GREENBUG RESISTANCE LEVELS IN COMMERCIAL GRAIN SORGHUM HYBRIDS IN THE SEEDLING STAGE

by

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INTRODUCTION

Commercial grain sorghum hybrids resistant to the greenbug, Schizaphis graminum (Rondani), first became available for extensive use in 1976. Their presence marked the result of more than seven years of research directed at developing high yielding grain sorghum hybrids resistant to this relatively recent sorghum pest.

The greenbug first caused widespread damage on grain sorghum in 1968. The appearance of a new biotype allowed this traditionally cool season small grain pest to survive the high temperatures that characterize summer in the Midwest. Harvey and Hackerott (1969) designated this new biotype as biotype C. For an in-depth review of the biology and historical importance of the greenbug the reader is referred to Hunter (1909) and Wadley (1931). Sources of resistance have been reported by Hackerott et al. (1969), and Wood (1971). Hackerott et al. (1969), Weibel (1972), Harvey and Hackerott (1974), Johnson et al. (1974) and Teetes et al. (1974b) demonstrated seedling and mature plant resistance in F_1 hybrids. Teetes et al. (1975b) demonstrated that greenbug resistance could be transferred to agronomically improved sorghum hybrids. Walter and Wilde (1977) reported that commercial greenbug resistant hybrids could yield as well as their susceptible counterpart in the absence of greenbugs, and yielded significantly better than the susceptible counterpart when infested with high greenbug numbers.

Two sets of near-isogenic hybrids which contained susceptible, one parent resistant, and two parent resistant hybrids were present in the advanced growth stage field evaluations reported by Walter and Wilde (1977).

The purpose of this study was to evaluate the degree of resistance displayed by seedlings of one of these isogenic sets.

MATERIALS AND METHODS

The near-isogenic hybrids tested were DeKalb E-59 (a susceptible hybrid), E-59+ (a one parent resistant hybrid) and E-59++ (a two parent resistant hybrid). The source of resistance for the E-59+ is believed to be KS 30, and the sources of resistance for E-59++ are believed to be KS 30 and SA-7536-1. Two other one parent resistant hybrids, TEY-101-R (source of resistance believed to be IS-809) and SG 40GBR (source of resistance believed to be SA-7536-1) were included in several of the tests.

Greenbugs used in the tests originated from a field population collected the summer of 1976 at the Garden City Experiment Station. They were maintained on susceptible Excel 733 grain sorghum. Wilde (personal communication) determined them to be biotype D (Teetes et al. 1975a).

Tests were conducted in the winter of 1976-77 in a growth chamber programmed for 16 hour day (ca. 1000 ft. c.), 8 hour night. Temperature varied depending on the test. Seedlings were germinated in vermiculite and held at a constant 26.7±2°C. Four days after planting, seedlings of uniform size were selected, transplanted into a modified Hogland's nutrient solution[1] and returned to the growth chamber. Respective tests were initiated 24 hours later.

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[1]Schweissing, F. C. 1974. Effects of certain environmental factors on greenbug resistance in host plants. Ph.D. Dissertation, Kansas State University, Manhattan.

Tests for Nonpreference

Three nonpreference tests were conducted, each at a different time. Plants were supported by a foam collar in holes cut in the lid of a waxed cardboard storage container filled with distilled water. Cellulose nitrate film cages, ca. 12 cm in diameter and 18 cm tall with nylon mesh tops, were secured around the containers. The first two tests, each with 8 replications, contained all three hybrids in a triangular pattern ca. 5 cm apart. Thirty adult or 4th instar greenbugs (10/plant) were introduced between the plants by a long stemmed glass funnel pushed through a hole in the top of the cage. Schuster and Starks (1973) demonstrated a high positive correlation between the preference of alate and apterous greenbug forms, thus both were used in these tests. The third test involved the hybrids in combination of two (E-59 vs E-59+, E-59 vs E-59++, E-59+ vs E-59++) with 20 greenbugs being introduced between the plants. The E-59 vs E-59++ comparison had seven replications, the other two comparisons had eight. Tests were conducted for 24 hours in a growth chamber under the conditions described previously at a constant 26.7°C. At the end of the test the number of greenbugs on each plant was recorded.

Tolerance Test 1

We measured the response of E-59, E-59+ and E-59++ when infested with five levels of greenbugs over four time periods. The levels tested were 0, 10, 20, 30, and 40 greenbugs per plant left on the plants for 2, 4, 6, and 8 days.

The experimental design was initially a balanced, incomplete block. Five plants of each of two of the hybrids were placed in each container

in the following hybrid combinations: E-59 and E-59+, E-59 and E-59++, E-59+ and E-59++. There were three containers per time period. Each plant was infested with one of the greenbug levels.

Replication three was modified by deleting the 40 greenbugs per plant treatment on days six and eight and the 30 greenbugs per plant treatment on day eight. Replication four was further modified by replacing the 30 and 40 greenbugs per plant treatments with 10 and 20 greenbugs per plant treatments at all four time periods. These modifications thus created an unbalanced design.

Five plants of each of two of the hybrids, which were germinated as described earlier, were randomly arranged in the test containers. Glass tube cages were placed over the plants and adult or fourth instar greenbugs were introduced through the top of the cage. The cages were plugged with foam stoppers, and the test containers were returned to the growth chamber. The chamber temperature was adjusted to fluctuate between 26.7°C during the light period and 15.6°C during the dark period. At the end of each time period the following measurements were taken on the plants of that time period: plant height from first node to tip of tallest leaf, plant leaf area (measured with a Licor area meter with belt attachment), and number of greenbugs per plant (if 10 or more greenbugs were observed on the cages, count for that plant was not made). A damage rating was also made in which each leaf was given a rating of from 0 to 10, 0 being no injury and 10 being a dead leaf. Damage ratings for each plant were totaled and divided by the number of leaves present, thus providing an average damage rating for the plant. Greenbugs were dried in an oven at 60°C for 48 hours and then placed in a desiccator. Weight was recorded after the samples had reached a constant weight.

