MECHANISMS OF RESISTANCE IN SORGHUM TO EARHEAD BUG, *Calocoris angustatus* Lethierry (HEMIPTERA : MIRIDAE)

By

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This is to certify that the thesis entitled **"Mechanisms of resistance in sorghum to earhead bug, Calocoris angustatus, Lethierry (Hemiptera: Miridae)"** submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculture of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Miss. A.P. Padma-Kumari under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee.

No part of the thesis has been submitted for any other degree or diploma. The published part has been fully acknowledged. All assistance and help received during the course of investigations has been duly acknowledged by the author of the thesis.

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DECLARATION

I, Miss. A.P. Padma Kumari, hereby declare that the thesis entitled "**Mechanisms of resistance in sorghum to earhead bug, Calocoris angustatus Lethierry (Hemiptera:Miridae)**" submitted to Andhra Pradesh Agricultural University for the degree of Master of Science in Agriculture is the result of original work done by me. I also declare that my material contained in this thesis has not been published earlier.

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Abstract

Experiments were undertaken to study the mechanisms of resistance in an array of ten diverse sorghum genotypes to the head bug, Calocoris angustatus Lethierry with major emphasis on nonpreference of adults for oviposition and/or feeding, and antibiosis effects on the survival and development in the 1989/90 rainy and postrainy seasons. Of the ten genotypes, IS 14334, IS 17610, IS 19955, IS 20740, IS 21444 and IS 23748 were nonpreferred by the adults in both field and laboratory under multi-choice conditions. In double-choice tests, IS 14334, IS 19955, IS 20740, IS 23748 and IS 17610 were nonpreferred compared with the susceptible control, CSH 1. Under no-choice conditions, the bug response was relatively less (26 to 33% bugs/panicle) towards IS 19955, IS 20740, IS 21444, IS 23748 and IS 17610 as compared with the susceptible controls, CSH 1, CSH 9 and ICSV 112 (53 to 56% bugs/panicle). Population build-up was low when the bugs were caged on IS 17610, IS 21444 at the half-anthesis and milk stages in both the seasons and IS 20740 in the postrainy season. Population build-up was lower in panicles infested at milk stage than those infested at half-anthesis stage. Results on oviposition were not consistent over seasons. Less oviposition was recorded in IS 17610 during the postrainy season. Antibiosis effects

were noticed under field conditions in IS 23748, as more number of nymphs failed to develop as adults. Nymphal development was prolonged by one day when reared on IS 14334 and IS 16357 in the laboratory. Nonpreference for feeding is a major component while nonpreference for oviposition and antibiosis showed a slight contribution towards genotypic resistance to head bugs.

INTRODUCTION

CHAPTER I

INTRODUCTION

Sorghum [Sorghum bicolor (L.) Moench] is the fifth most important cereal in the world. It is grown in the semi-arid areas of tropics and subtropics. The crop is also grown in high rainfall areas. Traditionally grown varieties are photoperiod sensitive, which have been selected to flower at the end of the wet period so that the grain ripens under dry conditions (Dogget, 1988).

Sorghum is an important grain and fodder crop of India. During 1988, it was cultivated in an area of 16 million ha with an average yield of 756 kg ha^{-1} (FAO, 1989). During 1986-87, with a cultivable area of 16 lakh hectares of sorghum, the average yield in Andhra Pradesh is 600 kg ha^{-1} (Statistical Abstracts of A.P, 1987). Grain yield on farmers fields is generally low and one of the factors limiting production is insect pests (Sharma and Lopez, 1990a). Nearly 150 species of insects have been reported as potential pests of sorghum (Jotwani et al., 1980; Seshu Reddy and Davies, 1978), of which several heteropteran species are known to damage the developing sorghum grain in different parts of the world. Preliminary observations in Western Africa showed that grain quality was seriously affected by the feeding of the

hemipterans (MacFarlane, 1989). Mirid head bugs, Calocoris angustatus Lethierry., Eurystylus immaculatus Odhiambo., Creontiades pallidus Rambur., and Campylomma spp. are the key pests in Asia and Africa. C. angustatus is the predominant species in India, while E. immaculatus is most damaging in Western Africa (Sharma and Lopez, 1990a).

Eurystylus rufocunealis Poppius damaged sorghum grain from soft to hard dough stages resulting in loss of grain yield and grain quality (MacFarlane, 1989). Similar is the case with Campylomma spp. which feeds on the milk grain (Sharma, 1985a). As early as 1916, Ballard reported C. angustatus as a major pest of sorghum in India. The problem seems to be increasing with the introduction of varieties and hybrids with compact panicle (Young and Teetes, 1977; Seshu Reddy, 1982). The ear head bug attacks in the soft-dough stage and is restricted to certain areas of Andhra Pradesh, Karnataka and Tamilnadu (Jotwani, 1982).

Among the various pest control methods host plant resistance is an important component in the head bug control (Sharma and Lopez, 1990b). Over 15000 germplasm accessions have been screened for resistance to this insect at ICRISAT. Mechanisms of resistance to this insect have been studied on a few lines by Sharma and Lopez (1990c). The present investigations were undertaken

to study the resistance mechanisms in a diverse array of sorghum genotypes to C. angustatus with emphasis on (i) Nonpreference of adults (oviposition and/or feeding), and (ii) Antibiosis effects on survival and development.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

2.1 ECONOMIC IMPORTANCE

Leuschner and Sharma (1983) estimated the avoidable losses due to panicle feeding insects on sorghum as 4.6% (Rs. 972.31 million/year). Head bugs accounted for 5.8 to 84.3% loss in grain yield in different parts of India. Head bugs affected 23000 ha from August to December in Dharwad, Bellary, Raichur, Gulbarga, Bijapur and Mysore districts of Karnataka (Hiremath and Thontadarya, 1983). Sharma and Lopez (1989) assessed avoidable losses due to head bug damage in commercial cultivars. Head bug density explained 43 to 94% variation in grain yield. Of the three cultivars studied, greatest avoidable losses were reported in cultivar ICSV 1(89%) followed by CSH 1 (70%) and CSH 5 (40% in 1986 and 55% in 1987). Natarajan and Sundara Babu (1988a) estimated a loss in grain weight up to 32 g/panicle when the panicles were infested with three adults of C. angustatus. Grain mass per panicle decreased as the number of ovipositing females increased.

Economic injury levels (EIL) were worked out by Natarajan and Sundara Babu (1988b). EIL's varied according to the insecticide used and the stage of the insect. EIL was 7.9 nymphs, 5.4 feeding adults or 0.06 ovipositing

adults per panicle when hexachlorocyclohexane (HCH) was used. EIL's were 15.1 nymphs, 10.5 feeding adults and 0.12 ovipositing adults per panicle when malathion was used for head bug control. Sharma and Lopez (1989) reported EIL's based on a cost benefit ratio of 1:1 and those calculated by Norton's (1976) formula as 1.3 - 1.4 insects/panicle for CSH 1, 0.4 for ICSV 1 and 0.4 - 0.6 (during 1986) and 0.2 - 0.4 (during 1987) for CSH 5.

Steck et al (1989) reported that Eurystylus (marginatus) immaculatus Odh (Sharma et al., 1990a, 1990b) causes yield loss of 19-62% in grain weight/panicle in Niger. Creontiades pallidus has been reported to cause 50% losses in cotton with a mean population of seven per 50 sweeps in Syria (Stam, 1987).

2.2 NATURE OF DAMAGE

Head bug attacks the panicle from the time of panicle emergence to maturity. Both the nymphs and adults suck sap from the developing grain. As a result, the grain remains unfilled, shrivelled and chaffy. Panicles infested at the pre-anthesis stage become completely tanned with little grain development, but those infested after complete-anthesis have less damage. When the pest attacks after the grain development, there was little damage (Cherian et al., 1941). The damaged grain showed distinct

feeding punctures and when the feeding was severe the grains were completely tanned (Plate 1). The damaged grains were more prone to disease attack and recorded poor germination (Sharma, 1985a). Ear head bugs derived their food by sucking up the easily available reserve food material such as endosperm and scutellum from the developing grains and caused considerable loss (Hiremath et al., 1983).

Feeding by the bug resulted in the depletion of starch (7 to 28%) and proteins (27 to 53%). There was an increase in free amino acids (Natarajan and Sundara Babu, 1987a). Among the five nymphal instars, fourth-instar nymphs were found to cause greatest damage (Natarajan and Sundara Babu, 1988a). It can complete at least two generations on the same crop as all the panicles do not flower at the same time (Teetes et al., 1983). The infestation was higher in genotypes with compact panicles than those with semi-compact and loose panicles (Cherian et al., 1941; Balasubramanian et al., 1979; Reed et al., 1980; Sharma, 1985a). It has also been recorded to feed on Pennisetum glaucum R.Br. and maize foliage and inflorescence, both during the rainy and postrainy seasons. During the summer season, this pest has been

Plate 1: Grain damage by head bugs in sorghum.

recorded on summer sorghum in farmer's field (Sharma and Lopez, 1990a).

2.3 BIOLOGY

The biology of C. angustatus was first studied by Ballard (1916). Subsequently some more detailed investigations were carried out by Cherian et al (1941); Natarajan and Sundara Babu (1987b) and Sharma and Lopez (1990a).

The adults are attracted to the sorghum panicle at the pre-anthesis stage. Female bugs oviposit in the spikelets after a pre-oviposition period of 2-4 days in the rainy season and 5-8 days in the postrainy season (Natarajan and Sundara Babu, 1987b; Sharma and Lopez, 1990a). The adult female lays bluish-green eggs in between the glumes of a floret. The colour of the egg varies with the stage of development. The oviposition period is 8-11 days during the rainy season and 3-6 days during the postrainy season (Natarajan and Sundara Babu, 1987b). A female lays 182±21 ($\bar{x} \pm$ SE) eggs in the rainy season and 113±12 eggs in the postrainy season. Eggs hatch in 7-8 days. Five nymphal instars have been recorded, and the development is completed in 8-12 days. Females survive for 14-23 days in the rainy season and 12-23 days during the postrainy season (Sharma and Lopez, 1990a).

Its life span is 31-35 days (Natarajan and Sundara Babu, 1987b).

The adult is about 5 mm long, and a little more than 1 mm broad and is yellowish-green (Teetes et al., 1983) (Plate 2). Wing pads are clear in nymphs. Males show darker pads and females have green pads. The clavus of the membrane regions of males is dark-brown whereas females have a light-brown tinge in the membrane region (Natarajan and Sundara Babu, 1987b). Biometric observations on all stages of insect have been reported by Sashibhushan et al (1984) and Natarajan and Sundara Babu (1987b).

