Effect of host plant resistance and chemical control of the head bug, *Calocoris angustatus* Leth., on grain quality and seedling establishment in sorghum

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Summary

The sorghum head bug, *Calocoris angustatus* Lethiery (Hemiptera: Miridae), is one of the most important pests of grain sorghum in India. Studies were conducted to quantify the effect of head bug damage on grain quality and seedling establishment on head bug-resistant cultivars (IS 17610 and IS 21443), a moderately susceptible cultivar (IS 9692), and a susceptible commercial cultivar (CSH 11). Differences in 1000-grain mass, seed germination and percentage of floaters were significant between protected and unprotected plots in CSH 11 and IS 9692, but not in IS 17610 and IS 21443. Grain damage ratings were significantly lower in IS 17610 than in IS 9692 and CSH 11 across different protection levels.

Head bug-damaged grain had greater protein content than the undamaged grain, possibly because of depletion in starch, and a marginal increase in soluble sugars. Amounts of proline and tyrosine were greater in the bug-damaged grain than in the undamaged grain, while the reverse was true for aspartic acid, methionine, leucine and lysine. Head bug damage also increased the tannin content in IS 9692 (which is a high-tannin genotype).

Moisture regimes and insecticide protection levels significantly affected seedling emergence. Seedling emergence of CSH 11 was lower than that in IS 17610. In the latter genotype, the differences between protected and unprotected plots were not significant. Head bug damage thus not only leads to quantitative loss in grain yield, but also spoils the grain quality and renders the grain unfit for seed purposes. These qualitative effects should be taken into account while estimating losses due to bug damage and determining economic thresholds.

Key words: *Calocoris angustatus*, mirid, sorghum, germination, grain quality, seedling establishment, host-plant resistance

Introduction

Sorghum head bug, *Calocoris angustatus* Lethiery (Hemiptera: Miridae), is one of the most important pests of grain sorghum in India (Cherian, Kylasam & Krishnamurti, 1941; Sharma, 1985*a,b*, 1993; Hiremath & Thontadaraya, 1984; Sharma & Lopez, 1990). Avoidable losses of 7–84% due to head bugs have been estimated from different parts of India (Leuschner & Sharma, 1983). Under experimental conditions, avoidable losses of 55–84% have been recorded in commercial cultivars CSH 1, CSH 5 and ICSV 1 (Sharma & Lopez, 1989).

Host-plant resistance is an important component for the management of head bugs (Sharma & Lopez 1992*a,b*), and can help reduce quantitative losses in grain yield (Sharma & Lopez, 1994). Head bug damage also spoils grain quality, rendering it unfit for human consumption (Sharma & Lopez, 1989; Sharma, Doumbia & Diorisso, 1992). The present studies examined the effects of different levels of insecticide protection and host-plant resistance against *C. angustatus* on grain quality and seedling establishment in sorghum.

Materials and Methods

The experiments were carried out at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India (18°N, 78°E), during the 1988 and 1989 rainy season. Studies were conducted on three sorghum genotypes during the 1988 rainy season (IS 17610 – resistant, IS 9692 – moderately susceptible, and CSH 11 – a susceptible commercial hybrid), and on two genotypes during the 1989 rainy season (IS 21443 – resistant, and CSH 11 – commercial hybrid). The crop was grown under rainfed conditions on deep black Vertisols during the rainy season (July to October). Seeds were sown on ridges, 75 cm apart, with a four-cone planter, and the seedlings thinned to a spacing of 10 cm between plants, 15 days after seedling emergence (DAE). Each plot measured 12 m × 4 m (16 rows, 4 m long). The experiments were laid out separately for each genotype (because of different maturities) in a randomised block design, with three replications. Seeds were sown with carbofuran (1.2 kg a.i./ha) as a basal application to protect the seedlings from sorghum shoot fly, *Atherigona soccata* Rond. At 20 DAE, the seedlings were sprayed with Cypermethrin 3ED (R) with an Electrodyn (R) sprayer at 1 litre ha^{-1} to further control *A. soccata*.

