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CORRELATION STUDIES INVOLVING

The Physical Characteristics of Wool Fibers From Different Breeds of Sheep

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CORRELATION STUDIES INVOLVING THE PHYSICAL CHARACTERISTICS OF WOOL FIBERS FROM DIFFERENT BREEDS OF SHEEP

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INTRODUCTION

The sheep, most important of the wool-bearing animals, was originally a hairy animal with an under coat of wool. Through years of selection and breeding, both mutton and wool production have been materially increased in each of the commonly recognized breeds. Although some breeds are maintained primarily for wool and others primarily for mutton, in either case wool production is of recognized importance. The significance of the wool clip in the United States is emphasized by the fact that approximately 400 million pounds are produced annually.

The factors which primarily determine the quality and value of wool are length, fineness, crimp, shrink, and strength. Weight is influenced to a marked degree by length. The weight of a fleece from a particular sheep depends on length, density, and the amount of yolk and foreign material present; but the grade of wool is determined by the diameter or fineness of fiber. Length of staple determines the classification of wool into combing, French combing, or the clothing class. The longer wools are classified as combing; and, as the name implies, wools of this class are combed. Combed wool is used in the manufacture of worsted and similar materials.

French or baby combing wool is intermediate in length between combing and clothing; it is too short to be combed by the ordinary comb but long enough to be combed by the use of the specially constructed French comb.

Since clothing wool is too short to be combed by the ordinary wool machinery it is carded in the preparation for spinning. This class of wool is used for the manufacture of the various kinds of woolens. Thread made from carded wool cannot be spun as tightly nor as firmly as worsted yarn, hence the difference in texture between woolen and worsted materials. The manufacture of certain of the higher quality materials requires the use of worsted yarn, which demands the use of the longer wools. This and the fact that combing wools are adapted to a greater variety of uses makes wool of this class more valuable than clothing wool.

OBJECT OF STUDY

Preliminary observations[2], made in 1925 on the fleeces clipped from the flocks owned by the Oklahoma Agricultural and Mechanical College, revealed a wide range of variation for length of fiber among the individuals within a breed. Among the Southdown and Rambouillet fleeces there was an impressive percentage that measured around two inches in length. These short fleeces on the whole were either fine or half-blood. These facts suggested the need for more knowledge concerning the relationship between various fiber characters. Thus the primary purpose of the investigation was to determine the degree of correlation existing between the principal physical characters that are considered in grading and classing wool. It was assumed that a knowledge of such relationships should prove helpful in flock selection.

MATERIALS AND METHODS

The data on which this report is based were taken from fleeces clipped from the breeding flock owned by the Oklahoma Agricultural and Mechanical College. The flock was maintained for teaching purposes and was fed in accordance with approved practices in sheep husbandry. This flock included the C type Rambouillet, Dorset, Shropshire, Southdown, Hampshire, and Oxford breeds.

The sheep were sheared in the spring, about the middle of April in accordance with the usual practice. Bulk samples of each fleece were taken at shearing time at a point immediately back of the shoulder about midway between the back and the belly. The bulk samples were placed in paper envelopes and taken to the laboratory where they were stored until examination could be made. Before measurements were determined, a small sample was taken from each of the bulk samples and scoured in benzine. After scouring, the small samples were placed in desiccator jars to maintain a reasonable minimum of change in moisture content. Hardy (1920) observed that the ultimate strength of scoured and unscoured wool was affected by humidity.

Preliminary measurements were made to determine the minimum number of fibers necessary for a sample. A minimum number was essential because of the time required in determining the individual fiber measurements. It was assumed empirically that a sample showing a relatively normal distribution curve and yielding a probable error of only 3 percent of the mean would be adequate to establish significant differences between the different fleeces for the characters observed. After a study of 20 fleeces chosen at random for the different breeds it was concluded that a sample of 100 fibers drawn from a lock should provide reasonably significant differences for the characters studied except for stretch and breaking strength. Hill (1911) pointed out that even much larger samples may not give reliable differences for these.

Diameter measurements were made at about the middle of the fiber with a Brown-Sharpe machinist's micrometer-caliper. This caliper is graduated in ten-thousandths of an inch. Burns and Koehler (1925) compared the measurements from this micrometer-caliper with microscopic measurements and concluded that one ten-thousandths of an inch shuold be added to the caliper measurements to give them the same value as microscopic measurements.

Length of fiber was determined by holding each end of the fiber with tweezers and drawing it over a scale so that the natural length was measured as nearly as possible. The results were recorded in millimeters.

Crimps in a one inch length of fiber were determined by counting the number of crimps that appeared in an inch space cut into a black cardboard when the fiber was drawn under this space.

Stretch and breaking strength were determined with a MacKenzie fiber testing apparatus. Stretch was recorded in millimeters and breaking strength in decigrams. Care was taken when a fiber was placed in the MacKenzie apparatus to avoid using the portion of the fiber that had been in the jaws of the micrometer-caliper. This was for the purpose of avoiding the introduction of errors which were thought to be possible in some cases due to accidental crushing of the fiber when diameter was measured. Thus the tip end was measured in some instances and the base end in others.

The method of calculation employed was that described by Wallace and Snedecor (1925). Simple correlation coefficients were calculated for a measure of the relationship between the various fiber characters. Correlation coefficients give a numerical measure of the relationship that exists between characters due to a common causal factor or factors. Although

TABLE I.—A Summary of the Means, Range of the Means,* and the Standard Deviations of the Fibers by Breeds.