2.4 POPULATION DYNAMICS

Balasubramanian and Janakiraman(1966) studied the influence of weather factors on the incidence of ear head bugs on CO 12 irrigated sorghum (Cholam). They found that high temperatures at the surface and at a height of 3 m and 6 m within the cropped field at flowering reduced the incidence of earhead bug. Balasubramanian and Balasubramanian (1979) reported a negative correlation between the bug population and the number of rainy days. They also found that there was no significant correlation with maximum temperature, sunshine hours and relative humidity in the morning and evening. Rainfall intensity

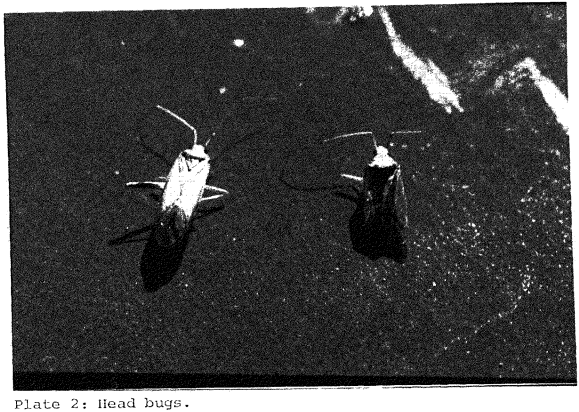

Plate 2: Head bugs.

was positively correlated. Hiremath and Thontadarya (1984a) indicated the occurrence of the bugs throughout the year except in the months of March, April and May in Karnataka. The adults were predominant during flowering where as nymphs were abundant during milk and ripening stages. A negative correlation was observed between the bug population at the milk stage and maximum temperature, while a positive and significant correlation was noted with relative humidity. A low incidence of bugs was observed in crops sown during June.

Natarajan et al (1988a) found that the head bug population at pre-flowering, milk, dough and maturity stages was influenced by weather parameters at one, two and three weeks before the respective stages of crop growth. In the ratoon crop, the populations at the pre-flowering and maturity stages were influenced by the weather factors of the same week. In most cases relative humidity had a positive influence. Natarajan et al (1989) found that early April sowings were severely infested while early June sowings had less infestation of bugs during April to June, 1984. A July sown crop supported a higher population compared to the one sown in September. In the crop sown during January, the bug population on main crop was nil, while the ratoon crop had a higher population than the main crop in all the sowings.

Studies by Sharma and Lopez (1990a) on population dynamics of head bugs revealed that low minimum temperatures(<18 °C) and relative humidity (<30%) during November to January had adverse effects on population of C. angustatus. During the postrainy season, high temperatures (>32 °C) and moisture deficit had a negative association with the populations of C. angustatus, C. pallidus and Eurystylus bellevoyei. However these factors were positively associated with the numbers of Campylomma spp. Weather parameter means for the same week and two preceding weeks showed a greater effect on C. angustatus population.

2.5 CONTROL

Several studies (Putta Rudriah, 1947; Usman, 1967; Sundaraju et al., 1977; Paul, 1976; Paul and Srinivasan, 1978; Subbarao et al., 1980; Sharma and Leuschner, 1987; Natarajan and Sundara Babu, 1988c) have been conducted on the chemical control of head bugs. Not much work has been done on other methods of control.

The only cultural practice recommended to avoid crop losses due to C. angustatus is to take up timely and uniform planting of the same cultivar in a geographical area (Thimmaiah et al., 1972; Sharma, 1984). Among other methods of control, growing plant varieties that are

resistant to insects is the ideal way to protect the crop against insect losses and at the same time prevent pollution of the environment.

2.6. HOST PLANT RESISTANCE

Resistance to insects in crop plants is genetically controlled and expressed as nonpreference, antibiosis and tolerance (Painter, 1951). The mechanism of nonpreference is a plant attribute that makes the plant less acceptable to the insect for food, shelter or oviposition. Nonpreference in general does not reduce insect population but it is not likely to select for biotypes. Recently a new term 'Antixenosis' has been proposed (Kogan and Ortman, 1978) in the place of nonpreference. It is a Greek word meaning something that keeps a 'guest away'. It is meant to convey that the plant is a bad host; therefore, it is avoided.

Antibiosis denotes the adverse effects of the host plant on the insect life history. The adverse effects may be in the form of reduced fecundity, decreased size, abnormal length of life and increased mortality.

Tolerance is the ability of a plant to withstand insect damage without affecting the yield significantly. The same level of infestation would reduce the yields in susceptible cultivars. Tolerance can be attributed to

plant vigour, production of new plant parts or repairing the plant parts injured.

Nearly 15000 germplasm accessions have been screened for head bug resistance in the sorghum improvement programme at ICRISAT. To increase the efficiency of this screening the use of infestor rows, staggered planting of the material to synchronise flowering in various maturity groups and use of overhead sprinklers, to maintain high humidity was suggested by Sharma (1985a). A headcage technique to screen under no-choice conditions was developed to screen for resistance to head bug (Sharma and Lopez, 1990b, 1990c). Ten pairs of field collected bugs released on a panicle at the pre-anthesis to half-anthesis stage completely damaged the susceptible cultivar, CSH 1. Maximum build-up in the population has been recorded 20 days after infestation (Sharma and Lopez, 1990b).

Sharma and Lopez (1990c) reported that moderate levels of resistance to sorghum head bug have been observed in germplasm accessions. The degree of susceptibility is influenced by the stage of the panicle, panicle size and compactness. Sometimes cultivars with loose panicles are also completely damaged. None of the floral characters seem to be associated with the head bug susceptibility. But some cultivars were non-preferred

under both field and laboratory conditions. They were also less suitable for growth and development of nymphs.

Natarajan et al (1988b) had screened 86 sorghum lines for resistance to head bug and identified IS 2205, IS 2394, IS 4663 and IS 5604 as highly resistant. Low levels of resistance have been reported in 'Chencholam' (Balasubramanian et al., 1979) and SPV 456, a selection from CS 3541 x SB 1079 (Shivanna et al., 1982). IS 17610, IS 17645, IS 17618, (Sharma, 1985a) IS 14334, IS 16357, IS 19955, IS 20740, IS 21444, and IS 23748 have been found to be moderately resistant to head bugs (Sharma, Personal communication).

Sharma and Lopez (1990c) studied the mechanisms of resistance in sorghum to C. angustatus. Cultivar nonpreference was found to be one of the components of resistance under multi-choice and double-choice conditions in some genotypes, but it was not evident under no-choice conditions. Reduced oviposition was recorded in IS 17610, IS 17618, IS 17645. Antibiosis effects were also noticed in IS 9692, IS 17610, IS 17645, which were expressed as delayed post-embryonic development by 1-2 days, and lower nymphal mass in the fifth instar nymphs on IS 17610 and IS 9692. IS 17610 was the most resistant and stable genotype over seasons and at different infestation levels (Sharma and Lopez, 1990d).

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

3.1 SORGHUM GENOTYPES

Ten sorghum genotypes, seven showing resistance to bugs under natural infestation (IS 14334, IS 16357, IS 17610, IS 19955, IS 20740, IS 21444 and IS 23748) and three susceptible controls (CSH 1, CSH 9, and ICSV 112) were used to investigate the mechanism(s) of resistance to the head bug, C. angustatus. The particulars of these lines are given in Table 1.

All the field and laboratory experiments were conducted at the International Crops Research Institute For Semi-Arid Tropics(ICRISAT), Patancheru, Andhra Pradesh, India.

3.2 EXPERIMENTAL DESIGN

Field trials were conducted in the rainy and postrainy seasons during 1989/90. The experiment was laid out in a completely randomized block design with two replications. Normal agronomic practices were followed for raising the crop. For every 16 rows of test material, four infestor rows were planted with CSH 1 to increase the head bug population (Sharma and Lopez, 1990a). During the rainy season, three sowings were taken up at 15 days interval,

Table 1. Characteristics of ten sorghum genotypes used to **study** the mechanism of resistance to C. angustatus

Sorghum genotype	Plant height in kharif(cm)	Days to 50% flow.(kharif)	Panicle type	Taxonomic group
CSH 1	150	58	SC	B
CSH 9	200	67	C	B
ICSV 112	150	66	SC	B
IS 14334	220	65	L	G
IS 16357	240	81	SL	C
IS 19955	410	82	L	G
IS 20740	330	77	L	B
IS 21444	330	61	SL	G
IS 23748	390	84	SL	GC
IS 17610	395	116	SL	G

SC - Semi-compact; C - Compact
L - Loose; SL - Semi-loose, G - Guinea, C - Caudatum,
B - Bicolor; GC - Guinea-caudatum

Source. Cereals Entomology Unit, ICRISAT

on 23rd June, 10th July, and 25th July, to reduce the chances of escape from bug infestation. In the postrainy season, two sowings were taken up, one on 15th October and the other on 5th December. Each genotype was planted in plots of 6x4m (i.e) 8 rows of 4 m length, ridges 75 cm apart. Plants were thinned to a spacing of 10 cm between the plants, 15 days after seedling emergence. All the cultural practices such as interculture, irrigation, weeding etc. carried on for a weed free crop. Two sprays of cypermethrin (a synthetic pyrethroid) were given to protect the seedlings from shoot fly damage.

3.3 TEST INSECT

Head bugs (C. angustatus) were collected from adjacent sorghum fields at ICRISAT by tapping the sorghum panicles into a muslin cloth bag (60 x 30 cm). Sorghum panicles at the pre-anthesis to complete-anthesis stage mostly have adult bugs, while the panicles at the milk and dough stages largely have nymphal population. Adults and nymphs were separated with the help of an aspirator in 200 ml plastic bottles. Adults collected from the field were confined with muslin bags on panicles of CSH 1 at the pre-anthesis or half-anthesis stage for oviposition. Panicles at the milk stage were used for rearing nymphs. This procedure minimized the transitional effect of the host cultivar from which the bugs were collected. Bugs reared

on CSH 1 were used for laboratory and field experiments.

3.4 BAGGING OF PANICLES

Panicles of sorghum genotypes under study were protected from natural C. angustatus infestation and other insects by covering the panicles at the flag leaf stage with a muslin cloth bag (36x25cm). These panicles were used for field and laboratory experiments.

