MECHANISMS OF RESISTANCE IN SORGHUM GENOTYPES TO SPOTTED STEM BORER, *Chilo partellus* SWINHOE

BY
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CERTIFICATE

Mr **V KISHORE KUMAR** has satisfactorily prosecuted the course of research and that the thesis entitled "**Mechanisms of resistance in sorghum genotypes to spotted stem borer, *Chilo partellus* swinhoe**" submitted, is the result of original research work and is of sufficiently high standard to warrant its presentation to the examination I also certify that the thesis or part thereof has not been previously submitted by him for a degree of any University

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CERTIFICATE

This is to certify that the thesis entitled "**Mechanisms of resistance in sorghum genotypes to spotted stem borer, *Chilo partellus SWINHOE***" submitted in partial fulfilment of the requirements for the degree of Master of Science in Agriculture of the Acharya N G Ranga Agricultural University, Hyderabad, is a record of the bonafide research work carried out by Mr **V KISHORE KUMAR** 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 the investigations have been duly acknowledged by the author of the thesis

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(V. KISHORE KUMAR)

DECLARATION

I, **V. KISHORE KUMAR**, hereby declare that the thesis entitled "**Mechanisms of resistance in sorghum genotypes to spotted stem borer, *Chilo partellus swinhoe***" submitted to Acharya N G Ranga 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

Sixteen sorghum germplasm accessions and five improved breeding lines with resistance to stem borer, three landraces from different geographical regions, and two hybrids were evaluated in comparison with a resistant and a susceptible check for antixenosis and antibiosis mechanisms of resistance to spotted stem borer, *Chilo partellus* Swinhoe under greenhouse and laboratory conditions Antixenosis or nonpreference for oviposition was studied in respect of relative oviposition preference by *C. partellus* females under limited limited-multi choice cage tests and multi-choice cage tests at ambient temperature and humidity conditions Antibiosis was investigated by studying the effect of different genotypes on larval survival, larval mass, post-embryonic development, pupal mass, and percentage pupation and adult emergence under pot culture conditions and on artificial diet impregnated with lyophilized leaf powder of different sorghum genotypes

In limited-multi choice tests, ICSV 112 ICSV 705 IS 2123, and IS 13100 showed nonpreference for oviposition However, in multi-choice tests, these genotypes were preferred for oviposition The genotypes IS 2205, IS 2309 and IS 18573 did not differ significantly from CSH 1 in limited-multi choice cage tests, but showed nonprefernce for oviposition under multi-choice tests Genotypes IS 2123 and IS 13100 were highly nonpreferred for oviposition by *C. partellus* females in both the tests Larval survival trends in artificial diet impregnated with lyophilized powder from different genotypes and on sorghum seedlings raised in the greenhouse were quite different Larval mass was considerably low for insects reared on IS 2309, CSH 9, ICSV 714, and ICSV 743 Post-embryonic development period of *C. partellus* was considerably longer on ICSV 705, ICSV 714, and IS 2123 in artificial diet compared to other test genotypes Similarly, in case of pot culture, prolongation of post-embryonic development was observed on IS 1054 and ICSV 1 In artificial diet, there was no larval survival in diet containing leaf powder of IS 2205 IS 2309, ICSV 743, and CSH 9 Pupal mass was adversely affected on IS 18573 and IS 5566 in the artificial diet, and on IS 1054 and IS 12308 under pot culture The genotypes IS 1054 and IS 12308 showed greater antibiosis than IS 2205 under pot culture Lower pupation was observed on ICSV 705, IS 2269, IS 2123, and IS 18573 None of the larvae survived / pupated on some genotypes In the pot culture, lower percentage of pupation was observed on IS 1054 and ICSV 714 Lower adult emergence was seen on ICSV 714, ICSV 705, IS 1054, and IS 2123 in artificial diet Similarly, in pot culture, IS 1054, ICSV 705, ICSV 714, and IS 2263 showed a reduction in emergence of adults The possibility of selection of parents in the breeding programme to develop cultivars with resistance to *C. partellus* has been discussed

INTRODUCTION

INTRODUCTION

Sorghum is one of the major cereal crops in the semi-arid tropics (SAT). The total world sorghum area is 44.06 million hectares with an annual production of 61.44 million tonnes (FAO, 1998). In India, sorghum is the third important cereal after rice and wheat, and is currently grown on 11.2 million hectares with an annual production of 9.0 million tonnes (FAO, 1998).

Grain yields of sorghum on peasant farms are generally low, (500-800 kg ha^{-1}), and one of the major yield limiting factors is insect pests, which cause an average loss of 32.1 percent (Borad and Mittal, 1983). It is damaged by over 150 insect species from sowing to the final crop harvest. Some of the important pests are shoot fly, stem borer, midge, and ear-head bug. Several species of stem borers attack sorghum in different sorghum-growing regions (Nwanze, 1997). Stem borers constitute the most widely distributed and serious group of insect pests on sorghum, of which the spotted stem borer, *Chilo partellus* (Swinhoe) is predominant in Asia and eastern and South Africa, while corn stalk borer, *Busseola fusca* Fuller, pink borer *Sesamia calamistis* Hampson, and sugarcane borer *Eldana saccharina* Walker is important in Africa, *Sesamia cretica* Laderer in Mediterranian Europe and Middle East, and *Diatraea spp.* in the America. (Young 1970; FAO, 1980). In India, the spotted stem borer, *Chilo partellus* (Swinhoe) is the most important pest of sorghum and maize, and cause serious damage (Jotwani and Young, 1972; Gahukar and Jotwani, 1980).

Assessments of sorghum grain yield losses due to insect pests are scarce and difficult to obtain. Annual losses due to insect pests differ in magnitude on a regional basis. They have been estimated to be $1089 million in the Semi- Arid Tropics (SAT), $250 million in United States, and $80 million in Australia. Stem borers cause an estimated loss of US $ 266 million annually (ICRISAT, 1992).

The spotted stem borer, *C. partellus*, attacks sorghum from 2 weeks after germination until crop harvest, and affects all the above-ground plant parts. The first symptom of attack is the appearance of irregular-shaped holes on the leaves, caused by the young larvae feeding on the whorl leaves. The older larvae leave the whorl and bore into the stem. In young plants, the larvae destroy the growing point and cause a characteristic "deadheart" symptom. In older plants, the larvae feed inside the stem causing extensive tunneling. They may also tunnel the peduncle and move up to the panicle. While early infestation may kill young plants by causing a deadheart thereby reducing the crop stand, the damage during the later stages of crop growth results in reduced grain yield due to larval feeding inside the stem. Stem tunneling may cause lodging and interfere with nutrient supply to the developing grains, resulting in chaffy panicles (Gahukar and Jotwani, 1980; Seshu Reddy, 1982; Agrawal et al., 1983).

Insecticide applicaton for stem borer control is uneconomic under subsistence farming, and is largely beyond the means of resource poor farmers. Therefore, host plant resistance (HPR) assumes a pivotal role in controlling stem borer damage either alone or in combination with other methods of control. HPR is an important component of integrated pest management and is well suited to the environmental

conditions of the semi-arid tropics. Host-plant resistance avoids environmental pollution, and is compatible with natural control processes. Besides, it integrates effectively with other pest control tactics, and involves no additional cost to the farmer.

A systematic screening of the world sorghum germplasm collection against spotted stem borer was initiated in 1962 in India under the cooperative efforts of the Accelerated Hybrid Sorghum Project (ICAR), the Entomology Division of the Indian Agricultural Research Institute, and the Rockefeller Foundation (Singh et al., 1968; Pradhan, 1971; Jotwani, 1978). Since then, this work has been continued at the All India Coordinated Sorghum Improvement Project (AICSIP) and the International Crops Research Institute for the Semi Arid Tropics (ICRISAT). Over 30000 germplasm accessions have been screened at ICRISAT, and many sources of resistance have been identified (Taneja and Leuschner, 1985; Singh and Rana, 1989; Sharma et al., 1992).

Dabrowski and Kidiavai (1983); Taneja and Wood head (1989); and Sharma and Nwanze (1997) reported that a wide range of mechanisms were involved in *C. partellus* resistance in sorghum including non-preference for oviposition, reduced feeding of first- instars on young leaves, reduced tunneling, and tolerance to leaf damage and stem tunneling.

Knowledge of the resistance mechanisms and associated factors involved is essential for effective utilization of resistant sources in the breeding programme.

To elucidate some of the mechanisms involved in stem borer resistance, the present investigations were undertaken to:

1) evaluate diverse sorghum genotypes for nonpreference (antixenosis) for oviposition and antibiosis components of resistance.

2) To quantify the relative contribution of different components towards resistance to spotted stem borer.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Sorghum is an important cereal crop in the semi-arid tropics In India, it is grown both during the rainy (kharif) and the postrainy (rabi) seasons In central and southern India, sorghum is cultivated for grain purpose, while in North India, it is primarily grown as a fodder crop In recent years emphasis has been placed on developing dual-type sorghum cultivars to meet both grain and fodder requirements

2.1 Nature of damage

Spotted stem borer, *Chilo partellus* attacks sorghum from 2 weeks after germination until crop harvest and affects all above ground plant parts The first symptoms of attack are the 'shot-holes' or irregular shaped holes on the leaves caused by the early-instar larval feeding in the whorl The older-larvae leave the whorl and bore into the stem In young plants, the larvae destroy the growing point and cause the characteristic 'deadheart' symptoms In older plants, the larvae feed inside the stem causing extensive tunneling It may also tunnel the peduncle and damage the panicle Early infestation by the borers may kill the young plants by causing a deadheart, and thereby reducing the crop stand the attack during the later stages of crop growth results in reduced yield due to larval feeding inside the stems Tunneling weakens the stems, which may result in lodging and interfere with nutrient supply to the developing grains resulting in chaffy panicles (Taneja et al , 1987)

Neupane et al (1985) published a detailed account of its bionomics in Nepal, Khan (1983) studied its biology in Pakistan Verma and Jotwani (1983) compared the biology and behaviour of specimens collected from Delhi, Indore, Nagpur and Hyderabad in India, and Alghali (1986) studied its biology in Kenya Length of life cycle, time of adult emergence, oviposition potential, location of egg masses on the plants and incidence of larval diapause vary appreciably across locations There are indications of the existence of different biotypes and seasonal variability across locations, but the factors determining these variations have not been fully investigated

The behaviour of first-instar larvae immediately after hatching has been studied by Chapman et al (1983) and Bernays et al (1985) They investigated the survival and dispersal of young larvae and mechanisms by which the newly hatched larvae reach the leaf whorl from the oviposition site near the base of the sorghum plants

2.2 Biology

The spotted stem borer females lay eggs in batches (50-100 eggs batch $^{-1}$), mostly on the basal leaves of sorghum plants Eggs hatch in about 4 – 6 days The larval period is mostly spent in the leaf whorls and stems, which lasts for 2 to 3 weeks Pupation takes place in the stem or in the soil and it takes about a week for adult emergence It completes the life cycle in about a month and there are 3 - 4 overlapping generations in a crop season Two generations can attack the same crop (Rahman, 1944, Trehan and Butani, 1949 Seshu Reddy 1969, Gahukar and Jotwani, 1980) In Northern India, the larvae enter diapause during the winter

(December - March) in stalks and stubbles However in southern India where temperatures do not fall too low in winter, it remains active throughout the year

2.3 Crop Losses

Although severe stem borer infestations in sorghum have been recorded at a number of locations in India, there have been only a few studies on the quantitative estimation of resultant crop losses Irehan and Butani (1949) reported upto 70% borer infestation, but estimated that the overall infestation in Maharastra does not exceed 5% In a field having 73 6% *C' partellus* infested plants, the grain loss was estimated to be about 112 5 Kg ha^{1} Pradhan and Prasad (1955) reported a 0 9 g decrease in grain yield per plant with an unit increase in percentage of stem length injured Overall losses due to stem borers may be 5 - 10% in many sorghum growing areas, especially where early infestation causes loss in plant stand The avoidable grain losses due to stem borer on a susceptible sorghum hybrid (CSH 1) and a variety (Swarna)have been estimated to be 55 to 83% in India (Jotwani et al , 1971, Jotwani,1972)

2.4 Host Plant Resistance

Painter (1951) defined plant resistance to insects as the relative amount of heritable qualities possessed by a plant which influence the ultimate degree of damage done by the insect Beck (1965) defined resistance as the collective heritable characteristics by which a plant species, race, clone or individual may reduce the probability of successful utilization of that plant as a host by an insect species, race, biotype or an individual

2.5 Screening for Resistance

The earliest report on sorghum cultivars resistant to spotted stem borer, *C. partellus* is by Trehan and Butani (1949). Later, Pant et al. (1961) and Swarup and Chaugale (1962) reported some differences in damage due to stem borers in different varieties of sorghum. A number of genotypes with resistance to stem borer have been identified by various workers in India and elsewhere (Singh et al., 1968; Jotwani et al., 1974; Kundu and Jotwani, 1977; Jotwani et al., 1979; Singh et al., 1980; Jotwani, 1982; Dalvi et al., 1983; Singh et al., 1983; Sharma et al., 1983; Taneja and Leuschner,1985).

2.6 Screening Techniques

Development of an effective and reliable screening technique that ensures uniform and desired level of insect pressure at the most susceptible stage of the crop is the backbone of a host plant resistance screening and breeding progaram. These requirements can be met either by selecting a location where the pest occurs regularly with adequate severity (hot-spot locations) or by testing the material under artificial infestation with laboratory reared insects. Agronomic practices such as planting time, use of diapausing insect population, trap crops, fertilizer use, irrigation, etc., can also be manipulated to increase borer infestation. A 3 step screening methodology was adopted for stem borer resistance testing in AICSIP (Pradhan, 1971). The first step was a general screening in a single row plot under natural infestation. The selected materials were then tested in a replicated trial under natural infestation. The final step has been the confirmation of resistance in a replicated trial by artificial infestation.

2.6.1 Screening under natural infestation

Screening under natural infestation at a hot-spot location requires the study of population dynamics of the insect so that planting time can be adjusted in such a way that the susceptible stage of the crop coincides with the peak activity period of the insect. For instance at Hisar, severe borer infestation has been recorded for several years (1979 - 86) on sorghum planted during first fortnight of July.

2.6.2 Screening under artificial infestation

The common practice to screen the test material under artaificial infestation involves fixing egg-masses at the black-head stage on the underside of the top leaves (Dicke et al., 1963) or dropping them in the leaf whorls (Jotwani, 1978). Another method involves infesting plants with neonate larvae with a camel hair brush (Starks and Doggett, 1970; Singh et al., 1983) or dispensing the larvae into the plant ;whorls along with an inert carrier through a 'bazooka' (Mihm et al., 1978). Bazooka or the applicator gun can be used to infest a large number of genotypes; both under greenhouse and field conditions. To assess the plant resistance for peduncle damage, the plants can be infested at the pre-boot leaf stage (Singh et al., 1983; Rana et al., 1984, 1985). Artificial infestation ensures uniform and sufficient level of pest infestation at desired stage of crop growth (Singh et al., 1983; Taneja and Leuschner, 1985).

