Comparison of economic injury levels for sorghum head bug, *Calocoris angustatus*, on resistant and susceptible genotypes at different stages of panicle development

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Sorghum head bug, *Calocoris angustatus* Leth. (Hemiptera: Miridae) is a major pest of grain sorghum in India. Studies were conducted to estimate economic injury levels (EILs) for the sorghum head bug on resistant (IS 17610 and IS 21443), a moderately susceptible (IS 9692) and a commercial cultivar (CSH 11) using different protection levels at the half-anthesis, complete-anthesis, milk and dough stages of panicle development. Data were recorded on bug numbers and grain yield. Two to four sprays of demeton-S-methyl (Metasystox) controlled the bugs on CSH 11 and IS 9692, whereas one spray was sufficient on IS 17610 and IS 21443. Maximum grain yield was obtained with four insecticide sprays on CSH 11 and IS 9692, whereas one and two sprays resulted in maximum yield on IS 17610 and IS 21443, respectively. Avoidable losses were greatest in IS 9692 (66%), followed by CSH 11 (38.4 and 55.7% during 1988 and 1989, respectively), IS 21443 (29.1%), and IS 17610 (8.2%). Cost:benefit ratios were > 1:3.4 with four insecticide sprays on CSH 11, IS 9692 and IS 21443; however, it was not economical to spray insecticides on the bug-resistant cultivar, IS 17610. Economic injury levels were 0.2–0.9 bugs per panicle for CSH 11 at the half-anthesis and complete-anthesis stages, respectively, compared with 0.8–4.2 bugs for IS 9692, 10–50 bugs for IS 17610 and 0.5–1.3 bugs for IS 21443. Based on multiple regression, the EILs varied from 0.04 to 0.30 bugs for CSH 11, from 0.9 to 6.6 bugs for IS 9692, 2.7 bugs for IS 17610, and 0.3–5.1 bugs for IS 21443 at the half-anthesis stage. EILs vary across stages of panicle development and cultivars. Head bug-resistant cultivars not only decrease the rate of population increase of bugs, but also withstand greater head-bug densities.

Keywords: *Calocoris angustatus*; mirid; economic injury level; losses; host-plant resistance; India

Sorghum head bug, *Calocoris angustatus* Lethiery (Hemiptera: Miridae), is one of the most important pests of grain sorghum in India (Cherian, Kylasam and Krishnamurti, 1941; Sharma, 1985a, b; Hiremath and Thontadaraya, 1984; Sharma and Lopez, 1990a). Avoidable losses of 7–84% due to head bugs have been estimated from different parts of India (Leuschner and Sharma, 1983). Under experimental conditions, avoidable losses of 55–84% have been recorded in commercial cultivars (cvs) CSH 1, CSH 5 and ICSV 1 (Sharma and Lopez, 1989). Head bug females lay eggs inside the spikelets before anthesis, and the nymphs emerge in 5–7 days. Both nymphs and adults feed on the developing sorghum grain (Sharma and Lopez, 1990a). Head bug-damaged grain shows red-brown feeding punctures, and under severe infestation becomes completely shrivelled and tanned. Head bug damage reduces grain yield and spoils the grain quality, rendering it unfit for human consumption (Sharma and Lopez, 1989; Sharma, Doumbia and Diorisso, 1992).

Hall and Teetes (1982) estimated the damage thresholds for pentatomid bugs feeding on sorghum grain. Natarajan and Sundara Babu (1988) reported economic injury levels (EILs) for nymphs, feeding adults, and ovipositing adults of *C. angustatus* on sorghum using a cage technique, while Sharma and Lopez (1989) estimated the EILs for adults of *C. angustatus* at the half-anthesis (HA) stage using partial protection techniques. Host-plant resistance is an important component in the management of head bugs (Sharma and Lopez, 1991). Plant resistance may delay the time required by the insects to attain threshold levels, or may increase the threshold levels *per se* (Sharma, 1993). In the studies described here the influence of host-plant resistance on EILs for the sorghum head bug, *C. angustatus*, was examined.

