Relative Resistance of Cotton Lines to Pink Bollworm

F. Douglas Wilson*

ABSTRACT

Pink bollworm (PBW), *Pectinophora gossypiella* Saunders, is a serious insect pest of cotton, *Gossypium hirsutum* L., in the irrigated deserts of the southwestern USA. Several sources of resistance to PBW have been identified in cotton. The objectives of this study were to determine whether certain other sources are equal or superior to a resistance standard, AET-5 (as shown by the amount of seed damage sustained by the plants), and whether F_1 hybrids show higher levels of resistance than expected based on parental response. A series of diallel and generation-mean experiments was grown in the field at Tempe and Maricopa, AZ, from 1982 to 1987. No insecticide was applied. The diallel analyses revealed significant general and specific combining ability (GCA and SCA) and reciprocal effects, as well as year × GCA and year × SCA interactions, which complicated the interpretation of the data. However, it was clear that of the 13 lines evaluated, only Stoneville 7A okra leaf was equal to AET-5 as a source of PBW resistance. The line 7203-14-104, while showing some PBW resistance, was inferior to AET-5. Furthermore generation-mean analysis of AET-5 × 7203-14-104 data revealed large nonadditive genetic effects, which would make it difficult to combine or transfer resistance. Texas 39C-1-L behaved inconsistently with respect to PBW resistance; however, this line has a higher yield potential than AET-5 and, from this standpoint, deserves continued evaluation. No F_1 hybrid and only one F_1 reciprocal hybrid had significantly lower seed damage than that of the lowest parent.

A N ADVANCED breeding line of upland cotton designated AET-5 shows a significant level of resistance to PBW and is used as a resistance standard in our experiments (Wilson and Szaro, 1988; Wilson et al., 1980). A number of other cotton lines have also shown resistance to the insect (Wilson et al., 1981). The resistance of AET-5 and certain other lines is not caused by a visible trait, such as the nectariless trait (Wilson et al., 1981). However, resistance has been identified by comparing the amount of seed damage done to experimental lines with the amount done to a susceptible check (Wilson and George, 1985).

The question arose as to the relative resistance to PBW of AET-5 and several other day-neutral lines. A diallel experiment is an effective method of comparing parents for GCA for resistance (low seed damage), as well as for identifying hybrid combinations that show SCA for a higher level of resistance than expected based on the response of the parents (Baker, 1978). Including the parents in the diallel experiment also allows direct comparison of their response to PBW attack (Wilson and George, 1979). A generation-mean analysis subdivides the genetic differences between two parents and assists the breeder in deciding on a strategy to combine or transfer desired traits.

In this paper, results are presented of a series of diallel and generation-mean experiments. Objectives were to determine whether certain of the other identified sources of PBW resistance are equal or superior in resistance to the resistance standard, AET-5, and whether any F_1 hybrids show higher levels of resistance than expected based on parental response.

MATERIALS AND METHODS

The 13 cotton cultivars, breeding stocks, and germplasm lines used as parents had shown resistance to PBW or had been used as checks in earlier experiments (Wilson et al., 1981). We used AET-5 as a resistance standard and 'Deltapine 61' as a susceptible standard. The four 7203-14 lines (-4, -7, 103, and -104) have a pedigree similar to that of AET-5 (W.D. Fisher, 1981, Univ. of Arizona, personal communication); 7203-14-104 sustained the least seed damage of the four lines in initial experiments and did not differ significantly from AET-5 (F.D. Wilson, 1980, unpublished data). 'DES 24-8 nectariless' (DES 24-8N) and 'Stoneville 825' (ST 825) are expected to show resistance in large plots because of the nectariless trait, but not in small plots contiguous with nectaried cotton. Texas 39 (T-39) showed resistance in a laboratory bioassay, but gave equivocal results in the field (Wilson and George, 1984; Wilson and Wilson,

1975). The T-39 plants selected individually in a PBW-infested field separated a susceptible line, T39C-1-H from two lines, T39C-1-L and T39B-2-L, that showed some resistance. The latter two did not differ significantly from AET-5 in seed damage (Wilson and George, 1984). Stoneville 7A okra leaf (ST 7A okra leaf) sustained less seed damage and had fewer PBW entrance holes per boll than its normal-leaf counterpart (Wilson, 1986; Wilson et al., 1986). Stoneville 7A okra leaf had never been compared directly with AET-5 before the 1982 diallel experiment.