			DIAMETER			LENGTH			CRIMP			STRETCH			BREAK		
Breed	Year	No. Flcs.	Mean Diam.	Range of Means	Ave. S. D.	Mean Length	Range of Means	Ave. S. D.	Mean Crimp	Range of Means	Ave. S. D.	Mean Strch.	Range of Means	Ave. S. D.	Mean Break	Range of Means	Ave. S. D.
Oxford	1926	8	12.31	10-14	1.76	101.47	90-116	7.74	5.31	3- 7	1.43	7.17	6- 8	2.32	196.84	161-267	57.46
	1927	12	9.61	7-11	1.68	107.35	77-132	11.40	7.90	6-10	1.61	7.55	6- 9	2.03	159,69	107-255	47.37
	1928	8	11.48	10-14	1.75	112.13	94-141	8.68	5.47	4- 7	1.22	7.88	7- 9	2.25	191.65	119-259	53,65
Mean		28	10.91			107.03			6.46			7.53			179.43		
Southdown	1926	14	9.54	8-11	1.52	66.37	52- 98	6.44	8.24	4-10	1.76	6.01	3-10	2.10	109.17	65-178	38.00
	1927	10	8.08	6- 9	1.60	75.04	53- 97	9.84	9.83	8-12	1.76	6.47	6- 8	1.85	110.01	62-154	33.22
	1928	24	8.79	7-12	1.50	56.37	39- 82	5.74	10.50	7-17	1.70	4.94	4- 7	1.66	115.07	81-184	38.54
Mean		48	8.86			63.17			9.70			5.57			112.29		
Hampshire	1926	3	11.13	10-11	1.65	64.27	56- 76	12.55	7.26	7- 8	1.68	6.02	5- 8	2.47	128.40	103-160	46.60
	1927	12	8.24	7- 9	1.47	82.08	51-109	10.38	8.98	7-10	1.71	6.94	6- 8	1.88	119.27	85-156	35.46
	1928	14	9.85	8-11	1.57	81.11	51-107	8.72	7.04	5-10	1.33	7.69	6- 8	2.08	147.06	97-229	44.42
Mean		29	9.31			79.76			7.86			7.20			133.63		
Shropshire	1926	17	9.52	8-10	1.78	79.94	63-112	7.83	7.70	6-10	1.80	6.16	3- 8	2.23	123.42	85-154	47.86
	1927	23	8.60	6-10	1.69	94.44	71-119	12.18	9.95	7-16	1.88	7.29	6- 9	1.91	134.39	99-170	39.51
	1928	24	9.66	6-13	1.86	85.46	54-102	8.71	7.89	5-12	1.51	6.46	5- 9	2.02	128.33	84-232	45.31
Mean		64	9.23			87.33			8.60			6.68			129.28		
Dorset	1927	31	9.48	7-13	1.54	98.57	80-137	10.92	8.54	7-13	1.69	7.65	7- 9	1.90	151.45	77-257	36.88
	1928	34	11.46	9-14	1.51	90.07	51-126	7.73	5.18	4- 9	1.13	7.56	4- 9	2.27	180.22	108-273	47.18
Mean		65	10.79			94.12			6.79			7.34			166.50		
Ramb.	1926	12	7.40	6- 9	1.19	52.47	49- 88	5.25	13.00	11-18	2.01	7.60	7- 9	2.35	69.40	44- 92	16.60
	1927	23	6.34	5- 8	1.48	69.62	52-111	10.10	14.27	8-18	2.52	6.00	5- 7	1.81	74.08	53-105	22.12
	1928	31	6.40	5- 8	0.99	63.46	49- 98	4.75	14.31	9-19	1.43	6.21	4-10	1.56	68.74	48- 91	20.01
Mean		66	6.56			63.60			14.05			6.38			70.72		

*These readings are to the closest whole number.

correlation implies a causal relation or an interrelation between separate characteristics by which they tend to move, its existence may not yield knowledge of the nature of the causes themselves. At the outset it was desired to determine if diameter and length of fiber were closely or loosely related, since a knowledge of this relationship should be helpful in flock selection.

RESULTS

Diameter of Fiber

In Table I a summary is given showing the mean* of the means for diameter, length, crimp, stretch, and breaking strength of the fibers for the different clips by breeds. The ranges between the means from the lowest to the highest for each year for the different breeds are shown. Averages of the standard deviations are also given.

Inspection of Table I reveals the variation among the means of the different fleeces of the six breeds studied. It is of interest that the means for diameter in 1927 are smaller for each breed than for either 1926 or 1928** but a reason for this is not apparent at present.

The variation of the means of fiber diameter among breeds, as indicated by an analysis of variance, is much greater than within breeds. The mean square for the means of breeds is 33 times greater than within breeds. This is about 10 times greater than is needed to give a highly significant value.

An analysis of variance of fiber diameter for the Hampshire and Dorset breeds is shown in Table II. (According to the method described by Snedecor 1934.) The difference for the mean square between the breeds and within the breeds is twice as large as is needed to give a highly significant value.

TABLE II.—Analysis of Variance of Fiber Diameter for the Hampshire and Dorset Breeds.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	93	298.87	
Between breeds	1	43.92	43.92
Within breeds	92	254.95	2.77

Dorset	M=10.79
Hampshire	M= 9.31
Difference	= 1.48

A similar analysis comparing the mean fiber diameter for the Rambouillet and the Southdown shows a highly significant difference between the means for these two breeds; but the difference between the means for fiber diameter for the Hampshire and Shropshire breeds is insignificant. Likewise the Dorset and Oxford breeds did not yield a significant difference between the means for fiber diameter. Inspection of the means shown in Table I reveals that further comparison of the differences between the breeds for fiber diameter is unnecessary.

*The mean as used in this report is the unweighted mean.

**Some of the data on the Dorset fleeces for 1926 were lost in moving or in the re-establishment of the wool laboratory after a fire in 1932.

On the whole, frequency distribution curves for diameter were somewhat asymetrical and about half of those constructed were multimodal. Spoettel (1925) reported asymmetrical frequency distributions for fiber diameter for several different breeds of sheep but according to Landauer (1926), Spoettel pointed out that monomodal frequency curves with a high mean could be established for some breeds including the Merino, Hampshire, and Oxford.

Two frequency distribution curves for diameter are shown in Figure 1. One of these (Curve A) is for an Oxford fleece which happened to give one of the symmetrical, monomodal, and relatively smooth curves. The other (Curve B) is for a Rambouillet fleece which gave the largest standard deviation found among the fleeces for this breed. It is representative of the asymmetrical and multi-modal type of curve observed for the samples studied.

