ELSEVIER

Crop Protection 19 (2000) 385–392

Crop Protection

www.elsevier.com/locate/cropro

Components of resistance to the sorghum head bug, *Calocoris angustatus*

A.P. Padma Kumari[a,]*, H.C. Sharma[b], D.R.R. Reddy[a]

[a]*Andhra Pradesh Agricultural University, Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India*
[b]*International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India*

Received 20 July 1999; accepted 3 January 2000

Abstract

Sorghum head bug, *Calocoris angustatus* Lethiery (Hemiptera: Miridae) is an important pest of grain sorghum. Population increase, grain damage, and nonpreference of *C. angustatus* were studied on 10 sorghum genotypes under multi- and no-choice conditions during the 1989–1990 rainy and post-rainy seasons. Under multi-choice field conditions, IS 14334, IS 19955, IS 20740, IS 21444, IS 23748, and IS 17610 (except in rainy season) were not preferred by the adults at the half-anthesis stage, and IS 14334, IS 19955, IS 21444, and IS 17610 also had lower head bug numbers at the milk stage. Head bug population increase was lower on IS 19955, IS 21444, IS 20740, and IS 17610 when infested with 10 pairs of adults under no-choice conditions in the headcage at the half-anthesis and milk stages as compared with the commercial cultivars CSH 1, CSH 9 and ICSV 112. IS 17610 showed high levels of resistance to grain damage, while IS 20740 and IS 21444 suffered moderate levels of grain damage under no-choice conditions in the headcage. IS 14334 and IS 17610 also showed tolerance to head bug feeding, i.e., they suffered lower grain damage per unit population of the head bugs. Multi-, double- and no-choice tests under laboratory conditions confirmed that nonpreference is an important component of resistance to head bugs in IS 14334, IS 19955, IS 23748 and IS 17610. Sorghum genotypes showing nonpreference to adults, low rates of population increase (antibiosis), and tolerance to head bug feeding can be used in a breeding program to increase the levels and diversify the bases of resistance to *C. angustatus*.

Keywords: Sorghum; Head bug; *Calocoris angustatus*; Plant resistance; Resistance mechanism

1. Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is an important grain and fodder crop in Asia, Africa, and the Americas. Grain yield on farmer's fields is generally low, and one of the factors limiting sorghum production is insect pests. Nearly 150 species of insects have been reported as potential pests of sorghum (Jotwani et al., 1980), of which several heteropteran species are known to damage the developing grain (Sharma and Lopez, 1990a; Mc Farlane, 1989; Steck et al., 1989). Among them, *Calocoris angustatus* Lethiery (Hemiptera: Miridae) is the predominant species in India, while *Eurystylus oldi* Poppius is the most damaging species in West Africa (Sharma and Lopez, 1990a; Sharma et al., 1994).

The extent of losses due to *C. angustatus* has increased with the introduction of improved sorghum varieties and hybrids having compact panicles (Young and Teetes, 1977). The adults and nymphs of *C. angustatus* feed on the developing grain from anthesis to the hard-dough stage, and this results in tanning and shriveling of the grain. Avoidable losses due to head bugs in commercial cultivars vary from 55.0 to 88.6% under experimental conditions at the research farm (Sharma and Lopez, 1989).

Even though head bugs are amenable for chemical control (Sharma and Leuschner, 1987), there is a considerable possibility of leaving residues on the grain as a result of insecticide application. The cost of chemical control is also beyond the reach of most farmers in the semi-arid tropics. So the use of resistant varieties forms an important component in integrated pest management for keeping bug populations below economic threshold levels (Sharma and Lopez, 1992). Over 15,000 germplasm accessions have been screened for resistance to this insect, and the mechanisms of resistance have been studied for a

* Corresponding author.

0261-2194/00/$ - see front matter
PII: S0261-2194(00)00017-X

few genotypes (Sharma and Lopez, 1990b, 1992). To gain more insight into various aspects of insect–plant relationships of *C. angustatus*, the studies examined the interaction of sorghum head bug with 10 diverse sorghum genotypes under field and laboratory conditions involving multi-choice and no-choice experiments to identify genotypes with diverse mechanisms of resistance to this insect.

2. Materials and methods

Interactions of 10 sorghum genotypes with *C. angustatus* were studied under field and laboratory conditions at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. The experiments were carried out in the rainy (July–October) and post-rainy (November–April) seasons during the 1989–1990 cropping seasons. Seven diverse germplasm accessions identified as less susceptible to head bugs (IS 14334, IS 16357, IS 17610, IS 19955, IS 20740, IS 21444, and IS 23748), and three susceptible cutlivars (CSH 1, CSH 9 and ICSV 112) were planted in a randomized complete block design with two replications. Each genotype was planted in 8-row plots (4 m long with a spacing of 75 cm between the rows and 10 cm between the plants). For every 16 rows of test material, four infester rows of CSH 1 were planted to increase head bug abundance (Sharma and Lopez, 1992). Two sprays of cypermethrin were given to protect the seedlings from sorghum shoot fly (*Atherigona soccata* Rond.) damage. No insecticide was applied during the reproductive phase of the crop.

