INSECT - HOST PLANT - PARASITOID INTERACTIONS : SORGHUM MIDGE *Contarinia sorghicola* (Coquillett)

BY

K.G. KAUSALYA

THESIS SUBMITTED TO THE
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

DOCTOR OF PHILOSOPHY
IN THE FACULTY OF AGRICULTURE

DEPARTMENT OF ENTOMOLOGY
COLLEGE OF AGRICULTURE, RAJENDRANAGAR
ANDHRA PRADESH AGRICULTURAL UNIVERSITY
HYDERABAD 500 030.

CROP PROTECTION DIVISION
CEREALS ENTOMOLOGY UNIT
ICRISAT, PATANCHERU P.O.
ANDHRA PRADESH 502 324

May, 1994

CERTIFICATE

Ms. **K.G. KAUSALYA** has satisfactorily prosecuted the course of research and that the thesis entitled **INSECT - HOST PLANT - PARASITOID INTERACTIONS : SORGHUM MIDGE *Contarinia sorghicola* (Coquillett)** 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 her for a degree of any University.

Date: 23rd May 1994

Major Advisor

Dr. D.D.R. REDDY
Professor and Head
Department of Entomology
Andhra Pradesh Agricultural University,
Rajendranagar, Hyderabad 500 030

CERTIFICATE

This is to certify that the thesis entitled "Insect—host-plant—parasitoid interactions: Sorghum midge *Contarinia sorghicola* (Coquillett)" submitted in partial fulfillment of the requirements for the degree of **'Doctor of Philosophy in Agriculture'** of the Andhra Pradesh Agricultural University, Hyderabad, is a record of the bona fide research work carried out by **Ms. K.G. Kausalya** 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.

Dr. D.D.R. Reddy
Chairman of the Advisory Committee

Thesis approved by the Student's Advisory Committee:

Chairman: Dr. D.D.R. Reddy
Professor and Head
Dept. of Entomology
College of Agriculture
Rajendranagar, Hyderabad 500 030

Members:

1. Dr. K.F. Nwanze
Principal Scientist (Entomology)
Crop Protection Division
ICRISAT, Patancheru
Andhra Pradesh 502 324

2. Dr. T.B. Gour
Associate Professor
Department of Entomology
College of Agriculture
Rajendranagar, Hyderabad 500 030

3. Dr. T. Nageswar Rao
Associate Professor
Dept. of Genetics and Plant Breeding
College of Agriculture
Rajendranagar, Hyderabad 500 030

4. Dr. K. Jagadeeshwar
Associate Professor
Dept. of Genetics and Plant Breeding
College of Agriculture
Rajendranagar, Hyderabad 500 030

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF PLATES

LIST OF TABLES

ACKNOWLEDGEMENTS

It gives me an immense pleasure to express my deep sense of gratitude and sincere regards to Drs. D.D.R. Reddy, Chairman of the Advisory Committee, Professor & Head, Department of Entomology, APAU, and K.F. Nwanze, Co-chairman of the Advisory Committee, Principal Entomologist, Crop Protection Division, ICRISAT, for their constant inspiration, patient counsel, sustained interest, valuable guidance and strenuous efforts in finalizing the manuscript of dissertation in the present form.

I am highly thankful to other members of the Advisory Committee, Drs. T.B. Gour Associate Professor, Department of Entomology, APAU, T.N. Rao, Associate Professor, Department of Genetics & Plant Breeding, APAU, and K. Jagadeshwar, Associate Professor, Department of Genetics & Plant Breeding, APAU, for their encouragement during the course of study.

I take this opportunity to express my gratitude to Dr. H.C. Sharma, Entomologist, Crop Protection Division, for his suggestions during the course of the work.

Special thanks to Dr. D.R. Butler, Principal Agroclimatologist, Crop Protection Division, for the suggestions and also providing the facilities on part of the present investigations.

I sincerely thank Mr. Y.V.R. Reddy, Senior Research Associate, Crop Protection Division, ICRISAT for his help and encouragement throughout the course of the work without which it would have been difficult to complete this work. I also acknowledge Dr. Ali Nur Duale, for reviewing the manuscript.

It is a privilege to me to thank Dr. B. Diwakar, Program Leader, HRDP, ICRISAT, for providing facilities for conducting the present study.

I am grateful to Commonwealth Agricultural Bureau, International Institute of Entomology, for identification of *Aprostocetus* sp. collected on midge.

My appreciation goes to Mr J. Rajarao, Mr. Md. Zaheeruddin, Mr. K. Harendernath and Mr. A. Narasimha for their technical contribution, hard work and help in carrying out the experiments. I express my sincere thanks to all staff of Cereals Entomology for fostering a friendly and positive interaction throughout my collaborative research at ICRISAT.

I acknowledge the help of Mr. Kanaka Reddy and Mr Lateef for recording observations on panicle microclimate and Mr. Swaminathan for statistical analysis. Thanks are due to Mr. A.B. Chitnis for developing and Mr. K. Satyanarayana for affixing the photographs presented in this thesis.

I affectionately acknowledge the help and encouragement received from my friends Mr. K. Srinivasa Murthy, and Ms. V. Anitha and my class mates during the course of this study.

I express my sincere regards and love to my parents and my husband whose moral encouragement and affection has been source of inspiration during my educational career.

Finally, I am grateful to the Government of Andhra Pradesh for providing financial assistance in the form of stipend during the course of this study.

(K.G. KAUSALYA)

DECLARATION

I, K.G. KAUSALYA, hereby declare that the thesis entitled **"INSECT - HOST PLANT - PARASITOID INTERACTIONS : SORGHUM MIDGE *Contarinia sorghicola* (Coquillett)"** submitted to ANDHRA PRADESH AGRICULTURAL UNIVERSITY for the degree of **Doctor of Philosophy in Agriculture** is a bona fide record of work done by me during the period of research at ICRISAT, Patancheru. This thesis has not formed in whole or in part, the basis for the award of any degree or diploma.

Date: 23rd May 1994

K. G KAUSALYA

Author	K.G. KAUSALYA
Title of the Dissertation	"INSECT - HOST PLANT - PARASITOID INTERACTIONS : SORGHUM MIDGE *Contarinia sorghicola* (Coquillett)"
Degree of which it is submitted	DOCTOR OF PHILOSOPHY
Faculty	AGRICULTURE (ENTOMOLOGY)
Major Advisor	Dr. D. DASARADHA RAMI REDDY PROFESSOR AND HEAD DEPARTMENT OF ENTOMOLOGY COLLEGE OF AGRICULTURE RAJENDRANAGAR HYDERABAD 500 030.
University	ANDHRA PRADESH AGRICULTURAL UNIVERSITY
Year of submission	1994

ABSTRACT

A series of studies on the species composition of natural enemies of sorghum midge *Contarinia sorghicola* (Coquillett), population dynamics of one of the predominant parasitoids, *Aprostocetus* sp., the effect of host plant resistance on its biology and other tritrophic interactions were undertaken. Three resistant (ICSV 745, ICSV 89058 and IS 10712) and three susceptible (Swarna, CSH 9 and ICSV 112) sorghum genotypes were sown on three dates each during the rainy (6, 15 and 30 Jul in rainy season 1992 and 2, 19 Jul and 6 Aug in rainy season 1993) and post-rainy (29 Oct, 13 Nov and 1 Dec 1992) seasons of 1992/93. A modified headcage was developed for easy and precise collection of emerging insects. The species composition of natural enemies included three larval parasitoids (*Aprostocetus* sp., *Eupelmus* sp. and *Apanteles* sp.) and one predator (*Orius* sp.). Parasitoid emergence commenced 1 - 3 weeks after initiation of midge emergence. The population dynamics of *Aprostocetus* sp. was similar in susceptible and resistant genotypes. *Aprostocetus* sp. activity was higher in the first and third sowing dates than in the second and greater numbers were recovered from susceptible than from resistant genotypes. The extent of parasitization of midge larvae did not follow a definite pattern with resistance or susceptibility of the host plant to midge. The lowest levels of parasitization were recorded from midge resistant ICSV 745. Studies on the tritrophic interactions indicated variations in preference for host stage for parasitization and development in rainy and post-rainy seasons. The diurnal emergence pattern of the

parasitoid did not vary in susceptible and resistant genotypes and the peak time of emergence was restricted to 0600 - 1000 hours. Neither the microclimate of the panicles nor host plant resistance factors *viz.*, the glume length and the rate of grain development significantly differed between susceptible and resistant genotypes. These results suggest that antagonistic effects on midge parasitoid development are not always associated with resistance factors. This indicates that there is the possibility of interphasing the breeding for host plant resistance with enhanced biological control in the integrated management of sorghum midge.

INTRODUCTION

CHAPTER I

INTRODUCTION

Sorghum (*Sorghum bicolor* Moench) is a vital source of food for millions of people in the semi-arid tropics and is often the principal staple food. It ranks fourth in hectarage and production among the world's major grain food crops after rice, wheat and maize. While the grain is an important human food and sometimes animal food, the stalk provides fodder, fuel, shelter, sugar and syrup. Three quarters of the world's sorghum hectarage is located in Africa and India which together produce one third of the world's production (Swarnasree, 1991).

Among the several constraints in sorghum production, insect pests of which there are at least 100 recorded species, are known to cause various levels of crop damage (Young and Teetes, 1977). The most common among them, shoot fly (*Atherigona soccata* Rondani), stem borer (*Chilo partellus* Swinhoe), midge (*Contarinia sorghicola* Coquillett) and head bug (*Calocoris angustatus* Lethiery and *Eurystylus immaculatus* Odhiambo) cause extensive damage to sorghum at different stages of crop growth.

The sorghum midge *Contarinia sorghicola* Coquillett (Diptera : Cecidomyiidae) is cosmopolitan and is recognized as an important pest in Asia, Africa, Australia, Europe and the Americas (Harris, 1976; Sharma, 1985 a and b). The female midge oviposits on flowering florets and on hatching, larvae feed on the developing ovary which affects normal seed development. Severely damaged panicles produce little or no grain. An extended flowering period in sorghum encourages rapid midge population build up and

is the main cause for severe crop losses (Harris, 1976). Such situations arise from staggered, non-uniform sowings and the use of mixed-maturity cultivars.

Therefore, the most effective control method of reducing losses due to midge involves the simple cultural practice of early and uniform regional planting so that flowering would occur over a relatively short period. The crop is thus able to escape the late season build up of midge populations. Additionally, host plant resistance can effectively contribute to keep midge populations below economic threshold levels especially under low input subsistence farming in the semi-arid tropics. Several natural enemies are associated with midge and an integration of host plant resistance with biological control can potentially further suppress the midge populations, provided that, plant resistance does not interfere with parasitoid activity.

The scbpe for host plant resistance in midge control is encouraging. Several sources of resistance have been identified in various countries. Examples include reports by Johnson *et al.* (1973) and Wiseman *et al.* (1973) from the USA; Henzell *et al.* (1989) from Australia; Rosetto *et al.* (1984) from Brazil and Sharma *et al.* (1993) from India.

In India, as early as the 1960s, Jotwani *et al.* (1971) screened 322 germplasm lines and identified 12 lines which were less susceptible to damage under both natural and artificial midge infestation conditions. Since then considerable progress has been made and a major breakthrough was the identification of midge resistance source DJ 6514 from Karnataka (Syamsunder *et al.*, 1975) and the development of ICSV 197 (from DJ 6514) in sorghum midge resistance breeding program at ICRISAT, A.P., India. The release of ICSV 745, a line derived from DJ 6514 for general cultivation in midge endemic

area in northern Karnataka during 1993 was the earliest event in utilization of host plant resistance on large scale (Hiremath and Bhuti, 1993) in India.

The mechanisms of resistance in DJ 6514 and ICSV 197 include nonpreference to oviposition/visitation, and antibiosis. Nonpreference to oviposition is associated with short floral parts. Initial faster grain development limits the space available for larval development (Sharma, 1985a; Johnson *et al.*, 1977). In contrast, glume length and the presence of awns in these genotypes were not related to midge resistance (Murthy and Subramanium, 1978).

Tannin content of the ripening grain was also associated with midge damage ratings (Santos and Carmo, 1974). However, Sharma *et al.* (1990a) suggested that it was not possible to establish a distinct relationship between midge damage and tannin content because a number of other factors also contribute to midge resistance.

The role of natural enemies in the population fluctuation of sorghum midge is well documented. Baxendale *et al.* (1983) observed four hymenopterous parasitoids attacking midge larvae in Texas. Each parasitoid was active at different times within the season but together resulted in only 8.2% parasitization. In India, Taley *et al.* (1971) recorded *Tetrastichus* sp. activity on midge to the extent of 25-60% parasitization in November, 60-70% in December/January and increasing to a maximum of 92% in March on susceptible CSH 1. These studies clearly indicate good prospects for host plant resistance and biological control in the management of sorghum midge. However it is not known whether plant resistance factors influence parasitoid activity i.e., whether sorghum resistance to midge and parasitoid activity are complementary or antagonistic or synergistic. In

breeding for resistance, an attempt is often made to modify plant characters which may have a direct effect on a pest's biology and/or behaviour. In this process of genetic manipulation or modification of a host plant, particular plant cues which are primary factors in the orientation of parasitoids to their hosts may be effected. The attraction of parasitoids to their hosts involves sequential response, first to the plant and then to its host on the plant. For example, *Aprostocetus diplosidis* was highly attracted from a distance of 3.1m to sorghum, which is the host plant of midge, but it was not attracted at this distance to its larval host (midge) in the absence of sorghum (McMillan and Wiseman, 1979).

On the other hand primary antibiotic resistance factors may also affect parasitoid development. The antibiotic factor in tomato, "α Tomatine", which is absorbed by the endoparasitoid *Hyposoter exiguae* (Viereck) from its host *Heliothis zea* (Boodie), prolonged the larval period of the parasitoid, reduced pupal eclosion, reduced the adult size and shortened its longevity. However, *H. zea* was totally unaffected by this chemical. This kind of toxicosis by a plant antibiotic chemical presents an enigma to Integrated Pest Management in breeding high concentration of a particular plant toxin to inhibit insect pests (Campbell and Duffey, 1979). Ishenhour and Wiseman (1989) also observed adverse effects on the biology of Fall army worm (FAW) parasitoid *Campoletis sonorensis* (Cameroon) reared on meridic diet blended with silks of resistant genotype "Zapalote Chico".

High yielding commercial hybrid sorghums in India are highly susceptible to sorghum midge. Although good levels of parasitization have been reported, these have

not been associated with reduced midge damage. With the identification and development of improved midge resistant cultivars, efforts are now being made to develop midge resistant hybrids. The extent to which increased host plant resistance could affect the complex of natural enemies and their activity is not known. This is an area of research with limited information.

The effect of resistance factors in sorghum genotypes on the development of midge larvae are likely to be exhibited on the next trophic level of association, i.e., on midge parasitoids as in other instances. Thus we examined this hypothesis in field and greenhouse experiments conducted at ICRISAT center with the following objectives :

i) To assess the natural enemies of sorghum midge and identify the predominant species; study their temporal distribution and seasonal fluctuations

ii) Seasonal dIstribution of predominant sorghum midge parasitoid

iii) Interactions between resistant genotypes, sorghum midge and the predominant parasitoid in different seasons.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Midge *Contarinia sorghicola* (Coquillett) (Diptera:Cecidomyiidae) is the most destructive pest of grain sorghum on a world-wide basis (Harris, 1976; Sharma, 1985 a and b;). In India, this insect has assumed the status of a serious pest after the introduction of dwarf sorghums (Jotwani *et al.*, 1972) and presently is one of the major limiting factors in the production of sorghum. Damage is caused by developing larvae which continuously feed on the ovary and prevent normal grain development. Females oviposit in flowering spikelets and each female lays 98-110 eggs (Passlow, 1973; Murthy and Subramaniam, 1975a). Incubation period lasts for 2 days (Murthy and Subramanium, 1975a). Four larval instars are reported (Taley et al., 1971) with a total duration of 7 - 16 days (Jotwani, 1978; Murthy and Subramanium, 1975a; Taley *et al.*, 1971). Pupation occurs close to the ovary and is completed within the spikelet in 5 - 10 days (Murthy and Subramanium, 1975a; Taley *et al.*, 1971). The pest completes its life cycle in 13 - 32 days. (Taley *et al.*, 1971, Murthy and Subramanium, 1975a)

2.1 POPULATION DYNAMICS AND CROP LOSS :

The distribution of midge is influenced by pest multivoltinism, natural enemies, larval diapause, climatic conditions and availability of flowering heads during the cropping season. These factors play an important role in IPM.

The main season crop, when sown in late July is prone to midge damage in South India (Thimmaiah *et al.*, 1969) as the pest is active from September (Garg and Taley, 1978) onwards when the crop is in flowering. Peak incidence also occurs on post-rainy season crop during October and November (Murthy and Subramanium, 1975a) when conditions are favourable for midge population build up.

In North India, midge activity commences from the second week of August with the termination of diapause, continues up to the first week of November (Rao, 1976; Hardass *et al.*, 1972) and declines later with the fall in relative humidity and temperature.

Wiseman *et al.* (1978) monitored the sorghum midge continuously for a period of three years at Georgia, USA and revealed that the insect's activity started in July and continued throughout the cropping season. These results were confirmed by Sharma and Vidyasagar (1992) using pheromones from virgin female-baited sticky traps to monitor adult male populations on the ICRISAT farm. During the 1989/90 post-rainy season, peak activity was recorded in the 1st and 4th weeks of March and in the 1st to 3rd weeks of February in 1990/91. Environmental factors play a key role in determining midge activity. The highest midge incidence was reported to coincide with minimum temperature of 18.5°C, maximum temperature of 27.7°C and relative humidity of 76% (Kulkarni, 1985). Mote and Ghule (1986) showed a positive and highly significant correlations between temperature and midge population and damage. Similarly, an increase in midge population was also associated with an increase in rainfall and relative humidity. On the contrary, Gowda and Thontadarya (1977) found no influence of temperature while humidity was associated with midge incidence.

Patel and Jotwani (1986) concluded that the meteorological conditions prevailing at the time of flowering were more important than the date of sowing. In their study, the crop sown on 2nd July suffered more damage than those sown on 9th and 16th July. This was attributed to the high temperatures (35 - 36°C) and low relative humidity (68 - 74%) which prevailed during the flowering period of the 9-16th July sown crop, which caused a decline in midge population and consequently significant decrease in damage.

