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Backcross Breeding to Increase Fiber Strength of Cotton[1]

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ABSTRACT

Three cycles of backcross breeding to increase fiber strength (T_1) of cotton (*Gossypium hirsutum* L.) were studied at Stoneville, Miss. The objective was to measure the effectiveness of the backcross procedure for maintaining an adequate level of T_1 and producing desirable combinations of yield and T_1. The source of greater T_1 was FTA 263-20 (FTA) and the recurrent parent was 'Deltapine 16' (DPL 16). In each cycle, 480 F_2 plants were grown. In both BC_1F_2 and BC_2F_2, 24 plants were selected. In BC_1F_3 and BC_2F_3, 12 and four progeny respectively, were used to initiate the next cycle. From each of the four families descending from the four selected BC_2F_3 progenies, 12 of 120 BC_3F_2 plants were selected. In 1974, four sets of families were grown at two locations with two replications each. In each replication of each set, two entries of DPL 16, FTA, and BC_1F_5 and BC_2F_4 parents, and one entry of each of the 12 BC_3F_3 progenies were evaluated for lint yield, yield components, and fiber properties.

Mean T_1's for DPL 16, FTA, BC_1F_5, BC_2F_4, and BC_3F_3 were 193, 230, 220, 211, and 216, respectively. Therefore, a satisfactory level of T_1 was maintained by the backcross procedure. Assuming yield and T_1 were uncorrelated, the observed average line yield of BC_3F_3 was 9.8% less than expected. The decrease in expected yield was partially caused by a lower than expected lint percentage. Significant variability in lint yield was detected among the four sets. The family with highest yield was only 5.3% less than expected and also had above average T_1 ($T_1 = 217$). These results suggest moderate success in developing desirable combinations of yield and T_1 by the backcross procedure.

Additional index words: Breeding method, Fiber quality, Linkage, *Gossypium hirsutum* L.

THE improvement of fiber strength of commercial cottons, *Gossypium hirsutum* L., by transferring high strength genes from other *Gossypium* species or strains has long been a practical breeding objective. However, the success of selection programs to improve both yield and fiber properties has been limited due to the negative correlation between lint yield and fiber strength. For example, Miller and Rawlings (9) were able to increase lint yield 29.7% with three cycles of recurrent selection for lint yield. However, fiber strength of the third cycle selections was 6.5% less than that of the base population. Genetic association of these traits is caused by either linkage or pleiotropism. Miller and Rawlings (8) suggested that if linkage were a major causal factor for these negative associations in cotton, random intercrossing should reduce genetic correlations. Their research (8) with random intercrossing of populations derived from the tri-species hybrid, (*G. arboreum* L. × *G. thurberi* Tod. × *G. hirsutum*), resulted in a reduction of yield-fiber strength correlation from -0.69 to -0.35. In a similar study, Meredith and Bridge (6) reported a reduction in the yield-fiber strength genetic correlation from -0.54 to -0.38. The practical disadvantage of random intercrossing is that no genetic advance is achieved during the several generations of intercrossing; thus, valuable time is used without any advance in mean performance.

The genetic characteristics of the inheritance of lint yield and fiber strength have been characterized by many investigators. Several studies (1, 2, 10, and 11) have indicated that the genotype × environment interaction is large for lint yield and small for fiber strength. Meredith and Bridge (7) reviewed previous research and investigated the gene action responsible for lint yield and fiber strength. In general, lint yield is conditioned by both additive and nonadditive gene action, whereas, fiber strength is conditioned by mostly additive gene action. These studies indicate that lint yield would require more tests for evaluation and that early generation testing would be less reliable for yield than for fiber strength.

From these previous studies, the characteristic behavior of yield and fiber strength can be summarized as follows:

(i) Yield and fiber strength negative genetic correlation is at least partially caused by linkage.
(ii) Yield has low heritability.
(iii) Fiber strength has high heritability.
(iv) The relative cost of yield evaluation is high.
(v) The relative cost of fiber strength evaluation is low.

