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Pink Bollworm Resistance, Lint Yield, and Earliness of Cotton Isolines in a Resistant Genetic Background[1]

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ABSTRACT

Natural resistance of cotton, *Gosspyium hirsutum* L., to pink bollworm (PBW), *Pectinophora gossypiella* (Saunders), may be increased by combining individual resistance traits. The objectives of this study were to determine: (i) the levels of resistance to PBW, as measured by seed damage, in germplasm lines carrying a single morphological resistance trait in a resistant genetic background; (ii) whether combinations of the morphological traits would increase the level of resistance; and (iii) the effects of those morphological traits in the resistant genetic background on lint yield and earliness. All possible combinations of the mutant traits nectariless (N), smoothleaf (S), and okra leaf (L), and of their normal counterparts in a resistant genetic background (AET-5), were grown for 2 yr in insecticide-free environments at Tempe, AZ. Check cultivars were the nectaried, semismoothleaf 'Deltapine 61' (DPL-61) and the nectariless, semismoothleaf 'Deltapine NSL' (DPL-N). Soil type was a Contine clay loam (fine, mixed, hyperthermic Typic Haplargid). Seed damage, lint yield, and earliness were determined from weekly harvests. The DPL-61 exhibited significantly more seed damage than any other cotton. The AET-5 showed more seed damage than the N, L, NL, and NSL isolines, but not more than the S, NS, or SL isolines or DPL-N. Contrary to expectations, AET-5NL did not have significantly less seed damage than AET-5N or AET-5L. In 1982, when PBW infestations were low, DPL-61 yielded significantly more lint than AET-5 or the isolines (except AET-5NSL). In 1983, when PBW infestations were high, DPL-61 yielded significantly less lint than all but the S isolines. The AET-5 and the N, L, and NL isolines were early maturing. The S isolines matured later and yielded as much lint as AET-5 and the other isolines in 1982, but significantly less in 1983. The low yield potential of AET-5 and of the N, L, and NL isolines emphasize that they should be used mainly as sources of multiple resistance to PBW for incorporation into more agronomically acceptable cottons rather than as cultivars themselves.

Additional index words: **Host-plant resistance, *Gossypium hirsutum* L., *Pectinophora gossypiella* (Saunders), *Bemisia tabaci* (Gennadius), *Trialeurodes abutilonea* (Haldeman), *Bucculatrix thurberiella* Busck, *Lygus hesperus* Knight, Nectariless cotton, Smoothleaf cotton, Okra-leaf cotton, Isolines.**

CULTIVARS with natural resistance to insects offer several advantages over other insect-control methods. Because fewer pesticide applications are required, resistant cultivars should cost less to produce than susceptible ones and their use should result in less environmental trauma. Resistant cultivars exert their effects during the entire growing season, and even into the following season because overwintering insect populations will be lower. In addition, resistant cultivars may be valuable components of integrated pest-management systems because they are compatible with other control methods.

Two simply inherited morphological traits in cotton, *Gossypium hirsutum* L., nectariless (15) and okra leaf (16), impart low levels of resistance to pink bollworm (PBW), *Pectinophora gossypiella* (Saunders). An earlier study (15) indicated that the T_1^{sm} (=Sm_2) smoothleaf trait imparts some resistance to PBW, but later studies failed to confirm that finding (7, 9). Early maturity also offers an escape mechanism from this late-season insect pest (11). Several cottons that are not visibly different from susceptible cultivars for nectaries, pubescence, and leaf shape show an antibiosis type of resistance (8, 12).

The objectives of these studies were to determine: (i) the levels of resistance to PBW, as measured by seed damage (14), in breeding stocks carrying a single morphological resistance trait in a resistant genetic background; (ii) whether combinations of the morphological traits would increase the level of resistance; and (iii) the effects of those resistance traits on lint yield and earliness.

MATERIALS AND METHODS

The reference breeding stocks and cultivars studied were AET-5, a nectaried, hirsute, regular-leaf shape breeding stock, developed by G.A. Niles, formerly of the Texas Agricultural Experiment Station (12), and used as a PBW-resistant standard; 'Deltapine 61' (DPL-61), a nectaried, semismoothleaf (t_3=sm_3), regular-leaf shape upland cultivar used as a susceptible standard; and 'Deltapine NSL' (designated DPL-N to avoid confusion with the smoothleaf and okra-leaf designations), a nectariless, semismoothleaf, regular-leaf shape upland cultivar. The latter two cultivars were developed by Delta and Pine Land Co., Scott, MS, and Casa Grande, AZ. I developed isolines of AET-5 that carried all possible combinations of nectaried vs. nectariless (N), hirsute vs. T_1^{sm} (= Sm_2) smoothleaf (S), and regular leaf shape vs. okra leaf (L)(5).

