MECHANISMS OF SORGHUM RESISTANCE TO THE SPOTTED STALKBORER, *CHILO PARTELLUS* (SWINHOE) LEPIDOPTERA PYRALIDAE

by

GREENMAN THEMBA MASINA

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in the University of Nairobi, Department of Zoology.

DECLARATIONS

This thesis entitled "MECHANISMS OF SORGHUM RESISTANCE TO THE SPOTTED STALKBORER, CHILO PARTELLUS (SWINHOE) LEPIDOPTERA: PYRALIDAE)" is my original work and has not been presented for a degree in any other University.

Signature: Greenman T. Masina
GREENMAN THEMBA MASINA

This thesis has been submitted for examination with our approval as University Supervisors.

Professor Canute P.M. Khamala
University Supervisor

Signature: ----------

Professor T.R. Odhiambo
International Centre for Insect
Physiology and Ecology

Signature: ----------

C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

A C K N O W L E D G E M E N T S

I would like to express my appreciation to many people and organizations that assisted me in the accomplishment of this study. First, my deepest gratitude goes to Professor C.P.M. Khamala, my University supersor, and the late Dr. R.O. Abasa of the Department of Zoology, University of Nairobi, from whom I greatly benefitted through the rich discussions I held with them on my research proposal which eventually shaped it into an acceptable format for registration as a Ph.D. candidate of the University of Nairobi.

Likewise, I owe my sincere thanks to Professor T.R. Odhiambo, Dr. Z.T. Dabrowski and Dr. R. Dransfield of the International Centre for Insect Physiology and Ecology (ICIPE) where I worked, for their continuous guidance and encouragement during the execution of field and Laboratory experiments. Special thanks go to Dr. Dransfield for the assistance with the statistical analysis presented herein and to both Professor Khamala and Odhiambo for carefully reading through the manuscript and for the many helpful suggestions as to its improvement bot in form and in content with respect to data interpretation.

These studies were carried out with the financial support from the British Council in the form of a fellowship to me tenable at the ICIPE for which I am equally and deeply grateful. The excellent research facilities placed at my disposal by the ICIPE played an enormous part to ensure the successful completion of my studies. For this I must, specially thank Professor T.R. Odhiambo, Director of the ICIPE. Similarly, my thanks are also due to the technical staff of the "Bases of Plant Resistance to Insect Attack Research Unit," ICIPE, Mbita Point Field Station, South Nyanza for their willingness and co-operation in assisting me to run the field and laboratory experiments.

Finally, I would like to thank my wife, Sebolelo, for the sacrifice, cheerful help and encouragement, without which all this work would not have been possible.

A B S T R A C T

Stalkborers are some of the most important pests of cereal crops in the tropics and in particular the semi-arid areas. Chilo partellus, the spotted stalkborer, is one of the most notorious pests of sorghum in that it occurs in almost all the areas where sorghum is grown in the semi-arid regions of Asia and Africa. Lately it has been found that this pest is gradually increasing its range and importance.

Of the various sorghum pest control methods available in the semi-arid regions none holds better prospects than the use of resistant varieties. In this study several experiments were conducted to elucidate the mechanisms of resistance of different sorghum cultivars and also to propose the methodology for mechanisms of resistance studies. Accordingly five criteria were used - for explaining these mechanisms. These criteria were : (a) Preference or Non-preference for oviposition of the moth on different sorghum cultivars, (b) Larval establishment of Chilo partellus first instar larvae on different sorghum cultivars, (c) Relative leaf damage and stem tunnelling in different sorghum cultivars by C. partellus larvae, (d) Biophysical and prelimary biochemical studies that elucidate the differences in cultivar

susceptibility to C. partellus, and (e) studies on different cultivar tolerances to C. partellus damage.

The oviposition preference studies revealed that sorghum cultivars differed in their suitability as a C. partellus oviposition substrate. Cultivar IS 2205 was the least preferred while IS 18363 was the most preferred. Experiments to identify the factors responsible were inconclusive. Evidence pointed to both biochemical and biophysical factors.

First instar larval establishment studies were also inconclusive even though it was demostrated that larval establishment was different among the cultivars used. The only definite evidence for poor establishment in some cultivars was biophysical.

Different cultivars were significantly different in their susceptibility to leaf damage. The tendency to form deadhearts was also significantly different. But reasons for these differences were not apparent. Cultivars were not significantly different in their susceptibility to tunnelling even though they had different amounts of fibre, lignin and sucrose.

The single most important factor for the different cultivar susceptibilities was in their different

tolerances to C. partellus attack. Tillering, in particular, was demonstrated to play an important role in compensation for damage. The ability to flower and to produce seed inspite of having a high infestation were also very significant. Susceptible cultivars dried up before they had flowered. Others still, flowered but could not form seed. Using tolerance as a criterion for resistance showed IS 18520 to be the most resistant. Formation of multiple heads was also shown to be an important factor.

