HETEROSIS AND HERITABILITY IN THE AMERICAN EGYPTIAN COTTON, (G. barbadense)

by

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ABSTRACT

An investigation was conducted in 1963 to study the expression of heterosis and heritability for agronomic and fiber properties in an intraspecific cross between two of the American Egyptian cotton, Pima (Gossypium barbadense L.). The two selected parents were, 279-9 a breeder's strain and Pima S-2 a commercial variety. The two parents were used to develop the F_1, F_2, and the backcross of the F_1 to each parent (B1 and B2).

The agronomic and fiber characteristics studied were seed index, lint percentage, boll size, seeds per boll, lint index, fiber length (UHM and Uniformity ratio), fiber strength (Pressley Index), and fiber fineness (Micronaire value). Heterotic effect was considered to be one in which the F_1 exceeded the better parent at the 0.05 level. Fiber strength was the only character that showed heterosis. No evidence of heterosis was found in boll size, seed index, lint percentage, lint index, seeds per boll, fiber fineness, and fiber length (UHM and Uniformity ratio). The lint percentage and lint index of the F_1 were intermediate between the two parents. Boll size, seed index, seeds per boll, fiber length, and fiber fineness were about equal to the higher parent.

Three methods were used to estimate the heritability of the characters studied. In two of these methods the average variances of the two parents and the F_1 generation were used as an estimate of non-heritable variance. In the third method the estimate of heritability was based entirely on the basis of the F_2 and the backcross of the F_1 to each parent. High values were obtained for fiber fineness, fiber strength, seed index, and lint index. The average values from the three methods were fiber fineness, 81; fiber strength, 78; seed index, 69; and lint index, 62 per cent, respectively. The average value for boll size was 42 per cent. Negative heritability values (zero) were obtained for fiber length (UHM), lint percentage, and seeds per boll.

A study of gene numbers and nature of gene action was undertaken in an attempt to obtain additional information about the characters besides the estimates of heritability. The Castle-Wright formula failed to give any reliable estimate of gene numbers except for lint index where three pairs of genes were found to be involved. The test for nature of gene action revealed that the differences between the arithmetic and geometric means for all characters were very small.

INTRODUCTION

Heterosis is an important tool of plant breeders. The commercial production of F_1 hybrids is considered one of the most important contributions of plant breeding to agriculture.

Heterosis and hybrid vigor are synonymous, and are terms used to describe the increase in vigor, growth, size, yield, or function of a hybrid over the better parents. On the other hand, they may be considered as the increase in vigor or growth of a hybrid progeny in relation to the average of the parents. Some illustrations of the practical commercial utilization of heterosis are found in corn, sorghum, and onions.

At the present time, cotton breeders have a great interest in the practical utilization of hybrid vigor in cotton. There are some problems that hinder the progress in the commercial production of hybrid cotton. Muramoto (18) pointed out that before the commercial production of hybrid cotton can become a reality the following problems must be solved:

"1. Emasculation by the application of a selective gametocide or the use of a male sterile line.

2. Effective cross pollination by insects.

3. Selection of suitable parents to produce hybrids."

With regard to the first problem discussed by Muramoto, male sterility may be useful in solving this problem. In 1963, Meyer and Meyer (17) working with Upland cotton, stated that cytoplasmic genetic male sterility has resulted from the combining of the cytoplasms of diploid species with the chromosomes of tetraploid (Upland) cotton. Incompatibility may exist between the nuclear genes and plasmagenes of the two species. Thus, male sterility is known to exist and can provide a means of emasculating the flowers, a necessary step for hybrid seed production.

Concerning the problem of pollination, natural cross pollination was found to increase about 50 per cent in some areas because of large populations of wild bees (22). Thus, introduction of insects, presumably honey bees, may provide effective pollination.

The selection of suitable parents is important in hybrid production. Hybrid vigor in cotton has been reported from interspecific crosses, (1, 3, 10, 19), especially in the crosses that involve Upland cotton, (*Gossypium hirsutum* L.) and Sea Island or Egyptian cotton, (*Gossypium barbadense* L.). During recent years, hybrid vigor has also been reported in crosses between varieties or lines of normally self pollinated crops within species. Thus, it is logical to believe that cotton may respond in the same way.

Most of the work in intraspecific hybridization has been done with Upland cotton, and heterotic responses were reported in some of these crosses. The intraspecific hybrid of G. barbadense has received little attention. Very little information can be found on the behavior of F_1 hybrid of G. barbadense.

This investigation was undertaken to study the effect of hybridization on eight factors; namely, lint percentage, lint index, boll size, seed index, number of seeds per boll, fiber length (UHM and Uniformity ratio), fiber strength, and fiber fineness of the F_1 of crosses between the American Egyptian cotton (G. barbadense), Pima S-2, a commercial variety, and 279-9, a breeders strain.

These eight quantitative characters mentioned above are the end result of the interaction between genes and environment. In an improvement program for these characters, it is important to know the relative effects of heredity and environment in determining the expression of these characters. Thus, part of this study was to evaluate the heritability of these characters. Knight (13) defines heritability as "the portion of the observed variance for which difference in heredity is responsible." It has value primarily as a method of qualifying the concepts of whether progress from selection for each of these characters is relatively easy or difficult to make in a breeding program.

Heritability gives a numerical description of the response of these characters to selection by measuring the extent a factor is transmitted from parent to offspring.

The heritability of the characters considered in this investigation has not been studied to any extent in G. *barbadense*. Stith (24), in his study of the heritability of quantitative characters in two species of G. *hirsutum* pointed out the limited work conducted on this subject.

REVIEW OF LITERATURE

Heterosis

The phenomenon of hybrid vigor in cotton has been reported from a long time ago. As early as 1894, Mell (16) working with interspecific and intraspecific crosses of Gossypium for the purpose of improving the cotton fiber in Alabama, reported the first known results about the increases in certain characters in cotton hybrids when compared to the parents. He stated:

> "The experiments conducted at Auburn give conclusive evidence that the improvement of the cotton plant under the influence of the crossing processes does not deteriorate the fibers but tends greatly towards making it superior in the properties. The length and the strength of the fibers have been increased in numerous crosses."

Balls (1), in 1908, when he made crosses within the Egyptian cotton (G. barbadense), and between the G. barbadense and American Upland Cotton (G. hirsutum), stated:

> "The most striking features are the intensification of certain characters which result when two botanically dissimilar cottons are crossed together. The intensification is shown in the height of the plant, the time of flowering, the length of the lint, the size of the seed, probably in the fuzziness of the seed, etc. Of these, the length of the lint has been observed most fully."

Cook (3), in 1909, working with interspecific crosses of the Egyptian cotton, (G. barbadense), and Kekchi, (G. hirsutum), found that the lint of the hybrids is longer than in either parent, the strength as well as the length is notably improved. He was the first one who suggested the utilization of F_1 hybrids on a commercial scale when he stated:

> "In the first generation of the Egyptian hybrids the intensification of the characters which gives superiority to the lint is so regular that it may be possible to utilize it in the commercial production of high grade fibers."

Kearney (10), in 1923, working with hybrids between Pima, (G. barbadense), and Holden, (G. hirsutum) found that the first generation showed intensification in respect to most of size characters. These may be interpreted as manifestations of heterosis.

Hybrid vigor, however, in intraspecific cotton hybrid has not received much attention from the cotton breeders. Most of the early studies on cotton hybrids were with interspecific crosses rather than with intraspecific crosses where the hybrid vigor will not usually be expected. The early information available in evaluating heterosis has been incidental to other studies such as genetic inheritance where the primary interest was in the segregates of the later generations. Very few investigations were done to compare the F_1 hybrids with the parents. A review of the literature reveals that there are great discrepancies between the results in certain characters. This is expected because researchers were working with different materials.

Pate and Duncan (19), in 1961, wrote this conclusion on hybrid cotton: "Interspecific hirsutum-barbadense hybrids are worthy of consideration. Heterosis in intraspecific hirsutum hybrids is a problem requiring additional study."

Cook (3) in 1909, working with intraspecific hybrids between the Kekchi cotton, (G. hirsutum), and the American Upland cotton, (G. hirsutum), found that in the F_1 generation the bractlets are suppressed and the lint shortened.

Kime and Tilley (12), in 1941, made an extensive investigation in intraspecific crosses of G. hirsutum. They selected inbred lines from the Coker 100, Stoneville, and Deltapine 11A, during the period of 1941-1945. Heterosis was considered as the increase of F_1 over its most productive parent. Heterosis was reported in yield of seed cotton, yield of lint, lint index, earliness, and the rate of blooming. The weight of seed cotton per boll was about equal to the best parent. No evidences of heterosis were observed for percentage of lint, height of plants, dry weight of the plant, fiber strength, and fiber length. The F_2 generation has lost much of the vigor shown in the F_1 but still significantly better than either parent for yield of seed cotton and yield of lint. The results of

Kime and Tilley introduce an evidence of heterosis for certain characters in the intraspecific crosses and reveals the importance of combining ability among the crosses if an advance or gain in a specific character is desired.

Simpson (22), in 1948, studied the hybrid vigor using seed produced in an area where the natural cross-pollination by bees and other insects approximated 50 per cent. Progenies from relatively pure seed of seven varieties of cotton G. hirsutum were compared with progeny from the crossed seed of the same varieties. Heterosis was found in yield of seed cotton, boll size, seed index, and lint index. Other seed and fiber characters were not significantly affected. He stated:

> "In general, no deleterious effects from crossing were noted on any of the characters measured."

Loden and Richmond (14), in a review of the literature on heterosis, reported evidence of heterosis in cotton, and discussing the practical application of hybrid vigor in cotton, they concluded: "evidences of significant increases in most characters and yield resulting from heterosis have been reported in interspecific, inter-varietal, and intravarietal crosses. The future of the commercial utilization of heterosis in cotton production is believed to be dependent upon basic investigations of the numerous phases of the general problem."

Jones and Loden (9) in 1951, working with nine F_1

hybrids and their parents from Upland cotton, G. hirsutum, reported heterosis for yield of seed cotton in seven crosses, maturity (percentage of total harvested at first picking) in all crosses and boll size in three crosses. No heterosis was observed in lint percentage, staple length, number of nodes or height of first fruiting node from ground. The yield of the F_1 in all the crosses was higher than the average of both parents with an average increase of 34.6 per cent, and was more than their most productive parent by an average of 29.1 per cent.

Turner (25), in 1953, studied the combining ability and inbreeding effect using seven inbreds from Upland cotton and found heterotic response for boll production and seed cotton yield. Heterosis was expressed by Turner as the increase of F_1 over the average of both parents, $(F_1 - \frac{P_1 + P_2}{2})$.

Crossing studies were carried out in Greece by Christidis (2), from 1948 until 1953, with a number of cotton varieties of Upland cotton, G. hirsutum. Heterotic response was reported for yield, boll weight, and earliness. The lint length of the hybrid was usually shorter in staple than their longer fibered parent. He concluded that hybrid vigor effects are generally unmistakable.

