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# Some Genetic Implications in the Transfer of High Fiber Strength Genes to Upland Cotton[1]

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## ABSTRACT

After 30 years of breeding, we have had recent success in overcoming the negative association between lint yield and fiber strength in upland cotton (*Gossypium hirsutum* L.). Lint yield and yarn strength were measured for at least 2 years on $F_5$ and $F_6$ lines derived from a series of crosses involving intermating and selection in the $F_2$, $F_3$, and $F_4$ generations. Correlation coefficients between lint yield and yarn strength were altered from −0.93 to 0.45 by this process. Several breeding lines recently developed by intermatings and selection have been successfully crossed to commercial cultivars with and without extra fiber strength genes, whereas previous crosses and backcrosses failed to produce segregates with both high yield and extra fiber strength. Moreover, the frequency of superior and rare plants have increased in the later segregating populations. The importance of linkage, rather than pleiotropism, in controlling the association between lint yield and fiber strength and its implications in breeding is discussed.


*Additional index words:* Breeding progress, Lint yield-yarn strength relationship, Linkage, Selection, Pleiotropism, *Gossypium hirsutum* L.

BREEDERS have long recognized a negative association between lint yield and fiber strength in upland cotton (*Gossypium hirsutum* L.). Studies have shown a strong, negative genetic correlation between these characters that holds true over a wide range in values. Since lint yield must be maximized and fiber strength increased significantly to improve a cultivar, we were interested in a practical breeding solution and the fundamental genetics involved in the association.

Al-Jibouri et al. (1958) suggested that the genetic correlations between lint yield and fiber strength observed in segregating cotton populations are probably caused by linkage or pleiotropism. Miller and Rawlings (1967) and Meredith and Bridge (1971) reduced the genetic correlations between lint yield and fiber strength in cotton populations with intermating and agreed that linkage, rather than pleiotropism, was more important in controlling the lint yield-fiber strength association. Recently, Scholl and Miller (1976) presented data suggesting that pleiotropic effects also may be important in explaining this genetic relationship.

Since 1946, we have placed major emphasis on transferring genes for extra fiber strength to improve upland cotton. Several recent breeding successes (Harrell et al., 1974; Culp and Harrell, 1977) in combining both high lint yield and fiber strength suggested a recent major change in the genetic association between lint yield and fiber strength. After 30 years of breeding (intercrosses, outcrosses, backcrosses, selection, and reselection) and over 25 years of testing for yield, quality, and adaptation, we have accumulated a mass of data that may be used to study the fiber strength-lint yield relationship in cotton. The purpose of this report is to demonstrate two types of breeding success and to offer a genetic explanation for the reversal in the yield-strength relationship that has occurred in some of our breeding stocks.

## MATERIALS AND METHODS

Cultivars and breeding stocks used in our study are as follows: *A, C, F, J, and T*, breeding stocks in the basic PD germplasm pool, developed from 1956 to 1972 (Culp and Harrell, 1974); *D*, 'Dixie King'; *E*, 'Earlistaple'; *G*, 'Auburn 56'; *H*, 'Coker 421'; *O*, 'Atlas'; *V*, 'Coker 310'; *W*, 'Coker 303'; *AC.FJA*, PD 2164, PD 2165; *AC.G*, PD 4381; *AC.FJA×H*, PD 9223, PD 9232; *AC.FJA×AC.G*, PD 0109, PD 0111, PD 0113; *FTA.O*, PD 4398; and *FTA.O×H*, PD 9241. 'Coker 201' was used as the check commercial cultivar.

Data on lint yield and yarn strength in breeding stocks developed in the PD program (Culp and Harrell, 1974) were used to calculate a regression equation (Fig. 1) applicable to the basic Pee Dee germplasm pool. Deviations from the regression line in the direction of higher yield and fiber strength are used to show superior combinations that resulted from two different breeding approaches (Culp and Harrell, 1977; Harrell et al., 1974).

Correlation coefficients between lint yield and fiber strength were determined for selections coming from the basic germplasm pool and from those outcrossed to various cultivars. Correlation coefficients were also determined after one, two, and three cycles of selection within several breeding lines coming from the germplasm pool.