Field plots were grown in 1982 and 1983 at the Arizona State University Farm Laboratory, Tempe. Soil type is a Contine clay loam (fine, mixed, hyperthermic Typic Hap-

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largid). Plot size was 20 rows, each row being 18 × 1 m. Seed were planted with a four-row mechanical planter in mid-April of each year. Plots were arranged in randomized complete blocks with four replications. Cultural practices were standard for the area except that no insecticides were applied. Plants in rows 9 and 11 of each plot were thinned to a uniform spacing of 30 cm. Seedcotton was hand-harvested once per week from 10 plants of one thinned row per plot, beginning in late August when bolls started to open, until late September (1982 and 1983) then once in late October, 1982. Plots were harvested six times in 1982 but only four times in 1983. Seedcotton was hand-harvested once for a yield estimate, at the end of the season, from a 6-m section of the other thinned row of each plot.

Seedcotton samples from each harvest of the 10-plant plots were weighed and ginned, and lint and seed sample weights were determined. Volumetric seed samples (35 mL) were x-rayed, and the number of undamaged seed and those damaged by PBW were counted on the resulting radiographs (14). Percent seed damage was used as an index of PBW resistance. Lint yields were determined from the 6-m plots; earliness was estimated by calculating the percentages of total lint yield at first, (Harvest 1) first plus second (Harvests 1 + 2), and first plus second plus third harvests (Harvests 1 + 2 + 3).

Data were analyzed by combined ANOVA's. The *F* tests were conducted using a fixed model. Means were compared with the use of the FLSD test (2).

For comparative purposes, seed-damage percentages observed were also expressed as percentages of that observed in the resistant check, AET-5, and in the susceptible check, DPL-61. Seed damage *expected* in the seven isolines, as a percentage of that observed in DPL-61, was calculated as the product of the relative seeed damage in AET-5 itself (79% as much as in DPL-61) and the relative seed damage (compared to AET-5) in a specific isoline. For example, expected seed damage in AET-5N would be 0.79 × 0.78 × 0.62 or 62% as much as in DPL-61. Relative seed damage in an isoline carrying more than one morphological trait e.g., AET-5NS, would be 0.79 × 0.78 × 1.04 = 0.64 or 64% as much as in DPL-61 (see Table 2).

RESULTS

Differences between years (Y) were significant for seed damage caused by PBW, for lint yield, and for two of the three earliness estimates (Table 1). The N and L effects were significant for seed damage, and the S effect was significant for lint yield and earliness. The N × S, S × L, and N × S × L interaction effects were significant (0.10 probability level) for lint yield; N × L was significant for the second earliness estimate; and N × L and S × L were significant (0.10 probability level) for the third earliness estimate. The Y × C (C = cotton) interaction effect was significant for seed damage (0.10 probability level) and for lint yield.

Seed damage was significantly lower in AET-5, in all seven isolines, and in DPL-N than in DPL-61 (Table 2). Also, seed damage was significantly lower in the N, L, NL, and NSL isolines than in AET-5 itself, but not in the S, NS, or SL isolines or in DPL-N. Seed damage was not significantly lower in AET-5NL than in AET-5N or in AET-5L. Except for rounding errors, observed and expected seed damage were equal in the N, S, and L isolines, but observed damage was 5 to 12% higher than expected in the isolines with two or more traits on the AET-5 background.

In 1982, no significant differences in lint yield were detected among AET-5 and the N, S, NS, SL, and NSL isolines (Table 3). DPL-61 yielded significantly more lint, and the L and NL isolines yielded less than AET-5. In 1983, no significant differences in lint yield were detected among AET-5 and the N, L, and NL isolines,

Table 2. Seed damage in AET-5 cotton; in its nectariless (N), smoothleaf (S), and okra-leaf (L) isolines; and in nectaried (DPL-61) and nectariless (DPL-N) semismoothleaf check cultivars.

Cotton	Resistance traits combined	Seed damage: Actual	Percent of: AET-5 Observed	DPL-61 Observed	DPL-61 Expected
	no.	%			
AET-5	1	32.9b†	100	79	–
AET-5N	2	25.6c	78	62	62
AET-5S	2	34.3b	104	83	82
AET-5L	2	24.2c	74	58	58
AET-5NS	3	28.4bc	86	69	64
AET-5NL	3	22.9c	70	55	46
AET-5SL	3	28.6bc	87	69	61
AET-5NSL	4	24.5c	74	59	47
DPL-61	0	41.4a	126	100	–
DPL-N	1	33.4b	102	81	–

† Means with letter(s) in common are not significantly different at the 0.05 level of probability, according to the FLSD test (2).

