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Combining Ability for Agronomic and Fiber Properties in Cotton Stocks Resistant to Pink Bollworm[1]

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ABSTRACT

Twelve agronomic and fiber properties were studied in six cotton parents (*Gossypium hirsutum* L.) and their hybrid and reciprocal combinations in 1977 and 1978 in insecticide-free environments at Tempe Ariz. Two parents, 'Deltapine 61' (DPL-61) and 'Stoneville 256' (St 256), are commercial cultivars and the other four are race and breeding stocks selected for resistance to pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), in earlier tests. One race stock, Texas 167 (T-167), was similar in all 12 characters with at least one cultivar.

Significant general combining ability (GCA) estimates for most characters suggested that transferring resistance to PBW from T-167 to a cultivar should pose no formidable breeding problems. Significant specific combining ability (SCA) estimates were few and probably of little consequence except perhaps for lint yield in DPL-61 × T-167 in 1977.

A resistant Upland breeding stock, AET-5, did not perform as well in relation to the cultivars as T-167 in 1977 when seed damage from PBW was low, but performed better in 1978, when damage was much higher. Results of the diallel analysis suggest that AET-5 will be more difficult to handle than T-167 as a breeding stock. Apparently, the mechanisms of resistance in T-167 and AET-5 are different. It may be possible to extract a segregate from T-167 × AET-5 hybrids with enhanced resistance, but probably not with agronomic and fiber properties equal to those of the cultivars. The best use for such segregates would be as sources of PBW resistance to be incorporated into superior germplasm. The other two race stocks, T-31 and T-55, were inferior to the cultivars as well as to T-167 and AET-5 for most characters.

***Additional index words:* *Gossypium hirsutum* L., *Pectinophora gossypiella* (Saunders), Host-plant resistance, Diallel analysis, Agronomic characters, Fiber properties.**

BREEDING stocks of cotton, *Gossypium hirsutum* L., that show natural resistance to pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), are usually inferior to commercial cultivars in agronomic and fiber properties (8, 9, 11). Some breeding stocks showing resistance are more desirable than others, however, and afford an opportunity to transfer resistance to cultivars in a relatively short time (13, 15).

We compared differences in combining ability in a previous paper (7), for PBW resistance in two cultivars and four breeding stocks in two diallel experiments. Two of the four breeding stocks, Texas 167 (T-167) and AET-5, showed significant general combining ability (GCA) for low seed damage; specific combining ability (SCA) was not significant.

We report the agronomic and fiber properties of the six parents in this paper, along with a diallel analysis of these properties in the parents, hybrids, and reciprocals. A major objective of this study is to identify breeding stocks with PBW resistance that are most closely related to cultivars and thus of most value in transferring resistance into superior germplasm.

MATERIALS AND METHODS

Seeds of six parents and 15 F_1 hybrid combinations and their reciprocals were planted on 31 Mar. 1977 and 5 Apr. 1978, in a greenhouse at Phoenix, Ariz. The parents included two cultivars, 'Deltapine 61' (DPL-61), and 'Stoneville 256' (St 256); three primitive race stocks, Texas 31 (T-31), T-55, and T-167; and an Upland breeding stock of complex parentage, AET-5 × (108 × Br-2)-7-69 (designated AET-5). The first two race stocks, T-31 and T-55, had been selected with diet bioassays (12), T-167 had been selected with a greenhouse antibiosis test (10), and AET-5 had been selected with field tests (11).

Plants were transplanted at the Arizona State Univ. Farm Laboratory, Tempe, Ariz. on 15 Apr. 1977 and 21 Apr. 1978. Each plot was a single row of 20 plants spaced 46 cm apart; rows were 1 m apart. Alternate rows were drilled with seed of DPL-61, so that each test plot was bordered by guard rows. Normal cultural practices were followed, except that no insecticides were applied.

The experimental design in 1977 was a 6 × 6 triple lattice with three replications. Analysis of 1977 data showed no advantage of the lattice design over a randomized complete block design; hence, 1978 plots were arranged in the latter configuration. Both years' data were analyzed as randomized blocks so that direct comparisons could be made. Means were compared with the use of the restricted L.S.D. test (3).

