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A STUDY OF THE QUALITY OF ABACA FIBER
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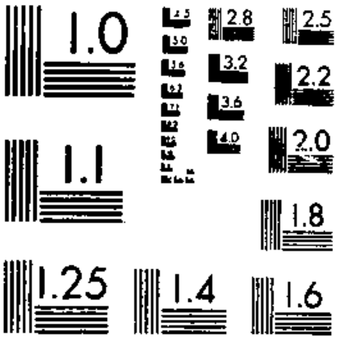

MICROCOPY RESOLUTION TEST CHART
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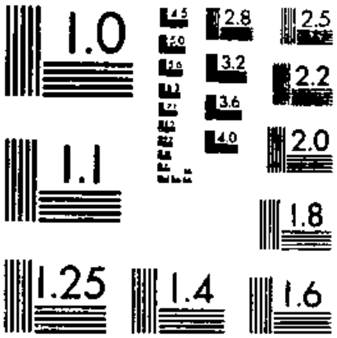

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NATIONAL BUREAU OF STANDARDS-1963-A

Technical Bulletin No. 999 • *October 1949*

UNITED STATES
DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

A Study of the Quality of Abaca Fiber[1]

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CONTENTS

INTRODUCTION[2]

ABACA is the most sought after of all cordage fibers where high standards of performance must be maintained. There are many special uses for cordage, and because of the different physical and chemical properties of fibers some are important for one use and others for another. The great strength of abaca and its suppleness, length, and freedom from impurities make it admirably suited for high production in manufacturing; and these properties, together with buoyancy and low swelling in water, make it the best of all fibers for marine purposes. Undoubtedly, its use for other purposes, such as for industrial ropes and tying and baler twines, would be proportionately greater in relation to other fibers if it were offered in international trade at a lower cost.

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[1] Submitted for publication May 16, 1949.

[2] Introduction by B. B. Robinson, Division of Cotton and Other Fiber Crops and Diseases.

To the Western Hemisphere abaca is of extreme importance. It is one of the strategic commodities in the United States primarily because of the large supplies needed and the small quantities now available. As a potential future crop in the Western Hemisphere, it ranks high. It is a tropical crop that can be grown under restricted environmental and soil conditions in the American tropics. It would not compete with American products and would provide a cash crop with which Latin American countries may stimulate their trade and further their industrial and agricultural development.

Although abaca was introduced into the Western Hemisphere a number of years ago, it did not become an important commercial crop until World War II. At that time its production expanded into Costa Rica, Guatemala, Honduras, and Panama as large plantation developments rather than as small units by individual farmers. Considerable doubt has existed in the minds of many experienced fiber technologists as to whether the crop can be successfully grown in the Western Hemisphere in competition with that in the Philippine Islands. Much time has been consumed in speculative discussions involving the economics of production, in conducting surveys to determine growth performance, and in seeking opinions in reference to the quality of the fiber. At the same time considerable factual information has been accumulated about the productive yield of the different plantations under their particular managerial conditions. Evaluation of the quality of the fiber produced as compared with Philippine "standard" has been much more difficult; tradition and manufacturers' preference have made it extremely difficult to arrive at definite conclusions on this point.

The primary object of the studies reported in this bulletin was to evaluate the quality of Western Hemisphere abaca for comparison with that of Philippine abaca. Unfortunately, as in most studies where quality is involved, the measuring tools available for recording quality were limited. Therefore, as an essential part of the work, a study was made of means whereby the technique and manipulation of machines used in handling the various fibers could be improved.

Certain factors generally associated with quality of fiber were studied to determine their influence on the Central American product. Fiber from different varieties of abaca was compared, since variety is believed to affect the quality as well as the yield of fiber. Fiber obtained from base sections of the plant was compared with that from top sections, and fiber from the inner or younger leaf sheaths was compared with that from the outer or older sheaths. The influence on the fiber of various environmental factors, such as location, climate, and soil, were also studied.

Of all the factors that may affect the quality of the fiber, however, the method used in extracting it is without doubt the most important. The introduction of abaca into Central America was considered to be possible only if machine methods were employed to extract it. These methods included the use of large, mechanical, semiautomatic machines for decorticating the fiber and artificial methods of drying it, in contrast to the more primitive methods generally used in the Philippine Islands, where less than 5 percent of the total production is cleaned on large decorticating machines.

This bulletin shows the effect of the various factors associated with fiber quality on fiber produced in a new environment and cleaned entirely by machine.

SUMMARY AND CONCLUSIONS

Two varieties of abaca fiber grown in Panama, Costa Rica, Honduras, and Guatemala were sampled to show fiber properties for different heights in the plant, different areas of the cross section, and different methods of drying. The results indicated the variety Bungulanon had significantly greater strength than the variety Maguindanao wherever the two varieties were grown. The fiber properties vary with height in plant for both varieties. Tall plants grown in deep shade show little difference in fiber properties up through the first 10 feet, but near the top the fiber strength, flex life, and resistance to abrasion decline. Short, stunted plants grown in inadequate shade show a marked reduction in physical properties with height in the plant above the first 4 or 5 feet. The fiber strength of abaca is greatest in the streaky sheaths, somewhat less in the outer brown sheaths and the ocher or cream-colored sheaths just beneath the streaky, and least in the white fiber near the center of the plant. Some differences in fiber properties were apparent in location of growth, but sun-dried and machine-dried fiber showed no consistent differences.

A comparison was made of two varieties of abaca fiber from Panama and six varieties from Costa Rica that were given special sampling consideration and were cleaned by two different methods on hagotan and raspador machines. The following physical properties were determined on the fiber: Fineness, strength, abrasion, flex life, and knot strength. The fiber structure was determined by X-ray methods, and machine damage to the fiber was evaluated. In general the raspador decorticated fiber was finer and showed greater resistance to abrasion, SS twist (along the fiber), and greater flex life. The hagotan stripped fiber was coarser, stronger, showed greater resistance to abrasion, SZ twist (across the fiber), and greater knot strength. The fiber structure (texture) and fewer injuries account for the greater strength of the hagotan stripped fiber. The greater yields by the machine method and economy of labor in harvesting justify the small reduction in quality in the machine-cleaned fiber.

In studying physical properties of fibers, an instrument and a method of measuring cross-sectional area of bundles of fibers were developed. Modifications of abrasion and flexure machines for long fibers are discussed and shown. Data are reported, along with some interpretation of the results, from six samples of fiber, three samples of hard fibers and three samples of soft fiber, obtained on the improved testing machines.

Physical properties of different abaca fiber grades from Central America and the Philippine Islands are given with a discussion of the various grading methods used by the two localities.

THE QUALITY OF CENTRAL AMERICAN ABACA FIBER AS AFFECTED BY VARIETY, LOCATION OF GROWTH, POSITION IN PLANT, AND METHOD OF DRYING

By Earl E. Berkley, Lyle E. Hessler, Edna B. Burneston, and Chester F. Chew[3]

The abaca plant, *Musa textilis*, resembles the banana plant in appearance and is closely related to it botanically. Abaca is native to the Philippine Islands, and is the source of the cordage fiber known commercially as Manila hemp and as abaca. It is the principal source of raw material used in the manufacture of marine cordage, and is used for many other types of cordage. Until recent years essentially all of the world's supply of this fiber was produced in the Philippine Islands. When the American supply of Philippine abaca was cut off early in 1942, it became necessary to produce this fiber in the Western Hemisphere.

The danger of having the production of the entire world supply of this essential raw material confined to a remote group of islands in the Pacific had long been recognized. In 1925 the United States Department of Agriculture (*3*)[4] brought from the Philippines to Panama planting material of six varieties of abaca. These plants were grown by the United Fruit Co. on a plantation located in the Changuinola Valley near Almirante, in the Republic of Panama, and by 1941 the original experimental plantings had been expanded to about 2,000 acres. Late in 1941, plans were formulated for the further expansion of this work, and new plantings were started early in 1942. All of the plantation operations, including the cleaning of fiber, were conducted by the United Fruit Co. under contract with the United States Government. The acreage was ultimately enlarged to about 28,000 acres in five plantation projects, located in Panama, Costa Rica, Honduras, and Guatemala. During the period of hostilities in World War II and up to January 1, 1946, Central America produced and made available to the United States more than 39 million pounds of abaca fiber of cordage grades.

Because of a number of factors, the quality of Central American abaca fiber differs from that grown in the Philippines. In Central America production has been from two varieties, Bungulanon and Maguindanao, whereas in the Philippines many different varieties are grown. The general methods of culture, harvesting, decortication, and drying were all somewhat different from those commonly used in the Philippines. The Philippine fiber is to a large extent hand-stripped or cleaned with small hagotan machines, and only a

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[3] The authors wish to acknowledge the assistance of the Reconstruction Finance Corporation and the United Fruit Co., and the field representatives in Panama, Costa Rica, Honduras, and Guatemala who made the work possible by aiding in the field studies and in obtaining the samples used in making the fiber measurements. The Textile Division, National Bureau of Standards, greatly assisted by lending apparatus used in obtaining some of the data. The authors gratefully acknowledge supervision and assistance given by B. B. Robinson of the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, and the aid of G. F. Vogel and the late O. A. Pope in the statistical analysis. The photography in the manuscript was done by M. L. Jaeger of the same Division.

[4] Italic numbers in parentheses refer to Literature Cited, p. 56.

small percentage is cleaned by the raspador method. It is sun or shed dried. The length of the fiber varies, depending on the length of the leaf sheath from which it is stripped. The Central American fiber is all decorticated on large semi-automatic machines of the raspador type, artificially or oven dried, and cut in lengths of 4 to 6 feet.

In May and June 1945, at the request of the Reconstruction Finance Corporation, specialists from the United States Department of Agriculture (*2, 9*) inspected the abaca plantations of Central America and studied the varieties and the methods of cultivation, harvesting, decortication, drying, and baling of the fiber. Samples were collected and the studies reported here were made in the United States Department of Agriculture laboratories at the Plant Industry Station, Beltsville, Md.

MATERIALS AND METHODS

Samples were taken from fruited abaca plants, that is, from stalks with either flowers or fruits. An attempt was made to select plants representative of the plantation in size and general growth habits, so that neither the largest nor the smallest plants were chosen. Five plants were selected for each sample. They were stripped of leaves and topped in the field, brought to the decorticating plant, weighed, and then cut into sections approximately 6 feet in length. The sheaths were then separated and grouped into three or four subsamples each according to place of origin—the outer, intermediate, and inner sheaths in the stalk. The outer dark sheaths were designated A; the streaky sheaths just beneath the surface B; the middle and inner sheaths C. At two locations, Honduras and Guatemala, the C group was again subdivided to give D, the extra white fiber near the center of the stalk, making four lots in all.

Each group of sheaths were then passed through the decorticating machine separately and the fiber was divided into two approximately equal portions. One portion was dried in the sun, the other in the machine drier. Tags were attached to the samples before they were put into the drier so that they could be readily identified. With the exception of that grown in Costa Rica, the machine-dried fiber was dried in the regular run, along with commercial lots of fibers.

In Panama (location 1) the abaca plants were very tall and three sections were obtained from each plant, whereas at the other locations the plants were only long enough for two sections. In all locations the sheaths of only the bottom two sections were separated into the three groups, the outer, intermediate, and inner sheaths. The top section in Panama was decorticated as a whole. In Costa Rica only the base section was used.

TEST METHODS

The test methods used in studying these fibers were modifications of those described by Schiefer (*10*). Specimens were cut into 15-inch lengths, beginning at the base end of the sample. The lower end of each sample was marked with a dye and each 15-inch section was numbered progressively, beginning at the base.

A yarn weighing 325 milligrams (21 milligrams per inch) with one turn per inch was prepared and placed in a rack with notched leather grips to prevent the loss of twist. Paper grips were then glued to the fiber at the appropriate points, one set one-half inch apart and another 3 inches apart, for fiber-strength tests. The glue was allowed to harden overnight and the specimens were conditioned at 70° F. and 65 percent relative humidity before testing.

The fiber strengths were obtained on a pendulum-type Scott Tester, capacity 150 and 300 pounds. The resistance to abrasion and flex life was obtained on modified Schiefer (*10*) machines that are discussed in detail later in this publication.

The abrasion tests were continued until one of the two strands failed. The flex tests were also continued until the yarn failed. The length of specimen between testing jaws affects the fiber strengths. It was not feasible to standardize the methods so that the lengths of all test specimens were uniform after they had been abraded or flexed a given number of times; therefore all tests were continued to failure and the number of revolutions recorded. Both the flex machine and the abrasion machine were equipped with cut-off switches so that when a bundle failed the machine stopped.

The fibers in each standard bundle, or yarn, 15 inches long and weighing 325 milligrams, were counted for each of the varieties at each location and for each position in the plant. It is recognized that the adjustment of the decorticating machine influences the fineness of fiber. All samples for a given location were decorticated, however, on the same machine without a change in setting.

The cross-sectional area of the individual bundles was measured by an instrument, the details of which are discussed in the section on improved testing machines.

Variance analyses were applied to a portion of the fiber-strength data. Missing values in the abrasion and flex data made analysis difficult and of questionable value.

RESULTS OF TESTS

The fiber strengths were calculated both on the basis of length of yarn required to break itself and in 1,000 pounds per square inch. Only the latter strengths are reported in the tables, but both were analyzed statistically and used in the interpretations.

In general for Panama (location 1) the fiber from the variety Bungulanon was slightly stronger than that from the variety Maguindanao (table 1). The sun-dried fiber was significantly stronger than the machine-dried fiber. In general, the fibers from the intermediate sheaths were strongest with respect to the cross section of the stem, those from the outer ones next, and the inner sheaths near the fruiting stock weakest. In all cases the first 6-foot section near the ground was stronger than the second, which was in turn stronger than the third at Panama. No attempt was made to separate the sheaths in the top section.

The fiber strengths from the varieties, Bungulanon and Maguindanao, grown in Honduras are given in table 2. Only two sections were available from the short plants. Here the differences in strengths between the first 6-foot section, near the ground, and the second, or top section, were more pronounced than those found between the first two sections at Panama. Although the sheaths were divided into four groups instead of three, as in Panama, the intermediate sheaths were

TABLE 1.—*Fiber strength*[1] *in 1,000 pounds per square inch for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in the Changuinola Valley, Panama*

Variety and position of fiber in plant	Sun dried				Machine dried				Average			
	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths
Maguindanao:												
Section 1	78.3	77.3	62.4	72.6	65.1	95.9	56.6	72.5	71.7	86.6	59.5	72.6
Section 2	67.8	73.4	57.3	66.2	60.8	66.1	53.7	60.2	64.3	69.7	55.5	63.2
Section 3	------	------	------	45.7	------	------	------	38.5	------	------	------	42.1
Average	73.0	75.3	59.8	69.5	62.9	81.0	55.2	57.1	68.0	78.2	57.5	59.3
Bungulanon:												
Section 1	83.8	91.6	73.0	82.8	68.1	67.0	79.1	71.4	76.0	79.3	76.1	77.1
Section 2	65.7	87.5	------	76.6	66.0	------	------	66.0	65.8	87.5	------	76.7
Section 3	------	------	------	40.5	------	------	------	68.6	------	------	------	54.6
Average	74.7	89.5	------	66.6	67.1	------	------	68.7	70.9	83.4	------	69.4
Both varieties:												
Section 1	81.0	84.4	67.7	77.7	66.6	81.4	67.8	71.9	73.8	82.9	67.8	74.8
Section 2	66.7	80.4	57.3	68.1	63.4	66.1	53.7	61.1	65.1	78.6	55.5	66.4
Section 3	------	------	------	43.1	------	------	------	53.6	------	------	------	48.3
Average	73.9	82.4	62.5	63.0	65.0	73.7	60.8	62.2	69.4	80.8	61.6	63.2
Over-all average	------	------	------	66.4	------	------	------	62.6	------	------	------	64.0

[1] 3-inch span between testing jaws.