Tolerance was evaluated as functional plant loss index (FPLI) and was calculated as follows:

$$FPLI = (1 - (1 - \frac{\text{Leaf area of control-leaf area of infested plant}}{\text{Leaf area of control}}) \quad (1\text{-Average damage rating})) \times 100$$

On day two damage was not severe enough to warrant a damage rating, thus FPLI for that time period reflects only the amount of stunting sustained, and was calculated as follows:

$$FPLI = (\frac{\text{Leaf area of control - Leaf area of infested plant}}{\text{Leaf area of control}}) \times 100$$

Greenbug response on the hybrids was evaluated as the following: greenbug numbers (GBN); greenbugs produced/adult/day (GBAD) thus compensating for the different initial infestation levels; and dry weight/greenbug (GBDW) calculated by dividing the dry weight of the greenbugs by GBN.

Tolerance Test 2

We measured the recovery potential of the three hybrids by infesting them with a greenbug population large enough to stunt the plants yet cause minimal visible tissue damage. The plants were germinated as described previously, but were transplanted five days after planting.

The experimental design was completely randomized with two plants of each of the three hybrids in each of seven containers. One plant of each hybrid was infested with 30 greenbugs and covered with a glass tube cage. The containers were placed in a growth chamber set at the fluctuating photophase and temperatures described previously. Two days later all

greenbugs were brushed from the infested plants, plant heights were measured, and the containers were returned to the growth chamber without replacing the cages. The plants were allowed to grow for seven days, and plant heights and leaf areas were then measured.

Tolerance Test 3

We measured the influence of artificially induced moisture stress on the expression of resistance by the seedlings of the three E-59 hybrids and two other hybrids reputed to have different sources of resistance; Coop SG 40GBR, believed to have SA-7536 as its original source of resistance; TEY-101-R, believed to have IS-809 as its original source of resistance. Moisture stress was induced by adding 150 ml of carbowax to 1500 ml of nutrient solution, as suggested by Paulsen (personal communication). Each of 7 replications was made up of one stressed and one nonstressed container. Each container held 2 plants of each hybrid, one of which was infested with 10 greenbugs. Plants were germinated in sand which delayed emergence by one day. Thus they were transplanted and infested one day later than the plants of tolerance test 1. Plants were stressed at the time they were transplanted. After eight days in the growth chamber, programmed at fluctuating light and temperature phases as described earlier, greenbugs on each plant were counted, a damage rating of individual leaves as described previously was made, and leaf area was measured.

Tolerance Test 4

To minimize the effects of crowding and plant deterioration on the susceptible hybrid (E-59), we infested it with six greenbugs, and the

resistant hybrids (E-59+, E-59++, TEY-101-R, SG 40GBR) with 12 greenbugs initially. The test was designed with an infested and uninfested plant of each hybrid in each of eight containers. Plants were germinated in vermiculite as described previously. They were transplanted five days after planting and infested the following day. Growth chamber temperature and photophase were similar to previous tests. After eight days, greenbug numbers, damage rating as described earlier, and plant leaf area were recorded. The development of secondary roots was also noted.

Test for Rate of Development

To test the rate of development, three alate greenbugs were placed on each of six seedlings of the three hybrids. The following day the adults were removed, leaving from two to six first instar nymphs on each plant. Plants were examined daily to determine when reproduction of another generation began.

Field Test for Antibiosis/Nonpreference

Greenbug counts were made in field plots of the following hybrids: DeKalb E-59, E-59+, E-59++; Golden Acres TEY-101-R and Co-op SG-40GBR. Plots were four rows wide by 9 meters long, and counts were made on five plants chosen at random in each plot. Two replications were counted on July 14, when plants were in growth stage 3 (Vanderlip 1972). Three replications were counted eight days later on July 22.

RESULTS AND DISCUSSION

Tests for Nonpreference

Results of the 3-way preference tests appear in Table 1. Data from the first test could not be pooled (Heterogeneity Chi-square = 35.88 with 14 degrees of freedom, P less than .01), thus the Chi-square values for each block are presented. Four of the eight blocks varied significantly from the assumption that the 3 hybrids were equally preferred. In three instances, blocks 6, 7, and 8, E-59++ had the highest number of greenbugs and in the fourth, block 1, E-59+ had the highest. The susceptible E-59 had the highest count only once, block 2, and that instance was not significant. Data from the second test (Table 2) could be pooled (Heterogeneity Chi-square = 13.26 with 14 d.f., $P > .5$). The resulting pooled Chi-square was highly significant with E-59 having the least number of greenbugs.

Results of the 2-way preference tests appear in Table 3. In all situations the data could be pooled, and in all situations the pooled Chi-square values were significant. E-59 had the lowest number of greenbugs when compared separately to both E-59+ and E-59++. In the test that compared the two resistant hybrids, E-59+ had the fewest number of greenbugs. These results are consistent with the first two tests, which indicates that the two parent resistant was most preferred. Previous workers (Hackerott et al. 1969; Schuster and Starks 1973; Harvey and Hackerott 1974; Teetes et al. 1974a) have documented nonpreference displayed by seedlings of Shallu grain, KS 30 and SA 7536-1 or related hybrids of approximately the same age, but no such nonpreference was detected in these tests.

Test for Rate of Development

On uncrowded, vigorously growing plants of all three hybrids, new reproducing adults developed in six days, indicating that developmental time was not altered by the resistant hybrids.

Tolerance Test 1

No significant hybrid x level interaction was detected for any of the variables at any of the time periods (Table 5), indicating that the individual hybrids, or the response of the greenbugs on the hybrids, were similar at all infestation levels. Graphs of functional plant loss index over time and the factors used in its calculation appear in Fig. 1. Graphs of the hybrid and level means at the four time periods for FPLI, GBN, GBAD and GBDW appear in Figs. 2-9.

