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Breeding Potentials of Noncultivated Cottons.
I. Some Agronomic and Fiber Properties of Selected Parents and Their F_1 Hybrids[1]

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ABSTRACT

Using a complete diallel set, we analyzed 12 agronomic and fiber characters in five cottons (*Gossypium hirsutum* L.), and their F_1 hybrids. Two of these were adapted cultivars, and the remainder were Texas race stocks. The cultivars were early and productive at Phoenix, whereas the three race stocks varied widely in earliness, lint characteristics, fruit size, growth habit, and other agronomic characters under consideration. Narrow sense heritability estimates for the 12 characters ranged from 0.04 for date of first flower to 1.29 for 2.5% fiber span length. Estimates of general combining ability were significant for number of bolls/plot, peduncle length, and five fiber traits. Thus, selection for these characters should be effective.

Nonadditive variance was significant for nine of the 12 characters measured, and comprised the majority of the genetic variance for three of these nine characters. There were no significant maternal effects. Reciprocal effects were significant for a few character/hybrid combinations. Fifteen of the possible 120 character/hybrid combinations showed specific heterosis. Eleven were positive, three negative, and one that may be neutral in the sense of agronomic fitness. Mean heterosis (F_1 vs. midparent) was significant only for date of first flower.

Additional index words: *Gossypium hirsutum* L., *Pectinophora gossypiella* (Saunders), Pink bollworm, Host-plant resistance, Additive variance, Nonadditive variance, Heterosis, Maternal effects, Reciprocal effects, Heritability.

In attempts to improve cultivated cotton (*Gossypium barbadense* L. and *G. hirsutum* L.), researchers are increasingly using wild and house-yard strains as sources of resistance to the limiting factors of production, including insects and mites (Hunter et al., 1965; Shaver et al. 1970; Schuster et al., 1973; Tingey et al., 1973; Wilson and Wilson, 1974). These cottons are usually inferior to currently grown cultivars in most agronomic and fiber-quality characters. Even though the use of such stocks might broaden the genetic base for purposes of selection, there will likely be deleterious associations between characters that will need to be changed.

Diallel crossing schemes have been commonly used for studying genetic systems in plant species. Many such studies in cotton have been reported, with both cultivars and noncultivated stocks (see Baker and Verhalen, 1973, for an example of such studies and a review of earlier work).

The objective of this paper is to report the inheritance of agronomic and fiber-quality properties by means of diallel crosses of two widely grown cultivars with three Texas race stocks previously selected for resistance to pink bollworm, *Pectinophora gossypiella* (Saunders).

MATERIALS AND METHODS

We used two upland cotton cultivars: 'Deltapine 16' (DPL-16) and 'Stoneville 7A' (St 7A), and three Texas race stocks: Texas 40Y (T-40Y), Texas 203 (T-203), and Texas 711 (T-711). Certain agronomic and fiber-quality characters of these stocks are summarized by USDA (1974.) These stocks were selected because of their day-neutral flowering habit and their resistance to pink bollworm demonstrated via a diet bioassay (Wilson and Wilson, 1974).

We crossed the race stocks and cultivars in all possible combinations, including reciprocals. Seeds of parents and crosses

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were planted in expanded peat pellets in the greenhouse March 27, 1973. Seedlings were space-planted in the field at the Cotton Res. Cen., Ariz. Agric. Exp. Stn., Phoenix, Apr. 12, 1973, 46.8 cm apart in the row; row width was 1.02 m. Each single-row plot had 20 plants, except when plants died and no replacements were available. Plots were arranged in three randomized blocks. Conventional cultural practices were followed.

We examined plants daily to determine the date of first flower. For 10 days, July 5 to 14, we tagged open flowers. Then we harvested tagged bolls on July 30 for estimates of productivity and to provide material for pink-bollworm diet studies. We also measured the length of the peduncle of each harvested boll.

Data were taken on the following characters: boll size, g seed cotton/boll; seeds/boll; seed index, wt in g of 100 seeds; lint percent, wt lint/wt seed cotton; T_1 fiber strength, measured on the stelometer with the jaws of the machine separated by a 3.2 mm spacer; E_1 fiber elongation, percentage elongation of the fiber bundle before breakage; fiber length, 2.5% and 50% span length in inches; and micronaire, a measure of fiber fineness in μg/in.