2.1. Head bug abundance on different genotypes under multi-choice field conditions

Head bug numbers were recorded on five randomly selected panicles of each genotype at the half-anthesis (50% flowering) and milk stages (10 days after flowering). For this purpose, bugs were collected from the panicles in a muslin cloth bag (60×30 cm), and the insects were immobilized by placing them in the deep freeze for 30 min. Bug numbers were counted under a magnifying glass (10X) in the laboratory.

2.2. Head bug population increase under no-choice headcage conditions in the field

At panicle emergence, 10 panicles tagged at random in each plot were covered with muslin cloth bags (30×15 cm) to avoid infestation and damage by natural head bug populations. At the half-anthesis and milk stages, ten pairs of adults (field collected nymphs reared on CSH 1) were released inside the headcages (Sharma and Lopez, 1992). Eight panicles were infested in each genotype. At the milk stage, only six panicles were infested in each genotype during the rainy season. Each infested panicle was considered as a replicate. Bugs were allowed to oviposit, feed, and develop for 20 days inside the headcages (period sufficient to complete one generation). After 20 days, head bugs from the infested panicles were tapped into a muslin cloth bag, brought to the laboratory, and inactivated in the deep freeze for 30 min. The number of head bugs on each panicle were counted under a magnifying lens. Panicles infested with head bugs under headcage were harvested at maturity and evaluated for grain damage on a 1–9 scale [damage rating (DR), 1 = grain fully developed with a few feeding punctures, and 9 = most grain showing >75% shriveling and highly tanned] (Sharma and Lopez, 1992).

Tolerance component of resistance to head bugs (tolerance index) was computed as grain damage rating in relation to mean head bug population during grain development (experimental period, i.e., 20 days) in panicles infested with bugs at the half-anthesis and milk stages.

$$\frac{\text{Grain damage rating}}{(\text{Number of bugs released per panicle} + \text{Number of head bugs 20 days after infestation})/2} \times 100$$

During the post-rainy season, grains from the infested panicles were also subjected to a germination test. One hundred grains from each panicle were placed between the folds of Whatman no. 1 filter paper moistened with 3 ml of water in a Petri dish and incubated for 72 h at $25 \pm 2°C$. The number of seeds germinated was recorded 72 h after incubation.

2.3. Cultivar nonpreference

Cultivar preference/nonpreference was studied under multi-, double- and no-choice tests in a confinement cage described by Sharma and Lopez (1990b) under laboratory conditions. Panicles at the half-anthesis stage were brought from the field and placed in 100 ml conical flasks containing water. Each panicle was wrapped in a muslin cloth bag to avoid direct contact by the head bugs with the panicle. Fifty pairs of adult bugs were starved for 2 h and released in the confinement cage in the middle. There were 10 replications. In the first experiment, the number of bugs attracted to the panicles of six genotypes were recorded at intervals of 30 min to record the time for maximal response by the head bugs to the host plant.

Subsequently, the number of bugs settling on the panicles covered with muslin cloth were recorded 4 h after releasing the bugs in the cage. During the post-rainy season, 10 genotypes were evaluated along with the susceptible controls. Each experiment was repeated 10 times. The arrangement of genotypes was changed in each test to avoid position effects.

In double-choice tests, head bug response to panicles of eight test genotypes was compared with CSH 1 (susceptible check) in a small confinement cage (30 cm diameter and 25 cm in height). Fifty pairs of bugs were released in the center of the cage, and the number of bugs attracted to each genotype was recorded after 4 h. Each experiment was repeated 10 times. Under no-choice conditions, only one panicle was offered to the bugs in the center of the cage. Fifty pairs of bugs were released in the cage. The number of head bugs attracted to the panicle was recorded 4 h after initiating the experiment. Each experiment was repeated 10 times.

The data were subjected to square root transformation for analysis of variance to determine the significance of differences between genotypes using F-test. The treatment means were compared by using least significant difference (LSD) at $P < 0.05$. Under two-choice tests, the significance of differences between cultivars was determined by the paired "t"-test at $P < 0.05$.