3.5 Cultivar Preference/Nonpreference of C.angustatus Under Multi-choice Field Conditions

Cultivar nonpreference under multi-choice field conditions was studied by recording head bug population in five randomly selected panicles in each plot at the half-anthesis and milk stages. Panicles were sampled for bugs in a muslin cloth bag (60 x 30 cm). The insects were immobilized by placing them in the deep freeze. Head bug numbers per panicle were recorded.

3.6 HEADCAGE

The headcage technique (Sharma, 1985a) was used to study the oviposition, population build-up, and nymphal survival and development. The headcage is made with a 1.5 mm galvanized wire and consists of two rings, each 16 cm diameter supported by three pieces of wire, each 20 cm long. There is another ring (2 cm diameter) which is 8 cm

below the upper ring and it helps in retaining the cage in position at the tip of the panicle. The three pieces of wire are 10 cm long below the lower ring and these are fastened around the peduncle with a clip. The cage was covered with a muslin cloth bag (60 x 30cm). A known number of bugs were released into the cage for different experiments (Fig. 1) (Plate 3).

3.6.1 POPULATION BUILD-UP OF C. angustatus UNDER HEADCAGE

The population build-up of C. angustatus was studied under headcage conditions both at the half-anthesis and the milk stages (15 days after flowering). Ten pairs of field collected bugs were released per panicle under a headcage. Bugs were allowed to multiply under headcage for 20 days (period enough for completing one generation). Head bugs were removed 20 days after infestation brought to laboratory, inactivated in a deep freeze for 30 minutes; and counted under a magnifying lens. Infested panicles were harvested at maturity and were evaluated for head bug damage on a 1-9 scale. (1 = All grains fully developed with a few feeding punctures; 2 = Grain fully developed, with feeding punctures; 3 = Grain showing slight tanning/browning; 4 = Most grains with feeding punctures, and a few showing slight shrivelling; 5 = Grains showing slight shrivelling and browning; 6 = Grains

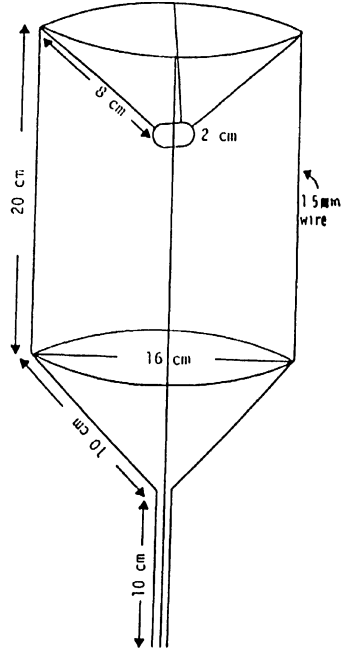

Fig.1: Headcage used in screening for resistance to head bugs (Sharma, 1985a)

Plate 3 Screening sorghum genotypes for resistance to bugs under headcage.

showing more than 50% shrivelling and turning brown or tanned; 7 = Most of the grain highly shrivelled with a dark coloration; 8 = Grain highly shrivelled and slightly visible outside the glumes and 9 = Most of the grains remaining undeveloped and invisible outside the glumes).

During the 1989 rainy season, 9 genotypes (IS 14334, IS 16357, IS 19955, IS 21444, IS 23748, IS 17610, CSH 1, CSH 9, and ICSV 112) were tested at the half-anthesis and at milk stages (except CSH 1 at the milk stage). The experiment was repeated in the 1989/90 postrainy season. Eight panicles were caged per genotype and each was considered as a replicate. At milk stage in the rainy season six panicles were caged in each genotype.

In the postrainy season, the damaged panicles were threshed and the grains were subjected to a germination test. One hundred grains from each panicle were taken in a petridish (5 cm diameter). The grains were placed in between the folds of Whatman No.1 filter paper at 25 ± 2°C and 3 ml of distilled water was added. After 72 hrs, the number of germinated seeds were recorded to evaluate the effect of head bug damage on seed viability.

3.7 CULTIVAR PREFERENCE/NONPREFERENCE UNDER LABORATORY CONDITIONS

Host preference of C. angustatus based on orientation to panicles of different sorghum genotypes at the half-anthesis was studied in the laboratory using multi-choice, double-choice and no-choice tests in specially designed cages. The number of bugs attracted to a genotype after 4 h was taken as the criterion for measuring cultivar preference/nonpreference.

3.7.1 Confinement Cage

The confinement cage used to study cultivar preference/nonpreference was fabricated by using an acrylic sheet of 0.5 mm thickness (Plate 4). Each cage was of 42 cm diameter and 25 cm in height. Two thermocole sheets (5 cm thickness) were cut to 42 cm diameter and each was kept at the ends of the cylindrical chamber, and secured to it with a tape. This served as a base and a lid for the cage. The thermocole was perforated equidistantly at six places to keep homoeopathic vials (5 cm long) filled with water. The panicles of the sorghum genotypes were placed in these vials at the time of conducting nonpreference tests. In the centre of the thermocole lid a hole of 12 cm diameter was made and this was covered with a wire mesh lid (11.5 cm). This facilitated the release of bugs in the centre of the cage.

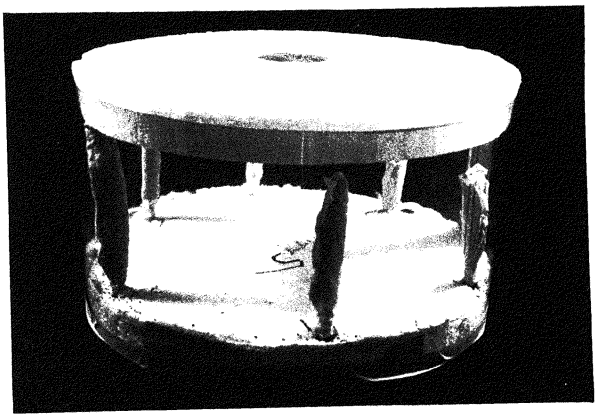

Plate 4 Confinement cage used for studying genotypic non-preference of adults under multi-choice conditions.

Pin-holes were made in the acrylic sheet above the thermocole base to facilitate air circulation. Panicles at the half-anthesis stage were placed into the vials, and tested for orientation of bugs. All the experiments using the confinement cage were conducted in a dark room.

3.7.1.1 Multi-choice conditions

The preference/nonpreference of C. angustatus to the genotypes was studied in three sets under multi-choice conditions. In the first set, panicles at the half-anthesis stage from CSH 9, IS 14334, IS 16357, IS 19955, IS 21444, and IS 23748 were tested. The panicles were covered with a muslin cloth to avoid direct contact by the head bugs with the panicle. CSH 9 served as a susceptible control. The panicles were placed in the homoeopathic vials containing water (one panicle per vial) in the cage (Plate 4). Fifty pairs of field collected bugs starved for two hours were released into the cage. To know the time required for obtaining maximum head bug response, the number of bugs attracted to the panicles of different genotypes were recorded at intervals of half-an-hour. Maximum response was recorded by 3h 30 min. after release and hence, head bug numbers were recorded 4 h after release to know genotypic preference/nonpreference of

C. angustatus. In the second set, six genotypes (CSH 1, CSH 9, ICSV 112, IS 16357,IS 20740, and IS 17610) were included in the multi-choice assay. CSH 1, CSH 9, IS 23748, IS 16357, IS 20740 and IS 17610 were studied in the third set. Each set of genotypes was repeated ten times and the arrangement of the panicles was changed in each test to avoid possible position effects. The first set was studied during the rainy season and the later two during the postrainy season.

3.7.1.2 Double-choice conditions

In the double-choice test, panicles of IS 14334, IS 19955, IS 17610, IS 20740, IS 21444, IS 23748, CSH 9 and ICSV 112 were compared with those of CSH 1 using the confinement cage (30 cm diameter and 25cm height) (Plate 5). The procedure followed was the same as in multi-choice test. Fifty pairs of bugs were released in the centre of the cage, and the number of bugs attracted to each panicle were recorded 4 h after releasing the bugs. Each test was repeated ten times.

3.7.1.3 No-choice conditions

Under no-choice condition, one panicle from a genotype was provided in the cage (30 cm diameter and 25 cm height). The panicles were covered with a muslin cloth to avoid contact with the bugs. Fifty pairs of adult

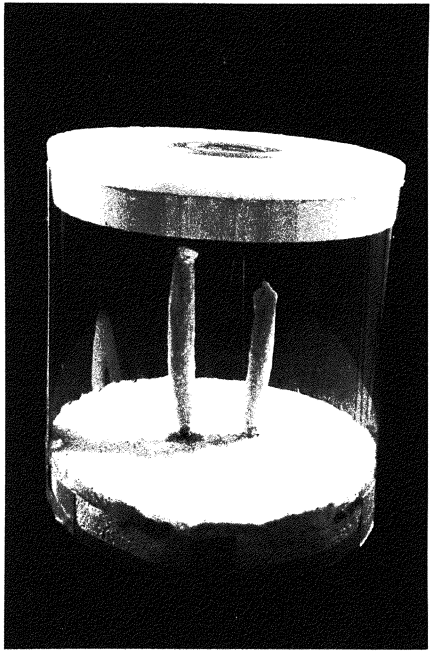

Plate 5: Co[illegible]nement cage used for studying ge[illegible] cypic nonpreference of adults under double-choic[illegible] conditions.

bugs were released in each cage. The number of bugs responding were recorded after 4 h. The experiment was repeated 10 times.

3.8. OVIPOSITION

Oviposition by C. angustatus on different sorghum genotypes was studied under headcage in the rainy and postrainy seasons.

During rainy season, field collected fourth or fifth instars nymphs of C. angustatus were reared in the lab in glass tubes(7.5 x 2.0 cm) containing 10 day-old milk grain of CSH 1. The food was changed on alternate days. Adults from this culture were separated and paired. Each pair was reared on milk grain for 3-4 days (pre-oviposition period). Later on, five pairs of bugs were released per panicle in each cage at the half-anthesis stage. Only 20 primary branches per panicle were retained for oviposition. Oviposition was studied on CSH 9, IS 14334, IS 16357, IS 19955, IS 21444, IS 23748, and IS 17610. There were two replications for each genotype, each comprising three panicles. The panicles were exposed to bugs for oviposition for 3 days. Panicles were excised, brought to the laboratory, and stored in the deep freeze. Five hundred spikelets/plot were dissected under a binocular microscope (10x) and the number of florets with

eggs and the total number of eggs were recorded.