The frequency of occurrence of "superior" and "rare" plant selections was determined in $F_2$ populations of outstanding crosses. Individual plants were field-selected for yield potential. Yield components and fiber properties were measured in the USDA laboratories at Florence, S.C. and Knoxville, Tenn. Plant selections with yield components and fiber properties equivalent to the check cultivar, but with an improvement in fiber strength, were yield tested for at least 2 years. Selections that continued to show an improvement in fiber strength and approached the yield of the commercial check were rated "superior". Plant selections with a major improvement in fiber strength that produced lint yields equal or superior to the check cultivars were rated "rare". Plants of the later types were easily distinguished in the $F_2$ populations and ranked first in trials for yield and quality during the testing periods.

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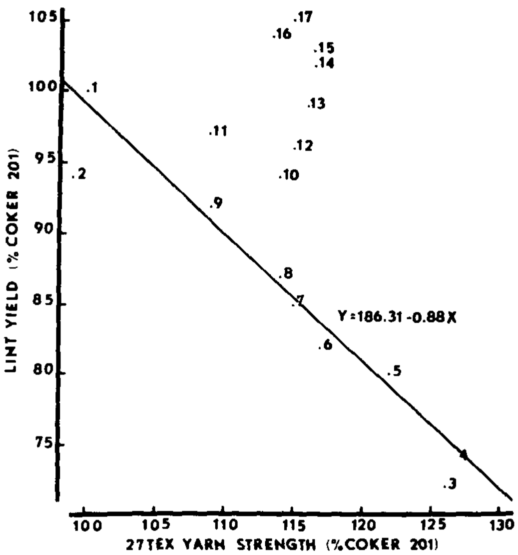


**Fig. 1. Lint yield and yarn strength of PD breeding lines from intercrosses within the Pee Dee germplasm pool and outcrosses with southeastern cultivars. Numbers are as follows: (1) Coker 201, (2) Auburn 56, (3) FJA, (4) FTA, (5) AC, (6) PD 2164, (7) PD 2165, (8) Atlas, (9) Coker 421, (10) PD 4398, (11) PD 4381, (12) PD 0109, (13) PD 9232, (14) PD 9223, (15) PD 0111, (16) PD 0113, and (17) PD 9241.**

## RESULTS AND DISCUSSION

Breeding progress in improving lint yield and fiber strength simultaneously in cotton is highly dependent on the occurrence of favorable recombinations. Hanson (1959) proposed that an effective procedure for breaking up linkage blocks and increasing genetic recombinations is to utilize four or more parents for one to four cycles of intermating. Since initial crosses in our study were made in 1946 (Culp and Harrell, 1974), we did not set out to test Hanson's theory, but our data are supportive of it.

In 1946, a collection of four cultivars and breeding lines with extra fiber strength was assembled in the Pee Dee breeding program at Florence, S. C. AHA6-1-4, Earlistaple, 'Sealand', and triple hybrid lines were crossed and intercrossed to form a germplasm pool of extra strength genes (Culp and Harrell, 1974). This germplasm pool first existed in a series of selections designated as lines *A, F, J, N, and T* (Culp and Harrell, 1975; Harrell and Culp, 1976), which were intercrossed and selected to give the basic breeding lines that exist today.

Breeding progress in improving lint yield and fiber strength in PD germplasm has occurred in two ways. First, lint yields were increased by reducing the extra-high fiber strength found in Beasley's (1940) triple hybrid material to acceptable levels of 10 to 20% above that of southeastern cultivars. Second, both lint yield and fiber strength have been increased simultaneously because of recent genetic changes in the association of these two characters.

Most outstanding PD lines (Culp and Harrell, 1974) and commercial cultivars, except those recently developed (Harrell et al., 1974; Culp and Harrell, 1977), fall on or very close to the regression line established between lint yield and yarn strength in the basic PD germplasm pool (Fig. 1). These data suggest that selection for higher lint yields demanded by growers has resulted in breeding lines with reduced fiber strength. The correlation coefficient ($r = -0.94$) between lint yield and yarn strength in the basic PD germplasm pool illustrates the problem faced by breeders in attempting to increase lint yield and fiber strength simultaneously in upland cotton.