Insecticide application for head bug control

Methyl-S-demeton (Metasystox 25 EC(R)) was sprayed with a Knapsack sprayer at 250 g a.i./ha (at 500 litre 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 m × 2m) was held down-wind to minimise the spray drift to the adjoining plots. Insecticide was sprayed at the half-anthesis (HA), complete-anthesis (CA), milk (M), and dough (D) stages, i.e. 0, 6, 12 and 18 days after HA, respectively. Plots were protected at HA, HA+CA, HA+CA+M or HA+CA+M+D stages (Sharma & Lopez, 1994). Unprotected plots served as checks. These treatments created a gradient of head bug infestation across stages of panicle development to establish the relationship between bug damage, grain quality and seedling establishment.

Observations

Data were recorded on bug numbers 24 h before and after each spraying, and the results have been reported earlier (Sharma & Lopez, 1994). At crop maturity, data were recorded on grain damage, 1000-grain mass, seed germination and percentage of floaters. Grain damage was rated visually on a 1 to 9 scale (1 = all grains fully developed with a few feeding punctures, 2 = grain fully developed with feeding punctures over the exposed surface, 3 = grain showing tanning/browning, and nearly 10% shrivelling due to head bug feeding, 4 = most grains with feeding punctures, and showing nearly 20% shrivelling, 5 = grains showing nearly 30% shrivelling, 6 = grains showing 40% shrivelling, 7 = grains visible outside the glumes, and showing 50% shrivelling, 8 = grains slightly visible outside the glumes, and showing 60% shrivelling, and 9 = grains showing > 80% shrivelling, and most of the grains invisible outside the glumes). After threshing, 1000 grains were taken at random from each replication using an automatic grain counter. The grains were equilibrated for moisture content at 37 ± 2°C overnight in an oven, and the grain mass recorded the following day. The grain samples were then subjected to a floater test to evaluate the effect of head bug damage on grain density, following the procedure described by Hallgren & Murty (1983). The grains were placed in a 100 ml measuring cylinder containing sodium nitrate solution with a density of 1.31. The number of grains floating on the surface were counted and recorded as a percentage of the total number of grains. The grains were also subjected to a germination test as described by Sharma & Lopez (1989).

Chemical analysis

Grain samples (100 g) were drawn at random from the threshed grain of each replication for chemical analysis. Tannin content of the grain was determined by the procedure described by Price, Scoyoc & Butler (1978), and expressed in catechin equivalents as a percentage of grain mass. Proteins were estimated by the method of Jambunathan, Rao & Gurtu (1983). The soluble sugars were determined by the method of Clegg (1956), and Dubois *et al.* (1956). Amino acid composition was determined using an automatic amino acid analyser as described by Subramanian, Seetharama, Jambunathan & Rao (1990).

Protein content of grain was determined in samples of CSH 1 and ICSV 1 protected with different number of carbaryl sprays during the 1985 rainy season (Sharma & Lopez, 1989).

During the 1989 rainy season, grain samples from protected and unprotected plots of CSH 11, IS 9692 and IS 17610 were analysed for protein, amino acid composition, soluble sugars and tannin contents.

Seedling emergence

Two field experiments were conducted to investigate the effect of different levels of head bug damage on seedling emergence in seedbeds with deficit moisture during the summers of 1989 and 1990 (April). There was no rain during this period. Experimental details were described by Soman (1990). The experiments were conducted in an Alfisol field (Udic Rhodustalf, Patancheru series) with 77% sand and 8% clay. The field was irrigated to allow the weed seeds to germinate, and rotovated and disced repeatedly to get a dry and fine seedbed. Ten broadbeds, each 1.2 m wide were prepared along the length of the field and levelled with a bed shaper.

The experiments were set up on 10 broadbeds on either side of a line source (LS) sprinkler irrigation line (Soman, 1990). The five broad beds on one side of the LS formed one replicate and five beds on the other side formed the second replicate for different treatments. Plots 2 m long, with 0.5 m path between them were laid out along each bed. Each plot was sown with four rows of seed with a 30 cm row-to-row spacing. There were three irrigation levels, located on the 1st (W1), 2nd (W2) and 4th (W3) broadbed, respectively from the irrigation line on each side. There were three entries (IS 9692, IS 17610 and CSH 11), each with five levels of insecticide protection in Expt 1 and two entries (CSH 11 and IS 21443) in Expt 2. In each irrigation level, entry × insecticide application plots were laid out randomly.