Muramoto (18), in 1958, studied the genetic combining ability of eight varieties of G. hirsutum. Hybrid vigor has been shown for yield, boll size, lint index, seed index, (in crosses where one of the parents was a small seeded variety) and seed per boll. No heterosis was observed in lint percentage, fiber strength, and fiber length, but the F_1's approached the length of the longer fibered parent in some crosses.

Fryxell (6), in 1958, presented an excellent review of the recent studies on heterosis. He concluded that "the work on intraspecific hybrids of G. hirsutum has shown a clear response potential of hybrids for yield."

Harrell (7) in 1961, working with intraspecific hybrids involving long and extra long staple Uplands cottons, G. hirsutum, at Florence, S. C., reported that the yield of seed cotton of F_1 will equal or exceed the shorter parent, lint percentage will approximate the arithmetic means of the parents and there is slight but consistent heterotic response for staple length and strength. No definite pattern was shown for the micronaire values, but the averages of several hybrids tend to be intermediate.

Douglas and Weaver (4), in 1962, working with hybrids between Empire W R and Coker 100A in New Mexico, reported heterosis for yield, fiber length, and fiber strength. No evidence of heterosis was found for boll size and fiber fineness.

A recent study was conducted on heterosis and combining ability in top and diallel crosses among primitive, foreign and cultivated American Upland cotton, G. hirsutum, by White and Richmond (27). Ten crosses from five parental stocks were made. Heterosis was noted for yield and earliness in two crosses and in the fiber character UHM in five crosses where the F_1's exceeded their longer parent by three to six per cent. Heterotic effect was considered to be one in which the F_1 statistically exceeds the longer parent at the .05 level for a particular character. Values for heterosis expressed on this basis would be lower than when compared to the average as was done by Turner.

Kearney and Wells (11) in 1918, working with two varieties of G. barbadense, Pima and Gila, found no expression of heterosis in boll index, leaf index, or fiber length, the means of the F_1 being, in general, intermediate between those of the parents.

The only recent data available is that of Peebles, et al (20) in 1953. They conducted an experiment at Sacaton, Arizona, to study the hybrid vigor in the American Egyptian cotton by crossing Pima S-1 and Pima 32. Pima S-1 was developed from a complex cross involving parental materials from G. barbadense (Pima, Sea Island and Tanguis) and G. hirsutum (Stoneville). Therefore, it is not a pure G. barbadense. The F_1 hybrids produced 125 per cent of the yield of lint of the Pima S-1 parent. It exhibited the fiber length of the longer parent, Pima 32, and the seed index of the highest parent, Pima 32. It was intermediate in fineness, lint index, lint per cent, seed per boll and it had the fiber strength of the weaker parent, Pima S-1. In spinning tests it proved to have stronger yarns than either parent, and was intermediate in yarn appearance and waste per cent. As Pima S-1 is not a pure G. barbadense, the cross is expected to show more heterosis.

Most of the investigations of intraspecific hybrids were done on G. hirsutum (Upland cotton). The majority of the work has shown a clear heterotic response in most of the characters; however, not all the crosses gave heterotic response. This may indicate the importance of combining ability, and that parents with best combination of characters should be sought among well adapted, productive lines.

The intraspecific hybrids of G. barbadense have received little attention. Because of the limited data available for this group, no general conclusion should be made about heterosis.

Heritability

Heritability is defined by Knight (13) as the proportion of observed variability which is due to difference in heredity, the remainder being due to environmental causes. More strictly, it is the proportion of observed variability due to the additive effects of genes.

Warner (26), in 1951, pointed out that the technique for estimating the degree of heritability fell into three main categories:

"1. Parent-offspring regressions.

2. Variance components from an analysis of variance.

3. Approximation of nonheritable variance

from genetically uniform population

to estimate total genetic variance."

He presented a method for estimating heritability on the basis of the F_2 and the backcross of the F_1 to each inbred parent. It will be unnecessary in this method to estimate the environmental and the total genetic variance. Also there are some assumptions underlying the method, i. e., additivity of genic effects, no epistasis, and independence of genotype and environmental variance.

Self and Henderson (21), in 1954, studied the inheritance of fiber strength in F_1, F_2, and F_3 populations of a cross between the high strength AHA 50 strains and the Half and Half variety, which was known to be low in fiber strength. Heritability of fiber strength in F_2 was estimated from the following formula:

Heritability = S^2G / S^2F_2 where

S^2G is the genetic variance in F_2, obtained as the difference between total F_2 variance and average variance of the parents; and S^2F_2 is the total variance in F_2. The estimate of heritability obtained was 86 per cent. They stated that a high portion of the F_2 variation was due to genetic causes, and that selection for fiber strength on the basis of individual plants in the F_2 and later segregating generations would result in lines with high strength. Estimates of heritability based on correlation between F_2 plant values and F_3 line means, and the regression of F_3 line means on F_2 plants, was reported to be 76 and 53 per cent respectively.

Stith (24), in 1956, studied the heritabilities and interrelationships for lint percentage, boll size, staple length, fiber strength, and fiber fineness in a cross between two Upland varieties, Acala and Hopi. Studies were made on the parents, F_1, F_2, and F_3 populations. He found all characters to be quantitatively inherited. He calculated the heritability from the genotypic variance of the F_2 population, where he obtained 45.3 per cent for lint per cent, 50.1 per cent for boll size, 22.2 per cent for staple length, 54.1 per cent for fiber strength, and 74.6 per cent for fiber fineness. He also estimated the heritability from the variance components among F_3 lines where he obtained 79.0 per cent for lint percentage, 62.5 per cent for boll size, 70.0 per cent for staple length, 87.3 per cent for fiber strength, and 69.9 per cent for fiber fineness. He concluded that selection for the desired fiber fineness can be made early in the F_2 on a single plant basis, and that selection for fiber strength, lint percentage, boll size, and staple length should be made on a progeny mean basis in successive generations of breeding.

Muramoto (18), in 1958, evaluated the heritability of some quantitative characters in crosses between eight varieties of Upland cotton. A high heritability value was obtained for boll size, lint percentage, lint index, and fiber fineness. The heritability estimates obtained were:

1. boll size 64.3%
2. lint percentage 46.6%
3. lint index 60.8%
4. fiber fineness 56.8%

All other characters varied greatly. These values were based on the total variance of F_2.

El-Sharkawy (5), in 1962, conducted a study of the inheritance of fiber strength and fiber elongation in the parents, F_1 and F_2 populations of a cross between two varieties of Upland cotton. Based on the variance of P_1, P_2, F_1, and F_2, he obtained 83.7 per cent for fiber strength.

The majority of the work on heritability show a high value for fiber fineness, fiber strength and lint index and a low value for the other characters. This may indicate that selection for fiber fineness, fiber strength, and lint index can be made early, possibly in the F_2 on a single plant basis, and that selection for the other characters should be made on a progeny mean basis in successive segregating generations.

MATERIALS AND METHODS

The materials used for this study consisted of two parental materials (279-9 and Pima S-2), which were used to develop the F_1, F_2, B1, and B2 generations.

279-9 (P_1) is a breeder strain from the long staple, American Egyptian cotton (G. barbadense). It was developed at The University of Arizona Agriculture Experiment Station after eight generations of selection from a cross between 126-5-23 (sib. progeny of PS-1) and P-9 (the F_1 of a cross between Ashmouni, an Egyptian cotton variety and Tanguis (G. barbadense).

PS-2 (P_2) is a commercial variety from the long staple American Egyptian cotton (G. barbadense). It was developed by the ARS, USDA after ten generations of selection from a cross between breeder strains 3-79 and PS-1. Pima S-1 is not a pure G. barbadense. It was developed by hybridization of G. barbadense with G. hirsutum. Therefore, both 279-9 and Pima S-2 are not a pure G. barbadense, but show some introgression of genes from G. hirsutum.

The crosses were made during the summer of 1962 through the use of a modification of the soda straws technique described by Humphrey and Tuller (8). Self-pollination was made by tying the petals with wire which were fastened to the axis of the flower. The first generation seeds were produced by crossing the two parents using Pima S-2 as male parent and 279-9 as female parent. The second generation seeds (F_2) were produced by selfing the flowers on the F_1 plants. The F_1 seeds were produced by Dr. Muramoto in 1961. The two backcrosses were also produced in 1962 by crossing the F_1 plants to both parents. The backcross of F_1 to 279-9 will be symbolized by B1 and the backcross of F_1 to Pima S-2 by B2.

The characters studied in this investigation were as follows and were measured as indicated:

1.	Boll size	Expressed as the number of bolls required to make one pound of seed cotton.
2.	Lint percentage	The relation of lint weight to the total weight of seed cotton expressed in per cent.
3.	Lint index	The weight of lint from 100 seeds expressed in grams.
4.	Seeds per boll	The average number of seeds in a boll, (based on 50 boll sample).
5.	Seed index	The weight in grams of 100 seeds.
6.	Fiber length (UHM)	The average length of the longer half of the fiber population expressed in inches, as determined by the Fibrograph.
7.	Uniformity Ratio	$\frac{\text{Mean length X 100}}{\text{Upper half mean}}$

8. Fiber strength — Also referred to as the Pressley index or the number of pounds required to break a milligram of fiber of a given length as determined by the Pressley Fiber Strength Tests using 1/8 inch spacer.

9. Fiber fineness — Expressed as the weight in micorgrams per inch of fiber, as measured by the micronaire.

The investigation was conducted on the Casa Grande Farm in Tucson, Arizona. The P_1, P_2, F_1, F_2, B1, and B2 seeds were planted on May 20, 1963. The statistical design used was a randomized complete block with four replications. The plots were made up of one row, 48 feet long and 2-3 seeds were planted per hill which were two feet apart, (24 hills per row). After the stands were assured, the cotton plants were thinned to one plant per hill.

A sample of 50 bolls was taken from each plot during the third week of October, 1963. Two to three bolls were taken at random from each plant.

Analyses of the samples were made in the cotton laboratory under controlled conditions of $70 \pm 2^{\circ}F$ and 65 ± 2 per cent relative humidity. The samples were conditioned for at least 24 hours before testing. Laboratory analyses included measurement for lint per cent, seed index, seeds per boll, lint index, boll size, fiber strength, fiber length, and fiber fineness.

The following steps were followed for the laboratory analyses:

1. The lint and seed for each sample was weighed to determine lint percentage.

   $$\text{Lint \%} = \frac{\text{weight of lint}}{\text{Total weight of seed cotton (lint + seed)}}$$

2. One hundred seeds were counted from each sample and weighed to determine seed index, (gms./100 seed).

3. From seed index the number of seeds per boll and lint index were obtained by the following procedures:

   a. $$\text{No. of hundred seed} = \frac{\text{Seed weight}}{\text{Seed index}}$$

   b. $$\text{No. of seeds per boll} = \frac{\text{No. of hundred seed}}{\text{No. of bolls in the sample (50)}}$$

   c. $$\text{Lint index} = \frac{\text{Lint weight}}{\text{No. of hundred seed}}$$

4. Boll size was determined by this formula.

   $$\text{Boll size} = \frac{\text{No. of bolls (50) X 453.63}}{\text{Weight of seed cotton by grams}}$$

5. About twelve grams from each sample were blended by passing them through a cotton fiber blender.

6. A breaking sample from each blended sample was taken and combed for strength measurement through Pressley fiber strength tester which measures tensile strength of the fiber. A check measurement was made for each four samples. The strength is based on the average of two break measurements decided by combined weight of the bundles broken.