Day two. Analysis of leaf area (Table 4) revealed no significant differences between the control and plants infested with 10 greenbugs, whereas plants of all other levels had significantly less leaf area than the controls. Significant[1] hybrid leaf area differences demonstrate the need to calculate stunting as a percentage of the check plants. There were no significant differences detected between tolerance (FPLI), greenbug numbers (GBN), greenbugs/adult/day (GBAD), or dry weight/greenbug (GBDW) produced on each hybrid (Figs. 2-5). As one might expect, there were highly[2] significant level differences found for FPLI (Fig. 6) and GBN (Fig. 7) and significant differences between levels with respect

[1]Significant at the .05 level.
[2]Significant at the .01 level.

to GBDW (Fig. 8). Dry weight/individual greenbug was approximately the same at levels 20, 30 and 40, but significantly heavier at level 10 (Fig. 9). This could be due to less physical crowding and/or some physiological condition of the plant. The functional plant loss index of level 10 was also significantly less than the other levels.

Day four. Tolerance was detected for the first time on day 4 with E-59+ displaying significantly less FPLI than E-59 or E-59++, which were not significantly different from each other. Highly significant level differences for FPLI, GBN and GBDW can be attributed to initial infestation levels. However, crowding and plant damage are beginning to reduce reproductive rate as well as dry weight of the greenbugs at the upper levels.

Day six. Day six data showed significant level differences for all categories, except GBAD, which was near significant[1] with lighter and fewer greenbugs per adult being produced at the upper infestation levels. Tolerance was again displayed by the resistant hybrids but at this time period E-59++ had significantly less FPLI than the susceptible but was not significantly different from E-59+. E-59 had the highest FPLI but was not significantly different from E-59+.

Day eight. GBAD and GBDW were not analyzed at this time period due to the possibility of having new reproducing adults on the healthier plants as indicated in the results of the developmental test. The sharp increase in the number of greenbugs produced and the number of greenbugs produced per adult per day, displayed in Table 6, clearly indicates that there were new reproducing adults on the level 10 plants of all three hybrids on day eight. Overall plant condition had caused the abandonment

[1]Significant at the .10 level.

of most of the susceptible and several of the resistant plants at the upper infestation levels. Thus only the plants infested with 10 greenbugs were used in the analysis of GBN for this time period. As in the previous time periods, there was no significant difference detected in the number of greenbugs found on each hybrid. Significant level differences were detected in FPLI with the highest level having significantly more damage and the lowest level having significantly less damage than the middle two levels which were not different from each other. Overall E-59 had a significantly higher FPLI than E-59+ or E-59++, which were not significantly different from one another.

FPLI hybrid means, adjusted for sample size, were plotted against time and a least squares line fitted to the data (Fig. 10). The slopes and intercepts of the lines were tested for equality.

Comparisons of the individual slopes and intercepts with one another revealed a significant difference (prob. $> F = .0533$) between the slope of E-59 and that of E-59++ with E-59 having the steeper slope. The intercepts were not found to be significantly different. The slope and intercept of E-59+ were not significantly different from either E-59 or E-59++.

This comparison provides a method of comparing the tolerance trends displayed by the resistant hybrids over time. E-59 had the steepest slope, indicating a more rapid increase in plant damage that was significantly greater than that occurring on E-59++. Again E-59+ took the intermediate position between the two other hybrids.

Another indication of the tolerance of the resistant hybrids is demonstrated in Table 7 where total greenbug samples counted (N) and

possible samples (PN) are compared for Day 6 and 8. The differences between the two numbers are the plants that were not counted because the greenbugs had or were abandoning them. This exodus began on the susceptible as early as Day 6, level 20, and on the E-59+ on Day 6, level 30. The E-59++ on the other hand, had no such abandonment on Day 6. The most striking contrast was found at level 20, Day 8, where only 2 of a possible 9 samples were counted for E-59 whereas 8 of 10 E-59+ and E-59++ were counted. No counts were possible for any of the hybrids on Day 8, level 40.

Tolerance Test 2

After two days on the plants the greenbugs had caused only a trace of visible feeding injury. Paired t-tests showed that the infested plants of E-59 and E-59+ had been significantly stunted by the greenbugs but no such stunting was detected for E-59++ (Table 8).

After being allowed to recover for seven days, the difference between the uninfested and infested plant height and leaf area means of E-59 and E-59+ were highly significant, indicating that neither hybrid had recovered from the suppression of growth caused by the greenbug. Plant height and leaf area means of the uninfested and infested E-59++ remained not significantly different. The results suggest that greenbug damage sustained in the seedling stage is due to more than leaf tissue destruction. Harvey and Hackerott (1974) demonstrated more rapid recovery and more secondary culms produced per plant on resistant hybrids exposed to greenbug feeding in the seedling stage.

Tolerance Test 3

Unpaired t-tests performed on the leaf area of the stressed and unstressed check plants showed that E-59, E-59++ and TEY-101-R were significantly stunted by the carbowax treatment, whereas E-59+ and SG 40GBR were not (Table 9).

Analysis of the unstressed plants of all five hybrids revealed highly significant hybrid differences, with E-59 sustaining significantly more damage than the other four hybrids (Table 10). No differences were detected in the number of greenbugs found on the hybrids. Analysis of the FPLI for the three hybrids stressed, E-59, E-59++ and TEY-101-R (Table 11), showed that E-59 had sustained significantly more damage than the other two hybrids. However, no significant differences could be detected in the FPLI of the stressed and unstressed plants.

Tolerance Test 4

No significant FPLI differences were detected between E-59 initially infested with six greenbugs, and the four other hybrids infested with twelve greenbugs (Table 12). Fewer greenbugs were found on the susceptible hybrid, but numbers were not significantly lower than those on the resistant hybrids. Crowding conditions on the resistant plants and the lack of crowding on the susceptible plants may account for the nonsignificant difference with respect to greenbug numbers. Table 13 shows that the development of secondary roots was inhibited by greenbug feeding on all five hybrids.