TABLE 2.—*Fiber strength*[1] *in 1,000 pounds per square inch for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Honduras*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	76. 1	101. 3	87. 9	85. 6	87. 7	96. 9	78. 5	93. 4	93. 3	90. 5	86. 5	89. 9	90. 7	89. 5	89. 1
Section 2	------	77. 3	75. 0	75. 1	75. 8	------	58. 2	61. 9	65. 2	61. 8	------	67. 7	68. 5	70. 2	68. 8
Average	------	89. 3	81. 5	80. 4	81. 8	------	68. 4	77. 7	79. 3	76. 6	------	78. 8	79. 6	79. 8	79. 0
Bungulanon:															
Section 1	107. 8	------	110. 8	78. 4	99. 0	97. 7	104. 5	132. 9	66. 7	100. 5	102. 8	104. 5	121. 8	72. 6	100. 4
Section 2	------	76. 7	70. 7	58. 1	68. 5	------	82. 0	84. 2	81. 8	82. 7	------	79. 3	77. 5	70. 0	75. 6
Average	------	------	90. 8	68. 3	83. 8	------	93. 2	85. 5	74. 3	91. 6	------	91. 9	99. 7	71. 3	88. 0
Both varieties:															
Section 1	92. 0	101. 3	99. 4	82. 0	93. 7	97. 3	91. 5	113. 1	80. 0	95. 5	94. 6	97. 2	106. 2	81. 0	94. 7
Section 2	------	77. 0	72. 9	66. 6	72. 2	------	70. 1	73. 1	73. 5	72. 2	------	73. 5	73. 0	70. 1	72. 2
Average	------	89. 1	86. 1	74. 3	82. 9	------	80. 8	93. 1	76. 8	83. 9	------	85. 4	89. 6	75. 6	83. 4
Over-all average	------	------	------	------	82. 8	------	------	------	------	84. 0	------	------	------	------	83. 5

[1] 3-inch span between testing jaws.

strongest in section 1, the outer ones next, and the inner ones weakest, and a tendency for the outer sheaths to be stronger in section 2 was observed. The ocher fiber just beneath the streaky sheaths was strongest in section 1. The sun-dried fiber was slightly but not significantly stronger than the oven-dried. The fiber from the variety Bungulanon was again stronger than that from Maguindanao.

Comparable data from these two varieties grown in Guatemala are given in table 3. The fiber of the first 6-foot section was again much stronger, 86, than that of the second, which was only 66. The sun-dried fiber from the outer sheaths was on the average slightly stronger than that from the intermediate and inner sheaths, whereas the machine-dried fiber from the intermediate sheaths showed the greatest strength. In Honduras and Guatemala the sheaths were divided into four groups. For statistical analysis, however, data for the fiber from the outer sheaths and that for the streaky fiber just underneath were combined for comparison with the fiber from Panama. In general, the streaky fiber was found to be the strongest fiber in the plant; therefore the apparent discrepancy in the data from this location may be due to the combinations used.

The oven-dried or machine-dried fiber from Guatemala was stronger than the sun-dried. The machine-dried fiber at this location was found to be quite moist after standing overnight. It was hung in the clubhouse and dried without exposure to the sun. Machine-dried fiber from the variety Bungulanon was weaker than that from Maguindanao, whereas the sun-dried fiber from Bungulanon was stronger than that from Maguindanao. It is indicated that the Bungulanon fiber was injured by the machine drying.

At Costa Rica only one section was studied and the data are reported in the summary tables. (See tables 13, 14, and 15.)

ABRASION RESISTANCE

Two types of abrasion tests were made: (1) Designated SS twist in which the fiber bundles, or yarns, each having an S twist, were looped around each other in the S or clockwise direction and (2) designated SZ twist in which the yarns, each with an S twist, were looped around each other in the Z or counterclockwise direction. In the SS twist the friction was along the individual fibers, whereas in the SZ it was across the fibers.

The data from the SS twist, on the samples from Panama are reported in table 4. Briefly, the greatest differences observed were shown by the samples from different heights in the plant. The base, or section 1, appeared to be significantly more resistant to abrasion than the middle section, 2, which was in turn more resistant than the top section, 3. In other words, resistance to abrasion decreases from the base upward.

Taking the data on resistance to abrasion as a whole, there were no significant differences in position in cross section, variety, or method of drying. There was a tendency for the fiber from the inner sheaths to be more resistant to abrasion than that from the intermediate and outer sheaths, but the high variability observed made the differences of doubtful significance.

TABLE 3.—*Fiber strength*[1] *in 1,000 pounds per square inch for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Guatemala*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	86.5	84.6	76.6	76.8	81.1	90.8	89.2	99.2	84.7	91.0	88.7	86.9	87.9	80.7	86.1
Section 2		53.9	61.7	66.9	60.8		79.1	75.4	59.0	71.2		66.5	68.6	62.9	66.0
Average		69.3	69.2	71.8	71.0		84.2	87.3	71.8	81.1		76.7	78.2	71.8	76.0
Bungulanon:															
Section 1	100.7	90.4	78.2	98.3	91.9	95.2	99.7	84.4	84.7	91.0	97.9	95.1	81.2	91.5	91.4
Section 2		61.7	83.4	72.1	72.4		67.8	61.1	55.9	61.6		64.8	72.3	64.0	67.0
Average		76.1	80.8	85.2	82.2		83.7	72.7	70.3	76.3		79.9	76.8	77.7	79.2
Both varieties:															
Section 1	93.6	87.6	77.4	87.5	86.5	93.0	94.4	91.8	84.7	91.0	93.3	91.0	84.6	86.1	88.8
Section 2		57.8	72.6	69.5	66.6		73.5	68.3	57.4	66.4		65.6	63.5	71.0	66.7
Average		72.7	75.0	78.5	76.6		83.9	80.0	71.1	78.7		78.3	74.0	78.6	77.7
Over-all average					76.6					78.7					77.7

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[1] 3-inch span between testing jaws.

TABLE 4.—*Abrasion resistance in number of revolutions to failure with the SS twist for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in the Changuinola Valley, Panama*

Variety and position of fiber in plant	Sun dried				Machine dried				Average			
	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths
Maguindanao:												
Section 1	1,633	902	863	1,132	592	1,585	3,293	1,823	1,112	1,244	2,078	1,478
Section 2	1,378	327	678	794	355	1,170	476	667	866	748	577	730
Section 3	------	------	------	483	------	------	------	399	------	------	------	441
Average	1,506	614	770	803	474	1,378	1,884	963	989	996	1,328	883
Bungulanon:												
Section 1	1,432	1,394	1,442	1,423	1,011	1,045	598	885	1,222	1,220	1,020	1,154
Section 2	375	701	------	538	193	------	------	193	284	701	------	492
Section 3	------	------	------	236	------	------	------	184	------	------	------	210
Average	904	1,048	------	732	602	------	------	421	753	960	------	619
Both varieties:												
Section 1	1,532	1,148	1,152	1,277	802	1,315	1,946	1,354	1,167	1,232	1,549	1,316
Section 2	876	514	678	689	274	1,170	476	640	575	724	577	625
Section 3	------	------	------	360	------	------	------	292	------	------	------	326
Average	1,204	831	915	775	538	1,242	1,211	762	871	978	1,063	756
Over-all average	------	------	------	770	------	------	------	715	------	------	------	753

The data for the SZ twist at Panama (table 5) were too variable to establish clear-cut trends for the variety Maguindanao but they indicate that in the variety Bungulanon the fiber from the base, section 1, is more resistant to abrasion across the fibers than that from section 2, which in turn is more resistant than that from section 3. The sun-dried fiber appeared to be slightly more resistant than that dried in the machine, and the fiber from the variety Maguindanao tended to be more resistant than that from Bungulanon. The variability was so great, however, that no reliance can be placed in the differences observed between areas of cross section.

The data obtained on the samples from Honduras (tables 6 and 7) showed the same trend as those from Panama. There is a marked difference between the first and second sections, the first being more resistant to abrasion both along the fiber, SS twist, and across the fiber, SZ twist (except sun-dried Maguindanao). Other comparisons are considered of doubtful significance.

The samples collected in Guatemala (tables 8 and 9) responded to physical testing more or less the same as those from Honduras. There appeared to be a significant difference between section 1 and section 2, both in resistance to abrasion along the fiber, SS twist, and across the fiber, SZ twist. Other comparisons were again doubtful.

FLEX LIFE

In general, the flex life of a fiber may be expected to increase as the fiber becomes softer and finer. It may be inverse to the strength, that is, increase as the fiber strength decreases. The samples from Panama showed a tendency for the flex life to be greatest in the samples with the greatest fiber strengths (table 10). In general, the base, section 1, gave the greatest flex life as well as tensile strength, but the variety Bungulanon showed the greatest flex life in the middle, section 2. The coarser fibers from the outer sheaths showed a tendency for greater flex life than the white, fine fibers from the inner sheaths. The sun-dried fiber was slightly better than the machine-dried, but the differences may not be significant.

In general, the flex life of the fibers from Honduras (table 11) and from Guatemala (table 12) followed the same trends. The flex life decreased up the plant but there were no outstanding differences between locations in cross section, varieties, and methods of drying.

TABLE 5.—*Abrasion resistance in number of revolutions to failure with the SZ twist for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in the Changuinola Valley, Panama*

Variety and position of fiber in plant	Sun dried				Machine dried				Average			
	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths
Maguindanao:												
Section 1	862	861	741	821	936	946	854	912	899	904	798	867
Section 2	1, 246	378	5, 096	2, 240	71	489	606	389	658	434	2, 851	1, 314
Section 3				455				860				658
Average	1, 054	620	2, 918	1, 172	504	718	730	720	778	669	1, 824	946
Bungulanon:												
Section 1	1, 636	423	625	895	706	1, 230	1, 302	1, 079	1, 171	826	964	987
Section 2	710	306		508	409			409	560	306		433
Section 3				558				200				379
Average	1, 173	364		654	558			563	866	566		600
Both varieties:												
Section 1	1, 249	642	683	858	821	1, 088	1, 078	996	1, 035	865	881	927
Section 2	978	342	5, 096	2, 139	240	489	606	445	609	370	2, 851	1, 277
Section 3				506				530				518
Average	1, 114	492	2, 889	1, 168	530	788	842	657	822	618	1, 866	907
Over-all average				998				647				818

TABLE 6.—*Abrasion resistance in number of revolutions to failure with the SS twist for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Honduras*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	882	2, 323	1, 355	736	1, 824	804	1, 725	1, 890	1, 547	1, 492	843	1, 982	1, 533	1, 142	1, 375
Section 2	------	282	1, 405	------	844	------	506	671	893	689	------	465	1, 038	893	799
Average	------	1, 302	1, 380	------	1, 334	------	1, 116	1, 280	1, 220	1, 090	------	1, 224	1, 256	1, 018	1, 087
Bungulanon:															
Section 1	3, 562	------	1, 367	1, 776	2, 235	875	1, 492	1, 118	14, 953	4, 609	1, 762	1, 492	1, 217	5, 189	2, 415
Section 2	------	944	1, 886	761	1, 197	------	305	936	328	523	------	936	1, 411	544	964
Average	------	------	1, 626	1, 268	1, 716	------	898	1, 027	7, 640	2, 566	------	1, 214	1, 314	2, 866	1, 689
Both varieties:															
Section 1	2, 222	2, 323	1, 361	1, 256	1, 790	840	1, 608	1, 504	8, 250	3, 050	1, 302	1, 737	1, 375	3, 166	1, 895
Section 2	------	613	1, 646	761	1, 007	------	406	804	610	607	------	700	1, 224	718	881
Average	------	1, 468	1, 504	1, 008	1, 398	------	1, 007	1, 154	4, 430	1, 828	------	1, 218	1, 300	1, 942	1, 388
Over-all average	------	------	------	------	1, 483	------	------	------	------	1, 828	------	------	------	------	1, 388

TABLE 7.—*Abrasion resistance in number of revolutions to failure with the SZ twist for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Honduras*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	676	5, 171	8, 865	1, 732	4, 111	870	18, 693	6, 545	12, 945	9, 763	773	11, 988	6, 458	7, 338	6, 639
Section 2	------	279	4, 843	------	2, 561	------	323	2, 566	2, 296	1, 728	------	301	3, 704	2, 296	2, 100
Average	------	2, 725	6, 854	------	3, 336	------	9, 508	4, 556	7, 620	5, 746	------	6, 144	5, 081	4, 817	4, 369
Bungulanon:															
Section 1	2, 978	------	12, 235	4, 782	6, 665	4, 942	2, 842	30, 277	12, 167	12, 557	4, 353	2, 842	20, 852	6, 157	8, 551
Section 2	------	1, 824	6, 079	12, 791	6, 898	------	342	2, 222	1, 718	1, 427	------	1, 724	4, 150	7, 254	4, 376
Average	------	------	9, 157	8, 786	6, 782	------	1, 592	16, 249	6, 942	6, 992	------	2, 283	12, 501	6, 706	6, 464
Both varieties:															
Section 1	1, 827	5, 171	10, 550	3, 257	5, 201	2, 906	10, 768	18, 411	12, 556	11, 160	2, 563	7, 415	13, 655	6, 748	7, 595
Section 2	------	1, 052	4, 961	12, 791	6, 268	------	332	2, 394	2, 007	1, 578	------	1, 012	3, 927	4, 775	3, 238
Average	------	3, 112	7, 756	8, 024	5, 734	------	5, 550	10, 402	7, 282	6, 369	------	4, 214	8, 791	5, 762	5, 416
Over-all average	------	------	------	------	5, 284	------	------	------	------	6, 369	------	------	------	------	5, 416

TABLE 8.—*Abrasion resistance in number of revolutions to failure with the SS twist for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Guatemala*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	717	1, 331	812	1, 736	1, 149	1, 130	1, 268	1, 049	1, 206	1, 163	924	1, 300	930	1, 471	1, 156
Section 2	------	658	597	344	533	------	410	425	999	611	------	534	511	672	572
Average	------	994	704	1, 040	841	------	839	737	1, 102	887	------	917	720	1, 072	864
Bungulanon:															
Section 1	2, 903	683	2, 208	1, 044	1, 709	999	916	818	1, 028	940	1, 860	800	1, 694	1, 216	1, 392
Section 2	------	384	331	205	307	------	552	327	514	464	------	534	360	360	418
Average	------	534	1, 269	624	1, 008	------	734	572	771	702	------	667	1, 027	788	905
Both varieties:															
Section 1	1, 810	1, 007	1, 510	1, 390	1, 429	1, 064	1, 092	934	1, 117	1, 051	1, 392	1, 050	1, 312	1, 344	1, 274
Section 2	------	521	464	274	420	------	481	376	757	538	------	534	436	516	495
Average	------	764	987	832	924	------	786	655	937	794	------	792	874	930	884
Over-all average	------	------	------	------	924	------	------	------	------	794	------	------	------	------	884

