Evaluation of the Optical Fibre Diameter Analyser (OFDA) for Measuring Fiber Diameter Parameters of Sheep and Goats[1,2]

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ABSTRACT: The Optical Fibre Diameter Analyser (OFDA) instrument is based on automatic image analysis technology and was recently introduced to provide a rapid, accurate measurement of average fiber diameter (AFD) and diameter distribution (SD) of textile fibers. Experiments were conducted with wool and mohair in various physical forms (top, core, and staple) to compare results produced by the OFDA with two other methods of determining fiber diameter parameters: the standard projection microscope (PM) method as described by the American Society for Testing and Materials (ASTM) and the Peyer Texlab FDA 200 System (FDA200). The results show that the OFDA fiber diameter measurements were very closely related to PM measurements, and the OFDA partially overcame one shortcoming of the FDA200, overestimation of SD. The results suggest that the OFDA is a promising system for rapid and accurate evaluation of fiber diameter and its distribution.

Key Words: Image Analysis, Wool, Mohair, Sheep, Goats

J. Anim. Sci. 1994. 72:1675–1679

Introduction

Average fiber diameter (**AFD**) is the primary criterion for determining trading price (value), processing performance, and end-use of wool from sheep (Stobart et al., 1986) and mohair from Angora goats (Hunter, 1993). Much effort has been expended to develop more rapid, accurate, and efficient methods of measuring fiber diameter. Projection microscopy (**PM**) is the most widely used method in the United States and is also considered the standard method (IWTO, 1989a; ASTM, 1993b). However, PM operation is tedious and slow. Airflow methods (ASTM, 1993a; IWTO, 1989b) are relatively quick and widely used in the wool trade, but they do not measure SD. The Peyer Texlab FDA 200 System (**FDA200**; Lynch and Michie, 1976) can measure AFD and SD quite rapidly, but it cannot measure fibers coarser than 80 μm. Further, coarse (> 38 μm) fibers cause blockages in the measuring cell that frequently interrupt measuring operations. In mid-1991, a new instrument called the Optical Fibre Diameter Analyser (**OFDA**) was introduced for measuring AFD and SD (Baxter et al., 1991) and is now under intensive evaluation throughout the world.

This study was designed to evaluate the performance of the OFDA for measuring AFD and SD of wool and mohair compared with existing technologies.

Materials and Methods

The Optical Fibre Diameter Analyser (BSC Electronics Pty Ltd, Attadale, Australia) was used to measure AFD and SD of clean wool and mohair snippets (1 to 2 mm in length) using the methodology outlined in a draft method (IWTO, 1993). It was calibrated for wool fiber measurements using seven 1989 Interwoollabs IH tops and for mohair fiber measurements with eight standard mohair tops provided by the International Mohair Association. The FDA200 was calibrated in accordance with the instrument manufacturer's instructions (Siegfried Peyer AG, 1991) using the calibration tops (T146 and T147) from the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) for Experiment 3. For Experiments 1 and 2, the FDA200 was calibrated with Interwoollabs IH tops. In contrast, the PM was calibrated using a stage micrometer as described in the standard test method (ASTM, 1993b).

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[1]Approved by the Director, Texas Agric. Exp. Sta. as TA 31410.

[2]Financial support from the Cooperative State Research Service, USDA under agreement no. 92-34148-6989 and the Advanced Technology Program of the Texas Higher Education Coordinating Board is gratefully acknowledged.

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Received December 20, 1993.

Accepted March 10, 1994.

Table 1. Comparison of average fiber diameter (AFD, μm) and standard deviation (SD, μm) of wool tops by the projection microscope (PM) and the Optical Fibre Diameter Analyser (OFDA)

Wool top identity	PM (ASTM)[a]			OFDA (IWTO)[b]			Difference (PM − OFDA)	
	AFD	SD	n[c]	AFD	SD	n[c]	AFD[d]	SD[e]
A	26.1	6.2	12,000	26.2	6.5	4,000	−.1	−.3
B	19.6	4.2	12,000	19.9	4.6	4,000	−.3	−.4
C	26.7	6.7	18,000	26.5	6.8	4,000	+.2	−.1
D	18.9	3.7	9,600	19.0	4.1	4,000	−.1	−.4
E	28.2	6.6	15,600	28.1	6.7	4,000	+.1	−.1
F	21.5	4.9	10,400	21.7	5.1	4,000	−.2	−.2
G	23.3	5.4	11,200	23.5	5.6	4,000	−.2	−.2

[a]American Society for Testing and Materials.
[b]International Wool Textile Organization.
[c]Number of fibers measured for each sample.
[d]No difference was found in the AFD measurements between the OFDA and PM ($P > .16$).
[e]SD measurements between the OFDA and PM differed ($P < .005$).