Field Study

No significant differences were detected in the number of greenbugs found on each hybrid either on July 14 or July 22 (Table 14).

SUMMARY

The resistant hybrids displayed varying degrees of resistance to greenbug feeding in the seedling stage. Preference tests indicated that hybrids E-59+ and E-59++ were more preferred than E-59 at the growth stage tested. Antibiosis and/or nonpreference were not demonstrated in laboratory or field counts, nor did rate of development differ in a laboratory test. However, antibiosis as measured by GBN, GBAD or GBDW may have been masked by crowding.

Data indicate that greenbug damage sustained in the seedling stage is due to more than leaf tissue destruction. Tolerance was displayed by all of the resistant hybrids, but we were not able to detect significant differences in tolerance levels between the three sources of resistance in the commercial hybrids tested. In addition, the overall superior tolerance of the two parent resistant hybrid, E-59++, suggests that homozygous resistant hybrids are advantageous in the seedling stage.

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Table 1. Results and Chi-square analysis of the first nonpreference test comparing E-59, E-59+ and E-59++.

Sum of replication Chi-squares		Pooled Chi-square		Homogeneity Chi-square
		Test for homogeneity between replications		
38.44	-	2.56	=	35.88**
(16 d.f.)		(2 d.f.)		(14 d.f.)

Replication	Hybrid	Greenbugs/plant 24 hr after infestation	Chi-square[a]
		Individual replication data and analysis	
1	E-59+	13	7.19*
	E-59++	6	
	E-59	3	
2	E-59	13	1.93
	E-59++	9	
	E-59+	7	
3	E-59+	13	3.77
	E-59	8	
	E-59++	5	
4	E-59+	12	0.44
	E-59	11	
	E-59++	9	
5	E-59++	9	0.08
	E-59+	9	
	E-59	8	
6	E-59++	14	6.89*
	E-59	10	
	E-59+	3	
7	E-59++	18	11.24**
	E-59+	7	
	E-59	4	
8	E-59++	12	6.91*
	E-59	8	
	E-59+	2	

[a]Chi-square analysis, 2 degrees of freedom.
*Significant at the .05 level.
**Significant at the .01 level.

Table 2. Results and Chi-square analysis of second nonpreference test comparing E-59, E-59+ and E-59++.

Sum of replication Chi-squares		Pooled Chi-square		Homogeneity Chi-square
Test for homogeneity between replications				
26.50	-	13.24	=	13.26 P>.5
(16 d.f.)		(2 d.f.)		(14 d.f.)

Pooled data

Hybrid	Total	
E-59	46	Pooled Chi-square = 13.24**
E-59+	66	
E-59++	88	

**Significant at the .01 level.

Table 3. Results and analysis of the third nonpreference test.

Test for homogeneity between replications					Pooled data		
Sum of replication Chi-squares		Pooled Chi-square		Homogeneity Chi-square	Hybrid	Total	
Comparison E-59 vs E-59+							
12.31 (8 d.f.)	-	6.08 (1 d.f.)	=	6.23 P>.50 (7 d.f.)	E-59 E-59+	59 89	Pooled Chi-square = 6.08*
Comparison E-59 vs E-59++							
15.52 (7 d.f.)	-	7.26 (1 d.f.)	=	8.26 P>.10 (6 d.f.)	E-59 E-59++	47 77	Pooled Chi-square = 7.26**
Comparison E-59+ vs E-59++							
10.76 (8 d.f.)	-	3.86 (1 d.f.)	=	6.90 P>.25 (7 d.f.)	E-59+ E-59++	57 80	Pooled Chi-square = 3.86*

*Significant at the .05 level.

**Significant at the .01 level.

Table 4. Summary of analysis of variance, leaf area (cm^2) of E-59, E-59+ and E-59++, day 2, tolerance test 1.

Analysis of Variance			
Source	d.f.	MS	Prob > F
Hybrid	2	4.839	.0008
Level	4	4.437	.0001
Hybrid x level	8	.226	.9269
Error	89	.590	

Hybrid	Sample No. N	Leaf area (cm^2) $\bar{x}$
E-59	37	4.47 a
E-59+	39	4.52 a
E-59++	39	5.16 b

Level	Sample No. N	Leaf area (cm^2) $\bar{x}$
0	23	5.27 a
10	29	4.87 a
30	17	4.68 ab
20	28	4.38 b
40	18	4.36 b

[1] Means followed by the same letter are not significantly different at the .05 level, L.S.D. for unequal samples.

Table 5. Summary of analysis of variance for functional plant loss index (FPLI) greenbug number (GBN), greenbug/adult/day (GBAD), and dry weight/greenbug (GBDW) from tolerance test 1.

Source	FPLI			GBN			GBDW			GBAD		
	d.f.	Ms.	Prob > F	d.f.	Ms.	Prob > F	d.f.	Ms.	Prob > F	d.f.	Ms.	Prob > F
Day 2												
Hybrid	2	473.99	.1722	2	141.98	.5014	2	.000157	.5047	2	.0735	.5543
Level	3	812.88	.0328	3	36633.74	.0001	3	.000063	.0438	3	.0822	.5635
Hybrid x Level	6	89.89	.9125	6	406.84	.0735	6	.000042	.0954	6	.1373	.1773
Error	65	263.90		69	201.05		51	.000217		69	.0891	
Day 4												
Hybrid	2	2696.65	.0057	2	31.02	.9504	2	.000004	.6616	2	.0107	.8608
Level	3	3957.88	.0002	3	73467.53	.0001	3	.000080	.0002	3	.1764	.0661
Hybrid x Level	6	192.22	.8758	6	564.36	.5159	6	.000019	.0758	6	.0631	.5078
Error	69	478.67		70	610.52		49	.000009		70	.0708	
Day 6												
Hybrid	2	2152.12	.0042	2	340.78	.6197	2	.0000006	.9718	2	.0069	.8885
Level	3	8315.14	.0001	3	69687.68	.0001	3	.0000936	.0069	3	.2287	.0131
Hybrid x Level	6	275.79	.5815	6	576.60	.5513	6	.0000212	.3930	6	.0377	.6917
Error	74	348.04		52	692.41		36	.0000197		52	.0580	
Day 8												
Hybrid	2	937.11	.0166	2	1099.22	.3896						
Level	3	5638.80	.0001									
Hybrid x Level	6	30.85	.9878									
Error	74	212.36		14	1083.55							

Table 6. Increase in number of greenbugs, presented as number of individuals (NI) and number of individuals/initial adult day (NI/A/D), over time, tolerance test 1.