3. Results

3.1. Head bug abundance in different genotypes under multi-choice field conditions

At the half-anthesis stage, the number of head bugs per panicle was lower on IS 14334, IS 19955, IS 20740, IS 21444, and IS 23748 compared with CSH 9 during both the rainy and the post-rainy seasons (Table 1). No bugs were recorded on IS 20740 during the rainy season. In this genotype, the grains are completely covered by the glumes. There was a considerable variation in head bug numbers on CSH 1, ICSV 112, IS 16357, and IS 17610 across seasons possibly because of changes in head bug abundance over time. At the milk stage, IS 14334, IS 19955, IS 21444, and IS 17610 had lower bug numbers compared with the susceptible controls CSH 1, CSH 9, and ICSV 112. Genotypes IS 16357, IS 20740, and IS 23748 had greater increases in bug numbers during the rainy season than during the post-rainy season. Relatively low bug population in the susceptible control, CSH 1 at the milk stage during the rainy season was because of early flowering when the bug population density is low.

3.2. Head bug population increase and grain damage under non-choice cage conditions

Head bug population increase at the half-anthesis stage during the rainy season was lower on IS 19955, IS 21444, and IS 17610 (86–170 head bugs/panicle) compared to the susceptible controls CSH 1, CSH 9 and ICSV 112 (219–338 bugs/panicle) (Table 2). During the post-rainy season, lower head bug population increase was recorded on IS 16357, IS 20740, IS 21444, and IS 17610 compared with CSH 1. Genotypes IS 14334, IS 20740, IS 21444, and IS 17610 suffered lower grain damage (DR 1.1–6.5) than the susceptible controls (DR 7.8–9.0). These genotypes also showed $> 75\%$ seed germination. When the panicles were infested with head bugs at the milk stage, significantly lower population

Table 1
Head bug, *Calocoris angustatus*, numbers on ten sorghum genotypes at the half-anthesis and milk stages under multi-choice conditions in the field (ICRISAT Center, Patancheru 1989–1990)[a]

Genotype	Days to 50% flowering		No. of head bugs/10 panicles			
			Half-anthesis		Milk stage	
	Rainy season	Post-rainy season	Rainy season	Post-rainy season	Rainy season	Post-rainy season
IS 14334	62	59	14 ± 6[a]	15 ± 5[a]	34 ± 1[a]	26 ± 1[a]
IS 16357	63	57	2 ± 1[b]	56 ± 9[c]	360 ± 33[d]	15 ± 4[b]
IS 19955	61	59	15 ± 7[a]	25 ± 8[a,e]	109 ± 16[b]	18 ± 5[b]
IS 20740	64	58	0 ± 0[b]	5 ± 2[b]	413 ± 49[f]	12 ± 4[b]
IS 21444	61	61	2 ± 1[b]	23 ± 9[a,e]	78 ± 2[e]	10 ± 4[b]
IS 23748	63	63	5 ± 3[b]	21 ± 8[a,e]	158 ± 23[e]	9 ± 10[b]
IS 17610	91	58	36 ± 4[a]	12 ± 4[a]	4 ± 2[b]	9 ± 10[b]
Susceptible controls						
CSH 1	57	62	4 ± 2[b]	30 ± 5[e]	145 ± 26[g]	94 ± 33[e]
CSH 9	66	67	24 ± 6[e]	78 ± 8[g]	141 ± 12[g]	78 ± 14[e]
ICSV 112	66	67	5 ± 3[b]	219 ± 62[d]	112 ± 3[c]	265 ± 31[e]
Mean	65	61	11	48	145	54

[a] Figures followed by the same letter in a column are not significantly different at $P < 0.05$.

Table 2
Population sizes and grain damage in 10 sorghum genotypes following infestation with 10 pairs of *Calocoris angustatus* adults at the half-anthesis stage under no-choice conditions in the headcage (ICRISAT Center, Patancheru 1989–1990)[a]

Genotype	No. of bugs/panicle		Damage rating (DR)		Seed germination (%)
	Rainy season	Post-rainy season	Rainy season	Post-rainy season	Post-rainy season
IS 14334	240 (15.4)[a,b]	130 (10.7)[a,b,c]	6.5[b,c]	4.9[b]	75 (8.5)[c,d]
IS 16357	429 (20.5)[c]	61 (7.6)[e]	6.6[b,c]	8.9[f]	2 (1.1)[e]
IS 19955	170 (12.8)[g]	170 (12.5)[c,d]	7.0[c,d]	5.6[c]	100 (10.0)[b]
IS 20740	—	102 (9.7)[a,b,e]	—	3.3[a]	100 (10.0)[b]
IS 21444	35 (5.5)[e]	98 (8.6)[a,e]	5.5[c]	4.7[b]	84 (9.0)[c,d]
IS 23748	340 (18.1)[b,c]	191 (13.4)[d]	6.0[a,b]	6.9[d]	61 (7.6)[b,c]
IS 17610	86 (8.9)[e]	68 (8.0)[e]	1.1[e]	2.3[e]	95 (9.9)[c,d]
Susceptible controls					
CSH 1	270 (15.8)[a]	435 (19.8)[f]	9.0[f]	8.5[g]	16 (3.0)[a]
CSH 9	338 (18.0)[b,c]	149 (11.1)[b,c]	8.6[g,f]	8.3[g]	50 (6.3)[b]
ICSV 112	219 (13.8)[a]	277 (16.5)[g]	7.8[d,g]	8.9[f]	2 (1.4)[a,e]
LSD at 5%	(3.6)	(2.1)	0.80	0.5	(1.7)

[a]1. Damage rating (1 = all grains fully developed with a few feeding punctures; 9 = most of the grains showing > 75% shriveling and highly tanned).
2. Figures in parentheses are $\sqrt{N}$ transformed values.
— = Data not recorded.
Figures followed by the same letter in a column are not significantly different at $P < 0.05$.