TABLE 9.—*Abrasion resistance in number of revolutions to failure with the SZ twist for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Guatemala*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	6, 746	1, 087	1, 488	12, 454	5, 443	6, 232	954	2, 840	3, 010	3, 259	5, 104	1, 020	2, 164	7, 732	4, 005
Section 2	------	670	2, 262	1, 026	1, 319	------	607	397	1, 792	932	------	638	1, 330	1, 409	1, 126
Average	------	878	1, 875	6, 740	3, 381	------	780	1, 618	2, 401	2, 095	------	829	1, 747	4, 570	2, 566
Bungulanon:															
Section 1	5, 752	1, 431	1, 986	8, 121	4, 322	2, 239	694	1, 884	12, 088	4, 226	2, 026	1, 062	1, 700	11, 256	4, 011
Section 2	------	473	424	3, 810	1, 569	------	1, 012	571	10, 873	4, 152	------	466	498	7, 342	2, 769
Average	------	952	1, 205	5, 966	2, 946	------	853	1, 228	11, 480	4, 189	------	764	1, 099	9, 299	3, 390
Both varieties:															
Section 1	6, 249	1, 259	1, 737	10, 288	4, 883	4, 236	824	2, 362	7, 549	3, 743	3, 565	1, 041	1, 932	9, 494	4, 008
Section 2	------	572	1, 343	2, 418	1, 444	------	809	484	6, 332	2, 542	------	552	914	4, 376	1, 947
Average	------	916	1, 540	6, 353	3, 164	------	816	1, 423	6, 940	3, 142	------	796	1, 423	6, 935	2, 978
Over-all average	------	------	------	------	3, 164	------	------	------	------	3, 142	------	------	------	------	2, 978

TABLE 10.—*Flex life in number of revolutions to failure for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in the Changuinola Valley, Panama*

Variety and position of fiber in plant	Sun dried				Machine dried				Average			
	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	All sheaths
Maguindanao:												
Section 1	1, 441	843	640	975	1, 351	1, 069	686	1, 035	1, 396	956	663	1, 005
Section 2	1, 018	753	782	851	317	661	914	631	668	707	848	741
Section 3								847				847
Average	1, 229	798	711	913	834	865	800	838	1, 032	832	756	864
Bungulanon:												
Section 1	991	1, 210	872	1, 024	2, 107	798	582	1, 162	1, 549	1, 004	727	1, 093
Section 2	3, 071	477		1, 774	668			608	1, 870	477		1, 174
Section 3				935				542				738
Average	2, 031	844		1, 244	1, 388			791	1, 710	740	727	1, 002
Both varieties:												
Section 1	1, 216	1, 026	756	999	1, 729	934	634	1, 099	1, 472	980	695	1, 049
Section 2	2, 044	615	782	1, 147	492	661	914	689	1, 269	592	848	903
Section 3				935				694				792
Average	1, 630	820	769	1, 027	1, 110	798	774	827	1, 370	786	772	915
Over-all average				1, 061				819				927

TABLE 11.—*Flex life in number of revolutions to failure for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Honduras*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	832	984	834	4, 003	1, 455	3, 330	1, 337	2, 571	1, 038	2, 069	2, 081	1, 160	2, 514	2, 520	2, 069
Section 2	------	------	1, 024	------	1, 024	------	598	505	523	542	------	598	764	523	628
Average	------	------	929	------	1, 240	------	968	1, 538	780	1, 306	------	879	1, 639	1, 522	1, 348
Bungulanon:															
Section 1	1, 838	------	1, 276	1, 252	1, 455	1, 029	1, 027	5, 894	1, 030	2, 245	1, 285	1, 027	3, 769	1, 141	1, 806
Section 2	------	1, 032	1, 123	------	1, 078	------	563	526	881	657	------	1, 020	824	881	908
Average	------	------	1, 200	------	1, 266	------	795	3, 210	956	1, 451	------	1, 024	2, 297	1, 011	1, 357
Both varieties:															
Section 1	1, 335	984	1, 055	2, 628	1, 500	2, 180	1, 182	4, 232	1, 034	2, 157	1, 683	1, 094	3, 142	1, 830	1, 937
Section 2	------	1, 032	1, 074	------	1, 053	------	580	516	702	599	------	809	794	702	768
Average	------	1, 008	1, 064	------	1, 276	------	881	2, 374	868	1, 378	------	952	1, 968	1, 266	1, 352
Over-all average	------	------	------	------	1, 261	------	------	------	------	1, 378	------	------	------	------	1, 352

TABLE 12.—*Flex life in number of revolutions to failure for different positions in the plant of sun-dried and machine-dried fiber of 2 varieties of abaca grown in Guatemala*

Variety and position of fiber in plant	Sun dried					Machine dried					Average				
	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths	Outer sheaths	Intermediate sheaths	Inner sheaths	Inside sheaths	All sheaths
Maguindanao:															
Section 1	1,090	832	298	678	724	1,186	525	787	617	779	1,138	678	542	648	752
Section 2		438			438										
Average		635			581					779					752
Bungulanon:															
Section 1	784	623	470	932	702	772	981	588	828	738	778	802	509	869	740
Section 2		316	425	590	444		278	1,035	268	527		310	730	429	490
Average		469	448	761	573		629	812	548	632		556	620	649	615
Both varieties:															
Section 1	937	728	384	805	714	979	753	688	722	786	958	740	526	758	746
Section 2		377	425	590	464		278	1,035	268	527		310	730	429	490
Average		552	404	698	589		516	862	495	656		525	628	594	618
Over-all average					581					689					662

When comparing samples from the different heights in the plant from all varieties, locations of growth, areas in cross section, and methods of drying, the fiber properties studied—fiber strength (3-inch and ⅛-inch span between testing jaws), resistance to abrasion with the SS and the SZ twists, and flex life—all decreased from the base to the top of the plant (table 13). Data are shown for three sections of sheaths from Panama and for two sections of those from Honduras and Guatemala. The more detailed data reported in other tables indicated that the maximum strength occurred near the top of the first 6-foot section in the fiber from Panama where there were three sections. The top section at Panama, however, was much weaker than the other two and showed lower resistance to abrasion and a shorter flex life. In the short plants from Honduras and Guatemala, the maximum strength was reached within 2 or 3 feet of the base. Only one section of the plant was studied at Costa Rica.

These results indicate that the fiber from the midregion and upper end of the lower section of tall plants with 16 to 20 feet of usable stalk is better than that from the butt and particularly that from the top section, whereas the best fiber in short plants is near the base. Two out of three sections produce high-grade fiber in tall plants, whereas only one or even less may produce high-grade fiber in short, stunted plants.

Statistical analysis of these data showed a difference in fiber strength with location of growth; the samples from Honduras, however, were tested promptly after harvesting, whereas those from Panama were tested about a year later. The fiber is known to lose some strength with age in storage; therefore comparison of location may not be valid in these tests.

The data in summary table 14 indicate that the variety Bungulanon is superior in fiber strength to that of Maguindanao, but that the two varieties are very similar in resistance to abrasion and flex life. The data in summary table 15 indicate that there were no consistent differences that could be attributed to method of drying. The detailed data, however, showed somewhat greater variability in the fiber dried in the machine drier.

DISCUSSION

Statistical analysis of the data on fiber strengths indicates that of the two varieties of abaca grown commercially in Central America, the fiber from Bungulanon is stronger than that from Maguindanao (table 16). The latter variety usually produces a finer fiber, but there was little if any difference in fiber from the two varieties in resistance to abrasion and flex life.

TABLE 13.—*Physical properties*[1] *of fiber for different positions in abaca plants grown in Guatemala, Honduras, Costa Rica, and Panama*

Location	Section 1					Section 2				
	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)
	Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist		Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist	
Guatemala	88. 8	82. 4	1, 274	4, 008	746	66. 7	64. 6	495	1, 947	490
Honduras	94. 7	85. 9	1, 895	7, 595	1, 937	72. 2	77. 7	881	3, 258	768
Costa Rica	67. 6	59. 1	777	3, 006	1, 051	------	------	------	------	------
Panama	74. 8	68. 6	1, 316	927	1, 049	66. 4	62. 1	625	1, 277	903

Location	Section 3					Average				
	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)
	Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist		Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist	
Guatemala	------	------	------	------	------	77. 7	73. 5	884	2, 978	618
Honduras	------	------	------	------	------	83. 4	81. 8	1, 388	5, 416	1, 352
Costa Rica	------	------	------	------	------	67. 6	59. 1	777	3, 006	1, 051
Panama	48. 3	53. 4	326	518	792	63. 2	61. 4	756	907	915

[1] Values used are averages for all sheaths dried by the different methods.

[2] Scott 3 inch and Scott ½ inch refer to the length of the breaking span.

TABLE 14.—*Physical properties*[1] *for varieties of abaca grown in Guatemala, Honduras, Costa Rica, and Panama*

Location	Bungulanon						Maguindanao						Average for both varieties					
	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number fibers in bundle)	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number fibers in bundle)	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number fibers in bundle)
	Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist			Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist			Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist		
Guatemala	79. 2	72. 4	905	3, 390	615	31	76. 0	76. 2	864	2, 566	752	36	77. 7	73. 5	884	2, 978	618	34
Honduras	88. 0	93. 4	1, 689	6, 464	1, 357	36	79. 0	79. 2	1, 087	4, 369	1, 348	43	83. 4	81. 8	1, 388	5, 416	1, 352	40
Costa Rica	71. 6	63. 5	822	1, 646	1, 019	22	63. 6	54, 8	731	4, 365	1, 084	[3] 39	67. 6	59. 1	777	3, 006	1, 051	30
Panama	69. 4	66. 1	619	600	1, 002	27	59. 3	58. 2	883	946	864	33	63. 2	61. 4	756	907	915	30

[1] Values used are averages for all sheaths dried by the different methods.

[2] Scott 3 inch and Scott ½ inch refer to the length of the breaking span.

[3] Base section only.

TABLE 15. *Physical properties[1] for different methods of drying abaca grown in Guatemala, Honduras, Costa Rica, and Panama*

Location	Sun dried					Machine dried					Average				
	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)	Fiber strength (1,000 pounds per square inch)		Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)
	Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist		Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist		Scott 3 inch[2]	Scott ½ inch[2]	SS twist	SZ twist	
Guatemala	76. 6	74. 6	924	3, 164	589	78. 7	70. 6	794	3, 142	656	77. 7	73. 5	884	2, 978	618
Honduras	82. 9	84. 8	1, 398	5, 734	1, 276	83. 9	80. 8	1, 828	6, 369	1, 378	83. 4	81. 8	1, 388	5, 416	1, 352
Costa Rica	67. 2	61. 2	614	3, 975	1, 148	68. 0	57. 1	939	2, 037	858	67. 6	59. 1	777	3, 006	1, 051
Panama	63. 0	60. 0	775	1, 168	1, 027	62. 2	61. 3	762	657	827	63. 2	61. 4	756	907	915

[1] Values used are averages for all sheaths dried by the different methods.
[2] Scott 3 inch and Scott ½ inch refer to the length of the breaking span.

TABLE 16.—*Summary of analysis of variance of the fiber strength and yarn strength of abaca fiber from Central America*

[1 asterisk indicates significant difference at 5-percent level and 2 asterisks indicate significant difference at 1-percent level. The error of measurement was used, in lieu of experimental error, as test of significance]

Variable	Degree of freedom		Degree of significance (fiber strength in 1,000 lbs. per sq. in.)			
			Individual locations			All locations combined
	Single location	All locations	Panama	Honduras	Guatemala	
Locations		2				**
Sections (S)	1		**	**	**	**
Variety (V)	1		*	**	*	**
V × S	1		*			
Drying (D)	1		**		*	*
D × S	1					
D × V	1				**	*
D × V × S	1		**			
Sheaths (Sh)	2		**		*	**
Sh × S	2		*	**	**	
Sh × V	2					
Sh × V × S	2		**	**	**	
Sh × D	2		**		**	
Sh × D × S	2		**		**	**
Sh × D × V	2		**		**	**
Sh × D × V × S	2				*	**
Error	24	118				
Total	47	143				
			(Yarn strength in length of yarn required to break itself in thousands of feet)			
Locations		2				**
Sections (S)	1		**	**	**	**
Variety (V)	1			**	*	**
V × S	1				**	
Drying (D)	1		*		*	
D × S	1		*			
D × V	1				**	*
D × V × S	1					
Sheaths (Sh)	2		**	**	**	**
Sh × S	2			**	**	*
Sh × V	2			*		
Sh × V × S	2		*	**	**	
Sh × D	2		**		**	
Sh × D × S	2				**	
Sh × D × V	2		**	*	**	**
Sh × D × V × S	2			*	**	**
Error	24	118				
Total	47	143				

The analysis of variance using fiber strengths (1,000 pounds per square inch) gave somewhat different comparisons than the analysis based on the length of yarn required to break itself (table 16). The significance found for location of growth, sections (height in the plant), and variety is the same for fiber strength and yarn strength for all locations combined. Differences between the two methods of expressing the data are apparent, however, in the significance found between the length of fiber to break itself and pounds per square inch at individual locations for variety, and sheaths. Variety was significant to the 5-percent level when the data were expressed in pounds per square inch at Panama, whereas it was not significant on the basis of length required to break itself. Differences between sheaths showed significance at the 1-percent level in length of the fiber to break itself at each location; whereas they were significantly different at the 1-percent level at Panama and at the 5-percent level at Guatemala and showed no significance at Honduras when tensile strengths were compared.

The greatest differences observed in all three properties measured, fiber strength, flex life, and resistance to abrasion, were at different heights in the plant. This was particularly true in the shorter plants at Guatemala and Honduras, but differences in height in plant were significant at all locations (table 16). In the fiber from Panama there was little difference in properties between the first and second sections, but the third or top section was appreciably weaker and gave lower resistance to both abrasion and flex. At the other two locations, the top or second section was much weaker than the base section. At Panama there was a 13-percent decrease in fiber strength between the first and second sections of the Maguindanao plants, 42 percent between the first and third sections, and 33 percent between the second and third sections. For the Panama Bungulanon variety, the decrease in fiber strength up the plant was 0.5 percent between the first and second sections, 29 percent between the first and third sections, and about 29 percent between the second and third sections. In the other locations, Guatemala and Honduras, the decrease up the plant for Maguindanao fiber was 23 percent and for Bungulanon fiber 26 percent. The abrasion and flex data also showed inferior fiber in the top region of the plants.

In the cross sections the streaky fiber was in general the strongest, the inner white fiber weakest, with the outer brown fiber and the ocher or buff fiber just beneath the streaky sheaths intermediate. These data tend to confirm those of Espino (*6*), Espino and Esguerra (*7*), and Tirona (*11*, *12*). Missing values made it difficult to establish significance between the different positions in the cross section in both the flex and abrasion resistance.

No consistent differences were apparent in the fiber properties between the sun-dried and machine-dried samples. At certain locations the sun-dried fiber was stronger, whereas at others the machine-dried fiber was superior. In handling the fiber in the laboratory, the machine-dried fiber appeared more variable, although the two could rarely be distinguished. It was observed that the surface of the hanks of fiber dried in the machine was overdried, and the cores underdried. The overdried part was possibly injured but the rest of the hank was probably in better condition than that dried in the sun so that the strength of the average machine-dried fiber was not significantly lower than that of the sun-dried fiber at all locations. Sunlight is known to injure cellulose fibers to some extent.