Because of these characteristics, it was suggested (6) that the backcross method of breeding might be an effective means of producing populations with desirable combinations of lint yield and fiber strength. The basic procedure would be to use a high lint pro-

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ducing cultivar as a recurrent parent. Selection for fiber strength would be practiced in each cycle. Thus, genes conditioning yield would be maintained through the recurrent parent, and genes for fiber strength would be maintained by the selection procedure.

The general objective of this study was to evaluate the effectiveness of the backcross breeding method for producing populations with better combinations of yield and fiber strength. Specific objectives were: 1) to evaluate the effectiveness of the backcross procedure in maintaining an adequate level of fiber strength and 2) to compare the observed yield with that of the expected, assuming no genetic association between yield and strength.

MATERIALS AND METHODS

Three cycles of backcrossing with selection only for higher fiber strength were conducted at Stoneville, Miss. The recurrent parent was Deltapine 16 (DPL 16) and the donor parent was FTA 263-20 (FTA). FTA was produced by the fiber quality breeding program at the Pee Dee Experiment Station, Florence, S. C. Its complex parentage and triple hybrid (*G. arboreum* L. × *G. thurberi* Tod. × *G. hirsutum*) background have been described by Culp and Harrell (3). In the first two cycles, selection for high fiber strength was practiced in two stages, first on a plant basis and then on progeny rows. Selection for the third cycle was practiced only on a plant basis. In this study, all plants sampled were spaced approximately 56 cm apart in rows 1 m wide and plots were one row 6.9 m long and 1 m wide. Fiber length was measured as 50% and 2.5% span length on a Digital Fibrograph. Strength, expressed as millinewtons per tex (mN/tex), and elongation (E_1) were measured with a 0.31-cm gauge Stelometer. Fiber fineness was expressed in micronaire units. Fiber determinations were made by the U.S. Cotton Fiber Laboratory of the ARS, USDA, at Knoxville, Tenn.

Backcross and Selection Procedure. A brief breeding and selection history of the backcross populations is given in Table 1. In 1969, approximately 600 BC_1F_1 plants were grown. One open pollinated boll from each plant was harvested and the bulked BC_1F_2 seed were planted in 1970 in 12 blocks of 40 spaced plants each. BC_2 crosses were made on these 480 BC_1F_2 plants. Fiber determinations were made on lint from these 480 plants. Fifteen hills of BC_2F_1 seed from each of the 24 plants with highest fiber strength were grown at Iguala, Mexico in 1970 and 1971. In 1971, the 24 BC_1F_3 progenies with highest BC_1F_2 plant fiber strength were grown at two Stoneville environments with two replications each. On the basis of fiber determinations from these progenies, 12 BC_1F_3 progney rows with the highest fiber strength were identified. Simultaneously, the 12 BC_2F_2 families descending from these selections were being grown in four blocks of 10 plants each. Fiber determinations were made and the 24 plants with highest fiber strength were grown as progeny rows at two environments and two replications in 1972. Descendents of all 12 BC_1 families were represented in the selections, with five families having one, four families having two, one family having three, and two families having four descendents. BC_3F_1 seed involving approximately 15 BC_2F_3 plants were produced from all 24 selections in 1972. The four BC_2F_3 progenies with highest fiber strength were identified and their BC_3F_1 seeds were grown at Iguala, Mexico as individual progeny rows with 30 hills from 1972 to 1973. In 1973, BC_3F_2 plants were grown in three blocks of 40 plants each per family. The 12 plants from each of the four families with highest fiber strength were retained for the 1974 evaluation of three cycles of backcross breeding.