During the postrainy season, 20 pairs of field collected adults were released for oviposition per panicle under headcage at the pre-anthesis stage. Twenty primary branches were retained per panicle for oviposition. Six panicles were caged in each genotype, and each was considered as a replicate. The panicles were excised three days after exposure to bugs, and stored in the deep freeze. From each panicle, 250 florets were selected at random and dissected under a binocular microscope (10x). Data on the number of florets with eggs and the total number of eggs were recorded.

3.9 ANTIBIOSIS

Antibiosis effects of the genotypes on C. angustatus were studied on nymphal survival and development in field conditions under headcage. Duration of post-embryonic development was studied in the laboratory.

Field collected adults of C. angustatus were confined on panicles of CSH 1 for oviposition. Freshly emerged first instar nymphs from these panicles were used for field and laboratory experiments.

In the rainy season, 100 freshly emerged first instar nymphs were caged per panicle at the milk stage on CSH 1,

CSH 9, ICSV 112, IS 14334, IS 16357, IS 19955, IS 20740 and IS 23748. Ten panicles were caged in each genotype. Each panicle had 20 primary branches. Fifteen days after the infestation (period sufficient for development of nymphs into adults), the cages were removed and the numbers of bugs were recorded as described before. Infested panicles were evaluated for grain damage on a 1 to 9 scale.

Post-embryonic development of bugs was studied by rearing them on CSH 1, CSH 9, ICSV 112, IS 14334, IS 16357 and IS 23748. For this purpose, freshly emerged first instar nymphs were reared in a plastic vial (3.5 cm diameter and 2 cm long) at 28 $\pm$ 2°C. Nymphs were fed on milk grain of different genotypes. The food was changed on alternate days. Twenty nymphs were separately reared on each genotype.

The nymphs were observed every day for moulting, and the duration of each instar was noted.

3.10 STATISTICAL ANALYSIS

Data on head bug numbers (transformed into square-root values), ovipositional preference, antibiosis and nonpreference of bugs to sorghum genotypes under multi-choice conditions was subjected to analysis of variance in

a randomised block design. The least significant difference (LSD) was used to compare the significance of difference between treatment means. Data on cultivar nonpreference under double-choice conditions were analysed by the paired t-test. Standard errors were individually calculated for the population of bugs on each genotype under natural conditions, and for the response of bugs to sorghum genotypes under laboratory conditions.

RESULTS

CHAPTER IV

RESULTS

4.1 CULTIVAR PREFERENCE/ NONPREFERENCE OF C.angustatus UNDER MULTI-CHOICE FIELD CONDITIONS

Cultivar preference of natural field populations of C. angustatus was observed during the 1989/90 rainy and postrainy seasons. IS 14334, IS 16357, IS 19955, IS 21444 and IS 23748 had relatively fewer bugs/panicle than the susceptible control, CSH 9 at the half-anthesis stage during the 1989 rainy season . IS 17610 recorded very high populations. No bugs were recorded on IS 20740 (Table 2). In general, head bug population was very low at the half-anthesis stage in the rainy season to obtain a reliable assessment of head bug preference to different genotypes. IS 14334, IS 16357, IS 19955, IS 20740, IS 21444 and IS 23748 and IS 17610 were less preferred by the bugs compared to the susceptible controls at the half-anthesis stage during the 1989/90 postrainy season (Table 2). The bug population on the less susceptible genotypes varied from 5 to 56 bugs/10 panicles as against 219 bugs/10 panicles on the susceptible control,ICSV 112.

At the milk stage, IS 14334, IS 19955 and IS 21444 recorded lower population compared to the susceptible controls, CSH 1 and CSH 9. IS 17610 had the least bug

Table 2. Population of C. angustatus on ten sorghum genotypes at the half-anthesis and the milk stage under natural field conditions (ICRISAT Center, 1989/90)

Genotypes	Days to 50% flowering		Bugs/10 panicles at			
			Half-anthesis stage in		Milk stage in	
	Rainy season	Postrainy season	Rainy season	Postrainy season	Rainy season	Postrainy season
CSH 1	57	62	4 ± 2	30 ± 5	145 ± 26	94 ± 33
CSH 9	66	67	24 ± 6	78 ± 8	141 ± 12	78 ± 14
ICSV 112	66	67	5 ± 3	219 ± 62	112 ± 3	265 ± 31
IS 14334	62	59	14 ± 6	15 ± 5	34 ± 1	26 ± 1
IS 16357	63	57	2 ± 1	56 ± 9	360 ± 33	15 ± 4
IS 19955	61	59	15 ± 7	25 ± 8	109 ± 16	18 ± 5
IS 20740	64	58	0 ± 0	5 ± 2	413 ± 49	12 ± 4
IS 21444	61	61	2 ± 1	23 ± 9	78 ± 2	10 ± 4
IS 23748	63	63	5 ± 3	21 ± 8	158 ± 23	9 ± 10
IS 17610	91	58	366 ± 37	12 ± 4	4 ± 2	9 ± 10

population (4 bugs/10 panicles). However, the bug population was relatively higher on IS 16357, IS 20740 and IS 23748 than the susceptible control, ICSV 112. The population on these genotypes was on par with CSH 1 and CSH 9. During the postrainy season, at the milk stage the head bug population was very low on all the genotypes except ICSV 112 (Table 2). IS 17610 flowered a month later compared with other genotypes in the rainy season. During postrainy season there was synchronisation of flowering.

4.2 POPULATION BUILD-UP OF C. angustatus UNDER HEADCAGE

4.2.1 Half-anthesis stage

Significantly lower populations were recorded on IS 21444 and IS 17610 (35 and 86 bugs/panicle, respectively) compared to the susceptible controls CSH 1, CSH 9 and ICSV 112 (229 to 338 bugs/panicle) (Table 3). IS 19955 also recorded a significantly lower population build-up compared with CSH 9. IS 14334, IS 16357 and IS 23748 were at par with the susceptible controls and the population build-up in these genotypes was higher than the susceptible controls. IS 17610, which supported low bug population had the least grain damage rating of 1.1 on a 1-9 scale. IS 21444, which recorded least bug population,

Table 3. Population build-up and grain damage by C. angustatus in ten sorghum genotypes at the half-anthesis stage under headcage (1989 Rainy season)

Genotype	Bugs/panicle[1]	Damage rating[2]
CSH 1	270(15.8)[3]	9.0
CSH 9	338(18.0)	8.6
ICSV 112	219(13.8)	7.8
IS 14334	240(15.4)	6.5
IS 16357	429(20.5)	6.6
IS 19955	170(12.8)	7.0
IS 21444	35 (5.5)	5.5
IS 23748	340(18.1)	6.0
IS 17610	86(8.9)	1.1
LSD at 5% t	(3.6)	0.80
CV(%)	(25)	12

1 Mean of 8 replications.

2 Damage rating (1 = All grains fully developed with a few feeding punctures;
9 = Most of the grains remaining undeveloped and invisible outside the glumes).

3 Figures in parentheses are $\sqrt{N}$ transformed values.

had a bug damage rating of 5.5, and was at par with IS 23748. The susceptible controls recorded a higher damage rating (7.8 to 9).

During the postrainy season, a significantly low population build-up of C. angustatus was observed on IS 14334, IS 16357, IS 17610, IS 19955, IS 20740, IS 21444, IS 23748 (61 to 191 bugs/panicle) compared with CSH 1 (435 bugs/panicle) and ICSV 112 (277 bugs/panicle) at the half-anthesis stage. CSH 9 recorded relatively lower population build-up compared to the other two susceptible controls, CSH 1 and ICSV 112.

IS 14334, IS 19955, IS 20740, IS 21444, IS 23748 and IS 17610 had significantly lower grain damage compared to the susceptible controls, CSH 1, CSH 9 and ICSV 112 (Table 4). The damage ratings in the above genotypes ranged between 2.3 to 6.9 as against 8.3 to 8.9 in the susceptible controls. The damage rating in IS 16357 was at par with the susceptible controls (Plates 6, 7 and 8). Seed germination was significantly lower (1.7 to 50.4%) in CSH 1, CSH 9, ICSV 112 and IS 16357 compared to 60.5 to 100% in IS 14334, IS 19955, IS 20740, IS 21444, IS 23748 and IS 17610.

Table 4. Population build-up, grain damage and seed germination in ten sorghum genotypes infested with C. angustatus at the half-anthesis stage under headcage (1989/90 Postrainy season)

Genotype	Bugs/ panicle[1]	Damage rating[2]	Germination(%)
CSH 1	435(19.8)[3]	8.5	15.9(3.8)
CSH 9	149(11.1)	8.3	50.4(6.3)
ICSV 112	277(16.5)	8.9	2.4(1.4)
IS 14334	130(10.7)	4.9	75.2(8.5)
IS 16357	61(7.6)	8.9	1.7(1.1)
IS 19955	170(12.5)	5.6	100.0(10.0)
IS 20740	102(9.7)	3.3	100.0(10.0)
IS 21444	98(8.6)	4.7	83.7(9.0)
IS 23748	191(13.4)	6.9	60.5(7.6)
IS 17610	68(8.0)	2.3	94.5(9.9)
LSD at 5% t	(2.1)	0.5	(24.8)
CV(%)	(35.6)	17.1	(1.7)

1. Mean of 8 replications.
2. See table 3.
3. Figures in parentheses are $\sqrt{N}$ transformed values.

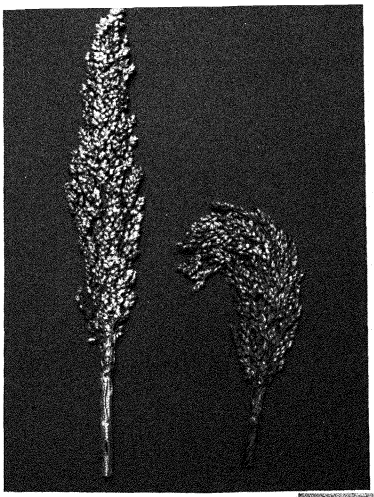

Plate 6:

1. CSH 9 (susceptible)
2. IS 16357 (resistant)

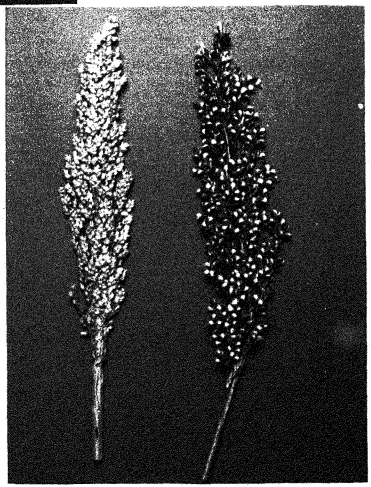

Plate 7:

1. CSH 9 (susceptible)
2. IS 17610 (resistant)

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Plate 6,7: Grain damage caused by head bugs in three sorghum genotypes under headcage (Panicles infested at the half-anthesis stage)

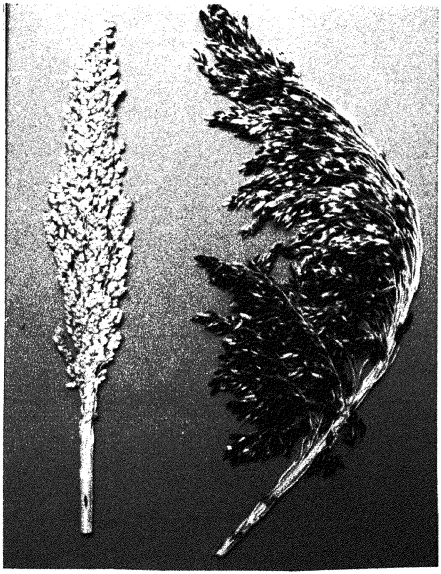

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Plate 8:
1. CSH 9 (susceptible)
2. IS 20740 (resistant)

Grain damage caused by head bugs in two sorghum genotypes under headcage (Panicles infested at the half-anthesis stage)

4.2.2 Milk Stage

During the rainy season; IS 16357, IS 21444, IS 23748 and IS 17610 supported significantly lower bug populations at the milk stage compared to CSH 9 and ICSV 112. IS 16357, IS 21444, IS 23748 and IS 17610 had 22 to 54 bugs/panicle as against 160 to 178 bugs/panicle on CSH 9 and ICSV 112 (Table 5). IS 14334, IS 16357, IS 23748 and IS 17610 recorded significantly lower grain damage (1.3 to 4.5) compared to CSH 9 and ICSV 112 (6 8 and 6.2) during the rainy season. However, IS 19955 and IS 21444 had damage ratings similar to that of the susceptible controls (Table 5).

At the milk stage during the postrainy season, population build-up was significantly lower in IS 16357, IS 19955, IS 20740, IS 23748 and IS 17610 compared to the susceptible controls CSH 1 and CSH 9. However, IS 14334 and IS 21444 supported a population at par with CSH 1. Bug population on ICSV 112 was at par with those of other less susceptible genotypes (Table 6).

IS 14334, IS 16357, IS 19955, IS 20740, IS 21444, IS 23748 and IS 17610 recorded significantly less damage rating (2.7- 4.8) than the susceptible controls which had a damage rating of 6.5 to 7.3 (Plates 9, 10 and 11). Seed germination was also significantly high in these genotypes

Table 5. Population build-up and grain damage by C. angustatus on ten sorghum genotypes at the milk stage under headcage (1989 Rainy season)

Genotype	Bugs/panicle[1]	Damage rating[2]
CSH 9	160(12.3)[3]	6.8
ICSV 112	178(13.1)	6.2
IS 14334	109(9.2)	4.5
IS 16357	54(7.2)	2.5
IS 19955	144(11.6)	5.7
IS 21444	47(6.3)	6.6
IS 23748	43(6.5)	3.5
IS 17610	22(4.6)	1.3
LSD at 5% t	(3.6)	1.4
CV(%)	(34)	25

1 Mean of six replications.

2 See table 3.

3 Figures in parentheses are $\sqrt{N}$ transformed values.

Table 6. Population build-up, grain damage and seed germination in ten sorghum genotypes infested with C. angustatus at the milk stage under headcage (1989/90 Postrainy season)

Genotype	Bugs/ panicle[1]	Damage rating[2]	Germination(%)
CSH 1	67(7.9)[3]	6.9	50.3(6.9)
CSH 9	105(9.9)	7.3	70.0(8.2)
ICSV 112	38(5.8)	6.5	56.9(7.5)
IS 14334	57(7.2)	3.0	88.4(9.4)
IS 16357	23(4.7)	4.1	81.3(9.0)
IS 19955	27(5.0)	3.7	97.3(9.9)
IS 20740	23(4.8)	3.7	79.6(8.7)
IS 21444	54(7.1)	2.7	81.3(8.9)
IS 23748	21(4.5)	4.8	96.0(9.8)
IS 17610	26(5.0)	2.6	87.9(9.3)
LSD at 5% t	(1.7)	1.5	(1.3)
CV(%)	(28)	34	(4.5)

1 Mean of 8 replications.
2 See table 3.
3 Figures in parentheses are $\sqrt{N}$ transformed values.

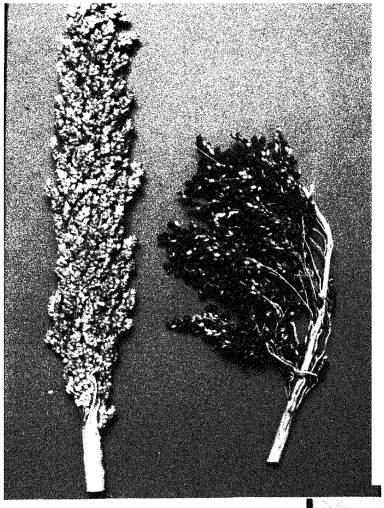

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Plate 9:

1. CSH 9 (susceptible)
2. IS 16357 (resistant)

Plate 10:
1. CSH 9 (susceptibl
2. IS 17610 (resista

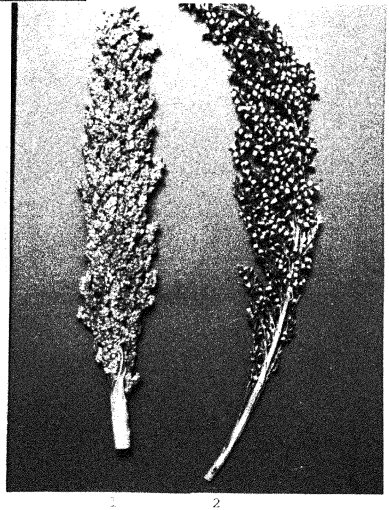

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Plate 9,10: Grain damage caused by head bugs in three sorghum genotypes under headcage (Panicles infested at the milk stage)

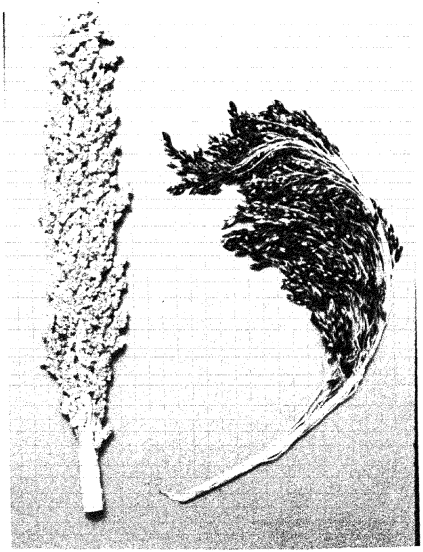

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Plate 11:

1. CSH 9 (susceptible)
2. IS 20740 (resistant)

Grain damage caused by head bugs in two sorghum genotypes under headcage (Panicles infested at the milk stage)

(79.6 to 97.3%) compared to the susceptible controls (50.3-70%) (Table 6).

4.3 CULTIVAR PREFERENCE/NONPREFERENCE UNDER LABORATORY CONDITIONS

4.3.1 Multi-choice Test

Maximum response of bugs to the sorghum panicles was observed at 3 hours 30 min after the release of the bugs in the confinement cage (Table 7, Fig. 2). Four hours after the release, the response of bugs to the panicles of IS 14334, IS 19955, IS 21444 and IS 23748 ranged from 5.6 to 6.9% and was significantly lower compared to the susceptible control, CSH 9 (14.8%). The response of bugs to CSH 9 was significantly high throughout the duration of the experiment (Fig. 3).

Among the resistant genotypes, the maximum response of bugs (8.3%) was observed towards IS 16357 compared to the other genotypes, 4 h after release. However, the response in the former was significantly lower than the susceptible control, CSH 9 (Fig.3).

The response of bugs to IS 17610 and IS 20740 during the postrainy season was very low (2.7-3.4% in IS 17610 and IS 20740) compared to 10.4 to 14.5% in the susceptible controls, CSH 1, CSH 9 and ICSV 112 (Table 8,

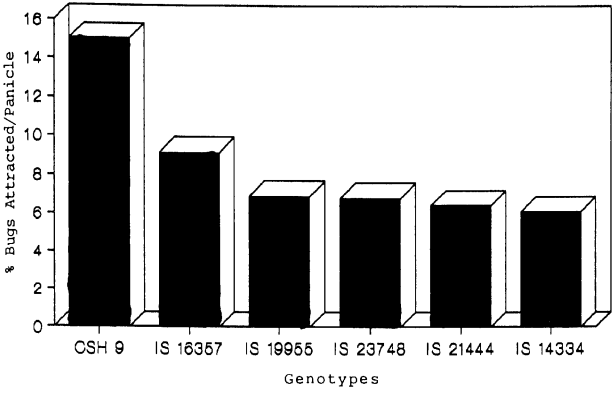

Fig.2:Response of C. angustatus to six sorghum genotypes under multi-choice conditions in a confinement cage (3h 30 min. after release) (1989 Rainy season).