The variability in the fineness of individual fibers observed in this study is in agreement with the work on wool reported by others. Three sources of this variation are apparent:

First, wool fibers are not entirely cylindrical, which should result in two possible measurements, namely, thickness and breadth. Therefore, it appears that caliper measurements should on the whole record the thinner dimension, since the fibers would have a tendency to turn in the jaws of the caliper so the smaller dimension would rest in the jaws of the instrument when the reading is taken.

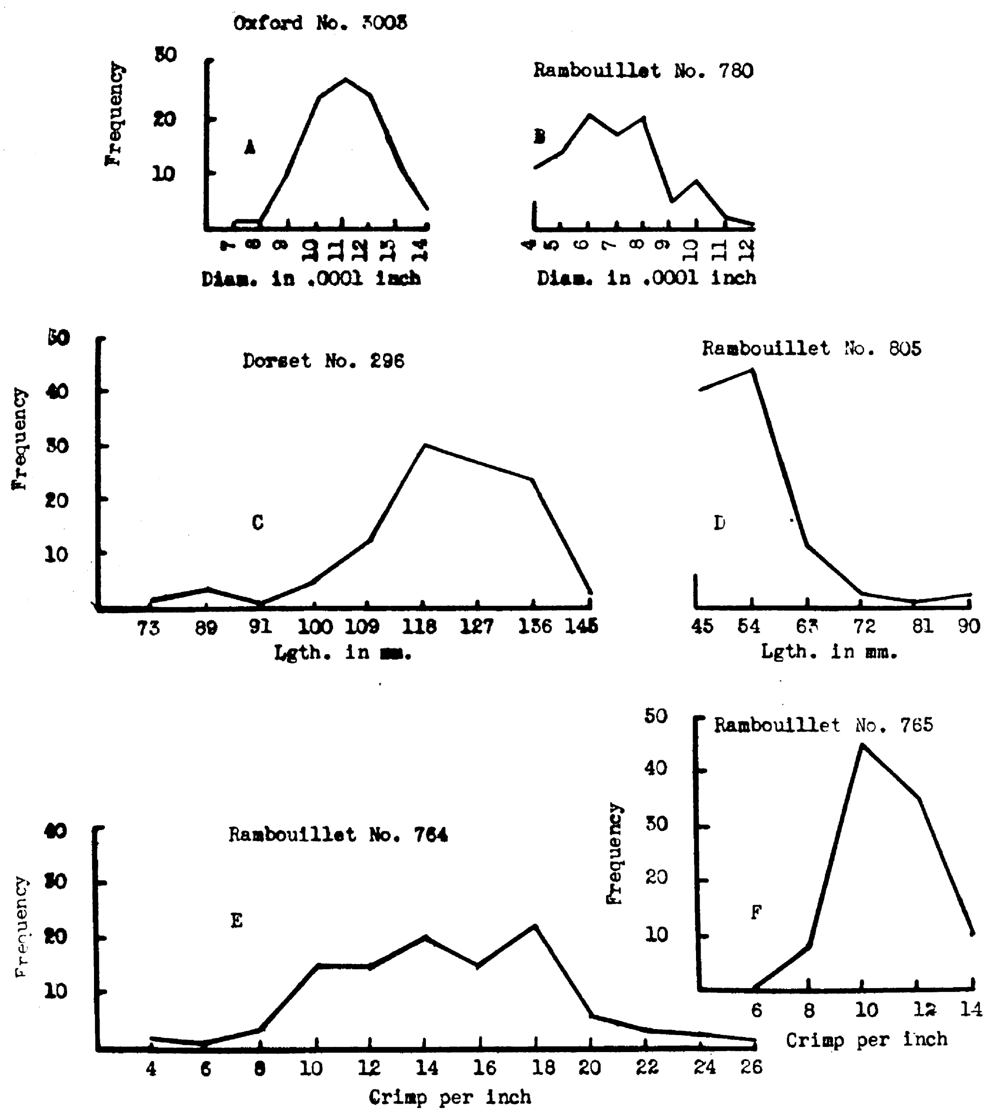
Second, wool fibers apparently vary somewhat in diameter at different points along their length. In general, however, it is reasonable to assume that measurements made near the middle of the fiber on 100 different fibers should include both the larger and smaller regions with approximately equal frequency. Duerden and Bosman (1926) have pointed out that the variations in fiber diameter at different places along the length of a particular fiber are so small in comparison with the range of diameter among different fibers that for all practical purposes the variations within a single fiber can be neglected.

Third, there are actually relatively fine and coarse fibers within a sample of fleece regardless of the body location from which it is taken.

Length

Averages of the means for length of fiber are shown in Table I. Two frequency distribution curves are presented in Figure 1 to show the general types of curves observed. One of these (Curve C) is for a Dorset fleece which yielded the largest standard deviation found for this breed. The other (Curve D) is for a Rambouillet fleece yielding a standard deviation of the lowest magnitude found among the fleeces for this breed. These two curves represent extremes of the two common types shown by the data presented in this report. Length was no more variable than diameter in relation to the size of the mean. The ranges of the means for the different years reveal that the fibers from some of the fleeces for each of the breeds except the Oxford were less than 2½ inches in length. This is an important fact, since length is of major importance in determining the class of wool and also influences the weight of a fleece.

For the Southdown fleeces, 20.8 percent were 50 mm. or less in length, and 9.1 percent of the Rambouillet fleeces were in this range, while the fleeces for the other breeds exceeded this length. A length range from 51 to 65 mm. was found to contain 51.5 percent of the Rambouillet fleeces, 37.5 percent of the Southdown, 3.1 percent of the Dorset, 17.2 percent of the Hampshire, and 6.3 percent of the Shropshire. Only 39.4 percent of the Rambouillet fleeces exceeded 65 mm. in the mean fiber length, 41.7 percent of the Southdown, 82.7 percent of the Hampshire, 93.7 percent of the Shrop-



Oxford No. 3003
Frequency
30
20
10
A
7 8 9 10 11 12 13 14
Diam. in .0001 inch
Rambouillet No. 780
B
4 5 6 7 8 9 10 11 12
Diam. in .0001 inch
Dorset No. 296
Frequency
50
40
30
20
10
C
73 89 91 100 109 118 127 136 145
Lgth. in mm.
Rambouillet No. 805
D
45 54 63 72 81 90
Lgth. in mm.
Rambouillet No. 764
Frequency
40
30
20
10
E
4 6 8 10 12 14 16 18 20 22 24 26
Crimp per inch
Rambouillet No. 765
Frequency
50
40
30
20
10
F
6 8 10 12 14
Crimp per inch

Figure 1

TABLE III.—Summary of the Averages of the Correlation Coefficients for Diameter of Fiber and the Other Characters Observed, and the Ranges of the Coefficients by Breeds.

