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Standard Deviation of Fiber Diameter and Other Characteristics of United States Wool[1,2,3]

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Summary

A study was conducted to quantify variability of fiber diameter for a broad cross-section of U.S. wools. Eight hundred sale lots representing eight grades of grease wool were measured for fiber diameter distribution and for wool base, clean wool fibers present and vegetable matter grease basis. No skirts or offsorts were included in the 800 lots which were predominantly staple wools from yearlings and mature ewes representing five different production years. Standard deviation of fiber diameter was below the maximum permitted level (ASTM, 1990; USDA, 1966) for 797 out of 800 lots. Standard deviation of fiber diameter was positively and highly correlated with mean fiber diameter ($r^2 = 0.91$; $P < 0.0001$). No evidence was found to indicate that domestic wools are more variable in terms of fiber diameter than Australian wools.

A discussion of standard deviation of fiber diameter as it affects top making, spinning, yarn properties, fabric properties and selection of sheep for breeding is provided to assist the reader in understanding the significance of these data.

Key words: wool, standard deviation of fiber diameter.

Introduction

Variability in wool fiber diameter is important because it affects spinning condition and the uniformity of yarns into which wool is spun. In turn, uniformity affects yarn strength and the appearance, performance and acceptability of fabric. Compared to several other measurable raw wool characteristics, variability in fiber diameter is considered to be of secondary importance. Table 1 shows an accepted ranking of raw wool properties from the perspective of worsted topmakers. Nevertheless, it should be pointed out that one of the conclusions of the Australian TEAM Project (1985) was that the relative importance of each raw wool characteristic, or group of characteristics, is different for individual mills and is dependent upon the range and type of wools processed. Unfortunately, in that monumental study involving 36,000 bales of wool in 232 commercial consignments, variability of diameter was not immediately available because an air-flow technique was used to measure mean fiber diameter (MFD). Consumers, on the other hand, tend not to be concerned with such things as yield and staple strength, except perhaps for their influence on retail price of the wool product. Rather, they are concerned more with appearance and comfort factors. It has been known for a considerable time that both of these properties are affected by mean fiber diameter and variability of fiber diameter. Because instruments are now available to measure both MFD and wool fiber diameter distribution (standard deviation [SD] and coefficient of variation [CV]) relatively quickly and inexpensively (Baxter et al., 1991; Baird and Barry, 1993), measurement of these two properties is currently attracting considerable industry attention. In November of 1991, CSIRO's Division of Wool Technology organized a workshop to discuss, evaluate and subsequently coordinate research into the effects of fiber diameter variability at all stages of wool production, specification, processing, manufacture and end use. From this meeting, a clearer perception of the use and importance of fiber diameter

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measurements emerged (Rottenbury, 1992).

Table 2 shows the official standards of the U.S. for grades of wool (USDA, 1966). It was recognized when these standards were formulated, as it is today, that an excessively high SD would result in a poorer spinning condition and/or a less uniform yarn. Thus commercial raw wool lots having higher SDs than the stated maxima are downgraded by one grade. Because the U.S. textile industry has been aware of this phenomenon, an insistence has been maintained over the years that a measure of variability always accompany the MFD measurement when trading domestic raw wool and tops. Thus as the rest of the world changed to air-flow measurements of MFD for their grease wools, the U.S. stayed with microprojection measurements, even though the latter were tedious and more expensive. For many years now, domestic textile companies have purchased Australian and New Zealand wools based on air-flow measurements and U.S. wool based on microprojection measurements and/or subjective assessments. Over time, a perception has evolved that imported wools are more uniform in terms of fiber diameter than their domestic counterparts.

Table 1. Significance of raw wool characteristics in processing to top.[a]

Characteristic	Importance[b]
Yield	4
Mean fiber diameter	4
Vegetable matter	3
Staple length	3
Staple strength/position of break	3
Color/colored fibers	3
Fiber diameter distribution	2
Staple length variability	2
Degree of cottedness	2
Crimp/resistance to compression	2
Staple tip	1
Age/breed of sheep	1
Style/character/handle	1

[a] Adapted from Andrews (1979) and Quirk (1983).
[b] Scale of importance from 1 to 4, with 4 being the most important and 1 being the least.

For the past several years, the American Sheep Industry Association (ASI) has been conducting a Quality Assurance Program on many aspects of the sheep industry. In the absence of a data base showing fiber diameter variability of U.S. wool over time, ASI sponsored this study with the following objectives: 1) quantify standard deviation of fiber diameter for a broad cross-section of U.S. wool in a recent five-year period; and 2) document data on scoured yield and vegetable matter content for commercial lots of U.S. wool.

Materials and Methods

The following information was supplied by Yocom-McColl Testing Laboratories, Inc., for 800 sale lots of grease wool: wool base (oven-dried scoured wool free of alcohol-extractable matter, mineral matter, vegetable matter and all impurities); clean wool fibers present; vegetable matter grease basis (vegetable matter present); grade; average fiber diameter; standard deviation of fiber diameter; and coefficient of variation of fiber diameter. Fiber diameter (ASTM, 1994b) and yield parameters (ASTM, 1994a) were determined using ASTM methods. Data were summarized for 20 lots in each of eight grades (50s, 54s, 56s, 58s, 60s, 62s, 64s and 70s) for each of five production years (1990-1994). Each lot within a grade was chosen at random from a year's accumulation of lots tested. Thus the reported data represent a random sample of all U.S. sale lots that were tested at this testing lab. These may not be truly representative of all U.S. wool. Because of the nature of the business, most wools were tested in early spring. Descriptions of the wool were also provided and included original bag, skirted and classed, bellies out untied, bellies out tied, etc. No skirts or offsorts were included in the 800 lots, which were predominantly staple wools from yearling and mature ewes representing production from many states. Data were analyzed to provide base-line statistics (mean values, variabilities, minimum and maximum values) for this broad cross-section of U.S. wools. In addition, simple regression and correlation analyses were performed on the data using procedures of SAS (SAS, 1992). Consideration was then given to the role of variation in fiber diameter from the perspectives of: top making; spinning and yarn properties; fabric properties (including the prickle phenomenon); and selection of sheep for breeding.