Date of first flowering was recorded for each of the 20 plants/plot. Plant height was measured and bolls were counted on the first 10 plants/plot. Seedcotton was picked every 2 weeks from all open bolls on the first 10 plants per row from 2 Aug. to 13 Sept. 1977 and from 15 Aug. to 12 Sept. 1978. The fifth (last) harvest was made on 25 Oct. 1977, 42 days after the fourth harvest. The fourth (last) harvest was made 30 Oct. 1978, 48 days after the third harvest.

Seedcotton samples were weighed, and ginned, and the following data were obtained: lint yield, lint percentage, boll size (g seedcotton/boll), and seed index (100-seed weight, g). The following fiber properties were determined at the USDA cotton fiber testing laboratory, Phoenix, Ariz.: 2.5% and 50% fiber span length, T_1 fiber strength, E_1 fiber elongation, and micronaire (fiber fineness).

Griffing's (4) model 1 (fixed effects), method 1 (parents, hybrids, and reciprocals) analysis was used to estimate general (GCA) and specific (SCA) combining abilities (in 1978, the wrong plants had been transplanted into the AET-5 plots, so AET-5 data were obtained from plots in an adjacent test). The reciprocal effects of Griffing (4) with $p(p-1)/2$ df were divided into maternal effects with $p-1$ df and into "specific" reciprocal effects with $(p-1)\ (p-2)/2$ df (5).

RESULTS

The two cultivars, DPL-61 and St 256, were similar in agronomic characters except that the former yielded more lint and slightly more bolls/plant and had larger bolls than the latter (Table 1). T-167 compared favorably with at least one of the cultivars in every character. AET-5 yielded less lint, had fewer bolls/plant and smaller bolls and seeds than either cultivar in 1977. AET-5 compared more favorably to the culti-

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Table 1. Lint yield, lint and seed-yield components, and GCA estimates for two cultivars and four breeding stocks of cotton, Tempe, Ariz., 1977 and 1978.

Parent	Lint yield		Lint percentage		Bolls/plant		Boll size		Seed index	
	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
	kg/ha		%		no.		g			
Means†										
DPL-61	1,336 a	1,201 a	37.5 bc	40.3 a	32.0 a	26.7 a	4.4 a	4.5 a	10.4 b	9.3 cd
St 256	1,123 b	662 c	37.2 c	39.7 a	28.5 ab	20.3 b	4.1 b	4.1 ab	10.1 b	9.8 bc
T-167	1,063 b	1,064 ab	39.1 a	40.2 a	24.0 bc	27.3 a	4.3 ab	4.2 a	10.0 b	10.2 b
AET-5	678 c	909 bc	38.4 ab	39.1 a	22.1 c	24.0 ab	3.5 c	3.4 b	9.1 c	8.8 d
T-31	480 d	387 d	29.8 d	33.4 b	15.5 d	11.3 c	4.4 ab	4.6 a	12.3 a	12.1 a
T-55	258 e	130 e	27.0 e	24.7 c	11.5 d	8.3 c	2.7 d	2.4 c	10.0 b	9.9 bc
GCA effects										
DPL-61	160*	126*	1.5*	2.1*	2.8*	1.8*	0.15*	0.15*	0.22*	−0.25*
St 256	143*	29	1.4*	0.9*	2.8*	1.2	0.04	0.05	−0.14*	−0.06
T-167	76*	175*	1.9*	1.7*	1.4*	2.4*	−0.03	0.08	−0.35*	−0.20*
AET-5	−10	81*	2.4*	1.9*	0.1	2.3*	−0.10*	−0.03	−0.37*	−0.40*
T-31	−57*	−99*	−2.4*	−1.5*	−1.8*	−3.0*	0.42*	0.29*	0.90*	0.96*
T-55	−312*	−310*	−4.7*	−5.1*	−5.2*	−4.6*	−0.47*	−0.54*	−0.27*	−0.06
Standard errors										
GCA effects	8	24	0.5	0.3	0.5	0.5	0.05	0.08	0.06	0.08
GCA-diff. bet. parents	12	37	0.8	0.5	0.8	0.8	0.08	0.12	0.10	0.13

* GCA effect significance ($t = 1.994$; 70 df) at the 0.05 level of probability. † Means with letters in common, within year and column, are not significantly different according to restricted L.S.D. tests at the 0.05 level of probability.

Table 2. Days to first flower, plant height, and GCA estimates in two cultivars and four breeding stocks of cotton, Tempe, Ariz., 1977 and 1978.

