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Combining Ability in Cotton for Resistance to Pink Bollworm[1]

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ABSTRACT

Seed damage by pink bollworm (PBW) (*Pectinophora gossypiella* Saunders), to cotton (*Gossypium hirsutum* L.) grown for 2 years at Tempe, Ariz. in insecticide-free environments was determined in six parents and in all of their hybrid and reciprocal combinations. The six parents included two cultivars, 'Deltapine 61' and 'Stoneville 256', three primitive race stocks, Texas 31 (T-31), T-55, and T-167, and an upland breeding stock of complex parentage, designated AET-5. The latter four parents had been selected for PBW resistance in earlier tests. Parents and hybrids grown in 1977 showed significant genetic variability only at the fourth of five harvest dates, whereas those grown in 1978 showed significant variability at all four harvest dates. For both years, at the only directly comparable harvest, general combining ability estimates (GCA) were significant for low seed damage in T-167 and AET-5 and significant for high seed damage in T-55. Significant effects from specific combining ability (SCA) were shown for six of the 15 hybrid combinations for at least one harvest date. The combinations of most interest, cultivar × T-167, cultivar × AET-5, and T-167 × AET-5, showed only GCA effects. Maternal effects were not significant. Significant reciprocal effects at two harvest dates were confined to two hybrid combinations. On the basis of GCA estimates, T-167 and AET-5 should each combine well for low seed damage.

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

WE have used diet bioassays (11), field tests (12), and greenhouse antibiosis tests (9) to identify several primitive races and breeding stocks of cotton (*Gossypium hirsutum* L.) that possess natural resistance to pink bollworm (PBW) (*Pectinophora gossypiella* Saunders). Without exception, these stocks are inferior to commercial cultivars in some agronomic characters and fiber properties. They are valuable as sources of resistance to the insect. Therefore, information on the transmission of resistance to their hybrids is of interest.

Diallel analysis has been used widely to predict the combining ability of parents based on performance of their hybrids. Diallel cross data also have been used to estimate various genetic effects. This latter use has been questioned and is not recommended because assumptions of independent distribution of genes in parents and lack of epistasis are rarely met (1).

The former use, however, can be of value to the plant breeder attempting to select parents to use in producing hybrids. Diallel-cross data also can be useful in a breeding program in which the breeder's primary objective is to transfer specific characters because it can assist him in identifying parents and hybrid combinations that are of most value.

This paper reports the results of diallel analyses of seed damage caused by pink bollworm. It encompasses six parents and their hybrids and reciprocals grown at Tempe, Ariz., for 2 years in insecticide-free environments. The objectives of these experiments were to evaluate several promising stocks, selected for resistance to pink bollworm in previous tests, and to predict their combining ability.

MATERIALS AND METHODS

On 31 Mar. 1977 and 5 Apr. 1978, seeds of six parents and 15 F_1 hybrid combinations and their reciprocals were planted 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 (11), T-167 had been selected with a greenhouse antibiosis test (9), and AET-5 had been selected with field tests (12).

On 15 Apr. 1977 and 21 Apr. 1978 plants were set out at the Arizona State University Farm Laboratory, Tempe. 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 guard rows bordered each test plot. 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. The restricted L.S.D. test (2) was used to compare means.

From 2 Aug. to 13 Sept. 1977 and from 15 Aug. to 12 Sept. 1978 seed cotton was picked every 2 weeks from all open bolls on 10 plants per row. In 1977 the last harvest was made on 25 October, 42 days after the fourth harvest. In 1978, the last harvest was made 30 October, 48 days after the third harvest.

Seedcotton samples were ginned and 200 to 300 seeds per sample were x-rayed (10) to determine amount of seed damage PBW caused. Percentages of damaged seed were determined by counting damaged and undamaged seeds on each radiograph.