Table 2. Official standards of the United States for grades of wool (USDA, 1966).

Grade	Range for average fiber diameter, µm	Maximum standard deviation, µm
Finer than 80s	less than 17.70	3.59
80s	17.70 to 19.14	4.09
70s	19.95 to 20.59	4.59
64s	20.60 to 22.04	5.19
62s	23.50 to 24.94	6.49
58s	24.95 to 26.39	7.09
56s	26.40 to 27.84	7.59
54s	27.85 to 29.29	8.19
50s	29.30 to 30.99	8.69
48s	31.00 to 32.69	9.09
46s	32.70 to 34.39	9.59
44s	34.40 to 36.19	10.09
40s	36.20 to 38.09	10.69
36s	38.10 to 40.20	11.19
Coarser than 36s	greater than 40.20	–

Results and Discussion

Standard deviation of fiber diameter and corresponding mean fiber diameter values were plotted for each of the 800 wool samples analyzed by Yocom-McColl Testing Laboratories, Inc. (Figure 1). Of the 800 lots tested, only three had SD of fiber diameter values that exceeded the maxima for grade listed in Table 2.

The linear relationship between SD and MFD for these 800 U.S. sale lots was:

$$SD = 0.36 \times MFD - 3.42$$

for which r^2, the coefficient of determination, was 0.91 ($P < 0.0001$). In other words, 91% of the observed variability in SD is accounted for by the variability in MFD. The same data were summarized by grade (Table 3) and the 95% confidence limits of SD were calculated for the mean SD value in each grade. Thus, for example, the observed mean SD for 60s grade wools was 5.06 µm. If one sample was picked out of the 100 tested, there would be a 95% chance that its SD value was in the range 5.06 ± 0.74 µm corresponding to a range in coefficient of variation (CV%) of 17.8 to 23.9.

The SD data were also summarized by grade and year (Table 4). Although differences between year means for a particular grade do not appear to be sizeable, within-grade differences among SD values due to year were significant ($P < 0.05$, Table 5). Similarly and as expected, grade and location also influenced SD.

Wool base (WB) data were summarized by grade (Table 6) and by grade and year (Table 7). Figure 2 illustrates the relationship between WB and average fiber diameter. Wool base is also affected significantly by year, location and grade ($P < 0.0001$; Table 5). The linear relationship between wool base and mean fiber diameter is:

$$WB = 0.26 \times MFD + 39.88$$

for which $r^2 = 0.05$. The fact that little of the variability in WB is accounted for by MFD is also obvious from Figure 3. Generally, finer wools are considered to be lower yielding than coarser wools. This is not apparent in this data set.

Vegetable matter grease basis (VMGB) data were summarized by grade (Table 8) and by grade and year (Table 9). Figure 3 illustrates the relationship between VMGB and MFD. The VMGB is also affected significantly by year, location and grade ($P < 0.02$; Table 5). The linear relationship between VMGB and MFD is:

$$VMGB = 0.02 \times MFD + 0.85$$

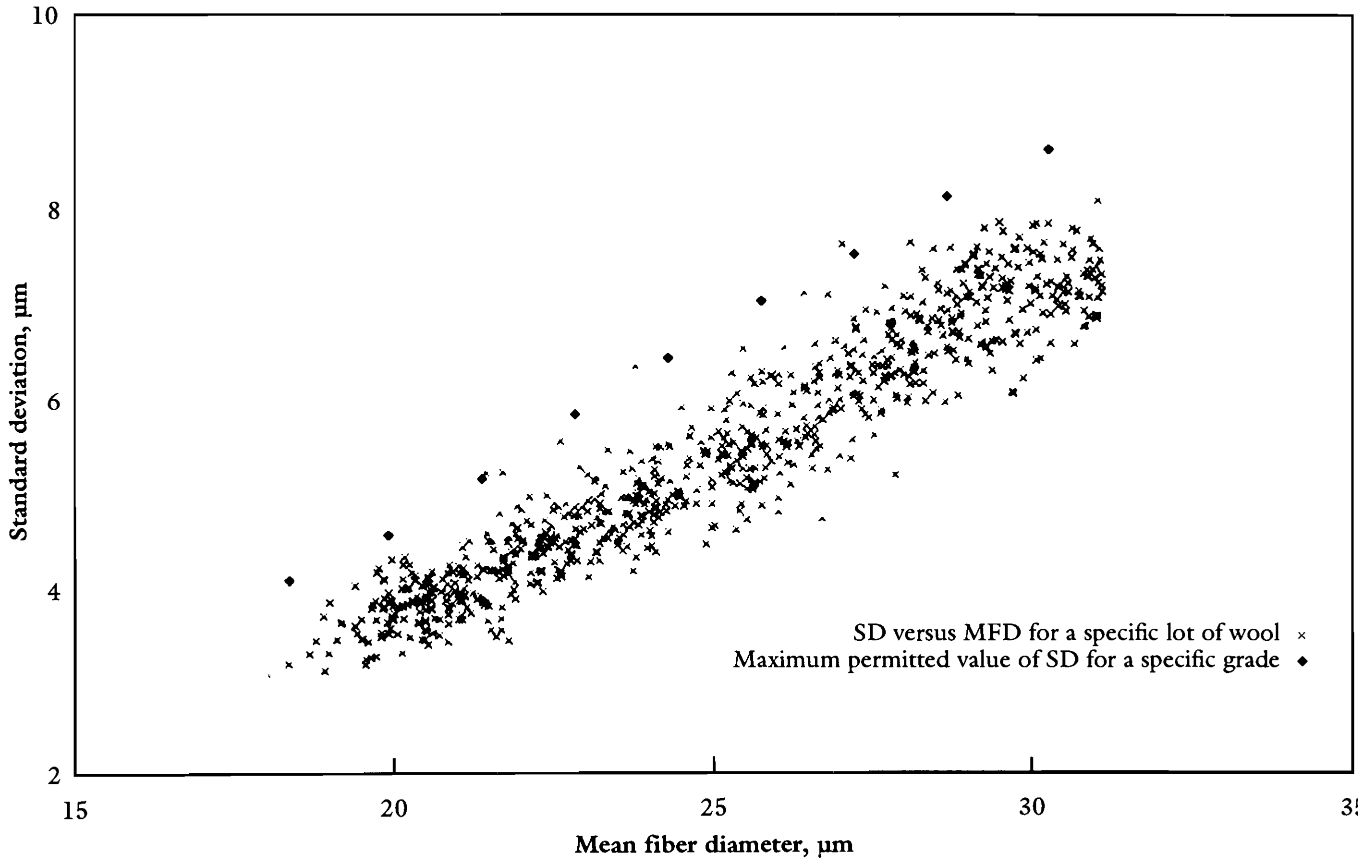
for which $r^2 = 0.01$. It is obvious from Figure 4 that VMGB can not be accurately predicted from a knowledge of MFD.