Hybrid	Level	Increase Day 0 to Day 2		Increase Day 2 to Day 4		Increase Day 4 to Day 6		Increase Day 6 to Day 8	
		NI	NI/A/D	NI	NI/A/D	NI	NI/A/D	NI	NI/A/D
E-59	10	17.9	0.90	27.9	1.40	20.4	1.02	64.8	3.24
	20	36.8	0.92	56.8	1.42	44.4	1.11		
	30	39.5	0.66	69.5	1.16	61.0	1.02		
	40	39.5	0.49	79.5	0.99	74.3	0.93		
E-59+	10	14.3	.72	24.3	1.22	30.4	1.52	68.5	3.43
	20	29.0	.73	49.0	1.23	57.9	1.45		
	30	34.0	.57	64.0	1.08	44.8	.75		
	40	6.2	.08	46.2	0.58	48.7	.61		
E-59++	10	18.2	.90	28.0	1.40	27.6	1.38	51.4	2.57
	20	29.3	.73	49.3	1.23	55.9	1.40		
	30	54.5	.91	84.5	1.41	31.0	.52		
	40	25.8	.32	65.8	.82	79.5	.99		

Table 7. A comparison of the number of samples counted (N) and the possible number (PN) that could have been counted had the greenbug remained on the plants, tolerance test 1.

Level	E-59		E-59+		E-59++	
	N	PN	N	PN	N	PN
Day 6						
10	9	9	10	10	8	8
20	8	10	10	10	10	10
30	3	6	5	6	6	6
40	2	4	3	4	4	4
Day 8						
10	7	10	10	10	10	10
20	2	9	8	10	8	10
30	1	4	3	4	3	4
40	0	4	0	4	0	4

Table 8. T-test analysis of plant height when greenbugs were removed, and plant height and leaf area after seven days of recovery, tolerance test 2.

Hybrid	Plant height at time greenbugs were removed (mm)[a]			Plant height after 7 days[b] (mm)			Leaf area after 7 days[b] (cm^2)		
	Uninfested		Infested	Uninfested		Infested	Uninfested		Infested
E-59	83.6	*	73.1	175.9	**	152.6	17.69	**	12.65
E-59+	95.1	*	87.4	199.71	**	164.3	23.64	**	17.15
E-59++	81.7		80.1	165.8		167.3	16.95		15.21

*Significant at the .05 level.

**Significant at the .01 level.

[a]Means test by paired t-test.

[b]Unequal samples forced the use of unpaired t-test.

Table 9. Unstressed and stressed hybrid means for functional plant loss index (FPLI), greenbug numbers (GBN), and leaf area of the uninfested plants, tolerance test 3.

Hybrid	FPLI		GBN		Leaf area of uninfested plants		
	Unstressed	Stressed	Unstressed	Stressed	Unstressed		Stressed
E-59	86.8	94.2	151.3	-	14.9	*	10.5
E-59+	50.9	46.9	130.1	132.0	15.5		12.4
E-59++	68.8	40.9	121.3	91.4	21.7	**	13.7
TEY 101-R	67.7	60.8	156.5	146.7	24.2	*	17.2
SG 40GBR	58.4	59.2	150.3	116.6	19.6		16.1

*Significant at the .05 level, unpaired t-test.

**Significant at the .01 level, unpaired t-test.

Table 10. Analysis of variance and means for functional plant loss index (FPLI) and greenbug numbers (GBN), from plants in unstressed containers, tolerance test 3.

Source	FPLI d.f.	FPLI Ms	FPLI Prob > F	GBN d.f.	GBN Ms	GBN Prob > F
Replication	6	237.04	.4884	6	1554.07	.7855
Hybrid	4	1086.58	.0070	4	1434.20	.7497
Error	22	232.43		19	2984.81	

Hybrids	Mean[1] FPLI	Mean GBN
E-59	86.8 a	151
E-59++	68.8 b	121
TEY-101-R	67.7 bc	157
SG 40GBR	58.4 bc	150
E-59+	50.9 c	130

[1] Means followed by the same letter are not significantly different at the .05 level, L.S.D. for unequal samples.

Table 11. Analysis of variance and means for functional plant loss index (FPLI) of hybrids stressed by carbowax treatment (E-59, E-59++, TEY-101-R), tolerance test 3.

Source	d.f.	Ms	Prob > F
Replication	6	137.88	
Stress	1	132.61	.3256
Replication x Stress (error a)	6	115.77	
Hybrid	2	2511.50	.0002
Stress x Hybrid	2	281.87	.2568
Error b	20	191.56	

Hybrid	Mean[1] FPLI
E-59	90.2 a
TEY-101-R	64.5 b
E-59++	61.8 b

[1]Means followed by the same letter are not significantly different at the .05 level, L.S.D.

Table 12. Analysis of variance and means of functional plant loss index (FPLI) and greenbug numbers (GBN), tolerance test 4.