Plants can be infested at 15, 20 or 25 days after seedling emergence (DASE) with 5 - 7 larvae per whorl. Infestation at 15 DASE produces most desired results in terms of reduction in plant growth and yield, and incidence of 'deadhearts' (Dabrowski and Kidiavai, 1983; Taneja and Leuschner, 1985), while at 20 DASE,

it mainly results in foliar damage and loss in grain yield (Starks and Doggett, 1970). Nwanze and Reddy (1991) developed a rapid screening method in which 9-day old sorghum seedlings sown in microplots or 5-day old sedlings in trays were evaluated under artificial infestation. The method requires 250 egg masses in 15 g of carrier to infest 1000 plants, compared with 500 egg masses and 80 g of carrier to infest 1000 plants under standard field-screening. The screening process was completed within 4 weeks and results were comparable to those from standard field screening.

2.7 Mass Rearing

Chilo partellus can be mass produced in the laboratory on artificial diet (Chatterji et al., 1968; Sarup et al., 1985; Taneja and Nwanze, 1988). The rearing facility should provide reliable control of environmental conditions (temperature, humidity, and light), and maintain a high standard of hygiene.

Pant et al. (1960) developed the first artificial diet to rear *C. partellus* which included casein, glucose, salt mixture, yeast, choline chloride, cholesterol, cellulose, leaf factor, agar-agar, methyl paraben, and water. Chatterji et al. (1968) reared *C. partellus* on a wheat germ-based diet which was earlier used by Keaster and Harrendorf (1965) for rearing *Diatraea grandiosella*. Dang et al. (1970) used the Kabuli gram based diet. This diet had fewer and more readily available ingredients. Later on, several diets have been used in the mass rearing of *C. partellus* (Laxminarayana and Soto, 1971; Moorty, 1973; Siddiqui and Chatterji, 1972; Siddiqui et al., 1977; Sharma and Sarup, 1978; Reddy and Davies, 1979).

Presently, the diet developed by Taneja and Leuschner (1985) is being used for mass production of borer larvae

2.8 Selection Criteria

Several parameters such as leaf injury index deadhearts tunnel length, larval recovery, and number of holes either alone or in combination are associated with resistance to *C partellus* in sorghum and maize Lal and Pant (1980 b) found that maize varieties having lowest leaf injury index were resistance to *C partellus*

Chundurwar et al (1982) screened 12 hybrids for resistance to stem borer, and observed that there were no significant differences in survival (deadhearts) of plants from borer infestation However, fewer deadhearts were recorded in SPH 185, SPH 176, and SPH 221 Significantly less stem tunneling was recorded in plants of SPH 185, SPH 176, SPH 196 and CSH 5 Based on these data, they observed that resistance to deadheart formation is not always linked to resistance to stem tunneling

Dabrowski and Kidiavai (1983) suggested that the penetration by the young larvae into the stem may be a factor associated with resistance in some of the genotypes and not the length of the tunnel in the stem The number of holes per plant, which were positively correlated with stem tunneling, have also been shown to be a good indicator for measuring resistance to *C partellus* (Singh et al , 1983)

Singh et al (1983) tested 70 cultivars of sorghum for *C partellus* resistance under artificial infestation, and observed significant differences among the varieties tested for leaf-feeding injury, percent 'deadhearts', number of holes, and stem tunneling Thirteen varieties were at par with the resistant check for stem

tunneling. Varieties with long peduncles were more susceptible than those with small panicles. Leaf feeding injury, percent 'deadhearts', and tunneling parameters were not correlated, and none of them could be related to reduction in grain yield. Number of holes, number of tunnels, and percentage stem tunneling were positively correlated. Number of holes per plant or internode were good indicator of percentage tunneling, and could be used as a criterion for evaluating germplasm to stalk-borer resistance. The varieties CSV 8R, SPV 5, SPV 140 and SPV 192 were identified as promising sources of resistance to *C. partellus*.

Dabrowski and Kidiavai (1983) reported that ovipositional non-preference, reduced leaf feeding, low deadheart formation, stem tunneling, and tolerance to leaf and stem feeding contribute to stem borer resistance in sorghum.

Dalvi et al. (1983) screened 32 sorghum genotypes in kharif and 30 genotypes in rabi for their susceptibility to stem borer at Rahuri, India. Maximum damage was noticed in CSH 1, a commercial hybrid, and minimum in E 303 and E 302, the improved lines with resistance to stem borer. The maximum and minimum leaf injury index was recorded in SGIRL MR-1 and Bilichigan, respectively.

Singh et al. (1987) investigated the stability of resistance to *C. partellus* using seven genotypes identified to be less susceptible to *C. partellus*. E 302 and IS 4664 showed stable resistance for number of holes per plant and percentage tunneling. E 302, IS 4664, and SPV 104 were also stable for stem tunneling. IS 4664 was highly stable for resistance to peduncle tunneling.

Reddy and Saxena (1988) evaluated 134 sorghum lines for number of borers per plant, foliar lesions (1-9 scale rating), % deadhearts, and stem tunneling. The

overall resistance based on 4 parameters was considered for determining the resistance levels. The first 7 lines with resistance to borer included: 83SR/KAT/Nos. 506, 511, 653, cross 60:6, ICSV Nos. 83570, 83369, and 83620. Patel and Sukhani (1989) screened 20 sorghum genotypes (grain, fodder, and dual-purpose types) for resistance to *C. partellus* in Delhi, India, in 1987-88, and at Hisar, Haryana in 1988. Nine genotypes were promising with regard to deadheart incidence, leaf injury, and stem and peduncle tunneling. The order of resistance levels was : IS 3962 > IS 18584 > IS 2235 > IS 1054 = SPV 102 > IS 5469 > IS 5619 > IS 1877 > P 37.

van den Berg (1990) examined nine cultivars of sorghum in South Africa in 1987-89, and reported that they differ significantly in yield response to natural *C. partellus* infestations. Cultivars exhibited significant differences in yield loss compensation by means of tillering, and had different degrees of deadheart formation and internal damage. The incidence of broken panicles did not have a significant effect on yield loss.

Kishore (1991a) studied the relationship between parameters for damage (leaf injury and stem tunneling) caused by the stem borer, *C. partellus* on grain yield of different sorghum cultivars. Results showed negative correlations between grain yield and stem tunneling (r = -0.95) and grain yield and leaf injury(r = -0.86), and a positive correlation (r = +0.89) between stem tunneling and leaf injury in a susceptible (CSH 1) and 12 moderately resistant-sorghum cultivars infested with *C. partellus*. Multiple regression analysis indicated that a unit increase in stem tunneling resulted in a decrease of 0.59 units of grain yield, and 1 unit of leaf

injury caused a decrease of 0.002 units of grain yield. It was concluded that stem tunneling was a more important parameter determining a reduction in grain yield than leaf injury.

Singh et al. (1991) screened 40 sorghum genotypes for their resistance to *C. partellus* in the field in Haryana, India, in 1984-85. Results revealed that IS 2123 and IS 5469 had the fewest deadhearts and least leaf injury or stem tunneling damage. IS 2205, IS 18578, and IS 18584 were moderately resistant to this pest, while CSH 1 and Swarna were susceptible.

Jalaluddin et al. (1995) observed 19 promising ICRISAT sorghum lines plus a local and a standard check in the field at Bhavanisagar during kharif and summer 1990 and 1991 for deadhearts caused by *C. partellus* at 35 and 45 days after germination. Results showed that 9 entries were resistant to stem borer. Patel et al. (1996) carried out field experiments in Delhi and Haryana, India during the kharif season of 1988 to screen 20 diverse sorghum genotypes for resistance to *C. partellus*. On the basis of deadhearts, leaf injury, stem tunneling, peduncle tunneling, and exit holes. The genotypes IS 18584, IS 18577, and IS 2205 were the most resistant.

2.9 Mechanisms of resistance

Painter (1951) put forth three bases or mechanisms of resistance viz., non-preference, antibiosis, and tolerance.

2.9.1 Nonpreference / Antixenosis

This denotes a group of plant characters and insect responses that lead to or away from the use of a particular plant or variety, for oviposition, food or shelter or for combination of the three (Painter, 1951).

Kogan and Ortman (1978) criticized the conciseness of the term "non-preference", which was used by Painter (1951) to describe the modality of resistance involving effects of behavioral process that result in avoidance of the plant as food or as an oviposition substrate with allelopathic relationship established at the animal's sensorial system. They proposed the term "antixenosis", a greek word "xenos" refers to guest. So antixenosis means to keep a guest away and that the resistant host is the bad host. The term antixenosis is parallel to antibiosis.

Lal and Pant (1980 a) observed wide variations in the ovipositional behaviour of *C. partellus* on resistant and susceptible varieties of maize and sorghum in the laboratory. Their observations on the behaviour of gravid females and males of *C. partellus* showed that susceptible varieties were preferred for the establishment of populations, indicating the possible preference for some volatile chemical factor in the foliage either attracting or repelling the adults.

Dabrowski and Nyangiri (1983) observed significant differences in the number of *Chilo* eggs laid on the susceptible maize inbred A and the other two lines tested (Inbred D and G) in the choice and non-choice situations. An average of 13 eggs per plant were recorded on the susceptible line A and only 10-11 on Inbreds G and D, respectively under the non-choice conditions. In the screenhouse

studies, where the three lines tested were grown on adjacent rows an average of 18 eggs per plant were recorded on the preferred Inbred A and 8 - 9 on the moderately-resistant lines Field observations in western Kenya on 100 promising lines of sorghum indicated that nonpreference for oviposition occurred in 11 lines (Dabrowski and Kidiavai, 1983), and most of the egg masses were laid on the upper side of the leaf

Singh and Rana (1984) carried out tests on ovipositional nonpreference of 70 sorghum genotypes to *C partellus* under cage conditions Less than 0 5 egg masses per seedling were recorded on 28 varieties compared to 1 6 egg masses on the local check, PJ 8K Amongst these, less than 4 eggs per seedling were observed on fifteen lines as compared to 12 7 eggs per seedling in case of PJ 8K

In greenhouse studies on factors contributing to plant resistance to *C hilo* in sorghum, Alghali (1985) reported that differences for the number of egg masses and eggs per egg mass laid were highly significant among the lines tested The mean number of egg masses laid varied from 1 8 to 5 0 Varieties with 0 0 to 2 5 egg batches were classified as group one 2 6 to 3 5 egg masses as group two and 3 6 to 5 0 egg batches as group three The number of eggs per batch laid on the lines ranged from 20 3 to 47 3, and were broadly classified in the same manner as in case of the number of egg batches

In a field trial on ovipositional preference of *C hilo partellus* in a set of 20 sorghum genotypes under natural infestation Taneja and Woodhead (1989) found that the total number of egg masses were significantly higher (25 and 41 egg

masses per 50 plants) on the susceptible genotypes ICSV 1 and CSH 1, respectively compared to the resistant ones (2–3 egg masses per 50 plants).

Saxena (1990) reported that the number of eggs laid on the plants was almost equally high on the three susceptible (IS 18363, IS 18463, and IS 2146) and two moderately resistant (IS 4660 and IS 2205) cultivars. But were significantly less on the borer-tolerant line IS 18520, and lowest on the highly resistant IS 1044, on which the number of eggs laid was one-third of that on the most susceptible IS 18363.

van den Berg and van der Westhuizen (1997) studied the moth response for levels of antixenosis for oviposition on four inbred lines (E 302, IS 2205, IS 2122, and SA 2681) in choice tests under cage conditions and observed significant differences in number of egg batches per line. E 302 received the greatest number of egg batches.

2.9.2 Antibiosis

The term "antibiosis" was proposed for those adverse effects on the insect life history which result from the use of resistant host-plant variety or species for food by the insects (Painter, 1951). These adverse effects on the insect may be in the form of reduced fecundity, decreased size, abnormal length of life, and increased mortality.

Kalode and Pant (1967 a) carried out experiments on the effect of host plants viz., sorghum, maize, and pearl millet on the larvae of *C. zonellus* under controlled laboratory conditions. Maize seemed to be more suitable as food than sorghum and pearl millet as measured by larval survival and growth-index values. In sorghum,

three varieties were exhibited antibiosis, the larval survival in these ranged from 24 4 to 36 7 % as against 40 to 71 1% in the susceptible varieties A certain proportion of the larvae invariably failed to pupate and remained in larval stage even after the end of the experiment The number of such larvae was much lower in young plants as compared to older plants Besides the age of the plant, varietal characters of the crop may also be responsible for undue prolongation of the development period It was noted that even after 100 days, 15 6% of the larvae did not pupate in one of the resistant varieties of sorghum

Jotwani et al (1978) carried out studies to determine the mechanisms of resistance to *C partellus* in seven sorghum varieties It was found that mortality in the early larval stage was higher, ranging from 45 4 to 58 7% in case of resistant varieties as compared to 30 6% in case of CSH 1 No correlation was observed between the larval period and larval weight There were no significant differences in larval mortality during late stage, the pupal period and adult emergence

Lal and Sukhani (1979) studied the biology of *C partellus* on four resistant and two susceptible genotypes They observed that larval survival in leaf whorls and stalks varied from 62 5 to 70% on susceptible controls as compared to 22 5 to 37 5% on the resistant lines

Lal and Pant (1980 b) conducted laboratory and field studies to screen two maize and two sorghum varieties for resistance to *C partellus* They found that percentage larval survival was significantly lower on Antigua Gr 1 and 124 (15 and 25%, respectively) than on CSH 1 and Basi Local (65% and 55% , respectively) under laboratory conditions Under field conditions too, larval

survival was significantly lower in Antigua Gr 1 and 124 (10 and 20%, respectively) than on CSH 1 and Basi Local (50 and 30%, respectively)

Lal and Sukhani (1982) carried out laboratory tests to determine the adverse effects of 4 resistant lines of sorghum on various aspects of post-larval development of *C partellus* Pupation was found to be significantly lower on resistant lines (22 5 to 37 5%) compared to susceptible hybrid, CSH 1 (70%) Pupae reared on resistant lines were much smaller and lighter (pupal mass ranging from 70 to 80 8 mg) than those reared on susceptible hybrid CSH 1 (pupal mass 86 7 mg) Female moths reared on resistant lines laid fewer eggs than those reared on susceptible ones (ranging from 197 4 to 260 8 eggs in case of resistant lines and 305 5 eggs in case of CSH 1) However, the differences between borer-resistant and- susceptible genotypes regarding pupal period percentage moth emergence, and incubation period of eggs were not significant

Dabrowski and Kidiavai (1983) made field observations on *Chilo* infestation on 100 promising sorghum lines and studied the different levels and mechanisms of resistance to *C partellus*

Singh and Rana (1984) stated that though ovipositional nonpreference and antibiosis act together to determine the degree of resistance, antibiosis has a greater effect on plant resistance to *C partellus* than the effect of ovipositional nonpreference In a laboratory study on larval development of *C partellus* on leaf whorls and stems of 70 sorghums comprising of released varieties and hybrids, experimental high-yielding varieties, lines selected for stalk borer-resistance, and local cultivars, they observed that larval duration was positively correlated with

larval mortality on both the leaf whorls as well on stems and negatively with pupal weight on the leaf-whorl. In case of borer-resistant varieties, larval development was 17 - 32 days on the leaf whorls and 33 - 62 days on the stems of various varieties. Larval mortality on the leaf whorl of early-maturing varieties was 8.1% more than on that of late-maturing varieties. The mean pupal weight was 65.6 ± 3.8 mg on the leaf whorl and 56.7 ± 4.9 mg on stem. Pupal weights were 47 - 75 mg the leaf whorls and 33.5 - 47.5 mg on stems of local varieties. There appeared to be some antibiotic factor(s) both in leaves and/or stems of the resistant varieties, which influenced the larval duration and mortality adversely.