Pairwise comparisons between parental and hybrid-array means were made with the FLSD test (i.e., when the entry effect mean square was significant, an LSD test was used to compare individual means, Carmer and Swanson, 1971).

We used the Schaffer and Usanis (1969) program to analyze the diallel cross data. This analysis estimates general combining ability (GCA), but subdivides the usual estimate of specific combining ability into SCA (specific combining ability estimated from hybrid data only) and a "self" effect. This latter component includes not only differences between parents, but other variation as well, and has no simple genetic interpretation. The Schaffer-Usanis program also estimates maternal and reciprocal effects. We tested the significance of each of these effects with Satterthwaite's (1946) approximation for unequal subclass numbers because some data were missing.

The "self" effect was significant only for date of first flowers. For this character, we recalculated the diallel data and subdivided the "self" variance into two components, "b_1" and "b_2" of Hayman (1954), each of which has a straightforward interpretation. The b_1 component measures the mean variance of the F_1's from their midparental values. The b_2 component, measures the consistency of the nonadditive variation over hybrid arrays. Finally, b_3 is equivalent to the Schaffer-Usanis SCA component, and tests the deviation from additivity unique to each F_1 (Mather and Jinks, 1971).

We calculated heritabilities and additive/total genetic variance ratios on the basis of an additive/dominance model, and assumed that the five parents constituted a set of inbred lines. Under these conditions, σ^2_g, the GCA variance, contains half of the additive variance, and σ^2_s, the SCA variance, contains the dominance variance. Narrow-sense heritability is therefore defined as $2\sigma^2_g/\sigma^2_p$, where the latter is the phenotypic variance. The ratio of additive to total genetic variance is defined as $2\sigma^2_g/2\sigma^2_g + \sigma^2_s$.

RESULTS

Parental and hybrid-array means for the 12 characters measured are presented in Table 1. Mean squares from the analyses of variance are presented in Table 2.

The two cultivars and T-40Y flowered 10 days to 2 weeks earlier than T-203 and T-711. All of the hybrid arrays flowered as early as the cultivars and T-40Y.

Productivity was markedly different among the parents. Stoneville 7A set significantly more bolls in the 10-day period than the other entries. Deltapine 16 and T-40Y set significantly more than T-203 and T-711, which were virtually sterile during that time. The hybrids involving St 7A produced significantly fewer bolls than their productive parent. Boll set was not significantly different in hybrids from DPL-16, St 7A, and T-40Y. It was, however, significantly lower in T-203 and T-711 hybrids than in those from the other entries.

Peduncles were conspicuously longer in T-711 than in the other parents. T-203 had slightly but significantly longer peduncles than DPL-16, St 7A, or T-40Y. Peduncles of the hybrid combinations with T-711 were significantly shorter than this parent, but longer than the other parents or hybrid arrays. Hybrids involving T-203 had peduncles as long as those of this parent (except T-203 × T-711 and reciprocal, which had longer peduncles).

Boll size, number of seeds/boll, and seed index did not differ significantly among the cultivars and T-40Y. T-203 had significantly smaller bolls, with fewer and larger seeds. Because T-711 was so unproductive in 1973, estimates of these parameters were not reliable. However, data obtained at another location in 1974 showed that T-711 was also small-bolled, had fewer seeds/boll, and smaller seeds than T-203. All three race stocks had lower lint percentages than the cultivars.

The hybrid array with T-711 as common parent had smaller bolls and seeds than the T-40Y array. It also had fewer seeds/boll than the DPL-16 and T-40Y arrays. Otherwise, hybrid arrays did not differ significantly in any of the four lint and seed characters measured.

T_1 strength was highest in DPL-16 in 1973 and in T-711 in 1974. Elongation was highest in DPL-16 both years, but T-711 ranked second in 1974. The two cultivars, DPL-16 and St 7A, differed significantly in fiber elongation but not in T_1 strength. These results agree in general with results from the 1971 Central and Delta Regional Variety Test Report, in which DPL-16 consistently exhibited higher T_1 and E_1 than St 7A (Ramey, Turner, and Worley, 1974). T_1 strength did not differ in the hybrid arrays, but elongation was highest in the arrays involving T-711, DPL-16, and T-40Y.