Griffing's (3) model 1, method 3 analysis (hybrids only) was used to estimate general (GCA) and specific (SCA) combining ability (parental data were not used because in 1978 we had inadvertantly planted the wrong seeds in the AET-5 plots). The reciprocal effects of Griffing 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 (4).

RESULTS

In 1977 seed-damage percentages were below an arbitrary economic threshold level of 10% (6) at the first four of five harvest dates. Differences among entries were significant only at the fourth harvest date (13 September). In 1978 damage approached 10% at the second harvest (29 August) and increased thereafter. Differences among entries were significant at all four dates.

At fourth harvest in 1977, neither the race stocks nor AET-5 had significantly less seed damage than the cultivars (Table 1). T-55 had more damage than DPL-61 and T-167. Among the hybrid-array means,

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Table 1. Seed damage caused by pink bollworm in six parents and 30 hybrid combinations of cotton in one harvest each of 1977 and 1978 at Tempe, Ariz.

	Seed damage			
	Self or cross	Reciprocal	Self or cross	Reciprocal
Parent or hybrid	13 Sept. 1977		12 Sept. 1978	
	%			
DPL-61	5.2 f-m*		23.0 c-i	
DPL-61 × St 256	4.6 g-n	5.2 f-m	22.2 e-j	20.1 g-k
DPL-61 × T-31	10.4 a	5.6 e-m	18.0 h-l	18.0 h-l
DPL-61 × T-55	8.9 a-f	10.1 a-c	32.1 a-c	35.5 ab
DPL-61 × T-167	3.7 j-n	3.9 i-n	18.2 h-l	12.9 kl
DPL-61 × AET-5	3.9 i-n	4.1 h-n	15.7 h-l	16.0 h-l
St 256	5.7 e-m		19.6 g-l	
St 256 × T-31	6.3 c-l	5.5 e-m	23.2 c-i	17.0 h-l
St 256 × T-55	9.7 a-d	6.4 b-k	30.5 a-e	37.8 a
St 256 × T-167	3.2 j-n	2.6 k-n	17.4 h-l	20.0 g-l
St 256 × AET-5	2.4 l-n	5.1 f-m	14.4 i-l	17.9 h-l
T-31	8.3 a-g		22.9 d-i	
T-31 × T-55	7.1 a-j	4.3 h-n	32.1 a-c	24.5 c-h
T-31 × T-167	5.3 e-m	2.0 mn	22.7 d-i	12.3 kl
T-31 × AET-5	3.3 j-n	7.9 a-h	16.1 h-l	15.9 h-l
T-55	9.2 a-e		26.4 b-g	
T-55 × T-167	7.7 a-i	10.3 a	24.6 c-h	19.6 g-l
T-55 × AET-5	8.0 a-h	6.7 a-j	31.3 a-d	32.4 a-c
T-167	3.4 j-n		13.2 j-l	
T-167 × AET-5	1.1 n	2.4 l-n	10.8 l	15.8 h-l
AET-5	6.0 d-l		–	

* Means, within date, with letters in common are not significantly different at the 0.05 level of probability according to restricted L.S.D. test.

T-55 ♂ had more damage than T-167 ♂, AET-5 ♂, and T-167 ♀. Seed damage in T-55 ranked highest at the second, third, and fourth harvest dates. Damage in T-167 ranked lowest or next to lowest at all five dates.

In 1978 T-167 had less seed damage than DPL-61 (but not less than St 256) at the first and third harvest dates, and ranked lowest among all entries for the first three dates (Table 1). DPL-61 had significantly less seed damage than all entries but T-167 at the fourth harvest date. T-55 ranked highest or second at the first three dates and had significantly more damage than T-167 at the second and third dates. AET-5 was not represented in the 1978 plots because the wrong seed source had been used. Genuine AET-5 and DPL-61 were planted in another test in the same field; the former had significantly less seasonal seed damage than the latter (30.2 vs. 41.9%), as had been true in previous years (12).

