THE JOURNAL OF AGRICULTURE
OF THE UNIVERSITY OF PUERTO RICO

Issued quarterly by the Agricultural Experiment Station of the University of Puerto Rico, for the publication of articles by members of its personnel, or others, dealing with any of the more technical aspects of scientific agriculture in Puerto Rico or the Caribbean Area.

Vol. XL January 1956 No. 1

Inheritance of Staple Length in Upland Cotton, (*Gossypium Hirsutum* L.) and Its Interrelationships with Perimeter, Wall Thickness, and Weight Fineness of Fiber[1]

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INTRODUCTION

Cotton production may become an important enterprise in the agriculture of Puerto Rico in the near future. On the basis of these possibilities, work has been started with the object of improving the Sea Island variety (*Gossypium barbadense*), which constitutes the bulk of the cotton grown in the Island.

Upland cotton (*Gossypium hirsutum*) is one of the possible sources of germ plasm that can be used in the improvement of Sea Island cotton. A combination of certain desirable fiber characters from both these types of cotton would probably yield a better fiber that would meet with the ever-increasing market requirements.

The quality of cotton, upon which market price and demand are based essentially, is governed by its physical properties or characteristics which determine its usefulness. Length of staple and fineness which are involved in this study, are among the principal physical properties or characteristics of cotton related to its quality.

At present the old measures of grade and staple length are being supplemented by tests for maturity, fineness, strength, and other quality

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[1] The author is greatly indebted to Prof. M. T. Henderson, of the Agronomy Department, Louisiana State University, Baton Rouge, La., for his valuable counsel during the course of these investigations and in the preparation of this manuscript; to Director Arturo Roque, of the Agricultural Experiment Station of the University of Puerto Rico, for his full cooperation and encouragement; to Associate Director for Research B. G. Capó, for his valuable help in the revision of the manuscript; and to Julian C. Miller, of the Horticultural Research Department, Louisiana State University, Baton Rouge, La., for his encouragement in the realization of this study.

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affecting characteristics, as a result of more strict market and industry requirements due to competition of other fibers.

The fiber of most of the American Upland cottons measures between 1 and 1⅛ inches, though varieties are found shorter than 1 inch and others as long as 1½ inches in staple length.

Staple length is the normal length by measurement of a typical portion of the cotton fibers. It is the oldest and most currently used fiber property for evaluating cotton. Although it is a varietal characteristic it is, nevertheless, influenced to some extent by environmental factors.

Results from research indicate that fiber fineness is of extreme importance in spinning, as it affects both skein strength and yarn appearance. This characteristic depends on two properties, namely, the perimeter of the fiber, which is largely an inherited trait, and the fiber-wall thickness which is dependent on both genetic and environmental factors.

For a long time cotton breeding has aimed mainly at improvement of yield and, as a result, varieties of satisfactory yielding capacity are currently available to farmers.

Today cotton breeders are giving primary attention to the improvement of fiber quality, which is in itself dependent on a number of characteristics such as staple length, weight fineness, and maturity. Since all of these characteristics are quantitative in their inheritance, their complex genetic behavior results in serious complications in a breeding program. Thus a basic knowledge of the genetic behavior of these characters is fundamental to a proper handling of them by breeders. In the past few years data have accumulated on the inheritance of these characters and today intensive studies are being conducted on their genetics and interrelationships in both public and private enterprises involved in cotton research. These studies will yield more conclusive facts which will enable cotton breeders to select more efficiently for these characters, and finally, will result in the production of better cotton varieties possessing a combination of these characteristics.

This paper presents the results of a genetic study of fiber length in Upland cotton and its interrelationships with perimeter, wall thickness, and weight fineness of the fiber. The parents used differed widely in all of the fiber characters involved in this study, which resulted in a broad range of segregation and gave a greater opportunity for expression of genetic relationships.

REVIEW OF LITERATURE

INHERITANCE OF STAPLE LENGTH

One of the most important factors affecting quality in cotton is staple length. In fact, it is the oldest and most widely known property used as a basis for evaluating cotton fiber. Consequently much work has been done concerning the inheritance of this fiber characteristic and its interrelationship with other fiber characters.

Mell (15)[3] was one of the pioneers in the study of the inheritance of fiber length while attempting to improve the cotton fiber. He made observations of a number of crosses among the leading upland varieties of his time. Comparisons were presumably between F_1 and their respective parents of 25 different crosses. He obtained the following results: In eight crosses involving parents of 1 inch or less the F_1 of six crosses had a mean fiber length equal to the longer parent, and one F_1 generation showed slight dominance in favor of short fiber. In crosses involving varieties having staple lengths of 1½ inches with varieties of 1 inch or less he observed that the F_1 of none of them reached the length of the long parent; the F_1 of three crosses was intermediate; the F_1 of one cross was nearer the short parent; and the F_1 of another cross was shorter than the shorter parent.

Fletcher (3) reported that long fiber is dominant over short in crosses between Asiatic cottons.

McLendon (14) got an F_1 ranging between intermediate and long in crosses of Egyptian long and Upland short. Furthermore, he reported that parental forms reappear in the F_2, indicating a segregation into a 3:1 ratio. According to Harland (7) his data are not convincing.

Balls (1) studied the inheritance of lint length. In a cross of Afifi (Egyptian) by Truit (Upland) he observed that segregation was simple, long being dominant over short. The Charara × King cross gave dominance of long fiber in F_1, with subsequent unimodal composition in F_2. Sultani × Afifi gave dominance of long fiber, and the F_2 curve was almost symmetrical between the parental extremes. He stated that subsequent generations have shown that pure parental length can be extracted, while new intermediate lengths may also breed true. On the basis of his observations he stated that probably lint length is inherited simply, in spite of the complication observed in the Charara × King second generation.

Kearney (12) in a cross of Holden (*hirsutum*, Upland) × Pima (*barbadense*, Egyptian) found that the mean lint length of the F_1 approached that of the long parent, and the F_2 gave a unimodal almost symmetrical curve, indicating that several factors are involved in determining this character.

Kottur (13) studied a cross between two other species using varieties, Dharwar No. 1 (*G. herbaceum*) × Rosea (*G. neglectum*). He reported that length of lint was practically dominant in the F_1, or about as long as the former or longer parent. Segregation in subsequent generations was not in accordance with any definite ratio. There was a close association between brown lint and short fiber and he stated that genes for brown lint interfered

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[3] Numbers in parentheses refer to Literature Cited, pp. 47–8.

with the normal Mendelian law and that all plants with brown lint were automatically drawn into a short class. In the F_2 generation he observed a segregation of 2.7 long to 1 short when the brown lint plants were not considered. F_3 progenies from 15 F_2 plants with white lint and long fiber were grown. Three F_2 plants were apparently pure for long staple, nine segregated in a 3:1 ratio, two segregated in an indefinite ratio, and one gave only short-staple plants.

Fyson (4) studied length of lint in several crosses among species of cotton in India. He reported that long and fine lint were dominant over short and rough, woolly lint in the cross Jowari (*Gossypium herbaceum*) × Jari (*G. neglectum*).

Ware (21) crossed Pima (*barbadense*) × Upland cottons (*hirsutum*) and made observations on the inheritance of length of lint. In crosses of Pima × Winesap, he reported practically complete dominance of long lint over short in F_1. Segregation in the F_2 indicated that several pairs of factors were involved in determining the length of fiber. Crosses of Pima × Upright showed complete dominance of long lint and some indications of hybrid vigor. The F_1 mean was 1.03 mm. longer than the mean of the long-linted parent. A Sea Island × Winesap cross showed practically complete dominance of long lint over short.

Harland (7) obtained an F_1 intermediate, but somewhat nearer the long parent, when he crossed *purpurascens* (short) and *barbadense* (long). In the F_2 he observed that continuous variation occurred between the plants, with no definite mode.

On the basis of data obtained by different workers, Harland (7) stated that probably a large number of genes with independent minute effects are involved in the determination of lint length, with secondary effects produced by some of the major genes.

Humphrey (9) conducted studies on the effects of inbreeding in cotton with special reference to staple length. Upon selfing of 200 or more plants from eight varieties of upland cotton, he reported as follows: The first observable effect was a rapid segregation of many plant types, frequently different from the variety from which they arose. This rapid segregation applied also to lint length. Most of the segregation for lint length occurred in the first generation and little after the third generation. He assumed that it would require at least three generations to produce a uniform strain.

Ware (22) studied the inheritance of lint length in a cross involving Florida Green Seed (3/4 inch) and Rowden (1 1/32 inches), two Upland varieties. He presented frequency distribution tables of parents, F_1, F_2, backcross to Florida Green Seed, and backcross to Rowden. Measurements of fiber length were obtained with the Fibrograph. He reported incomplete dominance of long fiber in the F_1, with monomodal segregation in the F_2.

The Florida Green Seed recurrent parent in the backcross tended to reduce the length of fiber below that of the F_1, but the Rowden recurrent parent did not pull the length above that of the F_2. The particular Rowden plant in this case, although a progeny of the original plant, was slightly superior.

Hancock (6) studied the effect of environment on length and fineness of the cotton fiber. He found that both of these fiber characters are greatly affected by seasonal changes. He suggested that since environment tended to alter the genetic properties of any variety, its effects should be studied at different locations over several seasons.

Simpson (19) planted "inbred" seed (obtained from isolated fields) and "open-pollinated seed" (obtained from open-pollinated plants in a yield trial for 25 varieties) in a split-plot design, to determine differences in lint length and other characters between inbred and open-pollinated progenies. He found no significant differences in lint length between these progenies nor did he find any indication of heterosis.

Isaac (10) studied the inheritance of staple length in an F_2 population of 212 plants from a cross between Delta Smooth Leaf and a Stoneville Composite. A unimodal segregation for the F_2 was obtained, but the difference between the parents was not sufficient to establish any additional knowledge on the inheritance of this character.

Henderson, *et al.* (8) studied the inheritance of staple length in two crosses involving different plants of Half and Half and Wilds. In one of the crosses, Half and Half-2 × Wilds-1, they obtained indications of a slight degree of partial dominance for long staple by comparing the mean staple lengths of the F_1 and F_2 with the average of the parents.

With a difference of 0.29 inch in staple length between the parents, they estimated a minimum gene difference of four to five pairs, based on the recovery of Half and Half-2 genotypes, the short-fiber parent.

The heritability value obtained for staple length in the F_2 population was 67 percent.

In the Wilds-7 × Half and Half-1 cross, the mean difference in staple length between the parents was 0.45 inch.

The evidence obtained in this cross indicated partial dominance of the long-staple condition of the Wilds-7 parent.

They estimated the minimum gene difference between the parents to be 9 pairs of genes and perhaps as many as 18 or 20 pairs.

The heritability value calculated for the F_2 of this cross was 73 percent.

The evidence accumulated from studies on the inheritance of staple length proves that this character is quantitatively inherited, and that it is governed by a large number of pairs of genes. It is safe to conclude that in most crosses long lint is partially dominant over short, and that unimodal segregation usually occurs, especially in intraspecific crosses. The bulk of the data available on the inheritance of this character has been obtained from interspecific crosses. Consequently, a more extensive search for additional data that will enrich our knowledge of its inheritance in American Upland cotton should be continued.

INTERRELATIONSHIPS OF LENGTH, PERIMETER, WALL THICKNESS, AND WEIGHT FINENESS OF THE FIBER

Information on the degree of association between plant characters is of great usefulness in plant breeding. The association between plant characters can be measured by linear correlation coefficients.

Two or more characters of a plant are often correlated, either because of the manifold effect of a gene or genes on different parts of the plant or of linkage among genetic factors.

In cotton such information pertaining to the various fiber characters is of extreme importance. With the advent of new equipment suitable for the measurement of some of the most important fiber characters, such as perimeter, wall thickness, and weight fineness, the knowledge of the interrelationships of these and other important traits of the cotton plant and fiber, should be broadened.

Iyengar and Turner (11) found that longer fibers of *hirsutum* generally had lower fiber weights per centimeter. *Herbaceum*, *neglectum*, and *indicum* showed less change in fiber weight associated with changes in fiber length.

O'Kelly and Hull (17) obtained significant positive correlations ranging from $r = 0.452$ to $r = 0.751$ between length of parent and that of the progeny.

Harland (7) stated that length and fineness were correlated. He pointed out that long cottons are usually fine, though some are relatively coarse, while short cottons may be either fine or coarse.

Moore (16) found the simple correlations among various fiber characters in five cotton varieties shown in table 1.

As shown in table 1, the correlation coefficients for the relation of average fiber length to average fiber weight per inch were negative for all varieties but were significant in only three: Mexican 128, Cocker-Cleveland 884-4, and Acala 4067. The values for the relationship of average fiber length to percentage of thin-walled fibers were all positive, but they were significant in only two varieties: Acala 4067 and Rowden 40. The correlation of average fiber length with average fiber diameter was significant only in variety, Mexican 128, for which it was negative. The values for the correlation of fiber weight with the percentage of thin-walled fibers were negative and highly significant for all the varieties. It is also indicated that the correlation of fiber weight with fiber diameter was significant in only one variety, Mexican 128, for which it was positive. The values for the relation of the

TABLE 1.—*The simple correlation within varieties of fiber length, fiber weight, percentage of thin-walled fibers, and fiber diameter for all 5 varieties of cotton*

Variables paired	Simple correlation coefficients for variety named[1]				
	Mexican 128	Coker Cleveland 884-4	Farm Relief No. 1	Acala 4067	Rowden 40
Average fiber length and:					
Ave. fiber wt. per inch	−0.4106**	−0.3853**	−0.1562	−0.4443**	−0.2495
Percentage of thin-walled fibers	.1076	.1338	.0454	.3467**	.2876**
Ave. fiber diameter	−.3433**	−.1894	−.1702	.0705	.1612
Ave. fiber weight per inch and:					
Percentage of thin-walled fibers	−.5919**	−.7202**	−.7928**	−.7725**	−.4416**
Ave. fiber diameter	.3561**	.2006	−.0743	.1539	.0985
Percentage of thin-walled fibers and:					
Ave. diameter	−.0001	−.0744	.2585*	.0169	.2740*

[1] * = Significant values at the 5-percent level of probability; ** = highly significant values at the 1-percent level of probability.

percentage of thin-walled fibers to the average fiber diameter were significant in only two varieties, Farm Relief No. 1 and Rowden 40, the association being positive.