Fiber was significantly longer in the two cultivars than in the race stocks. T-711 had the shortest fiber of any of the parents. Hybrid arrays with the three race stocks had shorter fiber than those with the cultivars. T-40Y and Deltapine 16 had the coarsest fiber, whereas T-203 had the finest in 1973, but T-711 had the finest in 1974. Paradoxically, the coarsest fiber among the hybrid arrays was found in that with T-203.

The diallel analysis revealed no significant maternal differences. However, reciprocal effects were significant for seed index, T_1 strength, elongation, and micronaire in a relatively few F_1 combinations. T-711 was combined at least once with each of the other parents. The most common combination, T-40Y × T-711, showed significantly lower strength and elongation and higher micronaire and seed index than its reciprocal combination. The next most frequent combination was T-40Y × T-203, which had lower strength and elongation and higher micronaire than its reciprocal. Deltapine 16, St 7A, and T-203 each showed one instance of a significance reciprocal difference when combined with T-711 for seed index, micronaire, and elongation, respectively.

Meyer (1973) reported significant differences in seed index, elongation, and micronaire in advanced *G. hirsutum* strains carrying cytoplasm from *G. longicalyx* Hutchinson and Lee vs. the reciprocal strains carrying *G. hirsutum* cytoplasm. She also reported recip-

Table 1. Parental and hybrid-array means for five cotton parents and their F_1 progenies.

Parent or hybrid-array	Date of first flower†	Bolls set/ 20 plants	Peduncle length, mm	Seed cotton/ boll, g	Seeds/ boll	Seed index	Lint, %	Fiber strength, T_1	Elongation, E_1	Span fiber length, in. 2.5%	50%	Micronaire
Deltapine 16	164.4 bc*	58.0 b*	20.9 de*	4.65 ab*	27.0 ab*	10.6 bc*	36.7 a*	21.7 a*	7.0 a*	1.13 a*	0.57 a*	4.6 abc*
Stoneville 7A	165.0 bc	82.7 a	19.7 e	4.36 abc	26.0 ab	10.5 bc	35.4 a	20.3 ab	4.3 d	1.18 a	0.58 a	4.4 c
Texas 40Y	168.2 b	43.3 b	21.2 de	4.33 abc	26.1 ab	11.0 bc	31.6 b	20.0 b	4.7 cd	0.88 d	0.47 f	5.1 a
Texas 203	178.1 a	4.3 c	26.1 c	3.47 c	19.6 c	12.7 a	28.7 c	20.1 b	5.8 b	0.98 c	0.53 cd	4.2 c
Texas 711	177.2 a	0.7 c	44.3 a	--	–	–	–	--	–	–	–	–
DPL-16 hybrids	161.4 c	45.3 b	26.4 c	4.64 ab	29.3 a	10.4 bc	32.8 b	20.8 ab	5.4 bc	1.05 b	0.54 bc	4.5 bc
St7A hybrids	162.0 c	49.0 b	25.1 cd	4.62 ab	28.4 ab	10.6 bc	33.2 ab	20.7 ab	4.8 cd	1.05 b	0.55 b	4.6 abc
T-40Y hybrids	164.5 bc	41.8 b	25.2 cd	4.87 a	29.1 a	11.5 ab	32.0 b	20.2 ab	5.1 b	0.99 c	0.52 d	4.7 abc
T-203 hybrids	165.8 bc	19.3 c	29.4 c	4.32 abc	25.6 ab	11.0 bc	31.5 b	20.4 ab	4.8 cd	0.99 c	0.53 cd	5.0 ab
T-711 hybrids	165.5 bc	15.5 c	37.7 b	3.68 bc	24.4 b	9.7 c	32.5 b	21.2 ab	6.2 ab	0.93 cd	0.50 e	4.3 c

* Means with letters in common did not differ significantly at the 0.05 probability level. † June 1 = 152.

Table 2. Mean squares and tests of significance.