Materials and methods

Experiments were carried out at the International Crops Research Institute for the Semi-Arid Tropics

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(ICRISAT), Patancheru, Andhra Pradesh, India (18 degrees N, 78 degrees E), during the 1988 and 1989 rainy seasons. EILs were estimated on three sorghum genotypes during the 1988 rainy season (IS 17610: resistant; IS 9692: moderately susceptible; CSH 11: susceptible commercial hybrid), and on two genotypes during the 1989 rainy season (IS 21443: resistant; CSH 11: susceptible commercial hybrid).

Crop

The sorghum crop, grown under rainfed conditions on deep-black Vertisols during the rainy season (July–October), was planted on ridges 75 cm apart. Seedlings were thinned to a spacing of 10 cm between plants, 15 days after emergence. Each plot measured 12 × 4 m (16 rows, 4 m long). The experiments were laid out in a randomized block design, with three replications. Seeds were planted with a four-cone planter together with carbofuran 3G (1.2 kg a.i. ha^{-1}) to protect the crop from sorghum shoot fly, *Atherigona soccata* Rond. At 20 days after seedling emergence, the crop was sprayed with cypermethrin 3ED (1 l ha^{-1}) with an Electrodyn sprayer.

Insecticide application

Methyl-S-demeton (Metasystox 25 EC) was sprayed with a knapsack sprayer at 125 g a.i. ha^{-1} (500 l spray fluid ha^{-1}). The sprayer was fitted with a hollow-cone nozzle and the pump pressure was 2.5–3.0 kg cm^{-2}. A polyethylene sheet (5 × 2 m) was held downwind to minimize the spray drift to the adjoining plots. Insecticide sprays were applied at the half-anthesis (HA), complete-anthesis (CA), milk (M), and dough (D) stages, i.e. 0, 6, 12 and 18 days after flowering, respectively. Plots were protected at the HA, HA plus CA, HA plus CA plus M or HA plus CA plus M plus D stages. Unprotected plots served as a check. These treatments created a gradient of head bug infestation across stages of panicle development to establish the relationship between bug numbers and loss in grain yield and quality.

Observations

Data were recorded on bug numbers 24 h before and after each spray. Five panicles were sampled at random in each plot in a polyethylene bag (30 × 45 cm). The number of bugs were counted and the bugs were released again in the same plot. Panicles sampled for bugs at a particular stage were marked, and such panicles were not sampled at the following observation dates. At maturity, grain yield was recorded in the central four rows.

Statistical analysis

Data on head bug numbers were converted to $\sqrt{n}$ or $\sqrt{(n + 0.5)}$ values, and subjected to analysis of variance to test the significance of difference between treatment means. Treatment means were compared by the least significant difference (l.s.d.). Avoidable losses were estimated from the grain yield recorded in unprotected and protected plots. Avoidable losses (L) were computed as follows: $L\ (\%) = [(a - b)/a] \times 100$, where a = grain yield in protected plots, and b = grain yield in the unprotected plots.

The relationship between loss in grain yield and bug numbers at different stages of panicle development was obtained by using regression and correlation analysis. EILs were computed for each stage of panicle development (based on loss of grain due to one bug per panicle before spraying or loss of grain due to one bug per panicle before and after spraying). Bug numbers before and after spraying across stages of panicle development, and mean bug numbers at different stages, were also regressed with grain yield to estimate the loss in grain yield. EILs were not computed when the regression coefficients were positive or the prediction of loss in grain yield was very low or positive. EILs were computed on the basis of loss of grain due to one bug per panicle across stages of panicle or by using rate of natural increase in bug numbers in the untreated plots at different stages of panicle development (Sharma and Lopez, 1989). Mean bug numbers before and after spraying were used to compute the rate of natural increase in bug populations. EILs were computed by the formula of Norton (1976) as described by Sharma and Lopez (1989). The cost of spraying was Rs250 per spray, and the prevailing market price of sorghum grain was Rs250 $(100\ kg)^{-1}$ for CSH 11 and IS 9692, and Rs500 $(100\ kg)^{-1}$ for IS 17610 and IS 21443.