Moore also calculated correlation coefficients for these characters from 300 regions on 50 seeds of these cotton varieties (6 regions per seed × 50 seed = 300 regions) based upon differences between regions within seeds and also between regions of seeds, or plants. Simple and partial correlations of these characters by regions on the seed and also by seeds, or plants are shown in table 2.

Hancock (6) found simple correlation coefficients of length and fineness among 10 varieties of American Upland cotton in two seasons to be $r = 0.699$ in 1941, and $r = 0.266$ in 1946. Measurements were obtained by using the Fibrograph for length, and surface-area data from the Arealometer for fineness. However, he stated that length and fineness were genetically independent. For the seasons of 1941 and 1942 partial correlation coefficients obtained for length and fineness among varieties holding strength constant were 0.734 and 0.438, respectively. He found correlations between length and strength to be environmental and he assumed that length is an independent variable when associated with strength.

Barker and Pope (2) obtained correlations for length of fiber with fineness (expressed as surface area) in three groups of samples from varieties of Upland cotton grown at several locations. Correlation coefficients for va-

TABLE 2.—*Simple and partial correlations of fiber length, fiber weight, percentage of thin-walled fibers, and fiber diameter for the entire experiment including all 5 varieties of cotton*

[Partial correlations include density of fiber population and fiber strength]

Characters correlated[1]	Simple correlation coefficients[1]		Characters held constant [2]	Partial correlation coefficients[1]	
	By regions ($n'' = 300$)	By plants or seeds ($n'' = 50$)		By regions ($n'' = 300$)	By plants or seeds ($n'' = 50$)
12	−0.2561**	−0.2455	12.3456	−0.3022**	−0.4237**
13	.0762	−.1006	13.2456	−.0710	−.1250
14	.0811	.1864	14.2356	.1664**	.2845
23	−.5924**	−.1143	23.1456	−.2562**	−.1330
24	.1801**	.4544**	24.1356	.2975**	.4532**
34	.0824	−.0058	34.1256	.2037**	.1940

[1] * = Significant value at 5-percent level of probability; ** = highly significant value at 1-percent level of probability.

[2] 1 = Ave. fiber length; 2 = ave. fiber weight per inch; 3 = percentage of thin-walled fibers; 4 = ave. fiber diameter; 5 = density of fiber population; 6 = ave. breaking-load per fiber.

rieties within stations were used as an indication of varietal effect or of the extent of the genetic correlation between the characters. Correlation coefficients for within-varieties were used as an indication of environmental effect on correlation. Varietal correlations of 0.32*, 0.46*, and 0.29*, and environmental correlations of −0.08, −0.12, and 0.05 were obtained by them on the same group of samples. They also obtained correlations of −0.53*, and −0.49* for length and weight per inch. Other values obtained were as follows:

1. For length and percentage of thick-walled fibers, −0.23* and 0.10.
2. For surface area and weight per inch, −0.77*, and −0.61*.
3. For surface area with percentage of thick-walled fibers, −0.60*, and −0.51*.
4. For weight per inch with percentage of thick-walled fibers, 0.58*, and 0.36*.

Stroman (20) studied correlations between length and other characters in a population composed of a mixture of related families. In the season of 1944 it was positively correlated with diameter of fiber ($r = 0.34$), and in that of 1945, with boll weight. In the 1946 data classer's length was associated with none of the other characters studied. In the 1945 and 1946 seasons, however, correlation of length and diameter of fiber was negative but not significant.

Green (5) obtained a correlation of −0.7114 between length and fineness of fiber among 285 different strains of cotton.

Henderson, *et al.* (8) obtained the following simple correlations in a study of a population of 228 F_2 plants of the Wilds-7 × Half and Half-1 cross:

Characters correlated	*r value obtained*
Length and perimeter	−0.117
Length and wall thickness	−.062
Length and weight fineness	−.126
Perimeter and wall thickness	.087
Perimeter and weight fineness	.545**
Wall thickness and weight fineness	.812**

** Significant at the 1-percent level of probability.

Highly significant positive correlations were obtained between perimeter and weight fineness, and between wall thickness and weight fineness.

To sum up, according to the information available, there seems to exist a fairly high degree of association, negative in nature, between length and fineness of fiber. Long-fiber cottons tend to be fine, whereas short-fiber ones tend to be coarse.

Very little genetic information is available on perimeter and wall thickness of the fiber, which are the components, or determiners, of weight fineness. This will enlarge our knowledge of the genetic behavior of these fiber characters, and their interrelationships, which would enable breeders to progress in their efforts to improve cotton fiber, as is demanded by present-day markets.

MATERIALS AND METHODS

PARENTS

The parents selected for this study were two Upland varieties (*Gossypium hirsutum*), designated as Florida 1377 and D.P.L. 45-867. Neither of these varieties is of any commercial importance, but they represent the extremes in the length range in the Upland cottons, and differ widely with regard to wall thickness and perimeter of the fiber. These properties qualify them for a genetic study of fiber length and its relationships with fiber-wall thickness and perimeter.

Plants of these two varieties were selfed for several generations until they had attained a relatively homozygous condition. At this stage, selfed seed of these plants were planted and each plant was properly identified by a number. Controlled crosses between them were made using the standard technique practiced in cotton.

The following season a number of F_1 plants from each of two crosses involving different parent plants were grown in the field and selfed in order to obtain ample F_2 seed.

In the spring of 1952, properly identified selfed seed of each parent, seed of the F_1 and F_2 populations were planted.

The parents were sown at the rate of three seeds per hill on an Olivier silt loam field at the Agronomy Farm, Louisiana State University, Baton Rouge, La. The hills were spaced 30 inches apart on 42-inch rows for convenient handling of individual plants. Border rows were planted to provide control over border effects.

Six hundred pounds per acre of a 6–8–8 fertilizer were applied previous to planting. A sidedressing of 100 pounds of nitrate of soda per acre was applied just after the appearance of the first aquares.

In general, the conditions for growth were favorable and the plants fruited well. Each plant was numbered in the field before harvesting and seed cotton was harvested from each plant separately, and properly identified as to the plant from which it had been harvested.

The seed cotton from each plant including parents, F_1 and F_2, was ginned separately on a small roller-type gin.

DETERMINATION OF FIBER LENGTH

Length of fiber from each individual plant was determined by the standard method of pulling and measuring staple length by hand. Staple length is the normal length of a cotton sample by measurement of a typical portion of its fibers.

Nearly 2 months were spent in training on the measurement of fiber length using cotton standards of varying lengths until skill and accuracy in measuring them within a tolerance of 1/16 inch was acquired.

Two samples from each plant were measured to 1/32 of an inch (0.03 in.) and the average between them was taken as the actual length for the plant if they were not different by more than 1/16 inch. In cases in which the difference between the two samples of one plant was greater than 1/16 of an inch (0.06 in.) a third sample was pulled and averaged with one of the two previous samples from which it did not differ by more than 1/16 inch. In cases where more than three samples had to be pulled the same procedure was followed.

Each day before starting, samples from length standards were pulled and measured in order to assure accuracy in determining staple length.

In total, samples from 26 plants of the Florida 1377 parent, 41 plants of the D.P.L. 45-867 parent, 24 plants of the F_1 progeny, and 1,388 plants of the F_2 progeny were stapled.

As the determination of fiber length was made for a plant the rest of the cotton from this plant was placed in its own bag, properly labeled, for further fiber studies. This was done for each plant.

CLASSIFICATION OF THE RESULTS AND CALCULATION OF STATISTICAL VALUES

A frequency distribution table and curve for the parents, F_1 and F_2 generations of this cross was prepared to show the nature of segregation and other facts about the mode of inheritance of length of fiber. The length classes corresponded to the actual length measurements obtained, thus the class interval was 0.03 inch, except in a few classes where 0.04 inch was taken. The mean, standard deviation, and coefficient of variability were calculated for parents, F_1 and F_2 populations.

An attempt was made to estimate the minimum number of genes differentiating the parents. Two methods were used for this, as follows. First, the estimate was made on the basis of the frequency of recovery of parental genotypes. In this case, any F_2 plant which is equal to or exceeds the mean of either parent, in length, is classified as a parental genotype, except when the following situation is involved.

When dominance is involved, only recoveries of recessive parental genotypes are used as a basis for estimating the number of genes. The ratio at which parental genotypes are recovered in an F_2 population is an indication of the number of genes segregating in the population for the particular character being studied. If 1 out of 16 F_2 plants proves to be a homozygous parent genotype there is an indication of segregation of two pairs of genes; likewise, 1 in 64 will indicate three pairs of genes segregating for that character in the population, and so on.

The other method used for estimating the number of genes differentiating the parents was by the use of the Castle-Wright formula. This is given as:

$$\text{Minimum number of genes} = \frac{D^2}{8(s_{F_2}{}^2 - s_{F_1}{}^2)}$$

where, D = difference between parent means,

$s_{F_1}{}^2$ = variance for the F_1 population, and

$s_{F_2}{}^2$ = variance for the F_2 population.

As already indicated the formula gives only an estimate of the minimum number of genes by which the parents differ.

On the basis of the number of genes differentiating the parents, an estimate of the average contribution per pair of genes to the expression of the character was made.

The nature of gene action involved in the inheritance of fiber length was also studied to determine whether it was arithmetic or geometric.

Actual means of F_1 and F_2 populations were compared with their respective calculated arithmatic and geometric means to determine which one they fitted more closely. The following formulas were used to calculate the expected arithmetic and geometric means.

$$\text{Expected arithmetic mean of } F_1 = \frac{\text{mean of } P_1 + \text{mean of } P_2}{2};$$

$$\text{expected geometric mean of } F_1 = \sqrt{\text{mean of } P_1 \times \text{mean of } P_2};$$

$$\text{expected arithmetic mean of } F_2 = \frac{\text{mean of } P_1 + 2\ (\text{mean } F_1) + \text{mean } P_2}{4}$$

and

$$\text{expected geometric mean of } F_2 = \sqrt{1/2\ (\text{mean } P_1 + \text{mean } P_2)\ \text{mean } F_1}$$

where P_1 and P_2 represent the two parents.

Heritability of fiber length was also studied. Heritability is that portion of total variance which is due to genetic variance alone. In other words it is the ratio of genetic variance to total variance, and it can range between 0 and 100 percent though neither extreme is likely to be reached. From F_2 data heritability can be estimated from the following formula:

$$H(F_2) = \frac{s_G^2}{s_G^2 + s_E^2} \times 100 \quad \text{or} \quad \frac{s_G^2}{s_{F_2}^2} \times 100$$

where $H(F_2)$ represents heritability in the F_2,

s_G^2 = genetic variance in the F_2;

s_E^2 = environmental variance in the F_2; and

$s_{F_2}^2$ = total variance in the F_2, i.e., genetic plus environmental variances.

Environmental variance (s_E^2) was calculated by averaging the variance of the two parents, i.e. $\frac{s_{P_1}^2 + s_{P_2}^2}{2}$ where $s_{P_1}^2$ and $s_{P_2}^2$ represent the variances of the two parents. Variance in F_2 is due to both environmental and genetic effects. Thus, a measure of the genetic variance (s_G^2) was obtained by subtracting environmental variance from the total variance of F_2, i.e., $s_G^2 = s_{F_2}^2 - s_E^2$.

FIBER LENGTH AS RELATED TO PERIMETER, WALL THICKNESS, AND FINENESS

Measurements of fiber fineness and immaturity obtained by use of the Arealometer were used for calculating perimeter, wall thickness, and weight fineness. These measurements were made by Mohammed Ali Bishr.

Perimeter (p) of fiber, expressed in microns was calculated from the formula $p = 12566\ I/A$ (microns), where I = immaturity ratio, and A, the low-resistance Arealometer reading (mm.^{2}/mm.^{3} or mm.$^{-1}$). Wall thickness (t), expressed in microns, was calculated from the formula

$$t = \frac{1000T}{A} \text{ (microns)},$$

where T (wall-thickness factor) $= 2/1 + \sqrt{1 - 1/I}$ (dimensionless number) and A, the low-resistance Arealometer reading, (mm.^{2}/mm.^{3} or mm.$^{-1}$).

Weight fineness (W), expressed as micrograms per inch, was calculated from the formula, $W = 38.6\ p/A$, micrograms/inch, where p = perimeter in microns, and A is as in the above formulas.

The association of fiber length with perimeter, wall thickness and weight fineness was studied by use of methods of linear correlation.

For calculating the correlation coefficients, 10 F_2 plants from each of the different length classes were picked at random. In those length classes with fewer than 10 plants, all the plants were taken.

The total correlation, r, was calculated from the formula

$$r = \frac{S(xy) - (Sx)(Sy)/n}{\sqrt{(S(x^2) - (Sx)^2/n)(S(y^2) - (Sy)^2/n}}$$

where S stands for summation, x for one of the variables, y for the other variable, and n for the number of observations of each variable.

To determine whether the association between these characters was real or not, partial correlation coefficients were calculated. Partial correlation is the correlation between two variables when a third one is eliminated as a factor influencing both of them.

Partial correlation was calculated from the formula

$$r_{12.3} = \frac{r_{12} - (r_{13} \times r_{23})}{\sqrt{(1 - r_{13}^2)(1 - r_{23}^2)}}$$

where $r_{12.3}$ = partial correlation between variables 1 and 2 when variable 3 is held constant;

r_{12} = total correlation between variables 1 and 2;

r_{13} = total correlation between variables 1 and 3; and

r_{23} = total correlation between variables 2 and 3.

The multiple correlation was also calculated. Multiple correlations measure the degree to which one dependent variable is associated with or influenced by two or more other variables.