Different cultivars had varying effects on the development of C. partellus (antibiosis). However, the antibiotic effect was either insignificant or only just significant statistically.

CHAPTER 1

INTRODUCTION, OBJECTIVE, AND LITERATURE REVIEW

1.10 GENERAL INTRODUCTION

Sorghum bicolor (L.) Moench, the cultivated sorghum currently ranks fifth in acreage and production among the world's major cereals, following wheat, maize, rice and barley. The world production of sorghum grain is currently about 67 metric tons produced on some 51 million hectares (F.A.O., 1980). According to Dogget (1970) there is evidence that sorghum as a grain crop was first cultivated in Ethiopia and the surrounding countries. There is no record of its origin nor is there a pattern of its dispersion (Hulse *et al.*, 1980). However, Ivanyukovich (1980) has concluded after examining the literature that sorghum as a cultivated crop species had a polytopic origin in the African Continent, arising from different wild species.

It is presently grown on all six continents and is of great importance in human diet, particularly in the arid and semi-arid tropics (Hulse *et al.*,1980). It is used as feed for livestock in the developed countries.

Management of the crop varies considerably from small subsistence plots under mixed cropping systems to immense monocultures. Productivity in the semi-arid tropics of the developing countries, for example, is about 910kg/ha compared with 3238kg/ha in the developed world (F.A.O., 1980.).

The semi-arid regions are defined as those in which evapo-transporation exceeds rainfall for more than half of the year (House, 1980). These countries include large areas of Africa around the Sahara and a considerable part of East and Central Africa, large portions of India, some areas of South East Asia, and a few areas in South America. In Africa, the semi-arid countries included are: Ethiopia, Kenya, Tanzania, Uganda, Zambia, Zimbabwe, Mozambique, Somalia, Botswana, Lesotho and Swaziland. In the semi-arid regions, 67% of the world's grain crop is produced from 88% the total world acreage.

Factors that contribute to this disparity in production include, insufficient soil fertility, drought, insect pests, diseases, birds and parasitic weeds. Several breeding programmes have thus been initiated with objective of developing a diverse array of agronomically stable elite varieties and

hybrids with reistance to a range of insect pests, diseases, drought and to witchweed (Striga spp.) (Jotwani et al., 1978).

In India systematic work on breeding for high yielding hybrids by using exotic material revealed that the main constraint was the high susceptibility of the hybrids to insect pests, especially the shoot fly (Atherigona soccata (Rondani), the spotted stalkborer (Chilo partellus (Swinhoe), and the sorghum midge (Contarinia sorghicola Coquilett) (Jotwani et al, 1978). Combining productivity and insect resistance has thus become the primary objective of the breeding programmes in the semi-arid tropics (Jotwani et al, 1978.).

The sources, mechanisms and genetic basis of resistance, in sorghum together with breeding implications have so far been examined for only eleven major insect and mite pests (Teetes,1980). This limitation is caused mainly by the fact that insect pests tend to be more severe in the tropics than in the temperate zones (Rao et al, 1979). Although initially emphasis was on the shootfly, emphasis has now shifted to the spotted stalkborer (chilo partellus)because of the realization that this pest is more widely distributed in the semi-arid

tropics, specifically in Africa and Asia, than any other pest. (ICRISAT, 1980).

The spotted stalkborer is not only a major or key pest in Central, East and Southern Africa (Nye, 1960; Ingram, 1958; Harris, 1962; Anon, 1926) but it is also a serious pest in Western Asia (Rao, 1965). In Africa it is thought to be of recent introduction from India. The fact that it is increasing its range and economic importance (van Rensburg and van Hamburg, 1975) is cause for concern. Besides, sorghum has been demonstrated to be a preferred host when compared with maize (Sarup et al., 1977).

Cultural control techniques for stemborers such as destruction of straw, trash, volunteer plants, and stubbles, manipulation of planting dates, soil tillage, variation of the number of crop generations annually, and use of resistant varieties, have all been considered by different workers (Jepson, 1954; Roome, 1976; Sarup et al, 1978; and Trehan and Butani , 1949). Early planting, manipulation of soil fertility and available water do not always cause an appreciable economical control of Chilo partellus infestations in the semi-arid tropics (Sarup et al., 1978). . In Botswana it was found that Sudan grass was often

heavily infested with C. partellus and possibly played as important a part, if not a more important role, in the carry-over of the pest from one season to the next (Roome, 1976).