Experiment 1

The AFD and SD of seven wool tops (18.9 to 28.2 μm) were determined using the OFDA. Results were compared with mean values obtained by U. S. fiber labs in round trials organized by Yocom-McColl Testing Laboratories (A. McColl, personal communication). Forty mohair tops representing a broad cross-section of AFD (22.1 to 36.6 μm) were tested using the OFDA and FDA200. Results were compared with those obtained using the standard ASTM PM method (ASTM, 1993b).

Experiment 2

Sixty wool and 25 mohair core samples (12.7-mm cores) were measured for AFD and SD using the OFDA, FDA200, and the standard ASTM PM method. Results generated by the different measuring systems were compared.

Experiment 3

One hundred fifty-five wool staples removed from mature Rambouillet rams (Lupton et al., 1993) were measured using the OFDA and FDA200.

In summary, our protocol was to evaluate the OFDA for measurement of AFD and SD and compare the results to those obtained using the PM and FDA200.

Statistical Analyses

The OFDA, FDA200, and PM measurements of the wool and mohair samples were compared using the paired *t*-test (Steel and Torrie, 1980). The analyses were accomplished using the MEANS procedures of SAS (1992). The AFD differences between OFDA and PM measurements were plotted against the PM AFD values to test the systematic bias of OFDA measurements. The linear correlation coefficients and Spearman's coefficients of rank correlation (Steel and Torrie, 1980) were calculated for measurements of the same wool and mohair samples by different measuring systems.

Results

Experiment 1

Compared with other physical forms, wool top is a relatively uniform structure; this uniformity is obtained by multiple mechanical blendings in worsted processing. Table 1 shows the results of PM and OFDA measurements on seven wool tops. No differences ($P > .16$) existed between AFD values generated by the OFDA and the PM. However, OFDA SD values were higher (.23 μm, $P < .005$) than the PM measure of variability. For the 40 mohair tops, no differences in AFD were found between the results generated by the OFDA and the FDA200 (Table 2); however, both the OFDA and FDA200 generated slightly smaller AFD values (−.22 and −.15 μm, respectively; $P < .05$) than those produced by the PM. The SD of AFD measurements was higher ($P < .0001$) for the OFDA and FDA200 than for the PM, whereas the SD of AFD measurements by the OFDA was lower ($P < .0001$) than that generated by the FDA200.

Experiment 2

For the 60 wool core samples, OFDA-generated AFD values were .26 μm smaller ($P < .001$) than the standard PM results (Table 3). The FDA200-generated AFD values were .66 μm larger ($P < .0001$) than values produced using the PM method. Though small, these differences have significant implications for the wool trade because large quantities of wool are regularly traded using results based on core samples. However, in selecting sheep for breeding, we are often more interested in ranking the sheep according to

Table 2. Comparison of average fiber diameter (AFD, μm) and standard deviation (SD, μm) of 40 mohair tops by the projection microscope (PM), the Optical Fibre Diameter Analyser (OFDA), and the Peyer Texlab FDA200 System (FDA200)[a]

Comparison[b]	Difference	SE	*t*-value	*P* <
AFD				
OFDA vs PM	−.22	.01	2.70	.0105
OFDA vs FDA200	−.07	.08	.81	.4218
FDA200 vs PM	−.15	.07	2.32	.0129
SD				
OFDA vs PM	1.10	.16	6.73	.0001
OFDA vs FDA200	−.61	.10	6.09	.0001
FDA200 vs PM	1.71	.23	7.41	.0001

[a]Average fiber diameter of 40 mohair tops ranged from 22.1 to 36.6 μm by the projection microscope method.
[b]Fibers measured per sample by different methods: PM: 800; OFDA: 4,000; FDA200: 2,000.

their fiber diameters than in absolute values. Using Spearman's coefficient of rank correlation, we analyzed the rank correlation between OFDA and PM ($r = .9743$, $P < .0001$), between FDA200 and PM ($r = .9830$, $P < .0001$), and between OFDA and FDA200 ($r = .9829$, $P < .0001$). The three measurement methods ranked the samples similarly.

The SD of AFD values for the 60 wool cores were much lower for the OFDA than for the FDA200 (−1.25 μm, $P < .0001$). One explanation for the inaccurate performance of the FDA200 with wool core samples involves the physical state of the samples as measured. During the aqueous cleansing process of greasy wool cores, a certain degree of fiber entanglement (felting) is unavoidable. Consequently, samples removed from scoured wool cores contain more entangled fibers than samples removed from wool staples or tops. To establish whether fiber entanglement is a factor in the performance of the FDA200 and OFDA, the 60 scoured wool core samples were remeasured after they were passed through a Shirley Analyser (SDL 102A-MK II, Wool Model, Shirley Developments Ltd, Stockport, U.K.), a machine designed to remove fiber entanglements and nonfibrous impurities. The results indicated that the Shirley Analyser can be used to partially overcome the felting effects of the cored wool samples on SD measurements by the FDA200 (Table 4). However, using the Shirley Analyser for sample preparation to measure fiber diameter is time-consuming and impractical. Therefore, we suggest that the FDA200 be used to measure solvent-cleansed cores, staples and tops only, caution being exercised when using it to measure wool cores that have been scoured in water.