7. Fineness was measured by the use of Micronaire.

8. Fiber length (UHM and M) was measured by use of Servo Fibrograph The uniformity ratio was determined as

   $$\text{Uniformity Ratio} = \frac{\text{Mean X 100}}{\text{UHM}}$$

STATISTICAL PROCEDURE

The method of analysis of variance described by Steel and Torrie (23) was used to analyze the data. The least significant difference (LSD) was used statistically to:

1. Determine the significance of heterotic effect. (In this study the heterotic effect is considered to be one in which the F_1 significantly exceeds the higher parent at the 0.05 level, for a particular character).
2. Test whether a given F_1 was significantly different from the parental mean.
3. Test the difference between P_1 and P_2.

The coefficient of variation (C.V.) was calculated to assess the relative variations of each character.

The nature of gene action was determined by comparing the F_1 with the geometric mean and arithmetic mean of the two parents.

Geometric mean $= \sqrt{(\bar{X}_{P_1})\cdot(\bar{X}_{P_2})}$ where

$\bar{X}_{P_1}$ = the observed mean of one parent

$\bar{X}_{P_2}$ = the observed mean of the other parent

For estimating the heritability the total within variance for each P_1, P_2, F_1, F_2, B1, and B2 was calculated. The heritability for each character was estimated by use of three methods reviewed by Warner (26):

1. By use of the variance of F_2 population, the parents and F_1 generation, through this formula:

   $$H = \left[V_{F_2} - \frac{(V_{P_1} + V_{P_2} + V_{F_1})}{3} \right] \div V_{F_2} \text{ X } 100 \text{ where}$$

   H = Heritability

   V_{P_1} = Variance of P_1 population

   V_{P_2} = Variance of P_2 population

   V_{F_1} = Variance of F_1 population

   V_{F_2} = Variance of F_2 population

2. By the use of the variance of the F_2 population, the parents and the F_1 generation, through this formula:

   $$H = \left[V_{F_2} - \frac{V_{P_1} + V_{P_2} + 2V_{F_1}}{4} \right] \div V_{F_2} \text{ X } 100 \text{ where}$$

   H, V_{F_2}, V_{F_1}, V_{P_1}, and V_{P_2} have the same meaning as in the first method.

3. By the use of three segregating population the F_2 and the summed backcrosses to each parent through this formula:

   $$H = \frac{(1/2)\ D}{V_{F_2}} \text{ where}$$

   (1/2) D = the additive genetic components of variance of F_2.

$$= 2\,(V_{F_2}) - (V_{B1} + V_{B2})$$

V_{F_2} = Total within variance of F_2

V_{B1} and V_{B2} are total within variance of the backcrosses of F_1 to the respective parent.

The number of pairs of genes controlling the difference between parents for each character were estimated by Castle-Wright formula (28):

" $$N = \frac{D^2}{8\,(V_{F_2} - V_{F_1})}$$ where

N = the minimum number of pairs of genes.

D = the difference between the means of the parents.

V_{F_2} = the total variance of the F_2 generation.

V_{F_1} = the total variance of the F_1 generation.

An unbiased estimate of the number of pairs of genes will be obtained from this formula if the following assumptions are applied:

1. Equal effect of the genes involved.
2. Additive gene action.
3. Absence of dominance or epistasis.
4. Maximum range exists between parents.
5. One parent supplies only plus factors and the other only minus factors among those in which they differ."

RESULTS

The studies of heterosis and heritability for agronomic and fiber properties were conducted at The University of Arizona Casa Grande Road Farm during the 1963 season. The experiment was planted in a randomized complete block design with four replications. Pima S-2 and 279-9 were used as parents making this an intraspecific cross of G. barbadense. There was no noticeable heterotic effect on the plant size. The parents and the hybrids were relatively identical for the plant size.

A sample of fifty bolls was taken from each plot. Laboratory analyses were made for seed index, lint percentage, lint index, seeds per boll, boll size, fiber length (HM and UF), fiber fineness, and fiber strength.

Table 1 contains a summary of the means of F_1, P_1, P_2 and the arithmetic mean of the two parents for all characters studied for heterosis. The standard error, L.S.D. at 0.05 level and the coefficient of variation are given for each character. The results for each character will be discussed separately in more detail.

For heritability estimates, the total variance for each of P_1, P_2, F_1, B1, and B2 was estimated and three methods were used.

Table 1. Average Performance of Parental Mean, Parents, and F_1 for Agronomic and Fiber Properties.

Population	Lint Index	Lint %	Seed Index	Boll Size	Seeds Per Boll	Fiber Length (UHM)	Fiber Strength*	Fiber Fineness
P_1 (279-9)	6.28	33.62	12.40	127.50	19.08	1.37	4.27	3.07
Mean Parents**	6.61	35.02	12.20	121.75	19.84	1.36	4.21	3.09
F_1	6.65	34.67	12.52	117.50	20.23	1.38	4.38	3.14
P_2 (Pima S-2)	6.94	36.42	12.00	116.00	20.61	1.35	4.14	3.13
L.S.D. 0.05	0.20	0.90	0.38	4.17	1.63	0.03	0.10	0.15
$S_{\bar{x}}$	0.057	0.265	0.141	1.24	0.47	0.012	0.034	0.045
C.V.%	1.73	1.52	2.20	2.00	4.77	1.63	1.66	2.92

* Pressley Index

** Mean Parent $= \frac{P_1 + P_2}{2}$

HETEROSIS

Heterosis percentages were computed by subtracting the mean of each P_1, P_2, arithmetic mean and geometric mean from the F_1; and the difference was divided by each corresponding mean.

Seed Index

Seed index is an important character to plant breeders because it is a guard against selection of high lint percentages with small seed. The mean seed index is shown in Table 2.

The results shown in Table 2 indicate that there is a slight increase in seed index of the F_1 over the heavier seeded parent, and the F_1 was also heavier than the mean of the two parents by 2.62 per cent. The two parents are significantly different from each other with P_1 (279-9) having the heavier seed than P_2 (Pima S-2). Simpson (22) and Muramoto (18) working with Upland varieties, reported a small gain in seed index of the F_1 over the higher parent. Peebles et al (20) working with Pima cotton reported that the F_1 exhibited seed index equaling the higher parent.

Figure 1 indicates the relationship between the parents, average of the two parents, and F_1 for the seed index graphically.

Table 2. Mean Seed Index of Parents, Mean of Parents, F_1 and percentage of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	12.40	0.97	ab
Arithmetic Mean Parents	12.20	2.62	abc
Geometric Mean Parents	12.22	2.45	abc
F_1	12.52		ab
P_2 (Pima S-2)	12.00	4.33	c

*Means having the same letter are not significant.
L.S.D. at 0.05 = 0.38
$S_{\bar{x}}$ = 0.141
C.V.% = 2.20

Lint Percentage

Lint percentage is a desirable trait to cotton breeders as well as the growers. It is one of three characters of economic importance which is used to determine the practical importance of the varieties. It is a valuable character since it greatly affects the amount of income the farmer will receive (at the end of the season) for this crop.

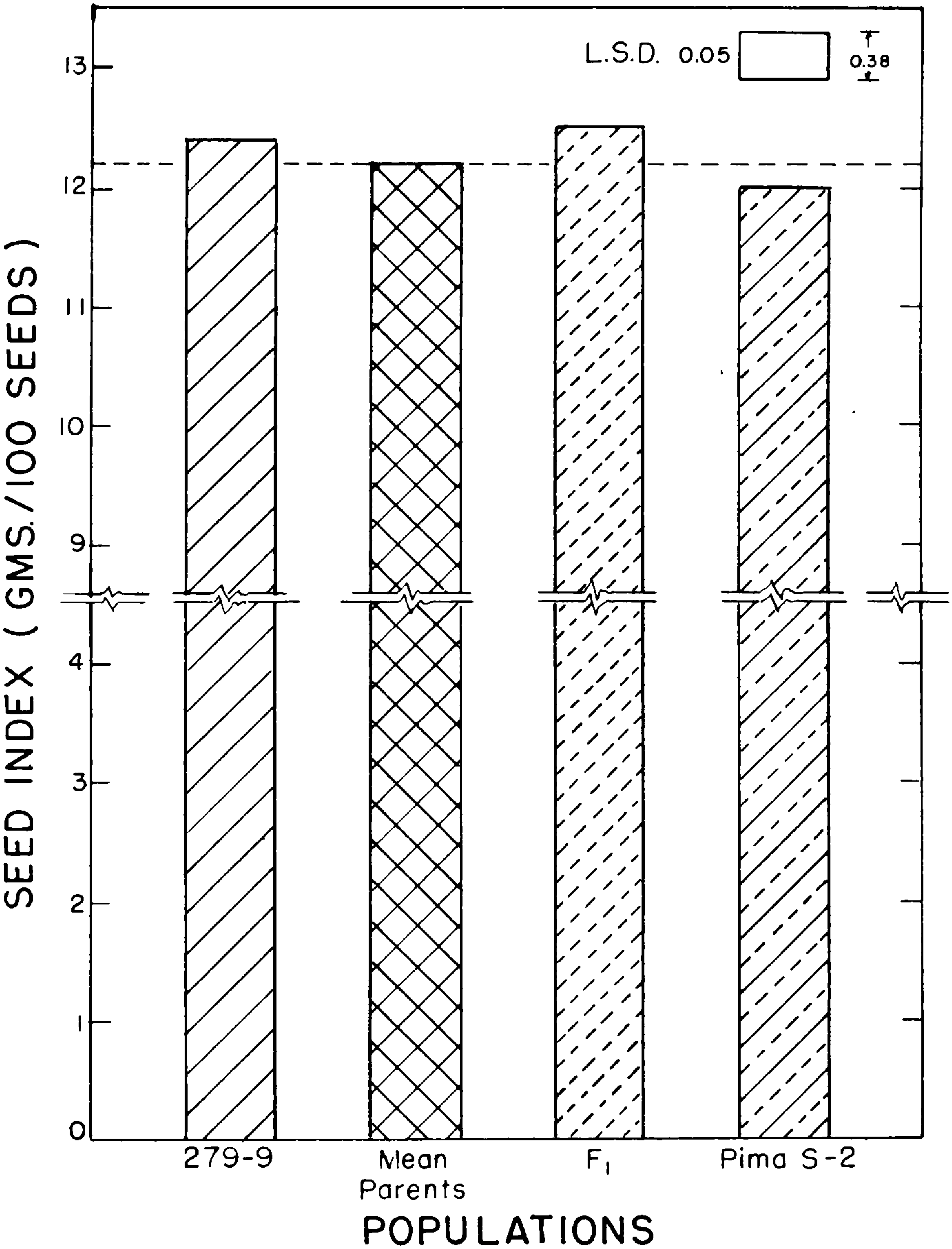

Fig. I.– Mean seed index of 279-9, Pima S-2, arithmetic mean of parents and F_1.