A 6 × 6 complete diallel experiment (six parents, 15 F_1 and 15 reciprocal F_1 hybrids) was grown in 1982 and repeated in 1983 (Diallel I). A second experiment was grown in 1984 and repeated in 1985 (Diallel II). A 6 × 6 half-diallel experiment was grown in 1986 and repeated in 1987 (Diallel III). A generation-mean experiment (two parents, F_1, F_2, and backcrosses to both parents) was grown in 1983 and repeated in 1984 (Genmean I); a second was grown in 1983 (Genmean II). The 1982-to-1984 experiments were grown at the Arizona State Univ. Farm Laboratory at Tempe on a Contine clay loam (a fine, mixed, hyperthermic Typic Haplargid). The 1985-to-1987 experiments were grown at the Univ. of Arizona Maricopa Agric. Ctr. at Maricopa on a Casa Grande sandy clay loam (a fine-loamy, mixed, hyperthermic Typic Natrargid). Natural populations of PBW were relied upon to infest the plots except in 1987, when the plots were sprayed with PBW eggs obtained from the Western Cotton Res. Laboratory rearing facility (Wilson and Szaro, 1988).

For all experiments, seeds were planted in a greenhouse at Phoenix, AZ, and seedlings were transplanted to the field 2 wk later. Plot size was one row with 20 plants. Plants were spaced 46 cm apart in the row; rows were spaced 1 m apart. To standardize border effects, each transplanted experimental row was bordered on both sides by a drilled row of Deltapine 61. Cultural practices were standard, except that no insecticides were used. The experimental design was a randomized complete block, with three replications for the diallel experiments and five replications for the generation-mean experiments. For the diallel experiments, seedcotton from 10 plants per plot was harvested every 2 wk as soon as bolls started to open and until all bolls had opened. For the generation-mean experiments, seedcotton was harvested from each plant. The number of plants per generation was 93 to 100 for parents, 99 to 100 for F_1, 176 to 200 for F_2, and 98 to 100 for the backcrosses. Seedcotton was weighed and ginned, and lint and seed samples were weighed. A volumetric (35 mL) sample of seed was drawn from each plot sample and X-rayed. Radiographs were prepared, and undamaged and damaged seed were counted to estimate percent seed damage (Wilson and George, 1985).

Data were analyzed by analysis of variance (ANOVA). Means were compared with the use of the FLSD test (Carmer and Swanson, 1971). For the diallel analysis, Griffing's (1956) Method 1 was used for the 1982-to-1985 diallel data and his Method 2 was used for the 1986 and 1987 data. A fixed model (Model I) was assumed. The relative importance of GCA and SCA was estimated by the ratio GCA/(GCA + SCA), where GCA and SCA represent the components of mean squares for each of these two sources of variability (Griffing, 1956; Baker, 1978). The methods of Rowe and Alexander (1980) were used to analyze the generation-mean data.

RESULTS

Combined analysis of data from Diallel I (1982 and 1983) showed that effects were significant for years (Y), GCA, SCA, reciprocal crosses (R), and all Y interactions (Table 1). Results were similar for Diallel

Table 1. Diallel analysis for percent seed damage caused by pink bollworm to parents and F_1 hybrids of cotton.

		Percent seed damage			
		Mean squares		Mean squares	
		Diallel I	Diallel II		Diallel III
Source	df	(1982–1983)	(1984–1985)	df	(1986–1987)
Years (Y)	1	90 128.6**	17 756.9**	1	3 036.1**
Reps/Y	4	157.9	16.3	4	16.6
Entries (E)	35	111.4**	25.1**	20	83.9**
GCA‡	5	425.3**	108.1**	5	235.5**
SCA‡	15	68.9**	15.0**	15	33.3**
Reciprocal (R)	15	49.3*	7.5	—	—
Y × E	35	85.7**	13.7**	20	53.3**
Y × GCA	5	264.2**	20.0**	5	112.3**
Y × SCA	15	65.1**	20.2**	15	33.6**
Y × R	15	46.7†	5.0	—	—
Error	140	28.1	6.9	80	10.9

*,**,† Significant at the 0.05, 0.01, and 0.10 levels of probability, respectively.
‡ GCA = general combining ability; SCA = specific combining ability.