Correlation coefficients (r-values) and probability values between the wool variables considered in this study are summarized in Table 10. The two highest correlations are between MFD and SD of fiber diameter (0.95) and between WB and clean wool fibers present (CWFP; 0.99).

Variation of wool fiber diameter in a particular population may be expressed as the standard deviation (SD) or coefficient of variation (CV) of fiber diameter:

$$CV\% = \frac{SD}{MFD} \times 100$$

Figure 1. Standard deviation (SD) versus mean fiber diameter (MFD).



The CV tends to provide a more useful statistic for comparing fiber diameter variance of wools differing in MFD since it accounts for the increase in SD with increasing MFD. However, both terms are used in the ensuing discussion.

Instrument Considerations

The shortcomings of airflow instruments for measuring MFD of wool are well known (James and David, 1968). Baxter (1993) recently summarized the numerous conditions that cause airflow instruments to produce incorrect results. These included fiber medullation (which affects specific gravity), atypical crimp, ellipticity, unusual scale geometry, substantially different CVs between calibration and measurement wools, high residual grease level, other contaminants and non-standard preparation methods. Edmunds (1993) also documented the effects of standard deviation on airflow measurements of MFD for 228 New Zealand wools and concluded that uncertainty arises as to the accuracy of MFD measurements whenever SD is unknown. For these and other reasons, scientists have invented and subsequently proven instruments that will ultimately replace even the commercial use of airflow while producing results more rapidly but still as accurately as the projection microscope (PM). Two such instruments are the Sirolan Laserscan (Baird and Barry, 1993) and the Optical Fibre Diameter Analyser (OFDA; Baxter et al., 1991). Even with these high-tech instruments, some potential problems remain. Naylor (1992) observed that precision of measurement of the "coarse edge" of fiber diameter distribution is sensitive to instrument calibration. However, precision increased as number of fibers measured increased. In earlier versions of the Laserscan (e.g., the fiber fineness distribution analyser [FFDA]), De Oliveira et al. (1990) reported that medullation and wools with high CVs produced finer MFDs on the FFDA versus the PM. This problem has reportedly been overcome in the Laserscan. More recently, Teasdale (1993) described the bias in CV of fiber diameter caused by using the average diameter of fiber snippets in the Laserscan versus projection microscope and OFDA measurements in which measurements at a point on the snippet are used. Theoretically, FFDA and Laserscan would produce lower CVs of fiber diameter than the PM and the OFDA. The effect is small, in the order of 0.5% of CV. For the current study, projection microscope measurements (ASTM, 1993) were used throughout.

Raw Wool Considerations

Only limited information is available concerning variability of fiber diameter in greasy wool sale lots. It is known, however, that the major source of variation exists within single staples rather than within the fleece or among fleeces within a lot (Dunlop and McMahon, 1974; Stobart et al., 1986). Whiteley et al. (1984) presented mean values observed for the SD of diameter of 2,921 sale lots of common Merino and crossbred fleece wools and skirtings (ranging in MFD from 18.5 to 36.6 µm). For all types of wool considered, SD increased with MFD. The relationships between SD and MFD were linear (but different) for each of the four types of wool considered. For the pooled results, the derived equation was:

$$SD = 0.263 \times MFD - 0.325$$

having a correlation coefficient, r = 0.903. The 95% confidence intervals for the SD of fiber diameter of an individual sale lot about the mean value for a given MFD value was ±1.0 µm. The regression equation derived in the present study for 800 sale lots of U.S. origin is somewhat different than that presented by Whiteley et al. (1984). First, the coefficient of determination of the equation for U.S. wools was higher (0.91 vs. 0.82) and the 95% confidence limits were lower (±0.72 µm vs. ±1.00 µm). One explanation for this difference was thought to be that the Australian data set included fleece wools and skirts whereas the U.S. data were from skirted and original bag wools with no lots containing skirts only. A particularly interesting aspect of the Australian work was that no difference in SD between fleece wools and skirts could be demonstrated. In fact, other research (Thompson et al., 1983) showed that variations in SD produced by different forms of clip preparation (on-farm classing, interlotting, bulk classing) are very small. The first obvious inference is that improvement (reduction) in SD cannot be achieved with skirting alone and a genetic approach must also be attempted. A second possible explanation for the different regression equations is that different instruments were used to quantify MFD and SD. In Australia, the FFDA was used while in the U.S., microprojection was the

Table 3. Standard deviation of average fiber diameter and its 95% confidence limits by grade.