The presence of a single developing larva within a spikelet is sufficient to prevent grain formation and occurs at a critical period during development of the crop. Rao (1976) noted that one sorghum midge caused 6.5% damage to the spikelets and 30 midges per earhead resulted in 65% damage, while, Harris (1961) reported an overall loss of 91,000 tons of grain valuing £1,822,000 in northern Nigeria. Similarly, Harris (1970) estimated an annual of '5-10% recurrent loss of grain which goes virtually unnoticed. A recent estimate (ICRISAT, 1992) places annual losses due to sorghum midge alone at $ 292 millions world-wide.

2.2 INTEGRATED PEST MANAGEMENT (IPM)

Integrated Pest Management (IPM) in cereal crops has received considerable emphasis in recent years. This is of special significance for sorghum, pearl millet and minor millets which are the major food crops of the world's poorest sector.

The basic unit of consideration in IPM is the agroecosystem of which the target crop is of main importance. The agroecosystem includes the biotic and abiotic

constituents that improve or constrain crop production. IPM primarily targets at re-establishing balance in the system with emphasis on sustaining both the biotic and abiotic aspects of the environment. Most IPM direct control tactics function to reduce insect pest density (insecticidal control), lower the general equilibrium position of the pest (biological control) or provide temporal or spatial separation of the crop and the pest (cultural control). The most effective IPM strategy should combine a optimum mix of all available tactics. For sorghum midge however, host plant resistance and a range of crop management practices form the core around which this pest is kept under control in India, Australia and the USA

2.2.1 Cultural Control

The most effective method of reducing loss by sorghum midge is its avoidance by uniform, regional planting of sorghum early in the growing season. This ensures that flowering occurs over a short period of time and no staggering occurs which otherwise is favourable to midge population build-up. However, such planting is not always possible since the planting periods may be delayed or extended due to drought or frequent rains.

Midge population carry over from one season to another is mainly through chaffy grains which contain diapausing midge larvae/pupae. Thus destruction of crop residues after threshing can considerably reduce the initial midge population.

2.2.2 Chemical Control

Chemical control applied at different stages of flowering has been reported by various workers (Roth and Pitre, 1973; Thimmaiah *et al.*, 1974; Macquillan *et al.*, 1975;

Gowda and Thontadarya, 1975; Murthy and Subramanium, 1975b; Gowda and Thontadarya, 1976; Rao, 1976; Garg and Taley, 1977; Sarkate *et al.*, 1978; Borle *et al.*, 1979; Mogal *et al.*, 1980) and chemicals belonging to a wide range of groups have been reported to be effective in reducing midge infestation. Macquillan *et al.* (1975) recommended that when the flowering of the crop is prolonged or wet conditions promote massive midge outbreaks, chemical application is necessary at 5-day intervals, while with restricted flowering, a single application is sufficient to manage this pest.

One major drawback of this control tactic is that some insecticides and/or their combinations are known to be toxic to midge parasitoids (Mogal *et al.*, 1980; Rao, 1976).

In general, the use of chemical insecticides is not an effective pest control method due to the behaviour and nature of damage by this pest. Insecticidal treatment after earhead emergence is less likely to kill adults migrating from other sources by way of residual toxicity prior to egg laying since females migrate early in the morning and start egg laying immediately. Oviposition is almost complete by noon and insecticides are less likely to kill adults by way of contact toxicity within such a short period. In some studies, females were even observed to oviposit on treated earheads (Mogal *et al.*, 1980).

A combination of chemical control and host plant resistance was examined by Natarajan and Chelliah (1986b). Resistant genotypes DJ 6514 and PVK 50 required reduced insecticide applications but not midge susceptible SPV 234 which needed either higher dosage or shorter intervals of applications. Resistant genotypes were less damaged by midge and timely application of chemicals had added advantage in managing the pest.

2.2.3 Varietal Resistance

The existence of resistance to midge in Sumac sorgho was first reported by Ball and Hastings (1912). Later Gable *et al.* (1928), Cowland (1936), Walter (1941) and Evelan (1951) found that some sorghum varieties were more resistant than others. Although Bowden and Neve (1953) reported resistance in Nunaba varieties, subsequent studies by Passlow (1965) showed their susceptibility under field conditions.

Efforts to identify resistant sources against midge began in Georgia during the 1950's (Painter, 1958) and 1960's (Wiseman *et al.*, 1974). Since then good progress has been made in identifying resistant sources such as SGIRL-MR-1 (Wiseman *et al.*, 1973) TAM 2566 (Johnson *et al.*, 1982) and research has been directed towards the development of commercially acceptable midge resistant sorghum hybrids.

In India, studies on varietal resistance began in the mid-sixties. Jotwani *et al.* (1971) screened 322 germplasm lines between 1965 and 1970 and 12 lines exhibited consistently less damage both under natural and artificial infestation conditions in the All India Sorghum Improvement Project (AICSIP) multilocational trials (AICSIP, 1969). DJ 6514 was found to have better levels of stable resistance to midge among various entries evaluated for midge resistance (Syamsunder *et al.*, 1975; Venugopal *et al.*, 1977; Kulkarni *et al.*, 1978). Significantly less damage was noticed in IS 2579C than in SGIRL-MR-1 and IS 2664C (Raodeo and Karanjkar, 1975; Jadhav and Jadhav, 1978)

Screening of 65 lines by Kulkarni (1985) belonging to different working groups such as sudanense, bicolor, roxburghii, conspicum, zera zera, roxburghii-shallu, durra, kaffir and other genetic stocks revealed that resistance was not confined to one sorghum

group. However, sorghum belonging to kaffir and zera zera groups recorded a low range of midge incidence.

More than 15,000 germplasm lines screened by Sharma *et al.* (1993) under headcage conditions over several seasons and locations, revealed 27 germplasm accessions to be resistant to midge. Majority of the present breeding lines developed for resistance to sorghum midge at ICRISAT are derived from crosses involving DJ 6514 or its progeny ICSV 197. Good progress has been made by using ICSV 197 as a midge resistant donor. Transfer of resistance from DJ 6514 to ICSV 197 was the most significant development in the sorghum midge resistance breeding program.

2.2.3.1 Mechanisms of resistance

All the three mechanisms of resistance reported by Painter (1958) have been found to contribute to resistance to sorghum midge. However, the role of tolerance appears to be restricted as the spikelet once infested by midge is a total loss although the scope for compensatory mechanism in uninfested spikelets has been reported (Henzell and Gillieron, 1973).

2.2.3.1.1 Nonpreference. Harris (1961) first reported the expression of nonpreference mechanism in a "Nunaba" variety in the presence of two or more other varieties, but this expression was lost in the absence of other preferred host (Passlow, 1965).

Resistant AF 28 is not preferred for oviposition, although this genotype can be severely damaged by midge in very late plantings. Nonpreference has been attributed to

the difficulty experienced by ovipositing females in introducing their ovipositors between the floral glumes which are tightly closed at the tip during anthesis (Rosetto *et al.*, 1984).

Waquil *et al.* (1986b) made a precise study on the oviposition behaviour of midge in resistant and susceptible genotypes. The females were found to search spikelets more rapidly in resistant genotype and a longer period of time was spent probing these spikelets. Secondly, at the same midge density and time interval, fewer eggs were deposited in resistant genotypes. Finally, ovipositional efficiency (% of ovipositional success when egg laying was attempted) was also very low in resistant (1%) compared to susceptible genotype (43%). Based on these results they proposed that nonpreference to oviposition was an important component of resistance to sorghum midge.

Rosetto (1985) classified the nonpreference mechanism into two components (i) adult nonpreference for visitation *viz.*, a variety may be less preferred for oviposition by the females which results in lower number of flies per sorghum earhead and (ii) adult nonpreference for oviposition, *viz.*, a variety may be attractive to females but actual oviposition is less. On the latter aspect, Sharma (1985a) identified 10 sorghum lines that were less attractive to midges. However, although DJ 6514 and IS 12666C were fairly attractive, these genotypes suffered less damage.

Natural infestation involves both resistance components (adult nonpreference for visitation and oviposition) whereas, artificial infestation involves only nonpreference to oviposition according to Waquil *et al.*, (1986a). In their study under free choice conditions, the susceptible genotype attracted 1.4 - 2.9 fold more flies at the time of anthesis which indicated some degree of midge nonpreference for visitation in resistant genotypes when

susceptible sorghums are available. However, under no choice condition, about five fold more eggs and four fold more infested spikelets were recorded in the susceptible genotype compared to the resistant one. This indicated that natural infestation involved both resistance components which could have additive effect. Based on the number of eggs laid in spikelets of both hybrids under a free choice situation with numbers laid in a no choice situation, they concluded that nonpreference for oviposition was a major mechanism of resistance in the midge resistant hybrid ATx2755xTx2767.

Franzmann (1988) also identified these two mechanisms but, he felt that "visiting nonpreference" would be of little value in commercial crops where no choice is available. He later confirmed (Franzmann, 1993) ovipositional nonpreference as the predominant mechanism in a study with 20 genotypes. Fewer eggs were laid in the spikelets and a lower percentage of such spikelets were infested in all resistant lines compared to susceptible ones. The expression of this mechanism was very erratic and did not follow any perceivable pattern so as to consider as a predominant mechanism in the studies of Melton and Teetes (1982).

Nonpreference to oviposition initially influences the adult oviposition behaviour which finally results in inability of the adult to deposit the egg(s) in the floret. Based on the available literature regarding this mechanism, it may be concluded that it is a predominant mechanism of resistance though there are instances of breakdown of resistance.

2.2.3.1.2 Antibiosis. Santos and Carmo (1974) found a certain level of correlation between the scores for infestation by *C. sorghicola* and tannin content in ripe seeds and this correlation was considered as an indication of antibiosis.

Sharma (1985a) reported that adult emergence in resistant cultivars (DJ 6514, AF 28, TAM 2566 and IS 15107) was low compared to control CSH 1 and Swarna (<71 flies/head vs 404/panicle) and delayed (20-27 days after oviposition compared to 15-24 days in control).

Examination of sorghum earheads by Kulkarni (1985) showed the presence of several eggs in DJ 6514; however, only 5 midges emerged and the life cycle lasted for 27.3 days. Based on these results he concluded that the mechanism of resistance was antibiosis.

Nataraјan and Chelliah (1986a) recorded antibiosis as one of the mechanisms of resistance in four entries in a resistance screening study. Both larval and pupal periods were prolonged in DJ 6514 while in AF 28 antibiosis was clearly seen in the form of reduced larval, pupal and adult weights. Similar investigations by Sharma *et al.*, (in press) also revealed significantly smaller size of larvae, lower number of eggs in the ovary, reduced fecundity and larval survival and low and delayed emergence of adults from 11 resistant genotypes compared to susceptible control CSH 1. However the degree of expression of antibiosis varied with season and was attributed to the effect of environmental conditions on insect development and chemical composition of sorghum grain.

Antibiosis is not the predominant mechanism in all midge resistant cultivars and its expression varies under different environmental conditions. Franzmann (1988) in his studies with two resistant lines in Australia, QL 32 and PM 12627 did not find any evidence of antibiosis to midge in these genotypes as the developmental period did not differ significantly from that of the susceptible QL 20.

Melton and Teetes (1982) investigated the antibiotic effects of two resistant hybrids on the number of progeny produced per the female fly. The hybrids reduced the number of progeny produced per female by approximately 40 - 60% regardless of midge density. However, there were no significant differences in developmental time of larvae between resistant and susceptible genotypes.

Rosetto *et al.* (1984) manually transferred midge eggs to uninfested florets to observe whether the nonpreferred genotype, AF 28 had any impact on the developing midge larva. The results indicated that this genotype was equally favourable as the susceptible genotype since the developmental time and the total number of emerging adults did not vary significantly from the susceptible "Sart".

The role of antibiosis is yet to be fully understood as the factors contributing to this mechanism are not clear.

2.2.3.1.3 Tolerance. The scope for tolerance mechanism in sorghum resistance is limited because of the nature of damage and inability of damaged grains to compensate for the damaged ones. A grain attacked by midge larva is always a total loss (midge larva continuously feed on the attacked grains for 10-12 days) (Sharma, 1985a).

Recovery tolerance as a mechanism of resistance may not hold promise (Alghali, 1984). The number of spikelets per panicle is normally determined at the panicle primordia initiation stage of plant growth, which usually occurs a few weeks prior to infestation and, as such, damage may not be followed by the initiation of the growth of extra spikelets. Similarly, since the shoot is not affected by the midge, nodal tillering as a means of compensating damage is usually not initiated.

However, compensatory mechanism may exist (Henzell and Gillieron, 1973) where, as a result of a moderate midge attack, yields may be higher than expected because the plant is able to compensate for loss up to one-third of the florets by increasing in grain size in the remainder of the panicle.

2.2.3.2 Factors Associated with Resistance

2.2.3.2.1 Morphological Factors. Sorghum resistance to midge was reported to be associated with characters such as short glumes (Ball and Hastings, 1912), degree of apposition of glumes (Geering, 1953) and cleistogamy in Nunaba group of sorghum which do not open at anthesis (Bowden and Neve, 1953). A sorghum selection, IS 2663 was found to be resistant due to an exclusion mechanism (Bergquist *et al.*, 1974) i.e. the glumes remain closed throughout anthesis and the loose nature of the panicle prevented the accumulation of moisture and excluded visitation by insects. Glumes of resistant entries are reported to be short and compact which remain closed during anthesis (Jadhav and Jadhav, 1978) so as to prevent oviposition by midge females. Johnson (1975) found that lines with high levels of resistance have either a brown pericarp with

pigmented testa or white/translucent pericarp with no testa and grains possessing a testa had high tannin content (Kofoid *et al.*, 1982) which could be a factor influencing larval development.

Rapid seed growth was found to be one of the factors associated with midge resistance (Johnson *et al.*, 1977, Sharma, 1985a). Oven dried seed weight of midge resistant lines, TAM 2566 and IS 2579C was higher during the first 15 days of growth than the susceptible line, Tx 7000 or moderately resistant, TAM 428 (Johnson *et al.*, 1977). Rapid seed growth coupled with short glume lengths of the floret is reported to restrict the space within the spikelet for larval development (Sharma, 1985a).

The presence or absence of awns and rachis length had no influence on the level of midge infestation (Murthy and Subramanium, 1978). However, varieties with compact panicles showed consistently low infestation than those with semi-compact ones. Semi-compact panicles provide more space for insect mobility within the interspace and thus more spikelets become infested. On the other hand, compact panicles restrict movement to the spikelets on the surface, with the result that these spikelets are the only ones infested.

Oviposition is also highly associated with floral parameters, i.e., length of glumes, lemma, palea, anther and style; while lodicule width was related to both oviposition and damage which indicates that initial faster grain growth and short floral parts are associated with midge resistance as it limits the space available for oviposition and larval development (Sharma, 1985a). The smaller the panicles, the less the damage they sustain due to midge, probably because they provide a lower visual stimulus to ovipositing females or they are actually less preferred for oviposition. (Alghali, 1984).

2.2.3.2.2 Biochemical Factors. Higher tannin content in the ripening sorghum grain has been related to midge damage ratings (Santos and Carmo, 1974). Kofoid *et al.* (1982) found that sorghum genotypes with grain possessing a testa had a high tannin content which could be a factor influencing the larval development. However, Martins (1977) failed to obtain a similar correlation with midge resistant AF 28. This genotype has low tannin content but is nonpreferred for oviposition.

Resistance to midge is largely influenced by the extent of oviposition and hence a realistic association between tannin content of grain and midge resistance may be difficult to establish (Sharma *et al.*, 1990a). Lower amounts of soluble sugars in midge resistant cultivars may have a direct bearing on the nutritional value of these genotypes to midge larvae and it may partly account for slow development.

2.2.4 Biological Control

2.2.4.1 Natural Enemies of Sorghum Midge. The parasitoids which attack sorghum midge are more or less the same world-wide. *Tetrastichus* sp., *Eupelmus* sp. and *Aprostocetus* sp. are the most commonly reported ones (Chundurwar, 1977; Gowda and Thontadarya, 1977; Wiseman *et al.*, 1978; Baxendale *et al.*, 1983; Brooks and Gillstrap, 1985; Brooks and Gillstrap, 1986; Diaz, 1988; Gillstrap and Brooks, 1991). However, the predominant parasitoid species varies with locations. *Eupelmus* sp is the predominant parasitoid in Texas (Brooks and Gillstrap, 1985) and India (Chundurwar, 1977), *Aprostocetus* sp. in Sau Paulo, Brazil (Busoli *et al.*, 1984) and Argentina (Diaz, 1988) and *Tetrastichus blastophagi* (Ashmead) in Texas, USA (Brooks and Gillstrap, 1986; Gillstrap and Brooks, 1991).

2.2.4.2 Population dynamics of parasitoids. The seasonal abundance of sorghum midge and its parasitoids was studied at Texas by Baxendale *et al.* (1983) through bi-weekly plantings from April so that flowering panicles were available from June to October. In general, a positive relationship was observed between sorghum midge and parasitoid densities with parasitization of up to 24% in sorghum. When all parasitoids were considered collectively, maximum parasitoid densities occurred during mid season with smaller peaks during spring and fall. *Eupelmus popa* (Girault) was the first parasitoid recorded early in the season (4th week of June) while *Aprostocetus diplosidis* (Crawford) was abundant during the later part of the season (July - October). *Tetrastichus venustus* (Gahan) was primarily a mid season parasitoid with maximum densities occurring during the last week of August. *Tetrastichus blastophagi* was most abundant during mid-summer (July - August). Later in the season parasitism declined considerably.

Chundurwar (1977) found that parasitoids appeared late in the season in India. Parasitoid activity was observed between November and March and three species were recorded. *Eupelmus* sp. remained predominant in the field from November to end of March. *Tetrastichus* sp. appeared early in November and was the predominant parasite in January and February. The activity of *Aprostocetus* sp. was restricted from November to January.

Another report from India indicated that *Eupelmus* and *Tetrastichus* were found to decrease in their numbers on crop sown during May and subsequently reaching low incidence level on October - December sown crop (Gowda and Thontadarya, 1977). The number of parasitoids emerging from earheads increased from the January-sown crop until it reached its peak in March and April sown crops.

Wiseman *et al.* (1978) monitored the populations of sorghum midge and associated parasitoids during the flowering period of sorghum for three years, 1975-77 at Tifton, Georgia. *Aprostocetus diplosidis* populations closely paralleled those of midge during the entire season in 1975 and only on one date did parasitoid numbers exceed those of midge. During 1976 and 1977, relatively low population densities of *Aprostocetus diplosidis* were recorded and only during late season in 1977 did populations of this parasitoid approach those of midge.