II (1984 and 1985), except that R and $Y × R$ were not significant. For Diallel III (1986 and 1987; no reciprocal crosses), all effects were significant.

In 1982, mean seed damage was significantly lower for ST 7A okra leaf than for all other parents except DES 24-8N (Table 2). In 1983, AET-5 and T-39 had significantly lower seed damage than all other parents except ST 7A okra leaf. No F_1 or reciprocal had significantly less seed damage than the lowest parent in 1982 or 1983. As shown by significant GCA estimates, both AET-5 and ST 7A okra leaf were better combiners for low seed damage than were 7203-14-104 and T-39 in 1982, and better than all other parents in 1983. No F_1 combination showed significant SCA in 1982 and only one showed significant SCA in 1983. The reciprocal effect was significant for only one comparison in 1982, and for three others in 1983.

In 1984, AET-5 had significantly lower seed damage than did three other parents, and in 1985, AET-5 had significantly lower seed damage than did two other parents (Table 3). Deltapine 61 had significantly more seed damage than the other five parents in 1984 and more than four in 1985. One F_1 reciprocal hybrid (Deltapine 61 × 7203-14-103) had lower seed damage than the lowest parent in 1984, but no other F_1 or reciprocal had lower seed damage than the lowest parent in 1984 or 1985. AET-5 was a significantly better combiner for low seed damage than all other parents except 7203-14-104 in both years. The SCA effect was not significant in 1984, but was significant for two combinations in 1985.

In 1986, ST 825 and T39C-1-L had significantly lower seed damage than T39C-1-H, but not significantly lower than the other three parents (Table 4). In 1987, AET-5 had significantly lower seed damage than the three T-39 lines, but not significantly lower than ST 825 or 7203-14-104. No F_1 had significantly less seed damage than the lowest parent in 1986 or 1987. In 1986, T39C-1-L, AET-5, and 7203-14-104 were better combiners than only T39C-1-H. In 1987, 7203-14-104 was a better combiner than all other parents except AET-5. The SCA effect was significant for three combinations in 1986 and three other combinations in 1987.

Table 2. Means and genetic estimates for percent seed damage in cotton, Diallel I.

Parent or hybrid	Parent code	1982			1983		
		Parent mean	GCA	GCA differs from parent code	Parent mean	GCA	GCA differs from parent code
		%			%		
7203-14-104	1	13.5	0.60	2,6	56.4	5.11**	2,4,5,6
AET-5	2	12.3	−0.89†	1,5	35.1	−6.11**	1,3,4,5
DES 24-8N	3	11.7	0.11	5	59.3	3.51**	2,5,6
ST 825	4	12.7	−0.28	5	55.6	1.63	1,2,6
Texas 39	5	14.3	1.61**	2,3,4,6	41.8	−0.71	1,2,3,6
ST 7A okra leaf	6	8.0	−1.15*	1,5	45.7	−3.43**	1,3,4,5
		F_1	Reciprocal		F_1	Reciprocal	
				%			
1 × 2¶		15.5	11.4		50.1‡	62.6	
1 × 3		13.5	14.5		58.0	63.9	
1 × 4		13.2	9.7		57.2	62.1	
1 × 5		16.1	16.5		63.1§	69.7§	
1 × 6		11.7	13.0		45.2‡	61.7	
2 × 3		9.9	12.4		51.8	49.7	
2 × 4		10.9	11.4		51.9	57.2	
2 × 5		12.9	14.6		46.6	41.3	
2 × 6		9.5	11.0		39.9	50.4	
3 × 4		15.0	12.3		50.3‡	65.0	
3 × 5		16.4	14.4		57.6	65.6	
3 × 6		16.1‡	8.3		55.2	51.1	
4 × 5		11.9	14.5		54.5	50.6	
4 × 6		13.8	13.3		53.2	51.5	
5 × 6		14.8	13.6		48.8	55.4	
Hybrid mean		13.4	12.7		52.2	57.2	
LSD (0.10)			4.2		LSD (0.05)	11.5	

*,**,† GCA (general combining ability) effect significant at the 0.05, 0.01, or 0.10 levels of probability, respectively.
‡ Reciprocal effect significant (0.10 level of probability in 1982, 0.05 in 1983).
§ SCA (specific combining ability) effect significant at the 0.01 level of probability.
¶ Hybrid descriptors use parent codes from Column 2, above.