Grade	Mid-point of grade, µm	Number of lots	Mean SD, µm	SD of SD, µm	Corresponding CV, %	Confidence limits 95% of SD, ± µm	Minimum SD, µm	Maximum SD, µm
50	30.15	100	7.25	0.40	24.05	0.78	6.15	8.15
54	28.57	100	6.89	0.44	24.12	0.86	6.04	7.86
56	27.12	100	6.27	0.48	23.12	0.94	4.81	7.69
58	25.67	100	5.60	0.42	21.82	0.82	4.68	6.62
60	24.22	100	5.06	0.38	20.89	0.74	4.23	6.40
62	22.77	100	4.62	0.32	20.29	0.63	4.00	5.61
64	21.32	100	4.13	0.36	19.37	0.71	3.44	5.26
70	19.87	91	3.81	0.27	19.17	0.53	3.18	4.35
80	18.42	9	3.44	0.25	18.68	0.49	3.11	3.86

measurement of choice. The FFDA is known to produce higher SD values than the microprojector while producing similar values for MFD, particularly when measuring minicored scoured wool (Qi et al., 1994). A third explanation for the different equations is that U.S. wools are more uniform in terms of fiber diameter than Australian wools. Using the Australian equation, a 20-µm Australian wool would be expected to have a SD of fiber diameter equal to 4.94 µm. This is actually higher than the maximum value of 4.59 µm permitted in the U.S. grading system. This compares to 3.78 µm for a 20-µm U.S. sale lot, obtained using the equation derived in this study.

A more recent study (Crook et al., 1994) conducted in conjunction with the Peppin Merino stud industry of New South Wales, Australia, produced measurements that tend to support the third explanation mentioned above. In addition, estimates of phenotypic correlations were calculated that indicated that standard deviation of fiber diameter is significantly ($P < 0.05$) and positively associated with traits such as handle, crimp definition, staple thickness and staple formation. Ewes displaying staple characteristics generally regarded as desirable by stud breeders tended to have lower SDs of fiber diameter. The authors advocated caution in using this phenotypic information until the genetic associations had been established. In this study, wool and fleece characteristics were examined on 100 unclassed hogget ewes in each of seven studs. Wool samples were removed from the midside region, minicored and measured for MFD and SD using the Sirolan-Laserscan (5,000 × 2 mm snippets per sample). The phenotypic correlation within a stud between MFD and SD ranged from 0.33 to 0.48. Overall, MFD was 20.10 µm with an average SD of 4.33 µm for these 700 side-samples. Using the regression equation derived for U.S. wool sale lots, a SD of fiber diameter of 3.82 µm would be estimated for 20.10-µm wool. Since midside samples would normally be more uniform in fiber diameter than commercial sale lots (of the same MFD) and since the Laserscan is known to produce SD values very similar to those resulting from projection microscope measurements (Stobart, 1994), it may be concluded that the U.S. sale lots measured in this study tend to have lower SDs of fiber diameter than the ewes in this particular Australian study.

Whiteley and Thompson (1985) estimated "coarse edge" in 2,192 greasy wool sale lots by recording the percentage of fibers greater than 1.5 times the MFD. However, they concluded that because of the close multiple correlation between this statistic and MFD and SD, any effects of coarse edge on fabric properties could be adequately predicted by these second order (MFD and SD) statistics. This was considered to be advantageous because MFD and SD can be measured more precisely than coarse edge statistics even with modern instruments. Work described in the next section (e.g., Garnsworthy et al., 1988a and b concerning fabric

Table 4. Mean values of standard deviation of fiber diameter by year and grade.

Grade	Number of lots/year	Year 1990	1991	1992	1993	1994
50	20	7.04	7.43	7.22	7.29	7.26
54	20	6.89	6.99	6.78	6.86	6.92
56	20	6.11	6.32	6.47	6.20	6.25
58	20	5.40	5.56	5.63	5.71	5.71
60	20	5.01	5.01	5.12	5.15	5.02
62	20	4.55	4.60	4.55	4.68	4.70
64	20	4.18	3.97	4.09	4.20	4.21
70	(15, 20, 17, 20, 19)[a]	5.85	3.83	3.75	3.80	3.81
80	(5, 0, 3, 0, 1)[a]	3.52	–	3.36	–	–

[a] The number of lots was not equal among years.

Table 5. Effects of year, location and grade on standard deviation of fiber diameter and other wool characteristics (P-values).

	SD[a]	AFD[b]	WB[c]	VMGB[d]
Year	0.0237	0.0064	0.0001	0.0019
Location	< 0.0001	< 0.0001	0.0001	0.0001
Grade	0.0001	< 0.0001	0.0001	0.0125

[a] SD = standard deviation.
[b] AFD = average fiber diameter.
[c] WB = wool base.
[d] VWGB = vegetable matter grease basis.

Table 6. Mean values of wool base by grade.

Grade	Number of lots	Mean wool base, %	Minimum wool base, %	Maximum wool base, %	SD of wool base, %
50	100	47.74	41.6	53.6	2.44
54	100	47.29	42.3	55.4	2.45
56	100	47.10	37.1	55.6	2.97
58	100	46.79	37.8	56.1	3.68
60	100	45.84	35.5	53.0	3.65
62	100	44.66	29.4	53.5	3.87
64	100	44.96	34.9	55.3	4.12
70	91	46.02	29.7	55.2	5.06
80	9	46.84	38.6	54.4	4.66

prickle) appears to contradict this conclusion.

