Chairman: D.J. Ward (Australia) **Report No. 12**
Vice-Chairman:
Technical Coordinator: G. Mercier (France)

Fibre diameter distribution characteristics of midside (fleece) samples and their use in sheep breeding

B.P. Baxter[a] & D.J. Cottle[b]

[a] SGS Wool Testing Services, Wellington, New Zealand

[b] Department of Wool and Animal Science, University of New South Wales, Sydney, Australia

Abstract

The relationship between fibre diameter mean and distribution was studied in a large dataset of midside samples from hundreds of flocks. The implications of the relationships are discussed in relation to using these measurements in sheep breeding programs. Some modifications to current phenotypic parameter estimates are suggested.

Introduction

With the advent of cost-effective technology for the measurement of fibre diameter distribution (FDD) as well as mean fibre diameter (MFD), there has been an explosion of FDD data, without much useful guidance on how the information can best be used on farm. Little of what has been written about peripheral parameters such as “prickle factor” and “coarse edge” is genuinely helpful at a farm level. In consequence, a number of rules of thumb have evolved, some of which are wrong, and some of which have been incorporated misleadingly into factors intended to simplify animal ranking.

Much has been published on the relationship between standard deviation of fibre diameter (FDSD) and MFD. Most sources agree that the relationship can be represented by simple linear regressions, although quadratic equations have also been proposed (see Baird et. al 1993). Whiteley et al. (1984) found that the addition of an extra term to the regression equation only improved the fit by 1%, and hence did not include it. A similar observation was made by Edmunds (1993).

A number of different linear regressions have been published, and a selection of these are shown in Table 1. Confusion may be caused by the different measurement techniques used (some of which have been demonstrated to give bias), and the different states of the wool.

The last column in the table attempts to simplify comparison of the relationships by calculating the fibre diameter coefficient of variation (FDCV) which would result from these equations at 20 µm and 30 µm respectively.(The coefficient of variation is simply the standard deviation divided by the mean fibre diameter and expressed as a percentage - it is easier to comprehend than standard deviation since it remains nearly constant for a wide range of diameters.)

Table 1: Examples of linear regression equations derived for standard deviation as a function of mean fibre diameter (FDSD = Constant+ Coeff x MFD)

Date	Author	Wool state	Instrument	Number samples	Const.	MFD coeff.	CV% @ 20µm	CV% @ 30µm
1958	Ott	Tops	PM	5855	-2.42	0.346	22.5	26.4
1983	Hadwich	IH Tops	PM	49	-2.13	0.318	21.2	24.7
1983	Lunney	Tops	FFDA	41	-2.55	0.346	21.9	26.1
1984	David	Tops	general	summary	-2.40	0.345	22.5	26.5
1991	Bow	Tops	FDA 200	222	-0.86	0.276	23.3	24.7
1993	Edmunds	IH tops	PM	n/s	-1.99	0.314	21.5	24.8
1994	Bow	Tops	Laserscan	156	+0.09	0.22	22.5	22.3
1996	Naylor	Tops	Laserscan	100	-2.59	0.337	20.8	25.1
1984	Whiteley	Sale lots	FFDA	2921	-0.33	0.263	24.7	25.2
1991	Bow	Sale lots	FDA 200	162	-0.35	0.244	22.7	23.3
1993	Edmunds	Sale lots	OFDA	228	-1.51	0.298	22.3	24.8
1995	Naylor	Sale lots	FDA 200	297	+0.08	0.23	23.4	23.3
1995	Naylor	Sale lots	Laserscan	297	-0.29	0.23	21.6	21.0
1982	Fleet	Fleece	FFDA	248	n/a	n/a	20.8	n/a
1994	Bow	Flc Mer	Laserscan	737	-1.19	0.25	19.1	21.0
1994	Bow	Flc Xbd	Laserscan	79	-0.23	0.20	18.9	19.2

Allowing for the known reduction in FDV of about 1% FDCV from the FFDA and FDA 200 instruments to the Laserscan (Naylor 1995), at 20 µm the average predicted FDCV values in the fleece, sale lot and top would be 19%, 22%, and 22% respectively.