Table 3
Population sizes and grain damage in 10 sorghum genotypes following infestation with 10 pairs of *Calocoris angustatus* adults at the milk stage under no-choice conditions in headcage (ICRISAT Center, Patancheru 1989–1990)[a]

Genotype	No. of bugs/panicle		Damage rating (DR)		Seed germination (%)
	Rainy season	Post-rainy season	Rainy season	Post-rainy season	Post-rainy season
IS 14334	109 (9.2)[a,b]	57 (7.2)[a,b]	4.5[b,c]	3.0[d]	88 (9.4)[b,c]
IS 16357	54 (7.2)[a,b]	23 (4.7)[d]	2.5[a,d]	4.1[a,d]	81 (9.0)[b,c]
IS 19955	144 (11.6)[b,c]	27 (5.0)[d]	5.7[b,c]	3.7[a,d]	97 (9.9)[c]
IS 20740	—	23 (4.8)[d]	—	3.7[a,d]	80 (8.7)[a]
IS 21444	47 (6.3)[a,d]	54 (7.1)[a,b]	6.6[e]	2.7[d]	81 (8.9)[b,c]
IS 23748	43 (6.5)[a,d]	21 (4.5)[d]	3.5[a,b]	4.8[a]	96 (9.8)[c]
IS 17610	22 (4.6)[d]	26 (5.0)[d]	1.3[d]	2.6[d]	88 (9.3)[b,c]
Susceptible controls					
CSH 1	—	67 (7.9)[b,c]	—	6.9[b]	50 (6.9)[d]
CSH 9	160 (12.3)[b]	105 (9.9)[c]	6.8[e]	7.3[b]	70 (8.2)[a,b,d]
ICSV 112	178 (13.1)[c]	38 (5.8)[a,d]	6.2[e]	6.5[b]	57 (7.5)[a,d]
LSD at 5%	(3.6)	(1.7)	1.4	1.5	(1.3)

[a]Damage rating (1 = all grains fully developed with a few feeding punctures; 9 = most of the grains showing > 75% shriveling and highly tanned).
Figures in parentheses are $\sqrt{N}$ transformed values.
— = Data not recorded.
Figures followed by the same letter in a column are not significantly different at $P < 0.05$.

increase was recorded on IS 16357, IS 20740, IS 21444, IS 23748, and IS 17610 than on CSH 9 and ICSV 112 (Table 3). IS 17610 suffered the least grain damage, followed by IS 16357, IS 14334, IS 23748, IS 19955, and IS 20740 (DR 2.5–5.7). IS 17610 showed low population increase under no-choice conditions in the headcage and also suffered low grain damage. The head bug-resistant genotypes IS 14334, IS 19955, IS 20740, IS 21444 and IS 17610 showed > 70% seed germination. IS 16357 and ICSV 112 showed very low seed germination because these genotypes were highly sensitive to head bug damage.

3.3. Tolerance

Genotypes IS 14334 and IS 17610 showed tolerance to head bug feeding as compared to IS 16357 and IS 21444 when the panicles were infested with 10 pairs of bugs under headcage at the half-anthesis and milk stages (Fig. 1). IS 19955 showed moderate levels of tolerance to head bug feeding, while panicles of IS 20740, IS 23748, CHS 1, and ICSV 112 showed greater tolerance to head bug feeding when infested at the half-anthesis stage than those infested at the milk stage.

3.4. Cultivar nonpreference

Attraction of head bugs under multi-choice conditions was significantly lower towards the panicles of IS 14334, IS 19955, and IS 23748 compared with CSH 9 (Table 4). Head bug attraction to the sorghum panicles was quite fast, and the bug response to the panicles of different genotypes was close to maximum by 30 min. Maximum response was recorded by 3 h and 30 min. We therefore, selected 4 h as a standard interval to measure head bug response to different sorghum genotypes. All genotypes