Among the hybrid-array means in 1978, damage in T-55 ♀ at third harvest date was significantly higher than in the other ♀ and ♂ arrays except in St 256 ♂ and T-55 ♂ (Table 1). Damage was higher in T-55 ♂ than in all but DPL-61 ♀ and ♂, St 256 ♀ and ♂, and T-31 ♀. Differences in hybrid arrays were not significant at the other harvest dates.

We directly compared each parental and hybrid mean from fourth harvest, 1977 (13 September), with those from third harvest, 1978 (12 September) (Table 1). In 1977 the only entry with significantly less damage than that in the cultivars was T-167 × AET-5 F_1. One race stock, T-55, and four hybrid combinations, three involving T-55, had more damage.

Table 2. Mean squares from the analysis of seed damage data in cotton parents and hybrids in 6 × 6 complete diallel tests, Tempe, Ariz., 1977 and 1978.

		Harvest date				
		13 Sept. 1977	15 Aug. 1978	29 Aug. 1978	12 Sept. 1978	30 Oct. 1978
	df	Mean squares				
Replications	2	78.95**	1.62	32.37	381.78**	315.72**
Entries	35	20.29**	3.77**	38.38**	155.75**	211.70*
GCA	5	47.13**	5.29**	72.44**	573.46**	244.13
SCA	15	20.00**	4.77**	74.40**	117.57**	202.24
Mat.	5	5.70	2.73	3.86	57.29	104.88
Reciprocal	10	14.43**	2.63	6.05	30.48	257.42*
Error	70	5.38	1.42	19.34	24.37	126.85
GCA						
DPL-61		0.44	0.25	1.34	−0.51	
St 256		−0.55	0.55*	−0.57	0.61	
T-31		0.19	−0.64*	0.48	−1.52	
T-55		2.18*	0.57*	2.85*	8.31*	
T-167		−1.26*	−0.40	−2.25*	−3.93*	
AET-5		−0.98*	−0.33	−1.85*	−2.93*	

*,** $P \leq 0.05$ and 0.01, respectively.

Table 3. Differences in estimates for general combining ability in two cultivars, three Texas race stocks, and an upland breeding stock of cotton resistant to pink bollworm.

		Parent 2 (P_2)				
Parent 1 (P_1)	Year	St 256	T-31	T-55	T-167	AET-5
		GCA P_1-P_2				
DPL-61	1977	1.48	0.37	−2.59*	2.54*	2.12*
	1978	−0.79	0.71	−6.21*	2.38*	1.70
St 256	1977		1.10	−4.07*	1.06	0.64
	1978		1.50	−5.42*	3.20*	2.49*
T-31	1977			−2.97*	2.16*	1.75
	1978			−6.92*	1.70	0.99
T-55	1977				5.13*	4.72*
	1978				8.62*	7.92*
T-167	1977					−0.42
	1978					−0.70

* Difference between GCA estimates for P_1 and P_2 are significant at 0.05 level of probability according to t-test, 58 df. (A significant positive difference means that P_2 combines better than P_1; a significant negative difference means that P_1 combines better than P_2).

In 1978 T-167 and T-167 × AET-5 (but not the reciprocal) had less seed damage than DPL-61 but not less than St 256 (Table 1). No other parent had significantly different levels of damage than DPL-61, but two hybrid combinations (involving T-55) had significantly more damage.

In 1977 GCA and SCA were significant only on the fourth harvest date (Table 2). In 1978, GCA and SCA were significant on the first three harvest dates but not on the fourth harvest date (Table 2).

Comparison of differences in GCA estimates between each pair of parents (Table 3) showed that T-55 combined much more poorly than all other parents in both years. T-167 combined better than all other parents except AET-5 both years, St 256 in 1977, and T-31 in 1978. AET-5 combined better than DPL-61 in 1977 and St 256 in 1978.

In 1977 three hybrids showed significant SCA effects (Table 4). In 1978 these same three plus three others showed significant SCA effects at one or two harvest dates. These effects were, however, inconsistent (Table 4).