The multiple correlation value was calculated from the formula

$$1 - (R_{1.23})^2 = (1 - r_{12}^2)(1 - r_{13.2}^2)$$

where $R_{1.23}$ = multiple correlation of variables 2 and 3 with variable one;

r_{12} = total correlation between variables 1 and 2; and

$r_{13.2}$ = partial correlation between variables 1 and 3 when the influence of variable 2 is removed.

The regression coefficient, b, was determined from the formula

$$b = \frac{S(xy) - (Sx)(Sy)/n}{S(x^2) - (Sx)^2/n}$$

where S stands for summation, x for one of the variables, the independent one, y for the other variable, the dependent one, and n for the number of observations of each variable.

To illustrate more clearly the degree of association between length and perimeter, wall thickness, and weight fineness, scatter diagrams were prepared for length and perimeter, length and wall thickness, and length and weight fineness.

Regression values can be used for predicting different values of one variable for different values of the other. This can be done from the equation: $Y = \bar{y} + b(x - \bar{x})$, where Y is any predicted value of the y variable for any value x of the other variable; $\bar{y}$ is the mean of the values of the y variable and $\bar{x}$ that of the x variable as obtained from the experimental data; and b is the regression of y on x.

EXPERIMENTAL RESULTS

INTRODUCTION

The inheritance of fiber length and its association with fiber perimeter, wall thickness, and weight fineness was studied in a cross between Upland varieties Florida 1377 and D.P.L. 45-867.

Plants of both parents, F_1 and F_2 from this cross were grown in the field in 1952. Cotton samples from each plant of these populations were analyzed for staple length in the laboratory. In addition, they were analyzed for specific area and immaturity, and subsequently fiber perimeter, wall thickness of fiber, and weight fineness were calculated.

GENETIC ANALYSIS OF STAPLE LENGTH

Like other quantitative characters, staple length is the end result of the interaction of a large number of genes under particular environmental conditions.

TABLE 3.—*Frequency distribution of staple length for parents F_1 and F_2 in the Florida 1377 × D.P.L. 45-867 cross*

Population	Number of plants in length classes (inches) indicated																													
	0.56	0.59	0.62	0.66	0.69	0.72	0.75	0.78	0.81	0.84	0.87	0.91	0.94	0.97	1.00	1.03	1.06	1.09	1.12	1.16	1.19	1.22	1.25	1.28	1.31	1.34	1.37	1.41	1.44	1.47
Florida 1377	3	7	11	4	1																									
D.P.L. 45-867																								1	3	12	15	6	3	1
F_1															3	4	9	5	2	1										
F_2								4	5	12	37	54	74	95	172	147	194	133	207	84	76	28	48	9	7		2			

TABLE 4.—*Statistical data for staple length in the Florida 1377 × D.P.L. 45-867 cross*

Population	Number of plants	Mean	Standard deviation (*s*)	Coefficient of variation (C.V.)
		Inches		*Percent*
Florida 1377	26	0.61	0.033	5.42
D.P.L. 45-867	41	1.37	.040	2.91
F_1	24	1.06	.039	3.72
F_2	1388	1.06	.096	9.07

Altogether the length study included 26 Florida 1377, 41 D.P.L. 45-867, 24 F_1 and 1388 F_2 plants. The parent plants were obtained from selfed progenies of the specific plants used in original crosses from which the F_1 and F_2 were derived.

The classified data obtained from the parents, F_1 and F_2 populations are presented in table 3 as frequency distributions for fiber length. The statistical data comprising number of plants studied, arithmetic mean, standard deviation and coefficient of variability for the parents, F_1 and F_2 population are presented in table 4.

In one of the parents, variety Florida 1377, fiber length varied from 0.56 to 0.69 inch, a range of 0.13 inch, (table 3). In this parent, the standard deviation, (*s*), was 0.033 which led to a coefficient of variability of 5.42 percent. The variation in fiber length in D.P.L. 45-867 spread from 1.28 to 1.47 inches, a range of 0.19 inch. This led to a standard deviation, (*s*), of 0.04 and a coefficient of variability of 2.91. This indicates that the variation of the Florida 1377 was somewhat higher, almost twice as much as that of the D.P.L. 45-867. To some extent, the greater variation in the short-fibered parent may be accounted for by chance variation resulting from hand-stapling, as short fibers are more difficult to staple, and thus more subject to a greater amount of chance variation. However, this variation was probably mostly due to the influence of environment, as the parent plants used were obtained after a number of consecutive selfings and thus were supposed to be relatively homozygous.

As shown in table 4, the mean length of the fiber of the Florida 1377 parent was 0.61 inch and that of the D.P.L. 45-867 parent was 1.37 inch. Thus the long-fiber parent was 2.2 times longer than the short-fiber parent. This mean difference in fiber length between the parents is an indication of the extreme genetic differences between them, representing almost the maximum genetic range in fiber length in Upland cottons.

The 24 F_1 plants varied from 1.00 to 1.16 inches in staple length, with a mean of 1.06 inches. The standard deviation was 0.039 and the coefficient of variability of 3.72 percent. Presumably the parents were homozygous, so this variation in the F_1 plants is the result of environmental influences. In fact the variation is reasonably small and within the limits of expectations. The mean of the F_1 population, 1.06 inch, was significantly higher than the mean of the parents, 0.99 inch.

The F_2 population numbered 1,388 plants which varied from 0.78 inch to 1.37 inches in staple length, with segregation following a unimodal distribution resembling a normal curve. Segregation for genes controlling staple length can be seen more clearly when presented graphically. The data for the distribution of the F_2 population together with the F_1 and parents are presented in figure 1. The distortions in the shape of the curve for F_2 are presumed to be the result of chance variations from hand-stapling.

The results obtained for the F_2 population are otherwise typical for the segregation of a quantitative character. These results fell into 19 length classes, a large number of classes, typifying the behavior of quantitative characters involving a large number of genes.

The standard deviation of the F_2 population was 0.096 as compared with

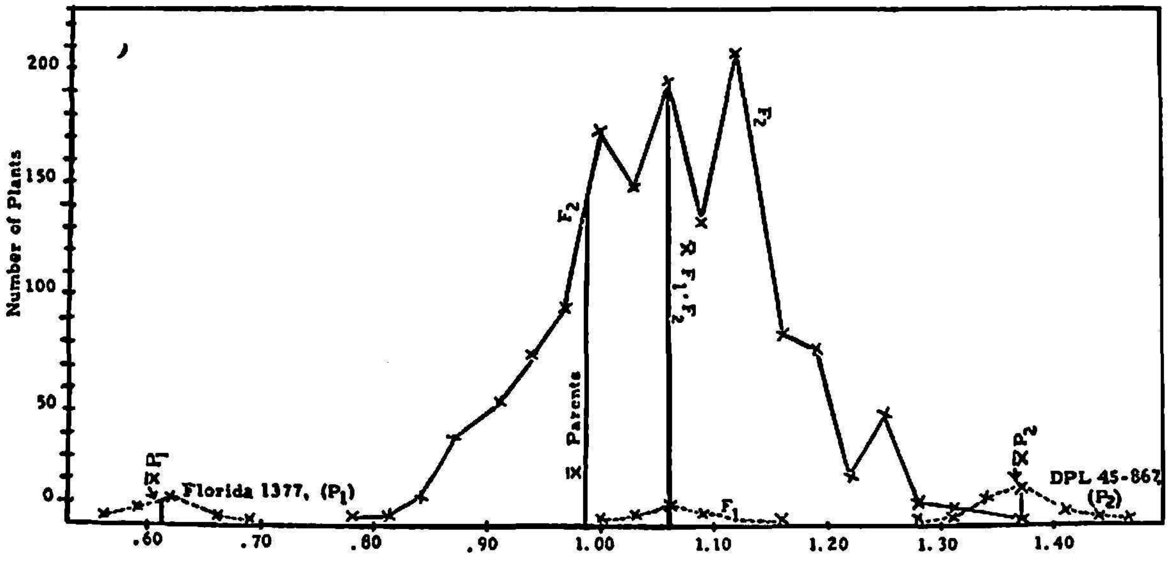

FIG. 1.—Frequency distribution of staple length in inches for parents, F_1, and F_2, in the Florida 1377 × D.P.L. 45-867 cross.

0.033, 0.04, and 0.039 for Florida 1377 and D.P.L. 45-867, the parents, and the F_1 progeny, respectively. The coefficient of variation in F_2 was 9.07-percent as compared with 5.42, 2.91, and 3.72 percent for Florida 1377, D.P.L. 45-867, and the F_1, respectively. As expected in an F_2 population, the degree of variation was much higher than for either of the two parents or the F_1. In the parents and the F_1, the variation is assumed to be the result of the influence of environment, whereas in the F_2, where segregation occurs, it is due to both genetic and environmental influences and their interaction.

Based on the results obtained for the F_2 population, fiber length is considered to behave as a quantitative character involving a large number of genes. From these results information regarding the occurrence and degree of dominance, the approximate number of genes by which the parents differed with respect to this character, the nature of gene action, and heritability of the character was obtained.

Degree of dominance

In order to determine the occurrence and degree of dominance the means of the F_1 and F_2 were compared with the arithmetic average of the parents. The mean of the parents was 0.99 inch while the F_1 and F_2 had identical means of 1.06 inches.

Quantitative characters are usually characterized by absence of dominance. With absence of dominance, the expected mean of the F_2 population should not differ from that of the F_1, or that of the parents. In this cross the difference between the mean of the parents and that of the F_1 and F_2 was significant, so it can be concluded that partial dominance for long staple over short staple was involved. This is also shown by the frequency distribution of the F_2 population presented in table 3. The distribution shows that a total of 1,107 plants exceeded the mean length of the parents while only 281 plants were shorter than the mean length of the parents. These 1,107 plants longer than the average length of the parents represent 80 percent of the total F_2 population. Moreover 18 plants had a length within the range of the long-fiber parent, and of these, 2 were as long as its mean length. The longest fiber segregate was 2.20 times that of the short parent. Also the modal class fell in the 1.12-inch length class, 0.06 inch in excess of the mean.

On the other hand, none of the F_2 plants was short enough to reach the range of the short-fiber parent. The shortest F_2 segregate was 1.28 times longer than the mean of the short-fiber parent. In fact there was a gap of three length classes, or 0.09 inch, between the shortest F_2 plants and the longest plants of the short-fiber parent.

There was also a difference of 0.17 inch between the shortest F_2 plants and the mean of the short-fiber parent.

Additional evidence on the occurrence of partial dominance in this cross can be obtained from the examination of figure 1, presenting the frequency curve of the parents, F_1 and F_2 populations. The curve is skewed toward the long-fiber parent, D.P.L. 45-867, shifting the mean length of the F_2 population, to 1.06 inches in contrast to the average length of the parents of 0.99 inch. The modal class has also been shifted to 1.12 inches.

Thus all of the evidence obtained from this cross points to the occurrence of partial dominance of long fiber over short fiber. The presence of partial dominance of long fiber would handicap selection for long fiber in the F_2. The primary objective in selection for long fiber is to obtain the desired degree of fiber length in a homozygous condition. But as partial dominance is involved in determining long-fiber length, a large amount of segregation in succeeding generations will be expected for many of the plants selected in the F_2 for long fiber. Long-fibered selections of a heterozygous nature might give rise to short-fibered segregates. In contrast, selection for short fiber would be relatively easy, due to a lower degree of heterozygosity in them. Thus partial dominance would not constitute such a handicap in selection of short fiber.

Estimate of number of genes involved

The exact number of genes affecting a quantitative character such as fiber length cannot be determined. However, an estimate of the number of genes involved can be made. Two methods were used in estimating number of genes, by which the parents differed for this character.

The first method was based on the relative frequency of parental genotypes recovered in the F_2 population, taking as parental genotypes those plants identical to or exceeding the mean of the parents in the expression of the character being studied.

In the F_2 population of the Florida 1377 × D.P.L. 45-867 cross, two plants were as long as the mean of the long-fibered parent, D.P.L.45-867. Length of fiber in these plants may have resulted from environmental influence interacting with genetic factors for length. Moreover, due to partial dominance, heterozygous plants are shifted towards the long-fiber parent. As a result of partial dominance and environmental effects, some plants, nonparental as to genotype, may appear to be similar to the long-fiber parent. Thus a partial dominance is involved in determining long-staple length, it is necessary to use the recoveries of the recessive parental genotype to estimate number of genes by which the parents differ. As already discussed, partial dominance tends to increase the frequency of long-staple plants, shifting the frequency distribution towards the long-staple parent.

The number of plants studied in this F_2 population totalled 1,388. For segregating F_2 populations, the frequency of recovery of parental genotypes is 1 in 16, when two pairs of genes are involved. Similarly, for five pairs of genes the frequency of recovery of parental genotypes is 1 in 1,024. But in this population of 1,388 plants not a single plant was recovered as short as the mean of the short-fiber parent, Florida 1377. From this evidence we can conclude that the parents probably differed by five or more pairs of genes.

Furthermore, none of the F_2 plants approached the upper range in length of the Florida 1377 parent. Moreover there was a difference of 0.17 inch between the mean length of the Florida 1377 parent, 0.61 inch, and the shortest class of the F_2 population, which measured 0.78 inch. Only four plants fell in this shortest class. If six pairs of genes were the case, the expected frequency of parental genotypes in the F_2 population would be 1 in 4,096 plants, but actually twice or more this number of plants would be required in order to obtain this parental genotype.

The evidence is not suitable for estimating by this method the number of genes segregating for fiber length in this population. However, we can conclude that at least, there was a difference of more than five pairs of genes between the parents.

An estimate of the minimum number of genes segregating for fiber length in the F_2 population can also be obtained by use of the Castle-Wright formula, referred to under Experimental Methods. This formula is based on the degree by which the variance in the F_2 exceeds the variance in the F_1. The variance in the F_2 consists of both genetic and environmental variance, while the variance in F_1 is attributed to the influence of environment, as the parents were supposed to be homozygous.