No heterosis was reported in lint percentage. The results of Kime and Tilley (12), Simpson (22), Muramoto (18), Harrel (7), and Peebles et al (20) indicate that the F_1 was intermediate and approximately the average of the parents.

Table 3 shows the mean lint percentage.

Table 3. Mean Lint Percentage of Parents, Mean of Parents, F_1, and Percentage of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	33.62	3.02	a
Arithmetic Mean Parents	35.02	-1.00	bc
Geometric Mean Parents	34.99	-1.00	bc
F_1	34.67		bc
P_2 (Pima S-2)	36.42	-5.04	d

*Means having the same letter are not significant.
L.S.D. at 0.05 = 0.90
$S_{\bar{x}}$ = 0.265
C.V.% = 1.52

The results indicate that the F_1 is intermediate in lint percentage between the higher parent P_2 (Pima S-2) and the lower parent P_1 (279-9). It approximates the mean of both parents. The F_1 is significantly different from both parents while it is not significantly different from the average of the parents.

The relationship between the parents and the F_1 are expressed graphically by Figure 2.

Boll Size

Boll size is expressed as the number of bolls required to make one pound of seed cotton - the smaller the number, the larger the boll. Table 4 shows the data for boll size.

Table 4. Mean Boll Size of Parents, Mean of Parents, F_1, and Percentage of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	127.50	8.51	a
Arithmetic Mean Parents	121.75	3.70	b
Geometric Mean Parents	121.61	3.60	b
F_1	117.50		cd
P_2 (Pima S-2)	116.00	-1.20	cd

*Means having the same letter are not significant.
L.S.D. at 0.05 = 4.17
$S_{\bar{x}}$ = 1.24
C.V.% = 2.00

The F_1 is not significantly different from either the larger parent or the average of the parents. It closely approached the larger boll parent P_2 (Pima S-2) rather than the average of both parents. This may suggest some

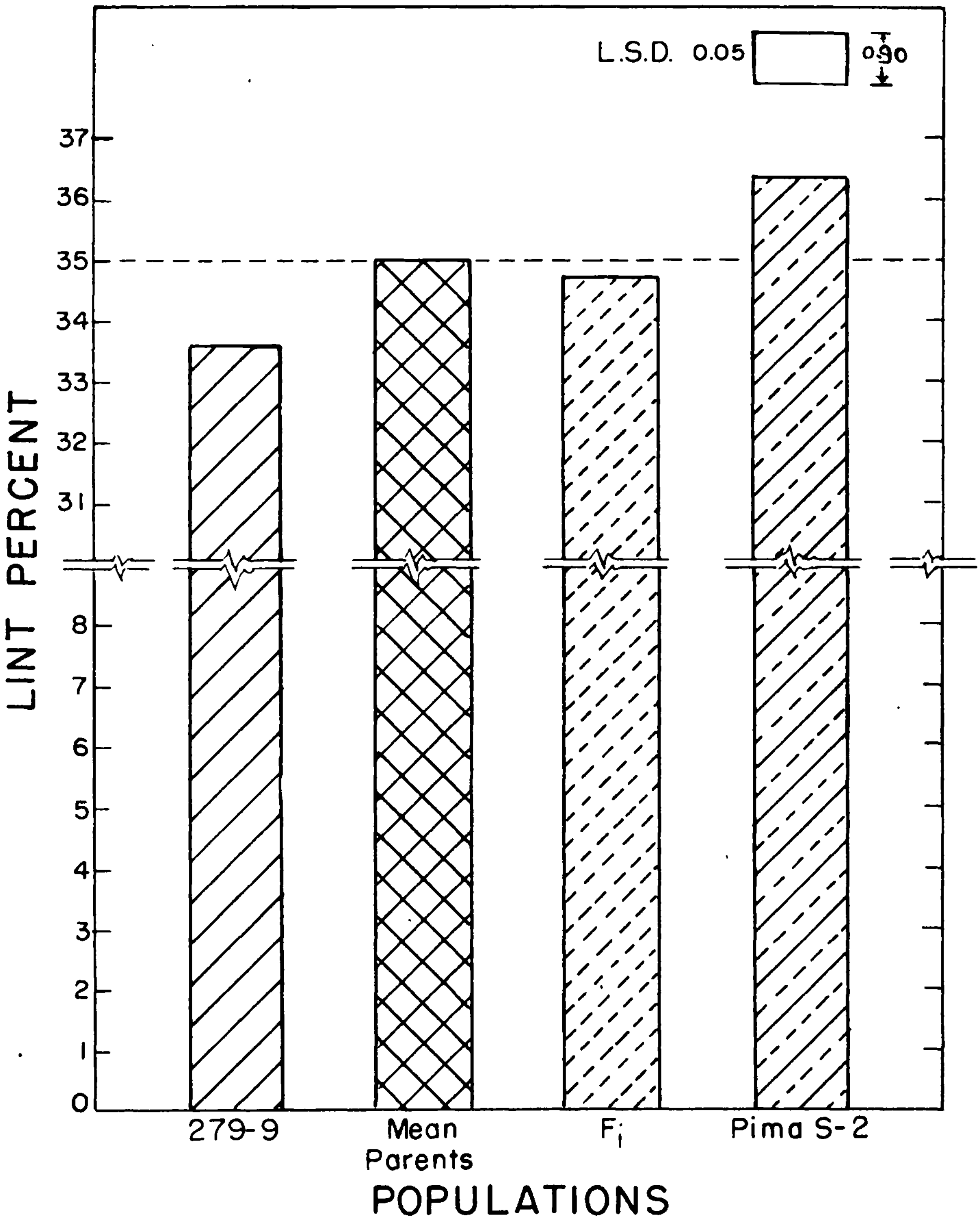

Fig. 2.– Mean lint percent of 279-9, Pima S-2, arithmetic mean of parents and F_1.

degree of dominance of the larger bolls over the smaller ones. This result agrees with the work of Turner (25) and Douglas and Weaver (4).

The relationship between the parents and the F_1 are expressed graphically by Figure 3.

Seeds Per Boll

The results are shown in Table 5 for the average seeds per boll.

Table 5. Mean Seeds Per Boll of Parents, Mean of Parents, F_1, and Percentage of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	19.08	6.0	abc
Arithmetic Mean Parents	19.84	2.1	abc
Geometric Mean Parents	19.83	2.1	abc
F_1	20.23		abc
P_2 (Pima S-2)	20.61	-4.87	abc

*Means having the same letter are not significant.
L.S.D. at 0.05 = 1.63
$S_{\bar{x}}$ = 0.47
C.V.% = 4.77

The results indicate that the F_1 was intermediate between the two parents. But F_1 closely approached the higher parent P_2 (Pima S-2) rather than the average of both parents. The F_1 was better than the average of both

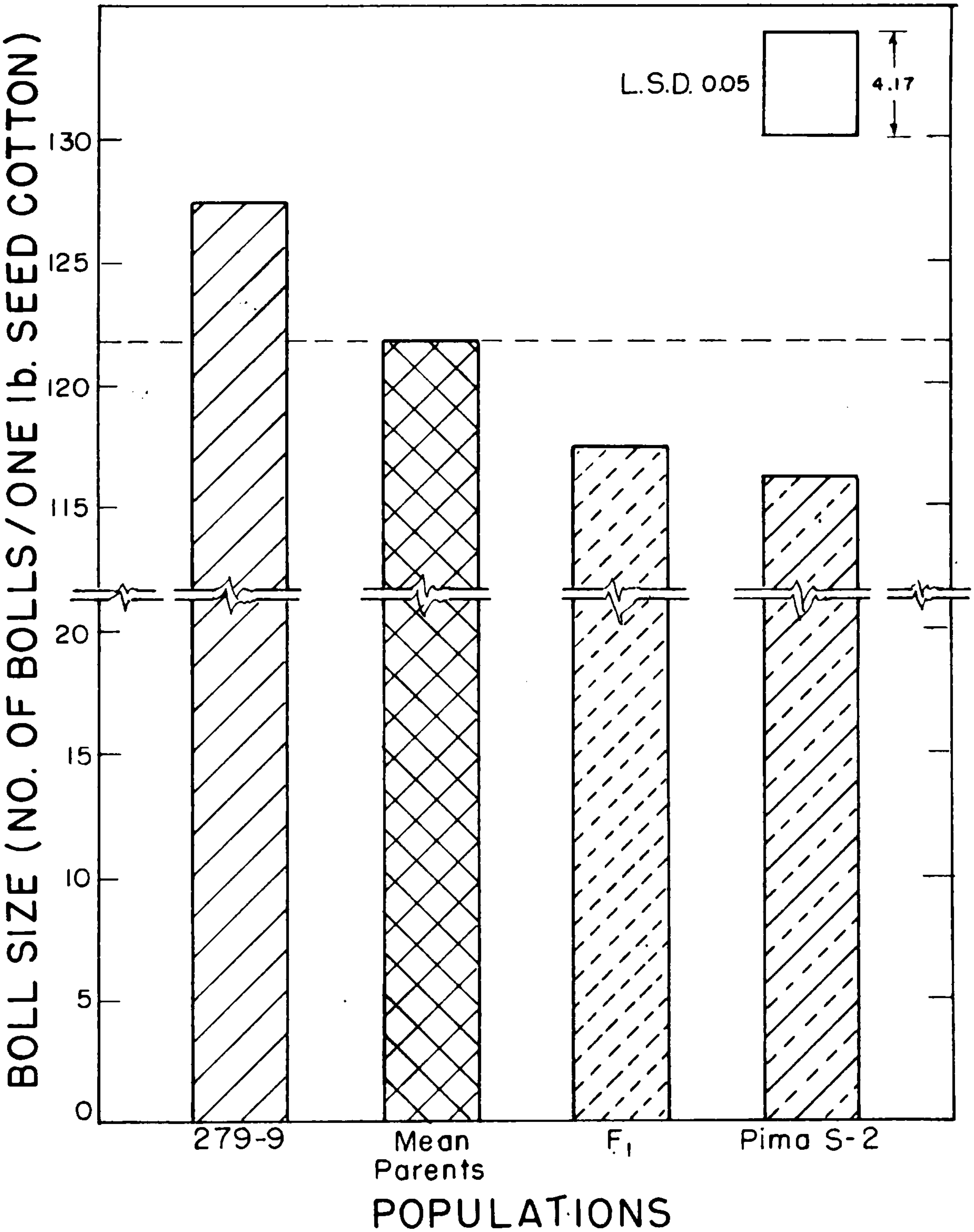

Fig. 3.- Mean boll size of 279-9, Pima S-2, arithmetic mean of parents and F_1.

parents by 2.1 per cent. This relationship also is represented graphically by Figure 4.