Processing and Fabric Considerations

From a theoretical viewpoint, Martindale (1945; 1969) concluded years ago that there is a real (but small) effect of variability of fiber diameter on yarn evenness. From Martindale's equation for ideal yarn evenness, it can be derived (De Groot, 1992) that:

$$CV\%_{yarn} = 3.208D\sqrt{\frac{1 + 5\left(\frac{V}{100}\right)^2}{T}}$$

in which: $CV\%_{yarn}$ = coefficient of variation of yarn cross sectional area; T = yarn linear density in tex; D = mean fiber diameter; and V = CV% of fiber diameter.

This relationship was supported by the work of Lang and Rankin (1968) and Corbett et al. (1968) who showed small increases in yarn evenness, strength and extension at break with decreasing CV of fiber diameter. Turpie's work (1977) also provided evidence that the level of variability in fiber diameter of wool top influences spinning performance. However, expected improvement in fabric handle with decreasing CV was not always apparent (e.g., Hunter, 1976).

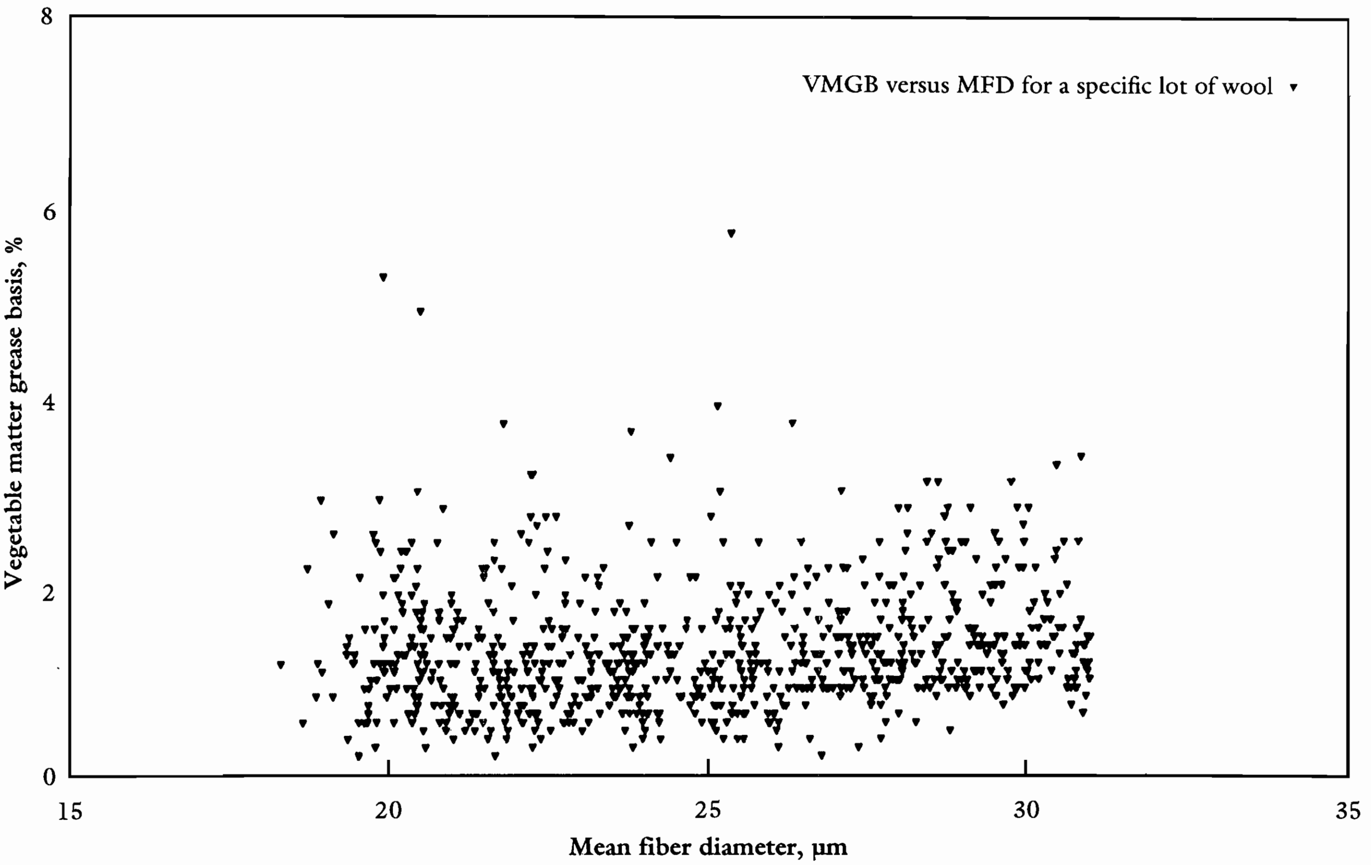
Bow and David (1992) noted the most comprehensive collection of data concerning standard deviation of fiber diameter is due to Ott (1958) who derived a relationship between SD and MFD based on measurements of 5,855 tops. In their study, Bow and David derived two linear regression equations for two different popula-

Table 7. Mean values of wool base by year and grade.

Grade	Number of lots/year	Year 1990	1991	1992	1993	1994
50	20	46.91	47.87	47.48	47.44	49.01
54	20	46.31	47.17	47.23	47.92	47.80
56	20	46.92	45.32	46.30	48.69	48.24
58	20	45.42	44.98	46.83	48.41	48.32
60	20	44.94	44.47	45.14	47.19	47.46
62	20	42.59	44.38	44.43	46.37	45.52
64	20	43.15	43.78	45.80	47.05	45.03
70	(15, 20, 17, 20, 19)[a]	41.31	45.82	49.44	47.02	45.83
80	(5, 0, 3, 0, 1)[a]	44.80	–	50.60	–	–

[a] The number of lots was not equal among years.