Comparison of Three Backcross Cycles. In 1974, various parental and backcross populations were grown at two Stoneville environments with two replications each. The experimental design was a split plot with the four families used as whole plots. Remnant seed of the BC_1 and BC_2 selections that produced the four BC_3 populations had been maintained throughout the selection procedure. Within each whole plot for each replication, two entries each of DPL 16, FTA, BC_1F_5, and BC_2F_4 parents were included. One entry per replication of each of the 12 BC_3F_3 selected progenies was included for a total of 20 plots per replication per whole plot. Lint yield, lint percentage, boll size, seed index, seed per boll, 50% span length, 2.5% span length, fiber strength, fiber elongation, and micronaire were determined for each plot.

Table 1. Crossing and selection history used to develop three backcross populations.

Year	Pedigree	Seed produced
1968	DPL 16 × FTA	F_1
1968-69	F_1 × DPL 16	BC_1F_1
1969	600 BC_1F_1 plants selfed	BC_1F_2
1970	480 BC_1F_2 plants fiber tested (24 selections)	BC_1F_3
1970	BC_1F_2 × DPL 16	BC_2F_1
1970-71	BC_2F_1 plants selfed	BC_2F_2
1971	24 BC_1F_3 progenies tested (12 selections)	
1971	480 BC_2F_2 plants fiber tested (24 selections)	BC_2F_3
1972	24 BC_2F_3 progenies tested (4 selections)	
1972	BC_2F_3 × DPL 16	BC_3F_1
1972-73	BC_3F_1 plants selfed	BC_3F_2
1973	480 BC_3F_2 plants fiber tested (48 selections)	BC_3F_3
1974	Comparison of three backcross cycles	

Statistical Comparisons. The within family error mean squares listed in Table 4 were used in computing various Duncan's multiple ranges shown in Table 2. Such comparisons assume no major interactions of populations with families or environments. The t-test was used for the observed versus expected comparison in Table 3. Expected values are based upon the weighted proportion of DPL 16 and FTA expected, assuming no linkage and expression of additive gene action only. For example, the expected value of the BC_1F_5 is: 3/4 (DPL 16) + 1/4 (FTA). The variance for such a comparison is: Variance of BC_1F_5 mean + 3/4 variance of DPL 16 + 1/4 variance of FTA. Thus, for the observed BC_1F_5 versus expected, the variance is error mean square b (1/48 + 9/256 + 1/256) where the error mean square b is listed in Table 3. This comparison assumes no environmental interaction between the backcross and the parental means.

The variation among DPL 16, 3 df, entries in different family groups and the DPL 16 × environment (E), 3 df, interaction plus the corresponding 6 df for FTA were pooled to be used as an estimate of experimental error among families given in Table 3.

RESULTS AND DISCUSSION

The average yield, yield components, and fiber properties for DPL 16, FTA, and their backcross populations are given in Table 2. Significant differences among parents were detected for all traits measured. Of primary interest is fiber strength and yield, with FTA having 19% greater fiber strength and 32% less yield than DPL 16.

While the backcross populations were not equal in fiber strength to FTA, it is evident (Table 2) that fiber strength was maintained at a satisfactory level. There is little practical difference among the three backcross populations, with BC_1F_5, BC_2F_4, and BC_3F_3 having an average fiber strength of 220, 211, and 216 mN/tex, respectively. In this study, a 10% plant selection differential in the BC_3F_2 for higher fiber strength was effective in maintaining fiber strength at least equal to the BC_2F_4. The BC_3F_3 averaged 12% greater fiber strength than DPL 16 or about 62% of the original difference between DPL 16 and FTA. These results indicate that a quantitative trait such as fiber strength can be adequately maintained by the backcross procedure. In maize (*Zea mays* L.), Duvick (4) has reported the success of the backcross procedure in transferring a quantative trait, ear prolificacy, into an established inbred line and its hybrids.