Singh and Verma (1988) studied the biology of *C. partellus* on 2 resistant (IS 2205 and IS 5469) and 2 susceptible (IIC 136 and ICSV 1) sorghum genotypes. Larval survival in the leaf whorls, larval period, larval mass, larval length, percentage pupation, pupal weight, fecundity, and total life cycle were all adversely affected on the resistant genotypes. Growth index was greatest in the susceptible lines compared with that on the resistant ones. It was concluded that high mortality of larvae on resistant lines is due to antibiosis. Larval period was the most important parameter influencing the growth index and total life span of *Chilo*.

Taneja and Woodhead (1989) carried out a study on the effect of 20 sorghum genotypes on biology of *C. partellus*, using blackhead stage eggs on plants of 15 - 20 DASE, and observed significant differences with respect to first-instar larval establishment in the whorl, time interval between larval hatching and boring into the stem, larval mass, and survival rate. A lesser proportion of larvae (25 - 40%)

established in the whorls of some of the resistant genotypes as compared to 51% in the susceptible genotype, ICSV 1 In some of the resistant genotypes, the larvae took more time to arrive at the base of the stem for boring In four resistant genotypes, less than 10% of the larvae were observed at the base of the plant 10 days after the infestation, compared to 21% on one of the susceptible genotypes

Larval mass was significantly lower (<90 mg per larvae) in 6 genotypes compared with 140 mg per larvae on IS 18573 and 115 mg per larva on ICSV 1 Survival rate as measured by the total insect recovery was significantly lower (8 - 10%) in IS 2205, IS 2309, and IS 18333 compared to 24% in case of CSH 1

Saxena (1990) studied the larval development of *C. partellus* for determining the resistance of seven sorghum cultivars in the laboratory and in the field in Kenya He found that the percentage of larvae completing development ranged from 64 8% on the most resistant IS 1044 to 79 6% on the most susceptible, IS 18363 The developmental periods ranged from 25 1 days on IS 2146 to 28 5 days on IS 1044 The growth index was highest on IS 18363 IS 18463, IS 18520, and IS 4660 It was medium for IS 2146 and IS 2205 The lowest growth index was observed on the highly resistant genotype IS 1044, which was therefore least suitable for larval development

Verma et al (1992) studied the development of *C. partellus* on a resistant (IS 5604) and a susceptible (CSH 1) sorghum cultivar under laboratory and field conditions They found that larval stage was prolonged on IS 5604 (28 8 and 21 2 days) as compared to CSH 1(19 5 and 15 2 days) The pupal period was also prolonged on IS 5604 (6 9 and 6 2 days) as compared to CSH 1 (6 7and 6 0 days)

Female pupae weighed less (61 0 and 63 5 mg) on IS 5604 than that on CSH 1 (89 0 and 90 5 mg) under both laboratory and field conditions These laboratory and field studies confirmed that some antibiotic factors exist in the leaves of the resistant cultivars resulting in prolonged larval and pupal periods and in reduced pupal mass

Saxena (1992) studied the relationship between the susceptibility of six sorghum lines to *C partellus* and the dietary quality of their leaf tissues when incorporated in an artificial diet and found that the leaf tissues of sorghum line IS 18520 incorporated in the artificial diet as a dry powder or fresh leaf-paste were as efficient in supporting larval development as natural host plants The diets with leaf-pastes made from the susceptible IS 18363 and IS 2146, as well as the moderately resistant IS 4660 also supported equally high larval development In contrast, the leaf paste of the highly resistant IS 1044 and of the moderately resistant genotype IS 2205 showed deleterious effect on larval development due to antibiosis Such an effect was eliminated by drying the leaves and incorporating the leaf powder in the diet

Singh and Marwaha (1996) studied the effect of four sorghum genotypes on the development of *C partellus* under laboratory conditions The growth index of *C partellus* was lowest (1 05) on the resistant sorghum line IS 18551, showing an antibiosis reaction as compared to susceptible lines CSH 1 and CSH 9, where the growth index was 3 02 and 2 39, respectively The tolerant sorghum line with a growth index of 1 12 revealed its intermediate level of susceptibility to *C partellus*

van den Berg and van der Westhuizen (1997) evaluated antibiosis and larval antixenosis with artificial infestation in the greenhouse The results showed significant differences in larval numbers and mean larval mass on the lines tested (E 302, IS 2205, SA 2681, and IS 2122) with E 302 showing the greatest level of antibiosis resistance

Patel et al (1996) screened 20 diverse sorghum genotypes for resistance to *C partellus* and found IS 18584, IS 18577, and IS 220 to be most resistant on the basis of deadhearts, leaf injury, stem and peduncle tunneling and exit holes

2.9.3 Tolerance

Tolerance is a basis of resistance in which the plant shows an ability to grow and reproduce itself or to repair injury to a marked degree inspite of supporting a population approximately equal to that damaging a susceptible host (Painter, 1951) Jotwani (1978) reported some tolerant sorghum genotypes with lower yield loss due to stem borer infestation and attributed this to tolerance mechanism Inspite of severe leaf injury and stem tunneling, the final plant stand was very good and most of the plants had normal-sized earheads Dabrowski and Kidiavai (1983) carried out field observations on *Chilo* infestation on 100 promising sorghum lines and recorded tolerance in some lines to leaf damage (in spite of high damage, plants formed panicles) and to larval feeding in stems (in spite of high tunneling, the plants formed seeds)

2.9a Development of cultivars resistant to *C partellus*

Kundu (1985) selected the sorghum derivative I 304, from a cross made between IS 2954 and BP 53 Its yield potential was comparable to the parents, but it was

more resistant to the *C. partellus* than the commercially released variety CSV 1. Kishore (1987, 1992) developed a borer-resistant sorghum variety P 311, by pedigree selection from the cross SPV 104 and P 151 and SPV 1015 (PGS 1), from P 601 and P 201 by pedigree selection.

2.9.b Factors associated with resistance

2.9.b.1 Morpho-Physiological factors

Studies carried out by Kumar and Bhatnagar (1962) on varietal resistance to sorghum stem borer involving 1140 varieties revealed that only 7 varieties were to be completely free from the attack of the borer. Dwarf and early varieties having short and thin stems, few narrow and short leaves, short and thin earheads, less weight, and threshing percentage were comparitively more resistant than the other genotypes. Genotypes with white exposed seeds, spreading earheads, and juicy stems were found to be highly resistant.

Sharma and Chatterji (1971 c) tested 12 maize varieties for resistance to *C. partellus*. They found that resistance was negatively related to plant height, internode length, and tassel ratio (width divided by length at the time of pollen shedding), and positively related to the hardness of the stem. Width of leaves, number and girth (circumference) of internodes, and the number of days to silking were related to *C. partellus* resistance. In a study on antibiosis in different maize germplasms against *C. zonellus*, Sharma and Chatterji (1971 a) found that the germplasms with less compact whorl (whorl index) seemed to have more antibiosis (lower number of surviving larvae per plant). In Antigua Gr 1, the whorl

index was 0.6 compared to 1.4 in the susceptible check, Basi local. Germplasm with more width of the leaves, in general, showed more antibiosis. For example, Antigua Gr 1, A1 x Antigua Gr 1 and Antigua Compesto, which showed maximum antibiosis, had broader leaves, i.e., leaf width was 3.8, 3.5 and 3.8 cm, respectively as against 3.2 cm in case of Basi local. Leaf area did not show any relationship with antibiosis to *C. partellus*.

Roome et al. (1977) stated that physical characteristics of the substrate preferred by ovipositing females are important for plant resistance to *C. partellus*. Leaves with distinct mid-ribs (mature maize) or with elongate creases (dry sorghum) offer concave areas in which egg batches can be placed. Such leaves were favoured for oviposition. Surfaces with minor irregularities such as hairs, were not favoured. The form of the egg batch, with the eggs overlapping each other, suggested that prevention of desiccation is important. Such egg batches could not be produced on a hairy surface, and the formation of the batch in a concavity may increase the degree of protection. Oviposition was low on the plant and on non-growing surfaces, and this may prevent dislodgement of eggs by growth, distortion, or wind movement.

Durbey and Sarup (1982) determined the density of trichomes on leaves 1-10 (starting at the bottom of plants) of the maize varieties, Antigua Gr 1, Mex 17 and Ganga 5, which are resistant to *C. partellus*, and the susceptible varieties, Basi local and Vijay Composite in laboratory studies. In general, there were no trichomes on the first 2 leaves. Trichome density was high (48 - 56 mm^{-2}) on the adaxial surface of leaves 6 - 8. Females preferred to oviposit either on the more or

less glabrous leaf surfaces or those having the optimum trichome density (1-7 mm ^{2}) without long and non-erect trichomes The marginal trichomes, which varied in shape according to variety, appeared to play no role in oviposition

Bernays et al (1983) studied the climbing behaviour of newly emerged larvae of *C partellus* on sorghum plants in the field and in the laboratory Although climbing speed was found to vary on different cultivars there was no correlation between speed and trichome density In case of IS 1151, larvae covered a certain distance on the culm faster when the surface wax bloom on the culm was removed In dry weather, the wax bloom on the culm of IS 1151 was very conspicuous in the bigger plants and many larvae accumulated a mass of wax round the prolegs which seemed to impede their movement These insects were readily blown off the plant, sometimes hanging by a silken thread until they regained a foothold, but often being swept away without achieving this Cultivar IS 2205 had no obvious wax bloom Many larvae were lodged in the axils and leaf sheaths of the plants On small plants of IS 2205, pockets at the leaf base were recognized as factors delaying the climbing and its leaf axils were less hairy than those of IS 1151 These micro anatomical features of the plant appeared to be of some importance in reducing larval establishment

Dabrowski and Nyangiri (1983) carriedout some field and screenhouse experiments on maize resistance to *C partellus* in western Kenya and found that the maize lines which were hairy, especially on the upperside of the leaves, had less oviposition, but had as much oviposition as the other lines on the underside of

the leaf. Higher pilosity or some unknown factor associated with it was suggested to have a negative influence on oviposition.

Singh and Rana (1984) studied the ovipositional non-preference and larval development of *C. partellus* on 70 sorghum varieties in the laboratory. These observations were correlated with the field observations on agronomic plant characteristics such as plant height, peduncle length, number of internodes, grain yield, and 100 seed weight. Larval duration on stem was positively correlated with plant height and number of internodes per plant and negatively correlated with peduncle length. Larval mortality on stem was positively correlated with plant height and negatively with peduncle length. Pupal weights on stem showed positive association with peduncle length and negative correlation with pant height and number of internodes per plant.

The influence of resistance or susceptibility of certain maize genotypes on colonization by *C. partellus* was studied in Kenya by Ampofo (1985). It was found that the lower surfaces were preferred on all leaves. Exudates from plants of maize genotype CCZ2 - CM increased oviposition by 9.7 % while exudates from ICZ1-CM and inbred A decreased oviposition by 57.7 and 25.8 %, respectively. Exudates from all three genotypes shortened moth longevity compared to distilled water. Fertility, measured as a proportion of eggs hatching, was not influenced by the source of moth diet. Preliminary examination of the exudates by high performance liquid chromatography suggested the presence of different chemicals in the exudates from the different maize genotypes. Four components with high absorbance were eluted from ICZ2 - CM exudates, and two from Inbred A and

ICZ1 - CM. It was observed that in all the genotypes tested, smooth areas of the plant (the lower leaf surface and the midrib concavity) were preferred for oviposition. The least hirsute Inbred A was preferred mostly for oviposition. Thus, plant characters that influenced oviposition included plant exudates (as the moth diet) and leaf surface trichomes.

Kumar and Saxena (1985) found that when two maize genotypes (Inbred A - susceptible and ICZ1 - CM- resistant) were presented together as a choice to female moths of *C. partellus*, the percentage of eggs laid on ICZ1 - CM was almost one-half of that on Inbred A. The upper surface of the leaves of ICZ1 - CM had a high density of trichomes whereas the lower surface was devoid of any. It was found that the percentage of eggs laid on the hairless side of the leaf was about 5 times that on the hairy side in both the basal and terminal portions of the leaf. This indicated that the trichomes of the resistant leaves inhibited oviposition by *C. partellus*.

Woodhead and Taneja (1987) screened 20 sorghum genotypes for resistance to *C. partellus* under artificial and natural conditions and found that physical plant characters correlated well with observed establishment. These characters were: (i) orientation of leaf to stem: a small angle between leaf and stem (i.e., upright leaves) affected the insect's ability to reach the whorl; (ii) elongated internode length between leaves three and four; (iii) Curling of leaf base (with respect to accommodation of first instar larvae); and (iv) detachment of the leaf sheath from the culm. The only physical character common to all resistant genotypes was found to be erect and narrow leaves.

Taneja and Woodhead (1989) also reported that early panicle initiation and rapid internode elongation were associated with resistance to *C. partellus* in sorghum. In resistant genotypes, these factors were reflected in the success of first-instar larval establishment in the leaf whorl, the interval between hatching and larvae boring to the stem, larval mass, and survival rate. Some genotypes have pronounced ligular hairs and it appeared that larvae may become trapped in such hairs. In case of native sorghums that are often tall and thin-stemmed, the internodal distances are large in contrast to short, high-yielding hybrids. In native sorghums, longer internodes operate as a resistance mechanism in that the further the larvae climb, the more likelihood of desiccation or attack by predators, and the greater the exposure to unfavourable environmental conditions. Larvae were found to climb almost twice as fast on stems of IS 1151 from which surface wax had been removed compared with stems prior to removal of wax. Thus, surface wax can have a gross effect on larval success rates. They also noticed that genotypes with early panicle initiation escaped deadheart formation due to inability of larvae to reach the growing point. Shoot length, i.e., faster internode elongation, was another significant growth characteristic in stem borer resistance. This characteristic also pushes the growing point upward, hampering the ability of the larvae to reach it, and thus preventing deadheart formation.

Patel and Sukhani (1990) reported some biophysical plant characters such as long and thin stems with fewer, but longer internodes, short peduncles, and yellowish-green leaves with high trichome density to be associated with resistance to *C. partellus*.

Kishore (1991 b) reported some morphological factors responsible for conferring resistance in sorghum to the stem borer, *C. partellus*. They are presence of ligular hairs, hairy carpet base, erect hairs, tightness of the leaf sheath enveloping the stem, and leaves forming an acute angle to the stem.

Sharma et al. (1997) reported that some of the factors associated with resistance to insects can be quantified/monitored easily in plant populations, and they can be used as ' marker-traits' to screen and select for resistance to insect pests. Factors include seedling vigor, glossiness, trichomes and other biochemical factors.

