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Agronomic and Genetic Analysis of Tarnished Plant Bug Tolerance in Cotton[1]

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ABSTRACT

We investigated at Stoneville, Miss., in 1973, the effects of heavy and light infestations of tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois), on six genetic populations of cotton, *Gossypium hirsutum* L. Mustard *Brassica juncea* (L.) Czern, planted in rows adjacent to cotton, was used to attract and accumulate large numbers of plant bugs. The light infestations of plant bugs were maintained by six early-season insecticide applications. The genetic populations used were 'Stoneville 213,' 'Coker 201,' their reciprocal F_1 and F_2 hybrids, and the reciprocal F_1 backcrosses to the recurrent parents. Lint yield, six yield components, and five fiber properties were determined for plants harvested on four dates: September 12 and 21, October 4, and November 9.

The presence of plant bugs resulted in more terminal damage on small plants, and higher lint percentage and decreased boll size and seed/boll on mature ones. Plant bugs had no effect on seed index, lint index, and fiber properties. The reduced number of bolls/plot caused by plant bugs resulted in decreased lint yields. Lint yield and bolls/plot of the more tolerant cultivar (Stoneville 213) were not appreciably reduced by plant bugs until the last harvest. However, in the less tolerant cultivar (Coker 201) yield and number of bolls/plot were reduced most in the first two harvests.

No reciprocal genetic effects were detected for any characteristic in this study. An analysis of generation means indicated that additive gene action and additive $\times$ additional epistasis, were both significant in accounting for terminal damage. Analyses of generation means for lint yield and bolls/plot indicated that additive gene action was responsible for conferring tolerance to plant bugs. No dominance or epistatic effects involved in tolerance to plant bugs were detected. Once the plants had recovered from the early-season plant bug damage, significant dominance for late-season production was detected.

Additional index words: Host plant resistance, Biological control, Breeding methods, Reciprocal effects.

IN the Mississippi Delta as much of the cotton (*Gossypium hirsutum* L.) growing area in the United States, biological control of tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois), is an essential part of the seasonal insect control program. The pest causes a direct loss in yield, but indirect effects are probably of greater importance. If insecticides are applied in early season to control plant bugs, the probability is greatly decreased that natural predator insects would control mid and late-season insect pests. If insecticides are not applied to control high plant bug populations in early season, the cotton crop is significantly delayed in maturity. Delayed maturity causes the crop to be more vulnerable to adverse weather and to late-season insects such as bollworms, *Heliothis zea* (Boddie); tobacco budworms, *H. virescens* (F.); and boll weevils, *Anthonomus grandis* Boheman.

The use of resistant cultivars in controlling plant bugs is a practical approach. Nectariless cotton offers one effective source of genetic resistance. Meredith et al. (7) and Schuster and Maxwell (10) have reported reductions of about 60% in plant bug numbers because of this trait. Other sources of resistance and tolerance need to be studied.

In this paper, our purpose was to investigate the effects of plant bugs on yield, yield components, and fiber properties. Because relatively few genetic studies of insect resistance or tolerance per se have been reported in cotton, a second objective was to determine the gene action primarily responsible for tolerance to plant bugs.

MATERIALS AND METHODS

In 1973 we evaluated several genetic populations of cotton exposed to heavy and light infestations of tarnished plant bugs. The procedure developed by Laster and Meredith (5) was used to insure large numbers of tarnished plant bugs on desired genetic populations.

Cotton and mustard, *Brassica juncea* (L.) Czern. 'Florida Broadleaf', were planted in a 2 $\times$ 2 row planting pattern. Plant bugs were attracted and increased in large numbers on

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the mustard, and adults and nymphs invaded the adjacent cotton rows when the mustard was cut. This treatment is defined as the "with" plant bugs treatment. The "without" plant bug treatment was achieved by making six applications of dicrotophos (dimethylphosphate ester with (*E*)-3-hydroxy-*N*,*N*-dimethylcrotonamide), 115 g/ha a.i., beginning on June 6 and ending on June 26.

The genetic populations evaluated were two commercial cultivars[3], 'Stoneville 213' and 'Coker 201,' their reciprocal F_1 and F_2 hybrids, and their reciprocal backcrosses: Stoneville 213 × (Coker 201 × Stoneville 213); (Coker 201 × Stoneville 213) × Stoneville 213; Coker 201 × (Stoneville 213 × Coker 201); and (Stoneville 213 × Coker 201) × Coker 201.