The seeds were sown at 50 mm depth using a John Deere 7100 precision planter. Seedlings were counted 7 days after sowing (DAS). There was no further seedling emergence 1 week after sowing (Soman, 1990). Data were recorded as percentage of the seeds sown.

Statistical analysis

Data on percentage of seed germination, percentage of floaters and percentage of seedling emergence were converted to Arcsin $\sqrt{\%}$ values. Data were subjected to analysis of variance to test the significance of difference between treatments means; the treatment means were compared by the least significant difference (LSD).

Results

Grain damage

Plots of CSH 11 sprayed with demeton-S-methyl suffered a grain damage rating (DR) of < 2 compared with a DR of 5.7 in the unprotected plots (Fig. 1). Plots of IS 9692 sprayed only once showed a grain DR of 5.0 as against a DR of 2.0 in plots sprayed four times. Unsprayed plots of IS 9692 were highly damaged by the head bugs (DR 9). In IS 17610, the unprotected plots showed low grain damage (DR < 3).

Grain mass

Grain mass of 1000 grains was greatest in plots sprayed four times (25.74 g compared with 22.65 g in the unprotected plots) in CSH 11 during the 1988 rainy season (Table 1). In IS 9692, the differences in 1000 grain mass were not significant between plots sprayed 2–4 times. The grain mass in the unprotected plots was significantly lower (19.40 g) than in the protected ones (26.24–28.24 g/1000 grains). In IS 17610, the differences in grain mass were not significant between the protected and unprotected plots (22.65–25.74 g/1000 grains).

During the 1989 rainy season, 1000-grain mass was greater in CSH 11 plots sprayed three to four times than those sprayed one to two times. Grain mass in the unprotected plots was significantly lower (18.61 g) than in the protected ones (21.21–23.82 g). In IS 21443, the differences in grain mass between the plots protected with one to four sprays were not

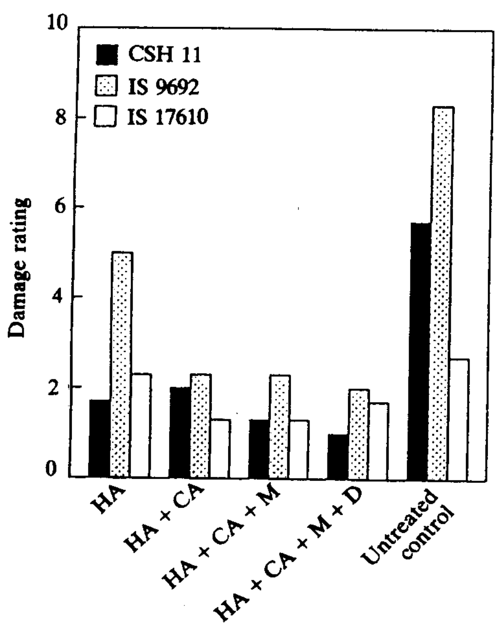

Fig. 1. Head bug damage in three sorghum genotypes across five protection levels. HA = Half-anthesis, CA = Complete-anthesis, M = Milk, and D = Dough stage (ICRISAT Centre, 1988 rainy season).

Table 1. *Effect of different levels of protection against head bugs on 1000-grain mass (g) in four sorghum genotypes (ICRISAT Centre, 1988–89 post-rainy season)*

Insecticide sprayed at	1988 CSH 11	1988 IS 9692	1988 IS 17610	1989 CSH 11	1989 IS 21443
HA[a]	24.16	26.24	22.73	21.21	18.46
HA + CA	24.65	28.08	24.65	22.68	18.48
HA + CA + M	25.42	28.24	25.42	23.49	18.78
HA + CA + M + D	25.74	27.87	25.74	23.82	18.96
Untreated control	22.65	19.40	22.65	18.6	17.22
Mean	24.52	26.02	22.24	21.96	18.38
SE	±0.769	±0.936	±0.769	±0.831	±0.280

[a] HA = Half-anthesis, CA = Complete-anthesis, M = Milk and D = Dough stage.

significant (18.46–18.96 g). Grain mass in the unprotected plots was significantly lower (17.22 g) than in the protected plots. Loss in grain mass in the unprotected plots as compared with those sprayed four times was 12% in CSH 11, 30.4% in IS 9692 and 4.2% in IS 17610 during the 1988 rainy season, and 21.9% and 3.2% in CSH 11 and IS 21443, respectively, during the 1989 rainy season.