Table 2. Yield, yield components and fiber property means for parental and backcross populations.**

Population	Lint	Lint	Boll size	Seed index	Seed/boll	Span length 50%	Span length 2.5%	Strength T_1	Strength E_1	Micronaire
	kg/ha	%	g	g						
FTA	728 d	34.0 e	5.75 b	13.8 a	27.6 c	15.4 a	32.8 a	230 a	6.3 d	3.91 bc
BC_1F_5	840 c	34.9 d	6.00 ab	13.5 a	29.0 b	15.2 a	32.3 b	220 b	7.4 c	3.82 c
BC_2F_4	935 b	36.9 c	5.93 b	12.6 b	29.7 b	14.7 b	31.4 b	211 c	8.3 b	3.89 bc
BC_3F_3	953 b	37.6 b	6.18 a	13.4 a	28.8 b	15.2 a	31.9 c	216 b	8.4 b	3.95 b
DPL	1,077 a	39.7 a	6.22 a	12.0 c	31.5 a	14.4 c	30.6 e	193 d	9.2 a	4.22 a

** Means within a column not followed by the same letter are considered significantly different at 0.01 protection level according to Duncan's multiple range test.

Table 3. Backcross populations' deviation from expected performance.†

Population	Lint	Lint	Boll size	Seed index	Seed/boll	Span length 50%	Span length 2.5%	Strength T_1	Strength E_1	Micronaire
	kg/ha	%								
BC_1F_5	-15.3**	-8.8**	-1.8	8.5**	-5.1**	3.6**	3.7**	9.1**	-12.0**	-7.8**
BC_2F_4	-9.7**	-5.3**	-3.9**	3.4*	-4.3**	1.3	1.7**	6.9**	-6.0**	-7.1**
BC_3F_3	-9.9**	-4.3**	-0.2	10.6**	-7.8**	5.0**	3.6**	10.9**	-6.4**	-6.0**

*,** Significant at the 0.05 and 0.01 levels, respectively. † Deviations expressed as a percent of the expected.

Lint Yield. The average yields of the BC_1F_5, BC_2F_4, and BC_3F_3 were 78, 87, and 88%, respectively, than that of DPL 16. The observed backcross population yields are greater than that of FTA and appear to be progressively nearer that of DPL 16. However, their observed yield is significantly lower than expected (Table 3), assuming yield is inherited independently of fiber strength. The results in Table 3 indicate significant differences between observed and expected performance for all traits. This strong genetic association is caused by either pleiotropism or linkage. In the case of linkage, repeated backcrossing would result in a narrowing of the difference between observed and expected performance. For example, the decrease in lint deviation of 15.3% in the BC_1F_5 to 9.7% in BC_2F_4 may be due to breaking linkages between negative yield genes and positive fiber strength genes. In the case of pleiotropic gene action, repeated backcrossing would not result in any deviational changes. For example, with yield there is no essential change between the deviations for the BC_2F_4 (9.7%) and BC_3F_3 (9.9%). There is little doubt that the backcross procedure was responsible for the BC_2F_4 and BC_3F_3 populations having higher lint yield than the BC_1F_5. Whether these differences were due to breakup of linkage blocks or due to gene sampling variation is a matter of speculation. It is also a matter of speculation as to whether any further yield increases could be obtained by backcrossing.

Yield Components. The backcross procedure was effective in improving lint percentage as the BC_1F_5, BC_3F_4, BC_3F_3 averages (Table 2) were 34.9, 36.9, and 37.6%, respectively. This compares favorably with 34.0 and 39.7% for FTA and DPL 16, respectively. The deviations from expected (Table 3) appear to be decreasing with successive backcrossing. Even after three backcrosses, seed index and number of seed per boll are nearer to that of FTA and DPL 16. There was little difference in boll size between FTA and DPL 16 and also the subsequent backcrosses. Harrell and Culp (5) have similarly reported that their higher fiber strength PD cultivars, of which FTA is one, tended to have boll size similar to commercial southeastern cultivars but had larger seed and fewer seed per boll. Their attempts to select from segregating populations of PD strains × southeastern cultivars for increased seed per boll and also maintain high yield and fiber strength had only limited success (5). This study reinforces theirs because it suggests that cotton breeders may have great difficulty in increasing lint yield of high strength cottons by selecting for increased seed number per boll.