Observations made in the drying sheds of the decorticating plants where the commercial fiber was being baled indicated that the overdried outer regions of the hanks were absorbing the excess moisture from the core of the hanks, thus equalizing both of them. The ideal condition would be to have this leveling off prior to baling, or at least have no more moisture than is needed to bring all the fibers to about 10 percent moisture when equalized. This is normally accomplished in Central America by seasoning or tempering the fiber by allowing it to stand for 24 hours before baling. If fiber containing excess moisture is pressed into a bale, biological decay may set in and the fiber will heat, causing appreciable losses in fiber strength and other properties. Such damage may be detected if present in the opened commercial bales by a tendency of the fiber to mat or stick together. A white mycelial growth or a discoloration due to fungal spores may also be visible and damaged bales may have a musty odor.

Unfortunately it was impossible to run all the fiber tests promptly on all the samples. Some samples were shipped by boat and were not received for several months after the samples brought back by air were tested. Care was taken, however, to complete each set promptly after it was begun so that all comparisons except that of location of growth should be valid. The delay in testing the fiber from Panama and Costa Rica makes comparisons with the data from Honduras and Guatemala inadvisable.

In collecting the samples only one of a kind at each location was taken; therefore interpretations of the data from statistical analysis are limited. The error of measurement was used as a test of significance. A factorial analysis of the totals of the measurements of 10 breaks on each of two bundles was used to determine the validity of using this error term. It is indicated that an index of differences may be obtained in this way, provided due allowances are made.

SUMMARY

Samples of fiber from two varieties of abaca, Maguindanao and Bungulanon, grown in Panama, Costa Rica, Honduras, and Guatemala were studied. The samples were selected to show fiber properties for (1) different heights in the plant, (2) different areas of the cross section, and (3) sun-dried and machine-dried fiber.

These data indicate that the fiber strengths of Bungulanon are significantly greater than those of Maguindanao wherever the two varieties are grown.

The fiber properties vary with height in plant for both varieties. Tall, thrifty plants grown in deep shade show little difference in fiber properties with height in plant up through the first 10 feet, but near the top the fiber strengths, flex life, and resistance to abrasion all decline. Short, stunted plants grown in inadequate shade show a marked reduction in physical properties with height in plant above the first 4 or 5 feet. In short plants the first 6-foot section, going up from the base, may be as much as 20 to 30 percent higher in fiber strength, flex life, and resistance to abrasion than the second section or top.

The fiber strength is greatest in the streaky sheaths, somewhat less in the outer brown sheaths and the ocher or cream-colored sheaths just beneath the streaky, and least in the white fiber near the center of the plant.

There were no consistent differences in fiber properties that could be associated with methods of drying the fiber.

Although the data showed significant differences in fiber properties in location of growth, certain of the samples were tested at least a year later than others; therefore comparison may be invalid.

A STUDY OF METHODS OF CLEANING CENTRAL AMERICAN ABACA FIBER

By Earl E. Berkley, Edna B. Burneston, and Lyle E. Hessler

General Background

Abaca fiber is obtained from the overlapping sheaths that constitute the false stem of the plant *Musa textilis*. Since the fiber must be stripped from the leaf tissue in which it grows, a study was made of the fiber resulting from two methods used commercially to clean the fiber. Most of the abaca fiber from the Philippine Islands is stripped by hand or by the hagotan method. The methods used in this study are (1) the hagotan method, which produces the same type of fiber as the hand method, and (2) the raspador, or machine method used in Central America. The manner of cleaning the fiber, as well as the amount of fiber extracted from the plant, differs in the two methods.

The leaf sheaths of abaca start about 10 to 15 inches above the ground and the inner sheaths extend the full length of the false trunk, which culminates in a rosette of leaves at the top. The dorsal or outer region of the semicircular leaf sheath is very rich in fiber, whereas the rest of the sheath tends to be fleshy or porous (*4*). The Filipinos learned to remove the outer skinlike surface by inserting a sharp-pointed instrument at a tangent to the curved sheath and stripping off the loosened portion. The ribbonlike strip is known as a tuxy.

In the hand method the tuxy was drawn between a knife and a block of wood to remove the nonfibrous tissue. The tuxy was pressed against the knife edge by the strip of wood held by a lever or weight. Frequently a bent sapling was used in conjunction with a weight. The strips, or tuxies, range from 4 to 15 or more feet in length. They are difficult to pull across the knife, particularly a smooth-edged knife, which is more satisfactory for the finer grades of fiber. Serrated knives are commonly used. The coarseness of the fiber increases with fewer serrations per inch, since more strands are left united into strips or ribbons.

Materials and Methods

The hagotan method (fig. 1) of cleaning may be considered a modification of the hand method. A motor-driven spindle was developed to do the major portion of the work in pulling the tuxies across the knife. It consists of a cone-shaped pulley around which the fibers are wrapped and held taut so that they are wound on the pulley. The pulley is motor-driven and the speed at which it draws the fiber over

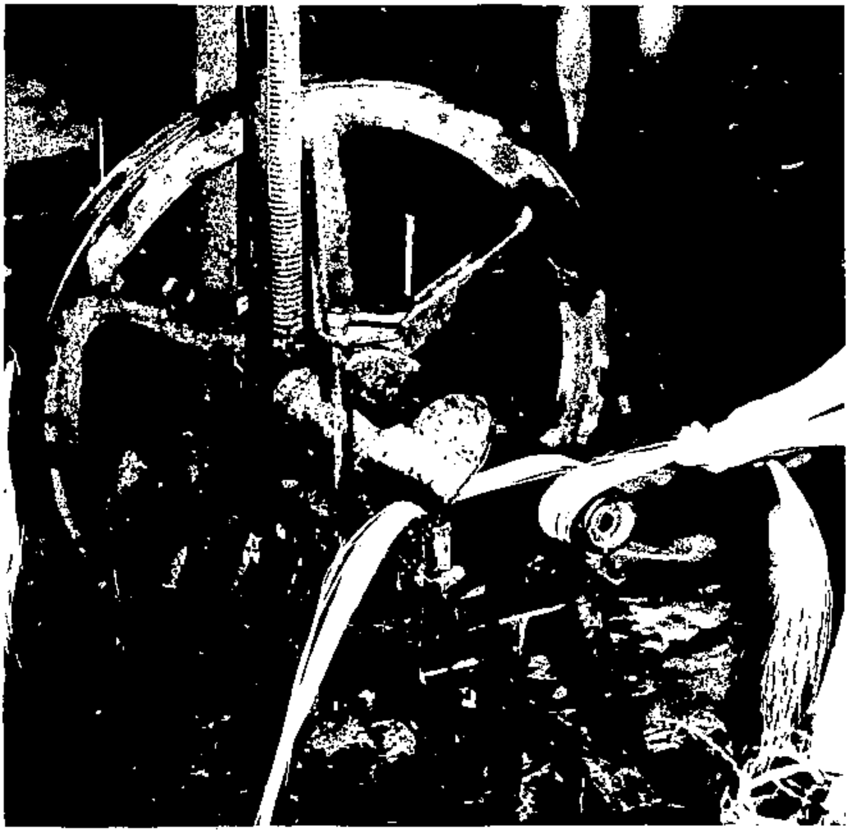

FIGURE 1. Hagotan method of cleaning abaca fiber.

the knife depends on the position along the cone. The large end will draw the fiber faster than the small end. In preparing the plants for the hagotan method the leaf sheaths are tuxied as by the hand method.

If the hagotan machine is properly adjusted and operated, there should be a minimum of damage to the fiber. Unfortunately the plant debris banks up against the unstripped portion of the tuxy and may break some of the fibers. Furthermore only a portion of the leaf sheath is used, and a part of the fiber is left with the discarded material.

Machine decortication (fig. 2) differs in many respects from the hagotan method. For the machine method of decortication, the leaf stalks when harvested are cut into sections from 4 to 6 feet in length. The dark outer sheaths may be removed and discarded in the field or decorticated separately. The sections are then crushed between rollers, and the fiber is scraped, one end at a time, by two large revolving wheels of the raspador machine. These wheels are similar to fly wheels that have paddlelike knives on their outer surfaces perpendicular to the direction of the movement of the wheel. The crushed stalks are scraped against a bed plate curved to fit the wheel. In contrast to the hagotan method the fibers are held more or less stationary and the knife is moved very fast.

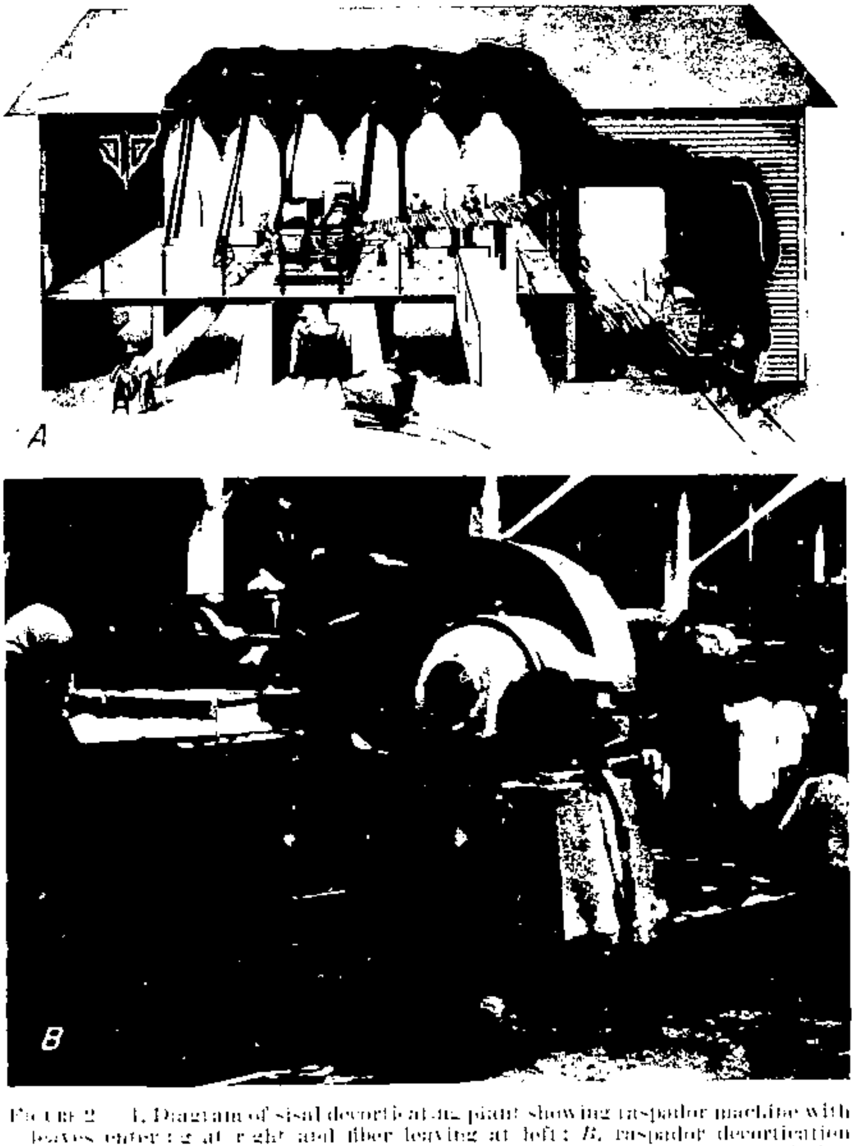

FIGURE 2.—A, Diagram of sisal decorticating plant showing raspador machine with leaves entering at right and fiber leaving at left; *B*, raspador decortication machine in operation with abaca sheaths entering at the left and cleaned fiber coming out at the right.

The crushed stalk is held by a system of rope grips while one end is being decorticated. The half-cleaned fiber and crushed stalk then move on to a new set of rope grips that hold the cleaned fiber while the other end is being decorticated. Some fiber is pulled out of the rope grips along with the other plant debris and lost as waste. The fiber is extracted from the entire cross section of the sheath in the machine method but only from the outer surface, or tuxy, in the hagotan method. A yield of about 2 percent fiber on the basis of the green weight of the stock is common for the hagotan method, whereas a yield of 3.5 percent or more is expected for the machine method.

RESULTS OF TESTS

In view of the wide differences in yield of fiber between the hagotan and raspador machine method of decortication, a study was made of (1) the physical properties of the fiber from each method, (2) the type of fiber produced, and (3) any injuries that might cause weakness. Two varieties were compared in Panama and six in Costa Rica.

The tensile strengths generally were slightly greater for the Hagotan-stripped fiber at both locations (tables 17 and 18). The machine-decorticated fiber from the varieties Libuton and Putian grown at Good Hope, Costa Rica, was stronger than that cleaned by the hagotan method (table 18).

In varieties grown in Panama the fiber from Bungulanon was slightly stronger than that from Maguindanao. No significant differences were found in the strength of the fibers from the different varieties grown in Costa Rica except perhaps that of Putian, which was slightly stronger when cleaned by the machine method than the other five varieties tested. Since this variety is known to produce a relatively weak fiber when grown in the Philippine Islands, further study should be made before final conclusions are drawn.

TABLE 17.—*Physical properties of machine-decorticated and hagotan-stripped fiber from 2 varieties of abaca grown in the Changuinola Valley, Panama*

Variety and method of cleaning	Fiber strength[1] (1,000 pounds per square inch)	Resistance to abrasion (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number of fibers per standard bundle[2])
		SS twist	SZ twist		
Maguindanao:					
Machine	59.3	883	946	864	33
Hagotan	72.8	595	1,220	670	20
Average	66.0	739	1,083	767	26
Bungulanon:					
Machine	65.4	619	600	1,002	27
Hagotan	78.5	536	692	713	17
Average	72.0	578	646	858	22

[1] 3-inch span between testing jaws.
[2] 15 inches long and weighing 325 milligrams.

TABLE 18.—*Physical properties of machine-decorticated and hagotan-stripped fiber from 6 varieties of abaca grown at Good Hope, Costa Rica*

Variety and method of cleaning	Fiber strength[1] (1,000 pounds per square inch)	Knot strength[1] (1,000 pounds per square inch)	Resistance to abrasion (revolutions to failure)		Flex life (revolutions to failure)	Fiber fineness (fibers per standard bundle[2])
			SS twist	SZ twist		
Maguindanao:						
Machine	71.7	16.7	551	1,380	515	32
Hagotan	77.3	15.4	3,216	2,107	596	27
Average	74.5	16.0	1,884	1,744	556	30
Bungulanon:						
Machine	68.9	15.4	837	456	425	28
Hagotan	80.5	18.8	593	879	554	23
Average	74.7	17.1	715	668	490	26
Tangongon:						
Machine	72.9	16.2	2,340	1,018	552	27
Hagotan	74.5	14.2	957	1,409	585	28
Average	73.7	15.2	1,648	1,214	568	28
Libuton:						
Machine	75.3	17.4	755	724	560	26
Hagotan	73.0	17.8	704	1,772	668	32
Average	74.2	17.6	730	1,248	614	29
Putian:						
Machine	84.7	17.3	2,145	844	1,132	36
Hagotan	71.7	16.5	545	2,378	732	26
Average	78.2	16.9	1,345	1,611	957	31
Sinaba:						
Machine	63.7	15.4	689	1,265	706	31
Hagotan	81.0	19.9	629	2,006	942	33
Average	72.4	17.6	659	1,636	824	32
Summary average:						
Machine	72.9	16.4	1,220	948	648	30
Hagotan	76.3	17.1	1,107	1,758	680	28
Over-all average	74.6	16.8	1,164	1,353	664	29

[1] 3 inch span between testing jaws.
[2] 15 inches long and weighing 325 milligrams.