Breed	Year	No. Fleeecs	Diam. and Length	Range of Coefficients	Diam. and Crimp	Range of Coefficients	Diam. and Stretch	Range of Coefficients	Diam. and Break	Range of Coefficients
Oxford	1926	8	+0.45	+.15 to +.66	−0.47	−.12 to −.78	+0.19	.00 to +.43	+0.75	+.59 to +.90
	1927	12	+0.26	+.06 to +.51	−0.20	−.01 to −.51	+0.29	+.07 to +.60	+0.66	+.21 to +.86
	1928	8	+0.38	+.24 to +.49	−0.10	−.02 to −.72	+0.09	+.06 to +.28	+0.48	+.08 to +.77
Southdown	1926	14	+0.43	+.14 to +.64	−0.62	−.42 to −.73	+0.05	−.11 to +.36	+0.62	+.23 to +.86
	1927	10	+0.29	−.02 to +.57	−0.25	−.09 to −.40	+0.36	+.04 to +.64	+0.70	+.34 to +.84
	1928	24	+0.28	+.07 to +.60	−0.10	−.03 to +.29	+0.15	−.04 to +.37	+0.56	−.26 to +.78
Hampshire	1926	3	+0.42	+.14 to +.92	−0.39	−.23 to +.54	+0.05	−.22 to +.21	+0.85	+.79 to +.95
	1927	12	+0.27	+.09 to +.69	−0.17	−.02 to +.41	+0.36	+.04 to +.65	+0.70	+.34 to +.84
	1928	14	+0.16	−.67 to +.33	−0.17	−.01 to −.52	+0.22	−.08 to +.55	+0.57	−.16 to +.78
Shropshire	1926	17	+0.53	+.34 to +.71	−0.61	−.07 to −.85	+0.12	−.11 to +.51	+0.81	+.66 to +.92
	1927	23	+0.26	+.01 to +.70	−0.16	−.55 to +.22	+0.39	−.03 to +.76	+0.69	+.38 to +.95
	1928	24	+0.28	+.01 to +.86	−0.20	.00 to −.69	+0.29	−.11 to +.54	+0.49	+.05 to +.78
Dorset	1926	20*	+0.30	−.01 to +.74	−0.42	−.20 to −.89	+0.05	−.44 to +.50	+0.61	+.29 to +.96
	1927	31	+0.21	−.16 to +.68	−0.12	−.54 to +.31	+0.33	−.01 to +.78	+0.64	+.36 to +.94
	1928	34	+0.16	−.34 to +.86	−0.16	−.58 to +.23	+0.10	−.42 to +.67	+0.53	−.19 to +.97
Rambouillet	1926	24*	+0.34	−.42 to +.75	−0.11	−.37 to +.40	+0.10	−.29 to +.88	+0.59	+.18 to +.95
	1927	23	+0.35	+.01 to +.55	−0.15	−.88 to +.24	+0.26	−.08 to +.49	+0.51	−.09 to +.82
	1928	31	+0.25	−.33 to +.70	−0.11	−.01 to −.69	+0.38	−.22 to +.68	+0.56	+.28 to +.77

The authors have previously reported in part the relationship observed for the Rambouillet and Dorset (1927a), the Oxford, Southdown, and Shropshire (1927b).

*The records of the coefficients for 1926 were preserved.

Averages of the coefficients for diameter and length, and for diameter and breaking strength, are slightly higher than those obtained by treating the samples as a composite for a breed. But the averages for diameter and crimp are lower than the coefficients for a composite sample for each breed. The lowest coefficient for diameter and crimp for the composite samples is −0.32 for the Rambouillet and the highest is 0.52 for the Dorset breed. Averages of the coefficients for diameter and stretch are essentially equal to those for the composite samples.

shire, and 96.9 percent of the Dorset fleeces exceeded this limit, and each of the Oxford fleeces yielded a mean fiber-length in excess of 65 mm. Fiber measurements exceeded staple length from 8 to 10 percent.

The significance of the variability among the fiber-length means for the different breeds is emphasized by the fact that the variance among the means of breeds exceeded that within breeds by more than 20 times, whereas a difference of only 3 times with the degrees of freedom available gives a highly significant value. Further analysis of variance shows that the difference between the fiber-length means for the Shropshire and the Dorset breeds is highly significant. (See Table IV.) Likewise the difference between the means for the Oxford and Dorset breeds is highly significant. But the difference between the fiber-length means for the Rambouillet and the Southdown is not significant.

TABLE IV.—Analysis of Variance of Fiber-Length for the Shropshire and Dorset.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	128	13463	
Between breeds	1	949	949.00
Within breeds	127	12514	98.53

Dorset	M=94.12
Shropshire	M=87.33
Difference	= 6.79

It is not known if these averages represent the differences between the breeds as a whole; but it does not appear unreasonable to assume that they indicate approximately what might be expected in average flocks, since all of the sheep in this experiment were purebred and had been selected for the breeding flock on a basis of reasonable individual excellence. If these data are representative of the average flock for the different breeds, they point out that there is probably an opportunity for profitable improvement of the average purebred flock through selection for greater length of fleece. Particular attention to the fleece of stud rams might prove to be profitable in many flocks.

Although the exact mode of inheritance of length of fleece has not been established, it is generally recognized that length is an hereditary trait. Therefore selection of breeding stock on a basis of length of fiber should result in a reasonable increase in the length of fleece produced under favorable environmental conditions. However, the breeder who is engaged in producing mutton sheep may be more interested in the type, size and conformation of his sheep than he is in producing wool of the combing class. Therefore the emphasis to be placed on length or any other property of wool by the breeder in his endeavor to improve the flock must remain a question to be determined by the individual sheep breeder.