2.9.b.2 Biochemical factors

A study was undertaken by Swarup and Chaugale (1962) to investigate the probable causes for the differences in susceptibility of 70 sorghum varieties to stem borer infestation. It was found that the varieties which were late-maturing and high in sugar content were less damaged by the stem borer than the early-maturing varieties and those having low sugar content, and stem borer attack was not related to the HCN content.

Kalode and Pant (1967 b) recorded high amounts of amino acids in maize varieties susceptible to *C. partellus*. Moisture content did not show much variation in early stages of crop growth (maize and sorghum). However, there were marked differences between resistant and susceptible varieties in later stage of plant growth; moisture content being higher in susceptible varieties than in the resistant ones. Total sugars were lower in resistant varieties as compared to the susceptible ones.

Laboratory and field studies carried out by Sharma and Chatterji (1971 d) to determine the effect of the chemical constitution of some maize lines on resistance to *C. partellus* revealed that susceptible plants had higher nitrogen, phosphorus, potash and sugar contents than resistant plants, but lower silica and iron contents. As the growth stage progressed from early to late whorl, the nitrogen, phosphorus and potash contents decreased while the iron, silica and sugar contents increased. Plants in mid-whorl and late-whorl stages were more susceptible than those in early-whorl stage. Larvae survived better in stems than in the leaf whorls; stems had higher potash, silica and sugar contents than the whorls, but lower nitrogen, phosphorus and iron contents. The data indicated that resistance was not related to nitrogen, phosphorus, potash, silica or iron contents but was possibly related to the sugar content.

Larval survival increased due to addition of dextrose, ascorbic acid and salt mixture No.2 to resistant maize plants. Decreased larval survival was recorded when these nutrients were removed from the diet (Sharma and Chatterji, 1972). This study suggested that resistance might possibly be due to the lack of these constituents in the resistant germplasms. On the other hand, removal of these nutrients from the diet under laboratory conditions did not affect the larval establishment and survival to such an extent as observed in the whorl of resistant germplasm, Antigua Gr 1. This apparently indicated that the lack of these nutrients might not be the cause of resistance, and under the field studies, may have acted as feeding stimulants or suppressor of some toxin, if at all present.

Narwal (1973) studied the size and frequency of occurrence of silica bodies in the leaves of six varieties and three hybrids of sorghum and compared these with *C. partellus* infestation. The varieties and hybrids that had the largest size and highest densities of silica bodies were resistant to insect attack.

Khurana and Verma (1982) carried out a study to determine whether the amino acid content of sorghum lines could be correlated with their level of resistance to *C. partellus*. All the 17 amino acids evaluated were present in both the susceptible and resistant lines, but the quantities of the acids were found to be greater in the resistant lines than in the susceptible ones. Out of the 17 amino acids estimated, 5 amino acids, viz., arginine, glycine, phenylalanine, lysine and valine were more in the resistant lines. Khurana and Verma (1983) also carried out a study to determine possible correlations between biochemical characteristics of sorghum plants and their susceptibility to *C. partellus*, using 6 moderately resistant lines and 3 susceptible ones. Total sugars, tannins and total phenols in 30-day-old plants, and natural-detergent fibre, acid-detergent fibre, cellulose, lignin, tannins and total phenols in 50-day-old plants were negatively correlated with susceptibility to *C. partellus*, while positive correlations were observed between insect damage and nitrogen and potassium contents.

Torto et al. (1990) made chromatographic examination of extracts of IS 18363 and IS 2205 and found that the more susceptible cultivar IS 18363 had higher phenolic and sugar contents than the resistant check, IS 2205.

Alborn et al. (1992) obtained extracts from freeze dried leaves of 14 sorghum cultivars. Dhurrin, a cyanogenic glucoside, was in greater quantities in susceptible

cultivars CSH 1, Swarna and IS 10795. Dhurrin was found on the surfaces of young leaves. It is suggested that dhurrin acts as an oviposition activator for the pests.

2.9.c Inheritance of resistance

Rana and Murty (1971) and Haji (1984) reported that resistance to stem borer is polygenic. They found that resistance to primary damage (leaf feeding) was governed by additive type of gene action, while additive and non-additive type of gene action were important for secondary damage (stem tunneling). Resistance to *C. partellus* for primary damage, i.e., deadheart formation was governed by both additive and non-additive type of gene actions, and by additive gene action for stem tunneling (Kulkarni and Murty, 1981; Pathak and Olela 1983). It has been observed that the inheritance pattern of primary and secondary damage were different. The epistatic gene effects were more pronounced under artificial borer infestation (Haji, 1984). He also noticed that under natural infestation, resistance was controlled by additive and dominant major gene effects. Cytoplasmic influences appeared to be present, which may play an important role for the inheritance of stem borer resistance.

Rana et al. (1983) studied the genetics of stem borer resistance in sorghum and reported that host-plant resistance to *C partellus* (measured in terms of leaf-feeding injury, deadhearts and stem tunneling) showed quantitative variation. The heterosis over mid-parent for these characters was 72, 12, and 19%, respectively. The susceptibility was partially dominant over resistance. Additive genetic variance was considerably low.

Pathak (1990) studied the genetics of resistance to *C. partellus* (leaf-feeding, deadhearts and stem tunneling) and observed it to be polygenic. Both additive and non-additive gene effects are important in the inheritance of resistance to *C. partellus*. Resistance to leaf-feeding and stem tunneling is governed predominantly by additive genes, while both additive and non-additive genes are important for the inheritance of resistance to deadheart formation.

Singh (1997) explained the genetic basis of host plant resistance to insects, expression of vertical and horizontal resistances, and genetic parameters that provide the basis for selection and improvement of crop plants for resistance to insects. Genetic parameters include additive gene effects, dominance, epistatic gene effects, heritability, and genetic advance.

MATERIALS AND METHODS

MATERIALS AND METHODS

Antixenosis and antibiosis components of resistance to the spotted stem borer, *Chilo partellus* were studied in a diverse array of 25 sorghum genotypes under greenhouse and laboratory conditions. The test genotypes consisted of sixteen germplasm accessions identified to be resistant to the stem borer, five improved breeding lines with resistance to the stem borer, three landraces from different geographical regions and two hybrids. Among them, IS 2205 and CSH 1 were used as resistant and susceptible checks, respectively.

The sorghum genotypes tested are listed in Table 1. These studies were carried out in the greenhouse and laboratory conditions at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India.

3.1 Nonpreference for Oviposition

Nonpreference for oviposition was studied under limited-multi test choice and multi-choice conditions. These studies were conducted under atmospheric conditions (25-27°C, 65 - 90% RH).

3.1.1 Limited multi-choice test

Under limited choice conditions, the moths were given a choice of 4 varieties (including the commercial check, CSH 1) for oviposition. For these studies, the test cultivars were placed in a wooden cage (80 x 70 x 60 cm). The wooden framed cages were covered with a wire-mesh screen on three sides, and a glass door in the front. The front doors had a 20 cm diameter cloth bag attachment for introducing the insects. The base of the cage had a wooden pan, while the top was covered

Table 1 Sorghum genotypes used to study antixenosis for oviposition and antibiosis components of reisistance to *Chilo partellus*

Germplasm/ Variety/ Hybrid	Pedigree/Classification	Origin (Country)
IS 1044	Durra	India
IS 1054	Cernuum	India
IS 2123	Durra	USA
IS 2146	Durra	Nigeria
IS 2263	Durra	USA
IS 2269	Durra	USA
IS 2309	Caudatum	Sudan
IS 5469	Durra	India
IS 5566	Durra/Membranaceum	India
IS 5604	Durra/Membranaceum	India
IS 12308	Durra-Bicolor	Zimbabwe
IS 13100	Bicolor	India
IS 18333	Durra	India
IS 18573	Bicolor	Nigeria
IS 21444	Guinea	Malawi
AF 28	Caudatum	EMBRAPA, Brazil
Naga White	Landrace	West Africa
Seredo	Landrace	East Africa
ICSV 1	(SC 108-3 x CS 3541)-19-1	ICRISAT
ICSV 112	(IS 12622 x 555) x IS 3612 x 2219B x M 35-1-5-2	ICRISAT
ICSV 705	(PS 21194 X ICSV 1)-3-1-2-3-3	ICRISAT
ICSV 714	((IS 5604 X 23/2) X CSV 4) X CSV 4-1-1-1	ICRISAT
ICSV 743	(ICSV 197 X A 13108)-1-1-2-3-2	ICRISAT
CSH 9	296A x CS 3541	India
Checks		
IS 2205	Durra	India
CSH 1	CK 60A X IS 84	India

with a glass pan. Plants of the test genotypes were grown in pots in the greenhouse. Potting mixture consisted of 2:1 ratio of red soil : FYM(Farm Yard Manure). DAP (diammonium phosphate) was applied before sowing @ 50 g per pot. Plants were thinned after 10 days after crop emergence and three plants were retained in each pot. Plants were watered every day. Urea was applied at 10 days after crop emergence @ 10 g per pot. Five days after crop emergence, Carbofuran 3G granules are applied in the whorl leaves (5-10 granules per plant) to prevent shoot fly infestation. Twenty-day-old plants were transferred to the cages. Four potted (3 test varieties and 1 check, CSH 1) plants were kept at the four corners of the cage.

Ten pairs of newly emerged stem borer adults were released into each cage *Chilo partellus* moths were obtained from a culture raised on artificial diet in the insect rearaing laboratory (Taneja and Leuschner, 1985). Moths were provided with water in a cotton swab through out the experiment. After releasing in the cage, the moths were allowed to oviposit for three nights on the test plants. To avoid predation by the ants, tanglefoot^{R} glue was smeared on all the four legs of the cages.

3.1.1a Observations

Observations were recorded on the number of egg masses on each plant. The leaves containing egg- masses were cut and kept in a small polythene bag (5 x 10 cm). Leaves with egg-masses were preserved for three days. When the eggs turned into black-head stage after three days the number of eggs in each egg-mass wee counted under a 40X simple microscope.

Each experiment was replicated three times. In each replication, the position of the pots was changed each day to avoid positional effect.

3.1.2 Complete multi choice test

Nonpreference for oviposition under complete multi-choice conditions was studied by keeping all the 25 test varieties inside a mosquito-net (2.0 x 1.0 x 0.6 m) placed around a wooden table. In this test, the moths were given choice among all the test varieties for oviposition. Plants of all the varieties were grown in pots under ambient conditions as described before.

Pots (containing 3 plants) of all the test varieties were arranged on the table in a completely randomized block design. Eighty pairs of newly emerged adults were released inside the net covering the test plants. Moths were provided with water in a cotton swab throughout the experiment. Moths were allowed to oviposit on the test entries for 3 consecutive nights. To avoid predation by the ants, tanglefoot^{R} glue was applied to all the four legs of the wooden table.

3.1.2a Observations

Observations were recorded on the number of egg-masses and number of eggs laid on each genotype.

The experiment was replicated four times.

3.2 Antibiosis

Effect of different sorghum genotypes on establishment and development of *C. partellus* under greenhouse conditions.

The experiments were conducted in the greenhouse during December1998 to March 1999. The experiment was laid out in a randomized block design with 25

treatments (genotypes) replicated 5 times. The plants were raised on medium sized pots (60 cm diameter) in the greenhouse at ambient atmosphere conditions (33±5°C, and 65±5% RH). The potting mixture consisted of red soil and FYM (2:1). Before sowing, DAP was applied @ 50 g per pot and 10 seeds were sown in each pot. At 10 days after emergence, three healthy seedlings were retained in each pot. Urea @ 10 g per pot was applied after thinning The plants were watered daily as needed.

3.2.1 Infestation

The plants were infested artificially with a camel hair brush @ 10 first-instar larvae per plant at 25 DASE. After releasing the larvae in the leaf whorls, the plants were covered with a selfing bag (5 x 30 cm). The selfing bag was sealed at the base of the plants with a piece of scotch tape to restrict the dispersal of larvae away from the plants.

3.2.1a Observations

Observations were recorded on larval survival at 5 days after infestation by destructive sampling. One plant was sampled from each replication to record the number of larvae surviving after five days in each genotype. Number of surviving larvae in the remaining two plants were counted at 25 days after infestation. Duration of larval development was recorded as number of days from the release of the larvae upto date of pupation. For this purpose, larvae from all replications were placed in a plastic jar along with 10 cm pieces of sorghum stems from the same genotype. The pupae were sexed on the basis of their relative size and genital openings (Sithanantham and Subramaniam, 1975 a &b). One day after

pupation, the pupal mass was recorded separately for males and females. Duration of pupal development was recorded in terms of number of days (date of pupation till adult emergence). For this purpose, the pupae were kept in glass vials separately.

3.2.2 Effect of Lyophilized leaf powder impregnated in artificial diet on survival and development of *C. partellus.*

3.2.2a Leaf powder

Leaves of different genotypes were collected from 25 - 30 day old plants raised under greenhouse conditions. From each plant, 2 – 3 central whorl leaves (on which the larvae feed under natural conditions) were removed from the plant at the growing point. The leaves were washed and then freeze dried in a lyophilizer for 36 hours to avoid changes in chemical composition of the leaves and then powdered in a Willey mill to < 80 mesh size.

To obtain an idea of the optimum amount of sorghum leaf powder needed in the artificial diet to measure antibiotic effect of different sorghum genotypes on *C. partellus*, two experiments were conducted on:

1) effect of different amounts of leaf powder in the artificial diet (Table 3) on survival and development of *C. partellus*, and
2) effect of different proportions of chickpea flour and sorghum leaf powder in the artificial diet on survival and development of *C. partellus*.