Seed germination

Seed germination was 89%-98% in CSH 11, IS 9692 and IS 17610 when sprayed one to four times with demeton-S-methyl during the 1988 rainy season (Table 2). Seed germination was significantly lower in the unprotected plots compared with the protected ones in CSH 11 and IS 9692. In IS 17610, the differences in seed germination between the protected and unprotected plots were not significant.

During the 1989 rainy season, seed germination in CSH 11 was greater in plots sprayed two to three times with methyl-S-demeton than those sprayed only once. Seed germination in the unprotected plots was significantly lower (53%) than in the protected plots (61–80%). In IS 21443, seed germination percentages were uneven in plots sprayed one to four times.

Percentage of floaters

Head bug-damaged seed becomes light. Light grain has a poor grain quality and floats on the surface of sodium nitrate solution with a specific density of 1.31 (Hallgren & Murty,

Table 2. *Effect of different levels of protection against head bugs on seed germination (%) in four sorghum genotypes (ICRISAT Centre, 1988–89 rainy season)*

Insecticide sprayed at	1988 CSH 11	1988 IS 9692	1988 IS 17610	1989 CSH 11	1989 IS 21443
HA[a]	89 (71)[b]	91 (74)	95 (77)	68	80
HA + CA	90 (72)	95 (77)	95 (78)	61	51
HA + CA + M	89 (71)	94 (76)	94 (76)	80	72
HA + CA + M + D	98 (82)	94 (76)	96 (80)	78	45
Untreated control	81 (64)	80 (64)	96 (78)	53	72
Mean	89 (72)	91 (73)	95 (78)	68	64
SE	± (2.7)	± (2.9)	± (1.5)	±4.0	±4.0

[a] HA = Half-anthesis, CA = Complete-anthesis, M = Milk and D = Dough stage.
[b] Figures in parentheses are Arcsine $\sqrt{\%}$ transformed values.

1983). Percentage of floaters is also an indicator of the extent of head bug damage. Percentage of floaters in CSH 11 decreased with an increase in the number of insecticide sprays (Table 3). Grain in the unprotected plots of CSH 11 had 72% floaters compared with 28–44% floaters in plots protected with one to four sprays. In IS 9692, the percentage of floaters was 71–98%. The grains of IS 9692 are floury and light, and a greater percentage of its grains float on the surface of sodium nitrate solution. Differences in the percentage of floaters between the protected and unprotected plots were not significant in IS 17610.

During the 1989 rainy season, there was a significant reduction in the percentage of floaters from 85% to 28% in CSH 11, with an increase in the number of insecticide sprays. Differences in the percentage of floaters in IS 21443 were not substantial when protected with one to four sprays (12–23%). However, the percentage of floaters in the unprotected plots was significantly greater (38%) than in the protected ones. Under unprotected conditions, the percentage of floaters was much greater in CSH 11 and IS 9692 than in IS 17610 and IS 21443.

Effect of head bug damage on the chemical composition of sorghum grain

There was a linear relationship between bug numbers recorded across stages of panicle development (Sharma & Leuschner, 1987) and the protein content of sorghum grain (Fig. 2*a*). Protein content of the grain was greater in plots sprayed 0–2 times than in plots sprayed 3–5 times with carbaryl in CSH 1 and ICSV 1. Lowest protein content was recorded in plots sprayed five times. Greater protein content was also recorded in the grain from unprotected plots than in the protected plots during the 1988 rainy season (Fig. 2*b*). Differences in protein content were greater in the bug-damaged and -undamaged grain of CSH 11 and IS 9692 than in IS 17610.

Head bug-damage led to a decrease in the amounts of aspartic acid in CSH 11 and IS 9692 (Table 4). Proline and tyrosine content was greater in bug-damaged grain of all the three cultivars tested (except proline content in IS 17610), while methionine content was lower in the bug-damaged grain. Leucine and lysine content was slightly lower in the bug-damaged grain. Soluble sugars were marginally greater in the bug-damaged grain; and such an increase was greatest in IS 9692, which has a floury grain (Fig. 2*c*). Tannin content was greater in the bug damaged grain in IS 9692 than in the undamaged grain. Tannin content of CSH 11 and IS 17610 was either very low or undetectable (Fig. 2*d*).