A split-plot experimental design was used with two tarnished plant bug levels as whole plots with six replications. Two entries each of the parental cultivars and their reciprocal F_1, F_2, and backcross populations were designated as subplots. The plots were planted May 8 and were one row (1-m wide × 13-m long). Plots were hand thinned to a uniform stand of about 125,000 plants/ha.

The mustard was cut on June 14, when the cotton had grown to about the six-leaf stage. Four days later we determined the percentage of cotton plants expressing terminal damage from 50 plants/plot. Terminal damage was expressed as wilted or blackened necrotic terminal leaves. On June 22, we pulled three plants/plot to determine the number of nymphs/plant.

Seed cotton was harvested four times by hand on the dates indicated in Table 3. Lint yield, six components of yield, and five fiber properties were determined for each harvest. Prior to each harvest, a 40-boll sample was taken from each plot. The samples from replications 1, 2, and 3 were bulked to form one composite sample and those from replications 4, 5, and 6 were bulked to form another.

Lint percentage was determined from these samples as lint/seed cotton. The average lint percentage for each population was multiplied by each plot's seed cotton yield to obtain lint yield/plot. Boll size was estimated by average weight in g/boll. An estimate of seed index was obtained by the weight of 100 seeds from each composite sample. The number of harvestable bolls/plot was determined as (total seed cotton in g)/(composite boll size estimate). Lint index/composite sample was computed as LI = (lint % × seed index) (100 − lint %). The number of seed/boll was computed from each composite sample as (100 − lint %) (boll size)/seed index.

Fiber length was measured as 50 and 2.5% span length on a Digital Fibrograph[3]. The 0.312 cm (1/8 inch) gauge Stelometer was used to determine fiber strength (T_1) and elongation (E_1). Fiber fineness was expressed in micronaire units. Fiber determinations were made by the U.S. Cotton Fiber Lab. of the ARS, USDA, at Knoxville, Tenn.

Genetic analysis of generation means to give unique estimates of additive (A) and dominance (D) effects were obtained by the methods suggested by Hayman (3, 4). These two parameters were estimated as follows:

$$A = (2\ P_1 - 2\ P_2 + BC_1 - BC_2)/5$$

$$D = (-10\ P_1 - 10\ P_2 + 14\ F_1 + 2\ F_2 + 2\ BC_1 + 2\ BC_2)/17.$$

The 5 df for genetic populations were partitioned into a 1 df test for the A and D parameters. The A estimate is essentially the linear regression of performance on additive genetic value; the D estimate is the linear regression of performance on heterozygosity or dominance value. The 3 df remaining involve combined epistatic effects (E). The estimates of A and D are independent and uncorrelated only if E is not significant. We used the F-test to determine significance of all effects and their interactions with tarnished plant bug levels.

[3] Mention of a cultivar, trademark, or proprietary product does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of the other products that may also be suitable.

Table 1. Damage and nymphs on plots with (TPB) and without (OPB) tarnished plant bugs.

	Terminal damage, %		Nymphs/plant	
Population†	TPB	OPB	TPB	OPB
Stv 213	34.0	2.5	0.67	0.00
Cok 201	51.5	2.4	1.22	0.00
F_1	38.2	1.9	0.86	0.06
F_2	30.3	2.5	0.89	0.00
F_1 × Stv	34.0	1.9	0.67	0.00
F_1 × Cok	47.5	2.5	0.50	0.00
Mean	39.2*	2.4	0.80*	0.01
L.S.D. (0.01)	8.4	ns	ns	ns

* Significantly higher than OPB at 0.01 probability level. † Stv = Stoneville and Cok = Coker.

RESULTS AND DISCUSSION

To estimate the various agronomic and genetic effects of plant bugs in this study, it was essential to establish two levels of insect populations (high and low). Nymph counts made 8 days after the mustard was cut (Table 1) showed that we were successful. The high population plots averaged 0.80 nymphs/plant, and the minimum treatment averaged 0.01 nymphs/plant. As indicated in Table 1, the large number of adult and nymph plant bugs caused significantly more terminal damage, 39.2 compared to 2.4% for the minimum-number treatment. Also, genetic differences in tolerance to plant bugs were evident in plots with a high level of plant bugs. Coker 201 and the backcross to Coker 201 sustained significantly more terminal damage than the other four populations. This difference in tolerance between Coker 201 and Stoneville 213 is consistent with previous field observations and the results reported by Laster and Meredith (5).