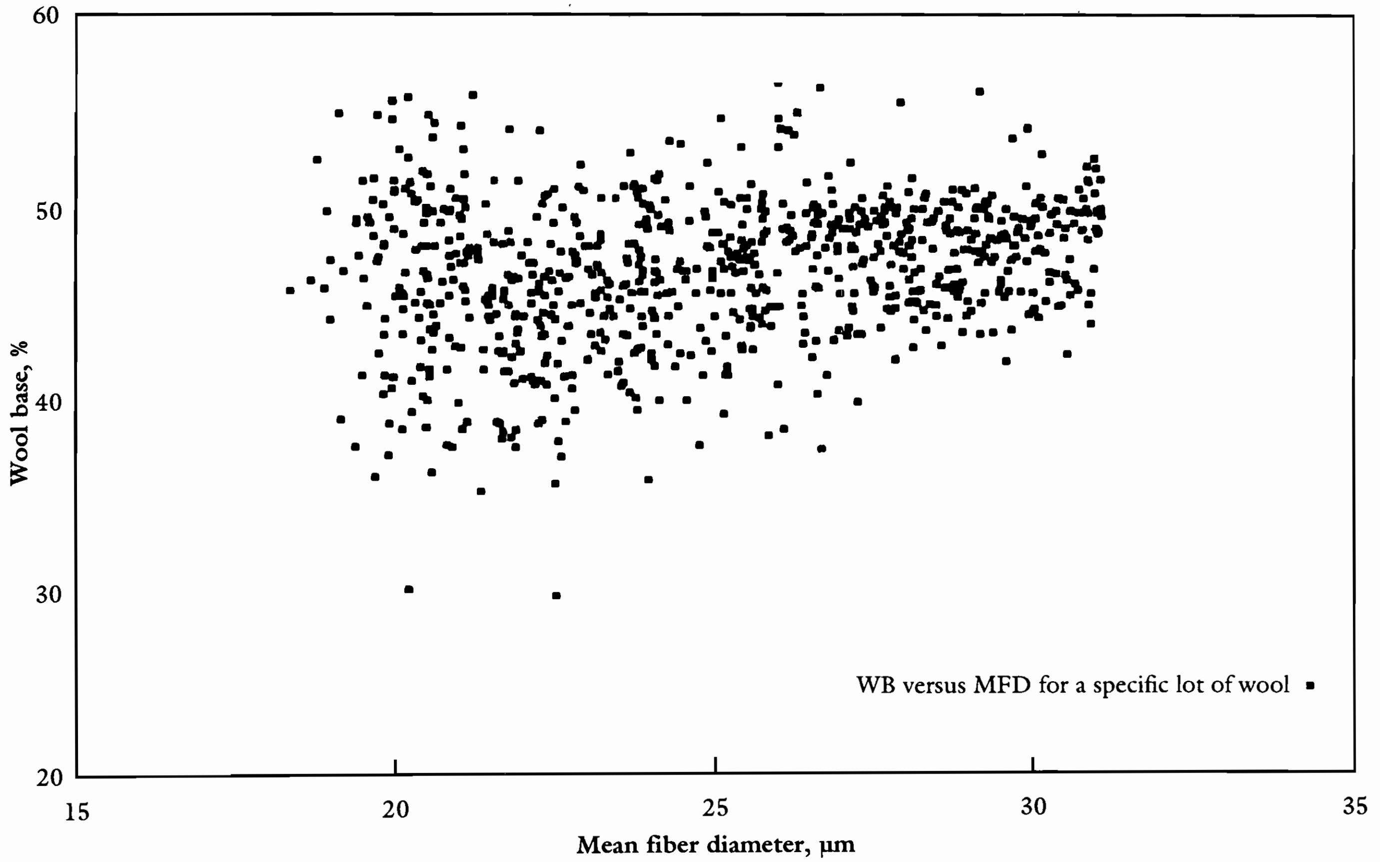
Figure 2. Vegetable matter grease basis (VMGB) versus mean fiber diameter (MFD).



tions of Australian wools. The first data set included 222 of the TEAM tops (large consignments processed commercially) while the second consisted of 162 sale display samples (processed at mini-scale plant). Measurements were made using the FFDA instrument (Lynch and Michie, 1976) on tops in the MFD range of 17 to 32 µm. Because the regression equations for the two data sets were different (and also different from a previously derived equation [Lunney, 1983]), Bow and David concluded there may not be a universal linear relationship for SD and MFD in wool tops. The authors did note that within this diameter range, CV of fiber diameter was relatively constant at 24%. Hunter (1980) pointed out that distribution of fiber diameter in raw wool closely resembles that in tops made from it despite the removal of noils and would therefore be worthy of consideration in a value-based marketing system. He also observed that CV of fiber diameter is important in processing because *(inter alia)* abnormal amounts of fine fibers in a blend result in excessive nep formation. Generally, as CV of fiber diameter increases, spinning performance decreases. However, compared to MFD, Hunter also concluded the effects of CV of fiber diameter are small. The effect on spinning limit of an increase of 1% in CV of fiber diameter is equivalent to an increase of 0.4% in MFD (Roberts, 1961). More recently, Lamb (1992) theorized that CV of fiber diameter is only about one-fifth as important as MFD. Thus a reduction in CV from 25% to 20% is equivalent to replacing a 21-µm with a 20-µm wool in terms of yarn evenness, strength and spinning performance. Such considerations increase in importance when textile mills attempt to spin the finest yarns possible at the fastest speeds possible from a specific production lot (invariably a mixture of sale lots). Hunter (1980) recognized, as many researchers have since, that an excessively high proportion of coarse fibers in an apparel wool blend would give rise to prickliness in the resulting fabric. Garnsworthy et al. (1988a,b) noted that fabric-evoked prickle in a knitted fabric is proportional to the number of fibers coarser than 30 µm, 5% being a critical cut-off point for most individuals. Kenins (1992) concluded prickle is not an allergic reaction to wool but a sensation caused by coarse fibers indenting the skin and activating pain nerve fibers. These conclusions were confirmed by Naylor (1992a), who produced similar reactions on human subjects using fabrics composed wholly of acrylic fibers.