Table 3. *Percentage of floaters in four sorghum genotypes across five protection levels (ICRISAT Centre, 1988–89 season)*

Insecticide sprayed at	1988 CSH 11	1988 IS 9692	1988 IS 17610	1989 CSH 11	1989 IS 21443
HA[a]	44 (42)[b]	93 (74)	44 (41)	85	23
HA + CA	40 (39)	89 (70)	44 (41)	71	15
HA + CA + M	38 (38)	89 (71)	40 (39)	51	15
HA + CA + M + D	28 (32)	71 (58)	41 (40)	28	12
Untreated control	72 (58)	98 (83)	45 (42)	93	38
Mean	44 (42)	88 (71)	43 (41)	66	21
SE	± (2.7)	± (2.4)	± (3.4)	±4.0	±4.0

[a] HA = Half-anthesis, CA = Complete-anthesis, M = Milk and D = Dough stage.
[b] Figures in parentheses are Arcsine $\sqrt{\%}$ transformed values.

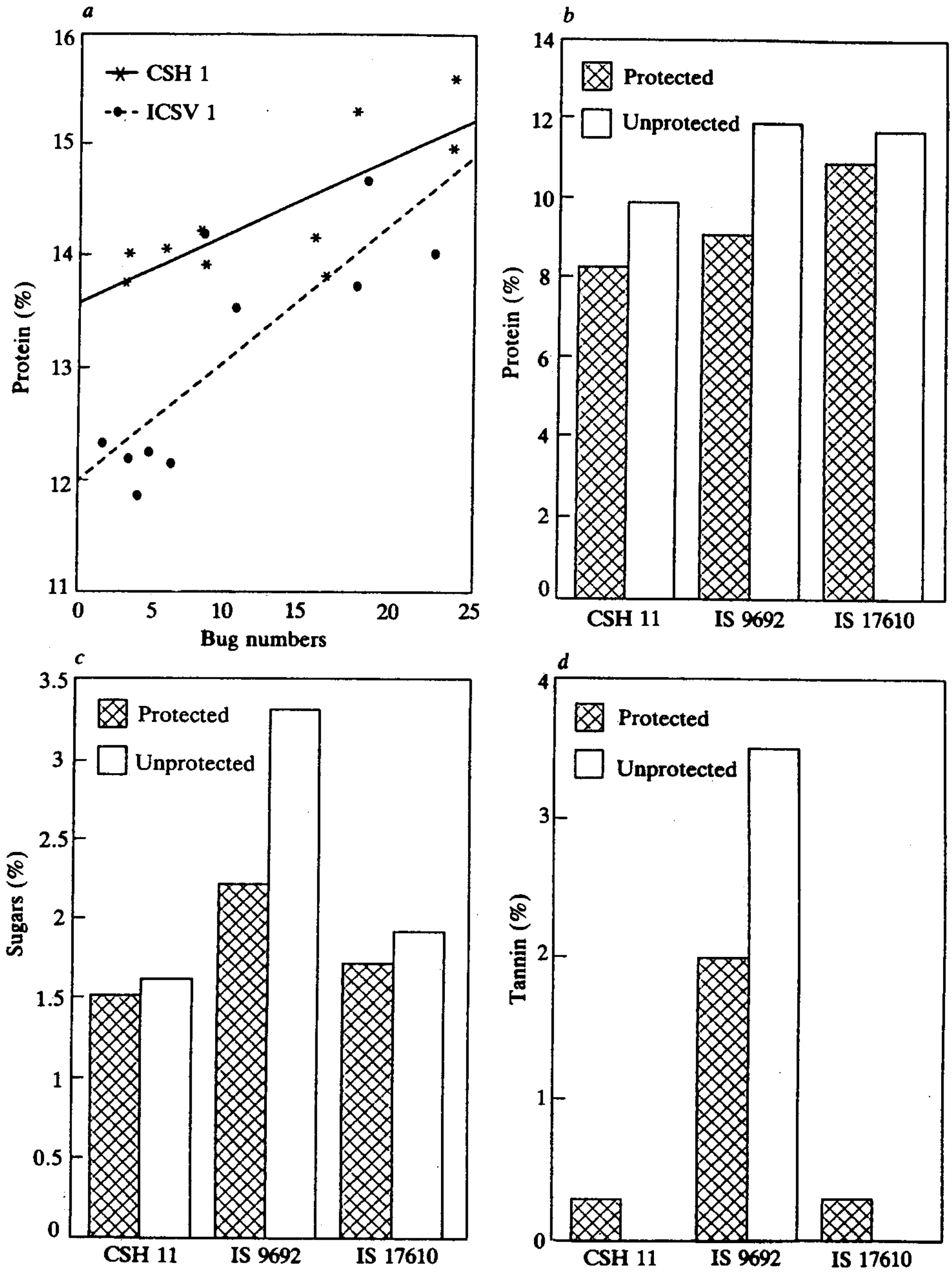

Fig. 2. *a* = Relationship between bug numbers and protein content of sorghum grain in two sorghum genotypes across 10 levels of protection against head bugs . (ICRISAT Centre, 1985 rainy season); *b* = Protein content; *c* = Sugar content; and *d* = Tannin content in sorghum grain from protected and unprotected plots of three sorghum genotypes (ICRISAT Centre, 1988 rainy season).

Seedling emergence in moisture-deficit conditions

The irrigation regimes resulted in distinct soil moisture contents in different broadbeds. The moisture treatment significantly affected seedling emergence (Table 5). In general, decrease in soil moisture reduced seedling emergence.

Table 4. *Amino acid composition (g/100 g protein) of sorghum grain in head bug-damaged (T5) and -undamaged grain (T4)*

