 0.02	-0.36 ± 0.02
FDSD	0.14 ± 0.06	-0.02 ± 0.08	0.33 ± 0.06	-0.11 ± 0.07	0.26 ± 0.06	-0.10 ± 0.06	-0.43 ± 0.06	-0.24 ± 0.06	0.40 ± 0.05	**0.58 ± 0.04**	-0.04 ± 0.03
MFC	0.80 ± 0.03	-0.03 ± 0.08	-0.38 ± 0.06	-0.64 ± 0.05	-0.55 ± 0.05	-0.75 ± 0.04	0.39 ± 0.06	0.78 ± 0.04	-0.32 ± 0.05	-0.04 ± 0.06	**0.67 ± 0.04**

Figure 1: Plot of the average breeding values for core bulk of each genotypic group born between 1987 and 2002. The value plotted for 1986 is the mean value for the screened foundation dams born between 1982 and 1986. The error bars plotted after 2002 are the average standard error across the last five years of plotted data.



the reduction in numbers of pure-line rams available for use following creation of the "first cross" and "back cross" lines. Both the back cross progeny and the original lines showed a symmetrical response from selecting for either increased or decreased wool bulk.

The compressibility of a fibre mass is dependent on the geometry of the individual fibres within the mass (Kozyreff *et al.,* 2003) with the result that approximately 85% of the variation in core bulk can be explained by mean fibre curvature and mean fibre diameter enabling wool bulk to be predicted with an acceptable accuracy using these two measurements (Edmunds & Sumner, 1996; Sumner & Upsdell, 2001). The published trials on the processing implications of variations in core bulk for carpet yarn were undertaken prior to the development of the software to facilitate the measurement of fibre curvature using either the OFDA or Sirolan Laserscan (CSIRO, Australia) instruments. There are no published data to indicate whether fibre curvature, singly or in association with fibre diameter, or core bulk is the better indicator of processing and end-product performance.

Both mean fibre curvature and mean fibre diameter were more strongly inherited than core bulk. On the basis of the estimates reported in Table 3, the relative efficiency of indirectly selecting for wool bulk by selecting for fibre curvature, compared with selecting directly for wool bulk, may be calculated as the co-heritability (Q), where

Q = genetic correlation between wool bulk and fibre curvature x (heritability of fibre curvature / heritability of wool bulk)$^{0.5}$

= 0.80 x (0.67 / 0.57)$^{0.5}$

= 0.87 or 87%

The procedure to measure fibre curvature is quick and can be undertaken in the field away from a laboratory using an OFDA2000 instrument. It can also be undertaken in conjunction with measuring fibre diameter, requires a smaller sample and is cheaper than measuring core bulk. There would thus be considerable practical advantages, despite the loss in efficiency through indirect selection, in farmers using mean fibre curvature, rather than the standard test method for wool bulk, as a basis for selection if they wish to improve the bulkiness of their wool clip to meet specific criteria for a supply contract. Selection indices using other associated production traits have yet to be calculated and evaluated.

Published estimates of average wool value and quality premiums that applied for several seasons (Maddever *et al.,* 1991), adjusted to the current average price of 350 c/kg clean equate to 0.4 c/mm for staple length and -2.5 c/µm for mean fibre diameter with no values available for crimp frequency, fibre diameter standard deviation or fibre curvature. At these levels premiums for core bulk would need to be 10c per unit of bulk (cm^3/g), or approximately 3% of the average clean price of the fleece to derive an equivalent wool return from wool produced by the H line as from the L line. The premium for wool bulk in the market at the time of the economic analysis (Maddever *et al.,* 1991) was equivalent to 5.0 ¢ per unit of bulk (cm^3/g) at current prices. Similar price relativities still apply (Sheep and Wool NZ, unpublished data). At current wool prices the lower fleece weight of Perendale sheep, in relation to some other breeds producing crossbred type wool, such as the Romney, places them at a significant disadvantage with respect to returns derived directly from wool despite the superior processing and end-product performance of their higher bulk fleece wool.

CONCLUSION

Wool bulk is clearly very responsive to selection in the Perendale breed but is associated with moderate negative genetic responses in staple length and clean fleece weight. High heritabilities and large initial responses to screening, early and on-going selection, suggest that genes with large effects on bulk may be involved.

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