Table 3. Comparison of average fiber diameter (AFD, μm) and standard deviation (SD, μm) of 60 scoured wool core samples by the projection microscope (PM), the Optical Fibre Diameter Analyser (OFDA), and the Peyer Texlab FDA200 System (FDA200)[a]

Comparison[b]	Difference	SE	*t*-value	*P* <
AFD				
OFDA vs PM	−.26	.08	3.48	.001
OFDA vs FDA200	−.93	.07	12.56	.0001
FDA200 vs PM	.66	.07	10.06	.0001
SD				
OFDA vs PM	.46	.07	6.78	.0001
OFDA vs FDA200	−1.25	.08	15.85	.0001
FDA200 vs PM	1.71	.06	27.63	.0001

[a]Average fiber diameter of 60 scoured wool core samples ranged from 18 to 33 μm using microprojection method.
[b]Fibers measured per sample by different methods: PM: 800, OFDA: 4,000; FDA200: 2,000.

Table 4. Effects of Shirley Analysis on wool core measurements by the Optical Fibre Diameter Analyser (OFDA) and the Peyer Texlab FDA200 System (FDA200)[a]

Item[b]	Difference[c]	SE	*t*-value	*P* <
OFDA				
AFD, μm	.17	.07	2.69	.0093
SD, μm	.18	.06	2.72	.0086
FDA200				
AFD, μm	−.04	.06	.62	.5361
SD, μm	.36	.08	4.51	.0001

[a]Average fiber diameters of 60 scoured wool core samples ranged from 18 to 33 μm using microprojection method.
[b]AFD: average fiber diameter.
[c]Differences between wool cores before and after Shirley Analysis.

Plotting the AFD differences between OFDA and PM methods vs the PM AFD values (Figure 1) indicated a significant linear correlation ($r = .51$; $P < .0001$). Compared with PM, AFD values generated by the OFDA seem to be slightly biased in a negative direction at the coarse end of the AFD spectrum. A similar observation was noted by the OFDA programmer (Brims, 1993) and efforts are underway to correct this problem.

Unlike their wool counterparts, the mohair core samples do not felt when scoured in water. As a result, the AFD of 25 mohair cores generated by the different testing systems (OFDA, FDA200, and PM methods) were within ±.20 μm limits (data not shown), indicating that the OFDA system is very well suited for measuring mohair in any of the common physical forms: staples, tops, and cores.

Experiment 3

For the 155 wool staples removed from mature Rambouillet rams (Lupton et al., 1993), the OFDA produced AFD values that were on average .23 μm

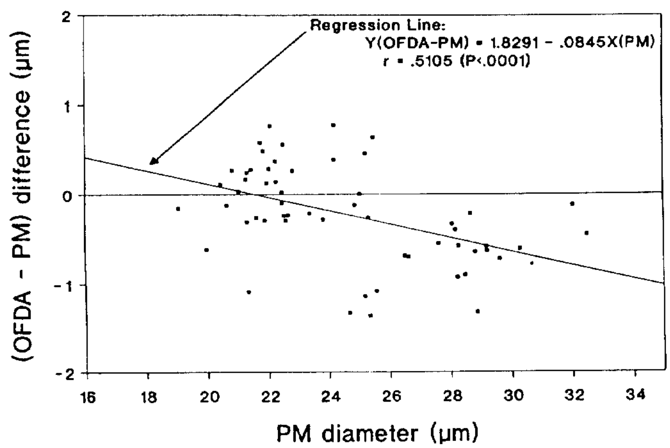

Figure 1. Differences between average fiber diameter (AFD) measurements of the Optical Fibre Diameter Analyser (OFDA) and standard microprojection (PM) on 60 wool core samples

smaller ($P < .0001$) than those measured using the FDA200 (Table 5). This difference was shown to be primarily due to the different calibration wool tops used (1992 Interwoollabs IH wool tops for the OFDA and Australian CSIRO wool tops T146 and T147 for the FDA200). Both T146 and T147 tops measured .2 μm finer ($P < .05$) than their stated values when measured on the OFDA calibrated with Interwoollabs tops. The SD values were again lower for the OFDA than for the FDA200 (−.18 μm, $P < .0001$) (Table 5), indicating that the OFDA partially overcame one shortcoming of the FDA200, overestimation of SD.