Differences between the knot strengths of fibers cleaned by the two methods were not consistent, although on the average the hagotan-stripped fiber was slightly but not significantly stronger than that from the machine method of cleaning. Among varieties no marked differences in knot strengths were apparent except for the variety

Tangongon, which was on the average slightly weaker than the others tested.

The methods used to study resistance to abrasion and flex life showed variations in fiber properties within a given sample. These variations are due in part to techniques that are not refined enough to permit the measurement of small differences.

In general the machine-decorticated fiber was more resistant to abrasion when looped with the SS twist than was the hagotan-stripped fiber (tables 17 and 18). The hagotan-stripped fiber on the other hand was more resistant to abrasion when looped with the SZ twist (tables 17 and 18). When grown at Panama and Costa Rica, the fiber from the variety Maguindanao was more resistant to abrasion than that from Bungulanon. Of the six varieties grown in Costa Rica, Maguindanao showed the greatest, and Bungulanon the lowest resistance to abrasion for the SZ twist.

The machine-decorticated fiber had a greater flex life than the hagotan-stripped fiber at Panama (table 17), whereas the reverse was true in Costa Rica (table 18). The differences were not consistent in Costa Rica, since in the variety Putian the machine-decorticated fiber had a greater flex life than the hagotan-stripped.

The machine-decorticated fiber from both varieties grown in Panama was finer (gave more fibers per bundle) than that stripped by the hagotan method (table 17). In Costa Rica certain varieties gave a coarser fiber (fewer fibers per bundle) for the machine method than for the hagotan method (table 18). Reasons for this behavior under the two methods of processing are not clear, however. Since reversals were found in other properties of these same samples, it is suggested that additional data be obtained on these varieties and methods of cleaning.

The machine method of cleaning extracts fiber from all parts of the leaf sheath, whereas the hagotan method takes only the outer or dorsal side. A study of the fine structure of the fiber, using an X-ray diffraction method, was made on the fiber from three locations in the leaf sheath—the dorsal, or outer side, the central pithy region, and the inner, or ventral side of the leaf. The X-ray diffraction patterns showed a higher degree of order of structure in the cellulose in the fiber from the outer regions of the leaf sheath (fig. 3, *a*) used in the tuxy than in the central and inner regions (fig. 3, *b* and *c*), which are also included in the machine-cleaned fiber. The crystallites were arranged more nearly parallel with the long axis of the fiber in the outer region used in the tuxy, as indicated by the short equatoral arcs in the X-ray diffraction pattern, with a progressively poorer orientation in the central and inner regions of the sheaths, as indicated by the greater lengths of the more prominent arcs in the patterns (fig. 4). The shorter the arcs, the more nearly the cellulose is arranged parallel with the fiber axis and vice versa. If the cellulose crystallites were arranged parallel with the fiber axis, the arcs would be sharp spots more or less equal in all directions.

It is recognized that fiber damage sustained in the decortication process may affect the physical properties of the fiber. The abaca fiber as known in commerce is a strand of many individual fiber cells. The individual fiber cells are about 7 millimeters long and 15 to 20 microns in diameter, whereas the strand may be 10 to 15 feet long and 0.5 millimeter or more in width. The properties of the commercial fiber are

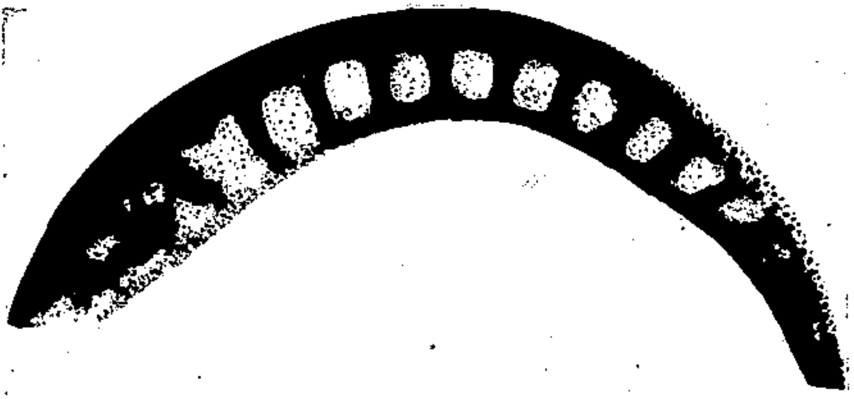

FIGURE 3.—A section of the overlapping sheath of the false stem of the abaca plant: *a*, Dorsal, or outer region of sheath; *b*, central region; *c*, inner or ventral region.

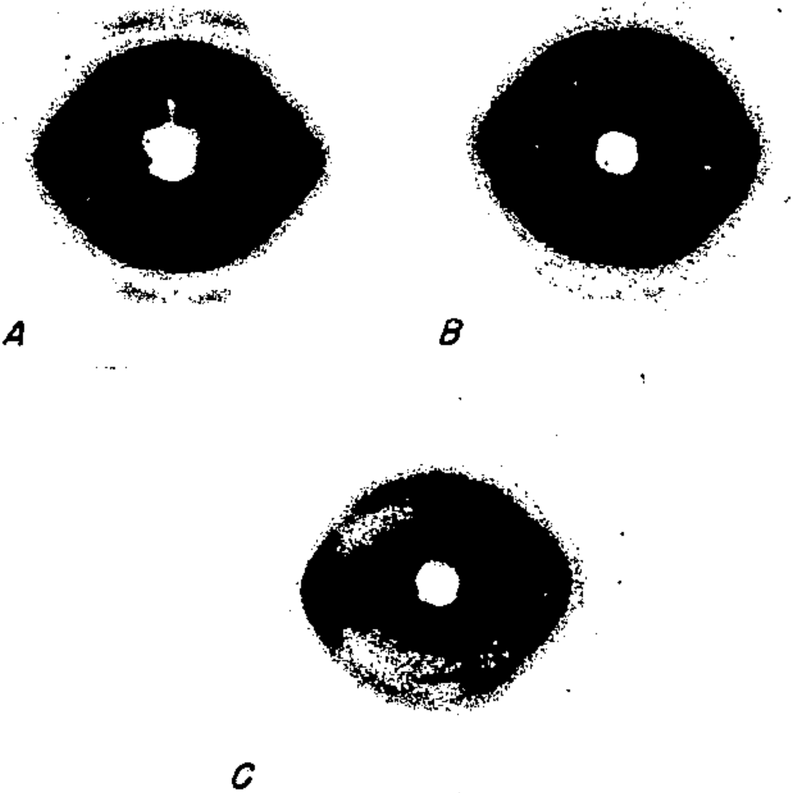

FIGURE 4.—X-ray diffraction patterns of: *A*, Fibers from the dorsal, or outer region of sheath (see figure 3, *a*, *b*, and *c*); *B*, the central region; and *C*, the inner or ventral region. The general clarity and sharpness of lines or arcs indicate the degree of order, and the length of the more prominent arcs indicates the orientation of the cellulose in regard to the fiber axis.

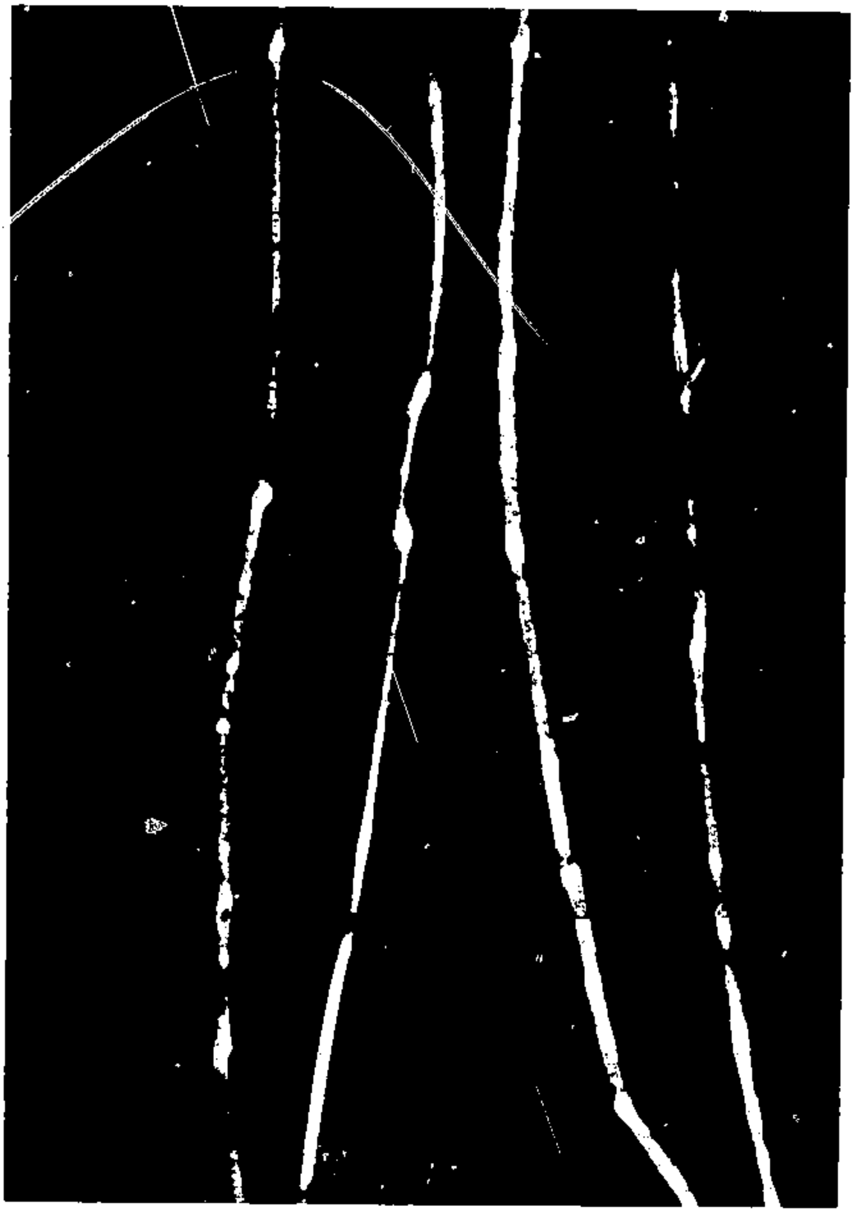

FIGURE 5.—Injuries or crushed fiber strands resulting in the machine decortication of abaca fibers.

dependent on those of the individual cells and the way they are bound together. Any injury that would tend to crush or separate these tiny units would weaken the whole member.

When examined under a hand lens, the machine-decorticated fiber showed what appeared to be bruises or crushed spots along the fibers (fig. 5). Some of the injuries appeared to be typical compression failures such as are commonly found in wood after failure under compression (*1*). For the most part, the individual cells were not ruptured, but in many instances the strand was so mutilated that the individual fiber cells were to a large extent separated (fig. 6). Usually these injuries were confined to a region within 1 foot of the ends of the fibers, but occasionally they could be found throughout its length. Test specimens taken near the ends of the 6-foot sections in the regions where the injuries were pronounced were about half as strong as bundles taken in the midsection, where few, if any, injuries could be found.

In addition to a loss in strength, these injuries may also cause difficulty in spinning. The fiber tends to bend or buckle more readily at the point of injury, which results in tangling and matting. Where the injuries are confined to the ends of the fiber, they can be trimmed off, but where they occur some distance from the ends, the quality of the fiber may be permanently reduced. Furthermore, any trimming causes both a loss in fiber and an increased cost of production.

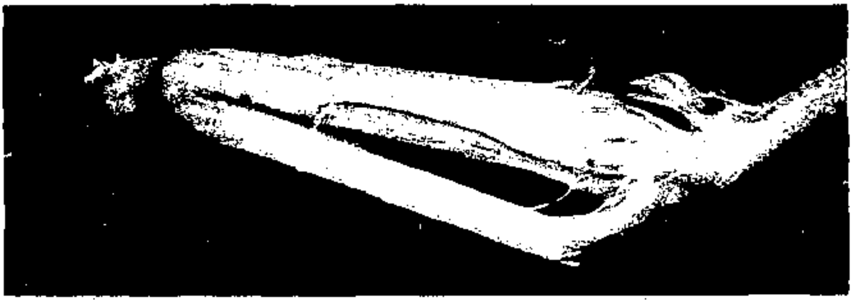

FIGURE 6.—Fiber injuries more highly magnified, showing separation of individual fiber cells.

DISCUSSION

The methods used in obtaining the fiber data reported here, particularly the resistance to abrasion and the flex life, are still in the process of development. They are, however, the best available. These methods were first described by Schiefer (*10*) and modified by Berkley.[5] The latter showed that the fiber strength, resistance to abrasion, and flex life decreased with height in abaca plant and varied from sheath to sheath in the cross section. Variety and location of growth produced fiber of different physical properties.

The hagotan method was developed to a high degree of perfection in the Philippines and later introduced on an experimental basis in Central America, prior to the use of the raspador-type machine. The hagotan-stripped fiber reported on here may not be of the same high quality as that from the Philippines because of a lack of experienced workers in Central America. The machine-decorticated fiber was finer, gave greater resistance to abrasion with SS twist (along the

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[5] See section in this bulletin on The Quality of Central American Abaca Fiber as Affected by Variety, Location of Growth, Position in Plant, and Method of Drying, p. 4, and also section on Improved Testing Machines for Studying Cordage and Other Long Vegetable Fibers, p. 38.

fiber), and greater flex life; whereas the hagotan fiber was coarser and stronger, gave greater resistance to abrasion with SZ twist (across the fiber), and had greater knot strength. The greater flex life of the machine-decorticated fiber may be due to the finer texture.

Since the abrasion method used is not entirely free of flex the greater life of the machine-cleaned fiber with the SS twist may also be associated with fineness. These fibers also pack more closely and give a smoother surface less subject to abrasion. The greater strength of the hagotan-stripped fiber can be attributed to its superior structure and freedom from injuries. The same properties may account for its greater resistance to abrasion (SZ twist), but coarseness may be a factor.

Natural cellulose fibers have a spiral structure in the cellulose strands, or fibrils, and lie in a spiral around the fiber as shown by the X-ray diffraction pattern. The steeper the pitch of the spiral, the stronger the fiber. Abaca fibers are in general stronger and have a more parallel structure than most hard fibers used for cordage. Similiarly the fibers from the region of the sheath used in the tuxy and in the hagotan method have a better structure and are stronger than those from the other regions of the leaf sheath. The machine-cleaned fiber comes from all parts of the sheath, and would be expected to be somewhat lower in strength than the more selective hagotan-stripped fiber.

The raspador-type decorticating machines used in Central America damage the fiber to some extent. Some of these machines injured the fiber more than others. Injuries consist of crushed fiber strands where the individual cells are separated. Where the damage was pronounced, the fiber strength was reduced. Indications are that in general few injuries should occur in properly adjusted machines. The injuries are usually confined to the ends of the fibers and probably cause more difficulty in processing than they do in the reduction in strength of the finished product.

These data indicate that although the differences in fiber structure in the various regions of the leaf sheath and the damage sustained in carefully adjusted decorticating machines may reduce the quality of the machine-decorticated fiber to some extent, the fiber is still of a high grade. They also indicate that the greater yields and economy of man hours in harvesting and cleaning the fiber by the machine method can be justified.