The increase in parasitoid population followed the same trend as sorghum midge and the highest population ratio of 1 midge : 6 parasitoids was recorded in the last week of October (Gahukar, 1984). Parasitoids outnumbered midges from November onwards but were effective in checking the pest only at the end of the cropping season, when a population ratio of 1 midge : 22 parasitoids was observed. There was a perfect synchrony of peaks of pest and parasitoids during October and November.

Garg and Taley (1978) studied the population fluctuation of *Tetrastichus* on CSH 1 at Nagpur through weekly plantings between the last week of June and last week of December. The gradual increase in sorghum midge population was followed by gradual increase in *Tetrastichus* sp. populations. Midges were observed to reach their peak during the 4th week of November and its decline thereafter was associated with an increase in the population of *Tetrastichus*. The activity of this parasitoid began in the 2nd week of November and later reached its peak in the 3rd week of February. The prime factor for the decline in midge population during January and February was due to an increase in the population of *Tetrastichus* and ecological conditions had little to do with this decline.

2.2.4.3 Extent of parasitization of sorghum midge larvae by various hymenopterous parasitoids. The pattern of seasonal parasitization generally shows little resemblance to that of midge or parasitoid seasonal abundance profiles at Texas (Baxendale *et al.*, 1983). Generally, parasitization increased through mid August reaching a maximum of 24% at the end of August. After this period, parasitism considerably declined. However, based on total midges and parasitoids collected during the season, only 8.2% of the midges were parasitized.

Studies on the biology of the parasitoids of sorghum midge under field and lab conditions by Busoli *et al.* (1984) showed that 33.18% of midge larvae were parasitized and *Tetrastichus diplosidis* was responsible for 90% of total parasitization at Sau Paulo, Brazil.

Population monitoring of *C. sorghicola* and its parasitoids *Aprostocetus diplosidis*, *Eupelmus popa* and *Tetrastichus* sp. by Diaz (1988) at Argentina revealed a parasitization of 28.3%. There was no corresponding increase in the parasitoid populations with an increase in the population of midge.

Chundurwar (1977) reported an average parasitization of 36.14, 17.14 and 21.95% by *Eupelmus* sp., *Aprostocetus* sp. and *Tetrastichus* sp. respectively between November and March in India.

Wiseman and McMillan (1970) attempted to measure the parasitization by *Aprostocetus diplosidis* and *Tetrastichus venustatus* of sorghum midge by utilizing the criteria of number of parasitoid exit holes in damaged sorghum seeds at Tifton, Georgia. On investigation of >12000 seeds from 27 sorghum lines, the average number of

parasitoid exit holes ranged from 11-16%. In a subsequent study by Wiseman *et al.* (1978) based on the total midges observed and total parasitoids collected, the % parasitization was 26% in 1975, 13% in 1976 and 11% in 1977.

2.3 INTERACTIONS BETWEEN HOST PLANT RESISTANCE, PEST AND PARASITOID

One of the crucial consequences of pest control combining more than one method is that interactions between the methods can also occur (Embden, 1981). These interactions are fundamentally important to the concept of integrated pest management.

The secondary chemistry of plants used as a resource by a herbivore not only affects the physiology and behaviour of the herbivore but also affects the quality of the herbivore as a resource for a beneficial insect. Changes in the host suitability due to host diet can influence the developmental rate, size, % emergence, success of parasitization, sex ratio, fecundity and life span of parasitoids. Resistant plants may limit the availability of nutrients to parasitoids both directly by making nutrients in the host inaccessible to a parasitoid and indirectly by limiting the availability of nutrients to the host which would in turn result in nutrient limitation for the parasitoid.

Plant resistance to insects can result from the presence of chemicals that are antagonistic to insects in various plant tissues (Campbell and Duffey, 1979). The antibiotic factor in tomato "α Tomatine" which is absorbed by the endoparasitoid *Hyposoter exiguae* (Viereck) from its host *Heliothis zea* (Boodie), prolonged the larval period of the parasitoid, reduced pupal eclosion, reduced the adult size and shortened longevity.

However, *H. zea* was totally unaffected by this chemical. This kind of toxicosis by a plant antibiotic chemical presents an enigma to IPM in breeding high concentration of a particular plant toxin to inhibit insect pests.

The combined effect of host plant resistance and biological control was investigated by Ishenhour and Wiseman (1987) in corn genotype with reference to Fall armyworm (FAW) *Spodoptera frugiperda* (Smith) and its parasitoid, *Campoletis sonorensis* (Cameroon). Feeding of FAW on resistant genotypes usually resulted in lighter body weights compared with those fed on susceptible genotypes. However parasitization by *C. sonorensis* further enhanced weight reductions and reduced the amount of foliage consumed. Feeding of FAW on foliage of resistant corn genotypes had no adverse effects on the parasitoid. In another study, Ishenhour and Wiseman (1989) used FAW resistant genotype "Zapalote Chico" to record the effect of resistance on parasitoid biology. Feeding of FAW on meridic diet blended with different silk concentration from "Zapalote Chico", resulted in prolonged developmental periods of the progeny of *C. sonorensis* compared with parasitoids from FAW that fed on diets without resistant silks.

On similar lines, using soybean, Orr and Boethel (1985) reported that the leaf area consumed by *Pseudoplusia includens* (Walker) increased upon parasitization by *Copidosoma truncatellum* (Dalman) in both resistant and susceptible genotypes. Weights of unparasitized one-day old pupae were significantly lower on resistant than susceptible genotypes. Overall mortality of unparasitized *P. includens* was 10% on the susceptible genotype and 70% on the resistant genotype. However when parasitized, the larva showed 100% mortality in both genotypes. Eventhough the number of parasitoids able

to develop per host is not significantly altered in resistant compared to susceptible genotypes, the high mortality of host larvae before pupation of *C. truncatellum* may adversely affect the population levels of this parasitoid in fields of resistant soybean.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

3.1 SORGHUM GENOTYPES AND EXPERIMENTAL DESIGN

Field and glass house studies on the natural enemies of sorghum midge (*Contarinia sorghicola* Coquillett); their temporal distribution, seasonal incidence and tritrophic interactions were conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P., India during three cropping seasons in 1992 and 1993 (1992 rainy, 1992/93 post-rainy and 1993 rainy seasons). Three sorghum resistant (ICSV 745, ICSV 89058, IS 10712) and three susceptible (Swarna, CSH 9, ICSV 112) sorghum genotypes were used in these studies.

Experiments were laid out in randomized blocks of eight 9m long rows, with three replications, and were planted on three dates in each season as follows :

Season	Planting dates
Rainy season 1992	6, 15 and 30 Jul
Post-rainy season 1992/93	29 Oct, 13 Nov and 1 Dec
Rainy season 1993	2, 19 Jul and 6 Aug

Staggered multiple planting dates were used to facilitate monitoring of midge and parasitoid populations throughout the season. Standard ICRISAT recommended agronomic practices were carried out throughout the study. Each crop received a basal

dose of ammonium phosphate at the rate of 150 kg ha^{-1} and topdressed with urea at the rate of 100 kg/ha^{-1}. Thinning to one seedling/hill (1,80,000 plants ha^{-1}) and 10 cm spacing between the hills was done at 10 days after seedling emergence (DAE). Each crop was protected from shoot fly infestation during early seedling growth (10 - 21 DAE) by applying Cypermethrin (22.5 g a.i. ha^{-1}) at weekly intervals. The rainy season crop received supplementary irrigation as and when necessary while the post-rainy season crop was grown under irrigated conditions.

3.2 SPECIES COMPOSITION OF NATURAL ENEMIES OF *Contarinia sorghicola*

In each season, three sorghum panicles at half anthesis (Plate 1) of each genotype, in each replication, and in each of the three planting dates were artificially infested with ȁ0 female midges on two successive days using the head cage technique (Plate 2 & 3) (Sharma *et al.*, 1988). Five days after infestation (DAI), the panicles were exposed to natural parasitization for 10 days and thereafter re-caged for parasitoid development and emergence. Similarly, another set of unexposed panicles was used to determine the level of midge infestation.

For collecting emerging insects, the upper end of the head cage was modified by fitting a 5 cm long (1.0 cm diameter) plastic connecting tube over the central ring of the head cage. This tube was held in place at its lower end by a thermocole cork while the collection chamber (an inverted 15 ml plastic cup), was fitted over the upper end of the tube (Plate 4a). To collect emerging insects, the cage was covered with a black cloth bag on the previous evening, leaving the collection container as the only source of light

Plate 1. Sorghum panicle at half anthesis.

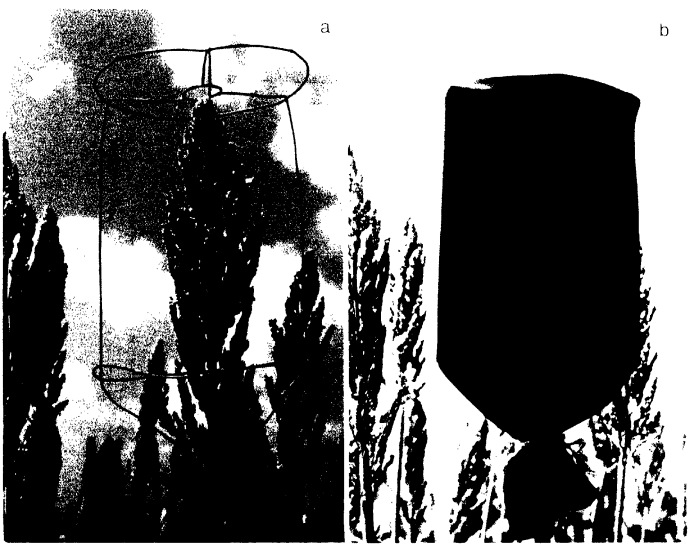

Plate 2 a. Frame of head cage for infesting sorghum panicles with midge
b. Head cage covered with blue cloth bag for confining midge flies to the panicle.

Plate 3 a. Midge fly ovipositing on sorghum panicle.
b. Overview of the field showing distribution of head cages afer midge infestation

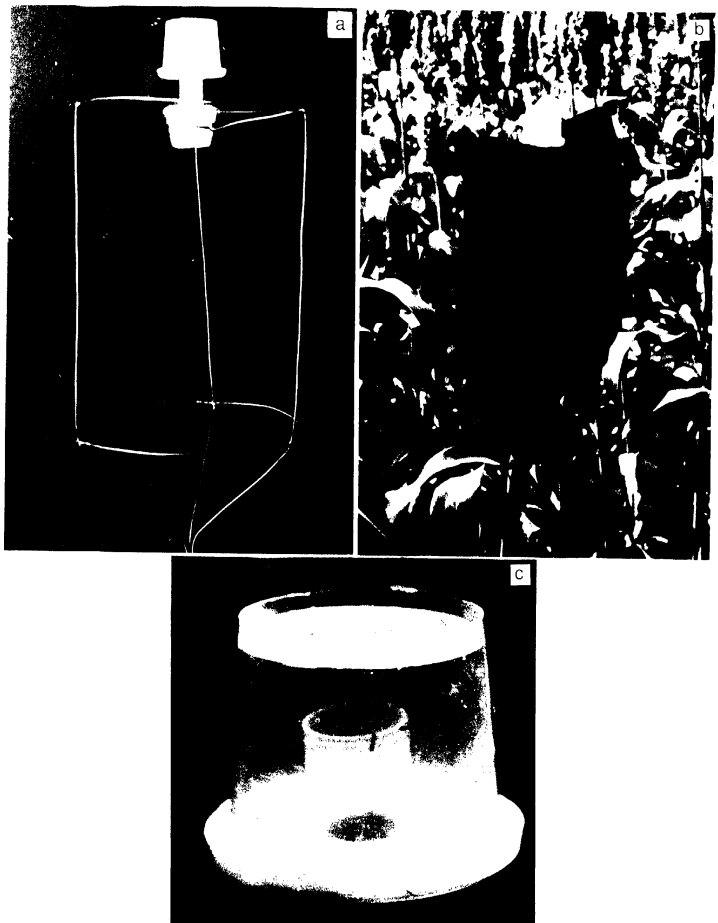

Plate 4 a. Modification of head cage with thermocole cork, connection tube and collection container
b. Modified head cage covered with black cloth
c. Collection chamber with insects.

(Plate 4b). Emerging insects were attracted to light and could thus be collected in the plastic cup the following morning (Plate 4c). After insect collection, the cloth bags were removed and the open end of the connecting tube was closed with a plastic lid. This procedure was repeated daily for ten days, to ensure that all emerging midge flies and natural enemies were collected. Natural enemies were initially identified to the genus level at the ICRISAT Insect Collection Museum and samples were sent to the British Museum for identification/confirmation to the species level.

3.3 POPULATION DYNAMICS AND PATTERN OF EMERGENCE OF MIDGE AND *Aprostocetus* sp.

Based on the results of experiments in 3.2, detailed studies were subsequently conducted in the population dynamics of midge and *Aprostocetus* sp., the predominant parasitoid at ICRISAT center. Populations of midge flies and *Aprostocetus* sp. were monitored on a daily basis on the panicles which were exposed for natural parasitization. Emergence records were kept for each planting and data were averaged for standard weeks.

The interactions between *Aprostocetus* sp. and host plant resistance to midge was investigated under field conditions by evaluating the emergence pattern of midges and *Aprostocetus* sp. from susceptible and resistant sorghum genotypes in the rainy and post-rainy seasons of 1992-93. Total emergence of midges and *Aprostocetus* sp. from panicles exposed for natural parasitization was compared to emergence of midge alone in panicles unexposed for parasitization. This was done in all three plantings of each season during the rainy and post-rainy seasons of 1992-93.

Based on preliminary identification of the parasitoid complex, the level of parasitization was calculated on the basis of total emerging midge flies (m) and parasitoids (p) from exposed panicles by using the formula :

$$\frac{p}{m+p} \times 100$$

3.4 LEVEL OF INFESTATION BY *C. sorghicola* IN SUSCEPTIBLE AND RESISTANT GENOTYPES

In the course of the studies referred to above, it was observed that the combined total number of midge and *Aprostocetus* sp. emerging from exposed panicles was higher than total number of midge alone emerging from unexposed panicles during the 1992/93 post-rainy season. In order to ascertain that the level of initial infestation by *C. sorghicola* at the time of panicle exposure to natural parasitization was similar in both treatments, an experiment was conducted during the 1993 rainy season. One week after infestation, spikelets were randomly sampled from the middle portion of exposed and unexposed panicles (when the florets were in anthesis during midge infestation) and stored in the refrigerator. They were subsequently dissected under light microscope and data were recorded on total number of florets with midge larvae and total number of midge larvae/100 florets.

3.5 STUDIES ON THE TRITROPHIC INTERACTIONS IN SORGHUM, SORGHUM MIDGE AND PARASITOIDS

The studies were designed to determine the effect of host insect developmental

stage and crop genotype on oviposition and development of *Aprostocetus* sp.. Initial experiments were carried out during the post-rainy season 1992/93 in glass house conditions. Based on the results obtained, the experiments were further modified and a detailed study was conducted during the 1993 rainy season under field conditions.

3.5.1 Parasitoid Culture for Interaction Studies

Midge infested sorghum panicles were collected from the field and held in plastic tubs partially filled with moist sand. They were then placed in a wooden cage which was designed for collecting emerging insects (Plate 5a). Insect collection was done following the same principles described earlier for the modified head cage (Plate 5b). The collection container in this case consisted of a larger plastic jar (11cm in diameter and 13 cm in height) (Plate 5c). Though midge flies and parasitoids emerged into the collection container, the former died during the day. All the insects other than *Aprostocetus* sp. were collected with the help of aspirator and separated out. *Aprostocetus* sp. were later transferred into a rearing cage and provided with 10% sucrose solution as source of food. They were held in the cage for two days for mating and preoviposition period (Taley *et al.*, 1978) and thereafter gravid female individuals were collected for use in the interaction studies.

3.5.2 Studies on Host Stage Preference of *Aprostocetus* sp. in Relation to Sorghum Genotypes

Eighteen panicles of each of the six test genotypes at half anthesis were artificially infested with midge using the head cage technique described earlier. Incubation period

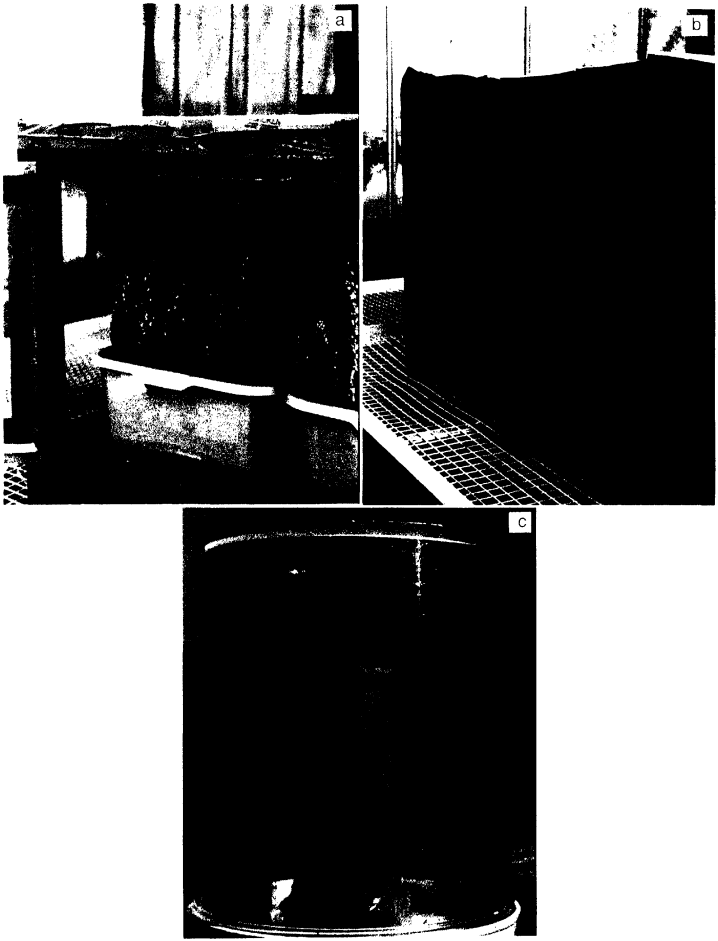

Plate 5 a. Midge infested panicles in plastic trays placed in wooden cage for collecting emerging insects.
b. Wooden cage covered with black cloth for collecting emerging insects.
c. Close view of the collection chamber with insects.

of midge lasts for 2 days (Murthy & Subramanium 1975a). Based on a duration of 2 - 3 days for each midge larval instar and a total of four instars (Taley *et al* 1971), the release of parasitoids into midge infested panicles was done at 3-day intervals, beginning at 3 DAI for a total of 5 treatments i.e., at 3, 6, 9, 12 and 15 DAI. This procedure ensured that each larval stage of midge was exposed to parasitization by *Aprostocetus* sp.. Each treatment consisted of three panicles of each genotype. For each treatment, 15 gravid females of *Aprostocetus* sp. (obtained from culture) were released into each midge infested panicle usually between 1730 and 1800 hours and retained for 48 hours in the head cage. After removal of the released parasitoids, the panicles were left in tact in the head cage for the development and emergence of adult parasitoids. Emerging insects were collected using the modified head cage as described earlier. Data were recorded for the emerging *Aprostocetus* sp. adults.