The role of natural enemies as a cause of population flactuations in lepidopterous stem borers has been investigated by several workers (Ingram, 1958; Jepson, 1974; Kapur, 1951; Mathez, 1972; Mohyuddin and Greathead, 1970; Roome, 1976; van Hamburg, 1980). The impact of the natural control agents is yet to be shown to work economically. For example, although there is high mortality of C. partellus in the first two weeks of its life, this mortality is due to such factors as larval competition, and the harzards of migration during the first larval instar rather than natural enemies (van Hamburg, 1980). Besides, C. partellus and its parasites and predators tend to breed continuously so that there are no apparent marked population flactuations of either the host or its natural enemies (Mohyuddin and Greathead, 1970).

Chemical control is quite effective in the temperate countries, but has neither been economical nor feasible on traditional varieties (Trehan and Butani, 1949; Ingram, 1958). Even in the temperate countries

where insecticides in spray and granular formulations have been used successfully, this control method has proved quite expensive and not particularly effective against heavy infestations (Painter, 1958). The dangers of environmental pollution and pest resistance make this control technique unfavourable.

Host plant resistance coupled with other control measures holds a strong promise for cereal stalkborer control in the tropics. Several sorghum varieties resistant to stalkborer attack have been reported in Africa (Dogget, 1970), in India (Indian Council for Agricultural Research 1975, and ICRISAT, 1980). Teetes (1980) also listed eleven sorghum lines that have shown resistance to different stalkborer species in different parts of the world. Of these, four had resistance to C. partellus. However, according to Gallun and Khush (1980), inheritance of resistance to pests in sorghum have been investigated in only four pest species namely, the corn-leaf aphid (Ropalosiphum madis), the greenbug (Schizaphis graminum), the shootfly (A. Soccata) and the Chinchbug (Blissus leucopterus).

These seemingly encouraging results have led to the intensification of further research in host plant resistance by several institutions among them the

International Crop Research Centre of Semi Arid Tropics (ICRISAT) and the International Centre of Insect Physiology and Ecology (ICIPE). There are also several regional and national programmes on sorghum resistance to C. partellus in particular. Examples of these regional programmes include the Department of Technical Services (Republic of South Africa), the Centre for Overseas Pest Research (England), the Division of Agricultural Research of the Ministry of Agriculture (Botswana), the Ethiopian Sorghum Improvement Project (Ethiopia), and the Kenya Sorghum and Millet Development Project (F.A.O. project in Kenya).

1.20 LITERATURE REVIEW

1.21 Taxonomic position and systematics of C. partellus

The taxonomic position, systematics, and biology of C. partellus (Swinhoe 1884) and the whole genus were uncertain until Bleszysky's (1970) studies (van Hamburg, 1975). The scientific name used in these studies is the one presently accepted and synonyms according to Bleszynsky (1970) include : Crambus zonellus (Swinhoe, 1884); Chilo simplex (Buttler) Hampson 1896); Diatraea calamina(Hampson,1919); Chilo zonellus (Swinhoe, Fletcher, 1928); Argyria lutulentalis(Tams, 1932). According to Bleszynsky (1970) the genitalia of Chilo tamsi Kapur put C.

partellus very close to this species taxonomically. The genus itself was erected by Zicken in 1817 and Duponchel, in 1936 selected Tinea phragmitella Hbn as the type-species (now Chilo phragmitellus (Hubner, 1806).

1.22 Economic importance and zoogeography

Bleszynsky (1970) reported that the larva of C. partellus is a notorious pest of bajra, bullrush millet, maize, sorghum, rice and even sugarcane when the latter is grown in the vicinity of infested maize, rice, or sorghum fields. As a polyphagous insect, C. partellus has been found also in the following host plants in different countries: Andropogon nardus, Coix lachrymajobi, Eleusine coracana, E. indica, Hyparrhenia rufa, Panicum maximum, P. frumentaceum, Pennisetum officinarum, Sorghum vulgare, S. vertifilliflorum, and Vossia cuspidata (Bleszynsky, 1970; Ingram, 1958; and Kapur, 1950). It is an important pest of sorghum in both Western and Eastern Asia. It has been recorded in Afghanistan, Bangladesh, India, Iran, Japan, Nepal, Pakistan, Sikkim, Sri Lanka and Thailand (Bleszynsky, 1970; Hill, 1975; Rao, 1975 and Sharma et al., 1967). In Africa it is a major sorghum pest in Central, East and Southern Africa and has been recorded in Botswana, Kenya, Malagasie, Malawi, Mozambique, South Africa, Swaziland, and Tanzania (Delobel, 1975;

Goncalves, 1970; Harris, 1963; Ingram, 1958; Nye,1960; Roome, 1975; and Schmutterer, 1979). In view of the evidence that its distribution range is increasing (Mohyuddin and Greathead, 1970; van Rensburg and van Hamburg, 1975) there is a possibility that the pest status of this insect is likely to attain even greater proportions.