Other Fiber Properties. Significant differences betwee DPL 16 and BC_3F_3 are evident in Table 2 for fiber length, elongation, and micronaire. As with most yield components, these fiber properties (Table 3) deviate more toward FTA's performance than that of DPL 16. It is evident that either the high fiber strength genes donated by FTA or other genes closely linked with them have a major effect on many physiological processes. In the case of yield and yield components, this association with high fiber strength was undesirable, but with fiber length and micronaire it is advantageous.

Significant genetic variation among families (Table 4) was detected for most traits within each backcross generation. The respective mean squares for BC_1F_5, BC_2F_4, and BC_3F_3 do not suggest any decreasing trend in genetic variance with advanced backcrossing. Significant variability among the four BC_3F_3 families was detected for all traits except lint percentage and seed index. In a practical breeding program, cotton breeders are more concerned with the performance of the best individual progeny than with average population performance per se. The family yield averages of four BC_3F_3 families were 1,001, 967, 921, and 925 kg/ha and their fiber strengths were 217, 217, 212, and 219 mN/tex, respectively. Thus, one family had significantly higher yield than the other three families and it also possessed very acceptable fiber strength. Significant variation within these families was detected for all traits except yield. Selection within families for such traits as lint percentage and fiber strength should therefore be effective and result in progenies with even better combinations of yield and fiber strength than those reported.

Table 4. Mean square variation among and within families for 10 traits.

Source	df	Lint	Lint	Boll size†	Seed index†	Seed/boll†	Span length‡ 50%	Span length‡ 2.5%	Strength T_1	Strength E_1	Micronaire†
		kg/ha	%†								
Among Family											
BC_3F_3	3	50,185**	103	182**	174	144*	314**	1,574*	518*	906**	328**
BC_2F_4	3	62,412**	882**	40*	545**	165**	114	331*	466*	222	626**
BC_1F_5	3	32,035	202	180**	403*	136*	88	217	618*	34	35
$BC_3F_3 \times$ E.	3	16,037	179	29	45	29	47	63	97	4	39
$BC_2F_4 \times$ E.	3	8,415	63	5	46	71	31	28	55	9	74*
$BC_1F_5 \times$ E.	3	30,405*	45	9	34	45	27	18	47	9	52*
Error a	12	7,722	61	11	91	27	37	68	113	18	13
Within Family											
BC_3F_3	44	23,950	351**	42**	276**	66**	74**	187**	154*	53*	104**
$BC_3F_3 \times$ E.	44	22,042	43	13	48	33	34	48	79*	29	19
Error b	88	17,372	42	11	37	23	28	37	54	29	22

*,** Significant at the 0.05 and 0.01 levels, respectively. † Mean squares $\times 10^2$. ‡ Mean squares $\times 10^4$.

This is the first study in cotton indicating the success of backcross breeding for a quantitative trait, fiber strength. This study also indicates that backcrossing is a desirable method to obtain improved genetic combinations of yield and strength genes in cotton. No selection for other traits such as yield or lint percentage was practiced in this study. In a practical program the elimination of undesirable plants and progenies might result in even greater progress than that reported here. The variation among and within populations is also indicative that better performing individual progenies might be obtained than is indicated in these results. Many breeders have apparently assumed that all quantitative traits are conditioned by many genes with small additive effects. If this is so, the probability of recovering a satisfactory number of these genes by backcrossing is too small to attempt such a program. The maintenance of a high level of fiber strength by a 10% plant selection differential in BC_3F_3 suggests that a relatively small number of major genes are conditioning fiber strength, perhaps as few as one or two in this material. In that event, relatively small plant numbers would be required for evaluation in each backcross cycle. This study encourages more use of the backcross method in cotton breeding.

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