In another set of studies to determine the preferred midge larval stage for oviposition by the parasitoid, destructive sampling of spikelets was done in all the treatments, a week after the release of *Aprostocetus* sp.. Data on the observations of total *Aprostocetus* sp. larvae upon dissection of 100 spikelets/replication were recorded.

3.5.3 Diurnal Pattern of Emergence of *Aprostocetus* sp.

The diurnal pattern of emergence of *Aprostocetus* sp. was studied during the 1992/93 post-rainy and 1993 rainy seasons. The 1992/93 post-rainy season study was conducted using field collected midge-infested sorghum panicles to obtain preliminary information. Midge infested panicles were randomly collected from various experimental

fields in the ICRISAT farm and placed vertically in moist sand in three sets of 10 - 15 panicles in each cylindrical plastic container (Plate 6a). Each container was fitted with a collection chamber as in the modified headcage and then covered with a black cloth bag (Plate 6b). Observations on the number of emerging adult *Aprostocetus* sp. were made at two hourly intervals for 24 hours. The collection chamber was replaced at each observation.

Similar procedures were followed under field conditions during the 1993 rainy season. Three panicles [each of the six test entries (three midge resistant and three midge susceptible) which had been artificially midge infested and exposed for natural parasitization] were used. Observations on the diurnal emergence of *Aprostocetus* sp. commenced at 10 days after exposure of the panicles for parasitization.

3.5.4 Effect of Glume Length and Rate of Grain Development on Midge Parasitization by *Aprostocetus* sp.

Based on earlier studies by Sharma *et al* (1985a) on sorghum resistance factors, namely glume length and rate of grain development, the effects of these factors on the development and emergence of *Aprostocetus* sp., were monitored during the three seasons of experimentation.

Glume lengths (gl_1 and gl_2) were recorded on 10 randomly selected florets from the mid portions of three panicles of each genotype at anthesis using a stereoscopic binocular microscope, fitted with an ocular micrometer. This was done for each replicate in Planting II of each of the three seasons of study.

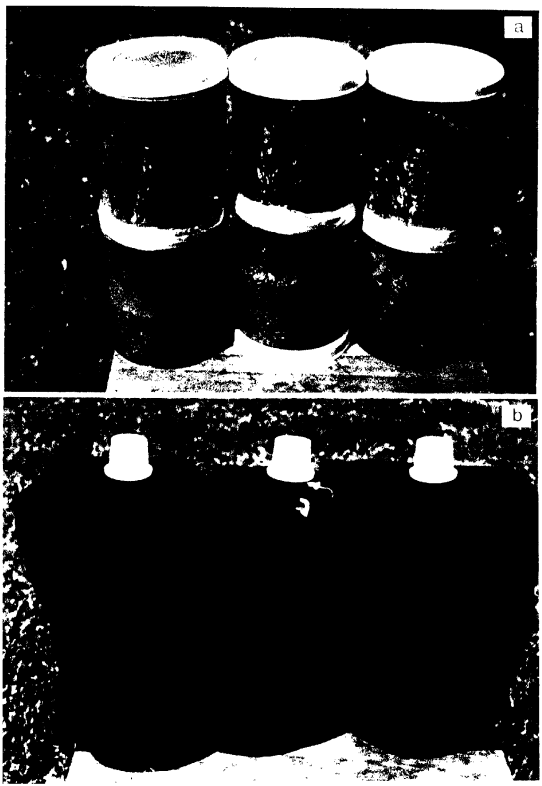

Plate 6 a. Cylindrical plastic containers with midge infested panicles for studies on diurnal pattern of emergence of *Aprostocetus* sp.
b. Cylindrical containers covered with black bags showing the collection container for emerging insects.

The rate of grain development was measured in random samples of 100 grains/replication in Planting II taken from the mid portion of three panicles of each genotype at two day intervals between 50% anthesis and nine days after anthesis. The fresh weights of the developing grain was recorded and thereafter, the grain was oven-dried at 80°C for 24 hours to a constant weight and the dry weight was recorded. This method provided data for both fresh and dry grain weights at various stages of development.

3.5.5 Microclimatic Variables within Sorghum Panicles

Measurements were made in the second planting during the 1993 rainy season to determine if there were differences in panicle microclimate between susceptible and resistant sorghum genotypes. Only two genotypes, CSH 9 (susceptible) and ICSV 745 (resistant) were used in this study. The morphology (compactness) of the two genotypes was similar, so air flow characteristics are expected to be similar. However, differences in the microclimate would be possible if, for example, there were differences in the rate of water loss from the two genotypes.

Measurements regarding air temperature and humidity, wind speed in the crop, and the average panicle temperature on panicle of each genotype were taken. Air temperature and humidity were measured with a dry and wet bulb ventilated psychrometer. The temperature sensors were thermistors (Omega Precision thermistors with 2252 ohms at 25°C) which had been individually calibrated. Run of wind was measured with a sensitive cup anemometer (Metone 014A) to give the average wind

speed every 30 minutes. In addition, the average temperature of one panicle on each genotype was measured. This was achieved using five pairs of copper/constantan thermocouples (0.1 mm diameter enamelled wire with PVC coating) connected in series. Each of the five measuring junctions was attached to the panicle so that they were evenly spaced around the head. The reference junctions were placed in a ventilated radiation shield so that the thermocouple output was proportional to the difference between panicle and air temperatures. This arrangement gave a resolution better than 0.05°C and an accuracy of 0.1°C. The outputs from all the microclimate sensors were measured every minute on a data logger (Campbell 21X), programmed to record the average values every 30 minutes. This microclimate variable was chosen because it was a straight forward measurement which did not disturb the structure of the panicles. A significant difference in the rate of water loss from the panicles would be reflected in a difference in panicle temperature.

3.3 STASTICAL ANALYSIS

To test the differences among the genotypes in the experiments conducted, Fisher's method for Randomized block design analysis of variance (ANOVA) and standard error were applied for analysis and interpretation of data (Fisher 1938).

RESULTS

CHAPTER IV

RESULTS

4.1 SPECIES COMPOSITION OF NATURAL ENEMIES OF *Contarinia sorghicola*

Natural enemies of sorghum midge collected during 1992-93, revealed that the composition included three larval parasitoids, *viz.*, *Aprostocetus* sp. (Eulophidae : Hymenoptera), *Eupelmus* sp. (Eupelmidae : Hymenoptera) and *Apanteles* sp. (Braconidae : Hymenoptera) and one predator, *Orius* sp. (Anthocoridae : Hemiptera). *Aprostocetus* sp. was the predominant parasitoid in both rainy and post-rainy seasons. The identification services report from International Institute of Entomology, Commonwealth Agricultural Bureaux, London, received at the end of the study indicated that two species of *Aprostocetus*, *A. gala* (Walker) and *A. coimbatorensis* (Rowher) occur at ICRISAT Center. For the purpose of this study, both species are considered as a complex of *Aprostocetus* sp.

All four species of natural enemies were present through out the rainy and post-rainy seasons (Figure 1). *Aprostocetus* sp. was the predominant species constituting about 90% of the total natural enemies collected in all the three seasons. *Eupelmus* sp. was active during early plantings and declined as the season progressed. *Apanteles* sp. was found to be active only during rainy season and was either totally absent or present in negligible numbers in the post-rainy season. Its activity in the rainy season increased as the season progressed and a maximum of 192 individuals were collected in the third planting alone during the 1993 rainy season. Of the two cropping seasons, the post-rainy

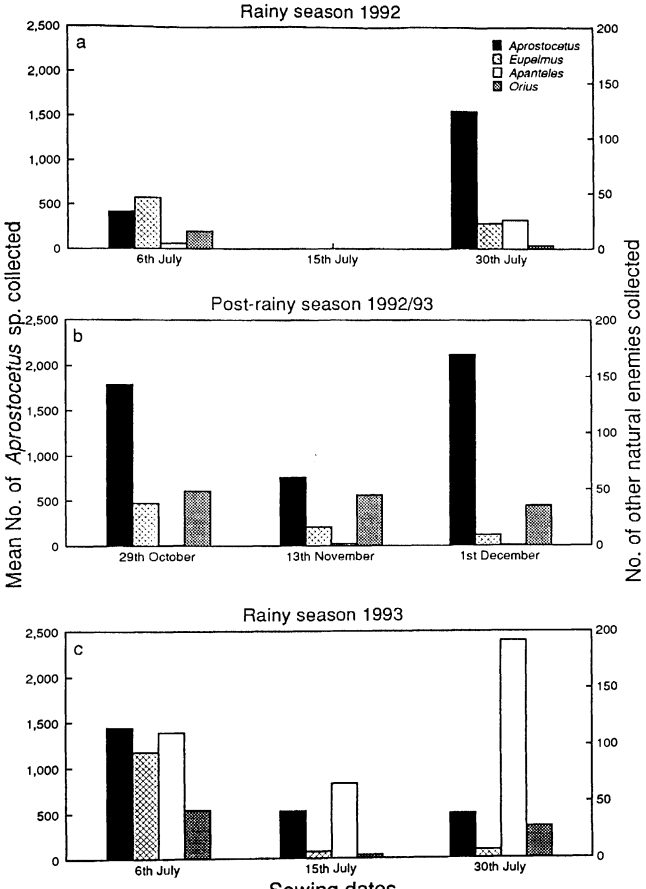

Figure 1. Natural enemies of sorghum midge collected at ICRISAT Asia Center during 1992-93

season was congenial for the activity of *Orius* sp. A decline in activity of all natural enemies was observed during the second planting of both rainy and post-rainy seasons (3rd week of July & 3rd week of November) in each of the three seasons.

4.2 POPULATION DYNAMICS OF SORGHUM MIDGE AND ITS MAJOR PARASITOID, *Aprostocetus* sp.

4.2.1 Rainy Season 1992

Being the first season of the study, only the parasitoid emergence was recorded during the rainy season 1992 and midge emergence was not recorded. *Aprostocetus* sp. was active from the 2nd week of October to the last week of November. Parasitoid activity was first recorded in susceptible genotypes during the 2nd and 3rd weeks of October (Figure 2, weeks 41 & 42) and the mean weekly collections ranged from 0.78 - 1.26 parasitoids/panicle. However, peak activity occurred in the 3rd planting during the 3rd week of November (Figure 2, week 47) and weekly collections ranged from 1.4 - 9.0 in susceptible and 1.5 - 4.5 parasitoids/panicle in resistant genotypes.

4.2.2 Post-rainy Season 1992/93

Adult midge flies emerged 2 - 3 weeks prior to parasitoid emergence during the 1992/93 post-rainy season. The first distinct peak in midge emergence occurred in the 2nd week of February (Figure 3, week 7) in susceptible ICSV 112, CSH 9, Swarna and resistant ICSV 89058. Several generations of midge flies occurred on susceptible genotypes during the season and the highest number of midges were recorded on ICSV 112 in the 4th week of February (Figure 3c, week 9).

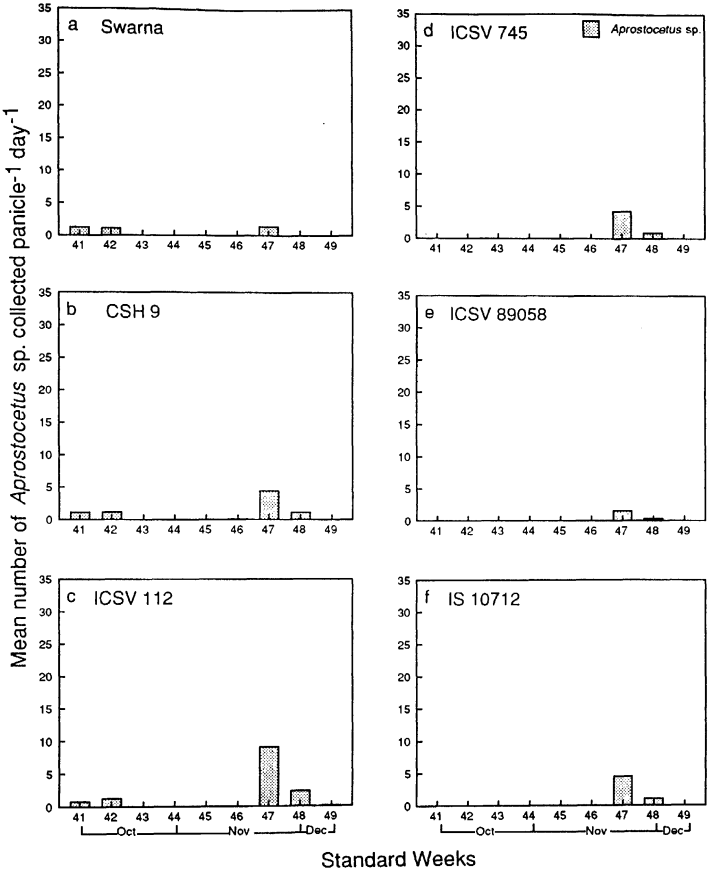

Figure 2. Population dynamics of *Aprostocetus* sp. during rainy season 1992 at ICRISAT Asia Center.

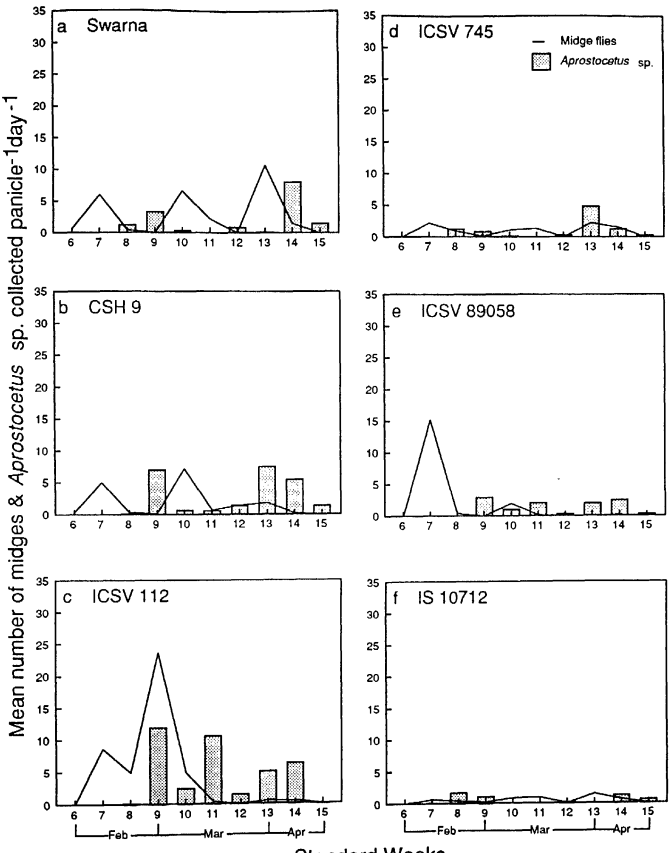

Figure 3. Population dynamics of Sorghum midge and *Aprostocetus* sp. during post-rainy season 1992/93 at ICRISAT Asia Center.

The first emergence of adult *Aprostocetus* sp. was recorded in the 3rd week of February (Figure 3, week 8). High activity of the parasitoid occurred in February (Figure 3 week 9), late March (week 13) and early April (week 14). More individuals were recovered from susceptible than from resistant sorghum genotypes. Irrespective of density, parasitoid activity was always associated with midge infestation, even at low levels, in resistant genotypes. However, this relationship was present only to a lesser extent in susceptible genotypes.

4.2.3 Rainy Season 1993

Midge fly emergence was recorded 1 - 2 weeks prior to *Aprostocetus* sp. during the 1993 rainy season. The first distinct peak in midge emergence occurred during the 2nd week of October (Figure 4, week 41) in all genotypes except ICSV 112 and ICSV 89058 in which it was recorded during the 3rd week of October (Figure 4c & e, week 42). Two distinct peaks occurred in all the genotypes except in ICSV 112 which had only one major peak (Figure 4c week 42).

The activity of *Aprostocetus* sp. occurred between the 1st week of October and last week of November (Figure 4, weeks 41 - 48) but varied among the genotypes. There was continuous activity from 1st week of October to last week of November (Figure 4, weeks 41 - 47/48) in susceptible genotypes while it was restricted to 3rd week of October and 1st week of November (Figure 4, weeks 42 - 44) in resistant genotypes. However, in IS 10712, considerable activity of *Aprostocetus* sp. was recorded during the 2nd fortnight of November (Figure 4f, weeks 47 & 48) as in susceptible genotypes. Swarna among the

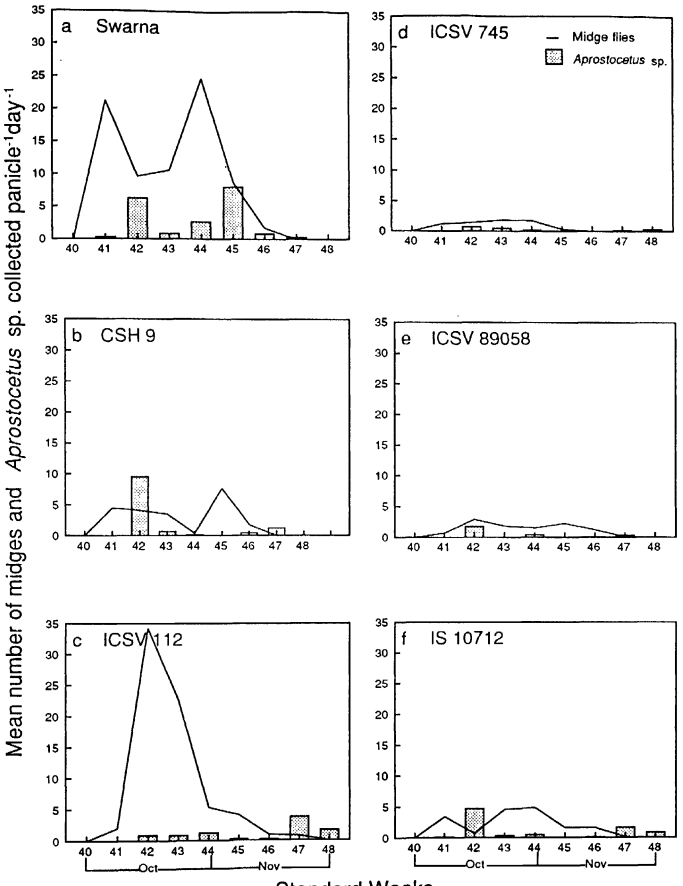

Figure 4. Population dynamics of Sorghum midge and *Aprostocetus* sp. during rainy season 1993 at ICRISAT Asia Center.

susceptible and IS 10712 among the resistant genotypes, recorded maximum activity of the parasitoid. As in the post-rainy season, *Aprostocetus* sp. was also found to be associated with low midge populations in resistant genotypes but this trend was not evident in susceptible genotypes.