SUMMARY

Two varieties of abaca fiber from Panama and six varieties from Costa Rica were given special sampling consideration and cleaned by two different methods on hagotan and raspador machines.

Fineness, strength, abrasion by SS (along the fiber) and SZ (across the fiber), flex life, and knot strengths were determined.

Fiber structure was determined by X-ray method.

Machine damage to fiber was evaluated.

In general the raspador-decorticated fiber was finer and showed greater resistance to abrasion (SS twist) and greater flex life.

The hagotan-stripped fiber was coarser and stronger and showed a greater resistance to abrasion (SZ twist) and a greater knot strength.

The fiber-structure texture and lack of injuries can account for the greater strength of the hagotan-stripped fiber.

The greater yields by the machine method and economy of labor in harvesting justify the small reduction in quality of the machine-cleaned fiber.

IMPROVED TESTING MACHINES FOR STUDYING CORDAGE AND OTHER LONG VEGETABLE FIBERS

By Earl E. Berkley and Lyle E. Hessler[6]

Introduction

The cordage industry until recently had little cause for concern over the quality of the fiber used. Before the last war the Philippine Islands furnished the United States enough good quality abaca fiber for our needs for marine cordage and to a large extent for rope, twine, and other domestic products as well. During the war and even more in the cordage-hungry postwar period the quality of the abaca fiber received from the Philippine Islands declined and the supply became inadequate. As a substitute the cordage industry used sisal for abaca in certain types of cordage. The possibility of even lower supplies makes it necessary that we know more about the quality of the fiber used so that one fiber may be better substituted for another.

Studies of the properties of cordage fibers have been, until recently, confined largely to physical strength of fiber. These data were not too well defined or correlated with use value. The National Bureau of Standards developed methods and instruments for abrasion and flexure tests for both soft and hard fibers that were considered of value in the war emergency. The general principle of the machines built by Schiefer (*10*) has been maintained in machines used in obtaining the data reported here. Improvements have been made, however, in the working parts, and automatic switches were installed to cut the machines off when a yarn failed.

The modified machines have been used in routine testing in a study of varieties and of effects on fiber properties of environmental conditions during growth.[7] More specifically the machines have been used to obtain physical data on how various hard and soft fibers react to long periods of storage and how they vary with processing methods, such as retting, degumming, and cleaning. They also have been used to study the time of harvest or optimum age for the best fiber quality and methods of sampling.

Preparation of the samples for testing in this study was very similar to that described by Schiefer (*10*). After careful sampling, the fibers were cut into 15-inch lengths and weighed into bundles of 325 milligrams each. A twist of one turn per inch to form a yarn was given each bundle prior to mounting in an especially designed rack where the

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[6] The authors wish gratefully to acknowledge the mechanical assistance and guidance in making the changes and improvements in machine design by the instrument shop, under the direction of J. F. Mullins, in the Division of Soil Management and Irrigation and the Division of Fertilizer and Agricultural Lime.

[7] See section in this bulletin on The Quality of Central American Abaca Fiber as Affected by Variety, Location of Growth, Position in Plant, and Method of Drying, p. 4.

bundles were held in position to be glued to paper strips. For mounting on the abrasion machine, a distance of 6 inches between the paper grips was necessary to give the correct length of yarn; whereas for flex life 8 inches was required. The crude yarns are spaced about 1 inch apart on the strips of paper. After gluing the fiber bundles to the paper strips, the paper is cut between each bundle, leaving a small tab glued to each end of the test specimens, and the tab is punched (fig. 7) for mounting on the testing machines. A more detailed discussion of the methods of preparation and mounting of samples is given by Schiefer (*10*).

In order that the fiber-strength data might be reported in terms of tensile strength an instrument was developed to measure the cross-sectional areas of the yarns or fiber bundles. The cross-sectional areas were measured by the instrument shown in figure 8. A slot (*a*) 0.04 of an inch in width was fitted with a plunger (*b*) with which the fibers were packed to a given density. The density was determined by a spring (*c*), which forced the plunger into the slot. The plunger could be lifted out of the slot for loading by a foot pedal (*d*), thus permitting the use of both hands in handling the fiber. The height of the fiber bundle in the slot was recorded by means of an Ames dial[8] (*e*), which was placed on a lever (*f*). The distance from the fulcrum (*g*) to the dial (*e*) was twice that to the plunger (*b*).

The area of the cross section of the bundle, in square inches, was obtained by multiplying the width, 0.04 of an inch, by the height as read on the Ames dial. For convenience of operation, the instrument was designed so that the cross-sectional area could be quickly obtained by adding the heights of the bundle as read from the dial at each end of the test specimen, just outside the paper grips. This was made possible by making the width of the groove a factor of 4 and the levers from fulcrum to dial and fulcrum to sample a ratio of 2 to 1, respectively. The height of the bundle at each end as read from the dial was multiplied by 2 in the lever system. When added together they were equal to the height times the breadth of the yarn, since the other dimension was 0.04 of an inch. In this way the calculations were greatly simplified.

A momentary lag in reading this instrument is due to the slow compression of the fiber; care is therefore necessary in making the diameter measurements. The best results are obtained by letting one individual make all the diameter measurements so that the personal element is eliminated.

ABRASION

Abrasion may be defined as a repeated stress action on the surface of the test specimen. Hamburger (*8*) listed the following as the more desirable properties of material subject to repeated stress:

1. Low modulus of elasticity.
2. Large immediate elastic deflection.
3. High ratio of primary to secondary creep.
4. High magnitude of primary creep.
5. High rate of primary creep.

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[8] B. C. Ames Company, Waltham, Mass. Mention of brand names should not be construed as an endorsement by the Department of Agriculture of the product. No discrimination is intended and no preference can be expressed or implied.

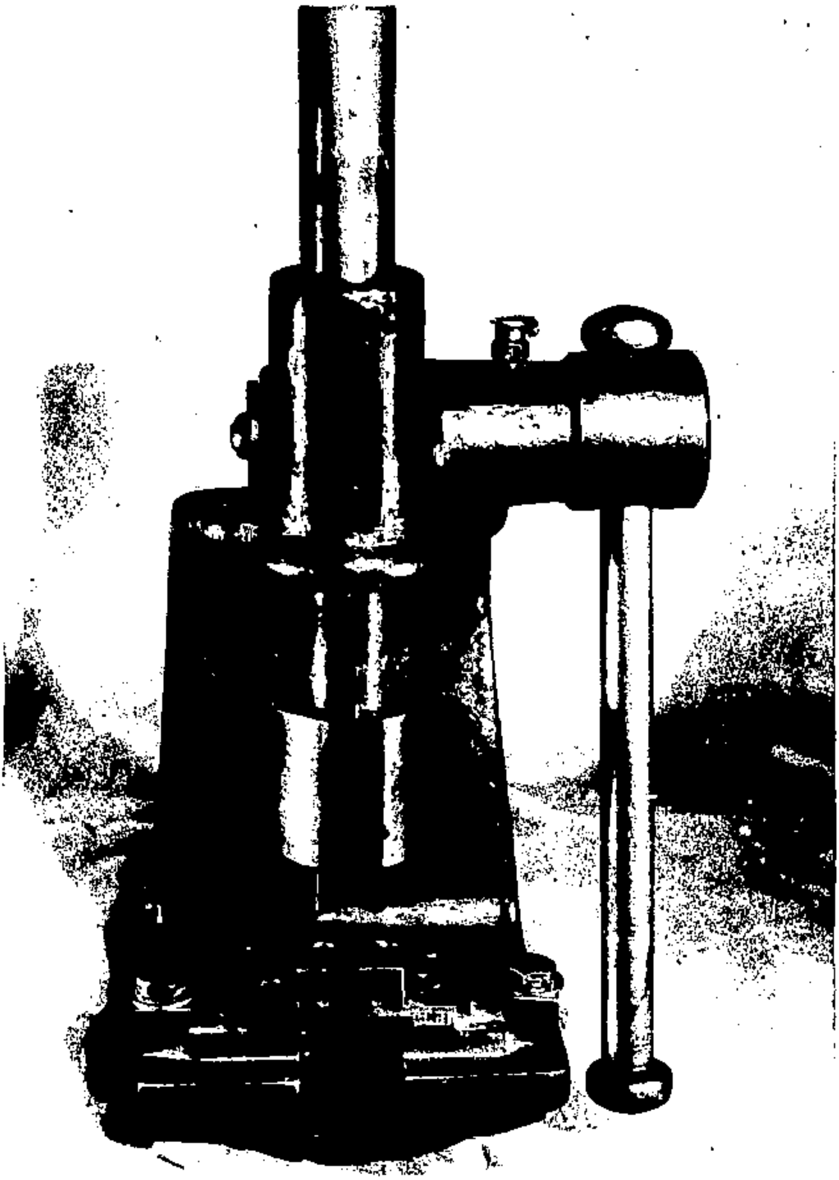

FIGURE 7.—Punch used in mounting fiber.

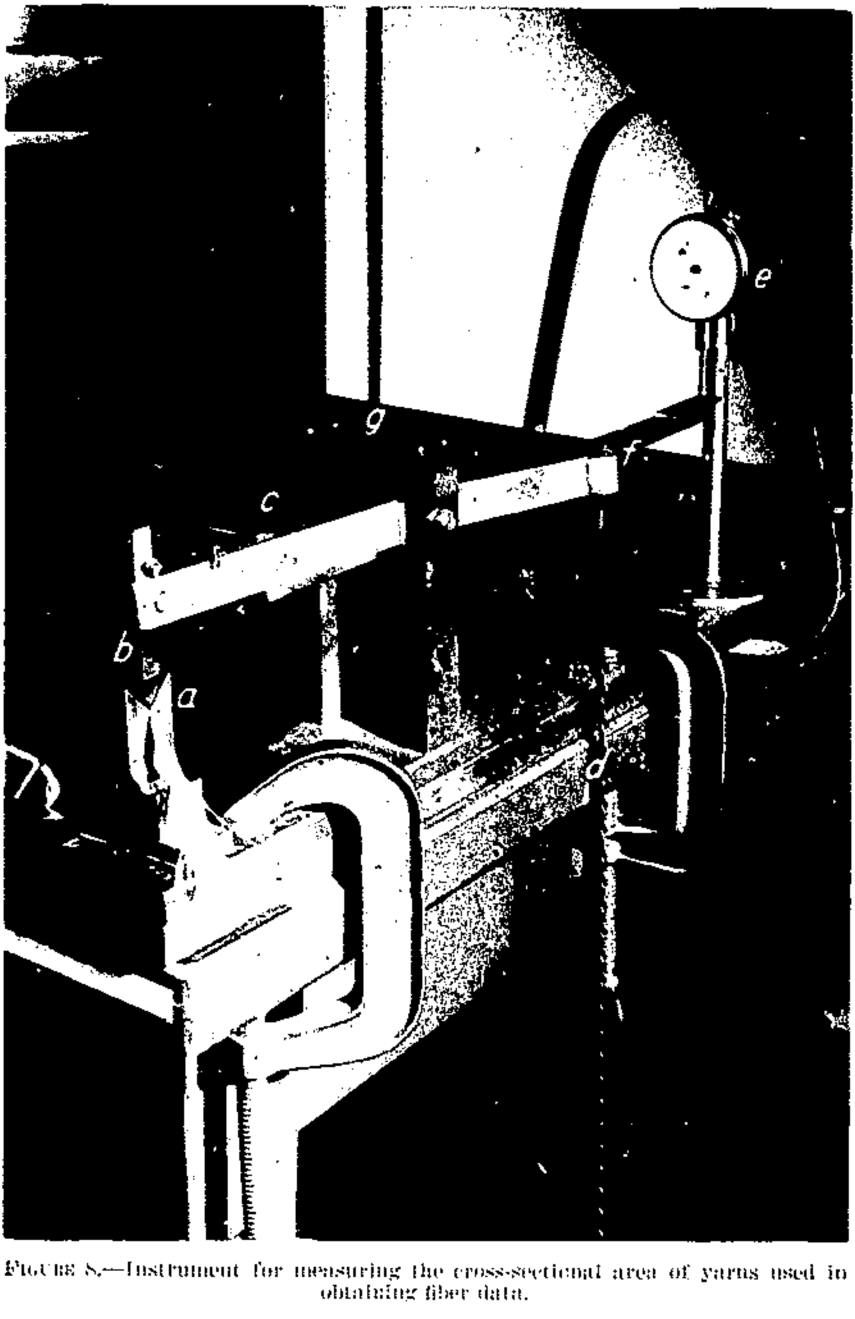

FIGURE 8.—Instrument for measuring the cross-sectional area of yarns used in obtaining fiber data.

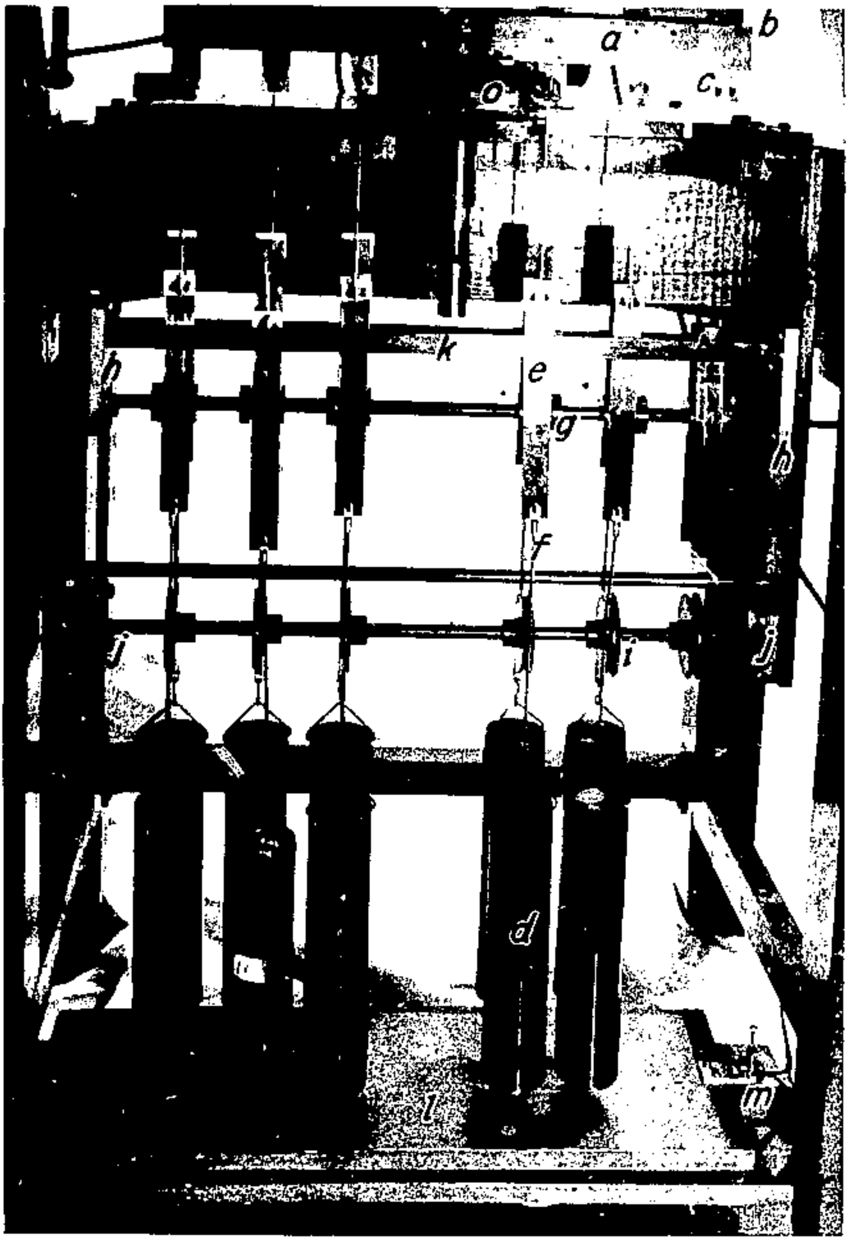

FIGURE 9.—Front view of abrasion machine, illustrating abrading operation.