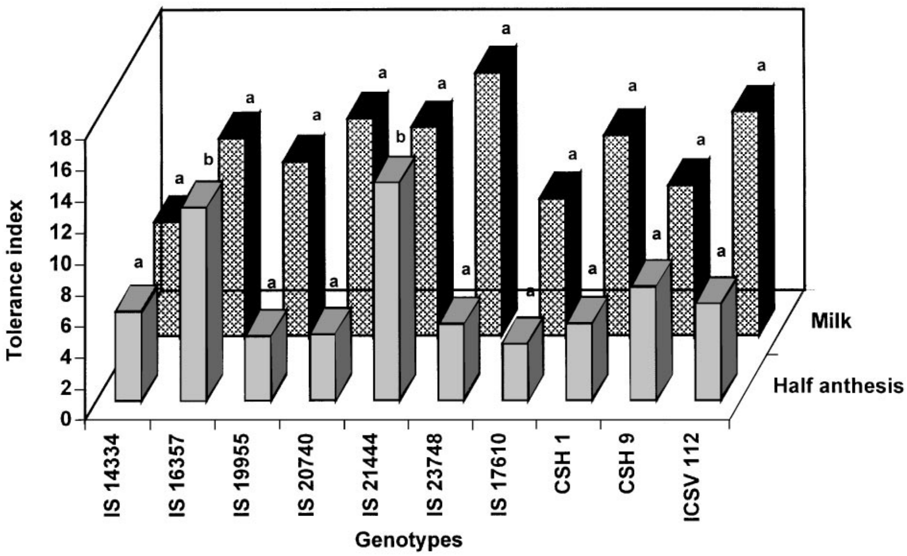

Fig. 1. Relative tolerance of 10 sorghum genotypes to head bug, *Cacocoris angustatus* feeding when infested with 10 pairs of adults at the half-anthesis and milk stages of panicle development under no-choice headcage conditions (ICRISAT Center, Patancheru, 1989–1990). Bars followed by the same letter within a stage (half-anthesis or milk stage) are not significantly different at $P < 0.05$.

Table 4
Numbers of of *Calocoris angustatus* adults attracted to six sorghum genotypes in multi-choice cage tests under laboratory conditions (ICRISAT Center, Patancheru 1989 rainy season)[a]

Genotype	No. of bugs attracted after							
	½ h	1 h	1½ h	2 h	2½ h	3 h	3½ h	4 h
IS 14334	6 (2.1)[a]	6 (2.2)[a]	6 (2.3)[a]	7 (2.4)[a]	6 (2.2)[a]	6 (2.2)[a]	6 (2.4)[a]	6 (2.4)[a]
IS 16357	5 (2.0)[a]	6 (2.3)[a]	7 (2.3)[a]	7 (2.3)[a]	7 (2.3)[a]	8 (2.3)[a]	9 (2.6)[a]	8 (2.5)[a]
IS 19955	6 (2.4)[a,b]	6 (2.5)[a,b]	7 (2.6)[a]	7 (2.4)[a]	5 (2.1)[a]	5 (2.0)[a]	7 (2.5)[a]	7 (2.4)[a]
IS 21444	6 (2.1)[a]	5 (1.9)[a]	6 (2.3)[a]	5 (2.0)[a]	5 (2.0)[a]	6 (2.2)[a]	6 (2.4)[a]	6 (2.2)[a]
IS 23748	5 (2.1)[a]	5 (2.1)[a]	6 (2.2)[a]	5 (2.0)[a]	5 (2.0)[a]	5 (2.1)[a]	7 (2.5)[a]	6 (2.4)[a]
Susceptible control								
CSH 9	10 (2.9)[b]	11 (3.1)[b]	11 (3.2)[b]	14 (3.5)[b]	13 (3.4)[b]	15 (3.6)[b]	15 (3.6)[b]	15 (3.6)[b]
LSD at 5%	(0.67)	(0.72)	(0.78)	(1.01)	(0.95)	(0.94)	(0.95)	(0.97)

[a]Figures in parentheses are $\sqrt{N}$ transformed values.
Figures followed by the same letter in a column are not significantly different at $P < 0.05$.

showing resistance (low levels of population increase and low grain damage) to head bugs under field conditions were less preferred as compared to CSH 9.

Under multi-choice tests during the post-rainy season, IS 17610, IS 20740, and IS 23748 were significantly less preferred than CSH 1, CSH 9, ICSV 112, and IS 16357 (Fig. 2). In double-choice tests, IS 14334, IS 17610, IS 19955, IS 20740, and IS 23748 were significantly less preferred than the susceptible control, CSH 1 (Fig. 3). Significantly lower number of bugs responded to the panicles of IS 17610, IS 19955, IS 20740, IS 21444, and IS 23748 as compared with those of CSH 1, CSH 9 and ICSV 112 under no-choice conditions (Fig. 4).