4.2.4 Influence of Climatic Factors on Parasitoid Activity

Data on climatic variables that are likely to influence parasitoid activity were obtained from the Meteorological laboratory at the ICRISAT farm. Data are for the period after 50% anthesis during rainy and post-rainy season trials which were sown in July and October respectively. This period coincides with both midge and parasitoid activity. During the 1992 rainy season, rainfall was distributed between week 39 and 46 (end of September to middle of November) (Figure 5a) and ranged from 0.6 - 11.0 mm/week. Maximum temperature recorded was around 30°C between week 38 and week 45 (mid September to early November) after which it declined to 27°C after week 45 (Figure 5a). There were considerable fluctuations in minimum temperatures. They ranged between 20 - 22°C between weeks 38 and 43 (mid September to 4th week of October (Figure 5a weeks 41 - 43), declined thereafter to 15 - 19°C in weeks 44 -47 (November) (Figure 5a) and 12 - 14°C during weeks 48 & 49 (early December). Relative humidity (RH) recorded at 0700 hours was more than 90% between weeks 38 and 41 (3rd week of September to 2nd week of October) and also between weeks 47 and 49 (3rd week of November and 1st week of December). There was considerable decline during weeks 42 to 46 (3rd week of October to 2nd week of November) (Figure 5a). The RH at 1400 hours fluctuated over the season

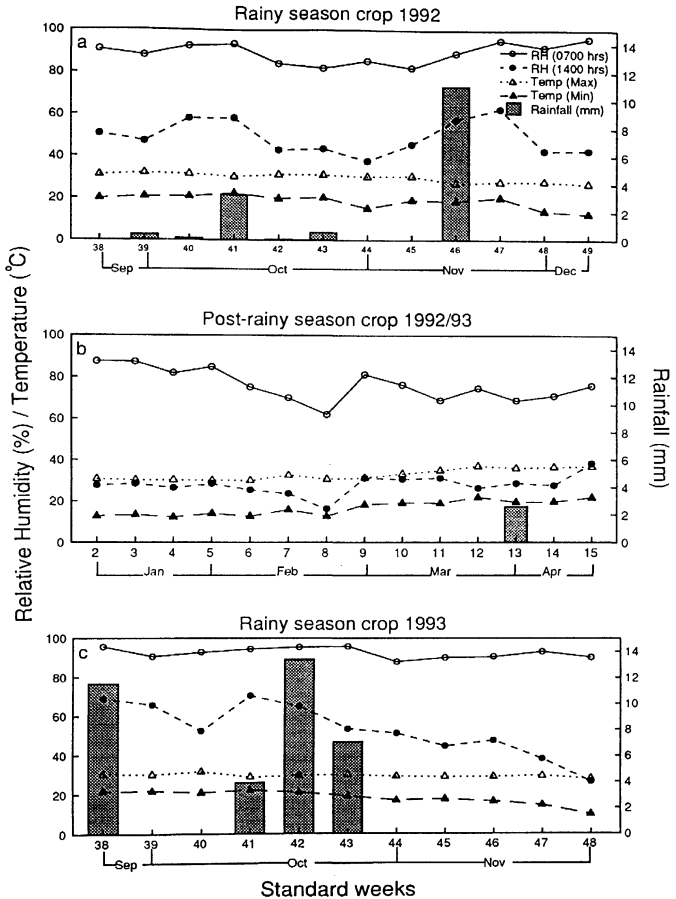

Figure 5. Seasonal fluctuation of climatic variables at ICRISAT Asia Center from 50% anthesis to crop maturity during rainy and post-rainy seasons 1992-93

but declined as the season progressed from 58 - 42% between weeks 38 (Figure 5a September) and 49 (December) (Figure 5a).

No rainfall was recorded during the 1992/93 post-rainy season until the last week of March (Figure 5b week 13). Minimum and maximum temperatures gradually increased as the season progressed and ranged from 13 - 22°C and 30 - 37°C respectively. RH at 0700 and 1400 hours fluctuated between 61 - 87% and 16 - 31% respectively throughout the season.

During the 1993 rainy season, rainfall was recorded during week 38 (3rd week of September) and between weeks 41 to 43 (2nd to 4th weeks of October) (Figure 5c) (4 - 13mm/week). Maximum temperature was constant at 28 - 30°C throughout the period while minimum temperature decreased from 22°C during week 38 (3rd week of September) to 10°C in week 48 (last week of November) (Figure 5c). RH at 0700 hours remained around 90% while RH at 1400 hours fluctuated considerably and dropped to 27% at the end of the season.

The results clearly show that climatic conditions influence the population dynamics of midge and *Aprostocetus* sp. and that the effect varied between the rainy and post-rainy seasons. Midge population was high when maximum temperature was 27 - 31°C and RH at 0700 and 1400 hours was 82 - 96% and 40 - 71% respectively in the rainy season 1993. However, *Aprostocetus* sp. was active at slightly increased temperature levels between 30 - 36 °C and RH at 0700 and 1400 hours was 61 - 76% and 23 - 31% respectively in the 1992/93 post-rainy season.

4.3 EMERGENCE PATTERN OF MIDGE AND *Aprostocetus* sp. IN SUSCEPTIBLE AND RESISTANT SORGHUM GENOTYPES

4.3.1 Rainy Season 1992

4.3.1.1 Exposed Panicles. Being the first season of study, data on emergence of parasitoid adults was only recorded on a daily basis and data was not recorded on midge emergence from both panicles that were unexposed and exposed to natural parasitization. There were distinct differences in the activity of *Aprostocetus* sp. among the three planting dates (Table 1). Parasitoids emerged from only susceptible genotypes in planting I while in planting II there was no parasitoid emergence from either group of genotypes. Activity increased considerably during planting III which gave the highest number of parasitoids. Although *Aprostocetus* sp. activity was low in midge susceptible Swarna in planting III (6.1/panicle) compared to planting I (15.9/panicle), emerging numbers in resistant ICSV 745 (35.9/panicle) and IS 10712 (39.3/panicle) were comparable to that in susceptible CSH 9 (38.8/panicle). The lowest numbers were recorded from resistant ICSV 89058 (13.0/panicle) and the highest (80.1) from susceptible ICSV 112.

4.3.2 Post-rainy Season 1992/93

4.3.2.1 Unexposed Panicles. Midge emergence from the unexposed panicles showed clear variations in the behaviour of genotypes across plantings, and marked differences between susceptible and resistant genotypes (Table 2). ICSV 112 differed significantly from other susceptible genotypes while IS 10712 differed from other resistant genotypes. The greatest number of midges emerged from ICSV 112 (196.4/panicle) in planting II and the lowest (1.3/panicle) from ICSV 89058 in planting III.

Table 1. Emergence of *Aprostocetus* sp. from panicles of resistant and susceptible sorghum genotypes exposed to natural parasitization, rainy season 1992, ICRISAT Asia Center.

	No. of *Aprostocetus* sp. emerged		
	Plantings		
Genotype	I*	II	III
Swarna	15.9	0.0	6.1
CSH 9	16.0	0.0	38.8
ICSV 112	14.3	0.0	80.1
ICSV 745	0.0	0.0	35.9
ICSV 89058	0.0	0.0	13.0
IS 10712	0.0	0.0	39.3
Mean	15.4	0.0	35.5
SE	±7.3	±0.0	±21.7

* Planting I, II and III = 6th, 15th and 30th July 1992 respectively

Table 2. Emergence of *C. sorghicola* (*C.s*) and *Aprostocetus* sp. (*A.*sp) from panicles of resistant and susceptible sorghum genotypes unexposed and exposed to natural parasitization, post-rainy season 1992/93, ICRISAT Asia Center.

	Plantings								
	I*			II			III		
	Unexp	Exposed		Unexp	Exposed		Unexp	Exposed	
Genotype	*C.s*	*C.s*	*A.*sp.	*C.s*	*C.s*	*A.*sp.	*C.s*	*C.s*	*A.*sp.
Swarna	49.7	69.9	28.1	61.4	45.0	9.2	83.0	46.1	66.1
CSH 9	39.3	87.8	52.6	54.2	37.0	11.7	23.8	20.9	69.1
ICSV 112	98.8	126.5	88.5	196.4	99.0	48.6	5.7	30.4	65.1
ICSV 745	22.3	16.9	8.4	16.9	10.0	2.5	26.0	11.1	4.6
ICSV 89058	13.9	38.2	15.3	53.5	38.0	11.8	1.3	8.8	22.1
IS 10712	4.7	11.5	10.4	12.3	5.0	0.9	15.4	11.4	12.3
Mean	38.1	58.0	33.9	65.8	39.0	22.1	25.9	21.4	39.9
SE	±16.2	±36.2	±26.4	±26.2	±37.3	±22.2	±17.3	±6.2	±22.2

* Planting I, II and III = 29th Oct, 13th Nov and 1st Dec 1992 respectively

Midge emergence was generally lower in resistant genotypes than in susceptible genotypes. However, resistant ICSV 89058 with the lowest figure (1.3/panicle) in planting III, recorded similar emergence (53.5/panicle) as susceptible CSH 9 (54.2/panicle) in planting II. With the exception of Swarna, midge activity was generally low in planting III in all the genotypes (Table 2).

4.3.2.2 Exposed Panicles. Adult midge flies from unparasitized midge larvae and *Aprostocetus* sp emerging from exposed panicles were collected in all the plantings during this season (Table 2). Midge emergence also showed clear variations in genotypic behaviour across plantings, and maintained distinct differences between resistant and susceptible genotypes. The greatest numbers of midges were collected in planting I, and was highest in susceptible genotypes, ranging between 69.9 - 126.5/panicle. The pattern of midge emergence in planting II was similar to that of unexposed panicles and the numbers generally declined in planting II and continued to decline in planting III. However, the distinction between resistant and susceptible genotypes remained evident.

In contrast to midge, emergence of *Aprostocetus* sp. was lower in plantings I and II but higher in planting III. It was however, higher in planting I than in planting II. Low numbers were recorded in resistant genotypes than in susceptible ones in all three plantings.

In planting I, emergence of *Aprostocetus* sp ranged between 28.1 - 88.5/panicle in susceptible genotypes and 8.4 - 15.3/panicle in resistant genotypes and the highest was recorded in ICSV 112. The activity of *Aprostocetus* sp. declined in planting II, though

moderately high emergence was observed in ICSV 112 (48.6/panicle). Low numbers were collected from susceptible CSH 9 and Swarna and resistant ICSV 89058 (11.7, 9.2 and 11.8/panicle respectively). Parasitoid emergence was negligible from ICSV 745 and IS 10712. In planting III, parasitoid emergence differed significantly between resistant and susceptible genotypes e.g., 65.1 - 69.1/panicle in susceptible and 4.6 - 22.1/panicle in resistant genotypes

Generally, the total number of insects, i.e. midge and *Aprostocetus* sp. combined, that emerged from the exposed panicles were higher in planting I and III compared to midges alone emerging from unexposed panicles (Table 2).

4.3.3 Rainy Season 1993

The total relative emergence of midge and *Aprostocetus* sp. was generally higher during the 1993 rainy season than during the post-rainy season (Table 2 & 3). However, in absolute numbers, midge population was higher during the rainy season than in the post-rainy season whereas, the reverse was true for *Aprostocetus* sp.

4.3.3.1 Unexposed Panicles. Midge emergence from unexposed panicles showed considerable variation for the same genotype across plantings but significant differences between resistant and susceptible genotypes. Among susceptible genotypes, it was consistently low in CSH 9 throughout the season. On the other hand, emergence pattern was not affected by planting date in resistant ICSV 89058.

In planting I, midge emergence from resistant genotypes ranged from 18.8/panicle in ICSV 745 to 28.4/panicle in IS 10712. In contrast, high figures were recorded in susceptible Swarna (216.6/panicle) and ICSV 112 (265.4/panicle). The trend was similar in planting II except on IS 10712 where it was slightly higher (67.2 midges/panicle). In general, midge emergence was low in planting III, and among resistant genotypes, it was negligible in ICSV 745.

4.3.3.2 Exposed Panicles. In general, the total midge and parasitoid populations collected from exposed panicles were higher than the total midge population alone from unexposed panicles. Midge emergence followed the same pattern as in earlier observations for individual genotypes, across plantings, and between resistant and susceptible genotypes (Table 3). Midge activity declined considerably during planting III compared to plantings I and II. Planting was found to have no influence on maximum emergence of midges. For instance, the greatest numbers were recorded in planting I for susceptible CSH 9 and ICSV 112 and resistant ICSV 745 and ICSV 89058; whereas for Swarna, it was in planting II, and planting III for IS 10712. Furthermore, for CSH 9, more midge flies emerged from exposed panicles in plantings I and III than from unexposed panicles in all three plantings (Table 3). This was also partly the case in ICSV 112.

The numbers of emerging *Aprostocetus* sp. were far lower than midges in exposed panicles. Parasitoid activity was negligible in planting II across genotypes (1.3 - 9.3/panicle) except in Swarna (59.0/panicle). In planting I, parasitoid emergence from ICSV 112, ICSV 745 and ICSV 89058 were generally low (7.7 - 12.4/panicle) while it was

Table 3. Emergence of *Contarinia sorghicola* (*C.s*) and *Aprostocetus* sp. (*A.*sp.) from panicles of resistant and susceptible sorghum genotypes unexposed and exposed to natural parasitization, rainy season 1993, ICRISAT Asia Center.

	Planting								
	I			II			III		
	Unexp	Exposed		Unexp	Exposed		Unexp	Exposed	
Genotype	*C.s*	*C.s*	*A.*sp.	*C.s*	*C.s*	*A.*sp.	*C.s*	*C.s*	*A.*sp.
Swarna	216.6	104.8	51.9	262.5	151.2	59.0	77.1	84.2	2.4
CSH 9	60.1	113.8	71.2	28.8	45.9	1.3	65.9	75.4	12.5
ICSV 112	265.4	276.7	12.4	197.4	251.0	9.3	101.1	57.6	29.1
ICSV 745	18.8	18.0	7.7	24.6	16.6	3.2	2.1	7.2	0.0
ICSV 89058	27.1	28.5	12.2	23.4	15.0	2.6	24.5	15.2	0.8
IS 10712	28.4	33.3	36.3	67.2	20.6	3.2	23.6	40.6	16.3
Mean	103.0	96.0	32.0	101.0	83.0	13.1	49.0	46.7	10.2
SE	±26.3	±19.7	±8.3	±56.0	±40.3	±8.2	±19.7	±15.5	±1.8

* Planting I, II and III = 2nd Jul, 19th Jul and 6th Aug 1993 respectively

high in Swarna, CSH 9 and IS 10712 (36.3 - 71.2/panicle). *Aprostocetus* sp. emergence was not associated with genotype resistance or susceptibility to midge.

4.4 LEVEL OF MIDGE INFESTATION IN SUSCEPTIBLE AND RESISTANT GENOTYPES DURING RAINY SEASON 1993

In general, midge infestation was significantly higher in susceptible genotypes than in resistant ones for total number of florets with midge larvae and total number of larvae/100 florets (Table 4). This was also the case irrespective of whether panicles had been exposed to parasitization or not. However, the values for exposed and unexposed panicles varied between planting dates. In planting I, except for Swarna and IS 10712, there were no differences between exposed and unexposed panicles for both parameters recorded. On the other hand, in planting II and III, the values were consistently higher in the exposed panicles for susceptible genotypes. For resistant genotypes however, there was no consistency either in the number of eggs or total number of larvae per 100 florets.

4.5 PARASITIZATION OF MIDGE LARVAE IN SUSCEPTIBLE AND RESISTANT GENOTYPES

4.5.1 Rainy Season 1992

In the 1992 rainy season being the first season of study the data on midge emergence was not available. Therefore, the level of parasitization by *Aprostocetus* sp. was assessed based on chaffy florets with parasitoid exit holes (Table 5). In the first planting, the level of parasitization was high in susceptible Swarna but negligible in other genotypes. No parasitization was observed in resistant ICSV 745 and ICSV 89058. No chaffy florets were observed in any genotype in planting II though midge infestation

Table 4. Level of infestation by *Contarinia sorghicola* on panicles of susceptible and resistant sorghum genotypes unexposed (Unex) and exposed (Exp) to parasitization in three plantings, rainy season 1993, ICRISAT Asia Center.

	Plantings											
	I**				II				III			
	Florets with larvae		Total no. of larvae*		Florets with larvae		Total no. of larvae		Florets with larvae		Total no.of larvae	
Genotypes	Unex	Ex	Unex	Ex	Unex	Ex	Unex	Ex	Unex	Ex	Unex	Ex
Swarna	58.0	52.7	80.3	67.3	48.0	63.7	68.0	103.0	52.7	60.0	69.3	73.7
CSH 9	31.7	31.3	35.7	34.0	32.3	40.3	38.3	47.3	45.0	64.0	52.7	85.0
ICSV 112	24.0	22.7	27.0	25.7	34.0	46.7	39.0	58.7	37.0	52.0	43.3	60.7
ICSV 745	5.7	5.3	5.7	5.3	7.3	11.0	7.7	11.0	6.0	6.3	6.0	6.3
ICSV 89058	8.3	9.3	8.3	9.0	7.0	13.7	7.0	16.3	13.0	14.0	13.7	15.0
IS 10712	13.7	18.3	14.3	19.0	18.7	20.7	22.0	22.0	11.0	19.7	11.0	20.7
Mean	23.6	23.3	28.6	26.7	24.6	32.7	30.3	43.1	27.4	36.0	32.7	43.6
SE	±12.5	±9.1	±14.4	±9.7	±7.8	±15.5	±15.7	±23.0	±6.2	±5.4	±9.6	±9.2

* per 100 florets

** Planting I, II and III = 2nd Jul, 19th Jul and 6th Aug 1993 respectively

Table 5. Levels of parasitization* of *C. sorghicola* by *Aprostocetus* sp. in three plantings of susceptible and resistant sorghum genotypes, rainy season 1992, ICRISAT Asia Center.