To resist destruction, the specimen must be capable of absorbing energy imparted to it upon stress application and of releasing this energy upon removal of the stress without the occurrence of failure. Fiber on fiber abrasion subject to two different degrees of stress as made use of by the SS twist (along the fiber) and the SZ twist (across the fiber) appears to have advantages for testing cordage fibers.

Abrasion tests were obtained on a modified Schiefer machine, figures 9 and 10. The specimens of hand-made yarns were mounted on movable bars (*a* and *b*) by means of two pins (*c*). As one bar (*a*) moved down the other (*b*) moved up, and vice versa. A five pound weight (*d*) was suspended from the other end of each yarn by a similar pair of pins on a flat metal strap (*e*), which was connected to the weight by a wire cable (*f*). The metal strap was held in position by a guide (*g*) activated by the movement of the strap and supported by ball bearings (*h*) to avoid changes of load due to friction. The friction bearings that guided these straps in the Schiefer machine were replaced in this model by ball bearings. The cables attached to the weights were also guided by pulleys (*i*) mounted on ball bearings (*j*). The pitch to the mounting plates (*e*) was made by increasing the diameter of the bottom roller guide (*i*), which gives a pitch inclined 4½° to the vertical. A metal strip (*k*) was placed on each side of the top rod to catch the mounting plate after the fiber bundle or yarn breaks. Below the weights a hinged platform (*l*) is connected to a microswitch (*m*), which is in turn connected to a mercury relay in the box (*n*) of figure 10. When a fiber bundle breaks the weight hits the platform, closing the circuit and shutting off the machine. This refinement makes it possible to have the machine running when not attended. The number

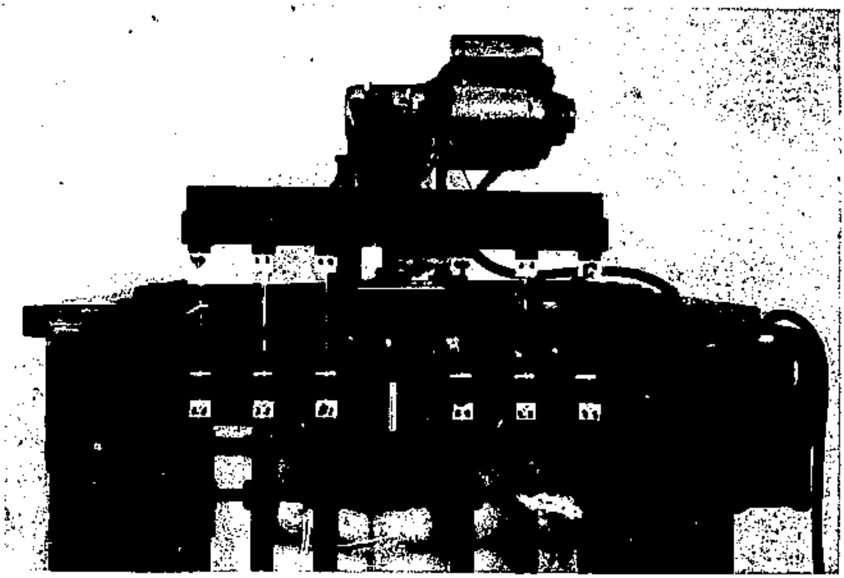

FIGURE 10.—Upper half of abrasion machine showing eccentric mechanism and fiber mounting.

of revolutions is recorded by the counter[9] (*o*) attached to the movable bar that activates the specimen. The machine is run until one of the two bundles of each pair fails. When one pair is eliminated the number of revolutions is recorded and the machine started again. This is repeated until all samples fail. New ones may be added as the others fail, thus keeping the machine loaded at all times.

FLEXURE

Flexibility may be considered the ability of a fiber to withstand repeated bending or bowing without rupture. If the fiber is pliable the flex life will be high, and, conversely, if the fiber is stiff it will be low. Shape and texture as well as the internal structure of the fiber appear to be important characteristics in flexibility.

The flexing machine was modified by adding a number of improvements. The principles and general form of the Schiefer machine (*10*) were retained and the modification consisted principally in refinements of action. A front view is shown in figure 11 and a side view in figure 12. The thickness of the stationary bar (*a*) was increased from one-quarter inch to 1 inch. The pulleys (*b*) on which the yarns are flexed (see figure 13 for detail) were each mounted on a shaft extending through the bar. The shaft was mounted on two sealed ball bearings, one on each side of the bar. This construction reduced the angular tortion and gave less friction in the samples. The lower bar was also enlarged to give stability and to support microswitches (fig. 13) for each specimen. The specimen, or yarn, was mounted on two sets of hooks (*e*) as in the Schiefer machine. When the yarn breaks, the weight (*f*) falls and trips the microswitch, stopping the machine. The weight (*f*) travels up and down along guides (*g*), which must be kept alined and lubricated with graphite. Friction on the guides will increase the load on the yarn and cause a differential result between positions on the machine.

The added weight of the parts made it necessary to counterbalance the machine to protect the motor and cut down vibration. A counterbalance weight (*h*), connected to a bar (*c*) by means of a chain (*i*), equalizes the load on the motor. The chain is run on two pulleys mounted on ball bearings and covered by the housing (*j*).

As in the abrasion machine the number of revolutions is recorded by a counter[9] (*k*). The microswitches activate a relay in the box (*l*) mounted on the table.

Both the abrasion and flex machines are mounted on casters and powered by a 110-volt electric circuit. They are simple to operate and can be turned on and allowed to run overnight or when the operators are busy at other work.

The flex machine as designed gives the best results on hard fibers such as abaca, sisal, and henequen and may not be entirely satisfactory for soft fibers such as flax and hemp.

In preparing the samples for mounting on the abrasion and flex machines it is necessary to punch two holes in the paper tabs glued to the ends. This may be done rapidly and easily, without changing

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[9] Productimeter. Durant Manufacturing Co., Milwaukee, Wis. See footnote 8, p. 39.

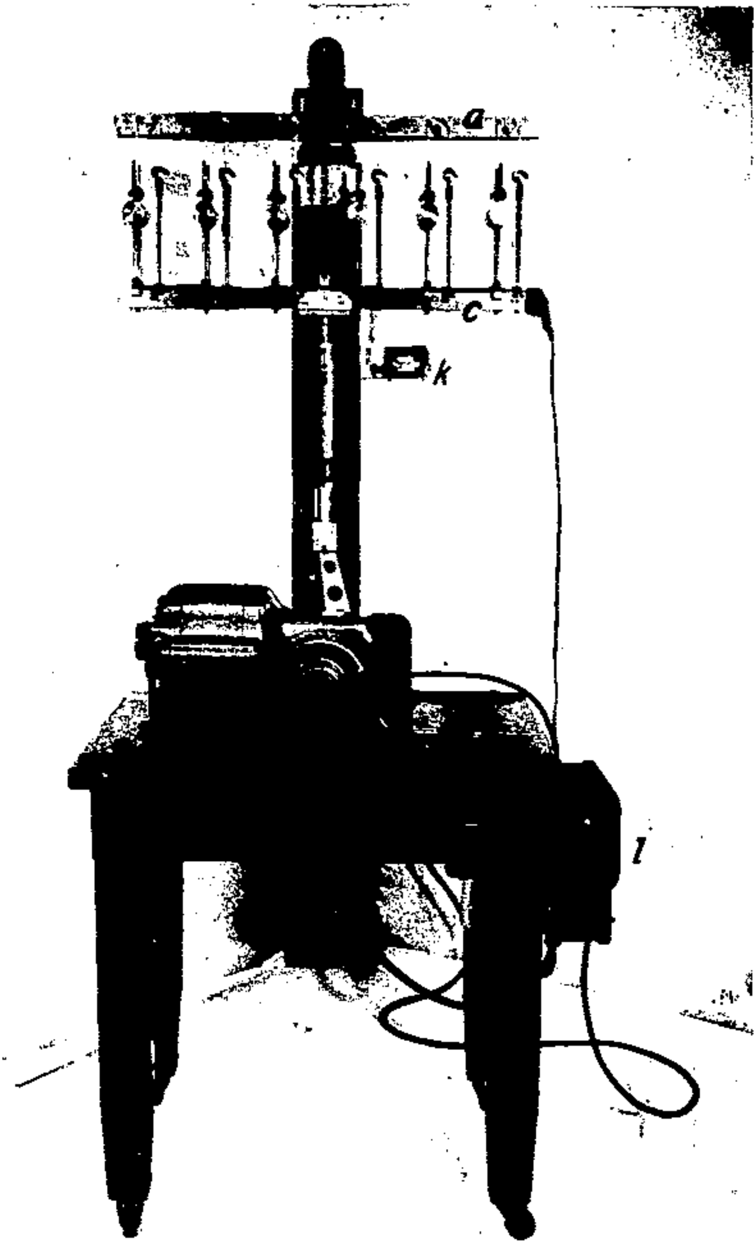

FIGURE 11.—Front view of flexing machine.

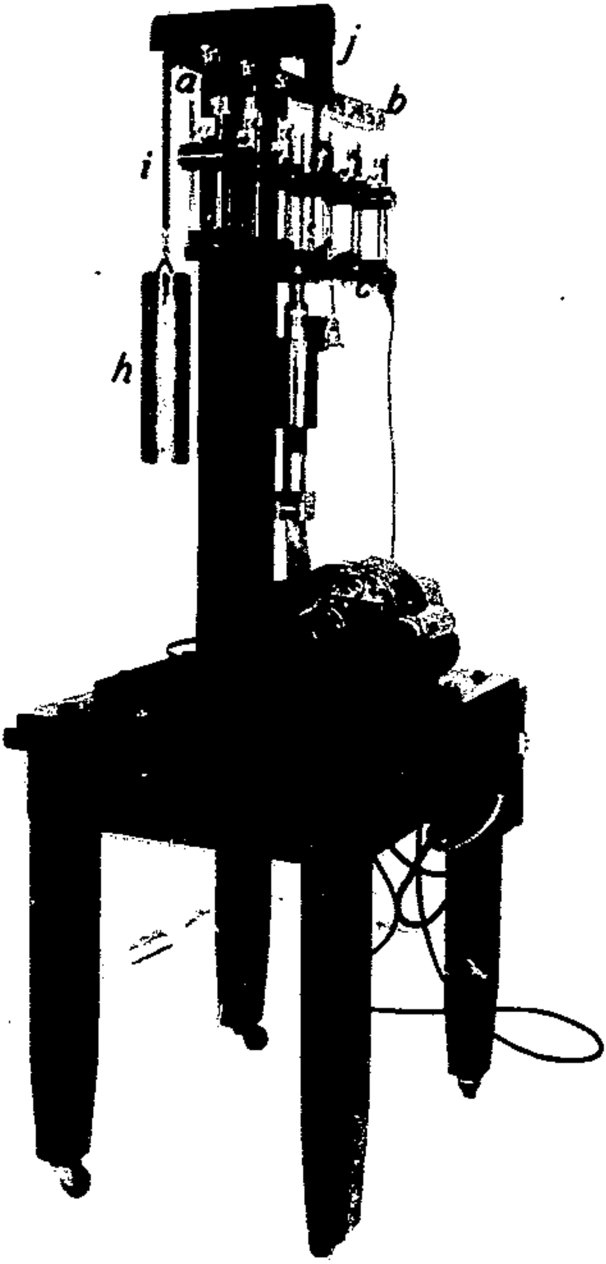

FIGURE 12.—Side view of flexing machine.

FIGURE 13.—Section of flexing mechanism, showing pulleys, weights, and microswitch.

the twist in the yarn, with the special punch developed for this purpose (fig. 7). The tabs can be punched and cut to the appropriate length simultaneously or can be punched after being glued to the specimen. The punch is mounted on either the abrasion- or the flex-machine stand so that it is always available. If the precut tabs are used, it is necessary to use an especially designed rack with pins to hold the tabs in place while glueing them to the specimen.

TEST DATA

Examples of the resistance to abrasion and of flex life of a number of cordage fibers are given in table 19. These data were obtained on modified Bureau of Standards abrasion and flex machines as described in this paper. The three hard fibers, abaca, sisal, and sansevieria, and the so-called soft fiber, kenaf, were machine decorticated from green plants; the flax was water retted; and the ramie decorticated green, dried, and then chemically degummed.

The hard fibers show variations in abrasion from 720 to 63,892 and flex life from 1,271 to 5,997 revolutions before failure. The soft fibers show about the same variation in flex life, but the number of revolutions, 116 to 2,634, required for failure were much less in the case of abrasion. The flax and ramie samples were finer than the sansevieria, which in turn was finer than the abaca and sisal. Abrasion and flexure data on these fibers of varying texture give added information for a better understanding of their use value.

TABLE 19.—*Resistance to abrasion and flex life of various cordage fibers tested on modified machines*

Classification and variety	Samples	Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)
		SS twist	SZ twist	
	Number			
Hard (leaf):				
Abaca	8	723	720	1, 271
Sisal	10	1, 349	1, 472	1, 789
Sansevieria	10	2, 782	63, 892	5, 997
Soft (bast):				
Kenaf	8	251	2, 259	1, 367
Flax	20	404	2, 634	4, 624
Ramie	6	116	392	6, 322

It was found in these studies that each method and instrument must be refined to the point where differences in fibers of the same general properties can be detected. It was also necessary to make the methods flexible enough so that usable data from widely different types of fiber could be obtained. The hard leaf fibers cannot be bent sharply without injury, whereas the soft bast fibers such as flax fail more from abrasion of fiber on fiber than from flexing in the apparatus used here. A soft, silky fiber that will bend sharply does not receive an adequate test in flex life but may be accurately evaluated in abrasion, whereas a stiff abaca fiber can be measured on the flex machine but is not adequately tested in abrasion. The abrasion tests are not free of flex, since the bundles of yarns bend a little where they contact each other. The low abrasion-test values for stiff fibers are therefore a poor index of the true abrasion resistance of the fiber.

The improvements made in these machines obviously increase their usefulness, but the limitation for measuring abrasion and flex life on all natural fibers is apparent. A better method of measuring flexibility of soft fibers and improved methods of measuring abrasion resistance of hard fibers are needed.

DISCUSSION AND CONCLUSIONS

Research to improve existing methods and a search for new and better methods are constant aims of the fiber technologists. A study of fiber properties is necessary in order to determine the use value of the fiber. A program is in progress to evaluate differences in fibrous raw material. In order to insure the best possible characterization of the fiber, the methods must be flexible enough to meet the needs for studying a large variety of natural fibers.