Results

Effect of spray schedules on head bug numbers

1988 rainy season. Head bugs were controlled in CSH 11 plots sprayed with demeton-S-methyl at the HA plus CA, HA plus CA plus M, and HA plus CA plus M plus D stages (*Table 1*). Initial levels of head bug infestation were quite high (30–45 bugs per five panicles) and did not differ significantly across treatments. Plots sprayed at the HA stage showed some increase in bug density at the M and D stages. Head bug numbers increased from 40 to 181 bugs per five panicles in the untreated plots. On IS 9692, there were 27 to 47 bugs per five panicles at the HA stage before spraying. Head bug numbers remained low in plots sprayed two to four times between the HA and D stages. In unprotected plots, the bug density increased from 34 bugs at the HA stage to 89 bugs per five panicles at the D stage. Initial bug infestation was also high on IS 17610 (22–32 bugs per five panicles), although it was slightly lower than that recorded on CSH 11 and IS 9692. Head bug numbers on this genotype remained low in plots sprayed one to four times between the HA and D stages. In the untreated plots, there was no increase in bug numbers across stages of panicle development, indicating that

Table 1. Effect of methyl-S-demeton (0.025%) sprays at different stages of panicle development on head-bug numbers in three sorghum cultivars (ICRISAT Centre, 1988 rainy season)

Stage^a of insecticide spraying	No. of bugs ($\sqrt{n}$) per five panicles																							
	CSH 11								IS 9692								IS 17610							
	HA		CA		M		D		HA		CA		M		D		HA		CA		M		D	
	(B)^b	(A)^b	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)
HA	5.6	1.1^c	1.4^c	1.0^c	3.1^c	1.3^c	2.2^c	2.7^c	5.0	0.7^c	4.4	3.9^c	2.0^c	2.5^c	3.0^c	2.1^c	5.2	1.2^c	3.6^c	2.5^c	1.5^c	0.7^c	1.5^c	1.2^c
HA + CA	5.8	1.2	1.8	0.7	0.9	1.1	0.7	0.7	5.4	1.1	2.9	1.0	1.1	2.0	1.1	1.3	5.4	1.2	3.2	0.7	0.9	0.7	1.2	0.7
HA + CA + M	5.4	0.7	2.2	0.7	0.9	0.9	1.0	0.7	6.8	0.7	3.1	0.7	0.7	0.7	1.0	0.7	4.9	1.0	3.4	0.7	0.7	0.7	0.7	0.7
HA + CA + M + D	6.5	0.9	1.8	0.7	0.9	0.7	0.7	0.7	5.7	0.9	3.5	0.9	0.9	0.7	0.7	0.7	4.5	0.9	4.4	0.7	0.7	0.7	0.7	0.7
Untreated control	6.3	4.9	4.8	4.9	11.0	10.7	11.4	13.3	5.8	4.9	6.7	5.9	9.7	9.1	8.1	7.5	5.5	5.1	5.2	4.6	1.7	2.2	3.0	3.3
Mean	5.9	1.7	2.4	1.6	3.1	2.9	3.2	3.6	5.7	1.7	4.1	2.5	2.9	3.0	2.8	2.5	5.1	1.9	3.9	1.8	1.1	1.0	1.4	1.3
± s.e.	0.8	0.3	0.5	0.3	1.5	1.8	0.5	0.8	0.8	0.5	1.8	0.5	0.7	0.5	1.5	0.8	0.7	0.5	0.7	0.4	0.3	0.1	0.3	0.3

^{a}HA, half anthesis; CA, complete anthesis; M, milk stage; D, dough stage (i.e. 0, 6, 12 and 18 days after flowering, respectively); ^{b}B, before spraying; A, after spraying; $^c\sqrt{(n + 0.5)}$ transformed values

levels of resistance in this genotype were sufficient to keep head bugs under control.