Table 1. Analyses of variance for seed damage, lint yield, and earliness in AET-5 cotton and in its nectariless (N), smoothleaf (S), and okra-leaf (L) isolines.

Source	df	Seed damage	Lint yield (× 10⁻²)	Cumulative lint yield/total lint yield at designated harvest(s): 1	1 + 2	1 + 2 + 3
Year (Y)	1	29 652.0**	6 137**	27.0	8 461.9*	6 073.7*
Reps w/n Y	6	86.3	236	175.1	635.9**	655.3**
Cotton (C)	7	140.0*	739**	487.2**	1 610.4**	2 263.5**
N	1	344.9*	13	0.1	117.8	110.2
S	1	107.7	2 657**	3 154.2**	9 594.9**	14 068.6**
L	1	441.1**	127	91.5	13.4	38.0
N × S	1	1.8	804†	2.1	231.4	359.5
N × L	1	62.6	158	74.1	1 133.1*	671.4†
S × L	1	3.5	808†	1.5	140.9	584.4†
N × S × L	1	18.3	604†	86.7	41.2	12.6
Y × C	7	120.0†	1 212**	135.4	160.1	71.4
Error	42	54.2	199	142.2	158.0	178.3

*,**,† Effects significant at the 0.05, 0.01, and 0.10 levels of probability, respectively.

Table 3. Lint yield and earliness in AET-5 cotton; in its nectariless (N), smoothleaf (S), and okra-leaf (L) isolines; and in nectaried (DPL-61) and nectariless (DPL-N) semismoothleaf check cultivars.

Cotton	Resistance traits combined	Lint yield 1982	Lint yield 1983	Cumulative lint yield at designated harvests(s) (2-yr mean) 1	1 + 2	1 + 2 + 3
		kg ha⁻¹		%		
AET-5	1	768b-d†	676a	28.1a	54.5ab	77.3ab
AET-5N	2	692de	688a	23.9ab	48.8a-c	73.9ab
AET-5S	2	734c-e	290d	12.4cd	38.4c-e	59.3cd
AET-5L	2	600ef	705a	21.5a-c	49.8a-c	76.2ab
AET-5NS	3	700de	299d	12.2cd	21.9f	44.6e
AET-5NL	3	513f	608ab	26.3a	57.7a	83.9a
AET-5SL	3	647d-f	277d	9.9d	24.5f	44.4e
AET-5NSL	4	863a-c	408cd	9.3d	28.9ef	44.4e
DPL-61	0	964a	368cd	18.5a-d	41.5b-d	68.0bc
DPL-N	1	880ab	491bc	14.9b-d	32.4d-f	51.7de

† Means with letter(s) in common are not significantly different at the 0.05 level of probability, according to the FLSD test (2).

but the S, NS, SL, and NSL isolines, and the two DPL-cultivars yielded less lint than AET-5. The AET-5 parent was not significantly earlier than the N, L, or NL isolines or DPL-61, but it was earlier than the S, NS, SL, and NSL isolines and DPL-N.

DISCUSSION

The previously observed resistant responses of AET-5, N, and L to PBW were reaffirmed (12, 15, 16). The lack of resistance of S, reported by Wilson and George (7, 9), also was reaffirmed and does not agree with earlier suggestions that S showed some resistance to PBW (13, 15).

Actual seed damage of AET-5N, AET-5S, and AET-5L were 62, 83, and 58%, respectively, of that for DPL-61 and equaled the percentages expected if AET-5, N, S, and L exerted their effects independently. Unfortunately, combining AET-5, N, and L did not further reduce seed damage as expected. The AET-5NL isoline had 90, 95, and 55% as much seed damage as AET-5N, AET-5L, and DPL-61, respectively, rather than the 74, 78, and 46% expected (Table 2). However, Wilson (unpublished) found that an early maturing NL isoline of 'DES 56' had 66% as much seed damage as DES 56N, 45% as much as the DES 56 cultivar, and 46% as much as DPL-61. In another study (6), okra leaf interacted strongly with genetic background; okra-leaf lines had 49 to 109% as much seed damage as the regular-leaf shape counterparts.