4. Discussion

The panicle size of sorghum genotypes varies widely. Therefore, extent of grain damage and the number of insects per panicle need to be considered in deciding on the susceptibility/resistance of a genotype. Monitoring head bug numbers at the half-anthesis

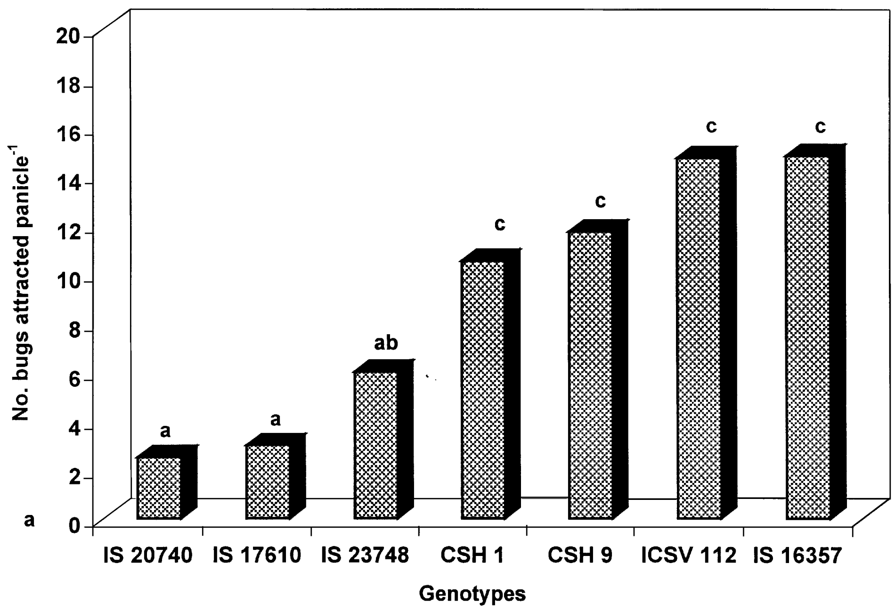

Fig. 2. Response of *Calocoris angustatus* adults to panicles of seven sorghum genotypes under multi-choice conditions (ICRISAT Center, Patancheru 1989–1990). Bars followed by the same letter are not significantly different at $P < 0.05$.

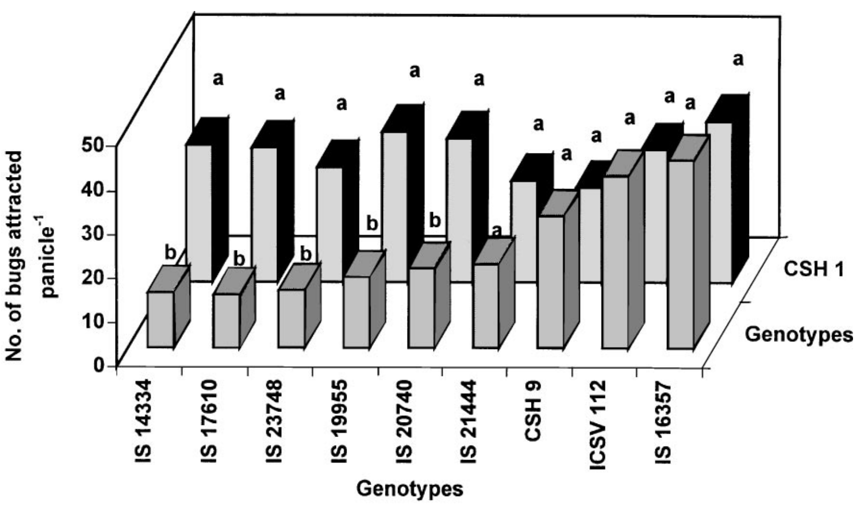

Fig. 3. Response of *Calocoris angustatus* adults to panicles of nine sorghum genotypes in comparison to panicles of CSH 1 under double-choice conditions (ICRISAT Center, Patancheru 1989–1990). A pair of bars followed by the same letter are not significantly different at $P < 0.05$.