Early stage processing of greasy wool thus has little effect on the FDV, but there appears to be a significant difference between the fleece results and the sale lot and top results. This is expected, given that fleece measurements are usually performed on the most uniform part of the fleece (the midside sample), whereas sale lots include between portions of the fleece and between fleeces variance. Qinnell et al. (1973) suggested that these two additional variances account for about 14 to 20% of the total. The 3% difference in FDCV figures quoted above is equivalent to 25% of total variance.

In view of the lack of published data, and the need that growers have for guidance in interpretation of fleece testing results, it was decided to investigate the FDD relationship for midsides in greater detail.

This paper presents data on the relationships between some measures of fibre diameter variability (FDV) and MFD for mid-side fleece samples. The data comprises approximately 100,000 test results from 1,129 flocks and has been accumulated from 3 laboratories which participate in round trials. It is intended to represent a cross-section of commercial fleece testing results from 3 broad geographic locations in Australia and New Zealand.

Materials and methods

Measurements

Samples of fleece test results from the 1996 season were collected from 3 commercial laboratories known to operate to a quality level consistent with the draft AS/SNZ Standard DR 96157-63 for fleece measurements. One laboratory used the Laserscan instrument (approx 48,000 results) and the other two used OFDA instruments (approximately 52,000 results).

The results were selected as far as possible to representatively cover the entire fleece testing season. The samples represent a very wide range of New Zealand wools from most types of breeding flock, but with a vast majority of Merinos; and a wide sample from the stud Merino population in New South Wales.

Analyses

The data were obtained from the laboratories as individual files, each representing a flock. In total 1129 sets of data were used, varying from one to several thousand animals. The data sets therefore covered a wide range of properties and circumstances.

The Statistica program (Statsoft 1997) was used to analyse files containing flock number, laboratory number, sheep tag, MFD, FDSD, FDCV, and prickle factor (PF - percentage of fibres above 30 µm). The combined dataset comprised 100,108 cases.

Results

Means

A summary of the principal characteristics of the datasets is shown in Table 2. A very wide range of wool types is covered. The distribution of wool types within the dataset is not uniform, and whilst reasonably approximating the distribution in the Australian flock, it is not representative of the entire range of NZ flocks. However it is representative of flocks in which objective wool measurement is used for sheep breeding selection.

Table 2: Dataset characteristics

Characteristic	Dataset			
	Aust 1	**Aust 2**	**NZ 1**	**Combined**
Number of results	6,663	48,849	44,596	100,108
Number of flocks	23	538	568	1,129
MFD mean	20.42	20.54	19.81	20.21
MFD standard deviation	2.47	2.66	5.77	4.34
MFD minimum	13.9	12.7	12.6	12.6
MFD maximum	33.1	48.6	52.0	52.0
FDSD mean	3.91	4.03	3.78	3.91
FDSD standard deviation	0.79	0.89	1.55	1.23
FDSD minimum	2.2	1.7	2.0	1.7
FDSD maximum	9.5	12.7	21.7	21.7
FDCV mean	19.17	19.53	18.77	19.16
FDCV standard deviation	3.04	3.19	2.82	3.04
FDCV minimum	12.0	11.0	11.9	11.0
FDCV maximum	38.3	36.0	98.0	98.0
PF mean	3.72	4.27	8.87	6.28
PF standard deviation	6.75	5.67	21.94	15.45
PF minimum	0.0	0.0	0.0	0.0
PF maximum	66.1	94.8	99.2	99.2

Regressions

The relationship between FDSD and MFD was initially examined in each dataset (Figs. 1a, b, c). Examination of Fig. 1 suggested that linear regressions would satisfactorily model the relationships.