	Undamaged grain (T4)					Damaged grain (T5)				
Amino acid	CSH 11	IS 9692	IS 17610	Mean	SE	CSH 11	IS 9692	IS 17610	Mean	SE
Aspartic acid	7.71	8.05	7.29	7.68	±0.220	7.48	7.38	7.26	7.37	±0.064
Threonine	3.12	3.20	2.91	3.08	±0.087	3.56	3.02	3.27	3.28	±0.156
Serine	4.76	5.04	4.71	4.90	±0.114	5.19	4.86	4.55	4.87	±0.185
Glutamic acid	23.35	23.63	24.50	23.83	±0.347	23.30	23.61	23.54	23.48	±0.094
Proline	7.39	7.36	8.51	7.75	±0.379	8.36	8.01	8.20	8.19	±0.101
Glycine	3.14	3.36	3.04	3.18	±0.095	3.53	3.23	3.03	3.26	±0.145
Alanine	8.46	9.36	8.98	8.93	±0.261	8.77	8.41	8.21	8.46	±0.164
Cystiene	1.19	1.26	1.13	1.19	±0.578	1.19	1.21	1.20	1.20	±0.006
Valine	4.46	4.67	4.34	4.49	±0.097	4.85	4.57	4.43	4.62	±0.124
Methionine	1.48	1.38	1.35	1.40	±0.039	1.29	1.24	1.26	1.26	±0.015
Isoleucine	3.64	3.95	3.93	3.84	±0.100	4.03	3.76	3.83	3.87	±0.081
Leucine	11.95	12.11	12.03	12.03	±0.046	11.86	11.80	11.78	11.81	±0.024
Tyrosine	3.26	3.33	3.31	3.30	±0.021	3.51	3.46	3.36	3.44	±0.044
Phenylalanine	4.70	4.73	5.04	4.82	±0.019	5.08	4.71	4.83	4.87	±0.109
Histidine	2.40	2.01	2.19	2.20	±0.113	2.30	2.21	2.20	2.24	±0.032
Lysine	2.50	2.16	2.11	2.26	±0.123	2.19	2.01	2.09	2.10	±0.052
Arginine	4.42	4.29	4.07	4.26	±0.102	4.01	4.67	4.92	4.53	±0.272
Protein (%)	8.30	9.10	10.90	9.43	±0.770	9.90	11.90	11.70	11.17	±0.637

T4—Sprayed at half anthesis + complete anthesis + milk stage and dough stage.
T5—Unsprayed control.