The effects of plant bugs and other variables, and their interactions on lint yield, six yield components, and five fiber properties are given in Table 2. No reciprocal differences for any characteristic were detected. The analysis indicated that there were no interactions of importance involving plant bug level with harvest or genetic populations, except for lint

Table 2. Yield, yield component, and fiber property $\overline{x}^2$ as influenced by tarnished plant bugs, harvests, and genetic populations.

Source†	df‡	Yield, kg/ha	Bolls/plot§	Lint %	Boll size	Seed index	Lint index	Seed/boll	Span length¶ 50%	Span length¶ 2.5%	T_1	E_1	Micronaire
H	3	33,526**	13,943**	208.70**	25.483**	72.71**	1.80	185.4*	3,403	14,340*	46.88	1.31	0.602
H × Rep	3	310	113	0.55	0.206	0.93	0.46	22.4	463	495	4.04	0.30	0.168
PB	1	2,577	488	12.55*	0.670*	1.24	0.19	10.2*	1	110	1.80	0.20	0.211
PB × H	3	2,347**	866**	1.86	0.031	0.46*	0.53	1.9	159	343	1.30	0.11	0.098
Error a	4	138	64	1.03	0.042	0.03	0.31	0.7	33	63	0.29	0.14	0.134
P	5	903	410	2.29**	1.286*	1.80**	0.29**	16.1**	33	172	0.87*	3.55**	0.205**
P × H	15	776	317	0.28	0.057	0.14	0.05	1.6	33*	62**	0.39	0.19	0.034
P × PB	5	113	30	0.32	0.129	0.12	0.09	1.3	29	42	0.18	0.15	0.065
P × H × PB	15	471**	172**	0.10	0.025	0.07	0.03	0.4	11	32	0.32	0.17	0.022
Reciprocal	64	65	28	0.15	0.015	0.11	0.05	1.3	19	39	0.36	0.16	0.19
Within parents	32	79	24	0.16	0.059	0.08	0.05	1.2	17	27	0.24	0.12	0.27
Error b	40	80	29	0.21	0.055	0.13	0.08	2.3	17	18	0.25	0.11	0.043

*, ** Significant at the 0.05 and 0.01 levels, respectively. † H = harvest, PB = plant bugs, Rep = replications, and P = population. ‡ df for H × Rep, error a, reciprocal, within parents, and error b, are 15, 20, 192, 96, and 200, respectively, for yield and bolls/plot. § $x^2 \times 10^{-2}$. ¶ 50% and 2.5% span length × 10^4.

yield and number of bolls/plot. Therefore, these two latter characters will be discussed separately from the remaining 10. Means for these 10 characters are given in Table 3 for the four harvests, two plant bug levels, and six genetic populations. Harvest dates had a more pronounced effect than either plant bug levels or genetic populations. As the season advanced, lint percentage increased. However, all other characteristics tended to decrease or remain constant. This seasonal trend is consistent with previous results reported by Meredith and Bridge (6). The "with" plant bugs treatment produced a small but significant increase in lint percentage and significantly smaller boll size and lower number of seed/boll. No significant differences were detected for seed index, lint index, and the five fiber properties. The averages for the six genetic populations in Table 3 indicate statistically significant differences for most characteristics. However, the practical phenotypic differences are small.

The more complex interactions for lint yield and number of bolls/plot were studied on an accumulative basis for each harvest. As indicated in Table 4, the varying effects of plant bugs on genetic populations were similar for both lint yield and bolls/plot. Plausibly, bolls/plot was the component of yield that contributed most to the yield differences detected in this study. Plant bugs are known to cause juvenile squares to abscise, which affects the number of bolls that reach maturity.