1989 rainy season. There were 10–22 bugs per five panicles at the HA stage before spraying in CSH 11 (*Table 2*). The fewest bugs were recorded in plots sprayed four times. Bug numbers increased considerably across different treatments at the M and D stages, possibly because of immigration of bugs from the neighbouring fields. There was a steady increase in bug population in the unprotected plots (13 bugs at the HA stage to 354 bugs per five panicles at the D stage). Plots sprayed at the HA and HA plus CA stages showed considerable increases in bug numbers at the M and D stages. In IS 21443 (which is moderately resistant to head bugs), bug numbers remained low in plots sprayed three or four times. There was a considerable increase in bug numbers at the D stage, which may be attributed to immigration of bugs from the neighbouring fields, a phenomenon also observed in CSH 11. Head bug density increased from 14 to 111 bugs per five panicles in the unprotected plots.

Grain yield

Grain yield (6592 kg ha^{-1}) was greatest in plots of CSH 11 sprayed four times (*Table 3*). Plots sprayed once or twice yielded 5366 and 5433 kg ha^{-1}, respectively. Grain yield in the unprotected plots was 4088 kg ha^{-1}. In IS 9692, the unprotected plots yielded 843 kg ha^{-1} compared with 2474 kg ha^{-1} in plots sprayed three times. Differences in grain yield in plots sprayed two to four times were not significant. Grain yield of IS 17610 did not differ significantly between unprotected plots (1908 kg ha^{-1}) and those sprayed four times (2075 kg ha^{-1}). Thus, there was no substantial increase in grain yield as a result of insecticide application on IS 17610. Differences in grain yield across different levels of protection were not significant. During the 1989 rainy season, grain yield in CSH 11 plots ranged from 2412 kg ha^{-1} in the unprotected plots to 5442 kg ha^{-1} in plots sprayed four times. In IS 21443, the differences in grain yield in plots sprayed one to four times were not significant (2388 to 2588 kg ha^{-1}) However, the untreated plots yielded significantly less (1804 kg ha^{-1}) than the protected ones. One spray was enough to afford protection against head bugs in IS 21443, whereas four sprays were necessary to realize maximum yield in CSH 11.

Cost:benefit ratios for insecticide application involving one to four insecticide sprays were 1:5.4 to 1:13.8 for the head bug-susceptible cvs CSH 11 and IS 9692, and 1:3.4 to 1:11.7 for IS 21443. However, it was not economical to spray insecticide on the head bug-resistant cv. IS 17610. Thus, to reduce losses in grain yield and quality, it is economical to spray one to four times on the bug-susceptible cvs, depending on the bug infestation levels at different stages of panicle development.

Table 2. Effect of methyl-S-demeton (0.025%) sprays at different stages of panicle development on head-bug numbers in two sorghum cultivars (ICRISAT Centre, 1989 rainy season)

	No. of bugs ($\sqrt{n}$) per five panicles															
	CSH 11								IS 21443							
	HA		CA		M		D		HA		CA		M		D	
Stage[a] of insecticide spraying	(B)[b]	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)
HA	3.8[c]	1.1	1.4	1.6	3.9	12.7[c]	20.6[c]	14.3[c]	3.6[c]	1.3	1.7	2.2	3.5[c]	4.5	8.3	3.8
HA + CA	4.7	1.5	2.9	3.1	3.0	12.7	22.0	11.1	3.0	1.5	2.2	1.0	4.0	2.3	8.8	3.3
HA + CA + M	3.1	1.4	1.3	2.3	2.8	11.2	11.8	28.7	3.1	1.1	1.8	1.0	6.5	3.8	5.2	2.5
HA + CA + M + D	3.4	2.2	2.2	1.3	3.1	7.2	12.7	8.7	3.0	1.0	2.7	1.2	2.0	1.3	7.1	2.8
Untreated control	3.6	3.0	2.0	4.1	6.2	14.8	18.5	18.2	3.7	3.4	2.8	10.3	5.0	9.8	9.9	5.3
Mean	3.7	1.8	2.0	2.5	3.8	11.7	17.1	16.2	3.3	1.7	2.3	3.1	4.2	4.4	7.8	3.5
± s.e.	0.4	0.5	0.7	1.0	1.0	1.9	2.4	3.3	0.5	0.4	0.7	0.8	0.9	1.6	3.1	0.7