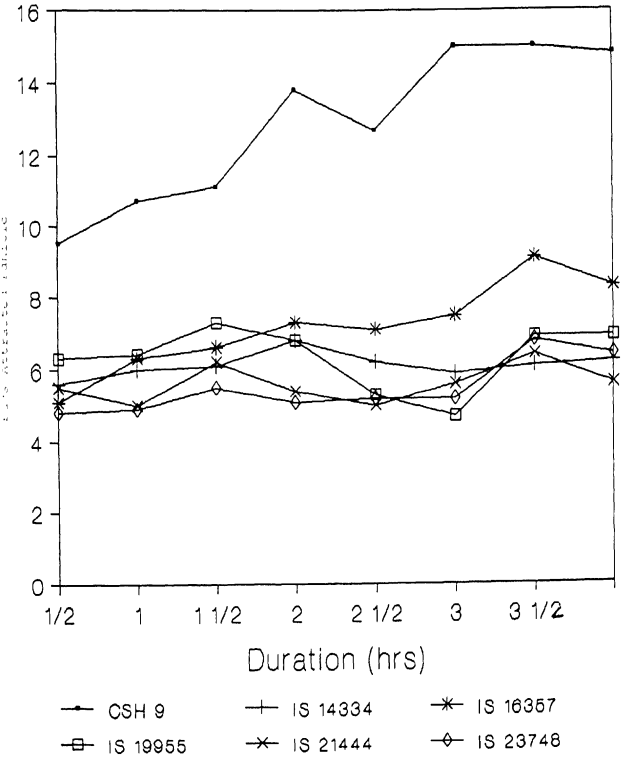

Fig.3: Response of C. augustatus to six sorghum genotypes under multi-choice conditions in a confinement cage (1989 Rainy season)

Table 7. Response of C. angustatus to six sorghum genotypes in multi-choice cage tests under laboratory conditions (1989 Rainy season)

Genotypes	Bugs[1] attracted(%) after							
	1/2 hr	1 hr	1 1/2 hr	2 hrs	2 1/2 hrs	3 hrs	3 1/2 hrs	4 hrs
CSH 9	9.50(2.91)[2]	10.70(3.13)	11.10(3.21)	13.80(3.53)	12.70(3.4)	15.00(3.63)	15.00(3.6)	14.80(3.58)
IS 14334	5.60(2.14)	6.00(2.16)	6.10(2.29)	6.80(2.37)	6.20(2.24)	5.90(2.22)	6.10(2.35)	6.20(2.40)
IS 16357	5.10(2.04)	6.30(2.29)	6.60(2.27)	7.30(2.34)	7.10(2.29)	7.50(2.30)	9.10(2.56)	8.30(2.52)
IS 19955	6.30(2.44)	6.40(2.47)	7.30(2.61)	6.80(2.39)	5.30(2.13)	4.70(1.98)	6.90(2.45)	6.90(2.42)
IS 21444	5.50(2.07)	5.00(1.87)	6.20(2.34)	5.40(2.04)	5.00(2.00)	5.60(2.16)	6.40(2.42)	5.60(2.16)
IS 23748	4.80(2.11)	4.90(2.09)	5.50(2.15)	5.10(1.99)	5.20(2.00)	5.20(2.14)	6.80(2.51)	6.40(2.41)
LSD at 5%t	(0.67)	(0.72)	(0.78)	(1.01)	(0.95)	(0.94)	(0.95)	(0.97)
CV(%)	(32.5)	(34.0)	(34.8)	(45.7)	(44.8)	(43.0)	(39.7)	(41.6)

1. Mean of ten replications.
2. Figures in parentheses are $\sqrt{N}$ transformed values.

Fig.4). Maximum response was observed towards IS 16357 compared with CSH 1 and CSH 9 (Table 8 and Table 9) though the genotypes were offered in two different combinations. Least response was recorded towards IS 20740 (2.7%) (Table 8). Similar response was noticed when different combination of genotypes were offered under multi-choice condition. IS 17610 and IS 20740 were least preferred (5.2 and 2.9 bugs/panicle respectively) compared to the susceptible controls, CSH 1 and CSH 9 (Table 9) (Fig 5).

4.3.2 Double-choice Test

IS 14334, IS 17610, IS 19955, IS 20740 and IS 23748 were significantly less preferred (12-18% bugs/panicle) than the susceptible control, CSH 1 (23-36% bugs/panicle). IS 16357 and IS 21444 were at par with the susceptible control, CSH 1. CSH 1, CSH 9 and ICSV 112 were equally preferred by the bugs (Table 10).

4.3.3 No-choice Test

Cultivar preference under no-choice conditions indicated significantly low preference towards IS 17610, IS 19955, IS 20740, IS 21444 and IS 23748 compared to the susceptibles. The response ranged from 26 to 33% towards less preferred genotypes as against 53 to 56% towards susceptible controls (Table 11, Fig. 6).

Table 8. Response of C. angustatus to six sorghum genotypes in multi-choice cage tests under laboratory conditions (1989/90 Postrainy season)

Replications	Bugs attracted (%) after 4 h towards					
	CSH 1	CSH 9	ICSV 112	IS 16357	IS 17610	IS 20740
1	6	21	37	24	2	1
2	1	17	25	12	2	8
3	13	3	20	5	5	7
4	31	6	20	30	4	3
5	8	6	16	9	1	1
6	12	18	2	8	1	1
7	5	27	6	20	5	2
8	20	10	6	13	2	1
9	8	4	15	16	7	3
10	22	2	4	8	5	0
Mean	10.4	11.4	14.5	14.5	3.4	2.7
SE±	3.9	2.8	3.8	2.1	0.7	0.8

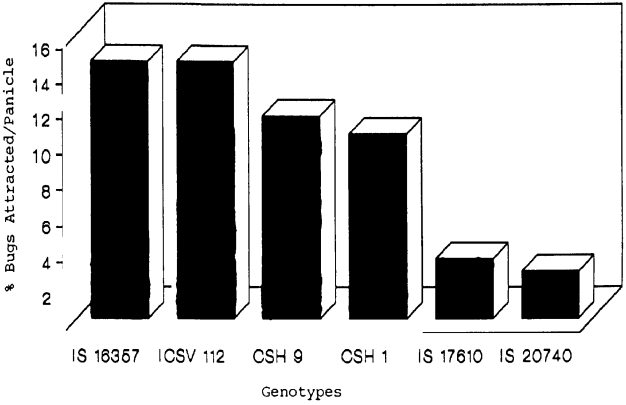

Fig.4: Response of C. angustatus to six sorghum genotypes under multi-choice conditions in a confinement cage (1989/90 Postrainy season)

Table 9. Response of C. angustatus to six sorghum genotypes in multi-choice cage tests under laboratory conditions (1989/90 Postrainy season)

Replication	Bugs attracted (%) towards					
	CSH1	CSH 9	IS 16357	IS 23748	IS 17610	IS 20740
1	6	15	14	4	6	5
2	10	7	13	11	2	1
3	9	26	34	5	2	0
4	1	1	0	5	5	3
5	4	5	6	11	1	2
6	6	17	4	9	13	4
7	5	21	4	2	5	4
8	11	7	16	2	3	1
9	16	18	25	7	4	3
10	21	4	9	4	11	6
Mean	8.9	12.1	12.5	6.0	5.2	2.9
SE ±	1.6	2.1	3.3	1.1	1.2	0.6

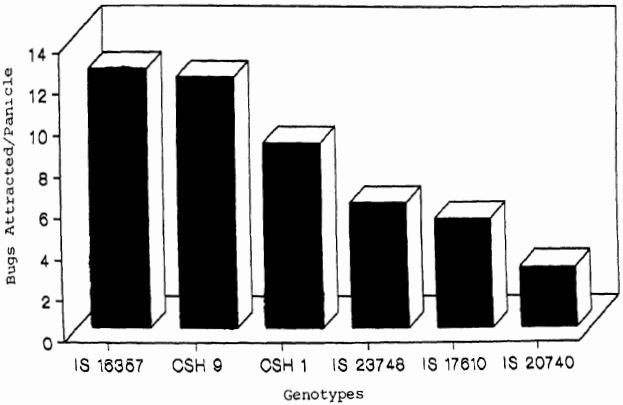

Fig.5: Response of C. angustatus to six sorghum genotypes under multi-choice conditions in a confinement cage (1989/90 Postrainy season)

Table 10. Response of C. angustatus to different sorghum genotypes in a double-choice test under laboratory conditions (1989/90 Postrainy season)

Bugs attracted/panicle[1]		T value[2]	Probability
Susceptible control	Test genotype		
CSH 1 22	CSH 9 30	-1.455	0.184
CSH 1 30	ICSV 112 39	-0.837	0.427
CSH 1 31	IS 14334 12	4.100	0.003*
CSH 1 36	IS 16357 43	-0.729	0.487
CSH 1 34	IS 17610 12	4.333	0.003*
CSH 1 34	IS 19955 16	3.075	0.015*
CSH 1 33	IS 20740 18	6.451	0.002*
CSH 1 23	IS 21444 20	0.818	0.437
CSH 1 26	IS 23748 13	4.937	0.001*

1 Mean of 10 replications
2 Analysed by paired t-test
* Significant at $P < 0.05$

Table 11. Response of C. angustatus to eight sorghum genotypes in a no-choice test under laboratory conditions (1989/90 Postrainy season)

Genotype	Bugs attracted/ panicle* (%)
CSH 1	56
CSH 9	54
ICSV 112	53
IS 17610	26
IS 19955	28
IS 20740	31
IS 21444	30
IS 23748	33
LSD at 5% t	12
CV (%)	33

* Mean of ten replications.

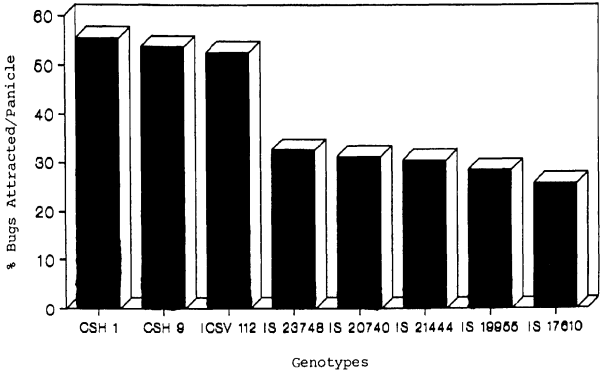

Fig.6: Response of C. angustatus to eight sorghum genotypes under no-choice conditions in a confinement cage (1989/90 Postrainy season)

4.4 OVIPOSITION

During the rainy season, no significant differences were recorded between IS 17610 and the susceptible control, CSH 9 regarding the number of florets with eggs/500 florets, % florets with eggs, and total number of eggs/500 florets. Percentage of florets with eggs were significantly different. IS 23748 and IS 16357 recorded 1.6% and 1.5% florets with eggs, and were significantly different from IS 21444 which had 4.5% florets with eggs. The total number of eggs/500 florets were significantly more in IS 21444 (134 eggs) and IS 14334 (139 eggs) compared to IS 23748 (46 eggs/500 florets). The mean number of eggs/floret was highest in IS 16357 (9.4 eggs/floret) and was significantly preferred for oviposition compared to other genotypes. No significant differences were noticed in the mean number of eggs/floret between the susceptible hybrid, CSH 9 and IS 17610, but significant differences were recorded between CSH 9 (4.97) and IS 14334 (7.85), where IS 14334 had more eggs (Table 12).