Table 3. Means and genetic estimates for percent seed damage in cotton, Diallel II.

Parent or hybrid	Parent code	1984			1985		
		Parent mean	GCA	GCA differs from parent code	Parent mean	GCA	GCA differs from parent code
		%			%		
7203-14-4	1	3.4	1.03*	4,5	27.9	1.77*	4,5
7203-14-7	2	3.0	−0.11	5	17.4	0.43	4,5
7203-14-103	3	5.2	0.41	5	18.5	0.41	4,5
7203-14-104	4	5.9	−0.85	1,6	16.5	−1.49*	1,2,3,6
AET-5	5	2.0	−1.93*	1,2,3,6	14.3	−2.40*	1,2,3,6
Deltapine 61	6	9.1	1.36*	4,5	26.0	1.27*	4,5
		F_1	Reciprocal		F_1	Reciprocal	
				%			
1 × 2§		3.6	3.7		23.3	24.5	
1 × 3		5.5	5.5		23.7	24.6	
1 × 4		3.5	4.3		24.1	22.7	
1 × 5		3.7	2.0		19.5‡	18.4‡	
1 × 6		4.9	7.4		23.3	26.5	
2 × 3		3.5	4.5		24.5	25.2	
2 × 4		2.8	2.6		19.6	25.6	
2 × 5		2.5	1.5		22.2	20.7	
2 × 6		6.8	4.6		23.8	25.9	
3 × 4		3.0	6.2		22.0	19.9	
3 × 5		2.9	2.3		21.4†	26.1†	
3 × 6		6.1	2.1		23.2	22.4	
4 × 5		1.7	1.9		20.2	18.1	
4 × 6		3.6	3.5		20.8	21.1	
5 × 6		3.1	4.5		19.4	21.7	
Hybrid mean		3.8	3.8		22.1	22.9	
LSD (0.05)			3.0			5.2	

* GCA (general combining ability) effect significant at the 0.05 level of probability.
†,‡ SCA (specific combining ability) effect significant at the 0.05 and 0.10 level of probability, respectively.
§ Hybrid descriptors use parent codes from Column 2, above.

In Genmean I, 7203-14-104 did not have significantly less seed damage than its sibline, 7203-14-103 (Table 5), but did have less than the check cultivar, Deltapine 61. However, the generation-mean analysis

indicated significant genetic variability between the two parents in 1983 (but not in 1984). Nonadditive effects were larger than additive effects.

In Genmean II, AET-5 had significantly less seed

Table 4. Means and genetic estimates for percent seed damage in cotton, Diallel III.

Parent or hybrid	Parent code	1986			1987		
		Parent mean	GCA	GCA differs from† parent code	Parent mean	GCA	GCA differs from† parent code
		%			%		
Stoneville 825	1	6.0	0.12	4	17.2	0.30	2,3,4
AET-5	2	8.0	−0.38	4	15.1	−2.56**	1,4,5
7203-14-104	3	8.6	−0.74	4	17.1	−3.25**	1,4,5,6
T39C-1-H	4	11.6	2.34**	1,2,3,5,6	41.1	5.38**	1,2,3,5,6
T39C-1-L	5	6.0	−1.37*	4	22.1	0.97	2,3,4
T39B-2-L	6	7.3	0.03	4	21.8	−0.84	3,4

F_1 hybrid means

Parent code	Parent code, 1986					Parent code, 1987				
	2	3	4	5	6	2	3	4	5	6
1	8.6	9.3	12.0	10.3*	9.2	21.0**	12.9	25.1	17.0	17.5
2		8.7	9.7	8.0	9.4		12.5	12.6**	18.3	14.1
3			9.6	6.1	7.9			16.9**	16.1	13.9
4				10.3	15.5**				25.0	20.4
5					5.7*					16.2
	1986 hybrid mean				9.3	1987 hybrid mean				17.3
	LSD (0.05)				4.1	LSD (0.05)				6.5

*,** GCA *or* SCA effect significant at the 0.05 and 0.01 level of probability, respectively.