Table V shows the different grades and the respective lengths of wool for the three recognized classes.

Attention should be called to the fact that the term "French combing" is rarely applied to wool other than fine wool. Half-blood and the coarser wools are usually placed in either the combing or the clothing class. The lengths for combing wool shown in the foregoing table represent minimum lengths. In ordinary grading, all three-eighths blood wool shorter than 2½ inches would be classed as clothing. Since combing wool is worth at least

10 percent more than clothing wool of the same grade, length of staple deserves the attention of the enterprising flockmaster.

TABLE V.—Grades and Length Standards for Wool*

New Standard Grades	Corresponding grade old U. S. System	NEW LENGTH STANDARD FOR WOOL CLASSED AS: Combing Inches	French-Combing Inches	Clothing Inches
80's				
70's	Fine	Over 2	1¼ to 2	Under 1¼
64's				
60's				
58's	Half Blood	Over 2¼	1¼ to 2¼	Under 1¼
56's	Three-eighths Blood	Over 2½	1½ to 2½	Under 1½
50's				
48's	Quarter Blood	Over 2¾	1½ to 2¾	Under 1½
46's	Low Quarter Blood	Over 3	2 to 3	Under 2
44's	Common**			
40's				
36's	Braid			

*Coffey, W. C., 1918. Productive Sheep Husbandry. 2nd ed., p. 319. (Reprinted here through courtesy of the publishers, J. B. Lippincott Co., Philadelphia.)
**Common and braid are practically always of combing length.

It is not the purpose of this report to discuss systems of grading wool but it should be pointed out that there may be differences in diameter between samples both of which would grade "fine" under the old system of grading. Breeders of fine-wool sheep in the past apparently believed that fineness was the one important consideration and they attempted to produce as fine a fleece as possible. At present some breeders question the value of fineness beyond that necessary to place the fleece in the grade of "fine," their contention being that sheep producing the coarser or more robust type of fine wool will clip heavier fleeces and that the fleeces will shrink less in scouring than will the finer fleeces.

Correlation Between Fineness and Length

A summary of the averages of the coefficients of correlation between fineness and length is given in Table III. It is of striking interest that the coefficients between diameter and length of fiber are on the whole positive for each breed and for each clip. Each of the Oxford fleeces gave a positive coefficient for these two fiber characters. Three Southdown and three Hampshire fleeces gave negative coefficients. Each of the Shropshire fleeces yielded positive coefficients for these two fiber characters. Dorset fleeces were more irregular than those from the other breeds. Eight of the Dorset fleeces yielded negative coefficients for these fiber characters. Three Rambouillet fleeces yielded a negative coefficient, and another zero.

On the whole the coefficients for diameter and length are relatively low, but in most cases the coefficients for individual fleeces are of sufficient magnitude to be significant. The relatively high consistency of the direction of the coefficients is interpreted to indicate that a correlation actually exists between diameter and length, although the coefficients are for the most part relatively low. This is of particular importance since fineness of fiber is the one thing that determines the grade of wool, and length of fiber determines the classification. McWhorter (1921) studied 2250 fleeces and found that without exception the wools became shorter in staple as they became finer in fiber. Length and weight of fleece have been found to be correlated in a positive manner by Hill (1921), McWhorter (1921), Lush and Jones (1923), and Spencer (1926). Since weight is an item of great interest to the producer, this relationship should appeal to him. It is perhaps fortunate that the relationship between diameter and length of fiber is relatively low since a high degree of correlation between these two traits would work at cross purposes.

Since diameter and length of fiber show a positive relationship the factors that influence these two fiber characters are of interest. Hardy and Tennyson (1930) have observed that rate of fiber growth has an influence on its fineness. It was found that the coarsest part of the fiber was produced during the period of most rapid growth, and that the smallest part of the fiber was produced during the period of least growth.

Wilson (1930) reported, from a study of three purebred Romney wethers, that the fleece produced by the sheep when well fed was 26.5 per cent coarser at the base of the fibers than was the fleece produced on a sub-maintenance ration. He suggested that in wool production the sheep is just as sensitive to an unfavorable nutritional regime as is the dairy cow in milk production.

Weber (1931) observed that sheep on a high plane of nutrition produced wool with fibers 15 percent larger and 14 percent longer than sheep on a low plane of nutrition.

Fraser and Nichols (1934), from a study of wool growth in sheep as affected by the carbohydrate content of the diet, found a definite increase in fiber thickness and a slight increase in fiber length in response to the addition of starch to the ration.

Joseph (1926) observed lower fiber-diameter values for samples of fleece taken from the shoulder of ewes wintered under range conditions than for ewes wintered under good farm conditions. Joseph also presented data obtained on wethers fed for 5 to 6 months during the winter in a study of the effect of feeding on the quality of wool. He concluded that the level of winter feeding should be determined according to the needs for other purposes than for wool production, since the additional weight of fleece produced by more liberal feeding of the sheep in good physiological condition was largely due to factors affecting shrinkage and only slightly to factors affecting wool fibers.

Darlow, Heller, and Felton (1934) observed, from a study of the effect of nutrition on wool production by a group of Rambouillet wethers, that both the amount and quality of fleece decreased as a result of continuous feeding of a sub-maintenance ration, but that both quantity and quality of wool remained normal when the ration was adequate in quantity regardless of the quality, provided the sheep remained in good health. It was observed, however, that wethers on an extremely low protein level for periods longer than one year went "off-feed" and wool production was retarded.

Crimp

An average of the mean number of crimps per unit of fiber length for the different breeds is shown for the different years in Table I. The ranges between the means from the lowest to the highest for each year are also shown in the table, and averages of the standard deviations are recorded. Inspection of the table reveals considerable variation among the means for different years for each of the breeds. The data show also that crimps were more frequent in fibers from Rambouillet fleeces than in those from any of the other breeds. The Rambouillet was followed by the Southdown, Shropshire, Hampshire, Dorset, and Oxford respectively. This is what should be expected if the finest fibers tend to have the greatest number of crimps.