For studying the effect of different amounts of leaf powder in the artificial diet on survival and development of *C. partellus*, 0, 7.5, 12.5, 17.5, and 22.5 g of sorghum leaf powder (Cultivar CSH 1) was added in the artificial diet (250 ml). Sorghum

leaf powder was soaked in 100 ml of warm water (70°C) and blended with Fraction A (Table 3) ingredients for two minutes Agar-agar was boiled in 80 ml of water (Fraction B) and cooled to 40°C, and then poured into the blender containing Fraction A ingredients Formaldehyde was added finally and all constituents blended for three minutes Each treatment was replicated five times (a small cup of 50 ml capacity containing 20 ml diet) Ten first-instar larvae were released into each cup At 15 days after infestation, data were recorded on larval survival and larval mass

In the second experiment, leaf powder from five sorghum genotypes was impregnated in the artificial diet For each genotype, five treatments with different proportions of chickpea flour and sorghum leaf powder (0 6, 2 4, 3 3, 4 2, and 5 1 sorghum leaf powder Chickpea flour) were tested The preparation of diet was same as stated above There were 5 replications for each treatment Ten first-instar larvae were released into each cup, ten days after infestation data were recorded on larval survival and larval mass

Antibiosis component of resistance to *C partellus* in 25 sorghum genotypes under in-vitro conditions was assessed by impregnating a 1 1 ratio of chickpea flour sorghum leaf powder, all the ingredients of Fraction A (Table 2), except the sorghum leaf powder, were blended for one minute Sorghum leaf powder was soaked in 70 ml of warm water (70°C) and blended with Fraction A ingredients for two minutes Agar-agar was boiled in 65 ml of water (Fraction B) and cooled to 40°C and then poured into the blender containing Fraction A ingredients Formaldehyde was added finally and all the constituents blended for three minutes

Table 2 Ingredients of artificial diet used for rearing *C. partellus* in the laboratory

Ingredient	Quantity
Fraction A	
Water	80.00 ml
Chick pea flour	12.00 g
Brewers yeast	1.28 g
Sorbic acid	0.16 g
Vitamin E (Viteolin capsules)	0.18 g
Methyl parahydroxy benzoate	0.26 g
Ascorbic acid	0.42 g
Sorghum leaf powder	12.00 g
Fraction B	
Agar-agar	1.64 g
Water	65.00 ml
Formaldehyde	0.13 ml

Source: (Taneja and Leuschner, 1985 modified)

There were three replications for studying post-embryonic development [large cups (250 ml capacity) having 150 ml diet], and five replications for measuring larval survival at 10 days after infestation [small cups (50 ml capacity) having 10 ml diet] After pouring the diet into the cups, it was allowed to cool for 2 to 3 h on the lab-table Ten first-instar larvae were released into each cup, using a fine camel hair brush The cups were kept in the rearing room in the dark for 3 days (because first- instar larvae have a strong photosensitive behaviour and settle better on the diet in the darkness) In the rearing room, temperature was maintained at 28 ± 1°C, RH at 60 – 70 % with a photoperiod of 12 h

Observations were recorded on larval survival and larval mass at 10 days after releasing the larvae into the artificial diet in small cups The mass of the surviving larvae at 10 days after release was recorded after removing the larvae from the rearing cups Duration of larval period was recorded in terms of number of days from the release of the larvae till pupation These observations were recorded on the larvae released in large cups Pupal mass was recorded for each sex separately on second day after pupation Duration of pupal period was recorded in terms of number of days from pupation till adult emergence For this purpose, each pupa was kept in a glass vial Percentage of pupation and adult emergence were calculated from the total number of larvae released in each replication

3.3 STATISTICAL ANALYSIS

The data was subjected to analysis of variance. Data on insect numbers were subjected to square root transformation and those on percentages to angular transformation before analysis of variance. Significance of differences between the treatments was judged by the f – test, while the treatment means were compared using least significance difference (LSD) at $P < 0.05$.

RESULTS

CHAPTER IV

RESULTS

4.1 Antixenosis for oviposition by *C. partellus* females in limited-multi choice tests.

Antixenosis for oviposition by the *C. partellus* females in relation to CSH 1 in limited-multi choice tests indicated that the genotypes IS 13100, ICSV 112, IS 5469, IS 18573, ICSV 705, ICSV 714, and IS 2123 were relatively less preferred for oviposition compared to CSH 1 (Table 3) Whereas the genotypes AF 28, IS 2146, IS 5604, ICSV 743, IS 1054, ICSV 1, and Seredo were preferred for egg laying by the *C partellus* females as compared to CSH 1.

4.2 Antixenosis for oviposition by *C. partellus* females under multi-choice conditions.

Oviposition preference under complete multi-choice tests showed that the number of egg masses per 3 plants varied from 1.7 to 3.2 on different genotypes, while the number of eggs per 3 plants varied from 11.3 to 26.7. Less than 2.0 egg-masses per 3 plants were deposited on IS 2123, and IS 13100. Wherever, less than 14 eggs per 3 plants were deposited on IS 13100, IS 2123, IS 2309, and IS 1054. The number of eggs laid on these varieties were significantly less than on the commercial check, CSH 1. The genotypes ICSV 112, IS 5566, and IS 5604 had more number of egg masses and number of eggs as compared to CSH 1. There were no significant differences in the number of egg masses and eggs laid on other genotypes in comparison to CSH 1.

Table 3 Relative oviposition preference by the spotted stem borer, *C. partellus* females in four-choice cage tests (ICRISAT center, Patancheru,1999 rainy season).

Genotype	No. of egg masses per 3 plants*	No. of eggs per 3 plants*	Relative oviposition within a set (%)**		Oviposition preference in relation to CSH 1(%)	
			Egg masses	Eggs	Egg masses	Eggs
AF 28	2.0 (1.6)	36.0 (5.8)	22.22	31.37	61.11	133.38
IS 12308	2.0 (1.6)	22.0 (4.7)	22.22	21.87	61.11	84 94
IS 13100	2.5 (1.7)	21.0 (4.6)	20.82	13.39	66.67	65 61
CSH 1	3.7 (2.0)	49.0 (6.4)	41.67	37.82	-	-
Mean	2.5 (1.8)	32.0 (5.3)	26.73	26.11	62.96	94 64
SE ±	0.20	1.25	4.76	7.71	19.77	53 98
ICSV 112	2.0 (1.6)	32.0 (5.7)	14.76	11.06	45.00	43 56
IS 2146	6.3 (2.5)	150.0 (12.0)	48.09	56.87	147.77	215 92
IS 2263	4.0 (2.1)	56.0 (7.4)	28.57	19.37	95.83	59 47
CSH 1	4.5 (2.2)	73.0 (8.6)	34.52	25.43	-	-
Mean	4.2 (2.1)	78.1 (8.43)	31.49	28.18	29.83	29 83
SE ±	0.21	1.03	7.22	7.62	33 43	48 58
IS 2269	4.7 (2.2)	80.0 (8.4)	38.59	31.12	105.83	73 05
IS 5469	2.5 (1.7)	43.0 (6.3)	13.45	14.01	38.75	53 50
IS 5566	3.5 (2.0)	57.0 (7.3)	18.71	18.82	51.25	71 64
CSH 1	5.0 (2.3)	90.3 (9.5)	39.95	46.97	-	-
Mean	3.9 (2.0)	68.0 (7.8)	27.68	27.73	65.28	66 06
SE ±	0.32	1.49	6.95	11.80	24.10	32 41
IS 5604	6.0 (2.5)	168.0 (12.3)	37 37	45.11	131.67	321 04
IS 18333	4.0 (2.1)	92.0 (9.6)	22.04	22.99	86.67	147 07
IS 18573	3.7 (2.0)	71.0 (8.3)	25 39	24.29	82.96	132 88
CSH 1	4.5 (2.2)	58.0 (7.6)	33.80	22.91	-	-
Mean	4.5 (2.2)	97.0 (9.4)	29.65	28.83	100.43	200 33
SE ±	0.23	1.58	4.92	8.65	27.10	84 34

Genotype	No. of egg masses per 3 plants	No. of eggs per 3 plants	Relative oviposition within a set		Oviposition preference in relation to CSH 1	
			Egg masses (%)	Eggs (%)	Egg masses(%)	Eggs(%)
IS 21444	2.0 (1.6)	37.3 (6.1)	33.16	41.76	56.75	73.38
ICSV 705	1.3 (1.3)	18.3 (4.3)	27.10	18.87	40.08	40 49
ICSV 714	2.5 (1.7)	34.5 (5.7)	24.73	21.80	70.84	57.15
CSH 1	3.5 (2.0)	54.0 (7.3)	34.83	37.22	-	-
Mean	2.3 (1.65)	36.0 (5.8)	29.96	29.91	55.89	57 01
SE ±	0.12	0.77	7.44	9.60	11.37	12 64
ICSV 743	5.0 (2.3)	120.0 (10.8)	33.09	44.81	200.00	309 17
IS 1044	4.0 (2.1)	43.0 (6.3)	35.87	52.99	133.33	110 79
IS 1054	8.5 (3.0)	109.0 (90.1)	44.70	38.07	283.33	278 05
CSH 1	3.0 (1.9)	38.0 (6.2)	16.31	14.18	-	-
Mean	5.1 (2.31)	77.4 (8.3)	32.49	37.51	205.55	232 67
SE ±	0.23	1.38	8.57	16.30	46.15	77 71
IS 2123	1.3 (1.3)	9.3 (3.1)	12.29	6.01	40.00	13.85
IS 2205	4.0 (2.1)	42.0 (6.2)	35.52	24.78	121.67	63.33
IS 2309	4.0 (2.1)	51.0 (7.1)	27.27	28.17	92.50	79 93
CSH 1	3.7 (2.0)	70.0 (8.4)	33.67	50.41	-	-
Mean	3.3 (1.8)	42.8 (6.2)	27.19	27.34	84.72	52 37
SE ±	0.23	0.80	5.84	6.84	26.90	21 00
CSH 9	5.0 (2.3)	77.3 (8.1)	29.37	26.18	127.77	117.55
ICSV 1	4.3 (2.2)	100 (10.0)	25.13	28.91	97.92	238 14
Naga white	3.7 (2.0)	64.0 (7.3)	23.86	22.87	84.72	85 91
Seredo	5.0 (2.3)	76.0 (8.6)	31.32	31.72	154.17	298 80
CSH 1	4.3 (2.1)	71 (7.9)	26 04	25.13	-	-
Mean	4.5 (2.2)	71 (7.9)	27.14	26.96	116.15	185 10
SE ±	0.30	2.10	2.49	5.00	26.60	120 05

* Values in parenthesis indicate square root transformed values

** Values in parenthesis indicate angular transformed values

Percentage of egg masses laid varied from 6 5 to 13 7, while the percentage of eggs laid varied from 5 5 to 13 7 Among the genotypes tested, IS 1054, IS 2123, IS 2205, IS 2309, IS 12308, IS 13100, IS 18333, IS 18573, and ICSV 714 were less preferred as compared to CSH 1 The genotypes IS 5566, IS 5604, ICSV 112 and ICSV 705 were preferred for oviposition, and were on par with CSH 1

Oviposition preference in relation to CSH 1 indicated that the genotypes IS 2123, IS 2205, IS 2309, IS 13100, and IS 18573 were relatively nonpreferred for oviposition Genotypes IS 5566, 5604, ICSV 112 and ICSV 705 were more preferred for oviposition in relation to CSH 1

Based on the number of egg masses and eggs laid and relative oviposition preference, the genotypoes IS 2123, IS 2309, IS 12308, IS 13100, IS 18333, IS 18573 and ICSV 714 were less preferred for oviposition compared to the borer-resistant germplasm accessions IS 2146, IS 5469, IS 5566, IS 5604, and the land races / commercial cultivars IS 21444, AI 28, ICSV 1, ICSV 112, and CSH 9 (Table 4)

The results suggested that there is a considerable variation for oviposition preference / nonpreference in the borer-resistant sorghum germplasms by the *C partellus* females

4.3 Antibiosis to spotted stem borer, *C partellus*

4.3a Effect of different amounts of sorghum leaf powder on survival and development of *C. partellus*

Maximum larval survival (86%) was recorded in the artificial diet having 12 5 g sorghum leaf powder per 250 ml diet, while minimum survival (72%)

Table 4 Relative oviposition preference by the spotted stem borer, *C partellus* females under multi-choice-cage conditions (ICRISAT Center, Patancheru,1999 rainy season)

Genotype	No of eggmasses per 3 plants*	No of eggs per 3 plants*	Relative oviposition preference		Oviposition preference in relation to CSH 1	
			egg masses (%)**	eggs (%)**	Egg masses (%)	Eggs (%)
IS 1044	7 6 (2 8)	588 (24 23)	4 0 (11 5)	4 6 (12 3)	80 76	92 29
IS 1054	6 0 (2 5)	215 (14 4)	3 6 (10 7)	1 9 (7 6)	70 44	37 56
IS 2123	2 3 (1 7)	186 (13 5)	1 3 (6 5)	1 4 (6 7)	25 50	27 35
IS 2146	7 5 (2 8)	643 (25 3)	4 3 (11 8)	5 7 (13 6)	86 01	111 74
IS 2205	5 0 (2 3)	330 (17 3)	2 8 (9 6)	2 5 (8 9)	56 12	48 94
IS 2263	7 0 (2 8)	406 (20 1)	4 0 (11 2)	3 5 (10 7)	79 61	70 05
IS 2269	12 2 (3 4)	599 (23 5)	6 4 (14 4)	4 6 (12 2)	132 07	90 49
IS 2309	4 0 (2 1)	185 (13 2)	2 3 (8 7)	1 5 (6 9)	46 13	29 15
IS 5469	8 5 (2 9)	547 (22 8)	5 0 (12 7)	4 7 (12 1)	97 68	94 14
IS 5566	9 5 (3 2)	649 (25 5)	6 0 (13 7)	5 6 (13 6)	112 01	110 94
IS 5604	9 8 (3 1)	708 (24 4)	6 2 (13 5)	6 8 (13 5)	121 77	131 87
IS 12308	6 5 (2 5)	394 (17 3)	3 3 (9 9)	2 8 (8 6)	67 33	53 95
IS 13100	2 7 (1 7)	183 (11 3)	1 5 (6 8)	1 2 (5 5)	29 96	23 11
IS 18333	5 5 (2 4)	343 (18 4)	3 1 (10 1)	2 8 (9 6)	62 08	55 73
IS 18573	4 0 (2 1)	334 (18 1)	2 2 (8 5)	2 7 (9 4)	44 38	53 37
IS 21444	6 7 (2 6)	524 (22 1)	4 0 (11 2)	4 1 (11 4)	76 46	80 32
AF 28	7 0 (2 6)	698 (24 1)	3 6 (10 6)	5 0 (12 2)	74 06	95 06
Naga white	6 5 (2 6)	408 (20 2)	4 0 (11 4)	3 6 (10 8)	78 03	71 78
Seredo	5 7 (2 4)	532 (23 0)	3 2 (10 2)	4 5 (12 2)	63 90	89 70
ICSV 1	7 0 (2 7)	589 (23 3)	4 0 (11 3)	4 8 (12 2)	78 73	95 57
ICSV 112	10 2 (3 0)	797 (26 7)	5 0 (12 5)	5 9 (13 7)	105 98	114 62
ICSV 705	9 0 (3 1)	570 (23 5)	5 5 (13 4)	5 3 (12 9)	107 00	106 86
ICSV 714	6 0 (2 5)	284 (15 6)	3 3 (10 5)	2 0 (7 8)	67 03	39 58
ICSV 743	6 0 (2 5)	458 (20 1)	3 2 (10 1)	3 5 (10 3)	64 43	69 20
CSH 9	8 3 (3 0)	615 (24 5)	5 0 (12 7)	5 7 (13 4)	97 10	113 88
CSH 1	8 8 (3 0)	624 (24 7)	5 0 (12 9)	5 1 (13 0)	-	-
Mean	6 9 (2 6)	20 66	11 03	10 83	76 98	76 29
SE ±	0 26	2 86	1 25	1 60	19 00	23 60
LSD at 5%	0 75	8 06	3 50	4 50	53 61	66 64

* Square root transformed values

** Angular transformed values

was observed in diets without sorghum leaf powder and the one having 22.5 g of sorghum leaf powder (CSH 1) per 250 ml diet (Table 5). Larval mass was minimum in larvae reared on artificial diet without sorghum leaf powder, while maximum mass was recorded in larvae with having 12.5 g sorghum leaf powder in 250 ml diet. Significant reduction in larval mass was observed at 22.5 g sorghum leaf powder per 250 ml diet. The results suggested that 12.5 g sorghum leaf powder is optimum for larval development , while adverse effects of sorghum leaf powder was appeared at 22.5 g per 250 ml diet.