Lint Index

The lint index represents the weight of lint borne on one hundred seeds. Table 6 shows the mean lint index of Parents and F_1.

Table 6. Mean Lint Index of Parents, Mean of Parents, F_1, and Percentage of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	6.28	5.89	a
Arithmetic Mean Parents	6.61	0.60	b
Geometric Mean Parents	6.60	0.76	b
F_1	6.65		b
P_2 (Pima S-2)	6.94	-4.40	c

*Means having the same letter are not significant.
L.S.D. at 0.05 = 0.20
$S_{\bar{x}}$ = 0.057
C.V.% = 1.73

The mean lint index of F_1 is intermediate between

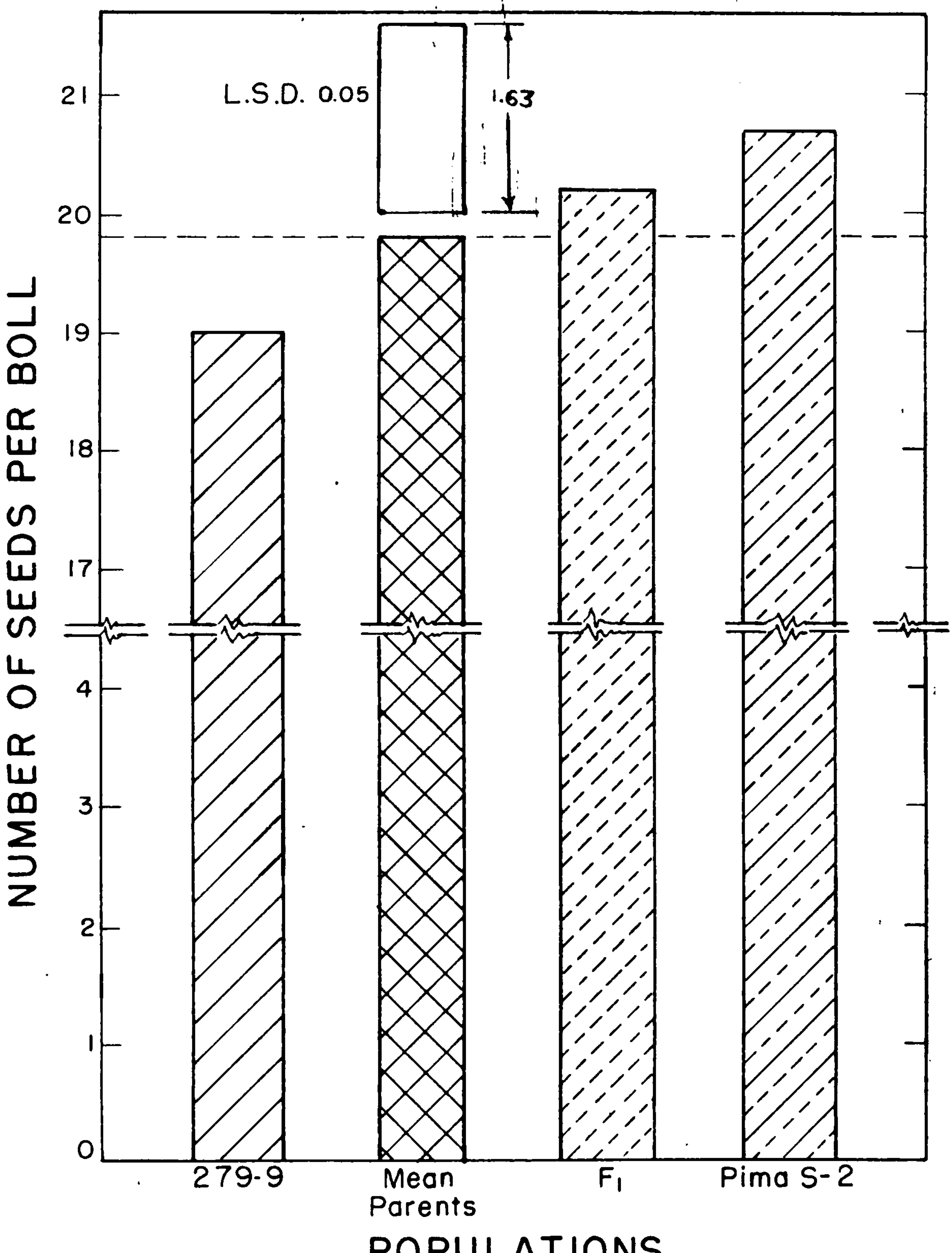

Fig. 4.-Mean seeds per boll of 279-9, Pima S-2, arithmetic mean of parents and F_1.

the two parents. It is slightly over the average of both parents. Peebles et al (20) reported the same result. Figure 5 indicates this relationship graphically.

Fiber Length (UHM and Uniformity Ratio)

Fiber length is one of the important characters by which the value of the lint can be determined. Cotton is bought and sold on grade and staple length, which closely approximate the UHM. A strain can show a large variation in length of the staple.

The data for Fiber length (UHM) is presented in Table 7.

Table 7. Average Fiber Length (UHM) of Parents, Mean of Parents, F_1, and Percentage of Heterosis.

Population	Mean Inch	Heterosis %	Statistical Significance*
P_1 (279-9)	1.37	0.73	abc
Arithmetic Mean Parents	1.36	1.47	abc
Geometric Mean Parents	1.36	1.47	abc
F_1	1.38		abc
P_2 (Pima S-2)	1.35	2.22	abc

*Means having the same letter are not significant.
L.S.D. at 0.05 = 0.03
$S_{\bar{x}}$ = 0.012
C.V.% = 1.63

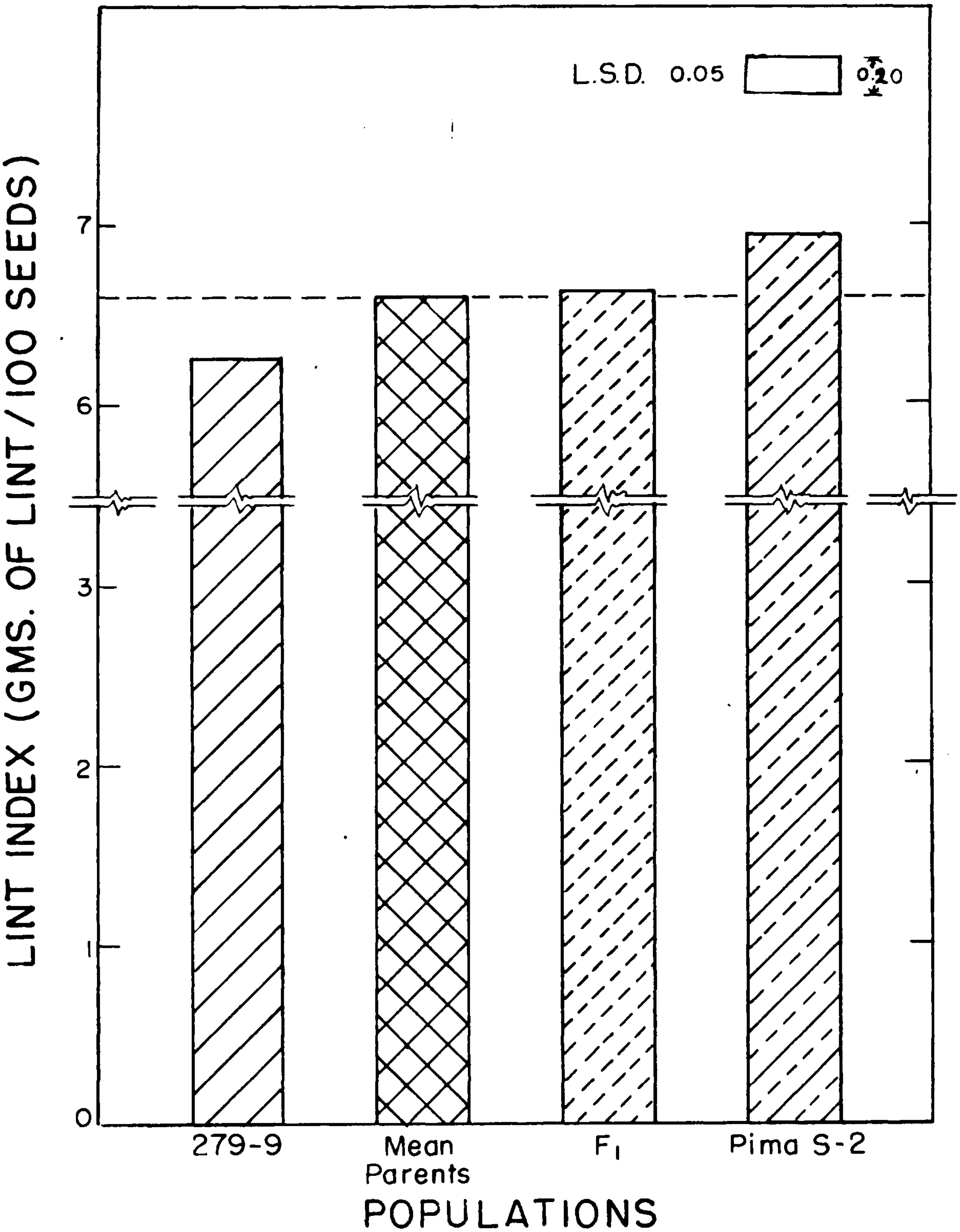

Fig. 5.- Mean lint index of 279-9, Pima S-2, arithmetic mean of parents and F_1.

The mean of the F_1 generation is slightly over the longer parent P_1 (279-9). It is longer than the average of both parents by about 1.47 per cent. But in both cases this increase is not significant. Also no real difference between the parents for this character has been detected, in this experiment. This result also is indicated by Figure 6.

Table 8 shows the results for the uniformity ratio.

Table 8. Length Uniformity of Parents, Mean of Parents, F_1, and Percentage of Heterosis.