Parent	First flower (days after planting)		Plant height	
	1977	1978	1977	1978
	days		cm	
Means†				
DPL-61	76.8 b	74.3 bc	90.2 cd	76.3 cd
St 256	76.4 b	79.0 a	84.1 de	76.7 cd
T-167	74.8 b	76.3 b	99.5 c	86.3 c
AET-5	71.3 c	73.3 c	76.7 e	71.0 d
T-31	80.0 a	74.7 b	129.3 b	102.3 b
T-55	77.5 ab	80.3 a	162.4 a	132.7 a
GCA effects				
DPL-61	0.1	−0.8*	−11.3*	−7.8*
St-256	−0.4	0.6*	−12.5*	−9.8*
T-167	−0.9*	0.1	−7.8*	−5.1*
AET-5	−1.3*	−0.6*	−14.8*	−12.2*
T-31	1.1*	−0.3	2.8*	1.8
T-55	1.3*	1.2*	43.7*	33.2*
Standard errors				
GCA effects	0.3	0.2	0.9	1.2
GCA-differences between parents	0.5	0.3	1.5	1.9

* GCA effect significant ($t = 1.994$; 70 df) at the 0.05 level of probability.
† Means with letters in common, within years and columns, are not significantly different at the 0.05 level of probability.

vars in 1978, however, probably because seed damage from PBW was higher and the resistance of this breeding stock was manifested. T-31 and T-55 were inferior in every character with the exception of the large boll size of the former and the large seed size of the latter. T-31 had significantly larger seeds than the cultivars, which may or may not be desirable.

In 1977, when PBW damage was low ($\bar{X} = 5.7\%$), both cultivars and T-167 showed significant GCA in a favorable direction for lint yield and for two of the three lint yield components (Table 1). Only DPL-61 showed favorable GCA for boll size. GCA in a favorable direction was significant in AET-5 only for lint percentage. GCA in T-31 and T-55 was significant in an unfavorable direction, except for boll size in the former. DPL-61 and T-31 showed significant GCA for larger seeds and the other four entries showed significant GCA for smaller seeds.

In 1978, when seed damage was much higher ($\bar{X} = 21.5\%$), DPL-61 was the only parent with significant favorable GCA for lint yield and all three yield components (Table 1). AET-5 and T-167 had favorable GCA for all but boll size while St 256 had favorable GCA only for lint percentage. T-31 had unfavorable GCA for every character except boll size and T-55 had unfavorable GCA for every character. Only T-31 had significant GCA for larger seeds; DPL-61, T-167, and AET-5 had significant GCA for smaller seeds. Because of their poor performance, T-31 and T-55 will not be considered further.

DPL-61 was the best combiner for lint yield and yield components but, in 1977, St 256 was not a significantly poorer combiner than DPL-61 for yield, lint percentage, and bolls/plant, while T-167 was not significantly poorer in the latter two parameters. T-167 and AET-5 in 1978 equalled DPL-61 in GCA for lint yield, lint percentage, and bolls/plant, but not in boll size (Table 1).

Plants of AET-5 flowered significantly earlier in 1977 than those of the other parents and were significantly shorter than all but those of St 256 (Table 2). Plants of AET-5 flowered earlier in 1978 than all but DPL-61 and were significantly shorter than the three Texas race stocks. GCA was significant for early flowering in T-167 and AET-5 in 1977 and for DPL-61 and AET-5 in 1978. GCA also was significant for short stature in the two cultivars, T-167, and AET-5, in both years.

T-167 was inferior to DPL-61 in 1977 in 2.5% fiber length and T_1 strength but was equal in fiber elongation (Table 3). Micronaire was lower in T-167 than in DPL-61 but probably was acceptable. T-167 was equal to St 256, on the other hand, in T_1 strength and micronaire, and higher in fiber elongation. AET-

Table 3. Fiber properties and GCA estimates for two cultivars and four breeding stocks of cotton Tempe, Ariz., 1977 and 1978.