[a,b,c]As in *Table 1*

Table 3. Grain yield (kg ha^{-1}) and benefit:cost ratios for four sorghum genotypes across five levels of protection with methyl-S-demeton for head-bug control (1988–1989 rainy season)

	1988			1989	
Stage[a] of insecticide spraying	CSH 11	IS 9692	IS 17610	CSH 11	IS 21443
HA	5366 (13.1)[b]	1918 (10.8)	1767 —	3788 (13.8)	2388 (11.7)
HA + CA	5433 (6.9)	2005 (5.8)	2075 (1.6)	4220 (9.0)	2425 (6.2)
HA + CA + M	5908 (6.2)	2474 (5.4)	1933 (0.4)	4333 (6.4)	2538 (4.9)
HA + CA + M + D	6592 (6.3)	2213 (3.4)	1875 —	5442 (2.8)	2479 (3.4)
Untreated control	4058	0843	1908	2412	1804
Avoidable losses (%)	38.4	66.6	8.2	55.7	29.1
Mean ± s.e.	5442 ± 330	1890 ± 108	1908 ± 194	4125 ± 290	2325 ± 178

[a]As in *Table 1*; [b]numbers in parentheses are benefit:cost ratios for insecticide application and the market value of the produce

Table 4. Correlation of head bug numbers at four stages of panicle development with grain yield (1988– 1989)

		CSH 11		IS 9692	IS 17610	IS 21443
Stage[a] of panicle	Before/after spraying	(1988)	(1989)	(1988)	(1988)	(1989)
HA	B[b]	0.17	− 0.12	− 0.27	0.52	− 0.35
	A	− 0.73**	− 0.14	− 0.81**	− 0.04	− 0.48
CA	B	− 0.57*	− 0.09	− 0.60*	− 0.04	− 0.26
	A	− 0.58*	− 0.45	− 0.85**	− 0.23	− 0.77**
M	B	− 0.77**	− 0.71**	− 0.96**	− 0.19	− 0.41
	A	− 0.71**	− 0.48	− 0.97**	− 0.13	− 0.77**
D	B	− 0.81**	− 0.40	− 0.72**	− 0.02	− 0.20
	A	− 0.81**	− 0.15	− 0.89**	0.14	− 0.65*

[a,b]As in *Table 1*; *, **significant at $p = 0.05$ and 0.01, respectively

Avoidable losses

Avoidable losses were 38.4, 66.0 and 8.2% in CSH 11, IS 9692 and IS 17610, respectively, during the 1988 rainy season. During the 1989 rainy season, the avoidable losses were 55.7% in CSH 11 and 29.1% in IS 21443. IS 17610 and IS 21443, which have desirable levels of resistance to head bugs, suffered lesser degrees of avoidable loss than CSH 11 and IS 9692.

Economic injury levels

Data on bug numbers at different stages of panicle development and grain yield were subjected to correlation and regression analysis. Head bug numbers before and after spraying showed a negative association with grain yield (*Table 4*) (except in IS 17610 at the HA and D stages). The correlation coefficients were highly significant ($p < 0.01$) for CSH 11 and IS 9692 during

Table 5. Simple regressions of head bug numbers before and after spraying on grain yield (kg ha^{-1}) in four sorghum genotypes (1988–1989 rainy season)