Population	Mean %	Heterosis %	Statistical Significance*
P_1 (279-9)	72.9	3.50	abc
Arithmetic Mean Parents	74.3	-1.62	abc
Geometric Mean Parents	74.3	-1.62	abc
F_1	73.5		abc
P_2 (Pima S-2)	75.7	-3.00	abc

*Means have the same letter are not significant.
L.S.D. at 0.05 = 3.69
$S_{\bar{x}}$ = 1.33
C.V.% = 3.57

The results for uniformity ratio was intermediate but it approached the less uniform parent rather than the uniform parent. However, no real difference exists between

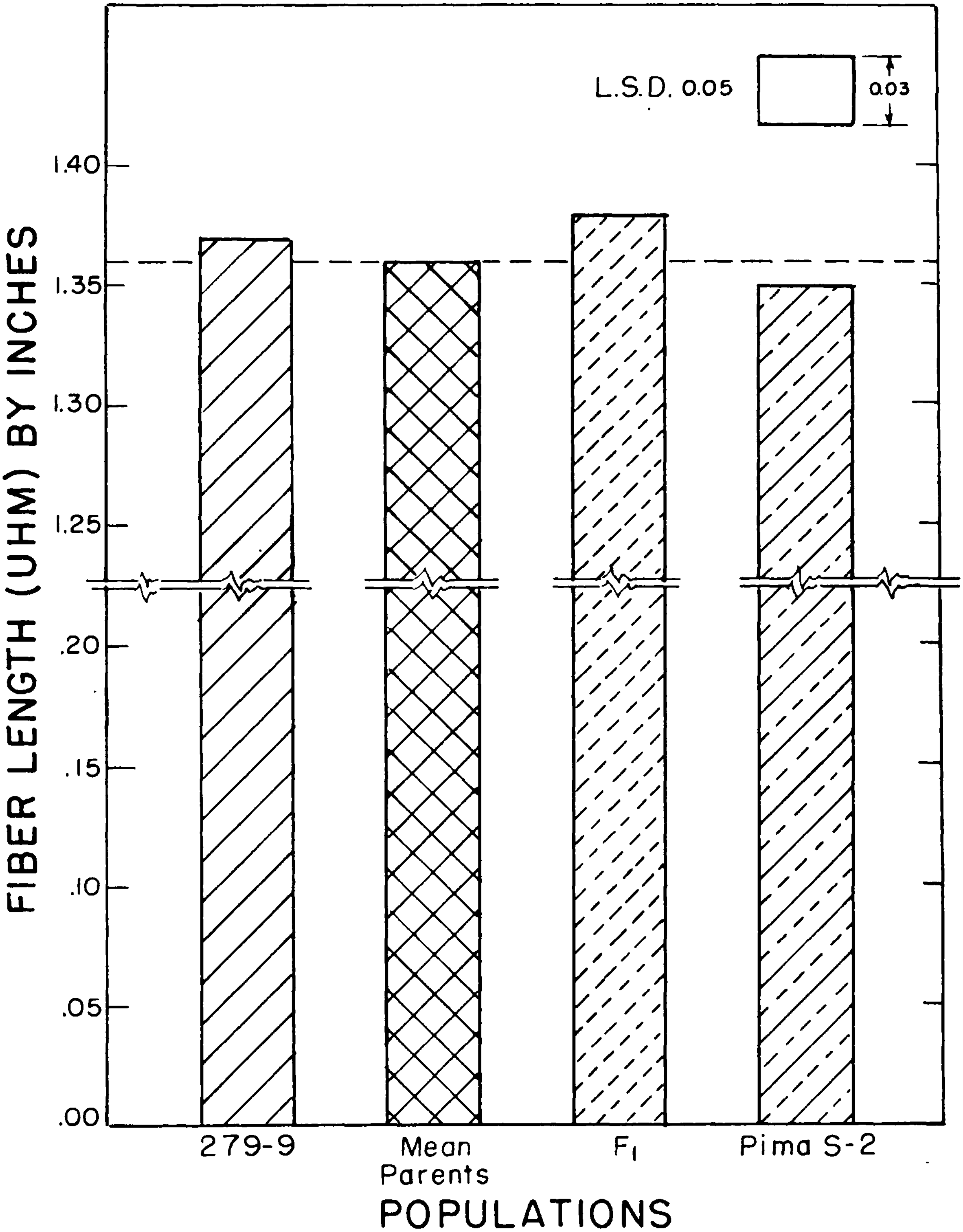

Fig. 6.- Mean fiber length (UHM) of 279-9, Pima S-2, arithmetic mean of parents and F_1.

the parents and F_1.

Fiber Strength

Fiber strength is desirable because of its high correlation with yarn strength.

The results from the two parents and F_1 are shown in Table 9.

Table 9. Average Fiber Strength of Parents, Mean of Parents, F_1, and Degree of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	4.27	2.57	a
Arithmetic Mean Parents	4.21	4.04	ab
Geometric Mean Parents	4.21	4.04	ab
F_1	4.38		c
P_2 (Pima S-2)	4.14	5.79	b

*Means having the same letter are not significant.
L.S.D. at 0.05 = 0.10
$S_{\bar{x}}$ = 0.034
C.V.% = 1.66

The results shown in the table show a heterotic effect on fiber strength. The F_1 is over the stronger parent 279-9 by about 2.57 per cent. Also the F_1 is stronger than the average of both parents by about 4.04

per cent. Both of the gains are significant.

Figure 7 represents this relation graphically.

Fiber Fineness

Fiber fineness is an important quality of cotton associated with long fibers and smaller cell diameter in combination with wall thickness. Therefore, it varies greatly according to fiber maturity.

The results are presented in Table 10.

Table 10. Average Fiber Fineness of Parents, Mean of Parents, and F_1 with the Percentage of Heterosis.

Population	Mean	Heterosis %	Statistical Significance*
P_1 (279-9)	3.07	-3.20	abc
Arithmetic Mean Parents	3.10	-1.27	abc
Geometric Mean Parents	3.10	-1.27	abc
F_1	3.14		abc
P_2 (Pima S-2)	3.13	-0.31	abc

*Means having the same letter are not significant.
L.S.D. at 0.05 = 0.15
$S_{\bar{x}}$ = 0.045
C.V.% = 2.92

From the results in the table it can be shown that the F_1 is about equal to the coarse parent, Pima S-2.

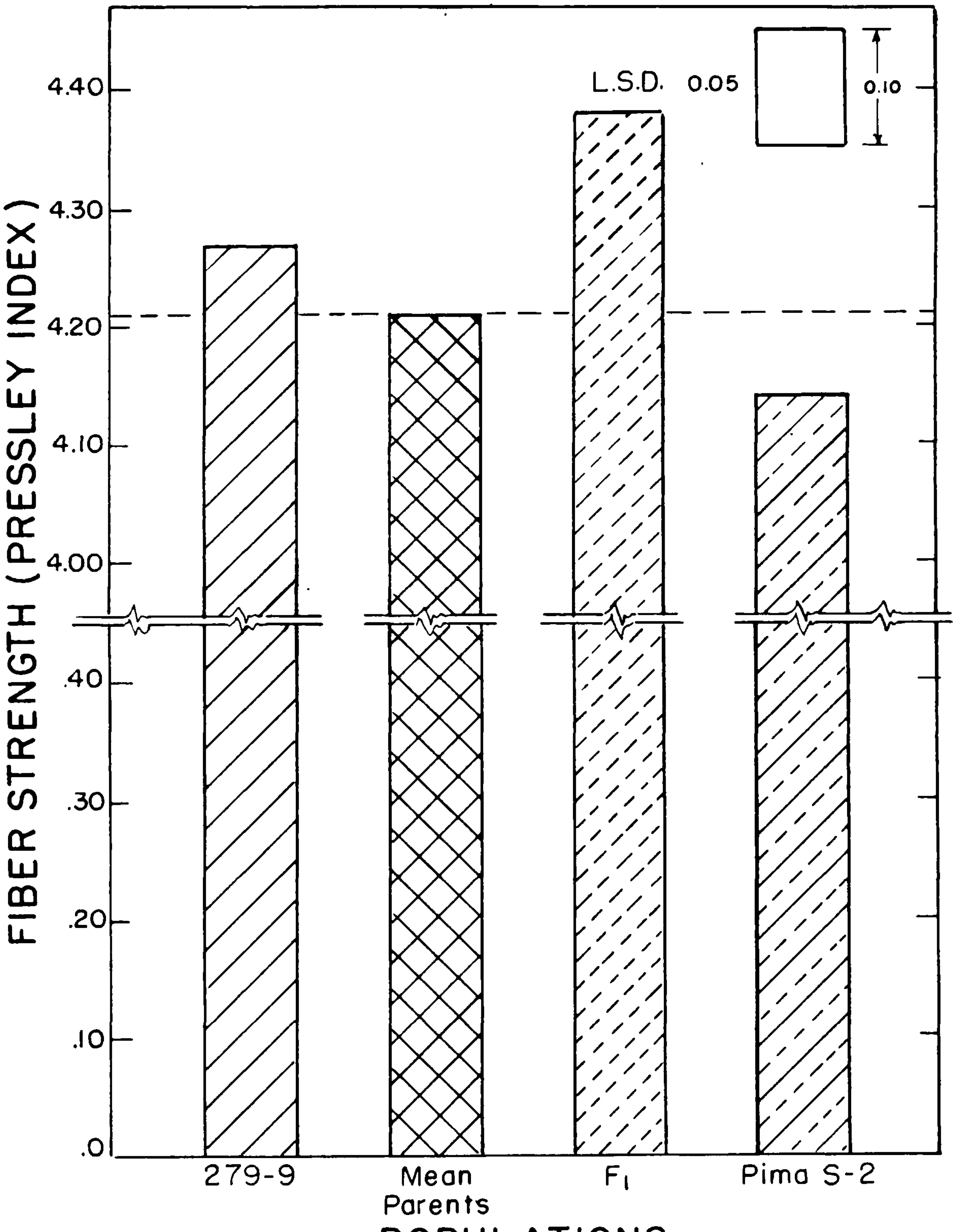

Fig. 7.- Mean fiber strength (Pressley index) of 279-9, Pima S-2, arithmetic mean of parents and F_1.

There were no real differences in this experiment between the two parents and F_1.

Figure 8 represents this result graphically.

Heritability

Character is defined as an attribute of an organism resulting from the interaction of a gene or genes with environments. The variabilities in some characters are caused primarily by differences in the genes carried by different individuals, where in other characters this variability is due primarily to differences in environments to which individuals have been exposed. The heritability estimates determines the relative importance of heredity and environment in determining the expression of characters.

Plant selection is the primary force whereby individuals with certain characteristics are favored in reproduction. Selection can act effectively only on heritable difference. The type of selection program to be followed and the progress in the breeding program depends on the heritability of the characters.