The formula involves the assumptions of equal additive effects of genes, none of which are linked with any others, and of homozygosity of all genes in one parent and of their alleles in the other parent. These conditions are rather extreme and very rare under actual conditions. It also assumes that the parents involved represent the genetic extremes within the Upland cottons. In this cross this assumption is quite closely fulfilled. In this F_2 population the evidence obtained points to the occurrence of partial dominance, so one of the assumptions of the formula is ruled out. This assumption of absence of dominance leads to an underestimation of the number of genes by which the parents differ. However, we can apply it to obtain a general estimate of the minimum number of genes involved.

The estimate of the minimum number of genes segregating for staple length as obtained by applying this formula was 9.38 pairs. Presumably this is the closest estimate obtainable of the minimum number of genes by which the parents in this cross differed. It can be concluded that the parents differed by not less than nine pairs of genes, but probably the difference is greater, as the formula only gives an indication of the minimum number of genes.

With this large number of genes involved, no parental genotypes are expected to occur in the F_2 grown, as the number of plants required in the population would be too large, almost impracticable to grow.

Estimated average contribution per pair of genes to length of fiber

We have already indicated that the estimated minimum number of pairs of genes involved in the difference between the parents in this cross is nine. The actual number of pairs of genes involved may have been higher.

Thus the estimated average contribution per pair of genes will be almost valueless as it will be only an approximate value.

With a mean difference of 0.76 inch in fiber length between the parents, the average contribution of each pair of genes would be 0.08 inch, assuming a minimum difference of nine pairs of genes involved between the two parents.

This figure is not of much help, as we do not know whether arithmetic or geometric gene action governs the genetic contribution to fiber length.

Nature of gene action

Results from crosses between types differing in quantitative characters have been extremely varied, due undoubtedly to complex anatomical and physiological conditions as well as to those of a genetic nature and to those resulting from environmental influences. Attempts have been made to analyze data for evidence indicating whether the gene action is more nearly arithmetic or geometric in effect, though neither one is expected to apply strictly to all genes or to all organisms.

The data are inconclusive to determine the type of gene action involved. Actual means of the F_1 and F_2 populations as compared with their respective expected arithmetic and geometric means as referred to under Experimental Methods, are presented in table 5.

The actual mean of the F_1 is significantly different from the expected arithmetic and geometric means.

The actual mean of the F_2 is also significantly higher than the expected

TABLE 5.—*Actual means and expected arithmetic and geometric means of the F_1 and F_2 populations in the Florida 1377 × D.P.L. 45-867 cross*

Population	Actual means	Arithmetic means (expected)	Geometric means (expected)
F_1	1.06	0.99	0.91
F_2	1.06	1.02	1.02

arithmetic and geometric means, both of which are alike. These were a little closer to the actual or observed means.

With this information it is impossible to determine the nature of the gene action involved, whether arithmetic or geometric.

Relative influence of environment and heredity on fiber length

Plant improvement through selection following hybridization depends on the relative efficiency with which genetic differences among individuals in the segregating population can be identified. Although environmental effects, plus complications resulting from other genetic phenomena, may interfere with the identification of genotypes, knowledge of the heritability of a character should be secured in order for selection to be practiced as efficiently as possible. The greater the degree of heritability, the smaller the relative variation because of the influence of environmental factors. Heritability gives an indication of the stability of a character as regards its variation due to environmental factors.

Heritability is expressed on a percentage basis, and the value obtained for this character was 85 percent. This is a high value, though a reasonable one for length of fiber, which is fairly high in stability. This indicates that most of the variation in the F_2 population was caused by genetic variation and only 15 percent of this variation resulted from the influence of the environment. The maximum degree of heterozygosity occurs in this population and it is fairly reliable to select for fiber length in this population as indicated by its high heritability value. However, it should be considered that partial dominance is involved in the inheritance of fiber length and this will be a complication in selection, as already indicated.

ASSOCIATION OF CHARACTERS

Phenotypic expression of a visible or easily measured character and its association with an invisible one, or one difficult to measure, may be useful in selecting more effectively in a segregating population.

This association may be caused by linkage of genes, physiological association, or pleiotropic effects of genes, or any combinations of these. However, when two quantitative characters are closely associated, it will be difficult independently to transfer one of them to another genotype. Since some characters are extremely unstable because of environmental factors, their association with one or more stable characters can be extremely useful in selecting for the more stable character. At the same time, this may result in selection for the unstable character.

Sometimes, however, these associations involve a desirable and an undesirable character, denoting the possible occurrence of deleterious genetic linkages, which obviously are causes of difficulties in a breeding program.

To determine the associations and interrelations of the characters studied, correlation and regression coefficients between characters were calculated for each variable with each of the others, using fiber-character data from 167 randomly selected F_2 plants, as shown in table 6.

A random sample of 10 plants from each length class in the frequency distribution was studied in order to measure the association among some important fiber characters, namely, fiber length, perimeter, wall thickness, and weight fineness. All the plants in those length classes with a frequency of less than 10 plants were included in this study.

Frequency distributions of the 167 F_2 plants studied for length, perimeter, wall thickness, and weight fineness are presented in table 7. As shown by these data, a marked degree of variation in the characters studied occurred among these F_2 plants which, of course, is essential for the determination of any association among them.

This is also shown graphically in the frequency distributions presented in figures 2, 3, and 4.

Table 8 presents the number of plants in each length class and the average perimeter, wall thickness, and weight fineness of the group of plants included in each length class.

These distributions appear to be normal. The data show a striking tendency of these characters to vary together, suggesting the existence of some association between them.

In all cases a similar relationship seems to exist between the characters concerned. Changes in fiber length in one direction appear to correspond with changes in the other characters in the opposite direction.

Correlation of characters

The simple and partial correlation coefficients between characters for the 167 F_2 plants are presented in table 9.

LENGTH AND PERIMETER.—A correlation coefficient of −0.319 was obtained for these characters. This is a highly significant negative correlation, meaning that as length of fiber changes in one direction perimeter changes in the other. However, the magnitude of the correlation coefficient reveals that length was not closely associated with perimeter.

The association between these fiber characters is also evident from the scatter diagram presented in figure 5.

Figure 5 shows staple length-perimeter relationships, presenting a wide range of dispersion. A somewhat smaller number of plants were found to be above average in length but below average in perimeter. About 32 plants (or 20 percent) were of the former type, which is a new combination of these characters. The latter type which is the D.P.L. 45-867 combination

TABLE 6.—*Data on fiber characteristics of 167 F_2 plants selected at random in each length class for the study of relationships among them*

Plant No.	Length	Perimeter (P)	Wall thickness (t)	Weight fineness (W)
	Inches	μ	μ	μg./*inch*
92-16	0.78	50.86	3.93	5.84
99-4	.78	50.62	3.71	5.58
107-30	.78	54.94	3.04	5.33
116-38	.78	55.19	3.42	5.88
95-5	.81	55.72	2.81	5.07
95-44	.81	59.46	4.01	7.24
102-13	.81	50.59	3.20	5.01
114-28	.81	56.58	3.17	5.72
118-36	.81	55.31	2.85	5.11
89-42	.84	52.91	2.89	4.89
91-34	.84	51.08	3.44	5.34
95-43	.84	57.22	3.75	6.57
96-4	.84	50.04	4.01	5.78
98-24	.84	54.46	2.47	4.44
99-38	.84	54.63	3.68	6.11
100-30	.84	57.09	3.16	5.75
102-6	.84	47.28	3.30	4.70
102-9	.84	50.40	3.44	5.27
110-7	.84	51.30	3.87	5.86
92-7	.87	42.94	3.92	4.64
95-25	.87	48.53	3.59	4.96
97-36	.87	50.63	2.46	4.08
98-22	.87	54.27	2.24	4.08
100-18	.87	53.81	2.94	5.05
102-7	.87	49.30	3.95	5.61
105-26	.87	52.61	3.33	5.41
110-16	.87	55.80	4.01	6.69
115-5	.87	55.60	3.75	6.33
118-60	.87	54.37	3.24	5.53
91-35	.91	51.92	3.29	5.27
94-3b	.91	48.96	3.30	4.91
100-31	.91	48.02	3.85	5.33
102-19	.91	53.18	3.37	5.53
106-4	.91	48.30	3.30	4.84
111-17a	.91	45.59	4.36	5.36
114-7	.91	47.30	2.79	4.14
117-14	.91	56.28	3.93	6.66
120-22	.91	54.16	3.65	6.01
123-18	.91	55.27	3.72	6.26
89-58-b	.94	47.46	3.59	5.02
93-8	.94	46.60	4.25	5.46
95-10	.94	56.63	3.04	5.53
97-21	.94	48.47	3.07	4.60
99-37	.94	48.85	3.69	5.31
103-9	.94	51.50	3.47	5.43
105-27	.94	50.20	3.11	4.87

TABLE 6.—*Continued*

Plant No.	Length	Perimeter (*P*)	Wall thickness (*t*)	Weight fineness (*W*)
	Inches	μ	μ	μg./*inch*
107-35	0.94	54.86	3.75	6.24
111-24	.94	56.44	2.81	5.15
116-55	.94	58.15	3.08	5.77
91-7	.97	56.78	2.71	5.02
93-17	.97	47.50	3.48	4.91
95-40	.97	53.18	3.37	5.53
99-18	.97	54.23	3.24	5.51
101-4	.97	47.12	3.56	4.94
107-16	.97	46.61	3.18	4.51
113-3	.97	48.43	3.31	4.87
118-35	.97	57.09	2.67	5.03
123-14	.97	46.67	3.35	4.68
126-42	.97	54.93	2.39	4.37
92-8	1.00	47.60	3.21	4.64
94-6	1.00	46.45	3.24	4.54
97-4	1.00	52.72	3.27	5.37
100-22	1.00	50.00	3.37	5.12
102-2	1.00	51.49	2.65	4.43
106-21	1.00	51.58	2.60	4.35
111-13	1.00	54.50	2.89	5.07
115-9	1.00	60.26	2.47	5.00
119-27	1.00	51.63	3.20	5.15
124-7	1.00	53.03	4.01	6.26
90-2	1.03	45.15	2.66	3.77
96-5	1.03	52.88	3.02	5.05
99-12	1.03	47.90	2.57	3.96
110-8	1.03	53.43	2.80	4.82
114-29	1.03	56.46	3.37	5.97
117-5	1.03	41.41	4.15	4.54
120-37	1.03	48.99	3.70	5.34
122-18	1.03	46.89	3.16	4.50
123-24	1.03	55.12	3.18	5.55
126-4	1.03	55.32	2.59	4.72
91-28	1.06	51.24	2.58	4.29
92-37	1.06	42.24	4.04	4.60
94-4	1.06	48.35	2.54	3.94
98-5	1.06	50.69	2.73	4.45
101-5	1.06	52.24	3.57	5.66
106-13a	1.06	50.14	2.96	4.65
111-10	1.06	59.47	2.86	5.57
115-20	1.06	58.11	2.86	5.43
121-26	1.06	52.22	3.35	5.40
127-3	1.06	47.61	3.82	5.23
95-42	1.09	49.54	3.74	5.46
111-23	1.09	52.97	2.96	5.01
116-36	1.09	49.49	2.62	4.18

TABLE 6.—*Continued*

Plant No.	Length	Perimeter (*P*)	Wall thickness (*t*)	Weight fineness (*W*)
	Inches	*μ*	*μ*	*μg./inch*
120-40	1.09	45.58	3.11	4.31
121-29	1.09	49.81	2.76	4.38
123-30	1.09	51.68	2.36	4.02
123-56	1.09	51.96	2.67	4.51
124-38	1.09	47.50	3.48	4.91
126-7	1.09	44.16	3.41	4.40
127-40	1.09	51.96	3.40	5.42
91-9	1.12	51.55	2.82	4.64
95-32	1.12	50.66	2.33	3.90
97-33	1.12	42.10	3.59	4.25
105-4	1.12	54.75	2.55	4.60
116-8	1.12	51.47	2.94	4.79
117-40	1.12	52.82	2.77	4.71
120-15	1.12	48.14	2.99	4.48
121-46	1.12	51.68	3.39	5.36
123-60	1.12	45.75	3.08	4.28
127-15b	1.12	46.45	3.24	4.54
91-1	1.16	45.03	3.07	4.21
93-23	1.16	51.28	2.69	4.44
100-19	1.16	51.10	2.92	4.72
115-17	1.16	55.07	2.77	4.96
118-8	1.16	50.91	2.56	4.23
120-30	1.16	47.88	3.03	4.48
121-40	1.16	51.37	3.51	5.48
123-7	1.16	51.47	2.59	4.33
124-25	1.16	47.08	3.64	5.01
126-36	1.16	47.87	2.62	4.00
94-10	1.19	48.23	2.32	3.66
105-30	1.19	55.57	3.04	5.39
112-9	1.19	45.99	2.91	4.14
116-21	1.19	56.66	3.24	5.80
117-11	1.19	51.60	2.95	4.81
119-11	1.19	44.97	3.14	4.25
121-6	1.19	48.70	2.97	4.50
122-41	1.19	51.93	3.16	5.11
123-39	1.19	44.81	3.38	4.47
127-29	1.19	53.56	2.81	4.84
91-22	1.22	50.99	2.95	4.75
113-14b	1.22	57.72	2.55	4.89
116-35	1.22	51.24	2.96	4.80
118-49	1.22	53.54	3.06	5.18
119-7	1.22	45.45	2.98	4.14
122-42	1.22	46.90	2.86	4.17
123-25	1.22	47.12	3.09	4.46
126-27	1.22	49.68	3.25	4.96
127-30	1.22	49.18	2.93	4.53

TABLE 6.—*Continued*

Plant No.	Length	Perimeter (P)	Wall thickness (t)	Weight fineness (W)
	Inches	μ	μ	μg./inch
127-41	1.22	47.93	3.27	4.77
96-23	1.25	49.21	2.84	4.43
105-14	1.25	55.69	2.60	4.79
117-20	1.25	53.63	2.45	4.33
118-31	1.25	51.23	2.92	4.74
120-56	1.25	46.75	2.96	4.28
122-13	1.25	48.26	2.99	4.50
123-31	1.25	50.49	2.76	4.45
123-65	1.25	49.91	2.88	4.55
124-54	1.25	49.81	3.20	4.92
127-6	1.25	54.48	2.77	4.90
91-42	1.28	43.45	2.97	3.92
98-30	1.28	45.64	2.69	3.86
120-21	1.28	52.21	2.92	4.87
121-23	1.28	50.80	3.42	5.28
121-43	1.28	48.98	2.83	4.38
122-3	1.28	47.37	2.83	4.20
123-34	1.28	45.53	3.07	4.25
124-10	1.28	48.04	2.87	4.32
126-25	1.28	52.71	2.95	4.96
117-35	1.31	47.68	2.72	4.11
117-48	1.31	54.36	2.54	4.56
119-21	1.31	54.35	2.77	4.88
121-44	1.31	46.35	2.73	3.97
121-39B	1.31	46.50	2.69	3.95
123-15	1.31	42.92	3.24	4.10
126-39	1.31	46.48	2.83	4.09
112-25	1.37	50.35	1.87	3.22
122-20	1.37	42.71	3.23	4.06

appeared in about 44 plants (or 26 percent). The same was true of the number of plants found below average in both characters. This type, also a new combination of these characters, appeared in about 30 plants (or 20 percent). Those of the Florida 1377 parental type, namely, those above average in perimeter, but below average in length, appeared in about 47 plants (or 28 percent).