Stage[a] of panicle development	Intercept (*a*)					Regression coefficient (*b*)					Economic injury level				
	CSH 11 (1988)	CSH 11 (1989)	IS 9692 (1988)	IS 17610 (1988)	IS 21443 (1989)	CSH 11 (1988)	CSH 11 (1989)	IS 9692 (1988)	IS 17610 (1988)	IS 21443 (1989)	CSH 11 (1988)	CSH 11 (1989)	IS 9692 (1988)	IS 17610 (1988)	IS 21443 (1989)
HA	5030	8789	2078	1458	5187	61	− 205	− 83	83*	− 223	—	0.6	1.5	—	1.2
CA	5938	8390	1789	1926	4863	− 322*	− 143	− 30	−5	− 159	0.4	0.9	4.2	50.0	1.6
M	5766	9558	1955	1942	4966	− 54*	− 367*	− 55*	− 156	− 73	2.3	0.3	2.3	1.6	3.4
D	5869	9917	1801	1912	4798	− 72*	−26	− 33*	− 6	−8	1.7	4.8	3.8	41.6	31.3

[a] As in *Table 1*; *regression coefficient significant at $p = 0.05$; —, residual > variance

the 1988 rainy season (except for bug population at HA before spraying). The correlation coefficients for CSH 11 during the 1989 season were negative but not significant. Association between bug numbers and grain yield in IS 17610 was poor, possibly because of its inherent resistance to bugs. In IS 21443, bug numbers after spraying at the CA, M and D stages showed significant and negative association with grain yield.

Simple regression coefficients for bug numbers before spraying at each stage of panicle development were negative (except for CSH 11 and IS 17610 before spraying at the HA stage) (*Table 5*). Regression coefficients were generally significant and their magnitudes were greater for bug numbers before spraying at the M and D stages. Head bugs accounted for most of the variation in loss in grain yield in the susceptible cvs at the M and D stages (except CSH 11 during 1988 at the D stage) than in the bug-resistant cvs IS 17610 and IS 21443. When bug numbers before and after spraying were regressed with grain yield for each stage of panicle development, the R^2 values were 58–93% for the CA and M stages (except for CSH 11 and IS 17610) during 1988 (*Table 6*). Bug numbers at HA for IS 17610 and the M stage for IS 21443 did not predict a loss in grain yield.

Multiple regression of bug numbers before and after spraying across stages of panicle development explained 59–97% of variation in grain yield (*Table 7*). However, the regression equation did not predict a loss in grain yield for CSH 11 and IS 17610 during 1988 on the basis of natural increase in bug numbers. Multiple regression of mean bug numbers at each stage of panicle development with grain yield explained 38–90% of variation in the susceptible cultivars (*Table 8*). Regression coefficients for bug numbers at CA, M, and D stages were negative (except for CSH 11 during 1988 and IS 9692 at the D stage). The bug population at the CA and M stages showed a greater negative effect on grain yield. Regression coefficients were not significant in the case of head bug-resistant cvs IS 17610 and IS 21443.

Based on simple regression of bug numbers before spraying on grain yield at each stage of panicle development, the EILs were 0.4–0.5 bugs per panicle for CSH 11 at the HA and CA stages compared with 1.5–4.5 bugs for IS 9692, 50 bugs for IS 17610, and 1.2–1.6 bugs for IS 21443 (*Table 5*). At the M stage (when maximum damage takes place), the EILs were 0.3–2.3 bugs for CSH 11, 2.3 bugs for IS 9692, 1.6 bugs for IS 17610 and 3.4 bugs for IS 21443. EILS based on multiple regression of bug numbers before and after spraying at each stage of panicle development were lower than those based on simple regression of bug numbers before spraying (*Table 6*); hence, it may be more appropriate to compute EILs based on bug population before and after spraying for each stage of panicle development. EILs ranged from 0.2 to 0.4 bugs for CSH 11 at the HA and CA stages compared with 0.5–10 bugs for IS 21443 and IS 17610.