Table 5. Cotton parental and hybrid mean seed damage and generation-mean (Genmean) analyses.

Generation	Genmean I		Genmean II
	1983	1984	1983
	%		
7203-14-103 (P₁)	43.5ab†	3.8b	—
AET-5 (P₁)	—	—	31.5e
B₁	48.5a	4.1b	37.4cd
F₁	42.1ab	3.7b	37.6cd
F₂	38.5b	5.0b	35.8d
B₂	43.7ab	3.4b	41.3bc
7203-14-104 (P₂)	38.9b	4.6b	44.9b
'Deltapine 61' (check)	46.9a	8.2a	51.7a
Genetic effects:			
Additive (A)	4.0 ± 1.3*	—	11.7 ± 1.2*
Dominance (D)	139.4 ± 18.9*	—	59.2 ± 18.6*
Epistasis:			
A × A	53.3 ± 7.4*	—	25.0 ± 6.9*
A × D	8.6 ± 5.6	—	−10.0 ± 5.8
D × D	−84.6 ± 12.1*	—	−35.2 ± 12.1*

* Genetic effects significant at the 0.05 level of probability.
† Means with letter(s) in common are not significantly different at the 0.05 level of probability, according to the FLSD test (Carmer and Swanson, 1971).

damage than 7203-14-104, and both had less than the Deltapine 61 check (Table 5). Again, the generation-mean analysis indicated that nonadditive genetic effects were larger than additive effects.

DISCUSSION

The value of AET-5 as a source of PBW resistance has been established through comparison with susceptible cultivars, germplasm lines, and certain race stocks (Wilson, 1987; Wilson and George, 1979; 1983), and we have used it as a resistance standard in our experiments. How does AET-5 compare as a source of resistance with other lines also selected for resistance?

The three diallel experiments indicated that of the 13 lines tested, three other lines (besides AET-5) might possess useful levels of resistance: ST 7A okra leaf, 7203-14-104, and T39C-1-L. However, a first impression of these data is that the significant SCA, reciprocal, and yr × genetic effects may not allow firm conclusions about the breeding value of specific cotton lines as sources of PBW resistance.

For example, the GCA/(GCA + SCA) ratio varied from 0.45 to 0.56, indicating that SCA was about as important as GCA in determining the performance of the F_1 progeny (Baker, 1978). Careful examination of the results, however, showed that significant SCA and Y × SCA effects were caused by only 1 of 30 F_1 combinations in 1 of the 2 years for Diallel I and only two F_1 combinations in 1 of the 2 yr for Diallel II. Those effects in Diallel III were caused by 3 of 15 F_1 combinations in 1986 and three others in 1987. In spite of significant SCA estimates, no hybrid (and only one reciprocal hybrid) had significantly less seed damage than that of the lowest parent. The significant reciprocal (R) and Y × R effects in Diallel I were caused by one reciprocal difference in 1982 and three other reciprocal differences in 1983.

Results thus suggest that SCA and R effects and their interactions with Y may not be as important as indicated by initial analyses, because effects tended to be small, even though significant, and were confined to relatively few hybrid combinations.

On the other hand, Y × GCA effects were generally large. In Diallel I, the significant Y × GCA effect apparently occurred mainly because two parents had nonsignificant GCA estimates in 1982 and significant estimates in 1983, whereas one had a significant estimate in 1982 and a nonsignificant estimate in 1983. On the other hand, both AET-5 and ST 7A okra leaf had significant GCA estimates for low seed damage in both years. This result suggests that ST 7A okra leaf is equal to AET-5 as a resistance donor. The germplasm line AET-5L, which carries okra leaf transferred from ST 7A okra leaf into the AET-5 genetic background, had significantly less seed damage than did the normal-leaf AET-5 (Wilson, 1987). These results suggest that combining these two sources of PBW resistance increases the level of resistance.

In Diallel II, the Y × GCA effect was apparently

caused mainly by the relatively minor difference in GCA estimates for 7203-14-104 in 1984 and 1985. The results of Diallel II suggest that 7203-14-104 approaches AET-5 as a valuable source of PBW resistance.