4.3b Effect of different proportions of chickpea flour and sorghum leaf powder on *C. partellus*

Larval survival and larval mass were significantly lower in artificial diet without sorghum leaf powder (except in for larval survival in artificial diet with leaf powder from ICSV 743 and IS 2205). Larval survival and larval mass were minimum in diets having sorghum leaf powder and chickpea flour in a ratio of 5 : 1 (except in case of CSH 1 and ICSV 743 for larval survival). Larval mass was maximum in artificial diets with a 3 : 3 ratio of sorghum leaf powder and chickpea flour (Table 6). At a ratio of 3 : 3, larval survival (56 – 66%) was lower in diets having leaf powder of CSH 1, ICSV 705, ICSV 743, and IS 2205 compared to IS 5469 (88% larval survival). At a 5 : 1 ratio of leaf powder to chickpea flour, larval survival was 56 – 62% in diet with CSH 1, ICSV 705, and IS 2205 leaf powder compared to 74% larval survival in case of ICSV 743 and IS 5469. At a ratio of 3 : 3, larval mass was lower in diets with CSH 1, ICSV 705, and IS 5469 leaf powder

Table 5 Effect of different amounts of sorghum leaf powder from CSH 1 in artificial diet* on survival and development of C partellus (ICRISAT, Patancheru, 1999)

Amount of sorghum leaf powder (g per 250 ml diet)	Larval survival (%) (15 DAI)	Larval weight (mg) (15 DAI)
0 0	72 0	20 3
7 5	82 0	36 5
12 5	86 0	45 1
17 5	78 0	37 3
22 5	72 0	34 7
Mean	78 0	34 78
SE ±	2 75	4 03

*Diet ingredients Fraction A (Ascorbic acid 0 52 g, Brewer's yeast 1 6 g, Methyl parahydroxybenzoate 0 32 g, Sorbic acid 0 2 g, Vitamin E 0 23 g Water 100 mL), and Fraction B (Agar-agar 2 05 g, Formaldehyde 40% 0 16 mL, Water 80 mL)

Table 6 Effect of variation in amounts of sorghum leaf powder and Chickpea flour in the artificial diet* on survival and development of C partellus (ICRISAT, Patancheru 1999)

Chickpea flour sorghum leaf powder (g per 250 ml diet)	Larval survival (%) (10 DAI)					Larval mass (mg) (10 DAI)				
	CSH 1	ICSV 705	ICSV 743	IS 2205	IS 5469	CSH 1	ICSV 705	ICSV 743	IS 2205	IS 5469
0 6	64 0	56 0	72 0	76 0	66 0	0 5	0 5	1 3	1 5	1 2
2 4	96 0	75 0	66 0	72 0	76 0	2 0	1 6	4 5	7 2	3 8
3 3	56 0	66 0	64 0	66 0	88 0	2 4	4 4	7 2	7 8	4 6
4 2	66 0	78 0	56 0	64 0	72 0	1 9	4 1	2 5	7 1	4 0
5 1	62 0	64 0	74 0	56 0	74 0	1 4	3 7	1 3	6 9	3 3
Mean	68 8	67 8	66 4	66 8	75 2	1 64	2 9	3 4	6 1	3 4
SE ±	7 0	3 9	3 2	3 4	3 6	0 3	0 8	1 1	1 2	0 6

Diet ingredients* as indicated in Table 5

DAI - Days after infestation

compared to diet with ICSV 743 and IS 2205 leaf powder Larval mass was low at 5 1 in diets with CSH 1, ICSV 705, ICSV 743, and IS 5469 leaf powders

Antibiosis component of resistance was studied on 25 sorghum genotypes both under in-vitro (lyophilized leaf powder impregnated in artificial diet) and in-vivo (sorghum seedlings grown in the greenhouse) conditions Larval survival, larval mass, duration of larval and pupal development, post-embryonic development period, pupal mass, and pupation and adult emergence were taken as a criteria to measure the antibiosis component of resistance to *C partellus* in different sorghum genotypes

4.3.1 Larval survival

Percentage of larval survival varied from 46 on CSH 9 to 94% on Naga White among the genotypes tested at 10 days after inoculation of first-instar larvae in artificial diet (Table 7) Larval survival was greater in artificial diet impregnated with freeze dried leaf powder of IS 2146, AF 28, Seredo, and Naga White Less than 55% larval survival was recorded in IS 18573, IS 21444, ICSV 705, ICSV 714, ICSV 743, and CSH 9

Under greenhouse conditions, percentage larval survival varied from 54% on IS 2146 to 88% on Naga White Larval survival declined drastically from 5 to 25 days after infestation (DAI) After 25 DAI, IS 2263 recorded high percentage of larval survival No significant differences were observed in percentage larval survival among the rest of the test genotypes

Table 7 Survival of spotted stem-borer, *C partellus* first-instar larvae on 25 sorghum genotypes under in-vitro and in-vivo conditions (ICRISAT Center,Patancheru, 1999 rainy season)

	Larval survival (%)**		
	In vitro (on artificial diet)	In vivo (plants)	
Genotype	10 DAI	5 DAI	25 DAI
IS 1044	70 (56 9)	84 (69 5)	41 (39 1)
IS 1054	75 (63 0)	78 (65 4)	41 (39 1)
IS 2123	88 (69 5)	82 (73 1)	37 (37 2)
IS 2146	94 (81 0)	54 (47 3)	52 (46 5)
IS 2263	75 (63 5)	90 (76 0)	61 (52 0)
IS 2269	68 (55 6)	90 (78 5)	56 (49 7)
IS 2309	88 (71 8)	70 (57 2)	42 (39 2)
IS 5469	73 (58 6)	92 (82 1)	46 (42 5)
IS 5566	85 (67 3)	78 (62 8)	44 (40 8)
IS 5604	78 (62 2)	88 (74 8)	42 (40 3)
IS 12308	82 (67 8)	82 (67 7)	39 (38 2)
IS 13100	86 (73 0)	72 (58 9)	48 (43 5)
IS 18333	74 (59 6)	92 (76 7)	34 (34 6)
IS 18573	65 (53 9)	88 (71 5)	43 (41 4)
IS 21444	65 (54 4)	76 (66 5)	35 (35 4)
AF 28	90 (76 0)	66 (58 2)	35 (36 2)
Naga white	94 (81 0)	88 (76 8)	24 (28 1)
Seredo	90 (76 0)	76 (64 1)	37 (36 4)
ICSV 1	86 (73 1)	73 (59 5)	35 (35 1)
ICSV 112	78 (62 2)	82 (70 2)	51 (45 6)
ICSV 705	65 (54 6)	82 (70 6)	40 (38 4)
ICSV 714	50 (45 0)	80 (69 0)	25 (30 0)
ICSV 743	60 (50 8)	76 (63 7)	34 (34 1)
CSH 9	46 (42 6)	84 (72 0)	34 (35 4)
IS 2205	76 (63 4)	72 (61 0)	60 (52 0)
Mean	76 (63 4)	80 (67 8)	41 4 (39 6)
SE ±	4 95	7 41	6 31
LSD at 5%	13 72	20 55	17 50

** Angular transformed values

Larval survival was greater (> 90%) on IS 2263, IS 2269, IS 5469, and IS 18333 compared to IS 2205 (72%) Larval survival was > 50% on IS 2146 IS 2263, and ICSV 112 as compared to IS 18333, IS 21444, Al 28, Naga White, ICSV 1, ICSV 714, and CSH 9 (35%) The genotypes IS 18333, AF 28, Naga White, Seredo, and ICSV 112 showed opposite trends in relative larval survival in in-vitro and in-vivo (25 DAI) conditions IS 21444, ICSV 743, and CSH 9, which suffer greater damage under field conditions, showed relatively greater larval mortality n artificial diet impregnated with leaf powder from these genotypes, and under greenhouse conditions

4.3.2 Larval mass (10-day-old larvae)

Mass of *C partellus* larvae reared on artificial diet impregnated with lyophilized leaf powder showed significant differences between the genotypes tested The larval mass ranged from 0 1g on IS 2205 to 11 1 g on AF 28 Larval mass was significantly greater for the larvae reared on artificial diet impregnated with leaf powder from IS 2146, AF 28, and Seredo compared to those reared on IS 2205 (Table 8)

4.3.3 Larval period

The larval period varied from 24 5 to 38 0 days for males and 23 3 to 39 0 days for females on artificial diet impregnated with leaf powder from different sorghum genotypes Larval duration was 35 0 to 47 0 days, and 31 0 to 51 8 days for male and female larvae under in-vivo conditions, respectively (Table 9)

Table 8 Mass of 10 day old spotted stem borer *C partellus* larvae reared on 25 sorghum genotypes under artificial conditions (ICRISAT Center, Patancheru, 1999 rainy season)

Genotype	Mass (mg)**
IS 1044	0 8 (1 1)
IS 1054	2 0 (1 5)
IS 2123	2 8 (1 7)
IS 2146	8 0 (2 9)
IS 2263	3 3 (1 9)
IS 2269	0 7 (1 1)
IS 2309	0 3 (0 8)
IS 5469	2 6 (1 7)
IS 5566	1 0 (1 2)
IS 5604	4 3 (2 1)
IS 12308	4 4 (2 2)
IS 13100	4 6 (2 2)
IS 18333	4 1 (2 1)
IS 18573	1 3 (1 3)
IS 21444	1 8 (1 5)
AF 28	11 1 (3 3)
Naga white	2 8 (1 8)
Seredo	8 1 (2 9)
ICSV 1	6 5 (2 6)
ICSV 112	2 4 (1 7)
ICSV 705	0 5 (1 0)
ICSV 714	0 5 (1 0)
ICSV 743	0 3 (0 9)
CSH 9	0 3 (0 9)
IS 2205	0 1 (0 8)
Mean	2 9 (1 7)
SE ±	0 090
LSD at 5%	0 25

** Angular transformed values

Larval duration for the males was significantly longer on IS 2269, ICSV 705 and ICSV 714 as compared to that on other genotypes There was no larval establishment on IS 2205, IS 2309, ICSV 743 and CSH 9 (Table 9) Larval duration was significantly shorter on IS 1044 and Seredo as compared to that on IS 2205 Variation in duration of larval period was longer in AF 28 on artificial diet and IS 5566 under greenhouse conditions, which was on par with that on IS 2205

Duration of larval period for the females was significantly longer on IS 5566 and ICSV 714 and minimum on IS 13100 in artificial diet as compared to that on the other test genotypes The minimum range in duration of larval period was observed in IS 13100 (35 – 42 days) under greenhouse conditions

In general larval period was longer on IS 2123, IS 5566, IS 21444, ICSV 112, and ICSV 714 as compared to IS 12308, IS 13100, and Seredo

4.3.4 Pupal period

The pupal period varied from 7 0 to 11 0 days for the males and 7 0 to 11 0 days for the females in artificial diet and 7 3 to 12 5 days and 8 7 to 11 7 days under greenhouse conditions, respectively (Table 10) Pupal period for the males was significantly longer on IS 1054, IS 5604, and Naga White as compared to the other test genotypes in artificial diet As there was no larval survival in IS 2205, IS 2309, ICSV 743, and CSH 9 pupal period could not be recorded Pupal period was longer on CSH 9 and ICSV 112 (12 and 12 50 days, respectively) compared to that on IS 2205 (10 1 days) under

Table 9 Duration of development of spotted stem borer, *C partellus* larvae on 25 sorghum genotypes (ICRISAT Center, Patancheru, 1999 rainy season)

	Larval duration (days)							
	In vitro (on artificial diet)				In vivo (plants)			
	Males		Females		Males		Females	
Genotype	Mean	Range	Mean	Range	Mean	Range	Mean	Range
IS 1044	35 1	33-37	34 0	34	35 2	31-43	43 3	35-52
IS 1054	28 6	25-30	30 7	28-37	47 0	47	43 0	35-47
IS 2123	31 5	30-33	34 3	28-42	40 9	31-54	47 0	32-55
IS 2146	-	-	-	-	34 7	31-38	46 7	35-55
IS 2263	27 5	25-28	28 0	25-31	38 4	31-45	43 7	32-55
IS 2269	38 0	37-39	x	x	38 8	35-47	41 5	38-45
IS 2309	x	x	x	x	39 0	32-47	41 3	35-52
IS 5469	29 8	25-33	32 4	28-42	39 7	32-55	49 0	40-59
IS 5566	33 0	33	38 5	35-42	44 1	31-59	44 7	35-59
IS 5604	25 5	22-30	24 6	24-28	38 3	31-47	48 7	35-55
IS 12308	26 3	25-28	27 6	24-30	39 7	31-50	40 2	35-52
IS 13100	24 5	20-28	24 1	20-28	38 1	31-50	37 1	35-42
IS 18333	27 4	22-33	28 0	24-30	41 6	31-55	46 8	38-55
IS 18573	31 0	31	33 0	30-36	39 1	32-55	39 3	31-52
IS 21444	28 7	28-30	30 7	28-33	43 0	38-55	41 3	31-52
AF 28	26 1	20-39	23 3	22-24	41 6	31-47	48 5	42-55
Naga white	27 3	24-29	32 9	28-37	37 0	31-42	46 4	38-52
Seredo	26 5	25-28	26 0	24-30	35 0	35	41 3	35-54
ICSV 1	25 3	20-28	27 1	24-30	43 3	31-52	50 8	47-55
ICSV 112	29 3	25-36	30 2	28-36	41 3	31-54	51 8	35-59
ICSV 705	37 0	37	x	x	42 5	35-52	43 8	35-50
ICSV 714	37 0	33-42	39 0	39	38 0	38	44 0	42-47
ICSV 743	x	x	x	x	41 6	31-59	31 0	31
CSH 9	x	x	x	x	41 8	38-47	50 7	45-54
IS 2205	x	x	x	x	41 5	31-59	48 4	32-54
Mean	29 8		30 2		40 1		44 4	
SE ±	0 89		1 03		0 59		0 95	
LSD at 5%	2 53		2 93		*		*	

- Data not recorded due to fungal infection
x no larval development
* Based on univariate analysis

Table 10 Pupal development period of spotted stem borer, *C partellus* on 25 sorghum genotypes (ICRISAT Center, Patancheru, 1999 rainy season)

Genotype	Pupal duration (days)							
	In vitro (on artificial diet)				In vivo (on plants)			
	Males		Females		Males		Females	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
IS 1044	7 0	7 0	x	x	9 7	8-11	10 2	9-13
IS 1054	10 0	10 0	x	x	8 0	8 00	9 3	8-11
IS 2123	x	x	8 0	8 0	10 6	8-13	9 7	8-11
IS 2146	-	-	-	-	8 4	5-10	9 1	5-11
IS 2263	8 5	8-9	8 0	8 0	9 0	9 00	10 8	9-14
IS 2269	x	x	x	x	10 2	7-14	9 0	9
IS 2309	x	x	x	x	8 7	7-10	10 0	10
IS 5469	8 0	7-9	8 0	7-9	10 4	9-12	10 3	8-12
IS 5566	x	x	x	x	8 2	7-11	8 8	7-12
IS 5604	10 0	9-11	10 3	9-12	11 0	10-12	9 9	8-13
IS 12308	7 8	6-11	x	x	8 8	5-12	9 5	8-12
IS 13100	6 7	6-9	8 9	6-11	8 3	5-9	11 4	9-12
IS 18333	7 8	6-10	8 7	8-10	9 0	7-11	9 4	5-12
IS 18573	x	x	8 0	8 0	10 3	8-12	9 1	5-12
IS 21444	x	x	7 5	6-9	8 8	5-11	10 4	9-13
AF 28	6 0	6-8	6 3	6-8	9 8	8-12	10 0	9-11
Naga white	11 0	11 0	8 0	8 0	7 3	9-12	11 3	8-15
Seredo	8 5	6-11	11 0	11 0	9 0	8-10	8 7	7-12
ICSV 1	9 0	9 0	8 0	8 0	9 5	7-12	10 9	10-13
ICSV 112	7 0	7 0	7 0	7 0	12 5	11-14	9 6	8-13
ICSV 705	9 0	9 0	x	x	10 5	9-12	11 0	9-12
ICSV 714	8 0	8 0	x	x	8 5	7-10	11 7	10-13
ICSV 743	x	x	x	x	8 5	5-13	11 0	11
	x	x	x	x				
CSH 9	x	x	x	x	12 0	12 00	9 3	4-12
	x	x	x	x				
IS 2205	x	x	x	x	10 1	6-14	10 2	7-14
Mean	8 3		8 3		9 5		10 0	
SE ±	0 36		0 45		0 25		0 17	
LSD at 5%	1 01		1 28		*		*	

- Data not recorded due to fungal infection
x No adult emergence
* Based on univariate analysis

greenhouse conditions. However, the range in duration of pupal period was significantly longer on IS 12308 and IS 5469.