Frequency distribution curves are presented in Figure 1 showing the two more common types observed for crimp. Both of these are for Rambouillet fleeces. One of them (Curve F) is for a fleece that gave the lowest standard deviation, and the other (Curve E) is for one that yielded the largest standard deviation found among the fleeces for this breed.

Analysis of the variance of fiber crimp for the six breeds revealed that the difference among the breeds is highly significant. Further analysis of variance showed that the difference between the mean crimp for the Southdown and Shropshire breeds is highly significant. Similar analysis for the Hampshire and Shropshire yielded a significant difference between the mean crimp for these two breeds. (See Table VI.) The difference between the means for the Oxford and the Dorset is not significant.

TABLE VI.—Analysis of Variance of Fiber-Crimp for the Hampshire and Shropshire Breeds.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	92	263.34	
Between breeds	1	15.24	15.24
Within breeds	91	248.10	2.73

Shropshire	M= 8.60
Hampshire	M= 7.86
Difference	= 0.74

Correlation Between Fineness and Crimp

The correlation coefficients for diameter and crimp are shown in Table III. A negative relationship was found to exist between these two fiber characters each year for each breed. Two Oxford fleeces gave a positive coefficient, one of these in 1927 and another in 1928. The coefficients were negative for all of the Southdown fleeces in 1926 and 1927, but in 1928, 9 out of 24 gave positive coefficients of low magnitude. All of the Hampshire fleeces yielded negative coefficients for the first two years, but 2 out of 14 gave a positive coefficient for 1928. In 1926 the 17 Shropshire fleeces each gave a negative coefficient, but in 1927 there were 3 out of 23 that yielded a positive coefficient while in 1928 the coefficient was zero for 2 fleeces and positive for 2 out of 24.

TABLE VII.—The Percentage of the Mean Fiber-Diameter and the Mean Crimp for the Different Breeds Compared With the Rambouillet.

Breed	DIAMETER		CRIMP	
	.0001 in.	Percent coarser than Rambouillet	Per inch	Percent as many crimp as Rambouillet
Oxford	10.91	66	6.46	46
Dorset	10.79	65	6.79	48
Hampshire	9.31	42	7.86	56
Shropshire	9.23	41	8.60	61
Southdown	8.86	35	9.70	69
Rambouillet	6.56		14.05	

The coefficients for diameter and crimp for the 20 Dorset fleeces in 1926 were all negative, but for the 1927 clip 6 out of 31 were positive and for the 1928 clip 6 out of 34 were positive. The clip from Rambouillets included 24 fleeces in 1926 and 5 of these yielded positive coefficients for diameter and crimp. Four of the 23 Rambouillet fleeces clipped in 1927 gave a positive coefficient and 11 out of 31 were positive for the 1928 clip.

The mean fiber diameter and the mean number of crimps for the different breeds compared with the Rambouillet on a percentage basis are shown in Table VII. It is evident that as the mean fiber diameter increases the mean number of crimps for the portion of the fibers observed decreases. This is interpreted to suggest that the relationship may be more real than is indicated by the size of the coefficients. The relationship between diameter and crimp is also emphasized by the coefficients found for crimp and length, crimp and stretch, and crimp and breaking strength. These are negative as should be expected if diameter, length, stretch, and strength are correlated in a positive manner and diameter and crimp in a negative manner. Apparently McMurtrie (1886) was among the first to point out that fineness of fleece increases with an increase in closeness of crimp. A negative correlation between these two fiber characters has been reported by Davenport and Ritzman (1926), Hultz (1927), and Reimers and Swart (1931). But Hill (Hultz and Hill 1931) suggests that not much importance can be given to crimp as a measure of fineness.

The variation observed in the size of the coefficients for diameter and crimp among the fleeces of the different breeds tends to strengthen the belief that the occurrence of crimps in the fiber is influenced by factors other than size of fiber alone. Although the Rambouillet fleeces yielded the lowest fiber-diameter value and the highest count of crimps, the coefficients were lower than for the other breeds. It should be borne in mind that both number and type of crimps may be influenced by breed. Hill (Hultz and Hill (1931) has pointed out that the Wanganella family of Australian Merinos has a crimp that is almost as coarse as that of the average three-eighths-blood wool grown in this country, although it has a fiber diameter finer than the average Rambouillet. Various authors have interpreted crimp to be an hereditary trait. If the production of crimps along the length of a fiber is an inherent quality, breed differences should be expected. Wilson (1930) observed wool produced by sheep during an experimental study of the effect on fiber characters of the plane of nutrition and concluded that wool produced while sheep were on a sub-maintenance ration is decidedly lacking in crimp. It has recently been reported, notably by Norris and Van Rensburg (1930), that the number of crimps per fiber in a lock of wool is constant and independent of the length of fiber. They maintain that adjacent wool follicles on the Merino sheep produce in a given period of time the same number of crimps regardless of the length of the fiber grown during that time. More recently Duerden (1934) has suggested that the crimping of wool represents a periodicity of reversals of rotation, due to a like succession of twists on a fundamental spirality. It is, therefore, apparent that the cause and frequency of crimps in wool fibers is not definitely agreed on at present.

The results of the present study are interpreted to lend emphasis to the value of crimp in evaluating wool. Since crimp is more easily recognized than fineness of fiber, crimp and length should be two useful observations in flock selection for fleece improvement. Hultz (1927) concluded, from a study of fleece from fine-wool sheep which had been placed on fleece alone by a competent judge, that density and crimp were given more consideration than fineness. But it is not known if the two former were emphasized intentionally over the latter.