In Diallel III, the significant $Y \times$ GCA effect was caused primarily because AET-5 had a nonsignificant GCA estimate in 1986 and a significant estimate in 1987, while conversely, T39C-1-L had a significant estimate in 1986 and a nonsignificant estimate in 1987. The results of Diallel III again suggest that 7203-14-104 is at least as good a resistance source as is AET-5.

Unfortunately, the other data on 7203-14-104 are not as favorable. In Diallel I, contrary to expectations based on previous results, this germplasm line did not show resistance to PBW. Subsequent examination of the planting records showed that two different seed sources had been used, one for Diallel I and a second for Diallels II and III. Thus, 7203-14-104, as represented by the second seed source, is apparently a good donor of PBW resistance. On the other hand, the generation-mean data (also based on seed from the second source) suggest that 7203-14-104 is not as good a source for PBW resistance as is AET-5. The lack of transgressive segregation for low seed damage in F_2 and backcross populations (data not shown) suggests that the level of resistance would not be increased by combining these two lines. Furthermore, the large estimates of nonadditive genetic effects suggest that transfer or combining of resistance would be difficult.

The comparison of T39C-1-L with AET-5 as a source of PBW resistance was inconclusive, because of equivocal results in 1986 and 1987. On the other hand, T39C-1-L has a high yield potential, apparently equal to that of ST 825 and significantly exceeding that of AET-5 and 7203-14-104 (F.D. Wilson, 1987, unpublished data). For this reason, we continue to use T39C-1-L in our breeding program, even though its level of PBW resistance may not be as high as that of AET-5.

REFERENCES

Baker, R.J. 1978. Issues in diallel analysis. Crop Sci. 18:533–536.

Carmer, S.G., and M.R. Swanson. 1971. Detection of differences between means: A Monte Carlo study of five pairwise multiple comparison procedures. Agron. J. 63:940–945.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. Aust. J. Biol. Sci. 9:463–493.

Rowe, K.W., and W.L. Alexander. 1980. Computations for estimating the genetic parameters in joint scaling tests. Crop Sci. 20:109–110.

Wilson, F.D. 1986. Pink bollworm resistance, lint yield, and lint yield components of okra-leaf cottons in different genetic backgrounds. Crop Sci. 26:1164–1167.

Wilson, F.D. 1987. Pink bollworm resistance, lint yield, and earliness of cotton isolines in a resistant genetic background. Crop Sci. 27:957–960.

Wilson, F.D., and B.W. George. 1979. Combining ability in cotton for resistance to pink bollworm. Crop Sci. 19:834–836.

Wilson, F.D., and B.W. George. 1983. A genetic and breeding study of pink bollworm resistance and agronomic properties in cotton. Crop Sci. 23:1–4.

Wilson, F.D., and B.W. George. 1984. Pink bollworm (Lepidoptera:Gelechiidae): Selecting for antibiosis in artificially and naturally infested cotton plants. J. Econ. Entomol. 77:720–724.

Wilson, F.D., and B.W. George. 1985. Innovations in the X-ray technique of evaluating cotton germplasm for resistance to pink bollworm. USDA-ARS. Rep. ARS-40. U.S. Gov. Print. Office, Washington, DC.

Wilson, F.D., and Jayne L. Szaro. 1988. A rapid field technique for infesting cotton plants with pink bollworm (Lepidoptera:Gelechiidae) eggs. J. Econ. Entomol. 81:959–962.

Wilson, F.D., B.W. George, and R.L. Wilson. 1981. Screening cotton for resistance to pink bollworm. USDA-ARS. ARM-W-22. U.S. Gov. Print. Office, Washington, DC.

Wilson, F.D., B.W. George, K.E. Fry, J.L. Szaro, T.J. Henneberry, and T.E. Clayton. 1986. Pink bollworm (Lepidoptera:Gelechiidae) egg hatch, larval success, and pupal and adult survival on okra- and normal-leaf cotton. J. Econ. Entomol. 79:1671–1675.

Wilson, F.D., R.L. Wilson, and B.W. George. 1980. Resistance to pink bollworm in breeding stocks of upland cotton. J. Econ. Entomol. 73:502–505.

Wilson, R.L., and F.D. Wilson. 1975. A laboratory evaluation of primitive cotton (Gossypium hirsutum L.) races for pink bollworm resistance. USDA-ARS. ARS W-30. U.S. Gov. Print. Office, Washington, DC.