De Groot (1992) evaluated fabrics composed of 23-µm wool having CVs ranging from 21 to 27%. He concluded that fabric bending rigidity, smoothness and perceived prickle were all related to CV of fiber diam-

Figure 3. Wool base (WB) versus mean fiber diameter (MFD).



eter. However, in his limited trial he was not able to demonstrate a relationship between CV of fiber diameter and yarn evenness or tensile properties. Participants in De Groot's subjective fabric evaluation were able to distinguish between fabrics containing 21 and 27% CV wools but not between 21 and 24% or 24 and 27%. Naylor (1992b) pointed out that the relationship between fiber diameter distributions in wool top and yarn surface fibers is actually more complex than it may first appear. In the top structure, fiber ends tend to be finer than in the bulk of the top. During spinning, coarser fibers tend to migrate to the yarn surface where relatively coarse fiber ends result in prickle.

To this point, the discussion has been concerned primarily with the effects of fiber diameter variability on apparel-type products made with apparel wools. Ross et al. (1987) studied the effects of MFD and CV in the manufacture of woolen and semi-worsted carpets from Romcross wools (MFD = 30 to 40 µm) and concluded that neither MFD nor variability of fiber diameter played a major role in either processing or product performance.

Table 8. Mean values of vegetable matter grease basis (VMGB) by grade.

Grade	Number of lots	Mean VMBG, %	Minimum VMBG, %	Maximum VMBG, %	SD of VMBG, %
50	100	1.67	0.7	3.7	0.65
54	100	1.67	0.5	3.4	0.68
56	100	1.42	0.2	3.3	0.54
58	100	1.38	0.3	6.3	0.88
60	100	1.31	0.3	4.0	0.64
62	100	1.37	0.3	3.5	0.71
64	100	1.28	0.2	4.1	0.66
70	91	1.56	0.2	5.8	0.92
80	9	1.53	0.6	3.2	0.84

Table 9. Mean values of vegetable matter grease basis (VMGB) by year and grade.

		Year				
Grade	Number of lots/year	1990	1991	1992	1993	1994
50	20	1.91	1.76	1.55	1.74	1.42
54	20	2.00	1.80	1.41	1.44	1.73
56	20	1.39	1.48	1.55	1.24	1.46
58	20	1.71	1.46	1.32	1.31	1.11
60	20	1.56	1.31	1.27	1.19	1.25
62	20	1.52	1.20	1.30	1.43	1.42
64	20	1.17	1.32	1.37	1.27	1.25
70	(15, 20, 17, 20, 19)[a]	1.88	1.70	1.80	1.33	1.18
80	(5, 0, 3, 0, 1)[a]	1.50	–	1.90	–	–

[a] The number of lots was not equal among years.

Table 10. Correlation coefficients between selected characteristics of U.S. wool (r-values and probabilities).

	MFD[a]	WB[b]	CWFP[c]	VMGB[d]
SD[e]	0.95 (< 0.0001)	0.18 (0.0001)	0.18 (0.0001)	0.17 (0.0001)
MFD[a]	–	0.23 (0.0001)	0.23 (0.0001)	0.11 (0.0014)
WB[b]	–	–	0.99 (< 0.0001)	–0.21 (0.0001)
CWFP[c]	–	–	–	–0.21 (0.0001)

[a] MFD = average fiber diameter.
[b] WB = wool base.
[c] CWFP = clean wool fibers present.
[d] VWGB = vegetable matter grease basis.
[e] SD = standard deviation.