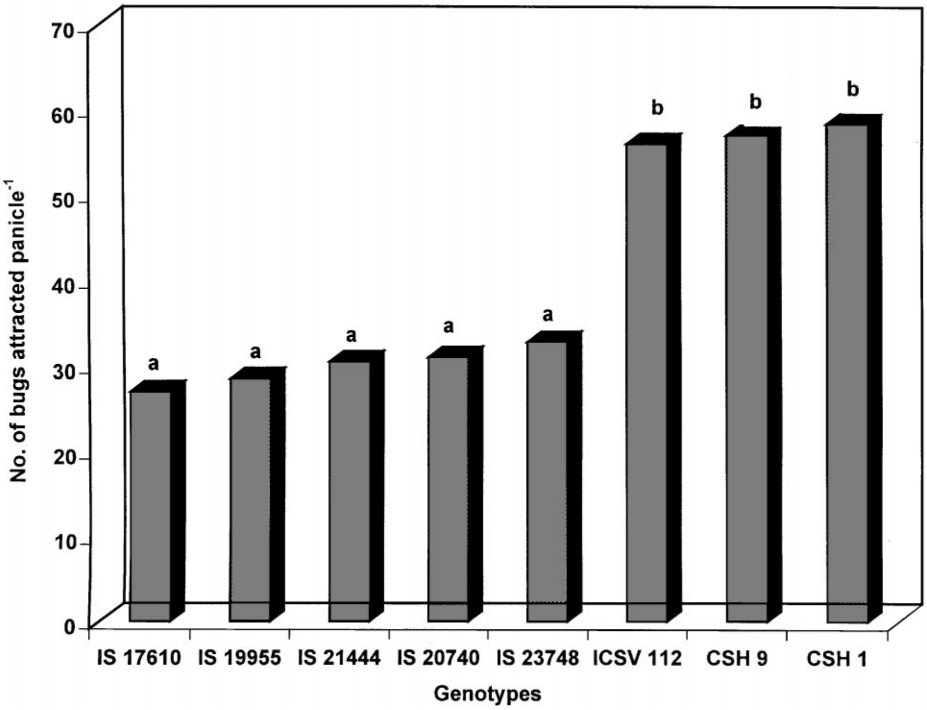

Fig. 4. Response of *Calocoris angustatus* adults to panicles of seven sorghum genotypes under no-choice conditions (ICRISAT Center, Patancheru 1989–1990). Bars followed by the same letter are not significantly different at $P < 0.05$.

Table 5
Components of resistance to *Calocoris angustatus* in 10 sorghum genotypes (ICRISAT Center, Patancheru 1989–1990)[a]

	Cultivar nonpreference					Head bug population increase				Grain damage rating				Tolerance	
	Field conditions		Cage tests			HA		M		HA		MA		HA	M
Genotype	R	PR	MC	DC	NC	R	PR	R	PR	R	PR	R	PR		
IS 14334	±	–	–	–	–	+	±	±	±	±	–	–	–	–	–
IS 16357	–	±	–	+	–	–	–	±	+	–	–	+	–	+	+
IS 19955	±	–	–	–	–	–	±	–	–	–	–	–	–	±	±
IS 20740	–	–	N	–	–	N	–	N	–	N	–	N	–	–	+
IS 21444	–	–	–	±	–	–	–	–	±	–	–	±	–	+	+
IS 23748	–	–	–	–	–	+	±	–	–	±	±	–	–	–	+
IS 17610	+	–	–	–	–	–	–	–	–	–	–	– –	–	–	–
Susceptible controls															
CSH 1	–	–	+	+	+	+	+	N	±	+	+	N	+	–	+
CSH 9	+	+	+	+	+	+	+	+	+	+	+	+	+	±	–
ICSV 112	–	+	+	+	+	+	+	+	–	+	+	+	+	–	+

[a] + = Genotypes showing preference, greater population increase and grain damage, or poor tolerance to head bug feeding.
± = Genotypes not significantly different from the susceptible controls.
– Genotypes showing nonpreference, low population increase (antibiosis), and low grain damage, and tolerance to head bug feeding.
N = Not studied.
R = Rainy season, PR = Post-rainy season, HA = Half-anthesis, and M = Milk stage.
MC, DC and NC = Multi-, double-, and no-choice conditions, respectively.

and milk stages under multi-choice field conditions, and recording head bug population increase by infesting the sorghum panicles under no-choice headcage serves as a useful tool to partition cultivar nonpreference, morphological barriers to oviposition, and antibiosis components of resistance (Sharma and Lopez, 1990b). Sorghum genotypes have diverse interactions with head bugs under multi- and no-choice conditions in the field and laboratory conditions (Table 5). Cultivar nonpreference is one of the components of resistance in sorghum to

C. angustatus (Sharma and Lopez, 1990b). Cultivar preference plays an important role in host–plant selection for feeding and oviposition, and thus, has an important bearing on genotypic susceptibility to insects. However, genotypic nonpreference sometimes is not a stable component of resistance, and it is not evident in the absence of a favored host (Harris, 1961). Therefore, it is important to quantify the contribution of nonpreference as a component of plant resistance in different genotypes under both multi- and no-choice conditions.

Genotypes IS 14334, IS 16357, IS 19955, IS 20740, IS 21444, IS 23748, and IS 17610 were nonpreferred by the adults at the half-anthesis stage in multi-choice field conditions in one or both seasons. Of these, IS 17610, IS 20740, IS 23748, and IS 19955 were also less preferred under multi, double- and no-choice cage-tests in the laboratory. However, nonpreference of IS 16357 and IS 21444 was not observed under double-choice and/or multi-choice tests in the cage, indicating that nonpreference is not a strong component of resistance to head bugs in these genotypes.