Table 5. *Effect of different levels of protection against head bugs on seedling emergence (% of seeds sown) in three soil moisture regimes in three sorghum genotypes (ICRISAT Centre, 1989 summer season)*

Insecticide treatment	CSH 11 W1	CSH 11 W2	CSH 11 W3	IS 9692 W1	IS 9692 W2	IS 9692 W3	IS 17610 W1	IS 17610 W2	IS 17610 W3
HA[a]	33	19	18	61	60	35	66	82	54
	(35)[b]	(24)	(20)	(53)	(51)	(32)	(55)	(66)	(47)
HA + CA	35	18	18	72	59	47	69	63	49
	(36)	(22)	(20)	(58)	(50)	(40)	(57)	(53)	(41)
HA + CA + M	31	25	25	62	61	49	81	73	35
	(33)	(28)	(25)	(54)	(53)	(41)	(65)	(59)	(33)
HA + CA + M + D	38	33	27	72	56	37	73	77	56
	(38)	(35)	(27)	(58)	(48)	(30)	(60)	(62)	(46)
Untreated control	28	19	14	41	37	33	85	68	64
	(31)	(23)	(17)	(40)	(37)	(31)	(70)	(58)	(51)
Mean	33	23	20	62	55	40	75	73	52
	(35)	(26)	(22)	(53)	(51)	(29)	(61)	(60)	(44)
SE	±1.7	±2.8	±2.4	±5.5	±4.4	±3.1	±3.5	±3.2	±4.6
	(1.1)	(2.3)	(1.8)	(3.2)	(0.9)	(6.5)	(2.7)	(2.1)	(3.0)

[a] HA = Half-anthesis, CA = Complete-anthesis, M = Milk and D = Dough stage.
W1 = Wet, W2 = Medium-wet, and W3 = Dry.
[b] Figures in parentheses are Arcsine $\sqrt{\%}$ transformed values.

The three entries differed significantly for emergence ($P < 0.001$) in the three moisture levels, with CSH 11 showing the lowest emergence in all moisture treatments. Insecticide application to the developing grain produced varying responses among the entries in terms of grain damage and seedling emergence, which could explain the significant entry × insecticide treatment interaction ($P < 0.01$). The overall effect of insecticide on emergence was also highly significant ($P < 0.01$). In general, these trends were repeated in the second experiment, though percentage of emergence was lower at all moisture levels (Table 6).

Poor crop stand results from low germination of seeds, and low emergence of seedlings. When seedbed conditions are less than optimum, for example, under moisture stress, the

Table 6. *Effect of different levels of protection against head bugs on seedling emergence (% of seeds sown) in three soil moisture regimes in two sorghum genotypes (ICRISAT Centre, 1989 summer season)*

Insecticide	CSH 11 W1	CSH 11 W2	CSH 11 W3	IS 21443 W1	IS 21443 W2	IS 21443 W3
HA[a]	18 (25)[b]	09 (17)	10 (18)	50 (45)	31 (34)	32 (34)
HA + CA	06 (13)	07 (15)	06 (15)	43 (41)	45 (42)	35 (36)
HA + CA + M	19 (26)	10 (18)	08 (16)	47 (43)	38 (39)	33 (35)
HA + CA + M + D	14 (22)	10 (18)	09 (17)	43 (41)	36 (37)	32 (33)
Untreated control	05 (13)	01 (06)	03 (09)	35 (36)	25 (31)	26 (30)
SE	± (5.4)	± (4.0)	± (5.2)	± (5.3)	± (3.7)	± (9.9)

[a] HA = Half-anthesis, CA = Complete-anthesis, M = Milk and D = Dough stage.
W1 = Wet, W2 = Medium-wet, and W3 = Dry.
[b] Figures in parentheses are Arcsine $\sqrt{\%}$ transformed values.

detrimental effect of head bug damage on seedling emergence is aggravated. Emergence under moisture stress [in the medium (W2) and dry moisture (W3) treatments] was greater in bug-resistant lines (IS 21443 and IS 17610) compared to the susceptible ones (Tables 5 and 6). Control of head bugs by insecticide improved emergence under all moisture levels in IS 9692. In IS 17610, application of methyl-S-demeton did not improve seedling emergence compared to unprotected control plots (Table 5). A positive effect of protection on seedling emergence was observed for CSH 11 and IS 21443 during the 1990 rainy season. In the case of CSH 11, the overall emergence was poor in both experiments. In the correlation analysis, bug numbers, percentage of floaters, 1000 grain mass and visual damage rating did not show significant correlation with field emergence in moisture stress conditions.