Discussion

Because AFD determines processing performance and end-use of wool from sheep (Stobart et al., 1986) and mohair from Angora goats (Hunter, 1993), AFD is one of the most important characteristics for determining the free market price of wool and mohair. More rapid, accurate, and efficient methods of measuring fiber diameter are therefore of considerable interest. Before 1920, evaluation of AFD was based on experience and expertise in visual and manual appraisal (Anderson, 1976). Although subjective techniques are still used as a preliminary means of evaluation, such methods are inaccurate due to human perceptual bias. Since 1920, the PM has been widely used for measuring AFD and SD and is still considered the standard method (Mennerich, 1936; IWTO, 1989a; ASTM, 1993b). Because measurements are performed manually, the PM method is subject to human error, tedious, time-consuming, and expensive. Trained technicians can measure only 200 fibers in approximately 15 min. With the amount of variability normally associated with the diameter of the fibers, it would typically be necessary to measure 3,014 fibers to obtain accuracy of ± .2 μm (95% confidence limit) when measuring a wool sample having an AFD of 21 μm.

Instruments based on airflow and pressure drop across a plug of fibers were developed to measure the linear density of cotton and were later modified to measure the AFD of wool and mohair. Airflow methods (e.g., IWTO, 1989b; ASTM, 1993a) are now widely used throughout the world. A critical drawback of the airflow system is its inability to measure the SD of AFD, which is also a very important parameter of natural fibers (Hansford, 1992; Lamb, 1992; Rottenbury, 1992).

Research in the 1970s resulted in the introduction of two instruments, the Particle Measurement Computer (**PiMc**) System (Pohle, 1975) and the Peyer Texlab FDA 200 System (FDA200; Lynch and Michie, 1976) based on image analysis and laser technology, respectively. Both instruments were capable of measuring AFD and SD of animal fibers in a relatively short time compared with the PM. The FDA200 was more automated and faster than the PiMc but suffered from three shortcomings. First, it was incapable of measuring animal fibers coarser than 80 μm. Second, fiber blockages at the measuring cell frequently interrupted measuring. Third, the FDA200 produced measures of SD that were substantially greater than the values produced by PM (Hansford, 1992). The latest version of the FDA200, the Sirolan Laserscan (Commonwealth Scientific, Industrial and Research

Table 5. Comparisons between the Optical Fibre Diameter Analyser (OFDA) and the Peyer Texlab FDA200 System (FDA200) on wool staple measurements[a]

			Paired t-test (OFDA − FDA200)			
Item[b]	OFDA[c]	FDA200[d]	Difference	SE	t-value	P <
AFD, μm	24.96	25.19	−.23	.04	5.08	.0001
SD, μm	4.46	4.64	−.18	.03	5.63	.0001

[a]n = 155.
[b]AFD: average fiber diameter, ranged from 19 to 32 μm.
[c]More than 4,000 fibers per sample were measured.
[d]1,000 fibers per sample were measured.

Organisation, Division of Wool Technology, Sydney, Australia), was recently introduced and seems not to contain the previously listed problems (Baird and Barry, 1993). However, the instrument is quite expensive (more than $100,000), considering that it is capable of measuring only two fiber parameters (AFD and SD).

To meet the need for a less expensive and potentially more versatile instrument, BSC Electronics Pty Ltd introduced the OFDA in mid-1991 (Baxter et al., 1991). The retail price of this instrument is $59,000. The OFDA combines attributes of the projection microscope with the latest automatic image analysis technology to produce a rapid and efficient method of measuring AFD and SD. It consists of a microscope fitted with a motor-driven stage, charge-coupled device (CCD) camera, a video monitor, and a computer installed with image acquisition and analysis hardware and software. This study was conducted to compare results produced by the OFDA, the standard PM method as described by ASTM, and the FDA200. Our results show that the OFDA fiber diameter measurements were very closely related to PM measurements, and the OFDA partially overcame one shortcoming of the FDA200, overestimation of SD. Our results suggest that the OFDA is a promising system for rapid and accurate evaluation of fiber diameter and its distribution.

Implications

The Optical Fibre Diameter Analyser is a promising system for rapid evaluation of average fiber diameter and its distribution. It can accurately and rapidly measure wool and mohair in the form of staples, tops, and cores. Further improvement of the Optical Fibre Diameter Analyser (OFDA) software is required to accurately measure the standard deviation of fiber diameter. Application to the International Wool Textile Organisation for official endorsement of OFDA (and other systems based on image analysis principles) indicates the considerable commercial potential for using image analyses for wool and mohair characteristics.

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