Heritability values may be estimated in various ways, but the general concept is that it is a ratio of the genetic variance to the total variance. This can be expressed by:

$$H = \frac{S^2_G}{S^2_G + S^2_E}$$

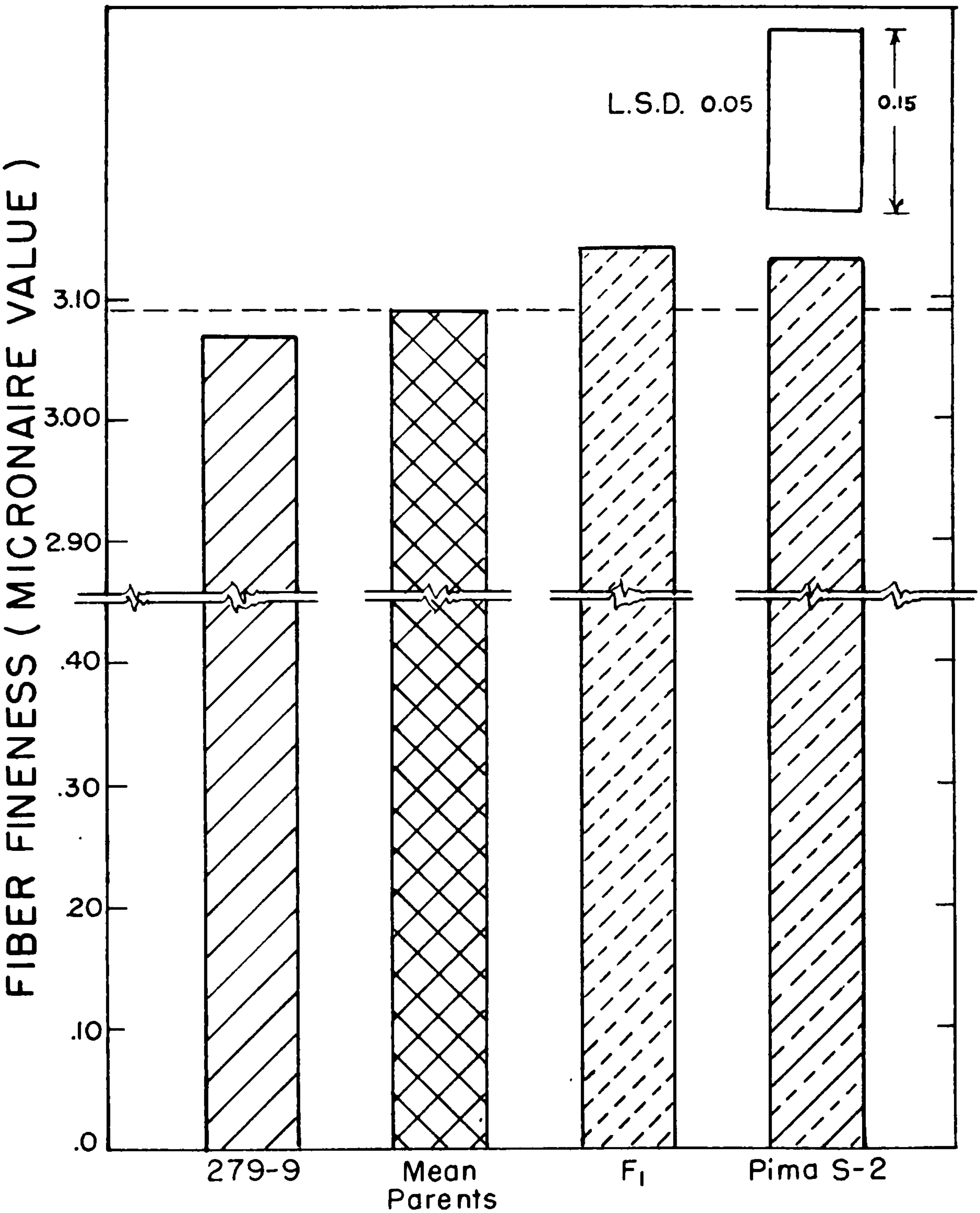

Fig. 8.- Mean fiber fineness (Micronaire value) of 279-9, Pima S-2, arithmetic mean of parents and F_1.

Where S^2_G is the genetic variance and S^2_E is the environmental variance. The genetic and environmental variances can be obtained by using several techniques, three of which were used in this study. These three methods and the formula involved in each of them were described previously in materials and methods. In two of these three methods, the variance of the parents and their F_1 afford an estimate of the non-heritable variance. The variance of the F_2 will include heritable and non-heritable variance. In the third method the estimate is made entirely on the basis of the F_2 and the backcross of the F_1 to each inbred parent. This, theoretically, should eliminate the discrepancies of estimating the variance component due to environment.

The heritability estimates derived by the three methods for all the characters studied are presented in Table 11.

For some of the characters measured the non-heritable variance exceeds the total variance of the F_2, so the value of heritability was zero. This was the case in seed per boll, lint per cent, and fiber length (UHM). Except for lint percentage the three methods gave the same value, zero. For lint percentage an estimate of 18.91 per cent was obtained by the third method. For the rest of the characters studied, the heritability was high for seed index, lint index, and boll size and very high for fiber strength and fiber fineness.

The three methods used in the estimation of

Table 11. Heritability Values of Agronomic and Fiber Properties Estimated by Three Methods.

Method	Seed Index	Lint Index	Boll Size	Lint %	Seeds Per Boll	Length (UHM)	Strength	Fineness
First*	64.70	60.00	42.86	0	0	0	75.86	81.39
Second**	66.17	56.00	41.87	0	0	0	77.00	76.95
Third***	76.47	70.00	43.25	18.91	0	0	82.40	84.79

* $$H = \left[V_{F_2} - \frac{(V_{P_1} + V_{P_2} + V_{F_1})}{3}\right] \div V_{F_2} \text{ X } 100$$

** $$H = \left[V_{F_2} - \frac{(V_{P_1} + V_{P_2} + 2V_{F_1})}{4}\right] \div V_{F_2} \text{ X } 100$$

*** $$H = \left[2V_{F_2} - (V_{B_1} + V_{B_2})\right] \div V_{F_2} \text{ X } 100$$

All negative values were considered zero as a figure representing no heritability.

heritability values gave different results. For seed index and fiber strength the first method gave the lowest value and the third method gave the highest value. Heritability values for seed index were 64.70 per cent by the first method, 66.17 per cent by the second method and 76.47 obtained by the third method. For fiber strength these values were 75.86 per cent by the first method, 77.00 per cent by the second method and 82.40 per cent by the last method. The values of heritability of lint index, boll size, and fineness were in different manners. The second method gave the smallest values and the third gave the highest. These heritability values of lint index estimated by the first, second, and third method were 60.00, 56.00, and 70.00 per cent respectively. In boll size the values were 42.86 per cent by the first method, 41.87 per cent by the second method, and 43.25 per cent by the third method. Finally, the heritability values of fineness were 81.39, by the first method, 76.95 per cent by the second method, and 84.79 per cent by the third method. In all cases, method three gave the highest estimates of heritability.

It is important to have a knowledge about the gene number and the nature of gene action for each of the characters studied besides the estimates of heritability. From the data obtained primarily for heterosis and heritability studies, an attempt was made to have a rough estimate of gene numbers controlling the differences between the two parents and to test the nature of gene action in this cross between American Egyptian cotton, (G. barbadense).

Castle-Wright formula was used to estimate the minimum number of genes controlling the difference between the parents for each character. The results indicated that Castle-Wright formula failed to estimate the number of genes. In all characters, except for lint index, the estimate was less than one. Gene numbers for lint index were three genes.

A test of the nature of gene action was made by comparing the observed mean of the F_1 generation with the calculated means on the basis of arithmetic and geometric gene action. Arithmetic gene action assumes that the effects of individual genes upon the genotype are additive, whereas the geometric gene action considers that they are multiplicative.

Although there was no great difference between the geometric and arithmetic means, the geometric assumption was in closer agreement with the observed F_1 mean in seed index, lint percentage, and boll size. In seeds per boll and lint index characters the arithmetic assumption was in closer agreement than the geometric mean. Still in fiber characters, length (UHM and UR), fineness and strength the geometric and arithmetic means were equal.

DISCUSSION

Heterosis

The first step in the utilization of heterosis is the selection of suitable parents which when crossed give an amount of heterosis that will make hybrid seed production economically feasible. There are no formulas from which one can predict the performance of F_1 hybrids and the selection of suitable parents, for the exact mechanism of heterosis still remains unsolved. The only reliable method is to measure the performance of the F_1 hybrid.

The two parents (Pima S-2 and 279-9) which were selected for this study represent as widely diverse but related types of the Pima cotton as are available. They were developed from different crosses followed by ten to twelve generations of selecting individual selfed plants, and therefore, may be considered relatively homozygous. The geneology of both parents suggests some possibility of introgression of G. hirsutum.

In evaluating the expression of heterosis, cotton breeders have used various methods. Some have used the mean of the two parents as a base with which to compare the F_1 hybrid, whereas, others have used the performance of the better parent. Still others have compared the F_1

hybrid with one or more of the best commercial varieties grown in the area. In this investigation, heterotic effects were considered to be one in which the performance of the F_1 hybrid exceeded the better parent at the 0.05 level of significance in the positive direction.

Yield is one of the most important characters for selection. It is frequently subdivided into some of the better known components such as seed index, lint percentage, lint index, boll size, and number of seeds per boll. Yield itself is difficult to understand, so cotton breeders try to evaluate each component separately, to get a better understanding of the parts which contribute to ultimate yield.

Seed index which was measured as the weight of 100 seed in grams showed no heterotic effects. Kime and Tilley (12), Simpson (22), Muramoto (18), Douglas and Weaver (4), Peebles et al (20) reported the same results. This may indicate that the genetic diversity between the parents used in this study was not enough to allow heterosis in seed index to be expressed. Selection for seed size probably accumulated the desirable combination of genes.

Cotton breeders are cognizant of the importance of seed index because large seed is attractive to the growers and because of the negative correlation that apparently exists with lint percentage. It is difficult to achieve high lint percentage and still maintain large seed in the same variety, therefore, cotton breeders must compromise between the high lint percentage and a desirable size seed which will give good germination and seedling vigor.

Since the lint is the most valuable part of a cotton plant, lint percentage is considered by cotton breeders as an important character to consider in selection. The result of this investigation showed no heterotic effects for this character. The F_1 hybrid approximated the mean of the parents in spite of the diversity of the two parents. This result agrees closely with what was reported by many workers such as Kime and Tilley (12), Simpson (22), Muramoto (18), Harrel (7), and Peebles et al (20). An explanation for this situation is that, since the F_1 has a high value for seed index, it must be expected that the F_1 will be low in lint per cent. This again expresses the negative correlation that is thought to exist between the two characters.

The ratio between the lint and seed may be expressed as lint index. It represents the weight of lint from 100 seeds. No heterosis was shown for this character and the F_1 hybrid was intermediate between the two parents. Peebles et al (20) reported that when Pima S-1 and Pima 32 were crossed the F_1 was also intermediate in lint index. This would suggest that since the F_1 hybrid seems to be intermediate in crosses involving parents of diverse lint index, cotton breeders should try to fix this character in future parents which may be considered for F_1 hybrid production.

Boll size was expressed in this study as the number of bolls required to make one pound of seed cotton. It is a factor that is strongly considered by farmers in countries where cotton is still harvested by hand. In this study no heterotic effect on boll size was observed as the boll size of the F_1 hybrid only approached that of the larger boll parent. This may suggest that dominance rather than heterosis is responsible for this result, or perhaps the accumulation of favorable combinations of genes through selection.

Number of seeds per boll is fairly consistent within a given variety. The amount of seed produced per acre is an important factor in the commercial production of the hybrid seed. An increase in the number of seeds per boll may help boose the seed yield for the commercial producers. Since the valuable lint fibers are produced on the surface of the seed, logically an increase in this surface will be followed by an increase in the total amount of lint. A greater number of seeds per boll could mean greater seed surface per boll, therefore, a greater amount of lint could be produced. The analysis for seeds per boll showed that the F_1 hybrid was about equal to the better parent. This again suggests that dominance rather than heterosis is responsible for this result.