Source	Date of first flower df	MS	Bolls set/ 20 plants df	MS	Peduncle length, mm df	MS	Seed cotton/ boll, g df	MS	Seeds/boll df	MS	Seed index df	MS	Lint percentage df	MS	T_1 strength df	MS	E_1 elongation df	MS	2.5% span length, in. df	MS	50% span length, in. df	MS	Micronaire df	MS
GCA	4	2,471.44	4	9,559.98**	4	9,799.83**	4	4.85	4	69.91	4	7.51	4	62.77	4	6.44*	4	8.85*	4	0.113**	4	0.0146**	4	1.17*
Adj. error	6	958.06	8	500.89	10	175.13	9	1.57	9	40.73	8	2.00	6	13.92	8	1.13	7	1.14	8	0.003	7	0.0009	7	0.20
Self	5	1,659.51**	5	200.79	5	122.17	4	1.00	4	33.87	4	1.42	4	3.29	4	0.57	4	1.46	4	0.003	4	0.0003	4	0.22
Adj. error	16	127.02	9	488.83	7	98.79	8	1.08	8	24.28	11	1.59	8	12.69	14	1.22	11	0.48	14	0.002	11	0.0010	17	0.16
SCA	5	230.13*	5	1,001.07**	5	240.80**	5	2.18**	5	47.76**	5	2.69*	5	25.37**	5	1.76	5	0.79*	5	0.002	5	0.0015*	5	0.18
Adj. error	1,375	80.48	45	200.69	681	23.15	49	0.37	49	9.20	48	1.11	46	4.26	50	0.94	49	0.31	46	0.001	46	0.0006	45	0.16
Maternal	4	154.82	4	170.18	4	95.31	4	0.26	4	10.29	4	1.40	4	4.31	4	0.59	4	0.12	4	0.003	4	0.0009	4	0.28
Adj. error	6	91.33	6	239.16	6	28.11	5	0.61	5	10.95	5	4.63	5	0.92	5	2.48	5	1.00	5	0.003	5	0.0005	5	0.62
Reciprocal	6	91.31	6	239.16	6	27.99	5	0.61	5	10.94	5	4.61**	5	0.94	5	2.47*	5	1.00**	5	0.0026	5	0.0005	5	0.60**
Adj. error	1,370	80.42	48	200.69	674	23.0	43	0.36	43	9.09	43	0.94	43	4.40	43	0.89	43	0.28	41	0.0014	41	0.0006	38	0.15

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

rocal differences for other characters involving cytoplasms from other *Gossypium* spp. transferred into *G. hirsutum*.

Mean heterosis (F_1 vs. midparent) was significant only for date of first flower. Of the possible 120 hybrid/character combinations (10 hybrids × 12 characters), only 11 showed significant positive (favorable) heterosis of F_1 vs. midparent, and three showed negative (unfavorable) heterosis. In addition, DPL-16 × T-711 F_1 had significantly longer peduncles than the midparental value, but we can only speculate at present on its practical significance (Table 3). Two combinations showed significant heterosis when compared with the better parent (boll size in DPL-16 × T-40Y and St 7A × T-40Y). Five of the 12 characters and one of the 10 parental combinations (DPL-16 × St 7A) exhibited no heterosis.

Narrow-sense heritability estimates ranged from 0.04 for date of first flower to 1.29 for 2.5% span length. Ratios of additive to total genetic variances ranged from 0.24 for seeds/boll to 0.98 for 2.5% span length (Table 4).

DISCUSSION

The GCA variation was significant for seven of the 12 characters studied, including the five fiber-quality parameters. The greatest deficiency in the race stocks was in fiber length, but heritabilities for the two length measurements were high. Therefore, selection for fiber length should be highly effective. Selection for fiber strength, elongation, and fineness should be less effective, but these characters are probably adequate in the race stocks except perhaps for the coarse fiber of T-40Y.

The first of the other two characters with high heritability and a significant GCA effect, peduncle length, may be of academic interest only. Long peduncles could be agronomically disadvantageous because they require more time and energy to grow and would thus detract from yield and contribute to lateness. On the other hand, long, densely pubescent peduncles could be a deterrent to pink bollworm movement because many eggs are laid on vegetative plant parts and larvae must migrate to squares or bolls to find food. The medium-length peduncle was apparently inherited as a complete dominant in hybrids of T-203 with T-40Y and the two cultivars. In hybrids involving T-711, partial dominance was displayed. The second character, number of bolls set in 10 days in midseason, was a convenient measurement obtained when we harvested green bolls for pink bollworm diet studies. Its relation to yield is unknown, because this test was not designed to furnish yield data.