Multiple regression of bug numbers before and after spraying across stages of panicle development resulted

Table 6. Regression coefficients of head bug numbers before and after spraying at each stage of panicle development on grain yield (kg ha^{-1}) (1988–1989 rainy season)

Cultivar	Year	Stage[a] of panicle	Intercept (a)	Regression coefficient[b] ($b\,x_1$)	Regression coefficient[b] ($b\,x_2$)	Coefficient of determination (R^2; %)	Economic injury level
CSH 11	1988	HA	5285	79	– 380**	51	0.4
		CA	5827	– 128	– 173	23	0.4
		M	5917	– 256**	154*	69	1.2
		D	5863	– 29	– 30	60	2.1
CSH 11	1989	HA	9068	– 200	– 387	—	0.2
		CA	9221	– 185	– 470	69	0.2
		M	11318	– 362**	– 61*	68	0.3
		D	10855	– 31	– 12	11	2.9
IS 9692	1988	HA	1649	35	– 153**	55	1.1
		CA	2094	– 1	– 147*	64	0.8
		M	2080	82	– 167	93	1.5
		D	1966	– 17*	– 61**	86	1.6
IS 17610	1988	HA	1396	103*	– 40	25	—
		CA	1889	25	– 50	—	10.0
		M	1949	– 136	– 57	—	1.3
		D	1928	– 372	332	5	6.3
IS 21443	1989	HA	5307	– 167	– 338	17	0.5
		CA	5125	– 135	– 59**	58	1.3
		M	4831	72	– 71**	60	—
		D	5336	14	– 327**	39	0.8

[a] As in *Table 1*; [b] $b\,x_1$ and $b\,x_2$, regression coefficients for bug numbers before and after spraying, respectively; *, **regression coefficient significant at $p = 0.05$ and $p = 0.01$, respectively

Table 7. Multiple regression coefficients (x_1–x_8) of head bug numbers before and after spraying across four stages of panicle development with grain yield (kg ha^{-1}) in four sorghum cultivars (1988–1989 rainy season)

			Regression coefficient (b) at panicle stage[a]									Economic injury level[d]	
		Intercept	HA		CA		M		D				
Cultivar	Year	(a)	(B[b], x_1)	(A[b], x_2)	(B, x_3)	(A, x_4)	(B, x_5)	(A, x_6)	(B, x_7)	(A, x_8)	R^2[c] (%)	(O)	(N)
CSH 11	1988	4692	110	406	568	2657	328	249	– 574	– 524	69	—	—
CSH 11	1989	13024	– 269	228	– 3	91	– 418*	– 41	– 23	– 5	67	0.04	0.30
IS 9692	1988	2130	55	74	– 43	22	443*	– 558*	– 12	—	97	0.90	6.60
IS 17610	1988	1423	127*	– 3	– 21	120	– 507	– 590	– 829*	734*	73	—	—
IS 21443	1989	5469	– 153	263	– 50	– 61	79	– 15	– 3	– 168	59	0.40	5.10

[a,b] As in *Table 1*; [c] R^2, coefficient of determination; [d] O, economic injury levels (EILs) based on one bug per panicle across stages of panicle development; N, EILs based on the rate of natural increase (from one bug at the half-anthesis stage) in bug numbers in the untreated control plots; *significant at $p = 0.05$

Table 8. Multiple regression coefficients (x_1–x_4) of mean head bug numbers across four stages of panicle development with grain yield (kg ha^{-1}) in four sorghum cultivars (1988–1989 rainy season)

			Regression coefficient (b) at panicle stage[a]					Economic injury level[c]	
Cultivar	Year	Intercept (a)	HA (x_1)	CA (x_2)	M (x_3)	D (x_4)	R^2[b] (%)	(O)	(N)
CSH 11	1988	4500**	273*	1184*	193*	– 414*	73	—	—
CSH 11	1989	1300**	– 570	– 434	– 120*	– 21	38	0.04	0.10
IS 9692	1988	1802**	123	– 37*	– 157**	103*	90	0.90	—
IS 17610	1988	1646**	160	– 91	– 38	– 123	3	—	2.70
IS 21443	1989	5228**	– 87	– 96	– 6	– 14	47	0.30	1.20

[a] As in *Table 1*; [b] coefficient of determination, [c] O, N, as in *Table 7*; *, **significant at $p = 0.05$ and $p = 0.01$, respectively

in estimates for EILs (based on one bug per panicle) similar to those obtained by regression of mean bug numbers across stages of panicle development (*Table 7*). Based on natural increase in bug population, the EILs based on bug numbers before and after spraying were greater than those obtained by mean bug numbers at each stage of panicle development. EILs were greater for IS 17610, IS 21443 and IS 9692 than for CSH 11.