	Extent of parasitization (%)		
	Plantings		
Genotypes	I**	II	III
Swarna	19.2	0.0	13.3
CSH 9	2.6	0.0	22.4
ICSV 112	5.2	0.0	25.2
ICSV 745	0.0	0.0	4.2
ICSV 89058	0.0	0.0	13.5
IS 10712	0.0	0.0	19.4
Mean	4.9	0.0	16.3
SE	±1.1	±0.0	±4.6

* Based on % chaffy florets with *Aprostocetus* sp. exit holes
** Planting I, II and III = 6th, 15th and 30th July

(% chaffy florets) ranged from 13 - 23% in resistant and 48 - 56% in susceptible genotypes. In the third planting, parasitization was recorded in all genotypes and the level ranged from 13.3 - 25.2%, with the highest on ICSV 112. The same levels were recorded on Swarna and ICSV 89058 while on IS 10712 it was slightly higher.

4.5.2 Post-rainy Season 1992/93

Although there were clear differences in midge infestation and parasitoid numbers between resistant and susceptible genotypes (Table 2), the levels of parasitization indicated a different picture (Table 6). Parasitization was highest in planting III (51.9 - 76.3%) and lowest in planting II (15.0 - 28.5%). It was the same or higher in resistant ICSV 89058 (30.5 - 72.2%) than in susceptible CSH 9 (23.7 - 76.3%) and ICSV 112 (28.5 - 68.0%) in all the plantings. Trends were also similar in resistant IS 10712 and susceptible Swarna both in which low levels were recorded. Overall, the lowest level of parasitization was recorded in ICSV 745 (20.2 - 29.7%).

4.5.3 Rainy Season 1993

Levels of parasitization were much lower in the rainy season than in post-rainy season. The trend in parasitization also varied considerably for genotypes and plantings and was not associated with resistance or susceptibility to midge (Table 7).

Mean parasitization levels were generally highest in planting I, and apart from ICSV 112 with 5.3%, it ranged between 30.1 and 45.8%. Mean parasitization declined in planting II and did not differ significantly from planting III. There was no distinct pattern

Table 6. Levels of parasitization of *Contarinia sorghicola* by *Aprostocetus* sp. in three plantings of susceptible and resistant sorghum genotypes, post-rainy season 1992/93, ICRISAT Asia Center.

	Extent of parasitization (%)		
	Plantings		
Genotypes	I*	II	III
Swarna	35.8	16.8	56.1
CSH 9	48.8	23.7	76.3
ICSV 112	41.1	28.5	68.0
ICSV 745	29.7	20.2	28.8
ICSV 89058	44.8	30.5	72.2
IS 10712	36.2	15.0	51.9
Mean	39.4	22.4	58.9
SE	±32.9	±0.8	±0.5

* Planting I, II and III = 29th Oct, 13th Nov and 1st Dec 1992 respectively

Table 7. Levels of parasitization of *C. sorghicola* by *Aprostocetus* sp. in three plantings of susceptible and resistant sorghum genotypes, rainy season 1993, ICRISAT Asia Center.

	Extent of parasitization (%)		
	Plantings		
Genotypes	I	II	III
Swarna	34.1	24.9	3.8
CSH 9	37.1	3.6	16.3
ICSV 112	5.3	8.2	31.4
ICSV 745	34.2	6.7	0.0
ICSV 89058	30.1	17.9	8.9
IS 10712	45.8	14.2	26.8
Mean	31.1	12.6	14.5
SE	±11.7	±10.7	±7.9

* Planting I, II and III = 2nd Jul, 19th Jul and 6th Aug 1993 respectively

of parasitization within and between genotypes and plantings. For example, for ICSV 745, it was 34.2 and 0.0% for planting I and III respectively whereas for ICSV 112, it was the reverse, 5.3 and 31.4% for planting I and III respectively.

4.6 STUDIES ON THE TRITROPHIC INTERACTIONS IN SORGHUM, SORGHUM MIDGE AND PARASITOIDS.

Studies on the preferred host developmental stage for parasitization in susceptible and resistant genotypes revealed that preference varied greatly with season and genotype.

During the 1992/93 post-rainy season, *Aprostocetus* sp. preferred 6 - 15 day old midge larvae, *viz.*, mid to late larval stages (Table 8). However, preference varied with genotype and was irrespective of resistance or susceptibility to midge. The greatest number of *Aprostocetus* emerged when parasitization occurred at the 6-day old larval stage in ICSV 89058 while it was at the 9-day old stage in CSH 9 and IS 10712. However, in other genotypes, late larval stages were preferred. Maximum emergence of *Aprostocetus* sp. was recorded upon parasitization of 12 day old midge larvae in ICSV 112 and ICSV 745 and 15 day old in Swarna.

The host stage preference varied during the 1993 rainy season. Maximum emergence of *Aprostocetus* sp. occurred upon parasitization of 3-day old midge larvae in all genotypes except ICSV 112 and IS 10712 in which maximum numbers emerged upon parasitization of 6-day old larvae (Table 9). Though the parasitoid preferred the early stage larvae, few individuals emerged upon parasitization of mid and late larval stages. No parasitoid emerged from 15 day old larvae in this season.

Table 8. Effect of genotype and developmental stage of *C. sorghicola* on development and emergence of *Aprostocetus* sp. in midge infested panicles of susceptible and resistant sorghum genotypes, post - rainy season 1992/93, ICRISAT Asia Center.

	Age of midge larva during release of *Aprostocetus* sp. for parasitization				
	3 DAI*	6 DAI	9 DAI	12 DAI	15 DAI
Genotype	No. of *Aprostocetus* sp.				
Swarna	1.0	5.0	14.3	11.7	24.3
CSH 9	1.0	9.3	47.3	20.3	22.3
ICSV 112	0.0	0.0	11.0	23.7	17.3
ICSV 745	0.0	0.3	1.0	6.0	1.3
ICSV 89058	0.0	12.7	1.7	0.0	2.7
IS 10712	0.0	0.0	0.3	0.0	0.0
Mean	0.3	4.6	12.6	10.3	11.3
SE	±0.9	±8.9	±19.7	±8.5	±6.9

* Release of *Aprostocetus* sp. 3 days after midge infestation (DAI)

Table 9. Effect of genotype and developmental stage of *C. sorghicola* on development and emergence of *Aprostocetus* sp. in midge infested panicles of susceptible and resistant sorghum genotypes, rainy season 1993, ICRISAT Asia Center.

	Age of midge larva during release of *Aprostocetus* sp. for parasitization				
	3DAI*	6 DAI	9 DAI	12 DAI	15 DAI
Genotype	No. of *Aprostocetus* sp.				
Swarna	40.0	12.7	3.0	0.0	0.0
CSH 9	116.0	37.3	0.7	0.7	0.3
ICSV 112	0.0	82.7	22.7	17.3	0.7
ICSV 745	2.0	0.3	0.3	0.0	0.3
ICSV 89058	3.0	0.7	1.7	1.7	0.0
IS 10712	8.0	12.7	2.0	0.0	0.0
Mean	28.0	24.4	5.1	3.3	0.2
SE	±42.7	±28.2	±4.5	±3.9	±0.5

Release of *Aprostocetus* sp. 3 days after midge infestation (DAI)

Further evaluation in the 1993 rainy season by destructive sampling of spikelets (dissection of 100 florets) one week after release of *Aprostocetus*, confirmed the results obtained from emerging adult parasitoids. The maximum number of *Aprostocetus* sp. larvae was recovered when parasitization occurred at the 3-day old larval stage in all genotypes except in ICSV 112 and IS 10712 in which 6- and 9-day old midge larvae were preferred respectively (Table 10). There was no recovery of *Aprostocetus* sp. larvae from ICSV 745 although midge infestation was recorded on this genotype (Table 10).

4.6.1 Diurnal Pattern of Emergence of *Aprostocetus* sp. in Susceptible and Resistant Sorghum Genotypes.

In the preliminary study using randomly collected panicles from the field during the 1992/93 post-rainy season, results showed that emergence of parasitoids started between 0400 - 0600, increased gradually and reached a peak between 0800 - 1000 hours (Figure 6). A smaller peak was also recorded between 1200 - 1400 hours.

During the rainy season of 1993, detailed field studies indicated that peak emergence was between 0600 - 0800 hours and declined between 0800 - 1000 hours in all genotypes (Figure 6b). Another peak was recorded in susceptible genotypes between 1600 - 1800 hours. A similar observation was not recorded in resistant genotypes. No emergence was recorded in resistant ICSV 745.

4.6.2 Effect of Glume Length and Rate of Grain Development on Midge Parasitization by *Aprostocetus* sp.

Susceptible and resistant genotypes did not significantly differ in glume length and rate of grain development in rainy and post-rainy seasons. However in 1993 rainy season,

Table 10. Effect of genotype and developmental stage of *C. sorghicola* on oviposition of *Aprostocetus* sp. in midge infested panicles of susceptible and resistant sorghum genotypes, rainy season 1993, ICRISAT Asia Center.

Genotypes	Age of midge larva during release of *Aprostocetus* sp. for parasitization									
	3 DAI* No.of larvae**		6 DAI No. of larvae		9 DAI No. of larvae		12 DAI No. of larvae		15 DAI No. of larvae	
	C.s	*A.*sp.	*C.s*	*A.*sp.	*C.s*	*A.*sp.	*C.s*	*A.*sp.	*C.s*	*A.*sp.
Swarna	115.7	19.3	106.3	9.4	112.0	1.7	45.0	1.3	63.8	1.0
CSH 9	95.0	14.7	57.3	3.0	60.7	0.0	62.0	0.0	77.7	0.0
ICSV 112	59.3	0.3	57.3	16.3	49.3	12.3	50.0	0.7	51.0	7.0
ICSV 745	2.7	0.0	3.7	0.0	2.0	0.0	1.7	0.0	1.3	0.0
ICSV 89058	7.0	0.3	6.0	0.0	1.7	0.0	1.7	0.0	3.3	0.0
IS 10712	23.7	0.3	13.7	1.3	15.7	2.0	4.3	0.0	5.3	0.0
Mean	50.6	5.8	40.7	5.0	40.2	2.7	27.4	1.3	33.8	1.3
SE	±12.9	±4.4	±15.1	±3.9	±23.2	±4.3	±13.4	±2.0	±9.5	±0.9

* Release of *Aprostocetus* sp. 3 days after midge infestation (DAI)

** Larvae recovered from 100 florets

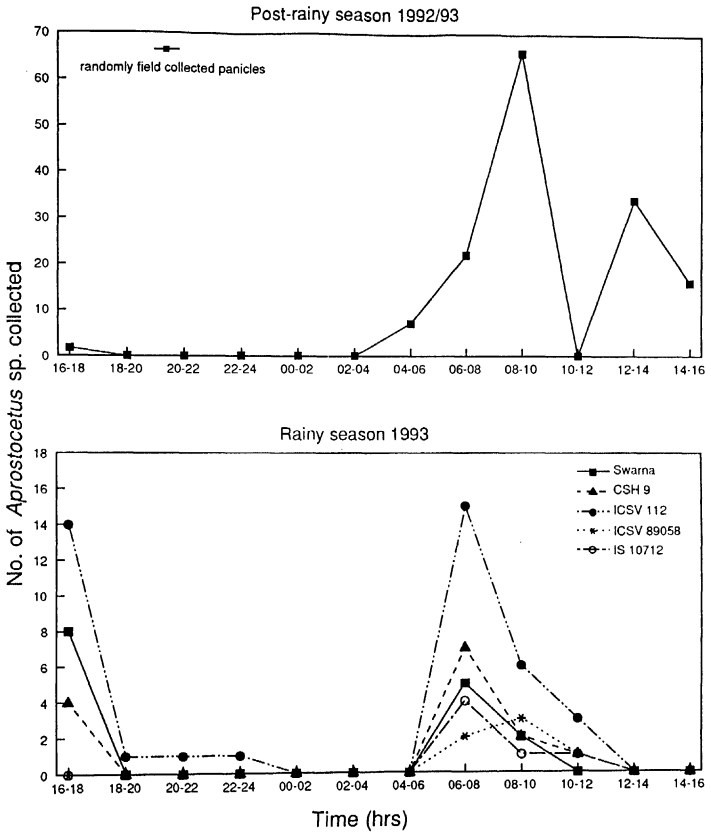

Figure 6. Diurnal emergence pattern of *Aprostocetus* sp. from midge infested susceptible and resistant sorghum genotypes at ICRISAT Asia Center.

the resistant genotypes recorded slightly lower glume lengths compared to susceptible genotypes.

During the 1992 rainy season, no differences in glume length were observed between resistant and susceptible genotypes. The values for minimum and maximum glume lengths were recorded in ICSV 745 and Swarna respectively (Table 11). The rate of grain development for both fresh and dry weights was maximum between 0 and 3 days after half anthesis. There was also no clearcut difference between resistant and susceptible genotypes for this parameter although a very low rate of grain development (fresh weight) was recorded in Swarna.

During the post-rainy season of 1992/93, the pattern was the same. No distinct differences were recorded for both parameters between resistant and susceptible genotypes (Table 12). Minimum and maximum values for glume length were recorded from IS 10712 and Swarna respectively.

Resistant genotypes had shorter glume lengths compared to Swarna and ICSV 112 while CSH 9 was similar to resistant genotypes during 1993 rainy season (Table 13). There was no significant difference in the rate of grain development between resistant and susceptible genotypes.

4.6.3 Microclimatic Variables within Sorghum Panicles.

The measurement of the microclimate in resistant (ICSV 745) and susceptible (CSH 9) panicles to determine its influence on parasitization by *Aprostocetus* sp., indicated no

Table 11. Glume length and rate of grain development in susceptible and resistant sorghum genotypes, rainy season 1992, ICRISAT Asia Center.

			Rate of grain development					
	Glume length		Dry weight			Fresh weight		
Genotype	gl1*	gl2	G1@	G2	G3	G1	G2	G3
Swarna	48.7	51.8	0.50	0.33	0.13	0.58	0.41	0.08
CSH 9	34.3	37.2	0.59	0.30	0.17	0.59	0.34	0.21
ICSV 112	37.9	39.7	0.63	0.16	0.16	0.62	0.17	0.27
ICSV 745	22.4	24.4	0.58	0.34	0.16	0.58	0.35	0.22
ICSV 89058	37.9	38.4	0.63	0.13	0.17	0.64	0.17	0.29
IS 10712	32.3	33.5	0.63	0.10	0.09	0.62	0.13	0.14
Mean	35.6	37.5	0.6	0.2	0.2	0.6	0.3	0.2
SE	±1.3	±1.0	±0.06	±0.06	±0.04	±0.02	±0.08	±0.1

* Linear measurements on ocular scale units (10 ocular units = 1mm)
@ Rate of grain development between 0 & 3, 3 & 6 and 6 & 9 respectively

Table 12. Glume length and rate of grain development in susceptible and resistant sorghum genotypes, post-rainy season 1992/93, ICRISAT Asia Center.

			Rate of grain development					
	Glume length		Dry weight			Fresh weight		
Genotype	gl1*	gl2	G1@	G2	G3	G1	G2	G3
Swarna	56.1	58.0	0.55	0.37	0.35	0.57	0.31	0.53
CSH 9	39.4	41.3	0.54	0.40	0.32	0.55	0.39	0.50
ICSV 112	42.7	43.8	0.58	0.37	0.15	0.59	0.38	0.19
ICSV 745	40.2	42.0	0.57	0.42	0.18	0.56	0.42	0.25
ICSV 89058	45.0	47.2	0.57	0.34	0.21	0.54	0.37	0.31
IS 10712	37.0	37.7	0.54	0.29	0.22	0.53	0.23	0.32
Mean	43.4	45.0	0.56	0.37	0.24	0.56	0.35	0.35
SE	±1.43	±1.2	±0.03	±0.05	±0.03	±0.02	±0.06	±0.04

* Linear measurements on ocular scale units (10 ocular units = 1mm)
@ Rate of grain development between 0 & 3, 3 & 6 and 6 & 9 respectively

Table 13. Glume length and rate of grain development in susceptible and resistant sorghum genotypes, rainy season 1993, ICRISAT Asia Center.

			Rate of grain development					
	Glume length		Dry weight			Fresh weight		
Genotype	gl1*	gl2	G1@	G2	G3	G1	G2	G3
Swarna	51.2	53.0	0.39	0.31	0.17	0.40	0.36	0.24
CSH 9	36.2	38.7	0.50	0.23	0.19	0.45	0.29	0.23
ICSV 112	40.4	42.8	0.51	0.29	0.14	0.50	0.36	0.23
ICSV 745	37.7	40.8	0.46	0.35	0.22	0.41	0.39	0.27
ICSV 89058	39.9	42.1	0.50	0.26	0.15	0.50	0.33	0.25
IS 10712	34.3	37.4	0.46	0.29	0.05	0.41	0.38	0.09
Mean	39.9	42.5	0.47	0.29	0.15	0.44	0.35	0.22
SE	±1.0	±0.7	±0.02	±0.03	±0.03	±0.03	±0.03	±0.03

* Linear measurements on ocular scale units (10 ocular units = 1mm)
@ Rate of grain development between 0 & 3, 3 & 6 and 6 & 9 respectively

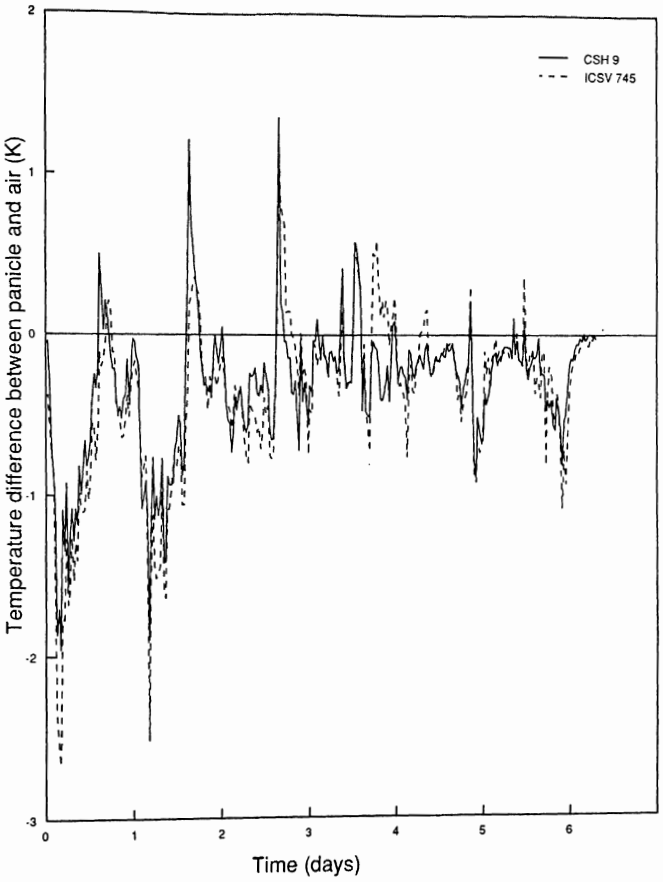

Figure 7. Microclimatic variable (Temperature) within midge susceptible and resistant panicles during rainy season 1993 at ICRISAT Asia Center.

consistent differences in panicle temperatures irrespective of their type and size (Figure 7). Since there was no differences in temperatures between genotypes, it is quite reasonable to assume that there were also no differences in other microclimate variables such as relative humidity. A difference in temperature values between groups of genotypes would reflect differences in other variables such as humidity within the panicle which is considered to also influence insect development.