Source	FPLI d.f.	FPLI Ms	FPLI Prob > F	GBN d.f.	GBN Ms	GBN Prob > F
Analysis						
Replication	7	2.787	.6949	7	1554.07	.7855
Hybrid	4	5.592	.2884	4	1434.20	.7497
Error	19	4.149		19	56711.46	

Hybrids	Mean FPLI	Mean GBN
E-59	83.7	106.2
E-59+	72.0	153.6
E-59++	59.2	144.0
SG 40GBR	78.1	166.8
TEY-101-R	71.0	157.6

Table 13. Number of plants of each hybrid, of a possible 8 plants, displaying secondary root development under infested (6 greenbugs/plant on E-59, 12 greenbugs/plant on the other four hybrids) and noninfested conditions, tolerance test 4.

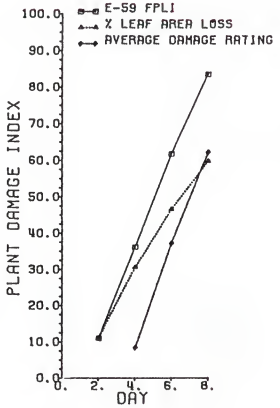
Hybrid	No. of plants displaying secondary roots	
	Not infested	Infested
E-59	8	2
E-59+	5	2
E-59++	6	1
SG 40GBR	5	2
TEY-101-R	7	0

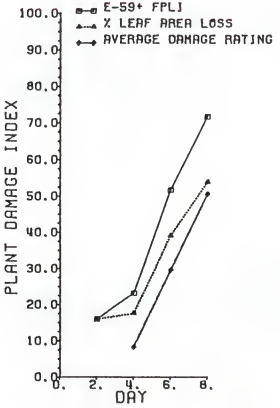
Table 14. Analysis of variance and means of field greenbug counts made July 14 and July 22, 1977, Manhattan.

Source	July 14 d.f.	July 14 Ms	July 14 Prob > F	July 22 d.f.	July 22 Ms	July 22 Prob > F
Analysis						
Block	1	5962.32		2	10940.92	
Hybrid	4	1568.07	.9760	4	80547.93	.3713
Error	44	14450.30		68	74252.59	

Hybrids	Mean Greenbugs July 14	Mean Greenbugs July 22
E-59	180	540
E-59+	184	414
E-59++	174	467
SG 40GBR	153	549
TEY-101-R	164	386

Fig. 1. Relationship of average damage rating and % leaf area loss to functional plant loss index (FPLI). Tolerance test 1.


E-59 FPLI
% LEAF AREA LOSS
AVERAGE DAMAGE RATING
PLANT DAMAGE INDEX
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.
2.
4.
6.
8.
DAY


E-59+ FPLI
% LEAF AREA LOSS
AVERAGE DAMAGE RATING
PLANT DAMAGE INDEX
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.
2.
4.
6.
8.
DAY

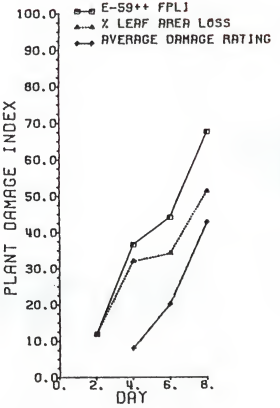

E-59++ FPLI
% LEAF AREA LOSS
AVERAGE DAMAGE RATING
PLANT DAMAGE INDEX
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.
2.
4.
6.
8.
DAY

Fig. 2. Functional plant loss index (FPLI) hybrid means, averaged over levels, for E-59, E-59+, and E-59++. Tolerance test 1.

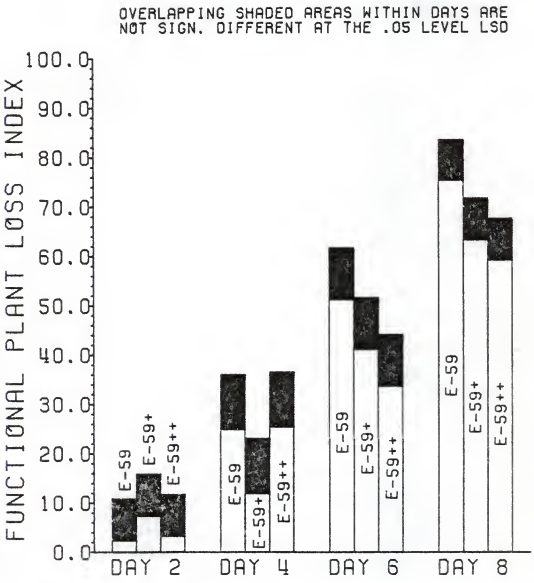

OVERLAPPING SHADED AREAS WITHIN DAYS ARE NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
FUNCTIONAL PLANT LOSS INDEX
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
E-59
E-59+
E-59++
DAY 2
DAY 4
DAY 6
DAY 8

Fig. 3. Mean greenbug numbers (GBN), averaged over levels, found on E-59, E-59+, and E-59++. Tolerance test 1.

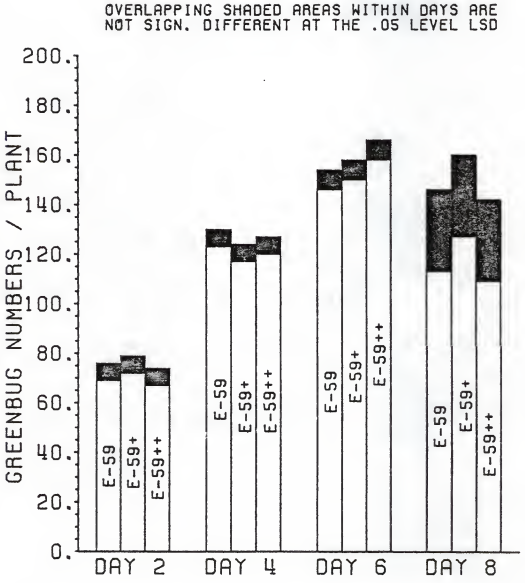

OVERLAPPING SHADED AREAS WITHIN DAYS ARE
NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
GREENBUG NUMBERS / PLANT
200.
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.
E-59
E-59+
E-59++
DAY 2
DAY 4
DAY 6
DAY 8

Fig. 4. Mean greenbugs produced/adult/day (GBAD), averaged over levels, on E-59, E-59+, and E-59++. Tolerance test 1.