During the postrainy season no significant differences were observed in eggs laid on different genotypes (Table 13). IS 16357 had more florets with eggs (8.2%) compared to IS 17610, which had only 4% florets with eggs. The highest number of eggs (114.3) were

Table 12. Oviposition by C. angustatus on seven sorghum genotypes at the half-anthesis stage under field conditions in headcage (1989/90 Rainy season)

Genotype	Florets with eggs/ 500 florets	Eggs/ 500 florets	% florets with eggs	Mean no.of eggs/floret
CSH 9	12.5(3.53)[1]	62(7.86)	2.5(9.08)[2]	4.97(2.23)
IS 14334	17.5(4.18)	139(11.75)	3.5(10.77)	7.85(2.80)
IS 16357	7.5(2.72)	69(8.30)	1.5 (7.00)	9.40(3.06)
IS 19955	14.0(3.70)	77(8.71)	2.8 (9.53)	5.60(2.37)
IS 21444	22.5(4.65)	134(11.39)	4.5(12.03)	6.01(2.45)
IS 23748	8.0(2.78)	46(6.61)	1.6(7.13)	5.60(2.37)
IS 17610	16.0(3.95)	73(8.12)	3.2(10.18)	4.11(2.00)
LSD 5% t	(1.63)	(4.56)	(4.24)	(0.5)
CV(%)	(20.5)	(23.3)	(20.8)	(9.2)

1. Figures in parentheses are $\sqrt{N}$ transformed values.
2. Arcsin $\sqrt{\text{percent}}$ transformed values.

$$\text{Mean no.of eggs/floret} = \frac{\text{Eggs/500 florets}}{\text{Florets with eggs/500 florets}}$$

Table 13. Oviposition by C. angustatus on five sorghum genotypes at the pre-anthesis stage under field conditions in headcage (1989/90 Postrainy season)

Genotype	Florets with eggs/250 florets	Eggs / 250 florets	% florets with eggs	Mean no.of eggs/floret
CSH 9	17.3(4.06)[1]	73.8(8.29)	6.93(14.91)[2]	4.25(2.04)
IS 16357	20.5(4.36)	114.3(10.22)	8.20(16.07)	5.55(2.34)
IS 17610	10.0(2.83)	61.5(6.84)	4.00(10.33)	4.79(1.98)
IS 20740	17.0(4.03)	90.0(9.11)	6.80(14.78)	5.15(2.25)
IS 23748	14.7(3.73)	78.5(8.49)	5.87(13.66)	5.18(2.26)
LSD at 5%t	(1.29)	(3.34)	(4.81)	NS
CV (%)	(28.2)	(32.3)	(28.70)	(24.5)

1 Figures in parentheses are $\sqrt{N}$ transformed values.
2 Arcsin $\sqrt{\text{Percent}}$ transformed values.

$$\text{Mean no.of eggs/floret} = \frac{\text{Eggs/250 florets}}{\text{Florets with eggs/250 florets}}$$

observed in IS 16357, followed by IS 20740 (90 eggs) and IS 23748 (78.5 eggs). The number of eggs/floret was also highest in IS 16357 which recorded more eggs/250 florets as well. However, the differences in the mean number of eggs/floret were not significant among the genotypes.

4.5 ANTIBIOSIS

4.5.1 Field Trial

Significantly more nymphs failed to develop into adults on IS 23748, 15 days after release in the headcage compared to the susceptible controls and IS 16357 (Table 14). The number of nymphs becoming adults did not differ significantly among the genotypes tested. The damage rating varied from 4.2 to 5.6 on 1 to 9 scale in resistant genotypes as against 6.0-8.6 in the susceptible controls. IS 23748, which recorded lowest damage rating (4.2), had more number of nymphs which failed to develop into adults. The sex ratio was in favour of females (except in CSH 1 where it was 1:1) in all the genotypes tested.

4.5.2 Laboratory Trial

The nymphs were reared in the laboratory on milk grain of different genotypes during the rainy season

Table 14. Nymphal survival and development of C. angustatus on eight sorghum genotypes under headcage (1989 Rainy season).

Genotype	Bugs/panicle[1] after 15 days				Damage rating[2]	Sex ratio
	Nymphs	Male Adults	Female Adults	Total Bugs		♂ : ♀
CSH 1	0.12(0.13)[3]	12.5(3.40)	12.7(3.4)	25.4(4.9)	6.0	1 : 1.0
CSH 9	0.0 (0.0)	22.4(4.6)	25.0(4.7)	47.4(6.6)	8.6	1 : 1.1
ICSV 112	0.54(0.29)	23.3(4.7)	32.5(5.6)	56.3(7.4)	7.5	1 : 1.4
IS 14334	0.38(0.22)	16.5(3.7)	20.2(4.1)	37.1(5.6)	4.3	1 : 1.2
IS 16357	1.75(0.80)	15.1(3.6)	17.6(4.0)	34.5(5.5)	5.4	1 : 1.2
IS 19955	0.62(0.30)	18.4(3.9)	22.9(4.6)	41.9(6.3)	4.5	1 : 1.2
IS 21444	0.00(0.0)	25.1(4.4)	27.1(4.8)	52.2(6.6)	5.8	1 : 1.1
IS 23748	3.81(1.46)	18.6(3.7)	24.8(4.6)	47.2(6.4)	4.2	1 : 1.3
LSD at 5% t	(0.8)	(1.9)	(1.8)	(2.4)	1.3	
CV (%)	(188.7)	(47.0)	(39.3)	(37.7)	22.6	

1. Mean of 10 replications.
2. See Table 3.
3. Figures in parentheses are $\sqrt{N}$ transformed values.

1989/90. The nymphal period of the bug was significantly prolonged when reared on IS 14334 and IS 16357 compared to the susceptible hybrids, CSH 1 and CSH 9. Eventhough the duration of nymphal period was significantly prolonged by a day on these genotypes, the differences were marginal (Table 15).

Table 15. Development of C. angustatus on six sorghum genotypes under laboratory conditions (1989/90 Rainy season)

Genotype	Duration (days)					
	I instar	II instar	III instar	IV instar	V instar	Total duratio
CSH 1	1.4	1.1	1.4	1.8	2.9	7.6
CSH 9	1.3	1.1	1.3	1.7	2.3	7.6
ICSV 112	2.0	1.3	1.8	1.5	1.7	8.3
IS 14334	1.3	1.3	2.0	1.5	2.6	8.7
IS 16357	1.8	1.4	1.9	1.2	2.1	8.4
IS 23748	1.6	0.9	1.6	1.6	1.7	7.4
LSD at 5%t	0.5	0.4	0.5	0.5	0.4	0.6
CV(%)	26	45	38	42	25	9

DISCUSSION

CHAPTER V

DISCUSSION

CULTIVAR PREFERENCE/NONPREFERENCE

Under multi-choice field conditions, both in the rainy and postrainy seasons, the head bugs preferred the susceptible sorghum cultivars ICSV 112, CSH 1 and CSH 9. Bugs showed less preference towards IS 14334, IS 16357, IS 19955, IS 21444 and IS 23748 during postrainy season than in the rainy season (Table 2). The lower head bug numbers observed in these genotypes may be due to cultivar nonpreference and/or antibiosis. Sharma and Lopez (1990c) reported genotypic preference by C. angustatus under field conditions. Cherian et al (1941) and Balasubramanian et al (1979) reported that genotypes with loose panicles support less population of head bugs. However, under situations of heavy head bug density, genotypes with loose panicles are also completely damaged (Sharma 1985a).

Sharma and Lopez (1990b) showed a relationship between the head bug numbers and the stage of panicle development. Their results suggested that the head bug numbers are higher in panicles at the milk stage than at the half-anthesis stage under natural field conditions. Larger population on IS 17610 compared to the susceptible controls observed under natural field conditions during

the 1989 rainy season can be attributed to late flowering (Table 2). IS 17610 flowered around 91 days after sowing whereas the days to flowering in other genotypes varied from 57-66 days (Table 2). Head bugs prefer pre-anthesis stage for oviposition (Hiremath and Thontadarya, 1984b; Natarajan and Sundara Babu, 1987b and Sharma and Lopez, 1990a). Late flowering in IS 17610 leads to greater number of ovipositing females on this genotype in the absence of more preferred genotypes, resulting in higher head bug numbers than in other genotypes. However, relatively low head bug populations in the susceptible CSH 1 at the milk stage in the rainy season (Table 2) may be because of early flowering or bug mortality due to fungal disease (Sharma and Lopez, 1990d). Lower bug population was recorded on IS 14334, IS 16357, IS 19955, IS 20740, IS 21444 and IS 23748 than on the susceptible controls, CSH 1,CSH 9 and ICSV 112 in the postrainy season. There was a greater synchronisation of flowering in all the genotypes during the postrainy season and this gave a better comparision of head bug preference to different genotypes.

Cultivar differences in host plant preference by head bugs were confirmed under laboratory conditions in the cage tests. Under multi-choice conditions in the rainy season, the bugs displayed a moderate to high degree of

nonpreference towards IS 14334, IS 19955, IS 21444 and IS 23748 at the half-anthesis stage (Table 7). In the postrainy season, IS 23748, IS 17610 and IS 20740 were less preferred by the bugs compared to susceptible control, CSH 9 (Table 8 and 9). Similar results have been reported by Sharma and Lopez (1990c) with sorghum genotypes IS 2761, IS 6984, IS 9692, IS 17610, IS 17618 and IS 17645 Differences in genotypic nonpreference were quite strong under double (Table 10) and multi-choice conditions (Tables 7, 8 and 9). The present results clearly indicate that nonpreference is one of the components of resistance for host selection and feeding in IS 14334, IS 17610, IS 19955, IS 20740, IS 21444 and IS 23748. It can be used as a component of resistance to head bugs in combination with other mechanisms of resistance. IS 16357 was as much equally preferred as the susceptible controls, CSH 1, CSH 9 and ICSV 112 under multi- and double-choice conditions (Tables 7,8,9 and 10).