Discussion

Two to five sprays of carbaryl have been found to be economic for suppressing head-bug populations, and protection at the CA and M stages is most important to minimize the quantitative and qualitative losses due to head-bug damage (Sharma and Leuschner, 1987; Sharma and Lopez, 1989). In the studies reported here, bugs were kept under check in plots of CSH 11 sprayed two to four times. On head bug-resistant lines (IS 17610 and IS 21443), one spray at the HA stage kept the bugs under check. These results confirm the earlier finding that it is important to protect the sorghum crop against head bugs at the HA and early M stages. During the 1989 rainy season, a sudden increase in bug numbers was recorded in different treatments at the M and D stages, possibly attributable to immigration of bugs from the adjoining fields.

Bug numbers in the untreated plots and the mean bug density across different treatments was lowest on the head bug-resistant line IS 17610, indicating that host-plant resistance can be used as an effective tool to keep bug populations under check and to reduce the losses in grain yield. Increase in bug numbers is low on IS 17610 and IS 21443 under field and no-choice cage conditions (Sharma, 1985b; Sharma and Lopez, 1992a, b). IS 9692 shows non-preference to the bugs (Sharma and Lopez, 1990b) and moderate levels of increase in bug numbers under headcage conditions (Sharma, 1985b); however, it suffers high levels of grain damage (Sharma and Lopez, 1992a). The yield potential of CSH 11 was nearly double that of IS 21443 and IS 17610. If the economic value of the grain, grain quality and its acceptability for food are taken into account, then economic returns per unit area would probably be at par between the commercial hybrids and the landraces resistant to bugs. Furthermore, the bug populations would show a constant decline in areas cropped with head bug-resistant cvs (Sharma, 1991), and there would be a minimum need to use pesticides. Avoidable losses due to head bugs have been estimated to be 54–87% in the commercial cvs ICSV 1, CSH 5 and CSH 1 (Sharma and Lopez, 1989). In the studies described here, the avoidable losses were 38–66% in the susceptible cvs compared with 8–29% losses in the bug-resistant cvs. The extent of losses was proportional to the level of head-bug resistance.

Economic injury levels differ across seasons, stage of panicle development and cvs (Sharma and Lopez, 1989) and for different stages of the insect (Natarajan and Sundara Babu, 1988). At the HA stage, the EILs vary from 0.2 to 1.4 insects per panicle in CSH 1, CSH 5 and ICSV 1. In these studies, the EILs varied from 1.2 to 4.6 bugs per panicle on the head bug-resistant line IS 17610 and IS 21443 compared with 0.4–0.9 bugs per panicle on the commercial hybrid CSH 11 at the HA and CA stages. Estimates for EILs were lower when bug numbers before and after spraying were considered for regression analysis at each stage of panicle development, and this may give a more appropriate estimate of loss in grain yield. Multiple regression involving bug numbers before and after spraying and their means across stages of panicle development resulted in similar estimates of EILs. The regression coefficients were negative when mean bug numbers were regressed against grain yield, and this may be a more appropriate method of estimating EILs to initiate spraying at the HA stage when the bug infestation takes place.

To realize maximum grain yield, four sprays of insecticide were economical on the commercial hybrid CSH 11 and IS 9692. However, only one or two sprays were enough to reduce the loss in grain yield on the moderately resistant genotype IS 21443. It was not economical to apply insecticides on the bug-resistant cv. IS 17610. EILs were lower on CSH 11 than on IS 21443 and IS 17610. Thus, host-plant resistance can be used effectively to check head bug populations, to reduce the losses in grain yield and to withstand greater levels of head-bug density to minimize the need for pesticides.

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