Combining NL with S ameliorated the susceptibility of S to PBW. Thus, NSL could be of value if S imparted resistance to other insects or had other desirable properties. Butler and Wilson (1) showed that AET-5NSL did not harbor significantly fewer adults of sweetpotato whitefly, *Bemisia tabaci* (Gennadius), than did AET-5NL; but it did harbor significantly fewer adults of bandedwinged whitefly, *Trialeurodes abutilonea* (Haldeman). Wilson (unpublished) observed that AET-5NSL did not have significantly fewer "horseshoes" (resting-stage larvae) of cotton leafperforator, *Bucculatrix thurberiella* Busck. H. M. Flint (1983, personal communication) observed that AET-5NSL shed significantly more squares (flower buds), presumably caused by lygus bugs (*Lygus hesperus* Knight), than did AET-5NL. These data taken together suggest that only for bandedwinged whitefly would the NSL combination be preferred to NL, especially since the S isolines were later maturing and lower yielding.

Mean seasonal seed damage was below the economic threshold for insecticide application for cotton in the experiment in 1982 [$\bar{x}$ = 6.1%, calculated economic threshold for DPL-61 in an earlier experiment was 10 to 18% (3)]. In 1983, however, mean seed damage was unusually high ($\bar{x}$ = 49.2%), exceeding the economic threshold for all entries in the experiment. Therefore, in 1982, no cotton would have required insecticide applications for PBW control; and the resistant isolines would have had no advantage over the susceptible check. In 1983, all cotton would have had to be protected with insecticide to minimize yield loss; but the resistant isolines presumably would have required less of the insecticide. For example, under severe PBW pressure near Brawley, CA, Wilson (unpublished) found that the economic threshold, based on PBW egg counts (4), was not reached in a NL germplasm line until 26 days after DPL-61. The Y × C (year × cotton) effect (0.10 probability level) for seed damage occurred because in 1982 none of the AET-5 isolines exhibited significantly less seed damage than did AET-5, but in 1983 five of the seven isolines had less damage.

As expected, mean lint yield was significantly lower in 1983 because mean seed damage was higher, but some significant interaction effects were shown. The significant Y × C interaction for lint yield occurred because AET-5 and all of the S isolines yielded less lint in 1983 than in 1982, whereas the N, L, and NL isolines actually yielded more lint in 1983 than in 1982, in spite of the much higher seed damage the second year. The N × S, S × L, and N × S × L interaction effects (0.10 probability level) for lint yield occurred largely because AET-5NSL yielded more than expected based on the generally lower yields of the S isolines.

By comparing 1982 and 1983 lint yields of DPL-61 with those of AET-5 and its N, L, and NL isolines, it is possible to illustrate the advantage of PBW resistance and the cost of each resistance trait to yield potential. Under low PBW pressure in 1982 (mean seed damage = 6%) AET-5 and N, L, and NL isolines yielded 80, 72, 62 and 53% as much lint, respectively, as did DPL-61. Under severe PBW pressure in 1983 (mean seed damage = 49%), however, they yielded 180, 187, 192, and 165%, respectively, as much as did DPL-61. Another study (10) showed that lower lint yield potential is not an inevitable consequence of combining PBW resistance characters. A strain that combined resistance from AET-5 and N in a DES 56 background displayed significantly less seed damage (16 vs. 29%, respectively) and a higher lint yield (1486 vs. 1021 kg ha^{-1}, respectively) than did the recurrent parent.

The Y effect was not significant for percentage of total lint yield at first harvest, showing that the first harvest was made both years at a comparable maturity stage. Therefore, the significant Y effect at Harvests 1 + 2 and 1 + 2 + 3 (all cotton was significantly earlier in 1983 than in 1982) were caused by true seasonal differences, rather than being an artifact caused by harvesting plots on arbitrary dates.

The N × L interaction effects for earliness at Harvests 1 + 2 and 1 + 2 + 3 (0.10 probability level) were a result of the considerably earlier maturity of AET-5NL compared to AET-5N and AET-5L. The S × L interaction effect for Harvests 1 + 2 + 3 (0.10 probability level) resulted from the earlier maturity of the L isolines rather than the regular-leaf counterparts in a hirsute background (AET-5L and AET-5NL), but their later maturity in an S background (AET-5SL and AET-5NSL).

This study demonstrated that the level of resistance to PBW was increased by transferring N or L, but not S, into the resistant AET-5 genetic background. Contrary to expectations, however, transferring both N and L into the AET-5 background did not further increase resistance significantly above the level found in either the N or L isolines. This study also showed the yield advantage of AET-5 and the isolines under severe PBW pressure, but emphasized the reduced yield potential of those cottons under reduced PBW populations. Thus, the AET-5 isolines will be of value as sources of multiple resistance to PBW to be incorporated into more agronomically acceptable cottons, rather than as cultivars themselves.

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