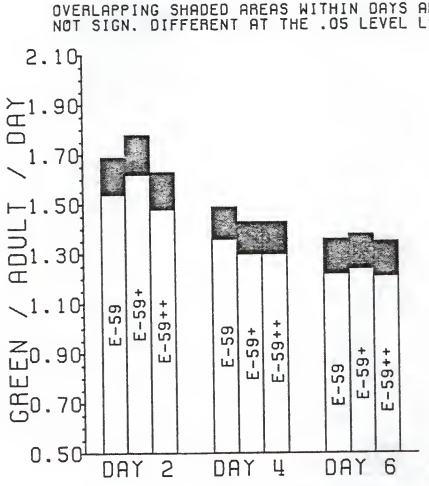

OVERLAPPING SHADED AREAS WITHIN DAYS ARE
NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
GREEN / ADULT / DAY
2.10
1.90
1.70
1.50
1.30
1.10
0.90
0.70
0.50
E-59
E-59+
E-59++
DAY 2
DAY 4
DAY 6

Fig. 5. Mean dry weight/individual/greenbug (GBDW), averaged over levels, produced on E-59, E-59+, and E-59++. Tolerance test 1.

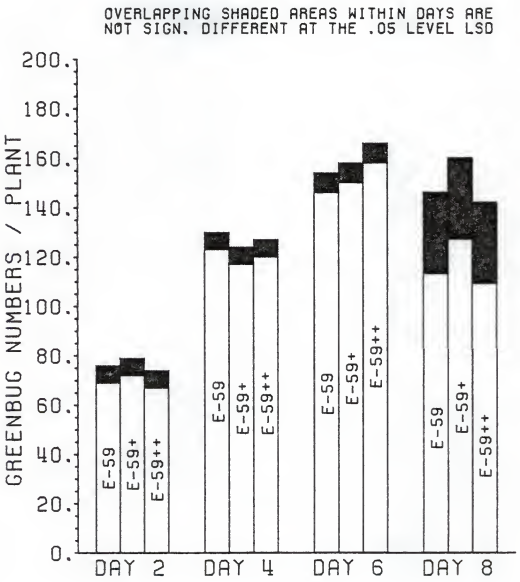

OVERLAPPING SHADED AREAS WITHIN DAYS ARE
NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
GREENBUG NUMBERS / PLANT
200.
180.
160.
140.
120.
100.
80.
60.
40.
20.
0.
E-59
E-59+
E-59++
DAY 2
DAY 4
DAY 6
DAY 8

Fig. 6. Mean functional plant loss index (FPLI), averaged over hybrids, for E-59, E-59+, and E-59++. Tolerance test 1.

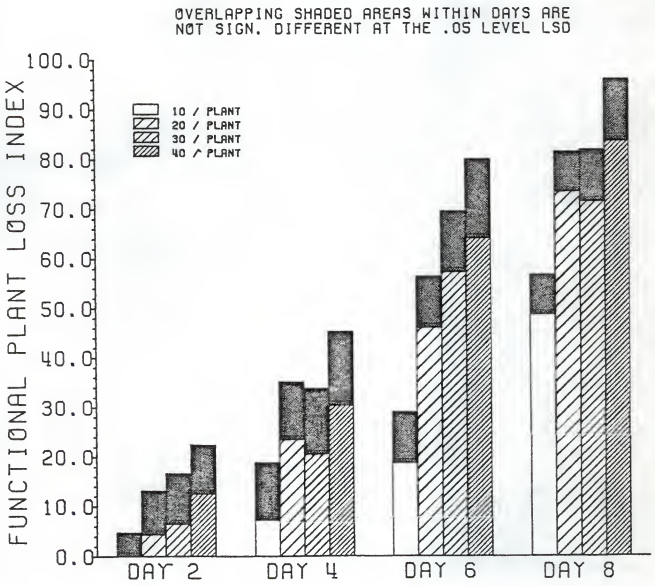

OVERLAPPING SHADED AREAS WITHIN DAYS ARE
NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
FUNCTIONAL PLANT LOSS INDEX
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10 / PLANT
20 / PLANT
30 / PLANT
40 / PLANT
DAY 2
DAY 4
DAY 6
DAY 8

Fig. 7. Mean number of greenbugs (GBN), averaged over levels, found on E-59, E-59+, and E-59++. Tolerance test 1.

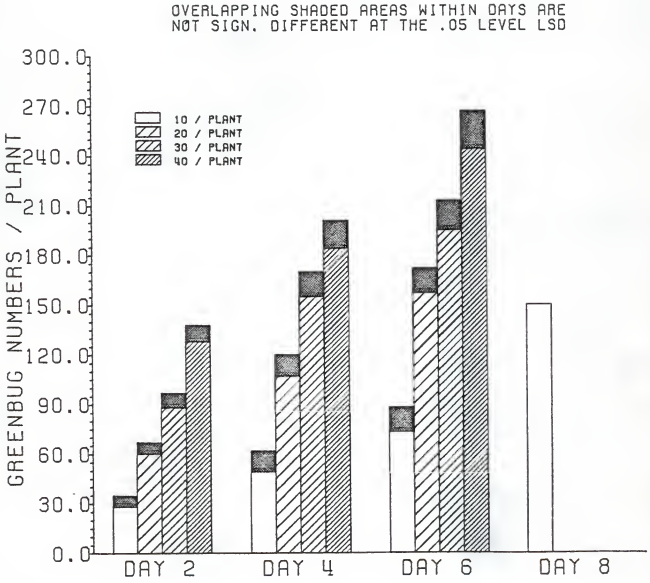

OVERLAPPING SHADED AREAS WITHIN DAYS ARE
NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
GREENBUG NUMBERS / PLANT
300.0
270.0
240.0
210.0
180.0
150.0
120.0
90.0
60.0
30.0
0.0
10 / PLANT
20 / PLANT
30 / PLANT
40 / PLANT
DAY 2
DAY 4
DAY 6
DAY 8

Fig. 8. Mean greenbugs produced/adult/day (GBAD), averaged over hybrids, on E-59, E-59+, and E-59++. Tolerance test 1.