Discussion

Feeding by bugs not only results in a reduction in grain yield, but also affects the grain quality (Natarajan & Sundara Babu, 1988; Sharma & Lopez, 1989). Damage by the head bugs also reduces the food quality of the grain (Sharma *et al.*, 1992). Effects of head bug damage on grain quality parameters such as 1000 grain mass, seed germination, and percentage of floaters were greater in CSH 11 and IS 9692 than in IS 21443 and IS 17610. Loss in 1000 grain mass in the unprotected plots was greatest in IS 9692, followed by CSH 11, IS 21443 and IS 17610. Plots with low head bug incidence and suffering lower grain damage had greater 1000 grain mass, better seed germination and a lower percentage of floaters. Therefore, grain quality of head bug-damaged grain decreases with an increase in bug damage. The extent of losses due to bug damage are therefore much greater than are reflected by the decrease in grain yield.

Head bug-damage leads to a reduction in starch and protein content (Hiremath, Thontadaraya & Nalini, 1983; Natarajan & Sundara Babu, 1987). Amylases, which degrade starch, are present in the saliva of mirids (Rautappa, 1969; Hori, 1975; Gopalan, 1976). Increase in percentage protein and sugar content was possibly because of reduction in grain weight. Greater protein and sugar content in bug-damaged grain was recorded across cultivars and seasons.

Head bug-damaged grain had greater amounts of tannin in the coloured genotype, IS 9692. However, such an increase in tannin content due to head bug damage was not observed in CSH 11 and IS 17610, which have a low tannin content, and these genotypes possibly have a limited or no capability to produce tannins. Tannins and other secondary plant substances are produced and accumulated in plant tissue because of damage by insects as part of an induced mechanism of defense (Ebel, 1986; Sharma & Norris, 1991). Similar increases in tannin content have been recorded in cotton leaves as a result of stress induced by the feeding of the cotton jassid, *Amrasca biggutula biggutula* Ishida (Bhat, Joshi, Mehta & Singh, 1981; Sharma & Agarwal, 1983*a*).

Head bug damage increased the amounts of proline (except in IS 17610) and tyrosine, while aspartic acid, methionine, leucine and lysine contents decreased. It is known that the relative concentrations of different amino acids change in organisms under stress (O'Brien, 1967), and the amounts of proline increase in plants under moisture stress (Bates, Waldren & Dteari, 1973) or due to the stress induced as a result of feeding by insects (Sharma & Agarwal, 1983*b*). Changes in amino acid content can alter the relative preference of crop plants by the insects, and thus may influence their resistance/susceptibility to insects. Changes in amino acid content can also affect the nutritional quality of food. Head bug feeding changes the nutritional composition of the sorghum grain, and also results in accumulation of secondary plant substances which may affect the food quality of the grain.

Tannins and other polyphenols in sorghum also act as antifeedant/antibiotic towards insects (Sharma, Vidyasagar & Subramanian, 1993). However, these changes need to be monitored in fresh-grain immediately after the grain has been damaged by the bugs.

Head bug damage reduced seedling emergence in head bug-susceptible cultivars. The seedbed environment including moisture regimes have a profound effect on seedling establishment (Soman, 1990). The reduction in seedling emergence due to insect damage is because of reduction in grain size (Sharma & Lopez, 1989), and production of low dry matter in the seedlings from bug-damaged grain (Natarajan & Sundara Babu, 1987).

To realise maximum grain yield, and to have acceptable seed quality, four sprays of insecticide were needed for the commercial hybrid CSH 11 and IS 9692. However, only one or two sprays were sufficient to reduce the loss in grain quality on the head bug-resistant genotypes IS 21443 and IS 17610. Thus, host-plant resistance can be used effectively to check head bug populations, reduce losses in grain yield and quality, and withstand greater head bug density, thereby minimising the need to use pesticides.

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