Table 4. Significant estimates of specific combining ability (SCA) in 30 hybrid combinations of cotton.

Hybrid combination	SCA estimate*			
	13 Sept. 1977	15 Aug. 1978	29 Aug. 1978	12 Sept. 1978
DPL-61 × St 256	NS	0.73	NS	NS
DPL-61 × T-31	1.86	−1.31	7.47	NS
St 256 × T-55	NS	NS	NS	3.51
T-31 × T-55	−2.38	1.13	NS	NS
T-55 × T-167	2.27	−0.99	NS	−3.42
T-55 × AET-5	NS	NS	NS	4.03

* SCA estimates listed are significantly different from zero at the 0.05 level of probability.

Maternal effects were not significant. The significant reciprocal effects at fourth harvest dates both years were confined to DPL-61 × T-31 and T-31 × AET-5 in 1977 and DPL-61 × St 256 in 1978.

DISCUSSION

Reliable data from field populations of insects are difficult to obtain because distribution patterns are sometimes erratic and numbers of insects vary. In 1977 significant genetic variability was shown at only one of five harvest dates. Fortunately, 1978 insect populations were higher and experimental error was lower so that significant genetic variability was revealed at all four harvest dates.

Data from the middle harvest dates were probably more reliable than those from first or last harvest dates. In the former, insect populations were low and in the latter, only remnant seedcotton was picked several weeks after the last of the sequential biweekly harvests. We chose to directly compare the harvests of 13 Sept. 1977 and 12 Sept. 1978 because plants were comparable in maturity at those dates. Even though damage percentages were quite different ($\overline{X}$=5.7% in 1977 and 21.5% in 1978), results of analyses were similar. These results increase our confidence in the value of stocks selected as parents in the breeding program.

The diallel analysis can be used to determine the importance of SCA and predict future performance of parents on the basis of performance of their hybrids. In the absence of significant SCA effects, performance of single-cross progenies can be predicted from GCA estimates of parental stocks (1).

In our tests SCA estimates were significant for six of the 15 hybrid combinations at one or more harvest dates. Fortunately, the combinations of greatest interest, cultivar × T-167, cultivar × AET-5, and T-167 × AET-5, showed no significant SCA effects. Therefore, we could predict future performance of these parents based on GCA estimates.

Two parents that showed significant GCA for low seed damage, T-167 and AET-5, were also fortunately nearer to the cultivars in agronomic characters and fiber properties (6, 12) than T-31 and T-55 (8). Seed damage in cultivar × T-167 and cultivar × AET-5 hybrids and reciprocals always ranked lowest among the cultivar × "other entry" combinations. Furthermore, in both years seed damage to T-167 × AET-5 ranked lowest among all parents and hybrids and its reciprocal ranked next to lowest. T-31 showed no consistent advantage in GCA. T-55 had more seed damage (7) and was a consistently combined poorly at Tempe in spite of its antibiosis in diet bioassay (11) and its lower seed damage in Puerto Rico during the short winter days (13).

The diallel analysis predicts performance of parents combined in single-cross hybrids. Our data could possibly be useful in that respect because hybrid cottonseed production requires adequate populations of insect pollinators, thus necessitating reduced use of insecticides for the control of insect pests (5).

For our immediate purposes, however, we are interested in identifying donor parents that could be used to transmit PBW resistance to agronomically acceptable genotypes and in identifying hybrid combinations from which we may extract segregates with higher levels of resistance. Our results have yielded two stocks and one hybrid combination that apparently meet these requirements, T-167, AET-5, and T-167 × AET-5, and two stocks that apparently do not, T-31 and T-55. However, resistance in the best of these stocks or hybrids is only slightly to moderately better than that in the cultivars. Work underway will determine the transmissibility of resistance from T-167 and AET-5 into advanced-generation hybrids and the practicability of stabilizing this resistance in cultivars of upland cotton.

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