The presence of plant bugs resulted in yield reductions for all gentic populations. However, yields were reduced at different stages of development. Yield of the tolerant cultivar (Stoneville 213) was reduced in late season, mostly in the last harvest. In contrast, yield of less tolerant Coker 201 was reduced early, mainly in the first two harvests. Because the total reduction of 168 kg/ha observed for Stoneville 213 was greater than the 72 kg/ha reduction for Coker 201, one might question the term "tolerance" assigned to Stoneville 213. However, for good agronomic practice and complete insect control programs, late-season production, such as Coker 201 exhibited, is undesirable. Also, late-season production generally results in poorer fiber properties, as is indicated in Table 3. Late-season production is not usually this effective in the Mississippi Delta. Probably, the late-season productivity of Coker 201 was favored by the low numbers of late-season insects observed, particularly boll weevils and bollworms. Also, the October mean temperature of 2.5 C above normal resulted in an excellent environment for maturation of late-season bolls. In a similar 1973 study at another location, Laster and Meredith (5) recorded a yield reduction, caused by plant bugs, of 294 and 405 kg/ha for Stoneville 213 and Coker 201, respectively.

Table 3. Yield component and fiber property averages for three characters.

Character	Lint %	Boll size	Seed index	Lint index	Seed/ boll	Span length 50%	Span length 2.5%	T_1	E_1	Micro-naire
Harvest date										
Sept. 12	35.7	6.68	12.8	7.1	33.6	0.56	1.20	20.2	6.3	4.85
Sept. 21	36.3	6.24	13.0	7.4	30.7	0.54	1.17	19.5	6.6	4.92
Oct. 4	39.5	5.39	11.1	7.2	29.4	0.51	1.10	19.6	6.7	4.78
Nov. 9	39.7	5.11	10.5	6.9	29.3	0.50	1.08	17.9	6.6	4.78
L. S. D. (0.05)	0.3	0.17	0.4	ns	1.8	ns	0.08	0.8	ns	ns
Plant bugs										
With PB	38.1	5.80	11.8	7.2	30.5	0.53	1.13	19.4	6.6	4.77
Without PB	37.5	5.92	11.9	7.1	30.9	0.53	1.14	19.2	6.5	4.84
L. S. D. (0.05)	0.2	0.04	ns	ns	0.2	ns	ns	ns	ns	ns
Population										
Stv 213	38.2	5.55	11.5	7.0	29.9	0.53	1.13	19.0	7.0	4.95
Cok 201	38.1	5.74	11.8	7.2	30.1	0.53	1.13	19.4	6.1	4.74
F_1	37.7	5.98	11.7	7.1	31.7	0.54	1.14	19.3	6.5	4.74
F_2	37.5	5.95	12.1	7.2	30.8	0.53	1.14	19.3	6.8	4.83
F_1 × Stv	37.8	5.81	11.8	7.1	30.7	0.53	1.14	19.5	6.2	4.80
F_1 × Cok	37 6	6.11	12.1	7.3	31.3	0.53	1.14	19.5	6.2	4.80
L. S. D. (0.05)	0.2	0.07	0.1	0.1	0.4	ns	0.01	0.2	0.1	0.06

Table 4. Yield and bolls/plot for populations grown with and without tarnished plant bugs.

Population	Accumulative yield, kg/ha Sept. 12	Sept. 21	Oct. 4	Nov. 9	Accumulative no. of bolls/plot Sept. 12	Sept. 21	Oct. 4	Nov. 9
Stv 213								
TPB	264	875	1,563	1,907	156	518	982	1,233
PB	285	845	1,589	2,075	162	504	977	1,284
Coker 201								
TPB	124	432	1,102	1,636	69	249	650	1,013
OPB	340	767	1,321	1,708	190	447	797	1,044
F_1								
TPB	305	840	1,525	1,814	176	484	911	1,096
OPB	496	1,080	1,733	2,098	271	599	993	1,220
F_2								
TPB	233	712	1,417	1,819	127	414	844	1,101
OPB	416	934	1,601	2,052	237	556	951	1,213
F_1 × Stv								
TPB	287	880	1,564	1,897	165	509	946	1,159
OPB	371	968	1,601	2,089	208	557	972	1,253
F_1 × Cok								
TPB	234	707	1,412	1,826	122	387	808	1,072
OPB	441	967	1,510	1,892	235	535	873	1,094
L. S. D. (0.05)*	78	102	95	122	44	54	53	91
L. S. D. (0.01)*	93	122	114	147	53	64	63	109

* L. S. D. comparisons for any two means within a column.