Therefore, despite the significance of the correlation coefficient, the association obtained is not high. It can be noted from figure 5 that several plants with long fiber (1.25 inches) also had relatively large perimeters (above 50 μ). Consequently selections of F_2 plants with any combination of the two characters could probably be obtained without great difficulty.

TABLE 7.—*Frequency distribution of 167 F_2 plants studied for associations and interrelationships among the indicated fiber characters*

Length		Perimeter		Wall thickness		Weight fineness	
Classes	Plants in classes	Classes	Plants in classes	Classes	Plants in classes	Classes	Plants in classes
Inches	*Number*	*μ*	*Number*	*μ*	*Number*	*μg./inch*	*Number*
0.78	4	42	6	1.8	1	3.2	1
.81	5	44	4	2.0	—	3.4	—
.84	10	46	20	2.2	1	3.6	1
.87	10	48	31	2.4	8	3.8	3
.91	10	50	25	2.6	20	4.0	12
.94	10	52	33	2.8	28	4.2	15
.97	10	54	21	3.0	31	4.4	22
1.00	10	56	21	3.2	26	4.6	17
1.03	10	58	3	3.4	20	4.8	20
1.06	10	60	3	3.6	11	5.0	20
1.09	10			3.8	9	5.2	10
1.12	10			4.0	9	5.4	17
1.16	10			4.2	2	5.6	10
1.19	10			4.4	1	5.8	8
1.22	10					6.0	2
1.25	10					6.2	4
1.28	9					6.4	1
1.31	7					6.6	3
1.34	—					6.8	—
1.37	2					7.0	—
						7.2	1
Total.......	167		167		167		167

The negative association would not cause serious difficulties in a breeding program.

The partial correlation obtained for length and perimeter when wall thickness was held constant, was −0.459, a highly significant, negative one. This value indicates that a considerable association exists between length and perimeter. When wall thickness varies, this association appears to be smaller due to a greater association of wall thickness with length. It seems as if wall thickness somewhat affects the association between these characters.

The partial correlation obtained for length and perimeter when weight fineness was held constant, was 0.029, which is not significant. This value indicates a very low degree of association between length and perimeter when weight fineness is held constant. This was expected because perimeter

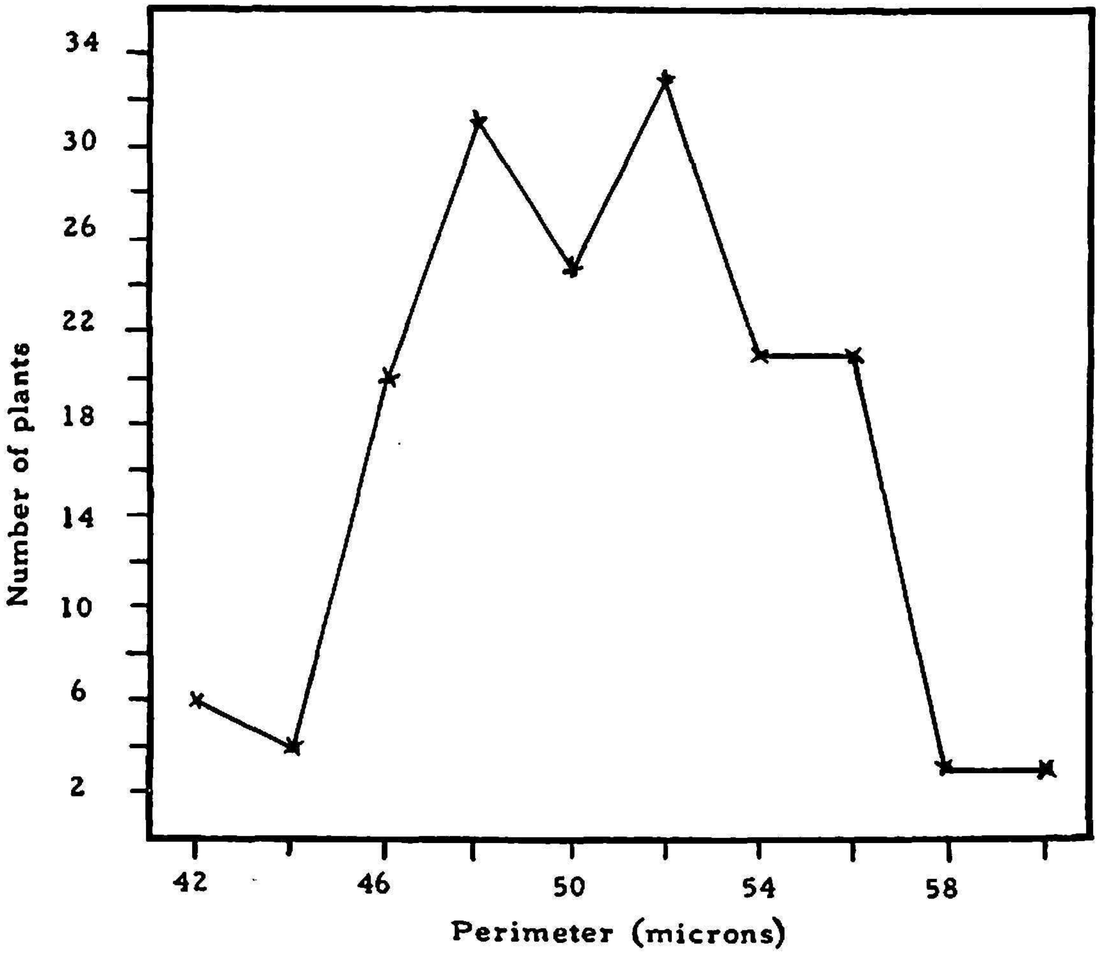

FIG. 2.—Frequency distribution of perimeter in microns for 167 random-selected F_2 plants in each length class in the Florida 1377 X D.P.L. 45-867 cross.

is a component of weight fineness. Thus, perimeter will not vary when weight fineness is held constant.

Weight fineness or fiber fineness, expressed in terms of "weight per inch" by cotton technologists, depends on two properties—that represented by the perimeter or diameter of the fiber, and that represented by the thickness of the fiber wall. In other words, perimeter and wall thickness of the cotton fiber are components or determiners of weight fineness. Perimeter is largely an inherited chacteristic, while wall thickness may be determined either by genetic or by environmental factors.

When weight fineness is held constant both perimeter and wall thickness are affected in their variation. If perimeter varies in one direction, wall thickness will vary correspondingly in the other, in order to hold weight fineness at a constant level. Thus, variations in perimeter and wall thickness are interdependent when weight fineness is held at a fixed level; variations in one of them will be accompanied by variations of the other in the opposite direction, independently of variations in fiber length. The effect

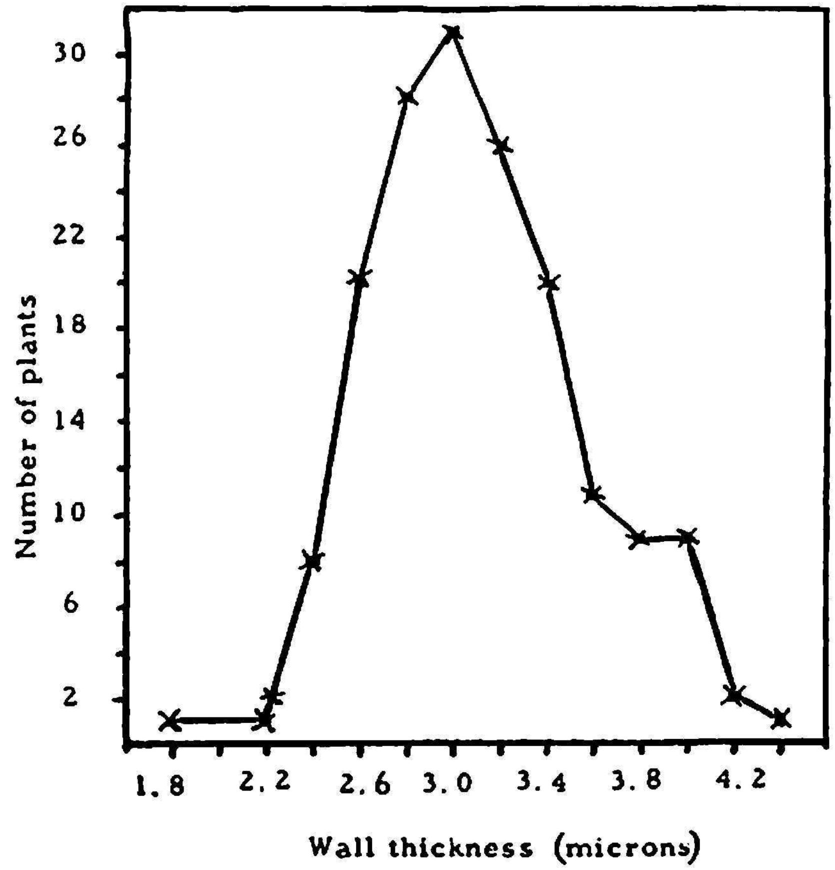

FIG. 3.—Frequency distribution of fiber-wall thickness in microns for 167 random-selected F_2 plants in each length class in the Florida 1377 X D.P.L. 45-867 cross.

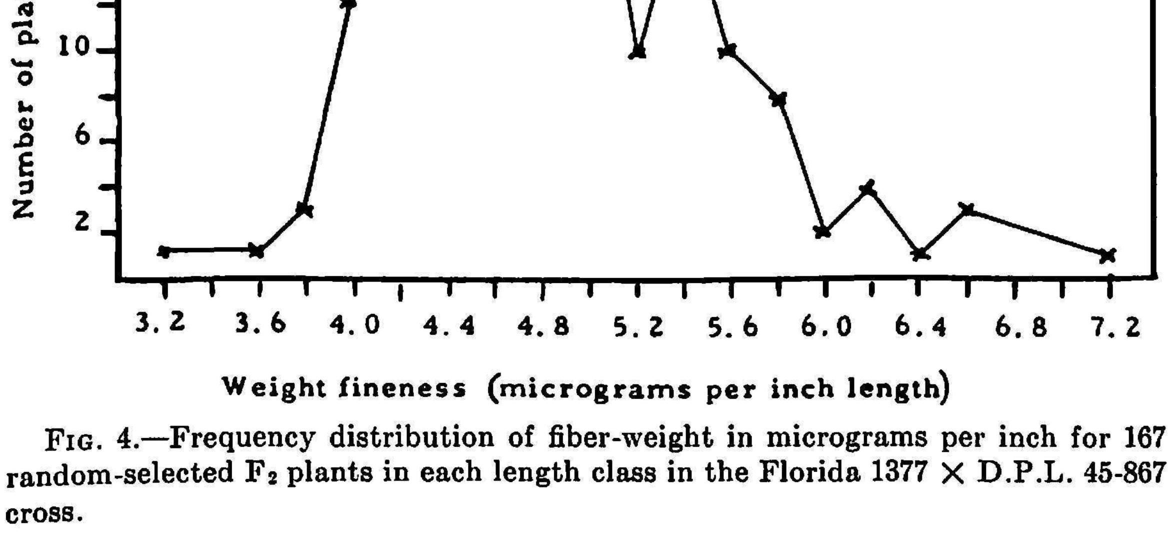

FIG. 4.—Frequency distribution of fiber-weight in micrograms per inch for 167 random-selected F_2 plants in each length class in the Florida 1377 X D.P.L. 45-867 cross.