4.3.5 Post-embryonic development period

Results of post-embryonic development period (larval + pupal duration) of *C. partellus* under both in-vitro and in-vivo conditions for males and females are presented in Table 11.

Post-embryonic development period varied from 30.2 to 46.0 days for the males and 29.7 to 42.2 days for the females on artificial diet, and 43.1 to 55.0 days and 42.0 to 61.7 days for the males and the females under in-vivo conditions, respectively. The development period was prolonged in case of larvae reared under greenhouse conditions as compared to laboratory conditions.

Development period for the males was significanlty longer on ICSV 705, ICSV 714, and IS 2269 as compared to that on other genotypes. Development was not completed on IS 2205, CSH 9, ICSV 743, and IS 2309 under in-vitro conditions. Development period was significantly longer on CSH 9 and IS 1054, and these were on par with IS 2205 (51.6 days) under in-vivo conditions. Post-embryonic development was quicker on IS 2146 (43.1 days) as compared to that on IS 2205.

In artificial diet impregnated with leaf powder from different genotypes, female development period was significantly prolonged on IS 2123 (42.3 days) compared to that on the other genotypes. Post-embryonic development

Table 11 Post-embryonic development period of spotted stem borer, *C partellus on 25* sorghum genotypes (ICRISAT Center, Patancheru, 1999 rainy season)

Genotype	In-vitro (on artificial diet)				In-vivo (on plants)			
	Males		Females		Males		Females	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
IS 1044	42 1	40-44	38 0	36-40	44 9	39-54	53 5	44-65
IS 1054	38 6	35-40	x	x	55 0	54-56	52 3	43-58
IS 2123	x	x	42 3	36-50	51 5	39-67	56 7	40-66
IS 2146	-	-	-	-	43 1	36-48	55 8	40-66
IS 2263	36 0	34-37	36 0	33-39	47 4	40-54	54 5	41-69
IS 2269	43 0	42-44	x	x	49 0	42-61	50 5	47-54
IS 2309	x	x	x	x	47 7	39-57	51 3	45-62
IS 5469	37 8	33-41	40 4	35-51	50 1	41-67	50 3	48-71
IS 5566	38 0	36-40	x	x	52 3	38-70	53 5	42-41
IS 5604	35 5	32-40	34 9	33-40	49 3	41-59	58 8	43-68
IS 12308	34 0	32-36	31 6	27-35	48 8	36-62	49 7	43-67
IS 13100	30 2	26-34	33 0	26-39	46 5	36-59	48 5	44-54
IS 18333	35 0	30-41	36 7	32-40	50 6	38-66	56 2	43-67
IS 18573	x	x	41 0	38-44	49 4	40-67	48 4	36-67
IS 21444	x	x	38 2	34-42	51 8	43-66	51 7	40-65
AF 28	32 1	26-35	29 7	26-32	51 4	39-59	58 5	51-66
Naga white	38 3	35-40	40 9	36-43	44 3	40-54	57 7	46-67
Seredo	35 0	33-37	37 0	35-41	44 0	43-45	50 0	42-66
ICSV 1	34 3	29-37	35 1	32-38	52 8	38-64	61 7	57-68
ICSV 112	36 3	32-43	37 2	35-43	53 8	42-68	60 4	43-68
ICSV 705	46 0	44-48	x	x	53 0	44-64	54 8	44-62
ICSV 714	45 0	41-50	x	x	46 5	45-48	55 7	52-60
ICSV 743	x	x	x	x	50 1	36-72	42 0	40-44
CSH 9	x	x	x	x	53 8	50-59	59 9	49-66
IS 2205	x	x	x	x	51 6	37-73	58 6	39-68
Mean	37 5		37 8		49 5		54 0	
SE ±	0 8		1 2		0 7		0 9	
LSD at 5%	2 29		3 26		*		*	

- Data not recorded due to fungal infection

x No adult emergence

* Based on univariate analysis

period varied from 40 – 41 days on IS 18573, IS 5469, Naga White, and IS 2123 Minimum duration was observed in case of AF 28 (29 7 days) Under greenhouse conditions the genotypes ICSV 1 showed longer duration (61 7 days) than the check, IS 2205 (58 6 days) The genotypes CSH 9, AF 28 and ICSV 112 were on par with check, IS 2205 The genotype, ICSV 743 showed short duration (42 0 days) and was significantly different as compared to IS 2205

Both in artificial diet and on plants in the greenhouse conditions, post-embryonic development periods were longer on IS 2123 IS 5469, ICSV 705, ICSV 714, CSH 9, and IS 2205 compared to those on IS 12308, IS 13100, and Seredo

4.3.6 Pupal mass

Mass of the male pupae was significantly lower than that of the female pupae (Table 12) Pupal mass varied from 46 0 to 72 5 mg for males and 81 1 to 143 5 mg for females under in-vitro conditions, and 30 8 to 50 9 mg for males and 57 0 to 99 6 mg for females under in-vivo conditions

Pupal mass for the males was significantly lower when the larvae were reared on artificial diet containing lyophilized leaf powder of IS 18573 (46 0 mg) than in Seredo (72 0 mg) Significantly higher pupal mass was observed in pupae from IS 13100 (50 9 mg) as compared to IS 2205 (38 2 mg) in in-vivo conditions

Table 12 Mass of spotted stem borer pupae on 25 sorghum genotypes (ICRISAT Center Patancheru 1999 rainy season)

	Pupal mass (mg)			
	In vitro (on artificial diet)		In vivo (on plants)	
Genotype	Males	Females	Males	Females
IS 1044	49 0	98 6	47 1	94 3
IS 1054	60 8	127 9	30 8	66 5
IS 2123	63 3	106 3	45 8	78 4
IS 2146	-	-	43 2	75 3
IS 2263	62 3	104 5	40 7	83 5
IS 2269	53 5	x	43 6	71 2
IS 2309	x	x	42 0	85 2
IS 5469	62 4	96 8	44 7	99 6
IS 5566	51 4	81 1	47 8	72 8
IS 5604	65 2	136 9	40 5	84 4
IS 12308	61 7	108 9	40 7	57 0
IS 13100	50 6	98 0	50 9	78 0
IS 18333	69 5	120 1	40 4	86 3
IS 18573	46 0	101 7	41 9	80 6
IS 21444	56 5	107 0	39 7	71 4
AF 28	61 2	116 3	34 8	69 9
Naga white	62 2	107 0	36 6	87 4
Seredo	72 5	143 5	33 6	75 8
ICSV 1	67 8	125 0	45 4	79 3
ICSV 112	58 8	111 8	44 6	78 7
ICSV 705	52 8	x	40 6	70 4
ICSV 714	49 8	91 4	46 0	89 5
ICSV 743	x	x	41 1	67 1
CSH 9	x	x	38 7	90 4
IS 2205	x	x	38 2	71 6
Mean	58 8	104 6	44 6	78 6
SE ±	2 82	4 82	0 92	1 95
LSD at 5%	8 01	13 68	*	*

- Data not recorded due to fungal infection
x No normal pupae recovered
* Based on univariate analysis

Female pupal mass was significantly greater on Seredo, IS 5604, IS 1054, and ICSV 1 (125 0 - 143 5 mg) compared to the other test genotypes under in-vitro conditions Significantly higher pupal mass was recorded on IS 5469 and CSH 9 (99 6 and 90 4 mg, respectively) as compared to IS 2205 under in-vivo conditions Significantly low pupal mass was observed in insects reared on IS 12308 (57 0 mg) as compared to IS 2205 (71 60 mg)

Pupae were heavier when the larvae were fed on IS 1054 IS 5604, Seredo, and ICSV 1 than on IS 5566, IS 13100, IS 18573, ICSV 705, and ICSV 714 on artificial diet

4.3.7 Percentage pupation

Percentage pupation (of the total larvae released) was comparatively greater in in-vitro than in in-vivo conditions for both males and females (Table 13) Under in-vitro conditions, significantly higher percentage of pupation was observed on IS 18333 (76 7%) as compared to the other test genotypes Similarly, the genotype IS 18573 (22%) recorded high percentage of pupation in in-vivo conditions

Significantly less pupation was recorded in ICSV 743, CSH 9, and IS 2309 as compared to IS 2205 under in-vitro conditions Similarly, low pupation percentage was recorded on IS 1054 and ICSV 714 (6%) as compared to check, IS 2205 (19%), under greenhouse conditions

Table 13. Percentage pupation of spotted stem borer, *C. partellus* reared on 25 sorghum genotypes (ICRISAT Center, Patancheru, 1999 rainy season).

	% pupation					
	In vitro (on artificial diet)			In vivo (on plants)		
Genotype	Males	Females	Total	Males	Females	Total
IS 1044	20.0	10.0	30.0	6.0	7.0	13.0
IS 1054	20.7	20.0	56.7	2.0	4.0	6.0
IS 2123	10.0	15.0	25.0	11.0	5.0	16.0
IS 2146	-	-	-	8.0	8.0	16.0
IS 2263	20.0	20.0	40.0	9.0	11.0	20.0
IS 2269	15.0	x	15.0	7.0	4.0	11.0
IS 2309	x	x	x	8.0	7.0	15.0
IS 5469	26.7	26.7	53.3	8.0	5.0	13.0
IS 5566	10.0	20.0	30.0	7.0	7.0	14.0
IS 5604	33.3	16.7	50.0	8.0	11.0	19.0
IS 12308	30.0	25.0	55.0	10.0	6.0	16.0
IS 13100	40.0	20.0	60.0	7.0	9.0	16.0
IS 18333	36.7	40.0	76.7	9.0	10.0	19.0
IS 18573	10.0	10.0	20.0	9.0	13.0	22.0
IS 21444	10.0	20.0	30.0	7.0	6.0	13.0
AF 28	43.3	13.3	56.7	5.0	2.0	7.0
Naga white	30.0	25.0	55.0	4.0	5.0	9.0
Seredo	20.0	30.0	50.0	2.0	6.0	8.0
ICSV 1	20.0	35.0	55.0	3.0	10.0	13.0
ICSV 112	20.0	26.7	46.7	6.0	8.0	14.0
ICSV 705	20.0	x	20.0	4.0	5.0	9.0
ICSV 714	20.0	10.0	30.0	2.0	4.0	6.0
ICSV 743	x	x	x	11.0	1.0	12.0
CSH 9	x	x	x	4.0	6.0	10.0
IS 2205	x	x	x	14.0	5.0	19.0
Mean	22.3	15.3	34.2	6.8	6.6	13.4
SE ±	5.63	3.7	4.45	0.63	0.58	0.89
LSD at 5%	15.98	10.52	12.65	*	*	*

- Data not recorded due to fungal infection.
x No normal pupae recovered.
* Based on univariate analysis.

4.3.8 Adult emergence

Percentage adult emergence (of the total number of larvae released) was comparatively higher in in-vitro than in in-vivo conditions (Table 14) Under in-vitro conditions, significantly higher percentage of adult emergence was observed on AF 28, IS 13100, and IS 18333 (33 3 to 36 7%) as compared to IS 2205 Similarly, the genotype IS 18573 recorded higher percentage of adult emergence (20%) in in-vivo conditions

Significantly less adult emergence was recorded on ICSV 743, CSH 9, and IS 2309 as compared to IS 2205 under in-vitro conditions Low adult emergence was recorded on ICSV 705, ICSV 714, IS 1054, IS 2263, and Seredo (5%) when compared to IS 2205 (2%) Percentage male adult emergence varied from 0 to 26 67% percent and 1 0 to 8 0 percent under in-vitro and in-vivo conditions, respectively

Table 14 Percentage adult emergence of spotted stem borer, *C partellus* reared on 25 sorghum genotypes (ICRISAT center, Patancheru, 1999 rainy season)

	Adult emergence (%)					
	In vitro (on artificial diet)			In vivo (on plants)		
Genotype	Males	Females	Total	Males	Females	Total
IS 1044	10 0	10 0	20 0	3 0	5 0	8 0
IS 1054	10 0	x	10 0	1 0	4 0	5 0
IS 2123	x	10 0	10 0	7 0	3 0	10 0
IS 2146	-	-	-	5 0	8 0	13 0
IS 2263	20 0	10 0	30 0	1 0	4 0	5 0
IS 2269	10 0	x	10 0	6 0	1 0	7 0
IS 2309	x	x	x	3 0	5 0	8 0
IS 5469	20 0	10 0	30 0	5 0	3 0	8 0
IS 5566	10 0	x	10 0	5 0	6 0	11 0
IS 5604	10 0	16 7	26 7	5 0	9 0	14 0
IS 12308	20 0	20 0	40 0	8 0	6 0	14 0
IS 13100	16 7	16 7	33 3	6 0	7 0	13 0
IS 18333	16 7	16 7	33 3	5 0	8 0	13 0
IS 18573	x	10 0	10 0	7 0	13 0	20 0
IS 21444	x	10 0	10 0	6 0	5 0	11 0
AF 28	26 7	10 0	36 7	4 0	2 0	6 0
Naga white	10 0	10 0	20 0	3 0	3 0	6 0
Seredo	20 0	10 0	30 0	2 0	3 0	5 0
ICSV 1	10 0	10 0	20 0	2 0	8 0	10 0
ICSV 112	10 0	10 0	20 0	2 0	5 0	7 0
ICSV 705	10 0	x	10 0	2 0	3 0	5 0
ICSV 714	10 0	x	10 0	2 0	3 0	5 0
ICSV 743	x	x	x	8 0	1 0	9 0
CSH 9	x	x	x	1 0	5 0	6 0
IS 2205	x	x	x	7 0	5 0	12 0
Mean	9 6	7 2	16 8	4 2	5 0	9 2
SE ±	1 15	2 02	2 51	0 50	0 55	0 77
LSD at 5%	3 28	5 76	5 04	*	*	*

- Data not recorded due to fungal infection

x No adult emergence

* Based on univariate analysis

DISCUSSION

CHAPTER V

DISCUSSION

Studies were carriedout under greenhouse as well as in laboratory conditions for evaluating 25 sorghum genotypes for nonpreference (antixenosis) for oviposition and antibiosis components of resistance to spotted stem borer, *Chilo partellus* Swinhoe. The parameters investigated included relative oviposition preference by *C. partellus* females in limited-multi choice cage tests and complete multi-choice cage tests, and antibiosis in terms of larval survival , post-embryonic development, and percentage pupation and adult emergence.