Table 5. Mean square estimates of genetic parameters.

Source†	df	Terminal damage	Accumulative yield, kg/ha				Accumulative no. of bolls/plot‡			
			Sept. 12	Sept. 21	Oct. 4	Nov. 9	Sept. 12	Sept. 21	Oct. 4	Nov. 9
A	1	365.1**	143	8,905	18,225	14,362**	110	3,798	9,531	8,115**
D	1	39.8	3,745**	9,506**	9,770**	3,193	1,049**	2,214**	1,675**	32
E	3	44.6	33	263	99	166	2	17	4	11
A × PB	1	340.8**	1,571**	4,851**	987*	612	548**	1,647**	7,093**	79
D × PB	1	29.8	231	306	206	957*	51	28	2	271
E × PB	3	52.3*	25	33	226	233	17	6	63	71
Error	50	18.5	82	143	117	184	25	47	40	79

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively. † A = additive; D = dominance; and E = combined epistasis. ‡ $\bar{x}^2 \times 10^{-2}$.

The yield distribution of the backcross populations was similar to the yield distribution of their respective recurrent parents. When grown without plant bugs, F_1 and F_2 hybrids produced considerably earlier crops than either of the parents. This result agrees with the summarization of cotton hybrid development reported by Galal, Miller, and Lee (2). However, when large numbers of plant bugs were present, F_1 and F_2 hybrids did not develop relatively early. For example, the accumulative yields by the second harvest for the F_1 and Stoneville 213 were 1,080 and 845 kg/ha, respectively, when grown without plant bugs and 840 and 875 kg/ha, respectively, when grown with plant bugs. Thus, it is evident that plant bugs reduced lint yield and significantly delayed maturity in the nontolerant cultivar.

Maternal effects, such as those reported in cotton seedlings by Christiansen and Lewis (1) and Scholl (9), and cytoplasmic effects, such as those reported by Meyer (8) appeared inoperative in these populations. The $\bar{x}^2$ estimates of the various genetic parameters for terminal damage, accumulative yield, and accumulative number of bolls/per plot are given in Table 5. The genetic $\bar{x}^2$ for yield and number of bolls/plant were similar in magnitude and again suggest a cause and effect relationship between these two characteristics in this study. Dominance effects were especially large for yield and bolls/plot through the first three harvests. This is in agreement with the general view that dominance gene action is particularly operative in the expression of early season productivity of hybrids (2). However, in our study, if one were to make decisions only on the basis of total yield and bolls/plot, dominance gene action would appear to be of little importance. On a total performance basis, additive gene action was of much greater magnitude for yield and bolls/plot than dominance. These results point out the value of having several harvests in obtaining a better understanding of gene action involved in cotton.

The genetic parameters mainly involved inheritance of tolerance to plant bugs are indicated by significant genetic parameter by plant-bug-level interactions. Because the effects of plant bugs were most obvious in the early harvest, one would expect the genetic-parameter-by-plant-bug-level interactions for this harvest to be more indicative of the gene action conditioning tolerance. For terminal damage, significant interactions are indicated in Table 5 for additive effects by plant bug levels and combined epistatic effects by plant bug levels. The epistatic interaction was further studied and the comparison of 2 F_2 — (F_1 × Stoneville)—(F_1 × Coker) was found to account for the significant interaction. This comparison is an estimate of additive × additive epistasis and is independent and uncorrelated with both A and D estimates. The presence of significant additive × additive epistasis indicates higher priorities for late generaton selection than for selection in the F_2. For example, the additive × additive variance is 125 and 206% higher for the F_3 and F_4 generations, respectively, than for the F_2.

Table 5 shows highly significant early harvest additive × plant bug interactions for lint yield and bolls/plot in the early harvest. Plant bug tolerance is conditioned mainly by additive gene action. Therefore, we conclude that no significant early-harvest dominance or epistatic interaction effects were detected. Although the dominance gene action does not appear to be involved in genetic tolerance per se, it became important once the cultivar recovered from the initial early-season damage. Genetic analyses and inspection of F_1 performance do not suggest any great advantage of F_1 hybrids when plant bugs are numerous. These results point out the importance of harvesting the crop several times to effectively analyze tolerance.

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