TABLE 8.—*Fiber characters of 167 F_2 plants classed as to length*

Number of plants per length-class	Length	Average magnitude within each length-class		
		Perimeter	Wall thickness	Weight fineness
	Inches	μ	μ	μg./*inch*
4	0.78	52.90	3.52	5.66
5	.81	55.53	3.21	5.63
10	.84	52.64	3.40	5.47
10	.87	51.79	3.34	5.24
10	.91	50.90	3.56	5.43
10	.94	51.92	3.39	5.34
10	.97	51.25	3.13	4.94
10	1.00	51.93	3.09	4.99
10	1.03	50.35	3.12	4.82
10	1.06	51.23	3.13	4.92
10	1.09	49.46	3.05	4.66
10	1.12	49.54	2.97	4.55
10	1.16	49.91	2.94	4.59
10	1.19	50.20	2.99	4.70
10	1.22	49.97	2.99	4.66
10	1.25	50.95	2.84	4.59
9	1.28	48.30	2.95	4.45
7	1.31	48.38	2.79	4.24
2	1.37	46.53	2.55	3.64
Mean..............	1.06	50.75	3.12	4.89

TABLE 9.—*Simple and partial correlation coefficients involving several fiber characters of economic importance in Upland cotton*[1]

Characters correlated	Simple correlation coefficient	Character held constant	Partial correlation coefficient
Length and:			
Perimeter	−0.319**	Wall thickness	−0.459**
	−.319**	Weight fineness	.029
Wall thickness	−.434**	Perimeter	−.523**
	−.434**	Weight fineness	−.081
Weight fineness	−.568**	Perimeter	−.497**
	−.568**	Wall thickness	−.414**

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[1] ** Significant at 1-percent level of probability. Levels of significance required: For simple correlation, 165 degrees of freedom at 5-percent level 0.153; for simple correlation, 165 degrees of freedom at 1-percent level 0.200; for partial correlation, 164 degrees of freedom at 5-percent level 0.153; for partial correlation, 164 degrees of freedom at 1-percent level 0.201.

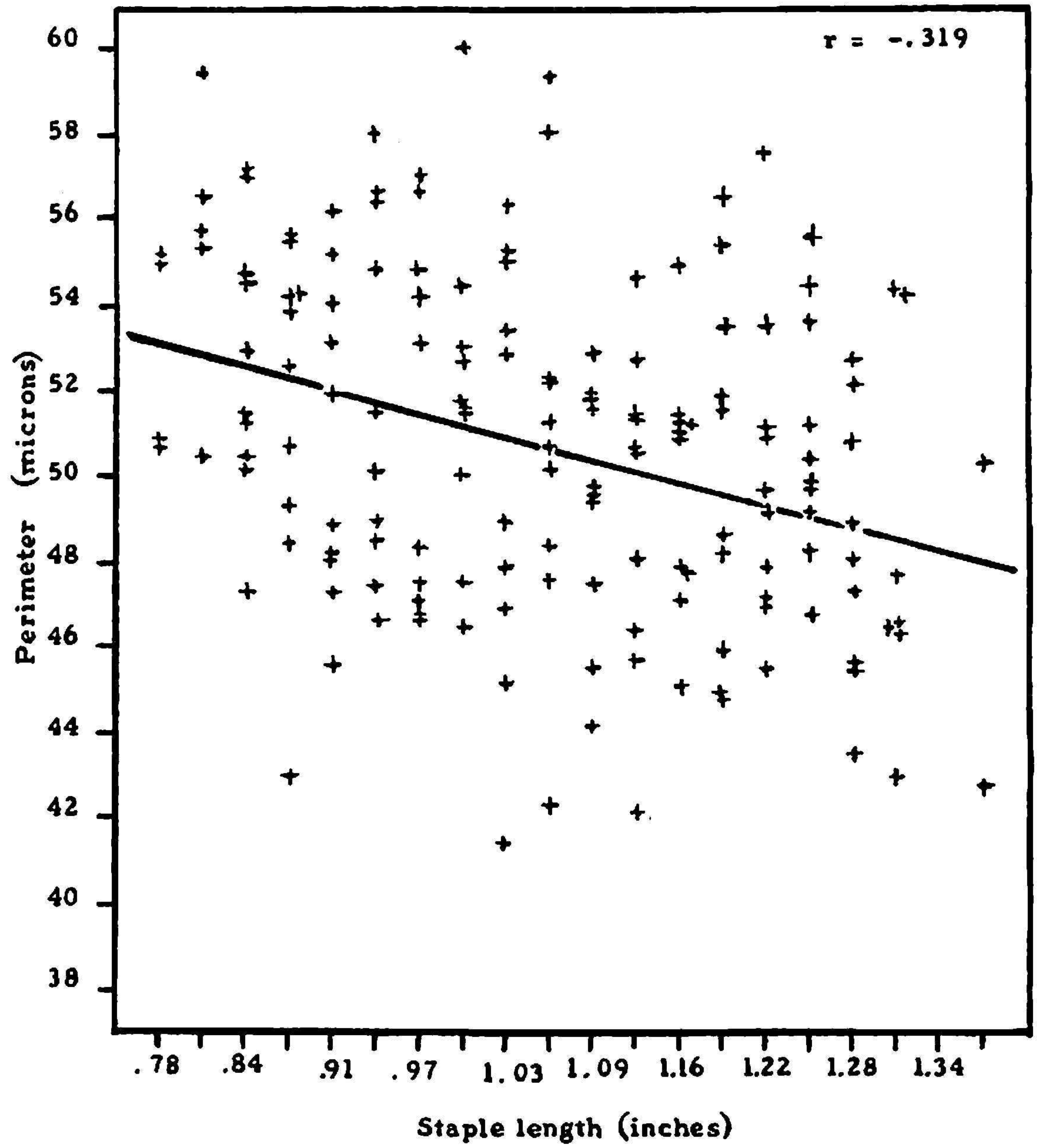

FIG. 5.—Scatter diagram of staple length-perimeter relationships for 167 random-selected F_2 plants in each length class in the Florida 1377 × D.P.L. 45-867 cross.

resulting from holding weight fineness constant affects variations in perimeter, reducing its association with length.

In conclusion, this association is not of much value in a breeding program. No difficulties should be encountered in obtaining any combinations of levels of expression of these two characters. However, certain difficulties may be encountered in obtaining combinations of extremely short fibers with small perimeter or extremely long fibers with large perimeter.

LENGTH AND WALL THICKNESS.—A highly significant correlation of —0.434 was obtained as a measure of the association of length of fiber and

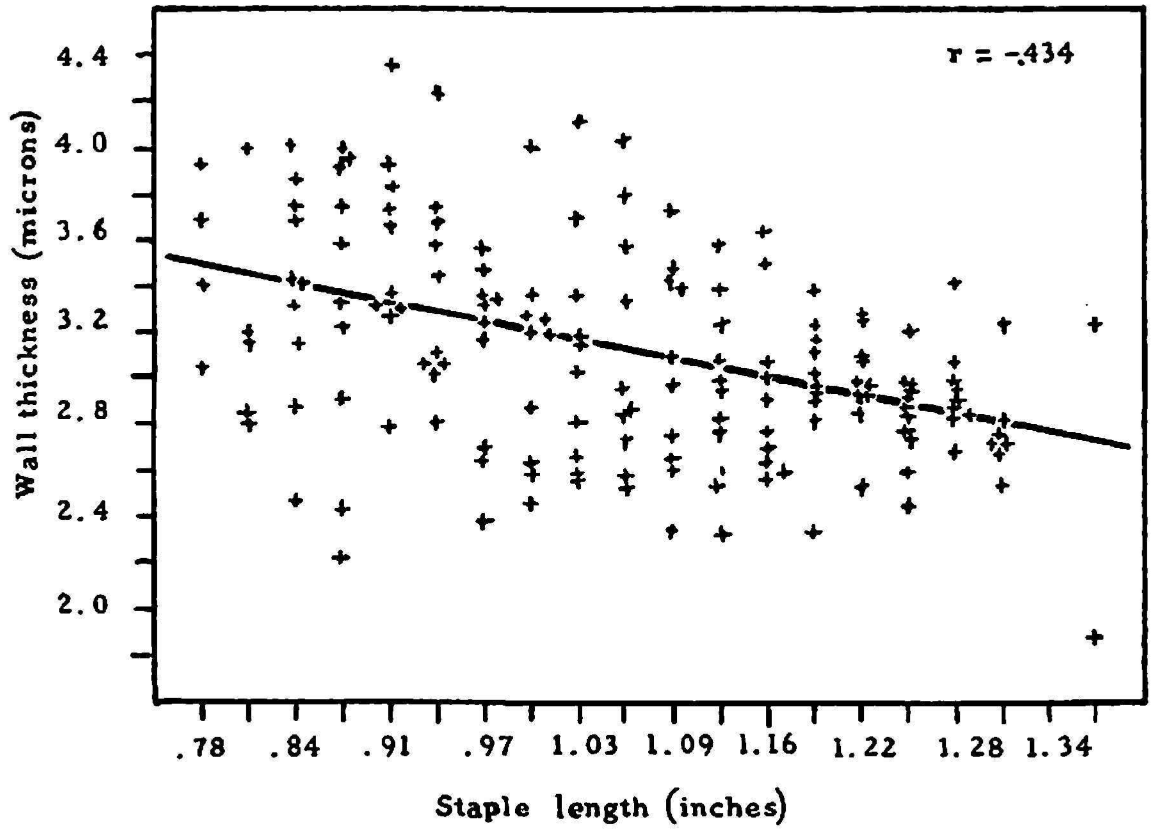

FIG. 6.—Scatter diagram of staple length-wall thickness relationships for 167 random-selected F_2 plants in each length class in the Florida 1377 × D.P.L. 45-867 cross.

wall thickness. This correlation indicates that changes in length of fiber are accompanied by changes in wall thickness in the opposite direction. The magnitude of the correlation coefficient reveals that length is appreciably associated with wall thickness.

The association is also evident from the scatter diagram presented in figure 6, which shows a somewhat strange relationship between length and wall thickness of fiber. For plants with fiber shorter than the mean length class, 1.06 inches, there is lower association with wall thickness than for plants with long fiber. Although most of the short-fibered plants had thicker than average walls, some of the short-staple plants were thin-walled types. On the other hand, essentially all F_2 plants with very long fiber, 1.25 inches or greater, had only thin to medium walls. No thick-walled fibers, 3.6 μ or greater, were very long. From this study, it appears perhaps impossible to combine the very long staple of the D.P.L. 45-867 parent with the thick fiber walls of the Florida 1377 parent.

The partial correlation coefficient obtained for length and wall thickness, holding perimeter constant, was −0.523. This is a highly significant value, negative in nature. This value indicates that a considerable true association exists between length and wall thickness. But when weight fineness was held constant the partial correlation was 0.081, a nonsignificant one.

When perimeter is held constant the association between length and wall thickness is still higher. Variations in fiber perimeter seem to affect the association between length and wall thickness.

When perimeter varies, the association appears to be smaller in magnitude because of the association of length with perimeter. Perimeter, then, seems to affect the association between length and wall thickness. It bears the same relationship to the association between length and wall thickness as wall thickness does to the association between length and perimeter. Furthermore, wall thickness is more closely associated with length than perimeter, as both its simple and partial correlations with length are higher than those of perimeter with length.

This relationship between fiber length and wall thickness might be accounted for by various conditions. One of these might be the existence of linkage between the genes governing length of fiber and those governing wall thickness. In this case, as the association indicated by the correlation coefficient is negative, it appears as if genes for long fiber are associated with genes for thin fiber wall. Likewise the reverse condition would also appear to occur.

Another explanation of this negative relationship between length of fiber and wall thickness is of a physiological nature. Fiber-wall thickness is determined by the thickness of the secondary wall. The thickening of the secondary wall starts after the fiber has completed its elongation, through successive depositions of cellulose on the inner wall of the fiber. These consecutive coatings of cellulose would vary in thickness depending on the length of the fiber and also on its perimeter, besides the length of the period throughout which this process of cellulose deposition occurs. The greater the length and the perimeter of the fiber, the larger the area to be covered by these depositions of cellulose and thus the thinner these coatings will be. Likewise the reverse condition would also occur.

If the first condition, namely linkage, is the one responsible for the association between these two characters, some difficulty will be encountered in obtaining new combinations of these characters. Still any combinations of different levels of these two characters could be obtained in a large segregating population through crossing over.

However, if the association is the result of the physiological process of cellulose deposition on the inner wall of the fiber, the thickness of the cellulose coatings would be determined by the area of the fiber to be covered. Therefore, this would result in serious implications in a breeding program. As a probable result combinations of either high or low expressions of both characters could not be obtained.

However, as shown by the scatter diagram in figure 6, one of the two plants with the highest expression of fiber length in the F_2, had a wall thickness over the mean of the F_2 plants involved in this study. Likewise, one of the four plants with the lowest expression of length of fiber was below the mean of these F_2 plants as regards wall thickness. But wall thickness is subject to variations as the result of environmental influences, as is evident from experimental results which are not very reliable.

Length and weight fineness

A highly significant correlation coefficient of −0.568 was obtained for length and weight fineness.

This highly significant, negative correlation indicates that length of fiber is appreciably associated with weight fineness. This association implies that changes in length of fiber correspond with changes in weight fineness in the opposite direction.

The scatter diagram in figure 7 presents the relationships between these characters. About 21 (or 12 percent) plants were found above average, and 22 (or 15 percent) below in both characters. These two groups comprise the new combinations of the two characters. Parental combinations of the two characters were more frequent. About 58 (or 34 percent) plants were above average in weight fineness, but below average in length, as in the Florida 1377 parent. About 57 (or 34 percent) plants were above average in length, but below average in weight fineness as in the other parent D.P.L. 45-867.

As shown in figure 7, there is a wide range of dispersion among individuals below the mean-length class, 1.06 inches. For individuals with fiber length above the mean-length class, the association between length and weight fineness seems to be stronger.

The partial correlation coefficient obtained for length and weight fineness, holding perimeter constant, is −0.497, a highly significant value. When wall thickness is held constant, the partial correlation coefficient obtained is −0.414. This is also a highly significant value.