For better understanding and interpretation of tests on the abrasion and flexure machines, some results on different types of fibers are shown in Table 19. The abrasion resistance and flex life of a fiber are usually not a function of fiber strength but depend largely on the type of fiber, on its shape, and on its texture (fineness), which is in turn partly influenced by the kind of processing. For example, the hard fiber sansevieria has greater flex life than coarser abaca and sisal fibers. Likewise, among the soft bast fibers fineness is greatest in ramie and least in kenaf. The flex life follows in the same general order. Abrasion with the SZ twist (across the fiber) for the hard fibers is correlated with fineness. For the soft fibers, the fiber having the largest amount of encrusting materials gave the longest SZ abrasion. Chemical degumming, with its tendency to degrade the fiber and free the finer fibers, makes the ramie much less resistant to SZ abrasion. Abrasion with SS twist (along the fiber) gives a greater abrading surface and, consequently, considerably more tension on the fiber bundle.

For the soft fibers, therefore, the pretreatment of the fiber plays an important part in the extent to which they withstand physical treatment. Ramie, although it is one of the strongest fibers of the group, does not stand up too well under the SS twist, because when the exceedingly fine fiber begins to break, greater friction is developed, which soon ruptures the fiber strands. Kenaf, a green-processed fiber, high in encrustments and brittle and weak, does not stand up well when abraded with an SS twist. Of the soft fibers, flax withstood the abrasion tests best, largely because it was water-retted, a process which leaves it flexible and soft with very little damage to the fiber. For the hard fibers, there was better abrasion resistance in the finer fiber. Coarse fiber such as abaca and sisal are not subject to stress differences, as obtained by changing from SZ to the SS twist, to the same extent as the finer fibers, which break up more readily when greater stress is applied. No apparent correlation was found between strength and resistance to abrasion and flex life. In machine decortication, as used on hard fiber, considerable damage may result from improper adjustment of the machines. These are factors that are hard to evaluate in a study of this kind.

SUMMARY

A method and an instrument for measuring the cross-sectional area of bundles of fibers were developed.

The abrasion machine described by Schiefer was modified and a switch was added to cut the machine off when a bundle failed.

The flexure machine described by Schiefer was also modified and microswitches were installed to cut the machine off when a bundle failed.

A punch was developed to prepare the test specimens for mounting on the testing machines.

Data from six samples of fiber, three of hard fiber and three of soft fiber, obtained on the improved instruments, are reported.

ABACA FIBER FROM CENTRAL AMERICA AND THE PHILIPPINE ISLANDS

By EARL E. BERKLEY and LYLE E. HESSLER

GENERAL BACKGROUND

Prior to the last war essentially all of the abaca fiber of commerce (Manila hemp) was produced in the Philippine Islands. The war made commercial plantings necessary in four Central American countries—Panama, Costa Rica, Honduras, and Guatemala (*3*). The scarcity and high price of abaca fiber and the question of ownership of land immediately after the war resulted in over harvesting of some Philippine plantings (*5*). Diversification of agriculture in the Philippine Islands may reduce the acreage of fiber plants still further, particularly in the Davao area where high-quality fiber was produced in large quantities before the war. Since labor costs were greater in Central America than in the Philippines, new methods of culture, harvesting, decortication, and drying the fiber were developed (*2, 9*).[11] For example, in Central America the so-called false abaca stems were cut into 4- to 6-foot sections, and the decorticating machines extracted fiber from all portions of the leaf sheaths rather than from the dorsal side only (the portion removed in tuxying) as is the practice in the Philippine Islands. The raspador-type decorticating machines used in Central America extracted a higher percentage of fiber from the plant than is customary by the hand method used in the Philippines.

Central American fiber production is a new industry and presents some difficult problems, particularly when comparison of the fiber with that from the Philippines is desirable.

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[11] See also the following sections of this bulletin:

The Quality of Central American Abaca Fiber as Affected by Variety, Location of Growth, Position in Plant, and Method of Drying, p. 4.

A study of Methods of Cleaning Central American Abaca Fiber, p. 28.

Saleeby (*9*) suggested a method of grading Central American fiber that takes into consideration color and degree of cleanliness. His grades were as follows:

1. Excellent white to cream-colored or ochre fiber, brushed. Excellent white to cream-colored or ocher fiber, unbrushed.
2. Streaky fiber, brushed. Streaky fiber, unbrushed.
3. Brown or highly colored fiber, brushed. Brown or highly colored fiber, unbrushed.

The unbrushed fiber was that decorticated and dried without further treatment, whereas the brushed fiber received a burnishing treatment after passing through the dryer. Later, the machine-decorticated fiber in Central America was separated into four grades. This grading has proved to be more practical than that used in marketing the hand-stripped Philippine fiber.

More recently the Office of Production of the Reconstruction Finance Corporation has established new standards for grading Central American abaca.

The five principal grades (Revision No. 2, Dec. 17, 1948) are as follows:

1. **Superior**: Color, very light ivory to dull white; length, usually normal; cleaning, good.
2. **Clear**: Color, dull white to ivory and light ocher, sometimes with a very light green or yellow tinge; length, usually normal; cleaning, good.
3. **Good**: Color, light ocher to ivory, sometimes with a very light green or yellow tinge; length, usually normal; cleaning, good.
4. **Streaky**: Color, mixed light ocher and/or light green, dull purple, or red; length, short to normal; cleaning, good.
5. **Brown**: Color, mixed dingy to light and dark brown or red; length, short; cleaning, fair.

The color of the decorticated abaca depends largely on the location of the sheath from which the fiber is extracted and ranges from dark brown in the outer sheaths to white in the innermost sheaths.

The streaky and ocher fibers were found[12] on the average to be strongest, the brown and cream-colored fibers intermediate, and the white fiber near the center of the plant the weakest. The fiber strength increased upward from the base of the plant for a short distance and then decreased towards the top. In short, stunted plants there was very little of the strong fiber, but in the tall, well-developed plants there was a preponderance of strong fiber. Little or no difference was found between the fiber dried by the machine method and that dried in the sun.

In a study of methods of cleaning[13] the hagotan-stripped fiber was stronger than the machine-decorticated fiber. The differences were attributed (a) to differences in fine structure of the fiber as shown by X-rays and (b) to injuries to the fiber by the raspador-type machine. In general the strength of the machine-produced fiber was somewhat lower than that produced from similar plants by the hagotan method. The yield of fiber from the machine method was from

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[12] See section in this bulletin on The Quality of Central American Abaca Fiber as Affected by Variety, Location of Growth, Position in Plant, and Method of Drying, p. 4.

[13] See section in this bulletin on A Study of Methods of Cleaning Central American Abaca Fiber, p. 28.

one-third more to approximately twice as much as that obtained from the hagotan method.

The studies reported here were conducted in order to compare the physical properties of the Central American abaca with those obtained from the Philippine fiber. Samples were taken from Philippine fiber received before and since the war and from Central American fiber during and immediately after the war. The samples from war-time production were taken before the grading system was inaugurated. The Central American abaca fiber was graded as to color and cleanliness according to Saleeby's method (*9*).

MATERIALS AND METHODS

Abaca is one of the strongest fibers known in commerce. Like all natural fibers, it varies in strength and other properties with origin, processing treatment, and age after harvest. It was not feasible to obtain samples from Central America and the Philippines that were grown and cleaned in the same way nor was it possible to know the date of harvest of all the samples. The Philippine fiber samples were furnished by the Boston Naval Shipyard, Boston, Mass., along with sample 11F from Central America. They are listed by grade and some of them may be identified by location of growth. The Central American samples were obtained by the senior author at the plantations (*2*) with the cooperation of the Reconstruction Finance Corporation and the United Fruit Company.

The methods used in obtaining the data have been described elsewhere (*10*).[34] The results given here represent averages of 10 or more observations for each test. Approximately 40 individual tests were made on most of the samples.

Knot strengths and fineness were not determined for the samples obtained from prewar stocks.

RESULTS

On the average, prewar Philippine abaca fiber was found to be about 16 percent stronger than the Central American fiber produced during World War II (table 20). Individual samples of the Central American fiber from Panama and Costa Rica were stronger, however, than the sample of grade 1 Philippine fiber from the prewar production. The different samples within the same grade varied appreciably in physical properties; consequently the values given in this paper should be considered for the particular sample tested rather than as representative of the grade or type of fiber.

The resistance to abrasion was greater for the SZ twist (across the fiber), than for the SS twist (along the fiber), for both types of fiber. The values obtained in the abrasion tests varied widely from sample to sample in each lot. The same was true for the flex life, but there was a trend for the samples with fine fiber to have a greater flex life than those with coarse fiber.

Samples collected from postwar production both in the Philippines and Central America varied widely in strength and other properties.

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[34] See also section in this bulletin on Improved Testing Machines for Studying Cordage and Other Long Vegetable Fibers, p. 38.

but in general the Philippine fiber was superior to the Central American. Samples from the various grades of brushed and unbrushed fiber produced in Panama since the war (tables 21 and 22) show stronger fiber than the postwar Philippine samples (table 23). Some of the Central American samples were lower in strength, however, than the better samples of postwar Philippine fiber.

Table 20.—*Fiber strength, resistance to abrasion and flex life of 5 samples of Central American and 3 grades of Philippine abaca fiber*[1]

Sample number	Place of growth	Grade	Fiber strength (pounds per square inch)	Abrasion resistance (revolutions to failure)		Flex life (revolutions to failure)
				SS twist	SZ twist	
2F	Panama		109, 663	4, 010	12, 631	852
3F	Guatemala		86, 732	1, 389	2, 156	1, 041
5F	Costa Rica (Good Hope).		99, 388	722	1, 798	535
4F	Honduras		72, 893	1, 374	4, 412	312
11F	Central America	Average	80, 949	465		745
10F	Philippines	F	103, 455	416	2, 576	597
8F	Philippines	I	92, 500	2, 421	2, 670	623
9F	Philippines	J_1	119, 541	1, 097	1, 899	864

[1] Central American samples produced during World War II, those from the Philippines before the war.

Table 21.—*Fiber strength, resistance to abrasion, and flex life of 3 grades of machine-decorticated abaca fiber from the Changuinola Valley, Panama, 1946 crop*

Fiber grades	Fiber strength (1,000 pounds per square inch)	Knot strength (1,000 pounds per square inch)	Resistance to abrasion (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number of fibers per standard bundle[1])
			SS twist	SZ twist		
First class brushed, excellent grade	109. 3	19. 0	556	1, 806	719	20
First class unbrushed, excellent grade	91. 6	17. 0	1, 270	1, 104	707	20
Brushed, streaky grade	74. 6	21. 7	1, 446	478	1, 297	26
Unbrushed, streaky grade	59. 6	15. 8	545	1, 263	763	23
Brushed, brown grade	67. 8	16. 3	309	557	469	23
Unbrushed, brown grade	64. 5	20. 0	1, 504	225	1, 052	26

[1] 15 inches long and weighing 325 milligrams.

TABLE 22.—*Fiber strength, resistance to abrasion, and flex life of 3 grades of hagotan-stripped abaca fiber from the Changuinola Valley, Panama, 1946 crop*

Fiber grades	Fiber strength (1,000 pounds per square inch)	Knot strength (1,000 pounds per square inch)	Resistance to abrasion (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number of fibers per standard bundle [1])
			SS twist	SZ twist		
Brown	75. 3	17. 0	672	646	983	19
Streaky	77. 8	18. 2	415	778	706	16
White	69. 1	16. 9	584	1, 294	456	20

[1] 15 inches long and weighing 325 milligrams.

TABLE 23.—*Fiber strength, resistance to abrasion, and flex life of 9 grades of abaca fiber from the Philippine Islands, postwar production* [1]

Fiber grades	Fiber strength (1,000 pounds per square inch)	Knot strength (1,000 pounds per square inch)	Resistance to abrasion (revolutions to failure)		Flex life (revolutions to failure)	Fineness (number of fibers per standard bundle [2])
			SS twist	SZ twist		
Da/CRC/G Davao	52. 1	13. 5	332	1, 132	225	29
I T/FEA/I Tabaco N. Albay	77. 2	20. 4	765	1, 466	1, 005	47
H Da/KC/H Davao	77. 2	23. 1	1, 180	784	655	22
K Da/CRC/K Davao	75. 8	18. 5	339	636	667	25
I Da/KC/I Davao	77. 0	19. 6	420	493	516	28
S_2 Da/KC/S_2 Davao	76. 2	24. 6	297	1, 071	729	25
F TG/FEA/F Tiagaon S. Cam	81. 2	22. 8	395	4, 964	866	50
J_1 Da/CRC/J_1 Davao	74. 8	16. 5	768	1, 118	760	37
J_2 MD MAC/J_2 Davao	77. 7	18. 7	876	1, 076	492	22

[1] This fiber was presumably hand cleaned.
[2] 15 inches long and weighing 325 milligrams.

The light fiber designated "excellent grade" was strongest among the machine-cleaned samples, whereas the streaky fiber was strongest among the samples from Panama cleaned by the hagotan method (tables 21 and 22). In general the hagotan-stripped fiber from Central America was about equal in strength to the fiber from the Philippine Islands. The machine-cleaned sample from Panama was above average strength for fiber produced in either area and would appear to represent more nearly the type of fiber harvested in the Philippines before the war.

Generally the knot strengths were closely related to the fiber strengths, but the brushed streaky grade mentioned in table 21 and grades H and S_2 from Davao (table 23) showed greater knot strength than expected from their fiber strengths.

The data in table 21 indicate that the finer the fiber from Panama (number of strands per bundle) the greater the resistance to abrasion with the SS twist and the greater the flex life. Conversely, the coarser the fiber the greater the resistance to abrasion with the SZ twist. The Panama fiber is much coarser in texture and shows less variation in physical properties than the Philippine fiber (table 23).

The Philippine fiber had a tendency to give greater resistance to abrasion with the SS twist in the coarser fibers. The finer fiber gave greater resistance to abrasion with the SZ twist. In general, however, the finer the Philippine fiber the greater the flex life.

Discussion and Conclusions

The fiber strengths of the prewar Philippine fiber tested were on the average greater than those of the Central American abaca fiber. The strengths of the postwar samples from the two locations are nearly the same. Other studies[15] indicated that the hagotan-stripped fiber from similar plants was usually stronger than the machine-decorticated fiber. The Philippine fiber used in these tests was no doubt hand-stripped fiber, particularly that from the postwar production and should be equal to or better than the hagotan-stripped fiber from the same type of plant.

An earlier study[16] showed that tall plants grown under full shade produced stronger fiber than stunted plants from overharvested fields. The samples of Philippine fiber harvested before the war seem to represent the better types of growth, whereas the fiber harvested after the war may have been adversely affected by the overharvesting practiced then in most areas of the Philippines. If the low values obtained from current samples of the Philippine fiber is due to overharvesting, the Central American fiber, although cleaned by the raspador machine, may, even under present harvesting conditions be essentially equal or perhaps superior to that being received from the Philippines.

If a supply of unusually strong fiber is needed for specific purposes it may be obtained from Central America by segregating the lower sections of the plant from the top secrions. If the best quality of fiber is desired care must be exercised in growing the plants and cleaning the fiber in both areas.

The brushed fiber from each grade was stronger than the unbrushed, but no consistent relationships existed between the other properties and the brushing treatment. In general, the finer the fiber is the greater is the flex life, and vice versa. Additional data will be required before relationships can be established between the other fiber properties.

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[15] See section in this bulletin on A Study of Methods of Cleaning Central American Abaca Fiber, p. 28.

[16] See section in this bulletin on The Quality of Central American Abaca Fiber as Affected by Variety, Location of Growth, Position in Plant, and Method of Drying, p. 4.

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