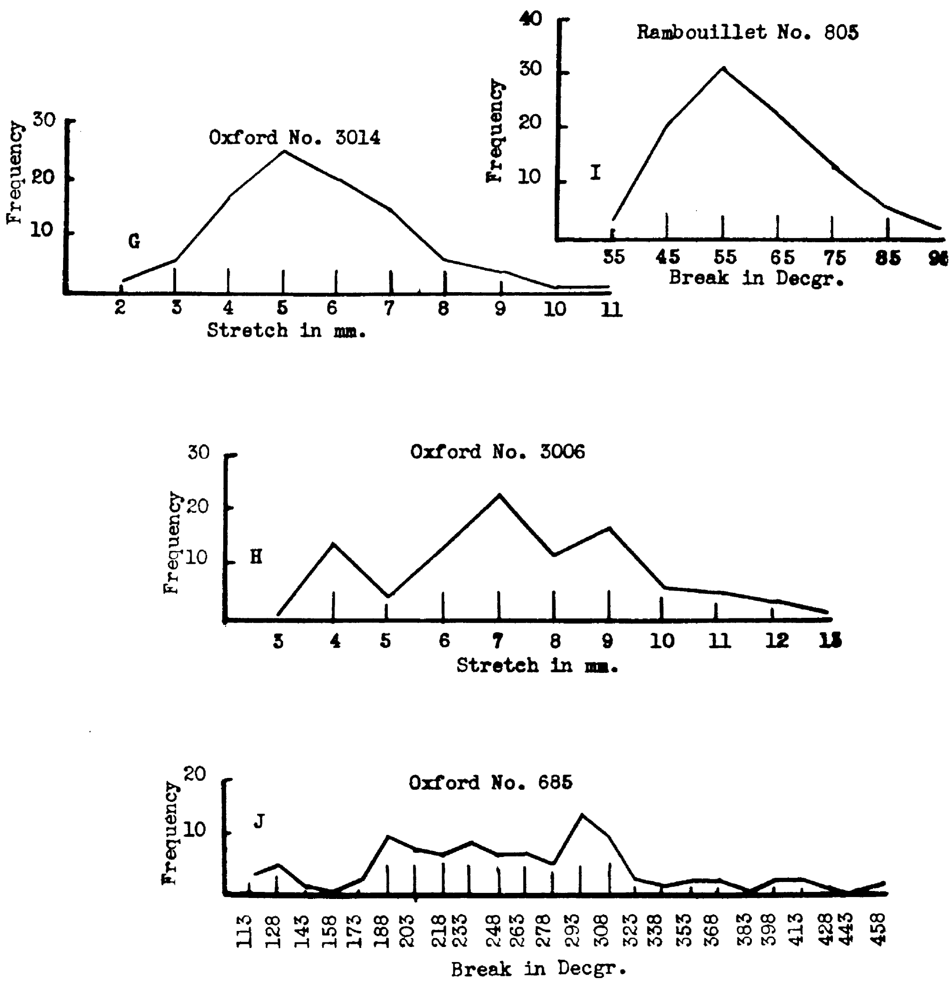

Oxford No. 3014
G
Frequency
Stretch in mm.
Rambouillet No. 805
I
Frequency
Break in Decgr.
Oxford No. 3006
H
Frequency
Stretch in mm.
Oxford No. 685
J
Frequency
Break in Decgr.

Figure 2

Stretch

The averages of the means of stretch for the three different clips are shown by breeds in Table I. These indicate that in general there may be a positive relationship between the size of the fiber and its stretch. Curves are presented in Figure 2 showing the dispersion of the fiber stretch for two Oxford fleeces. The behavior of the fibers for a sample taken from the fleece having the smallest standard deviation found among the fleeces of this breed is shown in Curve G, and that for the fleece having the largest standard deviation in Curve H.

Analysis of the variance of fiber stretch for the six breeds revealed that the variation among the means of the breeds was significantly greater than the variation within the breeds. Further analysis of the differences between breeds disclosed significant values for the difference between the Southdown and Rambouillet, and between the Shropshire and Rambouillet. But the differences between the Oxford and Dorset, and between the Hampshire and Shropshire, proved to be insignificant. The comparison of the Oxford and Dorset breeds is shown in Table VIII.

TABLE VIII.—Analysis of Variance of Fiber Stretch for the Oxford and Dorset Breeds.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	92	96.5	
Between breeds	1	2.0	2.00
Within breeds	91	94.5	1.04

Oxford	M= 7.53
Dorset	M= 7.34
Difference	= 0.19

Correlation Between Fineness and Stretch

Averages of the correlation coefficients between diameter and stretch are shown in Table III. The averages are positive for each breed and for each clip. They are rather low, however, and there is a wide range of difference in the size and direction of the coefficients within a breed. The 8 Oxford fleeces yielded seven positive coefficients and one zero for the 1926 clip. Each Oxford fleece yielded a positive coefficient for the 1927 clip, but in 1928 two fleeces out of eight yielded a negative coefficient. For the Southdown in 1926 seven coefficients were positive, two were zero, and five were negative, but in 1927 each fleece gave a positive coefficient. In 1928 two out of 24 yielded a negative coefficient.

Averages of the coefficients for diameter and stretch of fiber for the Hampshire were all positive except for two fleeces, one of which was clipped in 1926 and the other in 1928. Four of the 17 Shropshire fleeces clipped in 1926 gave a negative coefficient for diameter and stretch and one yielded a zero coefficient, but 12 of the fleeces yielded a positive coefficient. In 1927 and 1928 only one Shropshire fleece each year gave a negative coefficient for diameter and stretch, and 45 fleeces yielded positive coefficients. In 1927 only one fleece of the 31 Dorsets did not yield a positive coefficient and this one was zero, but in 1928 there were 7 fleeces out of 34 that yielded a negative coefficient. Seven out of 24 Rambouillet fleeces clipped in 1926 gave a negative coefficient for diameter and stretch, and in 1927 there were 3 negative out of 23, and in 1928 one out of 31 was negative.

The averages of the coefficients and the fact that most of the fleeces yielded positive figures indicate what one would suspect: that within a breed the larger fibers have a tendency to be more elastic than the smaller fibers.

Ogrizek (1926) also observed a positive correlation between diameter and stretch of fiber.

Break

In Table I the averages of the mean breaking strength of the fibers are recorded. On a basis of these means the order of fiber strength is from strongest to weakest Oxford, Dorset, Hampshire, Shropshire, Southdown, and Rambouillet.