Population increase was lower under field conditions on IS 14334 and IS 19955. Genotypes IS 23748, IS 14334, IS 20740, IS 21444 and IS 17610, also suffered lower grain damage and showed better seed germination as compared with the susceptible controls. Panicles infested at the milk stage recorded lower population increases and suffered lower grain damage than those infested at the half-anthesis stage. IS 14334 and IS 17610 also showed tolerance to feeding by the head bugs. Lower percentage of seed germination in ICSV 112, CSH 1 and CSH 9 (except in panicles infested at the milk stage) also confirms the susceptibility of these cultivars to head bugs. Hall and Teetes (1982) reported that sorghum grain was more susceptible to damage by green stink bug and the leaf footed bug during the early seed development, resulting in poor germination. Differences in population increase and grain damage across seasons may be due to the effect of environmental conditions on survival and development of bugs, or the influence of environmental conditions on physico-chemical properties of the grain, which in turn may affect the colonization and damage by the head bugs (Sharma and Lopez, 1990c). Variation in population increase under headcage may also be related to the use of wild population as reported in the case of *Lygus hespersus* Knight (Moshy et al., 1983).

Combination of different components of resistance to insects in the same genotype delays the development of biotypes capable of feeding on resistant genotypes irrespective of the levels of resistance (Gallun, 1972). The present studies showed that sorghum genotypes have different combinations of resistance mechanisms such as cultivar nonpreference, low rate of population increase (antibiosis), and tolerance to feeding by the head bugs which can result in less grain damage. Genotypes with diverse mechanisms can be used in a breeding program to increase and diversify the levels of resistance in sorghum to *C. angustatus*.

Acknowledgements

We thank Mr P. Vidyasagar, Mrs V.F. Lopez, Mr V.V. Rao, and Mr S. Raja Rao for their help in these studies. Approved as JA No. 1355 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India.

References

Gallun, R.L., 1972. Genetic interrelationships between host plants and insects. J. Environ. Qua. 1, 259–264.

Hall, D.G., Teetes, G.L., 1982. Damage to grain sorghum by southern green stink bug, Conchuela and leaf footed bug. J. Econ. Entomol. 76, 1372–1373.

Harris, K.M., 1961. The sorghum midge, *Contarinia sorghicola* (Coq.) in Nigeria. Bull. Entomol. Res. 52, 129–146.

Jotwani, M.G., Young, W.R., Teetes, G.L., 1980. Elements of integrated control of sorghum pests. FAO Plant Production and Protection Paper. FAO, Rome, Italy, pp. 159.

Mc Farlane, J.H., 1989. The hemipterous insects and spiders of sorghum panicles in northern Nigeria. Insect Sci. Appl. 10, 277–284.

Moshy, A.J., Leigh, T.F., Foster, K.W., Schreiber, F., 1983. Screening selected cowpea, *Vigna unguiculata* (L.) lines for resistance to *Lygus hespersus* (Heteroptera: Miridae). J. Econ. Entomol. 76, 1372–1373.

Sharma, H.C., Leuschner, K., 1987. Chemical control of sorghum head bugs. Crop Prot. 6, 334–340.

Sharma, H.C., Doumbia, Y.O., Haidra, M., Scheuring, J.F., Ramaiah, K.V., Beninati, N.F., 1994. Genotypic resistance and mechanisms of resistance to sorghum head bug, *Eurystylus immaculatus* Odh. in West Africa. Insect Sci. Appl. 15, 39–48.

Sharma, H.C., Lopez, V.F., 1989. Assessment of avoidable losses and economic injury levels for the sorghum head bug. *Calocoris angustatus* Leth. (Hemiptera: Miridae). Crop Prot. 8, 429–435.

Sharma, H.C., Lopez, V.F., 1990a. Biology and population dynamics of sorghum head bugs (Hemiptera: Miridae). Crop Prot. 9, 164–173.

Sharma, H.C., Lopez, V.F., 1990b. Mechanisms of resistance in sorghum to head bug, *Calocoris angustatus*. Entomol. Exp. Appl. 57, 285–294.

Sharma, H.C., Lopez, V.F., 1990c. Stability of resistance in sorghum to *Calocoris angustatus* (Hemiptera: Miridae). J. Econ. Entomol 84, 1088–1094.

Sharma, H.C., Lopez, V.F., 1992. Screening for plant resistance to sorghum head bug, *Calocoris angustatus*. Leth. Insect Sci. Appl. 13, 315–325.

Steck, G.J., Teetes, G.L., Maiga, S.D., 1989. Species composition and injury to sorghum by panicle feeding bugs in Niger. Insect Sci. Appl. 10, 199–217.

Young, W.R., Teetes, G.L., 1977. Sorghum entomology. Ann. Rev. Entomol. 22, 193–218.