The linear regressions for the 3 datasets were as follows:

Aust 1:

FDSD = 0.182 (0.003) MFD + 0.20 (0.07) se = 0.65 R^2 = 0.325 (1)

Aust 2:

FDSD = 0.229 (0.001) MFD - 0.67 (0.02) se = 0.65 R^2 = 0.468 (2)

NZ 1:

FDSD = 0.251 (0.000) MFD - 1.20 (0.01) se = 0.56 R^2 = 0.872 (3)

Quadratic regression was examined and the equations took the form:

Aust 1:

FDSD = 9.10 (0.36) - 0.66 (0.03) MFD + 0.020 (0.001) MFD^2 se = 0.62 R^2 = 0.382 (4)

Aust 2:

FDSD = -3.80 (0.12) + 0.53 (0.01) MFD - 0.007 (0.000) MFD^2 se = 0.65 R^2 = 0.475 (5)

NZ 1:

FDSD = -0.61 (0.04) + 0.20 (0.00) MFD - 0.001 (0.000) MFD^2 se = 0.56 R^2 = 0.872 (6)

It can be seen that, with the exception of the smaller dataset, the improvement in fit by using a quadratic regression equation was negligible, confirming the earlier observations by Whiteley et al.(1984) and Edmunds (1993).

The practical differences between the linear regressions can be highlighted by calculating the FDCV values from equations 1 through 3 at both 20 and 30 µm. The calculated values are: 19.2, 19.5 and 19.1%, and 18.9, 20.6, and 21.1% respectively for the Aust 1, Aust 2, and NZ 1 datasets. The differences are very small but statistically significant. For practical purposes the datasets can be combined. The relationship between FDSD and MFD for the combined dataset is shown in Fig. 2.

The regression equation for the combined data was:

FDSD = 0.246 (0.000) MFD - 1.07 (0.01) se = 0.61 R^2 = 0.752 (7)

The equivalent quadratic equation was:

FDSD = -0.74 (0.03) + 0.22 (0.00) MFD - 0.0006 (0.0001) MFD^2 se = 0.61 R^2 = 0.752 (8)

This confirms that the addition of an extra squared term was unjustified (note the very small value of the squared term coefficient).

Clearly, however, within this overall population, there were minor differences between datasets. There are significant differences in the relationships between FDSD and MFD in individual flocks. This may be illustrated by plotting dataset Aust 1 on a flock by flock basis after removal of the 3 smallest flocks (of 3, 13 and 31 animals) (Figs. 3a, b, c). It can be seen that there were very significant differences between the flocks for the relationships between MFD and FDSD, FDCV and PF.

The linear relationships between MFD and both FDSD and FDCV can be objectively examined using analysis of covariance. The two larger datasets were reduced to the largest 300 flocks, and 3 small flocks were removed from Aust 1, in order to remove groups of samples which were probably highly selective. Reducing Aust 2 dataset from 538 to 300 flocks (i.e. by 44 %) reduced the total number of animals from 48849 to 47008 (by 4%), in flocks ranging from 18 to 4695 samples; and in the case of NZ 1, reduction from 568 flocks to 300 (by 47%) caused the total animal numbers to reduce from 44596 to 41744 (6% reduction), in flocks ranging from 33 to 1661 samples.

The ANCOVA results for the model FDSD = flock + MFD + error were as follows:

Aust 1:

Effect	df effect	MS effect	df error	MS error	F	p-level
Flock	19	71.85915	6595	0.2154	333.6434	0.0000
MFD (cov.)	1	388.0112	6595	0.2154	1801.543	0.0000

Aust 2:

Effect	df effect	MS effect	df error	MS error	F	p-level
Flock	299	24.62371	45904	0.2658	92.6422	0.0000
MFD (cov.)	1	3847.856	45904	0.2658	14480.61	0.0000

NZ 1:

Effect	df effect	MS effect	df error	MS error	F	p-level
Flock	299	12.05193	41253	0.179967	66.96744	0.0000
MFD (cov.)	1	3551.802	41253	0.179967	19735.85	0.0000

In all cases the flock and covariate (MFD) effects were significant. The significantly lower MS error for NZ 1 indicated that flock and MFD explain FDSD variability in the NZ 1 dataset better than in either of the Australian datasets.