	2.5% Fiber span length		50% Fiber span length		T_1 Fiber strength		E_1 Fiber elongation		Micronaire	
Parent	1977	1978	1977	1978	1977	1978	1977	1978	1977	1978
	mm				mM/tex		%			
Means†										
DPL-61	28.2 a	27.2 ab	14.7 a	13.5 a	224.9 a	179.8 bc	7.5 a	7.2 ab	4.75 b	4.83 bc
St 256	28.4 a	27.4 a	14.5 a	13.5 a	182.8 cd	163.1 c	4.9 c	5.2 c	4.28 c	4.50 bc
T-167	26.9 b	26.4 b	13.7 ab	13.0 ab	186.7 c	171.0 bc	7.7 a	7.5 a	4.01 cd	4.52 bc
AET-5	25.1 c	24.4 c	13.0 bc	12.7 bc	175.3 d	197.5 a	5.1 c	7.0 ab	4.22 c	4.90 b
T-31	23.9 d	23.4 d	12.4 c	12.2 c	201.8 b	174.6 bc	6.9 b	6.8 b	3.68 d	4.31 c
T-55	20.3 e	19.1 e	10.9 d	10.7 d	218.8 a	182.2 ab	6.4 b	5.2 c	5.36 a	6.23 a
GCA effects										
DPL-61	1.3*	0.8*	0.6*	0.1	4.1*	1.4	0.49*	0.40*	0.06	−0.08
St 256	1.4*	1.2*	0.5*	0.3*	−7.1*	−7.0*	−0.68*	−0.59*	−0.01	−0.02
T-167	0.4*	0.5*	0.1	0.1	−2.8*	−5.3*	0.57*	0.46*	−0.26*	−0.24*
AET-5	0.0	−0.1	0.2	−0.1	−0.1	3.5*	−0.15*	−0.03	−0.06*	0.05
T-31	−0.4*	−0.4*	−0.3*	−0.1	−3.5*	−3.4*	0.03	0.06	−0.29*	−0.25*
T-55	−2.7*	−2.0*	−0.7*	−0.3*	5.0*	13.6*	−0.26*	−0.29*	0.56*	0.55*
Standard errors										
GCA effects	0.1	0.1	0.1	0.1	1.2	1.6	0.05	0.06	0.03	0.05
GCA-differences between parents	0.2	0.1	0.1	0.1	1.8	2.5	0.08	0.09	0.05	0.08

* GCA effect significant (t = 1.994; 70 df) at the 0.05 level of probability.

† Means with letters in common, within years and columns, are not significantly different at the 0.05 level of probability.

5 had shorter and weaker fiber than DPL-61 and T-167 but micronaire was not different from the latter. AET-5 equalled St 256 in strength, elongation, and micronaire. Rankings were similar in 1978 except that AET-5 had greater T_1 strength than DPL-61 but fiber elongation was equal to that of the cultivar.

GCA was significant both years in a favorable direction for 2.5% fiber span length in both cultivars and in T-167, but not significant in AET-5 (Table 3). For 50% span length, GCA was significant only in the two cultivars in 1977 and in St 256 in 1978. On the other hand, GCA was favorable for T_1 strength only in DPL-61, and for fiber elongation only in DPL-61 and T-167. GCA was significant for finer fiber in T-167 and AET-5 in 1977 but only in T-167 in 1978.

Among the four best parents, DPL-61, St-256, T-167, and AET-5, SCA was significant for eight of 72 possible character/hybrid combinations in 1977 and for five in 1978. Two of the eight SCA deviations in 1977 were for lint yield and fiber elongation, and one each was for seed index, 2.5% fiber length, T_1 strength, and micronaire (six of the eight were in one hybrid combination, T-167 × AET-5). Two of the five SCA deviations were for first flower date in 1978, and one each was for bolls/plant, T_1 strength, and micronaire (three of the five were in T-167 × AET-5) (Table 4).

Maternal effects in 1977 were significant for boll size, first flower date, and T_1 strength. Differences in hybrid array means for two of these three characters were not large in spite of the significant maternal effect indicated by the diallel analysis. The hybrid arrays for the third character, boll size, with DPL-61 as pistillate parent, and that with T-31 as staminate parent, had larger bolls than their respective reciprocal hybrid arrays.

Reciprocal effects were significant for the same three characters in 1977. Six of the 15 F_1 combinations showed significant reciprocal differences in at least one of the three characters. However, of the 18 character/hybrid combinations involving the four best parents, only two showed significant reciprocal effects, St 256 × AET-5 for first flower date and T_1 strength, and T-167 × AET-5 for boll size (data not shown).

Table 4. Number of agronomic characters and fiber properties with significant SCA effects in cotton hybrid combinations.