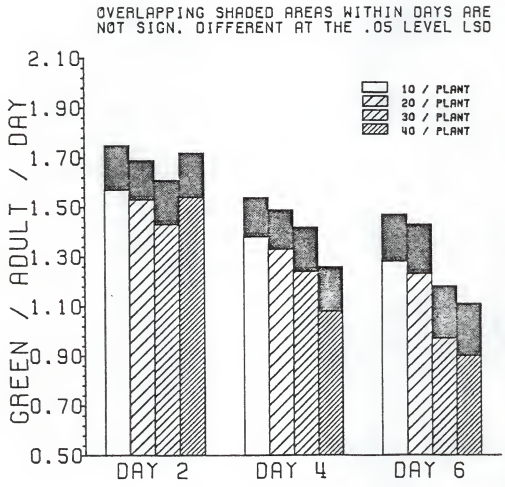

OVERLAPPING SHADED AREAS WITHIN DAYS ARE
NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
GREEN / ADULT / DAY
2.10
1.90
1.70
1.50
1.30
1.10
0.90
0.70
0.50
10 / PLANT
20 / PLANT
30 / PLANT
40 / PLANT
DAY 2
DAY 4
DAY 6

Fig. 9. Mean dry weight/individual greenbug (GBDW), averaged over hybrids, produced on E-59, E-59+, and E-59++. Tolerance test 1.

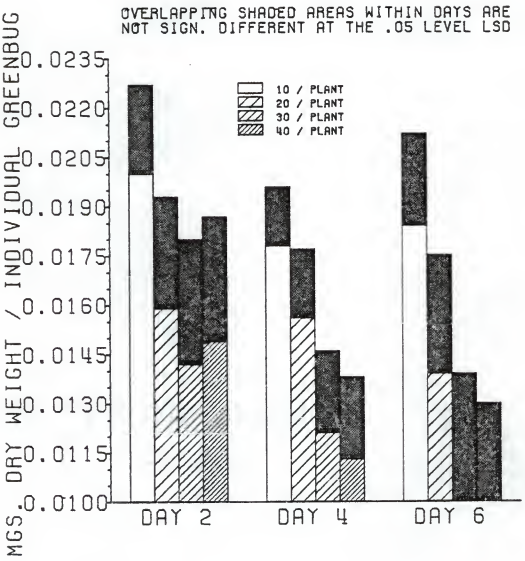
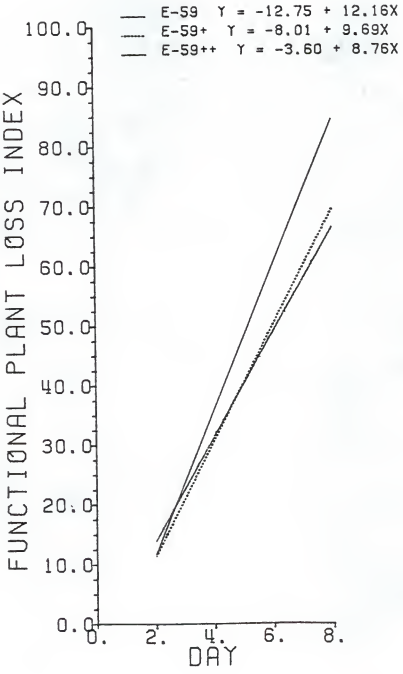

OVERLAPPING SHADED AREAS WITHIN DAYS ARE NOT SIGN. DIFFERENT AT THE .05 LEVEL LSD
MGS. DRY WEIGHT / INDIVIDUAL GREENBUG
0.0235
0.0220
0.0205
0.0190
0.0175
0.0160
0.0145
0.0130
0.0115
0.0100
10 / PLANT
20 / PLANT
30 / PLANT
40 / PLANT
DAY 2
DAY 4
DAY 6

Fig. 10. Regression of the mean functional plant loss index sustained by E-59, E-59+, and E-59++, over time. Tolerance test 1.


E-59 Y = -12.75 + 12.16X
E-59+ Y = -8.01 + 9.69X
E-59++ Y = -3.60 + 8.76X
FUNCTIONAL PLANT LOSS INDEX
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
0.
2.
4.
6.
8.
DAY

GREENBUG RESISTANCE LEVELS IN COMMERCIAL GRAIN SORGHUM HYBRIDS IN THE SEEDLING STAGE

by

JAC FORBY MORGAN

B. S., Kansas State University, 1975

AN ABSTRACT OF A MASTER'S THESIS

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requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

The purpose of this study was to evaluate the relative greenbug resistance displayed by commercially available grain sorghum hybrids in the seedling stage. Three heterozygous resistant hybrids, E-59+, TEY-101-R, and SG 40GBR, representing three prominent sources of greenbug resistance, KS 30, IS-809, and SA-7536, respectively, and a homozygous resistant hybrid, E-59++, representing both KS 30 and SA-7536, were evaluated. The hybrid E-59 was the susceptible standard.

Preference tests indicated that hybrids E-59+ and E-59++ were more preferred than E-59 at the growth stage tested. Antibiosis and/or nonpreference were not detected in any of the tests. Tolerance was displayed in varying degrees by the resistant hybrids but no significant differences were detected among the three sources of resistance represented in the commercial hybrids tested. The overall superior tolerance displayed by E-59++ suggests that homozygous resistant hybrids are more resistant than heterozygous resistant hybrids in the seedling stage. However, all are capable of being damaged by extremely high greenbug numbers if infested at plant emergence.