The relationships between FDCV and diameter were examined. They were again similar for each dataset, and the linear regression for the combined data is shown in Fig. 4:

FDCV = 0.196 (0.002) MFD + 15.20 (0.04) se = 2.92 $R^2 = 0.078$ (9)

The quadratic form showed no significant improvement in estimation:

FDCV = 12.7 (0.1) + 0.41 (0.01) MFD - 0.004 (0.000) MFD^2 se = 2.91 $R^2 = 0.081$ (10)

Variances and covariances

The within-flock variability of MFD (Fig. 5), FDSD (Fig. 6) and FDCV (Fig. 7) can be examined by plotting the within-flock variances for the largest flocks within each dataset against the MFD of the flocks. The within-flock variability would be reduced in any flocks where sheep were culled before measurement on the basis of their visually appraised MFD, FDSD or FDCV, if the correlations between visually assessed and measured FD traits were significant. This introduces an unknown level of bias in the variance estimates, which are therefore minimum estimates of variance. An attempt to minimise this bias was made by removing flocks from the analysis which had only small numbers of sheep measured.

The relationships for the three datasets were similar (Appendix 1), although in each case the within-flock variability was lower in NZ 1 at the higher values of MFD, FDSD and FDCV. The phenotypic within-flock variance for MFD, FDSD and FDCV for different flock average MFD are given in Table 3 based on the regressions in Figs. 5,6 and 7.

Table 3: Within flock variance of MFD, FDSD and FDCV for different average flock MFD

Flock average MFD (μm)	**MFD (μm^2)**	**FDSD (μm^2)**	**FDCV (%^{2})**
17	1.21	0.13	4.19
19	1.73	0.21	4.34
21	2.25	0.28	4.49
23	2.77	0.35	4.64
25	3.29	0.43	4.79
27	3.81	0.50	4.94
30	4.59	0.61	5.17
35	5.89	0.80	5.54
40	7.19	0.98	5.92
BVEST parameters	2.25		5.76

These values suggest that the phenotypic variances of MFD and FDCV assumed in the selection indices calculated by BVEST (Gilmour 1993), which are used by RAMPOWER and LAMBPLAN, may need modification, bearing in mind the variance estimates from this study are likely to be slight underestimates. In the case of MFD, the variance should be increased for flocks with MFD over 21 μm and possibly reduced for flocks less than 21 μm. The assumed FDCV variance appears to be too high and could be reduced towards the values in Table 3.

The phenotypic correlations within flocks between MFD and FDSD (Fig. 8) and FDCV (Fig. 9) showed very small increases in correlations with increasing MFD.

The correlation between MFD and FDCV currently assumed in BVEST parameter files is -0.10. This is close to the value estimated here for a wide range of flock MFD. However it can be seen that these correlations vary significantly between flocks and hence the realised rate of genetic gain from index selection could be expected to be different from predicted rates of gain in many flocks.

Prickle Factor

Finally, PF was examined as a function of MFD. The relationship shown in Figure 10 is similar to that shown by Naylor (1996) for tops, but illustrates very much greater variation.

Prickle factor is directly related to both FDSD and MFD (or FDCV and MFD). A number of relationships were examined to establish the predictability of PF. Initially, non-linear least squares regression was used to develop a relationship based on MFD, MFD^2, FDCV, FDCV^2, and MFD*FDCV. Whilst this regression enabled 95% of the variability to be accounted for, the relationship is over-complicated for routine use, and only yielded a standard error of prediction of 1.8 %.