In Figure 2, Curves I and J show the dispersion of fiber breaking strength for two fleeces which represent the extremes observed. One of these (Curve I) is for a Rambouillet fleece that yielded the smallest standard deviation found for this breed, while the other, (Curve J) is for a fleece which gave the largest standard deviation observed for the Oxford breed.

The variance of fiber breaking strength among the means for the breeds is significantly greater than that within the breeds. Further analysis of the variance between breeds reveals that the difference between the Hampshire and Shropshire, and the Oxford and Dorset is insignificant, but the differences between means for the other breeds gave significant values. The comparison of the variance of fiber breaking strength for the Shropshire and Southdown breeds is shown in Table IX.

TABLE IX.—Analysis of Variance of Fiber Breaking Strength for the Shropshire and Southdown Breeds.

Source of variation	Degrees of freedom	Sum of squares	Mean square
Total	111	69441	
Between breeds	1	9912	9912
Within breeds	110	59529	541.3

Shropshire M=129.28
Southdown M=112.29

Difference = 16.99

Correlation Between Fineness and Strength

The averages of the coefficients for diameter and breaking strength are shown in Table III. The correlation coefficients for these two properties are higher than for diameter of fiber and any of the other properties. All of the coefficients were positive except for one Southdown, one Hampshire, two Dorset, and one Rambouillet fleece, and these negative coefficients were below the lowest significant value.

Ogrizek (1926) observed a positive relationship between diameter and strength. The coefficient was of about the same magnitude as was found in the present study.

Deppe (1926) also observed a high positive relationship between diameter and breaking strength.

It is of interest that the relationship between diameter and strength of fiber is positive, since the presence of medulated fibers might possibly disturb this common relationship. The relative frequency of medulated fibers in the fleeces studied was not determined.

Correlation Between Fiber Characters and Commercial Grade

Correlation coefficients were calculated for a measure of the relationship between the commercial grade of the fleeces and the various fiber characters studied. (Except for the Rambouillet, the data on grade were too incomplete.) On the whole, these show a negative value for diameter and grade and a positive value for crimp and grade. In each of these cases the values are barely significant. There is a lack of consistency among the coefficients for grade and the other fiber characters. Bailey and Engledow (1914) also reported a relationship between fineness, as measured by average diameter, and the commercial grade of fleece. They point out, however, that the relationship is not absolute, and suggest that the distribution of fibers of different sizes has a modifying effect on the commercial grade which may be assigned to a fleece.

Effect of Age

The number of fleeces available for the same sheep is too small to permit a study of the effect of age on the fiber characters observed. It is of interest, however, that for the few fleeces available both diameter and length of fiber show an increase from the first to the third clip, and that from the fourth to sixth clip a decrease occurred.

Inheritance of Fiber Characters

Data available do not lend themselves to a study of the inheritance of fiber characters, since the number of fleeces for any particular mating is too small to offer opportunity for analysis of the mode of inheritance involved. A splendid review and an extensive bibliography on the inheritance of wool characters has been given by Miller (1933).

SUMMARY

1. Samples of 100 fibers for each of 300 fleeces were studied. These included fleeces from the Oxford, Southdown, Hampshire, Shropshire, Dorset, and Rambouillet breeds.

2. Individual fiber-measurements were determined for the following fiber characters: diameter, length, crimp per unit length, stretch, and breaking-strength. The means for each of the fiber characters were calculated for each fleece and by breeds.

3. Simple correlation coefficients were calculated for a measure of the relationship between diameter of fiber and the other fiber characters. The coefficients for diameter and length, diameter and stretch, and diameter and breaking strength were on the whole positive. These relationships indicate that the larger fibers within a breed tend to be longer, more elastic, and stronger than the smaller fibers. The coefficients between diameter and crimp were on the whole negative. This relationship indicates that the smaller fibers have a tendency to crimp more frequently than the larger fibers. Although the coefficients are relatively low, they are in general sufficiently high to be significant.

4. On a basis of fineness of fibers, the breeds ranked with means as follows: Rambouillet, 6.56; Southdown, 8.86; Shropshire, 9.23; Hampshire, 9.31; Dorset, 10.79; and Oxford, 10.91 ten-thousandths of an inch. The difference between the means for the Dorset and the Oxford, and for the Hampshire and the Shropshire, proved to be insignificant; but tests of the difference between the Hampshire and the Dorset, the Shropshire and the Dorset, and the Rambouillet and the Southdown gave significant values.

5. The mean fiber-length observed was, for the Oxford 107.03, for the Dorset 94.12, for the Shropshire 87.33, for the Hampshire 79.76, for the Rambouillet 63.60, and for the Southdown 63.17 millimeters. Tests for the significance of these differences gave significant values for the difference

between the Shropshire and the Dorset, the Oxford and the Dorset, and the Hampshire and the Shropshire; but the difference between the means for the Rambouillet and the Southdown proved to be insignificant.

6. The mean frequency of crimp per inch for the different breeds was found to be as follows: Rambouillet, 14.05; Southdown, 9.70; Shropshire, 8.60; Hampshire, 7.86; Dorset, 6.79; Oxford, 6.46. The difference between the means for the Southdown and Shropshire, and the Hampshire and Shropshire proved to be highly significant. The Rambouillet exceeded each of the other breeds by a significant value, but the difference between the means for the Oxford and the Dorset proved to be insignificant.

7. The relationships found in this study between diameter and crimp and between diameter and length indicate that in general a long staple with numerous crimps along the length of the fibers should also be relatively fine. Since crimp is more easily recognized than fineness of fiber, crimp and length should be two very useful observations in flock selection for fleece improvement.

8. If the samples available for this study were representative of the breeds studied, and it is believed that they were, it is apparent that (a) breeders of mutton sheep who have about average flocks can afford to give more attention to crimp, fineness, and length of fleece, and that (b) breeders of fine-wool sheep whose flocks average about as the Rambouillet here reported can well afford to give more attention to length and at the same time insist on stud rams having a high count of crimp. Since diameter of fiber and length tend to increase together and crimps increase with an increase in fineness, it is apparent that selections based on length alone should result in coarser wool with a decrease in the frequency of crimps.

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