Although these partial correlations are highly significant, they are a little below the value of the simple correlations between length and weight fineness. This indicates that the strong association existing between length and weight fineness results from the association of length with perimeter and with wall thickness. As already mentioned, both of these are components of weight fineness; thus they contribute to the strong association between length and weight fineness. The association between them is still strong when perimeter is held constant. This is also the case when wall thickness is held constant. However, when wall thickness is held constant,

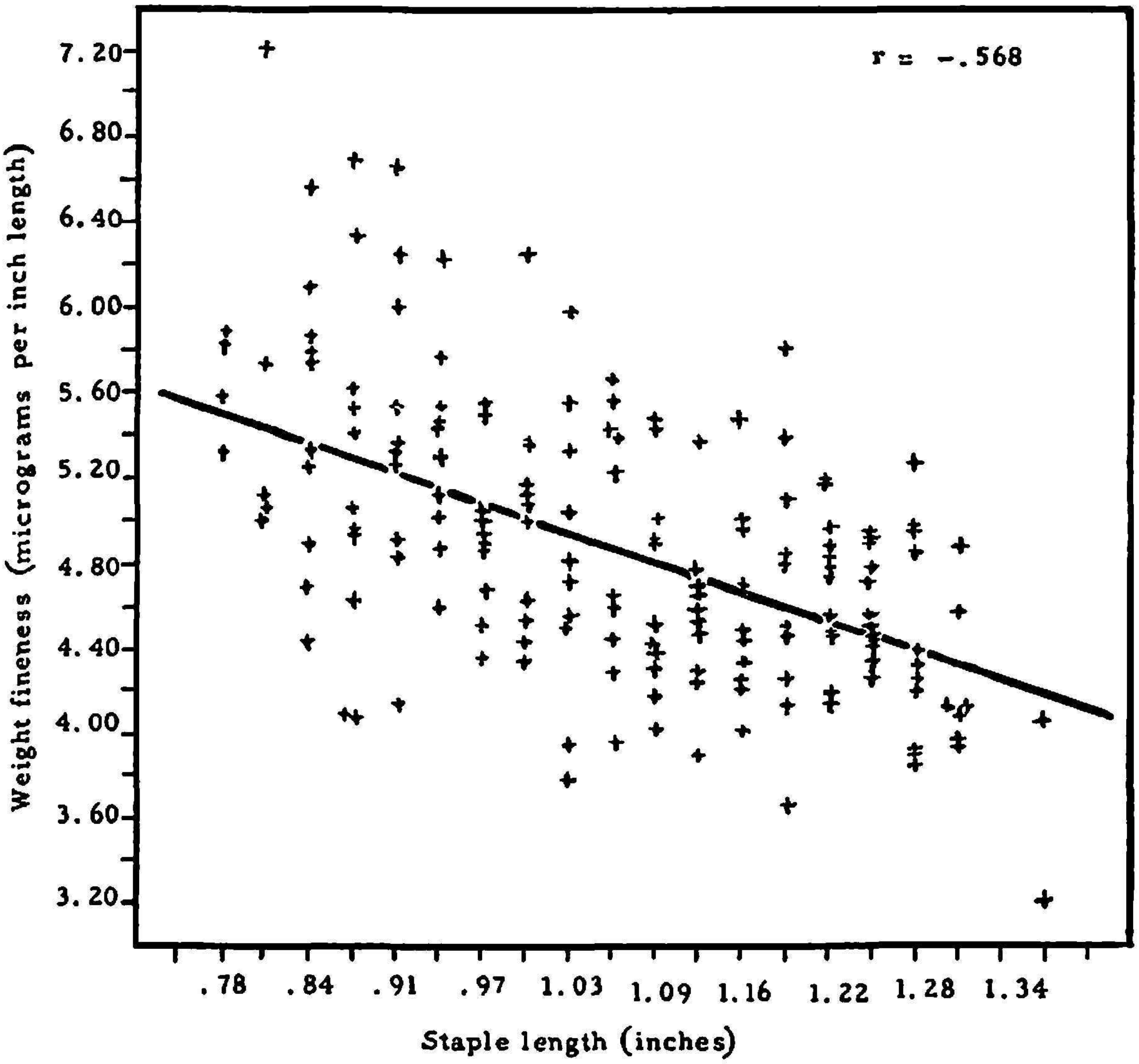

FIG. 7.—Scatter diagram of staple length-weight fineness relationships for 167 random-selected F_2 plants in each length class in the Florida 1377 × D.P.L. 45-867 cross.

the association between them is lower than that obtained when perimeter is held constant. This suggests that wall thickness contributes more than perimeter to the appreciably high degree of association between length and weight fineness.

The relatively strong, negative association between length and weight fineness indicates that some difficulties may be encountered in obtaining combinations of long staple (from the D.P.L. 45-867 parent) with coarse fiber (from the Florida 1377). The same difficulties might be expected in in obtaining a combination of short and fine fiber. The association between these characters indicates that selection for longer fiber should reduce fiber weight. Likewise, selection for short fiber should increase fiber weight.

Multiple correlation

Multiple correlations measure the degree to which one dependent variable is associated with two or more other variables.

A multiple correlation of 0.59 was obtained for the association between length and the two dependent variables, perimeter and wall thickness. This value indicates a highly significant association among the characters.

Multiple correlations are used extensively in plant-breeding studies in order to find more stable characters associated with less stable ones. This is of great help in selecting more efficiently for the less stable characters.

Regression coefficients

The regression coefficients of perimeter, wall thickness, and weight fineness on length of fiber are presented in the following tabulation:

Characters	*b*[1]
Length and perimeter	−8.16**
Length and wall thickness	−1.27**
Length and weight fineness	−2.445**

[1] ** Highly significant. The significance of these regressions is tested by the significance of the correlations between the corresponding variables. As the correlations between them were highly significant, their regressions are also highly significant.

The significance of these regressions is identical with the significance of the correlations between them.

Regression of perimeter on length

A regression coefficient of −8.16 for perimeter on length was obtained. This means that for every inch increase in average length of fiber there will be a corresponding decrease of 8.16 μ in perimeter of the fibers. Likewise a decrease of 1 inch in length will be accompanied by an increase of 8.16 μ in perimeter.

Regression of wall thickness on length

A regression coefficient of −1.27 for wall thickness on perimeter was obtained. This indicates that for every change in average length of fiber of 1 inch, there will be a corresponding change of 1.27 μ in wall thickness in the opposite direction.

Regression of weight fineness on length

A regression coefficient of −2.445 for weight fineness on length was obtained. This means that for every change of 1 inch in average length in one direction there will be a corresponding change of −2.445 μg. per inch in weight fineness in the opposite direction.

TABLE 10.—*Predicted values of perimeter, wall thickness, and weight fineness at different levels of fiber length in contrast with observed values*

Length class (inches)	Observed mean perimeter	Predicted mean perimeter	Observed mean wall thickness	Predicted mean wall thickness	Observed mean weight fineness	Predicted mean weight fineness
	μ	μ	μ	μ	μg./inch	μg./inch
0.78	52.90	53.04	3.52	3.48	5.66	5.58
.81	55.53	52.79	3.21	3.44	5.63	5.50
.84	52.64	52.55	3.40	3.40	5.47	5.43
.87	51.79	52.30	3.34	3.37	5.24	5.36
.91	50.90	51.97	3.56	3.31	5.43	5.26
.94	51.92	51.73	3.39	3.28	5.34	5.19
.97	51.25	51.48	3.13	3.24	4.94	5.11
1.00	51.93	51.24	3.09	3.20	4.99	5.04
1.03	50.35	51.00	3.12	3.16	4.82	4.97
1.06	51.23	50.75	3.13	3.12	4.92	4.89
1.09	49.46	50.51	3.05	3.09	4.66	4.82
1.12	49.54	50.26	2.97	3.05	4.55	4.75
1.16	49.91	49.93	2.94	3.00	4.59	4.65
1.19	50.20	49.69	2.99	2.96	4.70	4.58
1.22	49.97	49.44	2.99	2.92	4.66	4.50
1.25	50.95	49.20	2.84	2.88	4.59	4.43
1.28	48.30	48.96	2.95	2.84	4.45	4.36
1.31	48.38	48.71	2.79	2.81	4.24	4.28
1.34	[1]	48.47	[1]	2.77	[1]	4.21
1.37	46.53	48.22	2.55	2.73	3.64	4.14

[1] Data not available.

PREDICTED VALUES OF PERIMETER, WALL THICKNESS, AND WEIGHT FINENESS DERIVED FROM THEIR RESPECTIVE REGRESSIONS ON LENGTH OF FIBER

Regression values can be used for predicting different values of one variable for different values of the other.

This has been done as shown in table 10. The equation for predicting these values has been referred to under Experimental Methods.

When the association between the characters is not too high the accuracy of the predicted values is not high either. This is apparent in table 10. The accuracy of the predicted values is also affected by chance variations. The predicted values for perimeter wall thickness and weight fineness are relatively accurate.

Also the more accurate the predictions, the more accurate will be the ranking of them as to magnitude. In the cases of perimeter and wall thickness the ranking as to magnitude is not so accurate. However, this ranking is remarkably accurate for weight fineness.

DISCUSSION

PARTIAL DOMINANCE OF LONG FIBER

Previous studies on the mode of inheritance of staple length in cotton show that quantitative inheritance is involved in the determination of this character.

Kearney (12), Kottur (13), Ware (22), Harland (7), Henderson, *et al.* (8), and others obtained results indicating that several factors govern length of fiber.

This study throws additional light on the quantitative nature of this character. The results obtained in the F_2 of this cross, Florida 1377 × D.P.L. 45-867, are typical for the segregation of quantitative characters. It gave a unimodal distribution resembling a normal curve. Continuous variation occurred between the plants, ranging in length of fiber from 0.78 to 1.37 inches. The frequency distribution comprised 19 length classes indicating that a large number of genes involved in the determination of staple length were segregating in the population.

Results obtained by Fletcher (3), Fyson (4), Balls (1), McLendon (14), Kottur (13), Kearney (12), Henderson, *et al.* (8), and others indicate incomplete dominance of long lint over short lint.

According to this study, partial dominance is involved in the determination of this character. The mean of the F_1 was 1.06 inches, significantly higher than that of the parents, which was 0.99 inch. The mean of the F_2 was also 1.06 inches, or approximately 1.74 times that of the short-fiber parent. With absence of dominance, the expected mean of the F_2 should not differ from that of the F_1, or that of the parents.

This is also evident from the frequency distribution of the F_2. This shows that 1,107 F_2 plants, or approximately 80 percent of the total, exceeded the mean length of the parents. On the contrary only 281 F_2 plants, or about 20 percent, were shorter than the parental mean. Moreover 18 F_2 plants had a length within the range of the long-fiber parent, and of these, 2 were as long as its mean length. Also the modal class fell in the 1.12-inch length class, 0.06 inch or two classes above the mean. On the other hand none of the F_2 plants was short enough to reach the range of the short-fiber parent. The shortest F_2 segregate was 1.28 times longer than the mean of the short-fiber parent. In fact there was a gap of three length classes, or 0.09 inch, between the shortest F_2 plants and the longest plants of the short-fiber parent. The difference between the shortest F_2 plants and the mean of the short-fiber parent was 0.17 inch. In other words the shortest F_2 plants were 28 percent longer than the mean of the short parent.

Partial dominance shifted the mean length of the F_1 and F_2 to 1.06 inches as in contrast to the mean length of the parents, 0.99 inch. The same effect is observable on the modal class, which was shifted to 1.12 inches.

These results point to the occurrence of partial dominance of long fiber over short fiber. With partial dominance involved and the modifications resulting from environmental influences, some difficulties may be encountered in selecting for long fiber.

Plants with increasing doses of length factors over the F_1, will be shifted towards the long-fiber parent by the effect of partial dominance. Selections for long fiber will then be segregating in a wide range of length classes, and may also yield plants not having the desired fiber length.

Plants having fiber lengths below the mean of the F_1, or below its range, will most probably possess less factors for long lint than the F_1. Partial-dominance effects will not be so great in these, and selection will not encounter as many difficulties.

NATURE OF GENE ACTION

Of course this is subject to changes depending on the nature of gene action. It is not known whether gene action is arithmetical or geometrical. Moreover, it also depends on whether the individual effects of genes are the same or different. Furthermore, environment also affects this character, complicating the situation still more.The occurrence of partial dominance would handicap somewhat selection for long fiber in the F_2.

In a cross of Half and Half-2 × Wilds-1, involving a parental difference of 0.29 inch in staple length, Henderson *et al.* (8), estimated a minimum gene difference of four to five pairs of genes. This estimate was based on the recovery of the short-fiber-parent genotype. In the same cross the Castle-Wright formula gave a minimum estimate of two pairs, which undoubtedly is too low as several conditions assumed by the formula were not valid.

In the Wilds-7 × Half and Half-1 cross, with a mean parental difference of 0.45 inch, they estimated a gene difference of 9 pairs of genes and perhaps as many as 18 or 20 pairs.

An estimate of the number of genes affecting fiber length was made by applying the Castle-Wright formula in the present study. As already shown, partial dominance was involved in the determination of fiber length in this cross. Consequently the two F_2 plants reaching the mean length of the long-staple parent could not be used as parental-genotype recoveries to estimate the number of genes involved in the genetic difference between the parents. Partial dominance shifts the length of long-fiber plants towards the long-lint parent.

Among 1,388 F_2 plants, not a single one was recovered as short as the mean of the short-fiber parent. Theoretically, the frequency of recovery of parental genotypes for segregating F_2 populations would be 1 in 1,024 when five pairs of genes are involved. But among this 1,388 F_2 plants not a single one was recovered as short as the Florida 1377, the short-fiber parent. This evidence suggests that the parents differed by more than five pairs of genes.

With all its limitations the Castle-Wright formula enables us to estimate the minimum number of genes segregating in the F_2 population. The minimum number of genes segregating for fiber length was estimated as 9.38 pairs. Presumably this is the closest estimate that may be obtained of the minimum genetic parental difference as regards this character. But certain assumptions involved in this formula are not consistent with the data. Obviously this is an underestimate of the genetic difference between the parents. With a mean parental difference of 0.45 inch in fiber length, Henderson, *et al.* (8), estimated a minimum of 9 pairs of genes, and probably as many as 18 or 20. The mean parental difference in this cross was 0.76 inch. Therefore the number of genes involved in this case may have been over 20 pairs, and even as many as 30 or more.

Rasmusson (18) stated that the Swedish group of geneticists and plant breeders seem to be unanimous in assuming 100 to 200 genes for most quantitative characters in crosses between types not too closely related.