POPULATION BUILD-UP UNDER HEADCAGE

Exposure of sorghum genotypes to C. angustatus in headcage to measure gross population increase appears to be a reliable method to confirm the resistance to this pest (Sharma and Lopez, 1990b). Apart from confirming genotypic resistance, it also serves as a tool to differentiate between nonpreference and the other

mechanisms involved, and to assess the levels of resistance. In the present investigations, genotypic susceptibility was assessed based on bug numbers and grain damage rating over two seasons (rainy and postrainy seasons) at the half-anthesis and milk stages. Lower bug population was recorded at the half-anthesis stage in IS 17610, IS 19955 and IS 21444 (Table 3 and 4), and at the milk stage in IS 14334, IS 16357, IS 20740, IS 21444, IS 23748 and IS 17610 (Table 4 and 5). IS 19955 had lower bug population at the milk stage in the postrainy season, and IS 16357 at the half-anthesis stage only. These differences may be due to the effect of environmental conditions which not only affect the survival and development of head bugs but also influences the plant chemistry which may in turn affect the colonization and damage by the head bugs (Sharma 1990d). Variation in recovery of caged population may also be related to the use of a wild population as in Lygus hesperus Knight (Moshy et al.,1983). Higher bug numbers and lower damage rating recorded in IS 14334 shows that its resistance to bugs may be nonpreference for feeding.

In CSH 9 and ICSV 112 at 50% flowering in the postrainy season, grain damage was high though bug populations were low. This may be due to inadequate food supply. Increased feeding by the bugs on these cultivars

might have caused higher damage initially resulting in the depletion of food and subsequent mortality of bugs. Bug populations were low in panicles infested at the milk stage. This may be due to lack of suitable site for oviposition as the bugs oviposit in the spikelets before flowering (Sharma, 1985a). Greatest population build-up of bugs under headcage has been reported in panicles, infested at the half-anthesis stage (Sharma, 1985a). In bean plants screened for Lygus hesperus, advanced maturity of plant resulted in a decrease in population build-up of L. hesperus (Alvarado-Rodriquez et al., 1986).

Lower percentage of seed germination in ICSV 112, CSH 1, and CSH 9 (except at the milk stage) at the half-anthesis and milk stages (Table 4 and 6) may be because of higher grain damage by the bugs in these cultivars. Hall and Teetes (1982) reported that sorghum grain was more susceptible to damage by green stink bug and leaf footed bug during the early seed development resulting in poor germination of damaged seeds. At the milk stage, IS 14334, IS 16357, IS 17610, IS 19955, IS 20740 and IS 23748 recorded high percentage of seed germination compared to the susceptible controls. This suggests that damage caused by head bugs when infested at the milk stage may not affect the viability of the seed.

OVIPOSITION

Most insects lay fewer eggs on nonpreferred hosts (Pathak, 1970). Sharma and Lopez (1990c) reported reduced oviposition as an important component of resistance to head bugs under no-choice conditions. In the present studies, resistance to bugs was not evident because of the ovipositional nonpreference except in IS 17610 in postrainy season. IS 21444, IS 14334 (in the rainy season) and IS 16357 (in the postrainy season) had greater oviposition than the susceptible control, CSH 9 under no-choice conditions in the head cage (Table 12 and 13). In case of Nephotettix virescens (Distant) in rice, several resistant varieties received as many eggs as the susceptibles (Cheng and Pathak, 1972). The present findings indicate that further research is needed to get a better estimate of oviposition on different genotypes by C. angustatus.

ANTIBIOSIS

Antibiosis under field conditions was evident in IS 23748 where more number of nymphs were recorded 15 days after infestation as compared with the susceptible controls. However, the number of nymphs becoming adults did not differ significantly amongst the genotypes tested (Table 14). There was no significant difference in the

survival and development of nymphs among the genotypes tested. Similar situation was noticed in case of sorghum green bugs by Teetes et al (1974a). This suggests that resistance to bugs may be chiefly because of nonpreference to feeding.

Nymphal development was prolonged by one day when the nymphs were reared on IS 14334 and IS 16357. Antibiosis effects were not large enough to be a major component of resistance to head bugs.

CONCLUSION

From the results discussed above, it can be concluded that one or more mechanisms of resistance are operational in sorghum to head bug, Calocoris angustatus. Odour seems to play an important role in the orientation of bugs towards the panicles of IS 14334, IS 19955, IS 17610, IS 20740, IS 21444 and IS 23748 which were less preferred under multi-choice conditions both in the field and laboratory conditions. Nonpreference for orientation may be one of the components of resistance in these genotypes. Under double-choice conditions, IS 21444 was as much preferred as the susceptible control. So it can be concluded that this phenomenon may not be strong enough to express itself under double-choice conditions in this genotype (Table 10). Under no-choice conditions,

differences in cultivar nonpreference for orientation was significant.

Under head cage conditions, nonpreference for orientation as a major component of resistance is excluded. Nonpreference for feeding and oviposition and antibiosis may account for differences in head bug numbers observed under headcage conditions. However, no concrete results were obtained on oviposition nonpreference. The high populations and low damage on IS 14334 (Tables 3,4,5 and 6) in headcage and prolonged nymphal development (Table 15) in the laboratory indicated nonpreference for feeding as a mechanism of resistance. Antibiosis expressed as increase in duration of nymphal development was not significant practically. IS 21444, IS 17610 (Tables 3,4,5 and 6) and IS 20740 (Tables 5 and 6) supported low bug population compared to other genotypes. Nonpreference for feeding and antibiosis may be the factors imparting resistance to bugs in these genotypes. Sharma and Lopez (1990c) stated that all the three mechanisms of resistance i.e nonpreference, reduced oviposition and antibiosis are evident in IS 17610. Antixenosis to oviposition was observed during the postrainy season. The low damage caused by bugs at the milk stage in IS 19955 and IS 23748 may due to the faster rate of grain development of the ovary in these genotypes

as recorded by Sharma (1985b) in midge resistant genotypes.

In conclusion it may be stated that nonpreference is a component of resistance, to C. angustatus. Results on nonpreference to oviposition were not consistent while antibiosis showed a slight contribution towards genotypic resistance to head bugs (Table 16). Incorporation of more than one mechanism of resistance to insects delays the development of biotypes irrespective of the levels of resistance (Gallun,1972; Sharma et al., 1988). There were no significant differences in nymphal survival and development. However, there may be some differences in the consumption and utilization of food as evident in the case of green bugs in sorghum (Teetes et al., 1974b). Consumption and utilization of food on different genotypes needs further study. As the panicles come to maturity at different periods, the rate of development of grain in each genotype needs a careful study to gain knowledge on the population build-up and the subsequent grain damage. Finally, effect of resistant cultivars on adult survivorship, longevity and fecundity parameters needs a thorough study to gain a better understanding of the insect/plant interactions.

Table 16: Summary of the resistance mechanisms identified in the sorghum genotypes tested for C. angustatus

Genotypes	Non-preference			Oviposition	Antibiosis
	Multi-choice	Double-choice	No-choice		
CSH 1	-	-	-	-	-
CSH 9	-	-	-	-	-
ICSV 112	-	-	-	-	-
IS 14334	+	+	0	-	+
IS 16357	-	-	0	-	+
IS 19955	+	+	+	-	-
IS 20740	+	+	+	-	-
IS 21444	+	-	+	-	-
IS 23748	+	+	+	-	-
IS 17610	+	+	+	+	-

0 Not studied
+ Mechanism is involved
- Not apparent

SUMMARY

CHAPTER VI

SUMMARY

Experiments were conducted on ten sorghum genotypes (CSH 1, CSH 9, ICSV 112, IS 14334, IS 16357, IS 19955, IS 20740, IS 21444, IS 23748 and IS 17610) in the rainy and postrainy seasons of 1989/90 to study the preference of the head bugs under natural conditions, population build-up, ovipositional behaviour and survival and development of nymphs under headcage in the field and development of nymphs under laboratory conditions.

The genotypes IS 14334, IS 17610, IS 19955, IS 20740, IS 21444, IS 23748 were less preferred by the bugs under both laboratory and field in multi-choice conditions. In the double-choice conditions IS 14334, IS 19955, IS 20740, IS 23748 and IS 17610 were less preferred (12 to 18%) by the bugs compared to CSH 1 (23 to 36%). Under no-choice conditions also the preference was less towards IS 19955, IS 17610, IS 20740, IS 21444 and IS 23748 (26 to 33%) compared to the susceptible controls, CSH 1, CSH 9, ICSV 112 (53 to 56 %).

The population build-up was low when the bugs were caged on IS 17610, IS 21444 and IS 20740 at the half-anthesis and milk stages in both the seasons. High population build-up was noticed on IS 14334, IS 16357 and

IS 19955 at the half- anthesis stage The population build-up was low on IS 16357, IS 21444, IS 23748 and IS 17610 (22 to 109 bugs/panicle) compared to the susceptible controls, CSH 9 and ICSV 112 in the rainy season at the milk stage Low population build-up was noticed on IS 14334, IS 16357, IS 17610, IS 19955, IS 20740, IS 21444 and IS 23748 (61 to 191 bugs/panicle) compared with CSH 1 (435 bugs/panicle) at the half-anthesis stage In the postrainy season at the milk stage the population build-up was low in all the genotypes (21 to 57 bugs/ panicle) compared to the susceptible control, CSH 9 (105 bugs/panicle) The damage rating was high when the bugs were released at the half-anthesis stage But the damage rating was significantly low in all the test genotypes compared to the susceptible controls when the bugs were released at the milk stage in both the seasons Percentage of seed germination was high in IS 14334, IS 19955, IS 20740, IS 21444 and IS 17610 when the bugs were released at the half-anthesis stage compared to the susceptible controls in the postrainy season whereas at the milk stage except the three susceptible controls, all the other genotypes recorded high percentage of germination

Ovipositional nonpreference in sorghum genotypes could not be confirmed as some of the genotypes recorded more number of eggs/500 florets (IS 14334), more number of

eggs/floret and highest mean number of eggs (IS 16357) compared to the susceptible, CSH 9, in the rainy season. During postrainy season no significant differences were observed between the resistant and susceptible controls. IS 16357 recorded highest number of eggs in a single floret (5.6) and in a sample of 250 florets (114.3) compared to the susceptible control, CSH 9.

Significant effects of antibiosis were noticed under field conditions in IS 23748 as more number of nymphs failed to develop into adults when counted 15 days after caging. Prolongation of nymphal duration by 1-day was noticed when the first instar nymphs were reared on IS 14334 and IS 16357 in the laboratory.

Nonpreference for orientation and feeding in combination with low levels of antibiosis seems to be the mechanisms of resistance operating in sorghum genotypes to head bug, C. angustatus.

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