Sheep Breeding and Management Considerations

Hansford (1992) presented a wool "quality equation" (Figure 4) showing how wool growers can use breeding and management to affect fleece quality and then use clip preparation practices to impact on the raw product or clip quality. She emphasized that producers should persevere with raw wool specification in order to supply a more desirable raw material to their customers in the textile industry. Shearing interval, the timing of shearing particularly in relation to lambing and a satisfactory supplemental feeding program are other major factors that can impact wool quality. Dunlop and McMahon (1974) estimated variation in fiber diameter in five Merino strains in the following categories: among sheep (11 to 24%); among sites over the body of the sheep (6 to 12%); among fibers within sites (61 to 80%); and among points along the fiber (3 to 6%). Stobart et al. (1986) conducted a similar study in which fiber diameter variability of fleeces from U.S. Rambouillet, Columbia, Hampshire and western white-faced (Rambouillet-Columbia cross) commercial ewes was quantified. The components of variance in fiber diameter within a lot of wool due to different sources in the case of purebred fleeces were: among fleeces (9 to 13%); among body regions (5 to 14%); among fibers (67 to 82%); and among points along the fiber (3 to 6%). These results were very similar to the earlier findings of Dunlop and McMahon (1974) and also Quinnel et al. (1973). However, Stobart et al. noted substantially higher (25 to 57%) among-fleece variation for crossbred sheep. All these studies suggest that only limited reductions in variability of fiber diameter might be expected by closer control of the sheep's environment, greater attention to uniformity among fleeces and better skirting and classing. Theoretically, SD of fiber diameter might be reduced over time by selecting sheep having low among-fiber variation in fiber diameter. This assumes such sheep exist and heritability of this trait is at least moderately high. Piper and Lax (1992) reported the heritability of SD of fiber diameter to be 0.49. According to a recent study by Gifford et al. (1994) with South Australian Merino sheep, heritability of CV of fiber diameter ranges from 0.57 to 0.73 (0.51 to 0.67 for SD of fiber diameter). Both these estimates are substantially higher than that (0.14) due to Shelton and Lewis (1986) for side-britch MFD difference but similar in magnitude to the heritability of this latter trait (0.5) calculated by Jones (1986). James and Ponzoni (1992) had earlier concluded that fiber diameter variability would respond rapidly in selection of South Australian Merinos. These authors also predicted that selection for reduced SD of fiber diameter would lead to a concurrent reduction in MFD and fleece weight. In contrast, selection for reduced CV of fiber diameter would have little or no effect on these other characteristics. Ponzoni and Brien (1993) indicated that a measure of fiber diameter variability would be incorporated into WOOLPLAN (the Australian national performance recording scheme for wool sheep breeders) in the near future, despite the paucity of information concerning phenotypic and genetic parameters and economic significance of the variability in fiber diameter measurements. Only six years ago, Rogan (1988) argued that fiber diameter variability should receive no attention as a sheep breeding objective until such time as the wool processing industry established clear price differentials. At such time, progress in reducing fiber diameter variability genetically could be achieved rapidly due to the relatively high (0.46, Rogan's estimate) heritability of within-fleece fiber diameter variability. In the meantime, selection for reduced fiber diameter by apparel wool growers would likely result in reduced fiber diameter variability. Delport and Botha (1994) reached a similar conclusion in their consideration of reducing fiber diameter and coarse edge in South African Dohne Merinos. The value of including fiber diameter variability in breeding objectives and selection criteria for Merino sheep was also studied by Piper and Lax (1992) in the context of various WOOLPLAN options. They concluded that options which result in MFD reduction would concurrently reduce SD of fiber diameter but could result in a marginal increase in CV of fiber diameter. To date, there are still no clear price signals from the wool market that would enable estimation of a relative economic weight for fiber diameter variability in a selection index. Consequently, these authors predicted the effect on gain in economic merit ($ per ewe lifetime) of including CV of fiber diameter in the selection index would be negligible.

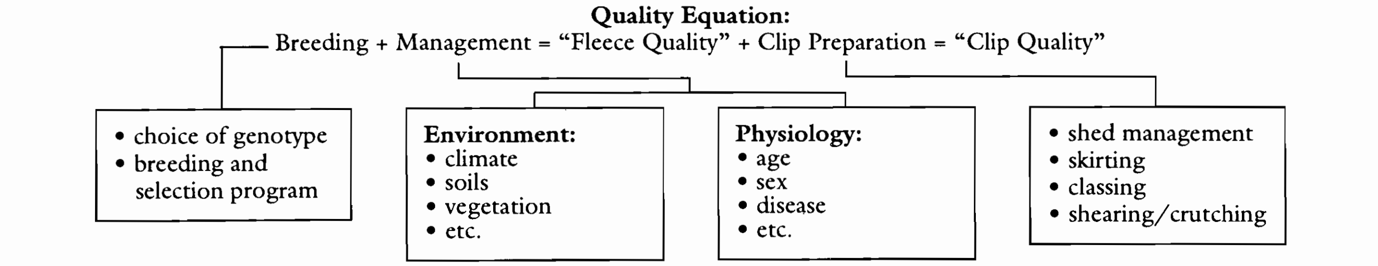
For yearling Rambouillet rams in two central performance tests, the CV of fiber diameter of whole fleeces is only poorly correlated (r = 0.15) with the difference in MFD between side and britch samples (Iman et al., 1990). These authors pointed out that even though CV provides the best estimate of fiber diameter variability for the whole fleece, it is not a good indicator of coarse edge. A major implication for ram testing and subsequent selection of stud rams is that CV is not a sensitive indicator of coarse britch wool. This objectionable trait is best examined by direct measurement or at least estimated from a histogram of the whole fleece. The former course of action, particularly when considering an animal for stud purposes, has long been advocated by Jones (1986) who concluded that the two traits "difference between side and britch MFD" and "fleece uniformity" (as indicated by CV or SD, respectively) are controlled by two different genes and thus must be selected separately.

With modern instrumentation and the availability of relatively inexpensive ($5 per sample) tests for fiber diameter distribution, the U.S. breeder now has access to a full histogram in addition to the basic fiber diameter statistics (mean, SD, CV). If samples representative of individual skirted fleeces are submitted for testing, the histogram may be used to calculate both coarse edge and potential prickle in fabrics. The former term is more general and potentially more applicable and useful to all breeds and grades of wool, though to date its use has been limited primarily to finewool breeds. The term "prickle" is more absolute, being an indication of whether fabric prickle will occur or not when a wool fabric composed of the wool being tested is worn next to the skin. Prickle, coarse edge and SD (or CV) might all be considered as selection criteria by breeders of finewool sheep.

Conclusions

This study has provided a data base containing SD of fiber diameter, yield and vegetable matter content from which progress can be assessed in future years. In addition, these data

Figure 4. Hansford's wool quality equation.



will permit an individual producer to compare the traits in his clip with the sale lots tested. The SD of fiber diameter of commercial sale lots is invariably below the maximum level permitted in the U.S. grading system. Nevertheless, further improvement in this trait is possible through selective breeding and continued attention to recommended management and clip preparation practices. Because of the continued efforts of breeders, county agents, warehousemen and many other concerned wool people and their industry associations, no evidence was found to indicate that domestic wools are more variable in terms of fiber diameter than Australian wools.

A discussion of SD of fiber diameter as it affects top making, spinning, yarn properties, fabric properties and selection of sheep for breeding was provided to assist the reader in understanding the significance of the data.

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