Recently, the cross of PD 2165 (AC.FJA) × PD 4381 (AC.G) has produced several outstanding progenies, PD 0109, PD 0111, and PD 0113 (Culp and Harrell, 1977). All three breeding lines perform above expectations for yield and quality based on deviations from regression (Fig. 1). In this cross, extra-strength genes came entirely from the PD germplasm pool. Auburn 56 (Smith, 1964) does not exhibit extra-strength genes, because its yarn strength is 98% of that of Coker 201, and it has not imparted extra fiber strength in other crosses with commercial cultivars of *G. hirsutum*. Instead, Auburn 56 contributed extra factors for yield and for resistance to the fusarium wilt root-knot nematode complex caused by *Fusarium oxysporium* f. spp. *vasinfectum* (Atk.) Snyd. & Hans., and *Meloidogyne* spp., respectively.

In two other crosses, PD 2164 (AC.FJA) × Coker 421 (H) and PD 4398 (FTA.O) × Coker 421 (H), several superior progenies were produced (Harrell et al., 1974) and breeding lines Pee Dee 9241 (H:FTA.O) (later became commercial cultivar SC-1), PD 9223 (H:AC.FJA), and PD 9232 (H:AC.FJA) were developed and released. All three breeding lines performed above expectations for yield and quality based on deviations from regression (Fig. 1). Coker 421 combined successfully with many PD lines, such as AC.D (Culp and Harrell, 1977), AC.FJA, and FTA.O, and 'TH-149' (Harrell et al., 1974). Over the past 15 years, no outside cultivar with extra fiber strength has combined with the PD germplasm and given such a series of outstanding selections. PD 4398 from Atlas, which is closely related to the PD germplasm, only mimics our success with Coker 421. We suggest that Coker 421 extra-strength genes may be similar to those that went into the PD germplasm pool because it combined so well with PD and other triple-hybrid-related lines.

The association between lint yield and fiber strength in the PD germplasm pool may be best explained by linkage as suggested by Miller and Rawlings (1967) and Meredith and Bridge (1971). The correlation coefficients between lint yield and yarn strength of selected progenies after crossing (essentially intermatings) in the PD material have been changed from highly significantly negative (−0.93) to positive (but not significant) (0.45) (Table 1). Initially, line F was the first major improvement in a high yielding cotton with superior fiber strength of triple hybrid origin (Beasley, 1940), but selection for high yield invariably resulted in reduced fiber strength. Intermatings with related lines such as A and T (FTA selections) did very little to alleviate the adverse association ($r= -0.92$). The correlations between lint yield and fiber strength were significantly reduced in the AC material and the intermating of AC lines with material from the high fiber strength germplasm pool. Although the negative correlations between lint yield and yarn strength of superior progenies in the AC.FJA

**Table 1. Correlation coefficients between lint yield and yarn strength in a series of crosses (essentially intermatings) involving triple hybrid ancestry and *G. barbadense* L. introgression or similar material crossed with southeastern cultivars of cotton.**

| Population | Selections | r | $r^2$ |
|---|---|---|---|
| F | 13 | −0.93 | 0.86 |
| FTA | 17 | −0.92 | 0.84 |
| AC | 11 | −0.76 | 0.58 |
| AC.FJA | 39 | −0.49 | 0.24 |
| AC.G | 28 | −0.61 | 0.38 |
| AC.FJA × | | | |
| AC.G | 6 | 0.22 | 0.05 |
| AC.W | 9 | −0.25 | 0.06 |
| AC.D | 12 | 0.04 | <0.01 |
| AC.V | 4 | 0.45 | 0.20 |
| H | 7 | 0.44 | 0.19 |
| AC.X† | 31 | 0.16 | 0.03 |

† With G, W, D, or V.

and AC.G crosses were reduced, the mean of these lines did not deviate significantly from regression (PD 2164, PD 2165, and PD 4381 in Fig. 1). Culp and Harrell (1973) have reported only two improved breeding lines with extra fiber strength resulting from numerous selections within selfed populations of cotton. They concluded that these improvements probably resulted from outcrossing because of drastic plant changes in the new selections. The correlation between lint yield and yarn strength in Earlistaple 808 (first cycle of selection) was −0.90 (Table 2) compared with −0.58 for Earlistaple 7 selections (second cycle of selection) which gave hope of improving lint yield and fiber strength simultaneously in upland cotton. Unfortunately, one or more cycles of selection in line F, PD 2165, and PD 4381 (excluding PD 4381-54 and its progenies) produced no significant breeding improvements or major changes in the correlations between lint yield and yarn strength. Additional intermating further reduced the correlations between lint yield and fiber strength (Table 1) and produced superior offspring with both high lint yield and increased fiber strength (PD 0109, PD 0111, and PD 0113 in Fig. 1).