5.1 Nonpreference or antixenosis for oviposition

There was considerable variation in number of egg-masses and eggs, and relative oviposition preference among the borer-resistant genotypes tested. In case of limited-multi choice cage tests, oviposition preference in relation to check, CSH 1 ranged from 14 to 65% in IS 2123, ICSV 112, ICSV 705, and IS 13100, which clearly indicates nonpreference for oviposition by *C. partellus* females on different sorghum genotypes (Table 3). In field trials, Taneja and Woodhead (1989) reported that the number of egg masses were significantly less on the borer-resistant genotypes as compared to the susceptible ones. In the present study, the numbers of egg masses and eggs laid were significantly fewer on the above listed genotypes as compared to other test genotypes (which had higher number of egg masses and eggs).

In case of multi-choice tests, number of egg-masses per 3 plants ranged from 1 7 to 2 3 and relative oviposition for egg masses from 6 5 to 9 6% Oviposition preference in relation to CSH 1 ranged from 25 5 to 56 1% in IS 2123, IS 2205, IS 2309, IS 13100 and IS 18573, suggesting nonpreference for oviposition by *C partellus* females (Table 4) In limited-multi choice tests, ICSV 112, and ICSV 705 also showed nonpreference for oviposition along with IS 2123 and IS 13100 However, in multi-choice tests, these genotypes were highly preferred for oviposition along with ICSV 112, and ICSV 705 The genotypes IS 2205, IS 2309 and IS 18573 did not differ significantly from CSH 1 in limited-multi choice cage tests However, these three genotypes showed nonpreferncе for oviposition under multi-choice tests Genotypes IS 2123 and IS 13100 were highly nonpreferred for oviposition by *C partellus* females in both the tests

In choice tests under cage conditions, van den Berg and van der Westhuizen (1997) observed significant differences in number of egg batches on 4 inbred lines (E 302, IS 2205, IS 2122, and SA 2681) E 302 had the greatest number of egg batches Lal and Pant (1980) observed wide variations in ovipositional behaviour of *C partellus* on resistant and susceptible genotypes, and inferred that the oviposition preference might be due to some volatile chemical factors in the foliage, which either attract or repel the adults

5.2 ANTIBIOSIS

Antibiosis was studied in terms of lower percentage of larval survival, low larval mass, slower larval and pupal development, low pupal mass, and low pupation and adult emergence. There was a considerable variation for these parameters among the genotypes tested.

5.2.1 Larval survival

Larval survival was low on CSH 9 and ICSV 714 (42.6 and 45.0%, respectively) on artificial diet (Table 7). Similarly, IS 2146 showed low larval survival (47.3%) at 5 DAI. In Naga White, ICSV 714, and IS 18333, larval survival ranged from 28 to 35 % at 25 DAI under greenhouse conditions. Larval survival trends in artificial diet impregnated with lyophilized leaf powder from different genotypes and on sorghum seedlings raised in the greenhouse were quite different. These differences may be due to escape of larvae from the sorghum seedlings under greenhouse conditions (due to nonpreference for feeding or mortality due to surface chemicals) or due to (influence of chemicals on insect development in the artificial diet, particularly those in mature leaves, on which the larvae do not feed under natural conditions). Similar results have been obtained by earlier workers with reference to larval survival on sorghum (Kalode and Pant, 1967; Lal and Sukhani, 1979; Lal and Pant, 1980; Singh and Verma, 1988; Taneja and Woodhead, 1989).

5.2.2 Larval mass

Larval mass was considerably low for insects reared on IS 2309, CSH 9, ICSV 714, and ICSV 743 (0.1 to 0.5 g per larvae) (Table 8). Hence, these sorghum varieties appear to possess some antibiosis factors in the leaves which may influence the larval development adversely. Similar results on larval survival have been reported by earlier workers with reference to *C. partellus* on sorghum (Jotwani et al., 1978; Taneja and Woodhead, 1989; van den Berg and van der Westhuizen, 1997).

5.2.3 Larval period

Another important effect of antibiosis was prolongation of larval period. There were significant differences between the genotypes tested. The male larval period was around 15 days longer on IS 2269 and 7 days on IS 1054 than the mean in in-vitro and in-vivo conditions, respectively (Table 9). Similarly, female larval period was prolonged by 18 days on ICSV 714 and 7 days on ICSV 112 than the mean under both conditions, respectively. In CSH 9, IS 2205, 2309, and ICSV 743; there was no larval survival in the artificial diet. Prolongation of larval period has been reported with respect to *C. partellus* on sorghum by Kalode and Pant (1967), Jotwani et al. (1978), Sing and Rana (1984), Taneja and Woodhead (1989), Saxena (1990), Verma et al. (1992), and Saxena (1992).

5.2.4 Pupal period

The male pupal period was longer on Naga White, IS 5604, and IS 1054 (11, 10, and 10 days, respectively in artificial diet) and in CSH 9 and ICSV 112

by 12 days in in-vivo conditions. Similarly, female pupal period was longer on Seredo (11.0 days) in artificial diet, and in ICSV 714 and IS 13100 (12 days) under pot culture (Table 10). No larvae survived in IS 2205, CSH 9, ICSV 743, and IS 2309 in artificial diet. Prolongation of pupal period of *C. partellus* has been reported by Verma et. al., (1992).

5.2.5 Post-embryonic development period

Post-embryonic development period of *C. partellus* was considerably longer on ICSV 705, ICSV 714, and IS 2123 in artificial diet compared to the other test genotypes. Similarly, in case of pot culture, prolongation of post-embryonic development was observed on IS 1054 and ICSV 1. In artificial diet, there was no larval survival on IS 2205, IS 2309, ICSV 743, and CSH 9 (Table 11). These results indicated that sorghum varieties possess some antibiosis factors and influence the development of *C. partellus* adversely. Prolongation of insect development has been reported by Kalode and Pant (1967), Jotwani et al. (1978), Taneja and Woodhead (1989), Verma et al. (1992), and Saxena (1992).

5.2.6 Pupal mass

Pupal mass was adversely affected on IS 18573 and IS 5566 in the artificial diet, and on IS 1054 and IS 12308 under pot culture (Table 12). The genotypes IS 1054 and IS 12308 showed greater antibiosis than IS 2205 under pot culture. Reduction in pupal mass was observed earlier in *C. partellus* on resistant sorghum varieties by Lal and Sukhani (1982), Singh and Rana (1984), Singh and Verma (1988), and Verma et. al., (1992).

5.2.7 Pupation

Lower pupation was observed on ICSV 705, IS 2269, IS 2123, and IS 18573. None of the larvae survived / pupated on some genotypes (Table 13). In the pot culture, lower percentage of pupation was observed on IS 1054 and ICSV 714. Singh and Verma (1988) reported that percentage pupation was adversely affected on some borer-resistant genotypes.

5.2.8 Adult emergence

Lower adult emergence was seen on ICSV 714, ICSV 705, IS 1054, and IS 2123 in artificial diet (Table 14). Similarly, in pot culture, IS 1054, ICSV 705, ICSV 714, and IS 2263 showed a reduction in emergence of adults. Singh and Verma (1988) reported that percentage of adult emergence and total life cycle were adversely effected in borer-resistant sorghum genotypes.

To explain the effects of the resistant genotypes on the developmental biology of stem borer, the following probable reasons have been presented: adverse effect of resistant genotypes on insect development resulting in low larval mass due to some nutritional abnormalities (Sharma and Chatterji, 1971b) and/or because of the poor food utilization by the larvae on the resistant varieties (Jotwani et al., 1978). Painter (1951) suggested that with rare exceptions, the feeding of insects during developmental stages on resistant varieties results in individuals that are smaller and have less weight. The sorghum varieties appear to possess some antibiosis factor(s) which exist either in the leaves or in stem or in both and influence the larval duration adversely (Singh and Rana, 1984). Prolongation of larval period

ultimately results in reduction of number of generations in a season/year. The adverse affects of resistant genotypes on post-embryonic development of stem borer might possibly because of some antibiotic factors (Lal and Sukhani, 1982). Thus, it can be concluded that the adverse effects of resistant genotypes on larval and pupal mass, prolonged larval and pupal period, and low pupation and adult emergence may be due to some nutritional abnormalities.

There was a considerable variation among the sorghum genotypes for nonpreference for oviposition and antibiosis mechanisms of resistance. It is evident from the results presented above that the resistance exhibited by IS 1054, IS 2123, IS 2205, IS 2309, IS 13100, IS 5604, ICSV 705, and ICSV 714 is mainly the result of antibiosis and nonpreference components of resistance. In the present study, nonpreference for oviposition was observed in case of IS 2123 and IS 13100. Genotypes showing antibiotic effects were IS 2205, IS 2309, IS 1054, ICSV 714, and ICSV 743. It is suggested that selection of parents to breed should be based on this information to increase the levels and diversify the bases of resistance to *C. partellus* in sorghum.

SUMMARY

CHAPTER VI

SUMMARY

Antixenosis and antibiosis components of resistance to spotted stem borer, *Chilo partellus* were studied on 25 diverse sorghum genotypes (IS 1044, IS 1054, IS 2123, IS 2146, IS 2263, IS 2269, IS 2309, IS 5469, IS 5566, IS 5604, IS 12308, IS 13100, IS 18333, IS 18573, IS 21444, AF 28, Naga White, Seredo, ICSV 1, ICSV 112, ICSV 705, ICSV 714, ICSV 743, and CSH 9) under greenhouse and laboratory conditions. Relative oviposition preference by the *C. partellus* females in limited-multi choice cage tests and complete multi-choice cage tests were assessed in relation to CSH 1. Antibiotic effects in terms of larval survival, larval mass, post-embryonic development, pupal mass, and percentage pupation and adult emergence were also studied under greenhouse and laboratory conditions. Greenhouse studies included the pot culture tests and laboratory studies involved the artificial diet impregnated with lyophilized leaf powder of 25 sorghum genotypes.

Nonpreference or antixenosis for oviposition showed considerable variation among the borer-resistant genotypes tested. Oviposition prefernce in relation to CSH 1 ranged from 14 to 65 % in IS 2123, ICSV 112, ICSV 705, and IS 13100, and 25.5 to 56.1 % in IS 2123, IS 2205, IS 2309, IS 13100, and IS 18573 in case of limited-multi choice and multi-choice cage tests, respectively, suggesting nonpreference for oviposition by *C. partellus* females. In the limited-multi choice tests, ICSV 112 and ICSV 705 also showed nonpreference for oviposition along with IS 2123 and IS 13100. However, in multi-choice tests ,

these genotypes were highly preferred for oviposition along with ICSV 112, and ICSV 705. The genotypes IS 2205, IS 2309, and IS 18573 did not differ significantly from CSH 1 in limited-multi choice cage tests. However, these three genotypes showed nonpreference for oviposition under multi-choice tests. Genotypes IS 2123 and IS 13100 were highly nonpreferred for oviposition by *C. partellus* females in both the tests.

Larval survival was low on CSH 9 and ICSV 714 (42.6 and 45.0%, respectively) on artificial diet. Similarly, IS 2146 showed low larval survival (47.3%) at 5 DAI. In Naga White, ICSV 714, and IS 18333, larval survival ranged from 28 to 35% at 25 DAI under greenhouse conditions. Larval survival trends in artificial diet impregnated with lyophilized leaf powder from different genotypes and sorghum seedlings raised in the greenhouse were quite different. This may be due to escape of larvae from the sorghum seedlings under greenhouse conditions (due to nonpreference for feeding or mortality due to surface chemicals) or due to (influence of chemicals in the sorghum leaves on insect development in the artificial diet, particularly those in mature leaves, on which the larvae do not feed under natural conditions).

Larval mass was considerably low on IS 2309, CSH 9, ICSV 714, and ICSV 743 (0.1 to 0.5 g per larvae). Hence, these sorghum varieties appear to possess some antibiosis factors in the leaves which influence the larval development adversely.

The male larval period was around 15 days longer on IS 2269 and 7 days on IS 1054 than the mean in in-vitro and in-vivo conditions, respectively. Similarly,

female larval period was prolonged by 18 days on ICSV 714 and 7 days on ICSV 112 than the mean under both conditions, respectively. In CSH 9, IS 2205, 2309, and ICSV 743; there was no larval survival in the artificial diet.

The male pupal period was longer on Naga White, IS 5604, and IS 1054 (11, 10 and 10 days, respectively, in artificial diet) and in CSH 9 and ICSV 112 by 12 days in in-vivo conditions. Similarly, female pupal period was longer on Seredo (11.0 days) in artificial diet, and in ICSV 714 and IS 13100 (12 days) under pot culture. No larvae survived in IS 2205, CSH 9, ICSV 743, and IS 2309 in artificial diet.

Post-embryonic development period of *C. partellus* was considerably longer on ICSV 705, ICSV 714, and IS 2123 in artificial diet compared to other test genotypes. Similarly, in case of pot culture, prolongation of post-embryonic development was observed on IS 1054 and ICSV 1. In artificial diet, there was no larval survival on IS 2205, IS 2309, ICSV 743, and CSH 9.

Pupal mass was adversely affected on IS 18573 and IS 5566 in the artificial diet, and on IS 1054 and IS 12308 under pot culture. The genotypes IS 1054 and IS 12308 showed greater antibiosis than IS 2205 under pot culture.

Lower pupation was observed on ICSV 705, IS 2269, IS 2123, and IS 18573. None of the larvae survived / pupated on some genotypes. In the pot culture, lower percentage of pupation was observed on IS 1054 and ICSV 714.

Lower adult emergence was seen on ICSV 714, ICSV 705, IS 1054, and IS 2123 in artificial diet. Similarly, in pot culture, IS 1054, ICSV 705, ICSV 714, and IS 2263 showed a reduction in emergence of adults.

In the present study, nonpreference for oviposition was observed in case of IS 2123 and IS 13100. Genotypes showing antibiotic effects were IS 2205, IS 2309, IS 1054, ICSV 714, and ICSV 743. It is suggested that selection of parents to breed should be based on this information to increase the levels and diversify the bases of resistance to *C. partellus* in sorghum.

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