	Characters with SCA effects†	
Hybrid	1977	1978
	no.	
DPL-61 × St 256	0	0
DPL-61 × T-167	1	0
DPL-61 × AET-5	1	0
DPL-61 × T-31	2	2
DPL-61 × T-55	3	2
St 256 × T-167	0	1
St 256 × AET-5	0	1
St 256 × T-31	2	1
St 256 × T-55	3	2
T-167 × AET-5	6	3
T-167 × T-31	1	1
T-167 × T-55	3	2
AET-5 × T-31	4	3
AET-5 × T-55	5	2
T-31 × T-55	3	0

† 12 characters possible in each year/hybrid combination.

Maternal and reciprocal effects were not significant in 1978.

DISCUSSION

The performance of single-cross progenies can be predicted from the performance of their parents if only GCA is significant in a diallel analysis (2). Parental and F_1 performance also should help the breeder to identify parents to use in programs designed to extract superior breeding stocks from advanced-generation progenies. The predictability of future performance will depend upon the ratio of the GCA component of variance to the total genetic variance if SCA is significant (2).

The significant GCA effect for T-167 in a favorable direction for most agronomic and fiber properties encourages us to believe that these properties, along with PBW resistance, could be transferred easily into a good agronomic background. The significant SCA effect for lower lint yield in DPL-61 × T-167 in 1977 (but not in 1978) lessens our ability to predict future yield performance. The significant SCA effect for earlier flowering in St 256 × T-167 in 1978 is probably not important because these parents differ little in maturity characteristics.

AET-5 will probably be more difficult to use as a breeding stock because, in 1977, it showed favorable GCA only for higher lint percentage, earlier flowering, and possibly for micronaire (finer fiber). However, in 1978, under more severe PBW pressure, AET-5 showed favorable GCA for higher lint yield, lint percentage, fiber strength and more bolls/plant. Fortunately, SCA was significant in cultivar × AET-5 hybrids only for fiber elongation (DPL-61 × AET-5, 1977) and for micronaire (St 256 × AET-5, 1978).

It is unlikely that we can extract a breeding stock from T-167 × AET-5 that is equal to the cultivars in agronomic and fiber properties. Neither T-167 nor AET-5 measures up in all characters to the cultivar standards. Also, significant SCA in a high percentage of the characters measured in T-167 × AET-5 suggests that breeding problems may be encountered.

It should be worthwhile, however, to attempt to extract segregates from T-167 × AET-5 hybrid families with enhanced resistance to PBW, then use the synthesized stocks in crossing with cultivars. T-167 and AET-5 were the best general combiners among the six parents for low seed damage by PBW, and SCA was not significant (9). Furthermore, mechanisms of resistance seem to differ in the two stocks. T-167 apparently has a modest amount of antibiosis, as measured by growth and survival of insects in bolls that had been hand-infested with larvae in a greenhouse test (10), or with eggs in the field (6). AET-5 also may have some antibiosis (10), but its main mechanism of resistance seems to be associated with moth nonpreference (antixenosis) for oviposition (6).

Thus, among the many stocks that we have screened for PBW resistance (12, 14), we have identified two that combine resistance with the Upland cotton phenotype. T-167 was collected by Manning and Ware (MW-11) in Guatemala in 1948 (1). Among the 145 collections of *G. hirsutum*, they collected 51 "typical Upland" plants in areas where growers had recently imported seeds from the U. S. for commercial planting or where government agencies had distributed seeds to growers. Therefore, T-167 is probably a deltatype cultivar from the U. S., rather than a race stock in the sense in which that designation usually is used. The antibiosis shown by T-167 when bolls were infested artificially had not been manifested previously in diet bioassays nor in field tests where bolls were naturally infested, except in the two diallel tests reported in this paper and by Wilson and George (7). One may have to infest bolls artificially with PBW eggs or larvae to detect antibiosis in T-167 or in its hybrids, at least until a biochemical basis for this antibiosis is established.

It should be possible to select for resistance by examining seed damage in AET-5 and in its hybrids, however, because AET-5 has consistently shown less damage in the field (11). A more rapid method of evaluating resistance may be to count PBW entrance holes in green bolls if future investigations confirm the presence of a deterrent to oviposition. We must emphasize that these cottons are only moderately resistant to PBW. A cultivar with the combined resistance of T-167 and AET-5 would not be resistant enough to escape PBW damage in the irrigated desert valleys of Arizona and southern California, unless these resistance characters work together in a way not anticipated. Rather, the resistance found in these cottons would presumably add to that conferred by other characters that we have identified (15) and should give rise to breeding stocks with high levels of resistance.

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