DISCUSSION

CHAPTER V

DISCUSSION

5.1 SPECIES COMPOSITION OF NATURAL ENEMIES OF MIDGE AND POPULATION DYNAMICS OF *Aprostocetus* sp.

The results of this study showed that sorghum midge is parasitized by *Aprostocetus* sp., *Eupelmus* sp. and *Apanteles* sp. and predated by *Orius* sp. (Figure 1). *Aprostocetus* sp. was the predominant parasitoid in both seasons and other parasitoids occurred in very low numbers. The species composition of natural enemies varied with season and was not affected by varietal resistance to midge. Parasitoids recorded in these studies have been reported elsewhere although the predominant species varied with location. *Aprostocetus* sp. was the predominant parasitoid in Australia (Franzmann *et al.*, 1989) while *Eupelmus* sp. in Maharashtra state (Chundurwar, 1977) of India and in the Philippines (Barrion and Litsinger, 1982). *Tetrastichus* sp. was also reported as predominant in Texas, USA (Baxendale *et al.*, 1983, Brooks and Gillstrap, 1986), Brazil (Busoli *et al.*, 1984), Senegal (Gahukar, 1984) and Karnataka state of India (Rao *et al.*, 1986).

Studies on population dynamics of midge and parasitoid revealed that midge activity was higher in the rainy than in the post-rainy season (Figure 4) while for *Aprostocetus* sp., it was the reverse situation (Figure 3). Although the trends in population fluctuations were more or less similar in midge resistant and susceptible genotypes, resistant genotypes supported lower numbers of both pest and parasitoid. In general, an increase in the midge activity was followed by an increase in *Aprostocetus* sp. activity. The result

of this study agrees with the report of Mote and Ghule (1986) where a positive relationship between sorghum midge and its parasitoids was recorded.

In these studies, irrespective of midge larval stage at the time of parasitization, the emergence of adult *Aprostocetus* sp. occurred 1 - 3 weeks after commencement of midge emergence. This delay period would favour the build up of midge populations in the cropping season. The life cycle of midge is completed in 17 - 20 days under favourable conditions and each female midge produces an average of >100 eggs (Passlow, 1973; Murthy and Subramanium, 1975a). In contrast, the life cycle of *Aprostocetus* sp. is completed in 21 - 25 days and fecundity of *Tetrastichus* sp. is much lower (50 eggs/female) (Taley *et al.*, 1978; Garg, 1979; Thontadarya *et al.*, 1983). Such a disparity in developmental period and fecundity between the pest and its parasitoid will still result in considerable midge damage in susceptible genotypes. Further more, it is not known whether the parasitization of early larval stages of midge is of any significance. The period between midge infestation and its parasitization by *Aprostocetus* sp. (irrespective of the host stage whether early, mid or late larval) which ranges from 5 - 15 days, may affect successful control of the pest.

The pattern of midge emergence from midge infested panicles which had not been exposed to parasitization varied with season; emergence being higher in the 1993 rainy season than in the 1992/93 post-rainy season (Table 2 and 3). This also agrees with the findings of Sharma (1985a) who reported a major peak in midge population in October. There was a marked overall difference in the pattern of midge emergence between resistant and susceptible genotypes throughout the study, in spite of considerable

differences within each group. Low emergence of sorghum midge in resistant genotypes was largely due to resistance factors, such as physical barriers to oviposition and/or antibiosis to larval development. It is postulated that these resistant factors could affect *Aprostocetus* sp. activity as it has been shown for *C. sonorensis* parasitizing fall army worm, *S. frugiperda* feeding on the meridic diet with extracts of silk from resistant genotypes of corn (Ishenhour and Wiseman, 1989), and *H. exiguae* parasitizing *H. zea* on resistant tomato with higher levels of "α Tomatine" (Campbell and Duffey, 1979).

The pattern of adult midge emergence from unparasitized larvae in exposed panicles was similar to that of unexposed panicles (Tables 2 and 3). However, in several instances, more individuals emerged from exposed than from unexposed panicles. This phenomenon is discussed later.

The emergence of *Aprostocetus* sp. varied substantially between genotypes, across plantings and seasons. The total number of emerging parasitoids was lower than midges except in planting III of the 1992/93 post-rainy season (Table 2). In general, the emergence was low in resistant than in susceptible genotypes and this is explained by the smaller number of available host insects in resistant genotypes. For example, in highly midge resistant ICSV 745, the host insect occurred in such low numbers (Table 3) that was probably beyond the searching capacity of the parasitoid. This corresponds with very low numbers of *Aprostocetus* sp. in resistant genotypes (Table 3). However, this does not explain the situation in planting II in all the seasons when parasitoid activity in general declined considerably in all genotypes.

The decline in midge activity in planting III was associated with an increase in parasitoid activity. Higher activity of *Aprostocetus* sp. at the end of each cropping season

at ICRISAT farm confirms earlier reports of Garg and Taley (1978) and Chundurwar (1977). Gahukar (1984) also reported the efficient control of sorghum midge by *Tetrastichus* sp. at the end of cropping season in Senegal. These reports associated increased parasitoid activity with higher sorghum midge infestations which occurred with delayed plantings. The decline in parasitoid activity in the intervening period when host insects are available, such as in planting II in these studies remains to be explained.

In both post-rainy (1992/93) and rainy (1993) seasons, it was observed that the total number of midge and parasitoids combined emerging from exposed panicles was higher than the total midge emergence from unexposed panicles (Table 4). This was referred to earlier. Hypothetically, the level of midge infestation should be the same in exposed and unexposed panicles since both groups of panicles would have received the same levels of initial midge infestation. Observations showed that *Aprostocetus* sp. laid only one egg in each midge infested floret although more than one midge larvae are known to develop from the same floret. Data recorded on number of florets with midge larvae and total number of larvae in 100 florets also indicated that the level of midge infestation was higher in exposed than in unexposed panicles (Table 4). This result contradicts the hypothesis, that the initial midge infestation level should be similar in unexposed and exposed panicles. Several factors may be responsible for this phenomenon. First, the caging of the panicles changes the microclimate within and in the immediate area of the panicle. Exposing the panicles for parasitization would be expected to affect midge development, and in this case, most favourably compared to unexposed panicles. Secondly, in view of multiple egg laying by midge in florets, parasitization in exposed

panicles reduces intra-floret competition between developing midge larvae. Since *Aprostocetus* sp. parasitizes only one midge larvae per floret, parasitized larvae would result in less intra-floret competition and increase the proportion of larvae which successfully complete their development. Finally, additional infestation by midge may have occurred during exposure of panicles to parasitization. These additional larvae are less likely to be parasitized. The possibility of oviposition by midge in post-flowering panicles has been suggested by Franzmann (1988-90). When there is no availability of panicles in anthesis, oviposition by midges in panicles in post anthesis can occur and normal development of the larva was reported.

5.2 TRITROPHIC INTERACTIONS

5.2.1 Influence of Host Plant Resistance on *Aprostocetus* sp. Activity

In the first season of the study, data were not collected on the emergence of midge flies and the level of parasitization was estimated by sampling of chaffy florets with parasitoid exit holes. However, this method is not appropriate as some of the parasitoid adults are known to emerge from the tip of the florets. (Taley *et al.*, 1978).

The results reported in this thesis also indicate that generally resistant genotypes did not influence successful parasitization of midge larvae by *Aprostocetus* sp.. The parasitoid was always associated with low midge densities in resistant genotypes.

However for midge resistant ICSV 745, a derivative of DJ 6514, low levels of parasitization were recorded throughout the study. Nonpreference of this genotype for oviposition (Sharma, 1985a) and faster rate of grain development (Sharma, 1990b) could

have resulted in very low numbers of host larvae. Since parasitoids were always associated with low midge densities in other resistant genotypes, it must be inferred that other resistance factors in ICSV 745 are responsible for the negative effect of this genotype on *Aprostocetus* sp.

The mechanism of resistance in ICSV 89058 is not known. In contrast to ICSV 745, the levels of parasitization were high in the 1992/93 post-rainy season and were either at par or higher than those in the susceptible genotypes (Table 6). It can only be assumed that some unknown factor(s) in this genotype positively affect(s) parasitoid oviposition, orientation behaviour and or predispose midge larva for parasitization which in either case, results in successful parasitoid development.

However in the case of IS 10712 where resistance is due to antibiosis (Sharma in press), the development of *Aprostocetus* sp. larva was not affected although resistance affects midge fecundity, larval development and adult emergence. Similar observations were reported by Ishenhour and Wiseman (1987) in corn and have been discussed earlier.

The reverse situation is also known to occur in which antibiosis adversely affects the activity of natural enemies. These have been referred to in earlier sections of this thesis (Campbell and Duffey, 1979; Ishenhour and Wiseman, 1989). The results reported in this thesis suggest that differences may exist between genotypes in the effect of midge resistance factors on the biology of *Aprostocetus* sp.

Our further analysis on two of the host plant resistance factors namely, glume length and rate of grain development indicated that they were similar in all the genotypes (Table

11 - 13). Sharma *et al.*, (1990b) reported that short floral parts and faster rate of grain development restrict the space within the spikelet for the development of midge larvae. However, the results of the present study do not indicate such phenomenon.

5.2.2 Host Stage Preference of *Aprostocetus* sp. for Oviposition and Development in Susceptible and Resistant Genotypes

Results of experiments on interactions indicated variations in the preference of *Aprostocetus* sp. for midge larval stages in rainy and post-rainy seasons (Table 8 and 9). These variations could be due to differences in environmental conditions between seasons. Higher temperatures (30 - 37°C) and low RH levels (61 - 71%) in the post-rainy season (Feb - Apr) were associated with high levels of natural parasitization and mid to late midge larval stages were preferred for parasitization. In the rainy season, temperatures declined (22° - 10°C) as the season progressed and there was a shift in parasitoid preference for midge from mid/late larval stages in the post-rainy season to early/mid larval stages in the rainy season.

Differences in host selection may also be attributed to the two species complex of *Aprostocetus* which could have varied in their predominance with season. No information is available either on their preferences for host larval stages or their efficacies in managing midge populations. Since these two closely related species parasitize the same host, slight variations in their preferences for host stages would greatly contribute towards suppressing midge populations. Further studies are necessary to identify their seasonal fluctuations and preferences for host stages in different seasons since their combined activity holds good prospects in biocontrol of midge.

5.3 ROLE OF ENVIRONMENTAL FACTORS IN TRITROPHIC INTERACTIONS

The peak in sorghum midge activity has been reported to occur in September/October when temperatures and relative humidity (RH) ranged between 25 - 27°C and 75 - 80% respectively (Sharma, 1985a; Garg and Taley, 1978). In the present study high midge activity was recorded in October when the maximum temperature and RH ranged between 27 - 31°C and 82 - 96% respectively (Figure 5). However, *Aprostocetus* sp. was collected under slightly higher temperature regimes of 29 - 36°C and RH levels of 61 - 76%. The role of rainfall in influencing *Aprostocetus* sp. populations was not clear. Studies by Mote and Ghule (1986) recorded a positive correlation between rainfall and sorghum midge populations. In this study, rainfall distribution during the period of midge activity could not be associated with any pattern.

From the results of the study on panicle microclimate (Figure 6), had there been differences in panicle morphology, for instance, the rate of water loss from the panicles would have resulted in variations in temperatures. Since differences were not recorded between the two genotypes tested, it may be concluded that the microclimate of resistant and susceptible genotypes is similar. This factor also does not appear to interfere with *Aprostocetus* sp. activity.

Lack of distinct pattern in the *Aprostocetus* sp. parasitization levels, similarity in diurnal pattern of emergence and also absence of distinct differences in microclimatic and host plant resistance factors studied between resistant and susceptible genotypes indicate that the resistance factors in the genotypes under study, were not antagonistic to parasitoid activity.

In conclusion it is evident from the present studies that the levels of parasitization were higher in the post-rainy than in the rainy season and the reasons for this trend are not known. The complex of species of *Aprostocetus* recorded in this study on midge larvae are likely to be responsible for these variations. Studies are needed to understand the differences in their seasonal abundance as well as their preferences for different midge larval stages. Parasitoid activity was higher at the beginning and end of each cropping season with a decline during the mid season. Further studies are required to understand the reasons behind this decline in order to enhance parasitoid activity during this period. No differences were recorded either in the microclimate of sorghum panicles or in two of the host plant resistance factors investigated and thus are not likely to affect *Aprostocetus* sp. activity in both seasons. The study has clearly indicated that host plant resistance is not antagonistic to parasitoid activity. However, it is yet to be shown whether this compatibility can be further enhanced during the rainy season when the pest is more active. The information obtained from this study provides a rational basis for the development of biological control as an interphase with host plant resistance in an integrated pest management program of sorghum midge.

SUMMARY

CHAPTER VI

SUMMARY

Studies were conducted during three crop seasons in 1992 and 1993 (rainy 1992, post-rainy 1992/93 and rainy 1993) at ICRISAT Center, Patancheru, A.P., to assess the natural enemies of sorghum midge, to monitor the population dynamics of predominant parasitoid and finally investigate the interactions between host plant resistance, midge and predominant parasitoid. Experiments were laid out in randomized block design using three midge susceptible (Swarna, CSH 9 and ICSV 112) and three midge resistant sorghum genotypes (ICSV 745, ICSV 89058 and IS 10712) on three sowing dates in each season.

Three sorghum panicles at half anthesis were artificially infested with midge flies using the headcage technique (Sharma *et al.*, 1988). Five days after infestation, the panicles were exposed to natural parasitization for 10 days and were recaged there after for the development of parasitoids and unparasitized midges. The headcage was suitably modified by fixing a thermocole cork, a connecting tube and a collection contanier to the central ring of the headcage to facilitate easy and precise collection of the emerging insects.

Species composition of natural enemies of sorghum midge included three parasitoids viz., *Aprostocetus* sp., *Eupelmus* sp. and *Apanteles* sp. and one predator *Orius* sp.. *Aprostocetus* sp. was the predominant parasitoid in both rainy and post-rainy seasons. Two species were identified under this genera at the end of the study namely,

A. gala and *A. coimbatorensis*. However, for the purpose of this study both the species are considered as a complex of the genera *Aprostocetus*. The species composition of natural enemies varied with season but was unaffected by varietal resistance. The activity of *Aprostocetus* sp. was observed to be more in the beginning and at the end of cropping season with a considerable decline in the middle. The population dynamics was similar in susceptible and resistant genotypes. The emergence pattern of sorghum midge indicated significant differences between susceptible and resistant genotypes across the plantings and seasons. The pattern in general was similar in unexposed and exposed panicles. *Aprostocetus* sp. emergence occurred in low numbers compared to midge and resistant genotypes recorded low numbers across plantings and seasons.

The level of parasitization of sorghum midge larvae was higher in post-rainy than in rainy season and did not follow a definite pattern with susceptibility or resistance of the host plant to midge. It was consistently low in resistant ICSV 745, which probably could be due to low number of host larvae encountered by the parasitoid. The other resistant genotypes did not appear to influence the *Aprostocetus* sp. activity though antibiosis was reported as the mechanism of resistance in one of the genotypes, IS 10712.

Studies on tritrophic interactions under controlled conditions indicated variations in the preference of midge larvae for parasitization by *Aprostocetus* sp. in rainy and post-rainy seasons. Early/mid larval stages were preferred for parasitization in rainy season while it was mid/late larval stage during post-rainy season.

The peak time of emergence of *Aprostocetus* sp. was between 0600 - 1000 hours in both rainy and post-rainy seasons and the pattern was similar in susceptible and

resistant genotypes. The panicle temperatures measured to investigate the variations in the microclimate within the panicles of susceptible and resistant genotypes was found to be similar as the panicles did not vary in compactness. Monitoring of host plant resistance factors *viz.*, glume length and rate of grain development in general, did not vary between susceptible and resistant genotypes indicating that factors other than these could be contributing to resistance in the genotypes studied.

However, lack of distinct pattern in *Aprostocetus* sp. parasitization levels, similarity in the preferences for the host stage within the seasons and in diurnal pattern of parasitoid emergence indicate that the host plant resistance did not influence *Aprostocetus* sp. activity. The absence of distinct differences in microclimate of the susceptible and resistant sorghum panicles and similar length of glumes and rate of grain development in all the genotypes studied suggests that resistance factors are not antagonistic to *Aprostocetus* sp. activity.

LITERATURE CITED

LITERATURE CITED

AICSIP 1969 Progress report All India Coordinated Sorghum improvement Project ICAR and cooperating agencies New Delhi.

Alghali A M 1984 Studies on the biology damage and crop loss assessment of the sorghum midge *Contarinia sorghicola* Coq. (Diptera : Cecidomyiidae).Insect Science and its Application 5:253-258.

Ball C R and Hastings S N 1912 Grain sorghum production in the San Antonio region of Texas. USDA Bur Plant Ind Bulletin 237:12-25.

Barrion A T and Litsinger J A 1982 The sorghum midge *Contarinia sorghicola* (Diptera : Cecidomyiidae) and its parasites in the philippines. Philippines Entomologist 5:463-467

Baxendale F P, Lippincott C L and Teetes G L 1983 Biology and seasonal abundance of hymenopterous parasitoids of sorghum midge (Diptera : Cecidomyiidae). Environmental Entomology 12:871- 877.