The second approach was based on a power law relationship as proposed by Naylor (1996). The regression took the form:

$$\log_e PF = 10.45\ (0.02) \log_e MFD - 30.99\ (0.05) \qquad se = 2.0 \quad R^2 = 0.792 \qquad (11)$$

The poorer correlation coefficient suggests that, contrary to Naylor's assertion, MFD is not sufficient on it's own to explain the variation in PF. This can be seen visually if we compare Figure 10 with Figure 11, which shows PF plotted against effective fineness (EF).

EF combines MFD and FDCV in a single number, which is based on the premise that 5 % FDCV is equivalent in limit spinning performance to 1 μm in MFD. It can be seen in Figure 11 that EF values of less than 25 μm ensure that the PF is below 5%; and similarly, it would not be possible to obtain a PF value less than 5% with EF values much over 27 μm. This provides a usefully close pair of boundaries (i.e. 25 to 27 μm) for general use.

Using the power law relationship, PF can be predicted from EF:

$$\log_e PF = 10.00\ (0.01)\ \log_e EF - 31.34\ (0.03) \qquad se = 1.6 \quad R^2 = 0.907 \qquad (12)$$

This provides a significant improvement over the relationship in equation 11, but the precision of the prediction diminishes significantly above a PF value of 10. A predicted PF of 5 % would equate to actual PF values ranging from approximately 4 to 7 %.

Finally, the z transform proposed earlier by Naylor (1995) was used. This assumes that the shape of a FDD closely approximates the normal curve, and in this case z is the standard Gaussian score: $z = (30 - MFD) / FDSD$ (13)

Using the relationship proposed by Naylor, the following regression is obtained:

$$PF = 17.30\ (0.01)\ (1/z) - 4.21\ (0.01) \qquad se = 1.0 \quad R^2 = 0.943 \qquad (14)$$

Whilst this a more cumbersome formula to apply, the precision of prediction is very much better than that achieved with the other approaches, and is relatively uniform throughout the useful range, as can be seen from Figure 12. At a predicted PF of 5 %, the actual PF ranges from 2 to 6%.

The combination of MFD and FDCV values that are predicted to result in PF values less than 20% are shown in Fig. 13. For typical FDCV values of 15-25% the 5% PF line passes through a MFD range of 21-23 µm.

Discussion

The relationship between FDSD and MFD on the combined dataset is similar to the relationship quoted by Bow (1994) for Merino fleeces. The relationship appears to be robust over a wide range of MFD, but can vary significantly from that shown within individual flocks.

It has been shown that for the fine wool end of the spectrum, which dominates these datasets, an average FDCV value is typically 18 to 19%. However, the 95% confidence limits at 20 µm range from approximately 13 % to 25 %, suggesting that there is much scope for improvement in reducing FDV in many flocks.

Naylor et al. (1995), and de Groot (1995) recently suggested EF as a means of incorporating FDV and MFD into one number, although there is no necessity to do this with multitrait index selection, which can incorporate both MFD and FDCV. Butler & Dolling (1992, 1995) took this one stage further and “normalised” EF to a “benchmark” FDCV of 24 %. The work here suggests that the 24 % value used in the definition of Spinning Fineness (SF) may be too high for Merinos. If the SF values are simply used for ranking, this is of no consequence, but it has been stated that a SF value lower than the MFD on any sample indicates that the wool will spin better than normal - this may not be the case for Merino midside fleece samples, where the average FDCV is closer to 19%.

There appears to be no simple way of predicting PF without taking into account both MFD and either FDSD or FDCV. Whilst EF provides good predictability, equation 14 based on the standard Gaussian score appears the most robust, precise and conservative of the approaches considered. To include PF properly in a selection index requires knowledge of its heritability, within-flock variance, independent linear economic value and its phenotypic and genetic correlations with other traits, eg. MFD and FDCV, in the index. The results from this study provide phenotypic variance and covariance estimates only (Appendix 2). Using independent culling levels for PF, which is a simpler approach, does not lead to much loss in selection efficiency as it is a trait which has a high phenotypic correlation with other traits in the index (Young 1961). PF is highly correlated to MFD and FDCV (Appendix 2). The non-inclusion of PF in selection decisions is likely to have a very minor impact on genetic gain if MFD and FDCV are both included in the selection process.