Thus, we have reached a point in cotton breeding whereby progress in improving lint yield and fiber strength can be made by simultaneously selecting superior plants, with and without extra fiber strength genes, in segregating populations from crosses between PD lines and commercial cultivars. Commercial seed breeders (Culp et al., 1979) have recently used PD material with extra fiber strength to improve the fiber quality of their cultivars. Culp et al. (1979) also have developed, for the first time, an insect-resistant breeding line with extra fiber strength without prior selection for improved fiber quality. These results support a recent major change in the lint yield-fiber strength relationship in this germplasm pool of upland cotton.

With this change in the association between lint yield and fiber strength, we expected greater compatibility between PD germplasm and commercial cultivars. Crosses have been made with Auburn 56, Coker 303, and Dixie King (Culp and Harrell, 1977), and Coker 421, Atlas, TH-149, and Coker 310 (Harrell et al., 1974). PD lines that contain the germplasm of these cultivars (Table 1) produce high lint yields with

**Table 2. Correlation coefficients between lint yield and yarn strength after several cycles of selection within four PD breeding lines.**

| | Selections | | | | | |
|---|---|---|---|---|---|---|
| | Cycle 1 | | Cycle 2 | | Cycle 3 | |
| Population | No. | r | No. | r | No. | r |
| Earlistaple | 11 | −0.90 | 24 | −0.58 | – | – |
| Line F | 5 | −0.95 | 9 | −0.92 | – | – |
| PD 2165 (AC.FJA) | 11 | −0.48 | 10 | −0.60 | 29 | −0.49 |
| PD 4381 (AC.G) | 9 | −0.48 | 19 | −0.59 | – | – |

**Table 3. Frequency of superior and rare plants in five $F_2$ populations of PD material.**

| Population | Approximate $F_2$ plants | $F_2$ selections | Lines released | Plants: Superior | Plants: Rare |
|---|---|---|---|---|---|
| | No. | | | % | |
| AC.FJA | 320 | 10 | 1 | 3.3 | 0.3 |
| AC.G | 320 | 6 | 1 | 2.0 | 0.3 |
| AC.G × AC.FJA | 120 | 8 | 3 | 6.7 | 2.5 |
| H:AC.FJA | 120 | 8 | 3 | 6.7 | 2.5 |
| H:FTA.O | 120 | 4 | 2 | 3.3 | 1.7 |

improved fiber strength and all show a reduction in the negative lint yield-fiber strength relationship.

In the early stages of this study, plants with superior lint yield potential and extra fiber strength were rare occurrences. Lint yield and fiber strength of thousands of selections (Culp and Harrell, 1974) were measured over a 5-year period before line F was found. Outstanding lines A, J, and N were developed after an additional 1 to 5 years of similar work. Selection of superior and rare plants became more frequent in PD 2165 (AC.FJA) and PD 4381 (AC.G) when genetic linkages were broken and the association between lint yield and fiber strength were reduced. Approximately 1 in 30 to 1 in 50 superior $F_2$ plants with high yield potential and extra fiber strength were found in these two populations (Table 3). Rare plants occurred in a ratio of about 1:300. With additional crossing (intermating) the frequency of superior plants increased to 1 in 15 and rare plants to 1 in 40.

Our data indicate that linkage is the major cause of the negative association between lint yield and fiber strength in upland cotton. We have been successful in breaking these linkages through modified intermating and selection. Other breeding methods (Culp and Harrell, 1973) have been tried numerous times but none have produced superior progenies. Meredith (1977) had similar results with the backcross method. Hanson (1959) predicted that these results could be expected in self-pollinated crops, particularly if the chromosome segment carrying the linkage block was short and difficult to break up. Our data do not rule out pleiotropic effects in the lint yield-fiber strength relationship as suggested by Scholl and Miller (1976); however, such effects appear to be of minor importance in the PD high fiber strength material.

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