Attempts made to estimate the number of factors segregating for quantitative characters have largely been unsuccessful. Only in cases involving a small number of segregating genes has it been possible to estimate the number with some certainty. It is very difficult to determine them even with such a small number as five.

Because of the complexity of the problem, the number of genes determining quantitative characters is generally underestimated.

Obviously, with this large number of genes segregating for fiber length, no parental genotypes are expected in the F_2, as the population required would be too large and impracticable to grow.

With such unreliable results as to the estimation of the number of genes, and estimate of the average contribution per pair of genes responsible for fiber length is useless.

The data obtained were not suitable for determining whether the type of gene action involved was arithmetic or geometric in nature.

HERITABILITY OF QUANTITATIVE CHARACTERS

Information on the heritability of quantitative characters may be of value to breeders, since it may indicate to what extent selection can be effective in heterozygous populations. Heritability estimates for fiber length in cotton have been usually high and consistent.

Henderson, *et al.* (8), obtained a heritability value of 67 percent for staple length, using F_2 data from a cross of Half and Half-2 × Wilds-1. In the Wilds-7 × Half and Half-1 cross they obtained a heritability of 73 percent.

In this study heritability of fiber length was high, 85 percent. This is in agreement with previous results. From this it appears that selection for length of fiber would be relatively effective among an F_2 population.

INTERRELATIONSHIPS BETWEEN FIBER CHARACTERS

Correlation values supply valuable information to cotton breeders on the interrelationships of fiber characters. The simple correlation obtained indicates the existence of a significant correlation between length and perimeter of fiber. This is in agreement with the general belief that length and perimeter of fiber are negatively correlated, as long Upland cottons are usually fine while the shorter ones are coarse. Very little information is available on correlation studies between these characters. Henderson, *et al.* (8), found no correlation between these characters. But in their cross, the difference for this character was not as great as in this cross. Consequently their data may not be suitable for showing any association between these characters.

Before the Arealometer was made available, diameter of the fiber was usually measured instead of perimeter. The results on correlation studies between length and diameter are very inconsistent. Stroman (20) obtained a significant, but low value in 1944, and in 1945 and 1946, the values were negative but not significant. Moore (16) conducted extensive studies on the association between these characters. The simple correlation for the association by regions on the seed was not significant, but the partial correlation was positive and highly significant. Neither the simple nor partial values by plants or seeds indicated a real association for fiber length and fiber diameter. He stated, however, that independently of all other fiber characters, there is probably a positive association of fiber length with average fiber diameter. Raising the fiber length should theoretically increase fiber diameter, and lower fiber weight.

The association between length and perimeter, as indicated by these results, is not strong enough to cause any difficulties in a breeding program. It should be possible to develop any combinations of levels of expression of these two characters.

The partial value for the association between these characters when the influence of wall thickness was removed, was a highly significant, negative one. However, when the influence of weight fineness was removed, the partial value showed no correlation at all.

Henderson, *et al.* (8), obtained no indication as to the existence of an association between perimeter and wall thickness. These two latter characters being independent from each other should then have not much influence on the association of each other with length.

But both of them, and wall thickness to a greater extent, as indicated by the evidence available, are closely associated with weight fineness. They are the components of weight fineness.

This explains why the partial correlation for the association between length and perimeter is so high when the influence of wall thickness is removed. However, when the influence of weight fineness is removed no association appears to exist.

The majority of Upland varieties, no matter how long a fiber they possess, appear to differ very little in regard to perimeter, although there are exceptions.

Wall thickness of the fiber is the other component of its weight fineness. According to this study, there is an appreciable association between length and wall thickness of the fiber. This association is analogous to the relationship between length and perimeter already discussed.

Henderson, *et al.* (8), reported a nonsignificant association between these characters. However, in this cross, there was very little genetic difference between the parents as regards wall thickness of the fiber, and no conclusions could be drawn.

Moore (16) studied the association between length and percentage of thin-walled fibers, by regions on the seed, and by plants or seeds. In all cases, the simple and partial values indicated no significant association between these characters. Wall thickness and percentage of thin-walled fibers are negatively associated.

Barker and Pope (2), obtained correlations of −0.23, a significant value, and 0.10 for length and percentage of thick-walled fibers. Though the significant value was very low, it indicated a tendency towards a decrease in the percentage of thick-walled fibers as length of fiber increased. In other words, it suggested a negative association between length of fiber and wall thickness.

Although the thickness of the fiber wall is determined by genetic factors, to a certain extent, much of the variation occurring in this character is the result of the influence of environment. To a certain extent, the duration of the period of deposition of the secondary wall of the fiber affects wall thickness. In addition, environmental fluctuations during this period exert a great influence on this character.

The partial correlations obtained for the association of length and wall thickness were significant when the influence of perimeter was removed, but nonsignificant when the influence of weight fineness was removed.

As already discussed, wall thickness and perimeter may be independent of each other. However, being components of weight fineness, both of them appear to be associated with length because of the association of the latter with fineness. The apparently higher association of length with wall thickness than with perimeter seems to be due to the fact that the wall thickness-weight fineness relationship is also greater than that with perimeter.

Most published studies are in agreement with the accepted belief that length and weight fineness are negatively associated. Highly significant, negative simple and partial values were obtained for length and weight fineness, indicating that a real association exists between these characters. These results are in agreement with the evidence already available from various sources.

Moore (16) obtained similar results indicating a real association between these characters. There was a real negative association of average fiber length with average fiber weight per inch by regions of the seed, as indicated by both simple and partial values. By plants or seeds the simple correlation between these characters was not significant, but the partial value was negative and highly significant.

Green's (5) results also indicate that a real association exists between these characters. He obtained a highly significant correlation of −0.711 in 285 different strains of cotton.

Hancock (6) and Barker and Pope (2) obtained similar results as to the association between these characters.

Evidence indicates that this relationship is influenced to a greater extent by wall thickness than by perimeter of the fiber. In general, the results obtained indicate a closer association for weight fineness with wall thickness than with perimeter of the fiber.

Most studies have shown that a real association exists between these characters. It is true that the high association reported by Green (5) might be explained as due to the fact that extralong Upland varieties have been developed from strains which also were fine, and similarly shorter than average varieties from strains with coarse fiber.

These results indicate that selection for long cottons tends to reduce weight fineness, and similarly short cottons will tend to be higher in weight fineness. Because of this association it may be difficult to obtain combinations of either high or low levels of expression of both characters.

Regression values of perimeter, wall thickness, and weight fineness on fiber length are all highly significant. These values also suggest the existence of an association between length and each of the other fiber characters mentioned. Values for each of these characters at different levels of fiber length may be predicted with relative accuracy.

CONCLUSIONS

The information obtained from genetic analysis of quantitative characters, such as fiber length, is of great value as regards breeding for the improvement of such characters. A knowledge of their dominance relationships, number of genes constituting the genetic parental difference, type of gene action involved, heritability, and other genetic characteristics, is essential to the success of the breeding program. A consideration of these different aspects is fundamental for the effectiveness of selection for these characters.

As the present situation demands types of cotton fiber combining certain levels of the various important fiber characters, the inheritance of these various characters should be better known. A determination of the interrelationships among them is also essential in the breeding of better cottons combining the desired fiber characters.

SUMMARY

1. An attempt was made to investigate the inheritance of degree of dominance, number of genes involved, estimated contribution per pair of genes, nature of gene action, and heritability of staple length in Upland cotton, and its interrelationships with several important fiber characters, namely perimeter, wall thickness, and weight fineness.

2. Varieties Florida 1377 and D.P.L. 45-867, which represent the extremes in the length range in Upland cotton, were selected for this study. These noncommercial varieties also differ widely with regard to perimeter and wall thickness. Crosses were made and F_1 and F_2 populations were grown in the same year with the parents.

3. Staple length was determined by hand for each of the 1,388 F_2, 24 F_1, 26 Florida 1377, and 41 D.P.L. 45-867 plants.

4. Florida 1377 had a mean fiber length of 0.61 inch as compared with 1.37 inches for the D.P.L. 45-867. The mean parental difference was 0.76 inch. The F_1 and F_2 populations had a mean fiber length of 1.06 inches.

The F_2 segregated as a typical quantitative character. Its frequency distribution comprised a large number of classes (19), indicating that a large number of genes were segregating for this character.

There was a significant difference between the mean of the parents and those of the F_1 and F_2 populations, indicating partial dominance of long staple over short. This was also apparent from the F_2 distribution. This condition may handicap selection of long fiber in the F_2.

The minimum number of genes, as estimated by the Castle-Wright formula, was 9.38. Based on this estimate, the average contribution per pair of genes was estimated as 0.08 inch.

The data were not adequate to determine whether arithmetic or geometric gene action was involved.

Staple length gave a high heritability, 85 percent in F_2.

5. The relationships of perimeter, wall thickness, and weight fineness with fiber length were studied. A significant negative correlation of -0.319 was found between length and perimeter of fiber. It is evident that some difficulty could be encountered in attempting to combine long fiber with large perimeter.

There was a closer negative association between length and wall thickness ($r = -0.434$). It appears very difficult to combine the very long staple of the D.P.L. 45-867 parent with the thick fiber wall of the Florida 1377 parent. However, it should be easy to maintain the parent combinations of long fiber, small perimeter and thin walls, or short fiber, large perimeter and thick walls.

A very close association was found to exist between length and weight fineness. This association was still close when either one of the other characters, i.e., perimeter and wall thickness, was held constant. This relationship might result in difficulties in obtaining combinations of long staple with coarse fiber, or short with fine. Selection for long fiber should reduce fiber weight, while selection for short fiber should increase it.

A highly significant multiple correlation of length with perimeter and wall thickness was obtained, indicating a close association among these characters.

Highly significant regression coefficients of perimeter, wall thickness, and weight fineness on length of fiber were also obtained.

6. A broader knowledge of the inheritance of the important characters of the cotton fiber and their interrelationships will be very useful to the cotton breeder.

RESUMEN

1. Se realizó un estudio en el algodón "Upland" con el propositó de investigar el grado de dominancia, el número de genes envueltos, la contribución estimada por cada par de genes, la naturaleza de la acción génica y la heritabilidad del largo de fibra. Fueron también objeto de estudio las relaciones entre el largo de fibra y varios caracteres de la fibra, especialmente perímetro, espesor de la pared y fineza, todos los cuales son de importancia comercial.

2. Para este estudio se seleccionaron las variedades Florida 1377 y D.P.L. 45-867, las cuales representan los extremos en la variación del largo de fibra en el algodón "Upland". Estas variedades difieren ampliamente la

una de la otra con respecto al perímetro y al espesor de la pared de la fibra. Después de efectuados los cruces entre estas variedades, las generaciones F_1 y F_2 fueron sembradas simultáneamente con las generaciones progenitoras.

3. Se midió a mano el largo de fibra del algodón de cada una de las 1388 plantas de la F_2, de las 24 plantas de la F_1, de las 26 plantas de la variedad Florida 1377 y de las 41 plantas de la variedad D.P.L. 45-867

4. El largo de fibra medio en la Florida 1377 fué de 0.61 pulgada y el de la D.P.L. 45-867 fué de 1.37 pulgadas. La diferencia media fué, por tanto, de 0.76 pulgadas. El largo de fibra medio en las generaciones F_1 y F_2 fué de 1.06 pulgadas.

La segregación en la F_2 fué típica de un carácter cuantitativo. La distribución de frecuencia comprendió un gran número de clases (19), señal de que había un gran número de genes segregando para esta característica.

Se encontró una diferencia significativa entre el promedio de los progenitores y los de las generaciones F_1 y F_2, lo cual indica dominancia parcial de fibra larga sobre corta. Esta misma indicación se obtiene al examinar la distribución de la F_2. Esta condición puede entorpecer la selección para fibra larga en la F_2.

El número mínimo de genes envueltos, estimado por la fórmula de Castle-Right, fué 9.38. A base de este estimado, se calculó que la contribución promedio por cada par de genes en la determinación del largo de fibra fué de 0.08 pulgadas.

Los datos obtenidos no permitieron determinar si la acción génica envuelta era aritmética o geométrica.

El largo de fibra tuvo un alto grado de heritabilidad, que alcanzó 85 por ciento en la F_2.

5. Se estudiaron las relaciones que hay entre el largo de fibra y el perímetro, espesor de la pared y la fineza. Entre el largo y el perímetro de la fibra se obtuvo una correlación de -0.319, la cual resultó ser significativa. Aparentemente, el combinar fibra larga y perímetro grande en una misma variedad resultará algo difícil.

Hubo una asociación negativa mayor entre el largo y el espesor de la pared de la fibra ($r = -0.434$). Tal parece que es muy difícil combinar el largo de fibra del D.P.L. 45-867 con el espesor de la pared de la fibra del Florida 1377.

Sin embargo, deberá ser fácil el conservar las combinaciones de estos caracteres tal como los mismos aparecen en los progenitores, es decir, fibra larga, perímetro pequeño y pared de la fibra delgada en el uno, y fibra corta, perímetro grande y pared de la fibra gruesa en el otro.

Hay una asociación muy estrecha entre el largo de la fibra y la fineza. Esta asociación es muy estrecha y se mantiene así hasta cuando uno de los caracteres componentes varía y el otro permanece constante. Esta relación puede crear dificultades al tratar de combinar estos caracteres con el fin de obtener una fibra larga y gruesa, o fibra corta y fina. El seleccionar para fibra larga reducirá el peso por unidad del largo de fibra, esto es, la fibra será más fina. Lo contrario ocurrirá cuando se seleccione para fibra corta. Entre el largo de fibra y el perímetro y el grueso de la pared hay una correlación múltiple altamente significativa, lo cual prueba que entre estos caracteres la asociación es muy estrecha.

También se obtuvieron coeficientes de regresión altamente significativos de perímetro, grueso de la pared y fineza de la fibra en el largo de la fibra.

6. Un conocimiento más amplio de la herencia de los caracteres importantes de la fibra del algodón, así como de sus interrelaciones, será de gran ayuda al geneticista empeñado en mejorar la calidad del algodón.

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