The value of the cotton crop comes from the ultimate uses of the cotton fiber. Not only high yield of cotton is desirable in a breeding program, but also high quality of fiber. The spinning performance of cotton depends upon specific properties of the fiber, and the most important of these are those properties associated with the length, strength, and fineness. The inter-correlation of these three characters is determined by the way these characters are measured.

Fiber length (UHM) is important to producers because the length of the fiber presently determines the price of the long staple cotton and its ultimate end use. There is a premium paid for each 1/16 inch increase in length. The data obtained from this study indicated that there were no heterotic response for fiber length. Since the fiber length of the F_1 was longer than the longer parent, this may suggest that dominance rather than heterosis could be responsible for fiber length, or perhaps the artificial selection over the years may have accumulated the favorable combinations of genes.

The cotton spinning mills are particularly concerned with the strength of the finished yarn because yarn breakage or "ends down" in the spinning and weaving operation is an added cost to production. Cotton breeders know that fiber strength is positively correlated with yarn strength, and selection for fiber strength should result in stronger yarns. The analysis of data obtained by the Pressley Fiber Tester using a 1/8 inch spacer showed a definite heterotic effect for fiber strength (Pressley Index). The F_1 was 2.69 per cent stronger than the stronger parent, 279-9. Harrel (7) and Douglas and Weaver (4) also reported heterotic effects for fiber strength. This type of manifestation of heterotic response in fiber strength is very desirable and should be considered together with yield when hybrid cotton potentials are assessed.

Fiber fineness is determined partly by hair cell diameter and partly by wall thickness which is a function of fiber maturity. Micronaire value for the F_1 was about equal to the coarser parent. In other words, the F_1 was as coarse as the coarser parent. Most of the results reported on this character by other workers showed no definite pattern. The results from this study and those obtained by other workers suggest micronaire values cannot be predicted on the basis of the parental mean value, because fiber maturity may be involved.

For each character studied there appeared no definite pattern of relationship between the performance of the parents and the mean performance of the F_1 hybrid. The obvious phenotypic differences between the parents selected for this study was not the type of genetic diversity necessary for the expression of heterosis, thus prediction of F_1 hybrid performance must be determined by actual performance.

Heritability

Mather (15) studied the variation of many types of populations, such as true breeding strains, F_1 generation of a cross between two strains, F_2 generation, and the backcross generations. Not only did he partition the variation as being due to heritable and non-heritable portions, but he also further subdivided it into that portion attributable to additive genetic effects and that due to deviation from the additive scheme. Most of the methods used for estimation of heritability are based on the techniques described by Mather.

There are several methods to measure heritability in plants. Statistical work has shown that any of the methods give estimates that vary primarily in degree only, therefore, a breeder can choose the method that is most adaptable to his situation. In this study, the three methods reviewed by Warner (26) were used for comparative purposes. In two of the three methods used for heritability estimates in this study, the average of the variances of the two parents and F_1 generation were used as estimates of non-heritable variance. In the third method which was described by Warner (26), the estimate of heritability is based entirely on the performance of the F_2 and the backcross of the F_1 to each parent. The estimating of non-heritable variance is unnecessary.

Negative heritability values (zero) were obtained from the three methods for number of seeds per boll and fiber length (UHM). In lint percentage a negative heritability value (zero) was obtained from the two methods that utilize the variance of the F_1 and both parents as an estimate for non-heritable variance. The third method gave 18.91 per cent. Since the heritability values of these characters were very low, theoretically it would be difficult to make progress from plant selection based on the phenotype of the plant. However, in a crop such as cotton, where artificial selection has been going on for a long time, the low heritability value obtained in this study would be of no consequence. Since the selection pressure has been in one direction, the best gene combinations available in the gene pools of both parents have already been accumulated in the parents used in this study. If this is true, these traits can be ignored in further selection out of this cross.

For the character boll size, seed index, lint index, fiber strength, and fiber fineness there were no great differences between the values obtained by the first and second methods. The Warner's method always gave higher estimates than the others. Perhaps the direct estimate of variance due to environment in the non-segregating generations must obviously included some segregating genes. For although the parents have been selfed for about 10 to 12 generations, complete homozygosity is seldom attained in cotton, except by doubling a haploid plant. In the Warner's method, the partitioning of the components of variance make it possible to subtract out all but the additive component. This can explain why the Warner's method always gave a higher estimate of heritability.

Highest values were obtained for fiber strength and fiber fineness. The first, second, and Warner method gave 75, 77, and 82 per cent respectively for fiber strength. For fiber fineness, the values were 81, 76, and 84 per cent from the first, second, and Warner's method respectively. High heritability values for fiber strength were also reported in a number of studies on Upland cotton by El Sharkawy (5) and Self and Henderson (21) using the second method.

Seed index had high heritability values of 64, 66, and 76 per cent and lint index had 60, 56, and 70 per cent from the first, second, and third method respectively.

The high values that were obtained for fiber fineness, fiber strength, seed index, and lint index show that great improvement can be achieved from the phenotypic selection of these characters because there is enough genetic diversity present that can be transmitted from parents to offsprings through selection. However, if fineness, strength, seed index, and lint index are not all positively correlated, improvement of one factor may lead to reduction in another.

The heritability values for boll size were 42, 41, and 43 per cent based on the first, second, and third method respectively. These values agree closely with the value obtained by Stith (24) of 50.1 per cent. It is, therefore, expected that most of the variation for boll size in the F_2 population is due to environment, or perhaps the desired combination of genes for boll size has already been accumulated in the parents used in this study through selection.

Plant breeders working with economic characters that are quantitatively inherited need information about gene numbers, nature of gene action, and the heritability of each of these characters. Such information is needed in designing the most effective breeding program to pursue. Knowledge of gene action and gene number is an important factor in evaluating the various possible breeding procedures, while heritability values indicate the possibility and extent to which improvement is possible through selection.

The primary objectives of this study were to study the effect of heterosis on agronomic and fiber properties and heritability values of these characters in a cross of two types of G. barbadense. The study of gene numbers and nature of gene action was undertaken in an attempt to obtain additional information about the characters beside the estimates of heritability.

An estimate of the minimum number of pairs of genes controlling a character can be obtained from

Castle-Wright formula if certain assumptions are true, namely, that maximum differences for the character exist between parents, all genes controlling the character will have equal effect, additive gene action, no dominance or epistasis, and one parent supplies only plus factors and the other minus factors.

The Castle-Wright formula failed to give any reliable estimate of gene numbers except for lint index where three pairs of genes were found to be involved. The failure of this formula may be due to the reason that it is highly improbable that all of the assumptions are true in the materials used for this study. Although the two parents were developed from different crosses, the direction of the selection was the same. Hence, the two parents most likely carry essentially the same combinations of genes for most of the characters under study.

The test for nature of gene action revealed that the differences between the geometric and arithmetic means for all characters were very small. It is possible for such characters, namely, seed index, lint percentage, lint index, seeds per boll, fiber length, fiber strength, and fiber fineness that both types of gene action, the geometric (multiplicative) and arithmetic (additive), might have been operating. For boll size the geometric assumption was in closer agreement with the observed mean of the F_1. This suggests that the gene action was predominantly geometric for this character.

SUMMARY

An experiment was conducted at The University of Arizona Agriculture Experiment Station, Tucson, Arizona in 1962-63 to study heterosis and to estimate heritability values obtained from an intraspecific cross of *G. barbadense*. The two parents used were Pima S-2, a commercial variety, and 279-9, a breeder strain. They represented diverse but related types of Pima cotton.

The crosses were made during the summer of 1962. The two parents, F_1, F_2, and the backcross of the F_1 to each parent were planted in a randomized complete block design with four replications in 1963. Agronomic characters measured were seed index, lint percentage, lint index, seeds per boll, boll size, fiber length, (UHM), fiber strength (Pressley Index), and fiber fineness (Micronaire value). All analyses were made in the cotton laboratory of The University of Arizona.

The method of analysis of variance and the least significant difference (LSD) were used for testing the expression of heterosis. A heterotic effect was considered to be one in which the F_1 significantly exceeded the better parent at the 0.05 level. For estimation of heritability, three methods were used. The first two

methods were based on the total variance of each, the P_1, P_2, F_1, and F_2. The third method was based on the total variance of F_2 and the backcross to each parent.

A summary of the results of this investigation is presented in the following:

1. Seed Index: No evidence of heterosis. The F_1 had seed index equal to the higher parent.
2. Lint percentage: No heterotic effect was found. The F_1 approximated the arithmetic mean of the two parents.
3. Lint Index: No heterosis was observed. The F_1 was intermediate.
4. Seeds per boll: Number of seeds per boll of the F_1 was about equal to the higher parent.
5. Boll size: The F_1 approximated the larger boll parent. No effect of heterosis.
6. Fiber Length (UHM): No heterosis was detected in UHM. The F_1 was slightly longer than the longer parent.
7. Fiber fineness: The micronaire value of the F_1 approximated that of the coarse parent.

8. Fiber strength: An evidence of heterotic effect in this character was observed. The F_1 exceeded the stronger parent by 2.69 per cent.

9. Negative heritability values (zero) were obtained for number of seeds per boll, lint percentage, and fiber length (UHM).

10. Boll size gave a low heritability value.

11. A very high heritability value was obtained for each of seed index, lint index, fiber strength, and fiber fineness.

12. Warner's method for estimation of heritability always gave a higher estimate than method one and two which use the non-segregating populations to estimate the non-heritable variance. There was no great difference between the values obtained from methods one and two.

13. The minimum number of pairs of genes involved in the inheritance of these characters was calculated using Castle-Wright's formula, $N = \dfrac{D^2}{8(V_{F_2} - V_{F_1})}$.

Except for lint index the formula failed to get any estimates. The number of genes for lint index was three pairs. The failure of this formula may be due to accumulation of favorable genes in the parental materials through selection.

14. A test for the nature of gene action in these studies indicated that it was predominantly geometric (multiplicative) for boll size. The failure of the test to distinguish between the types of gene action in case of the other characteristics suggested that both types might have been operating.

GLOSSARY OF TERMS[1]

Heterosis	1. The increased vigor often exhibited by hybrid individuals. 2. The state of being formed from the union of gametes of dissimilar genetic constitution; heterozygosis.
Hybrid Vigor	The increased vigor often exhibited by hybrid individuals; heterosis.
Species	Groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups (Mayr 1942).
Variety	A group of strains or a single strain which, by its structural or functional characters, can be differentiated from another group.
Strain	A group within a variety which constantly differs in one or more genetic factors from the variety proper.
Interspecific Cross	Crossing between species.
Intraspecific Cross	Crossing between varieties in a species.
Heritability	The portion of the observed variance for which differences in heredity are responsible.

[1]Knight, R. L. Dictionary of genetics. Chronica Botanica Co., Waltham, Mass. 1948.

Combining Ability--------The relative ability of a biotype to transmit, upon crossing, desirable performance to its progeny.

General----------is "the average performance of a line in hybrid combinations with several different lines."

Specific---------is used to indicate "those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average of the lines involved." (Sprague and Tatum).

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