Acknowledgments

The authors would like to thank Paul Cocks of Riverina Fleece Testing Services; Jude Davidson of SGS Wool Testing Services, Timaru; and David Petrie of UNSW Fleece Testing Services for provision of the data used in this work.

References

Baird, K., Barry, R.G. and Marler, J.W. (1993) Mean fibre diameter measurement differences using airflow, projection microscope and Sirolan-Laserscan. IWTO tech. report 8, Nice

Bow, M.R. and David, H.G. (1991) A further study of the relation between the standard deviation of diameter and mean diameter for tops. IWTO tech. report 5, Lisbon

Bow, M.R. and Hansford, K.A. (1994) Fibre diameter variability, in CSIRO Woolspec 94 seminar.

Butler, K.L. & Dolling, M. (1992) Calculation of the heritability of spinning fineness from phenotypic and genetic parameters of the mean and CV of fibre diameter. Aust. J. Agric. Res. 43, 1441-6

Butler, K.L. & Dolling, M. (1995) Spinning Fineness for wool. J. Text. Inst. 86, No. 1, 164-166

David, H.G. (1984) The relation between standard deviation of diameter and mean diameter for commercial wool tops. IWTO tech. report 4, Paris

de Groot, G.J.J.B. (1995) The use of effective fineness to determine the effect of wool fibre diameter distribution on yarn properties. J. Text. Inst. 86, No. 1, 33-44

Edmunds, A.R. (1993) Effects of standard deviation on airflow measurements of mean fibre diameter. IWTO tech. report 5, Nice.

Fleet, M.R., Irvine, P.A., Ponzoni, R.W. and Bow, M.R. (1982) Comparison of measures of fibre diameter variability in Australian merino wools. Wool Tech. Sheep Breed., Sept/Oct, 139-147

Gilmour, A.R. (1993) BVEST A multiple trait animal model Best Linear Unbiased Predictor breeding value estimation program. NSW Agriculture Biometric Bulletin No. 2.

Hadwich, F. (1983) Wechselbeziehung zwischen der mitterleren Wollfeinheit eines Kammzuges und der Streuung der einzelnen Wollfeinheiten. IWTO tech. report 7, Copenhagen

Lunney, H.W.N. (1983) Distribution of fibre diameter in wool tops. Text. Res. J. 53, 281-289

Naylor, G.R.S., Phillips, D.G., and Veitch (1995) The relative importance of mean diameter and coefficient of variation of sale lots in determining the potential skin comfort of wool fabrics, Wool Tech. Sheep Breed., 43 (1), 69-82

Naylor, G.R.S. (1966) The coarse fibre component and fibre end diameter characteristics of Australian wool tops. J. Text. Inst., 87, Pt. 1, No. 2, 265-273

Ott, R. (1958) Etude d'une Nouvelle Classification des Laines. Bull. Inst. Text. France. No. 77 October

Quinnell, B., Whiteley, K.J. and Roberts, E.M. (1973) Variation in diameter of wool fibres - a review. Objective measurement of wool in Australia - technical report of the Australian wool board's Objective Measurement Policy Committee, AWC, Melbourne

Standards Australia - Standards New Zealand draft DR 96157 - 63 (1966) Wool - fleece testing and measurement

Statsoft (1997) Statistica v5.1, Statsoft Inc, 2300 E 14th St., Tulsa, OK 74104

Whiteley, K.J., Thompson, B., Stanton, J.H. and Welsman, S.J. (1984) Distribution of fibre diameter in greasy wool sale lots. Part 1: Standard deviation. Text. Res. J., 54, 459-462

Young, S.S.Y. (1961) A further examination of the relative efficiency of three methods of selection for genetic gains under less restricted conditions. Genet. Res., 2, 106-121.

<u>Figure 1a:</u> Scatterplot of FDSD against MFD for dataset Aust 1.