Bergquist R R, Rotar P and Mitchell W C 1974 Midge and anthracnose head blight resistance in sorghum. Tropical Agriculture 51:431-435.

Borle M N, Doiphode S M and Deshmukh S D 1979 Efficacy of some modern synthetic pyrethroid insecticides against important pests of sorghum. Pesticides 13:25-26 & 31.

Bowden and Neve R A 1953 Sorghum midge and resistant varieties in the gold coast. Nature (London) 172:551.

Brooks G W and Gillstrap F E 1985 Parasitism of sorghum midge in Jhonson grass in major vegetational areas of Texas. South Western Entomologist 10:171-175.

Brooks G W and Gillstrap F E 1986 Seasonal incidence and relative abundance of sorghum midge and associated parasitoids in Jhonson grass. South Western Entomologist 11:119-124.

Busoli A C, Lara F M, Gravena S and Malherios E B 1984 Bioecological aspects of the sorghum midge and natural enemies in the region of Jabotical. Anais do Sociedade Entomologica do Brasil 13:167-176.

Campbell B C and Duffey S S 1979 Tomatine and parasitic wasps : Potential incompatibility of plant antibiosis with biological control. Science 205:700-702.

Chundurwar R W 1977 A note on the parasitoid complex of sorghum midge. Madras Agricultural Journal 64:767-768.

Cowland J W 1936 The sorghum midge in the Anglo egyptian Sudan. Annals of Applied Biology 23:110-113.

Diaz S M 1988 Taxonomy of the main micro hymenopterous parasitoids of sorghum midge and preliminary observations on some characters of their populations in Manfredi. Revista de Ciencias Agropecuarias 6:52-72.

Emden H F V 1981 Ecological interactions with in plant protection systems In Kommendahl (ed.) Proceedings of symposia IX International congress of plant protection. Washington D.C. U.S.A. August 5-11, 1979 1:5-7

Evelan S H 1951 Sorghum breeding in the Sudan. World Crops 3:65- 68.

Fischer R A 1938 The statistical use of multiple measurements. Annuls of Eugenics 8:376-386.

Franzmann B A 1988-90 Midge oviposition on post-flowering panicles. Sorghum News Letter 31:60.

Franzmann B A 1988 Components of resistance to sorghum midge in grain sorghum. In proceedings of ninth Australian plant breeding conference.

Franzmann B A 1993 Ovipositional antixenosis to *Contarinia sorghicola* (Coquillett) (Diptera : Cecidomyiidae) in grain sorghum. Journal of Australian Entomological Society 32:59-64

Franzmann B A, Titmarsh I J, Greig J C and Mc Alpine J D 1989 Life table studies on sorghum midge in midge susceptible and resistant grain sorghum. In Proceedings of Australian sorghum workshop Toowoomba, Queensland, 28th February - 1st March 1989 Eds. Foale, M A , Hare, B W and Henzell, R G Brisbane, Australia, Australian institute of agricultural science Occasional publication No. 43.

Gable C H, Baker W A and Woodruff L C 1928 Sorghum midge with suggestions for control. USDA Plant Growers Bulletin 1566:1-9.

Gahukar R 1984 Seasonal distribution of sorghum midge and its hymenopterous parasites in senegal. Agronomie 4:393-397.

Garg D O 1979 Observations on the fecundity on *Tetrastichus* sps. (Eulopidae:Hymenoptera) an ectoparasite of sorghum midge larvae *Contarinia sorghicola* (Cecidomyiidae:Diptera). Cecidologia Indica 14(1/3):187-190.

Garg D O and Taley Y M 1977 Chemical control of sorghum earhead midge *Contarinia sorghicola* Coq. Pesticides 11:37-38.

Garg D O and Taley Y M 1978 Note on trends in population fluctuation of sorghum midge and *Tetrastichus* its parasite on sorghum during 1975-76. Indian Journal of Agricultural Sciences 48:51-53.

Geering Q A 1953 The sorghum midge *Contarinia sorghicola* (Coq.) in East Africa. Bulletin of Entomological Research 44:363-366.

Gillstrap F E and Brooks G W 1991 Sorghum midge and midge parasitism on Jhonson grass. Journal of Economic Entomology 84:431-435.

Gowda B L V and Thontadarya T S 1975 Bionomics and control of *Contarinia sorghicola* Coquillett (Cecidomyiidae : Diptera). Mysore Journal of Agricultural Sciences 9:204-205.

Gowda B L V and Thontadarya T S 1976 Chemical control of sorghum midge (*Contarinia sorghicola* Coq.) (Diptera : Cecidomyiidae). Current Research 5:11-13.

Gowda B L V and Thontadarya T S 1977 Effect of differential sowing on the incidence of sorghum midge and its parasites. Mysore Journal of Agricultural Sciences 11:59-63.

Hardass M G, Supare N R and Chopde P R 1972 Studies in the seasonal incidence of sorghum midge (*Contarinia sorghicola*) infesting sorghum hybrids. Sorghum News Letter 15:88-89.

Harris K M 1961 The sorghum midge, *Contarinia sorghicola* (Coq.) in Nigeria. Bulletin of Entomological Research 52:129-146.

Harris K M 1970 The sorghum midge. PANS 16:36-42.

Harris K M 1976 The sorghum midge. Annals of Applied Biology 84:114-118.

Henzell R G and Gillieron W 1973 Effect of partial and complete panicle removal on the rate of death of some sorghum bicolor. Queensland Journal of Animal Sciences 30:291-298.

Henzell R G, Brengman R L and Franzmann B A 1989 Improved resistance to sorghum midge in grain sorghum. In proceedings of Australian workshop, Toowoomba, Queensland, 28th Feb - 1st March 1986 pp 130 - 133.

Hiremath I G and Bhuti S G 1993 DSV 3 - A new high yielding midge resistant variety released for Karnataka. Paper presented in "International sorghum research planning workshop" held at Brisbane (Australia), 14-19 November 1993 (In Press)

Isenhour D J and Wiseman B R 1987 Foliage consumption and development of the fall armyworm (Lepidoptera : Noctuidae) as affected by the interactions of a parasitoid, *Campoletis sonorensis* (Hymenoptera : Ichneumonidae), and resistant corn genotypes. Environment Entomology 16:1181-1184

Isenhour D J and Wiseman B R 1989 Parasitism of the fall armyworm (Lepidoptera : Noctuidae) as affected by host feeding on silks of *Zea mays* cv. Zapalote chico. Environment Entomology 18:394-397

ICRISAT (International crops research institute for semi-arid tropics) 1992 Medium term plan 1994 - 98 Volume I Main report Board approved draft for submission to Technical advisory committee/CGIAR ICRISAT Patancheru Andhra Pradesh India 80 pp.

Jadhav R B and Jadhav L D 1978 Studies on preliminary screening of some sorghum hybrid and varieties against earhead midge (*Contarinia sorghicola* Coq.). Journal of Maharashtra Agricultural Universities 3:187-188.

Johnson J W 1975 The development of pest resistant sorghum. In the proceedings of US-USSR symposium. The integrated control of the arthropod disease and weed pests of cotton, grain sorghum and deciduous fruits. Sept. 28 - Oct 1, 1975, Hilton Inn, Lubbock, Texas, USA. pp 50-63

Johnson J W, Phillips J M and Teetes G L 1977 Seed growth rate of selected midge resistant and susceptible sorghums. Sorghum Newsletter 20:115

Johnson J W, Rosenow D T and Teetes G L 1973 Resistance to the sorghum midge in converted exotic sorghum cultivars. Crop Science 13:754-755

Johnson J W, Rosenew D T, Teetes G L and Miller F R 1982 Registration of TAM 2566 sorghum germplasm line (Registration No. GP 75). Crop Science 22:1271.

Jotwani M G 1978 Investigations on insect pests of sorghum and millets with special reference to host plant resistance. Final technical report (1972-1977). PL 480 Project grant No.FG-IN-469, Project No. A7-ENT-120. Research Bulletin, Division of Entomology, Indian Agricultural Research Institute. New Delhi.

Jotwani M G, Singh S P and Chaudari S 1971 Relative susceptibility of some sorghum lines to midge damage. In Investigations on insect pests of sorghum and millets (1965-1970) (Ed. by Pradhan, S.) pp 123-130 Final technical report PL 480 Project grant No.FG-IN-227, Project No. A7-ENT-31. Division of Entomology, Indian Agricultural Research Institute. New Delhi.

Jotwani M G, Sukhani T R and Singh S 1972 Population fluctuation and of the sorghum midge, *Contarinia sorghicola* (Coq) on sorghum crop sown in different dates. Entomologists' Newsletter 2:50-51

Kofoid K D, Maranville J W and Ross W M 1982 Relationship of a testa to agronomic and nutritional traits in sorghum. Crop Science 22:352-357.

Kulkarni K A 1985 Screening sorghums for midge resistance. In Proceedings of the international sorghum entomology workshop, July 15 - 21, 1984 Texas A & M University, College station, Texas, USA, ICRISAT, Patancheru, AP 502 324. India. pp 265 - 274.

Kulkarni K A, Parameswarappa R and Kajjari N B 1978 Screening sorghum entries to sorghum (*Contarinia sorghicola* Coquillett). Mysore Journal of Agricultural Sciences 12:577-578.

Macquillan M J, Badley A R and Hodyson P J 1975 Control of sorghum midge with chlorpyrifos in Australia. Journal of Economic Entomology 68:713-715.

Martins A J 1977 Influencia do teor de tanino en genotipos de sorgo *Sorghum bicolor* (L.) Moench sobre o ataque da *Contarinia sorghicola* (Coquillett, 1898) (Diptera : Cecidomyiidae). M.Sc thesis, Universidade Federal de Ceara, Fortalez, Brazil.

McMillan W W and Wiseman B R 1979 Attraction of sorghum midge (*Contarinia sorghicola*) and its parasites (*Aprostocetus diplosidis*) Florida Entomologist September 1979 62:281-282.

Melton K D and Teetes G L 1982 Effects of resistant grain sorghum hybrids on the biology of sorghum midge, *Contarinia sorghicola* Coquillett. Sorghum Newsletter 25:86

Mogal B H, Mali A R, Rajput S G and Pawar K L 1980 Chemical control of sorghum midge (*Contarinia sorghicola* Coq.). Journal of Maharashtra Agricultural Universities 5:5-9.

Murthy A D and Subramaniam R 1975a Biology of the sorghum midge (*Contarinia sorghicola* Coq.) (Cecidomyiidae : Diptera). Madras Agricultural Journal 62:572-574.

Murthy A D and Subramanium T R 1975b Control of sorghum midge *Contarinia sorghicola* (Cecidomyiidae : Diptera). Pesticides 9:45-46.

Murthy A D and Subramaniam T R 1978 Varietal susceptibility of sorghum to midge (*Contarania sorghicola* coq.). Madras Agricultural Journal 65:180-182.

Mote U N and Ghule B D 1986 Relationship of sorghum midge incidence with climatic factors and parasites. Sorghum Newsletter. 29:71

Natarajan K and Chelliah S 1986a Studies on the mechanism of resistance in sorghum accessions to the grain midge Insect Science and its Application 7:751-755.

Natarajan K and Chelliah S 1986b Management of sorghum grain midge *Contarinia sorghicola* Coq. using plant resistance and insecticides. Indian Journal of Plant Protection 14:77-79.

Orr D R and Boethel D J 1985 Comparative development of *Copidosoma truncatellum* (Hymenoptera : Encyrtidae) and its host, *Psedoplusia includens* (Lepidoptera : Noctuidae), on resistant and susceptible soybean genotypes. Journal of Economic Entomology 14:612 - 616

Painter R H 1958 Resistance of plants to insects. Annual Review of Entomology 3:267-290.

Passlow T 1965 Bionomics of sorghum midge (*Contarinia sorghicola* Coq.) in Queensland, with special reference to diapause. Queensland Journal of Agricultural and Animal Sciences 22:150-167.

Passlow T 1973 Insect pests of grain sorghum. Queensland Agricultural Journal 99:620-628.

Patel J R and Jotwani M G 1986 Effect of ecological factors on incidence and damage by sorghum midge, *Contarinia sorghicola.* Indian Journal of Entomology 48:220-222.

Rao S V R 1976 Studies on the biology, bionomics and chemical control of the sorghum midge, *Contarinia sorghicola* (Coquillett) Entomologists' Newsletter 6:14-15

Rao N G P, Rana B S and Jotwani M G 1979 Host plant resistance to major insect pests of sorghum All India Coordinated Sorghum Improvement Project, IARI - Regional station pp 63-78

Rao K J, Thontadarya T S and Suhas Y 1986 Investigations in parasitoids and predators of sorghum pests Sorghum Newsletter 29:59-60

Raodeo A K and Karanjkar R R 1975 Screening sorghum lines for relative damage by the sorghum midge *Contarinia sorghicola* (Coq) Sorghum Newsletter 18:48-49

Rossetto C J 1985 Sorghums midge: Host-plant resistance mechanisms In Proceedings of the international sorghum entomology workshop, July 15 - 21, 1984 Texas A & M University, College station, Texas, USA, ICRISAT, Patancheru, AP 502 324 India pp 293 - 299.

Rosetto C J, Nagai V and Overman J 1984 Mechanism of resistance in sorghum variety AF-28 to midge Journal of Economic Entomology 77:1439-1440

Roth J R and Pitre H N 1973 Sorghum midge population dynamics and control Sorghum Newsletter 16:117-118

Santos J H R D and Carmo C M D 1974 Evaluation of resistance to *Contarinia sorghicola* by sorghum lines from the cameroon, Africa collection in Ceara, Brazil. Sorghum Newsletter 17:10-11

Sarkate M B and Raodeo A K 1978 Studies on chemical control of sorghum midge *Contarinia sorghicola* Coq Indian Journal of Plant Protection 7:67-69

Sharma H C 1985a Screening for sorghums midge resistance and resistance mechanisms In Proceedings of the international sorghum entomology workshop; July 15 - 21, 1984 Texas A & M University, College station, Texas, USA, ICRISAT, Patancheru, AP 502 324 India pp 275 - 292

Sharma H C 1985b Strategies for pest control in sorghum in India. Tropical Pest Management 31:167-185

Sharma H C and Vidyasagar P 1992 Orientation of males of sorghum midge, *Contarinia sorghicola* to sex pheromones from virgin females in the field. Entomologia Experimentalis et Applicata 64:23-29

Sharma H C, Vidyasagar P and Leuschner K 1988 No choice technique to screen for resistance to sorghum midge. Journal of Economic Entomology 81:415-422

Sharma H C, Leuschner and K Vidyasagar P 1990a Factors influencing oviposition of the sorghum midge *Contarinia sorghicola* Coq. Annals of Applied Biology 116:431-439

Sharma H C, Vidyasagar P and Leuschner K 1990b Components of resistance to the sorghum midge. Annals of Applied Biology 116:327-333.

Sharma H C, Vidyasagar P and Subramanian V Antibiosis mechanism of resistance to sorghum midge, *Contarinia sorghicola* Annals of Applied Biology (In Press)

Sharma H C, Agarwal B L, Vidyasagar P, Abraham C V and Nwanze K F 1993 Identification and utilization of resistance to sorghum midge *Contarinia sorghicola* (Coquillet) in India. Crop Protection 12:343-350

Swarnasree P 1991 Factors associated with resistance in sorghum to shoot fly *Atherigona soccata* Rondani Ph D Thesis Andhra Pradesh Agricultural University, Rajendranager, Hyderabad 500 030. Andhra Pradesh.

Syamasunder J, Parameswarappa R, Nagaraja H K and Kajjari N B 1975 DJ 6514 (Pasyana) - A new genotype in sorghum resistant to midge (*Contarinia sorghicola* Coq.). Sorghum Newsletter 18:33

Taley Y M, Deore B P and Thakare K R 1971 Bionomics of *Contarinia sorghicola* Coquillett (Cecidomyiidae : Diptera) Indian Journal of Entomology 33:202-208

Taley Y M, Garg D O and Borle M N 1978 Life history of *Tetrastichus* sp. (Hymenoptera : Eulophidae) A parasitoid of the sorghum midge, *Contarinia sorghicola* Coquillet Journal of Maharashtra Agricultural Universities 3:189-193

Thimmaiah G, Mutalkidesai K S, Panchabhavi K S, Kajjari N B and Usman S 1969 Study on the occurrence of midgefly (*Contarinia andropogonis* F) in Mysore state. Sorghum Newsletter 12:50

Thimmaiah G, Panchabhavi K S and Kulkarni K A 1974 Chemical control of midge *Contarinia sorghicola* Coq. Current Research 3:82-83

Thontadarya T S, Jairao K and Rangadhamiah K 1983 Biology of *Tetrastichus diplosidis*, a larval ectoparasite of the sorghum midge. Mysore Journal of Agricultural Sciences 17:36-40

Venugopal M S, Mani M, Palaniswamy S and Meenakshi K 1977 Relative resistance of some promising sorghum lines to sorghum midge *Contarinia sorghicola* Coq. Sorghum Newsletter 20:68

Walter E V 1941 The biology and control of the sorghum midge. USDA Technical bulletin No 778

Waquil J M, Teetes G L and Peterson G C 1986a Adult sorghum midge nonpreference for a resistant hybrid sorghum. Journal of Economic Entomology 79:455-458

Waquil J M, Teetes G L and Peterson G C 1986b Sorghum midge adult oviposition behaviour on resistant and susceptible sorghum hybrids. Journal of Economic Entomology 79:530-532

Wiseman B R, Gross Jr H R and Mc Millan W W 1978 Seasonal distribution of the sorghum midge and its hymenopterous parasites 1975-77 Journal of Economic Entomology 7:820-822

Wiseman B R and Mc Millan W W 1970 Parasites of sorghum midge. Sorghum Newsletter 13:21

Wiseman B R, Mc Millan W W and Widstrom N W 1973 Registration of SGIRL-MR-1 sorghum germplasm (Registration No GP 19) Crop Science 13:398

Wiseman B R, Mc Millan W W and Widstrom N W 1974 Techniques, accomplishments and future prospects of breeding for resistance in corn to the corn earworm, fall armyworm, maize weevil and in sorghum to the sorghum midge In proceedings of the summer institute of biological control of plant insects and diseases (Eds) Harris, F A and Maxwell F G) pp 381-390 Mississippi Press, Jackson

Young W R and Teetes G L 1977 Sorghum entomology Annual Review of Entomology 22:193-218