Nonadditive variation was significant for nine of the 12 characters studied; for three characters it comprised the majority of the genetic variances (Table 4). Included in these nine were boll size, seeds/boll, seed index, and lint percentage. For these characters, the GCA variation was not significant, and heritability estimates were relatively low, indicating that progress

Table 3. Heterosis (F_1 vs. midparent) in specific F_1 combinations.

Character (favorable condition)	Heterotic combinations: Favorable	Neutral	Unfavorable	Total
Date first flowers (earlier)	6	0	0	6
Peduncle length	0	1	0	1
Seed cotton/boll, g (heavier)	2	0	0	2
Seeds/boll (more)	3	0	0	3
Lint percent (higher)	0	0	1	1
E_1 elongation (higher)	0	0	1	1
Bolls set/20 plants (more)	0	0	1	1
Total	11	1	3	15

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Table 4. Heritabilities and ratios of additive to total genetic variances.

Character	Narrow-sense heritability	Ratio of additive/ total genetic variance
Date of first flower	0.04	0.81
Bolls set/20 plants	0.94	0.82
Peduncle length	1.09	0.95
Seed cotton/boll	0.29	0.43
Seeds/boll	0.10	0.24
Seed index	0.19	0.59
Lint percent	0.34	0.49
T_1 strength	0.27	0.73
E_1 elongation	0.43	0.87
2.5% span length	1.29	0.98
50% span length	0.80	0.86
Micronaire	0.26	0.96

through selection might be more difficult than for the fiber-quality characters.

The very low heritability estimate for date of first flower seems inconsistent with the high additive/total genetic variance ratio. This discrepancy resulted from a large, statistically significant, "self" variance component. Reanalysis of the flowering data, using Hayman's (1954) method, showed that 95% of the genetic variation due to deviations from additivity can be attributed to b_1, interpreted as the average deviation of the F_1's from the midparental value. Only 2% of the total is attributed to b_2 and 3% to b_3, even though these two effects are statistically significant.

These results emphasize the virtually complete dominance for early flowering in hybrids between the early and late-flowering parents, and suggest the possibility of a major gene for earliness. Al-Rawi and Kohel (1969), in a diallel that included the study of date of first flower in nine upland cultivars, concluded that heterosis was due to dominance alone because no significant epistasis was detected for that trait. Their average dominance estimate was 0.81 (partial dominance). However, they also found a significant additive component, whereas we did not, and a narrow-sense heritability estimate of 0.46, whereas ours was 0.04. There is also some evidence in our study for the over-dominance of earliness in hybrids between T-203 and T-711, the two late-flowering stocks.

The two cultivars were apparently genetically the same for earliness, whereas T-40Y may differ, judging from hybrid performance even though the analysis revealed no significant differences among these three entries.

We expected more instances of favorable heterosis (performance of F_1 vs. better parent) than the two (boll size in two hybrids) we observed in this study, because the cultivars and race stocks are presumably not closely related. Even the instances of F_1 vs. midparent heterosis were not numerous (Table 3). For the majority of character/hybrid combinations (105/120), F_1 values did not differ significantly from the midparent value.

Two of the heritability estimates are above unity. There could be several possible reasons for these results. Data from a single environment could bias heritability estimates upward. There could also be a large sampling error in estimating variances. According to Jana (1972), the very method of estimating genetic effects by variance component analysis may overestimate additive effects. However, four of the 12 characters are obviously highly heritable, and three have heritabilities low enough to constitute obstacles to progress through selection. The remaining five characters (seed cotton/boll, lint percentage, T_1 strength, E_1 elongation, and micronaire) may not be as susceptible to progress through selection as our estimates indicate.

Obviously, our results apply only to the specific entries studied in one environment, and are of value only in that context. T-40Y was comparable to the cultivars in the characters we measured, except for fiber length, fineness, and lint percentage, all of which could be improved by selection. T-203 and T-711, on the other hand, may be more refactory. Besides being late and unproductive, T-203 had a sprawling growth habit, small bolls, few seeds/boll, large seeds, low lint percentage, and short fiber. Its T_1 strength, elongation, and micronaire were satisfactory. T-711 suffered from many of the same deficiencies as T-203. However, it had a superior growth habit and, as shown by our 1974 data, higher fiber strength coupled with acceptable fineness.

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