The polyphagous habits would also accelerate the development of these new pest status dimensions by extending its spectrum of host plants. However, studies on Ostrinia nubilalis in Hungary revealed that this may not necessarily happen since the moths' eggs are often found on non-host plant species which do not suffer even from an initial attack (Nagy, 1976). C.partellus importance as a pest is underlined by the fact that it has several names namely, sorghum borer, juar borer, grain sorghum stalkborer, and the spotted stalkborer. In Africa, it is thought to be of recent introduction (Ingram, 1958, and Mohyuddin and Greathead, 1970).

1.23 C. partellus biology

Kapur (1950) and Dogget (1970) studied the size and colour of C. partellus moths. They reported a wingspan of 20-30 mm, the males being much smaller

and darker than the females. The forewings of the males are whittish brown to straw-coloured, with dark brown piceous scales usually darker. The hind wings are light straw-coloured. Females have much lighter forewings while the hind wings are almost white. The adults, they reported, are short-lived. According to Ingram (1958) even when provided with food the adults died within 60 hours. The pre-oviposition period was found to be 24 hours (Dogget, 1970; Hill, 1975; Ingram 1958; Roome and Padgham, 1977). Several workers have studied the life history of C. partellus. The duration of the life cycle and the number of generations per year appeared to depend on the weather as illustrated in Table 1.

Schultes (1978) also demonstrated that non-diapause larvae of different sexes in C. partellus, not only took different times to reach maturity, but also grew at different rates after about 20 days from hatching.

According to van Hamburg (1980) monitoring of the C. partellus life cycle was complicated by the fact that generations overlapped. When, for example, he sampled for larvae in 43 day old plants 4 weeks after

Table 1 : Development of C. partellus under different conditions as studied by different authors

Country	Number of Generation	Temperature	Development Period(days)				Authority
			Egg	Larva	Pupa	Average Life Cycle	
East Africa, Sudan, Malawi, etc.	6	-	7-10	28-35	7-10	29-33	Hill, 1975
ICRISAT, India	-	-	8	-	-	-	Roome & Padgham, 1977.
COPR England	-	Ambiet	5	-	-	-	Woodhead et al, 1980
India	4	-	4-5	19-27	7-10	30-50	Gahukar & Jotwani, 1980
India & East Africa	2	-	-	-	-	30-40	Young & Teetes, 1977
India (Punjab)	6-7	26°-28°c	2-4	15-31	2-9	21-39	Gomez, 1948
Kenya	-	25°c	-	30-36	-	-	Scheltes 1976
South Africa	-	28°c	5	-	8	-	van Rensburg, van Hamburg, 1975
Uganda	11	-	8	28-33	8-10	49 32-39	Ingram, 1955

artificial infestation with first instar larvae he recovered third instars to sixth instars as well as pupae. In this way several workers have found as many as four to eleven generation in a year (Gahukar and Jotwani, 1980; Gomez, 1948; Hill, 1975 and Ingram,1958).

C. partellus eggs were described by Hill (1975) as well as Kapur (1950) as flattened, scale-like, ovoid, measuring about 0.8 mm in length. They said the eggs were laid in imbricate rows in groups of 50-100 in a batch and eggs in excess of 400 could be laid. Ingram (1958) observed that the eggs were almost translucent at first turning to opaque white on the first day and finally greyish. Roome and Padgham (1977) further observed that the larval head within the eggs darkened just before hatching and hence described this stage of egg development as the "black head" stage. These larvae, they continued, cut semi circular flaps through the egg surfaces and forced their way out without eating the egg shell.

Girling (1978) recorded a 95.4% hatching rate in Uganda, while in South Africa van Rensburg and van Hamburg (1975) recorded a 89% hatching order. Roome and Padgham (1980) observed that the egg hatching was

usually well synchronized even though Woodhead et al. (1980) argued that the hatching times were determined among other things, by the relative amount of light and darkness. Dick (1945) and Waiyaki (1968) in their respective studies obtained a 95% hatching rate.

The egg stage as well as the first instar larvae appear to be the most vulnerable stages in the moths life cycle since in a COPR/ICRISAT combined study Roome and Padgham (1977) only 30% of the first instar larvae got established in the same plants as they were hatched. Twenty five percent, they found, distributed 50cm downwind and another 45% were lost altogether. After 7 days they could recover only 1-5% of the larvae originally hatched. Both Singh et al. (1974) and Woodhead et al (1980) found that rainfall immediately after egg hatching caused a very high mortality. Furthermore, Mohyuddin and Greathead (1970) in their biological control studies observed Formicid ants to regularly cause a 90% mortality on the eggs in East Africa. Dick (1945), Dodds (1939), Girling (1978) and Waiyaki (1968) all found similar results according to Girling (1978). But van Hamburg (1980) in S. Africa found that the high mortality was due to harzards of first instar migration rather than parasites and

predators. At the same time van Hamburg (1980) found that first instar migration was very essential to ensure an even distribution. In fact, he found that late instar infestation was always even and always at the same level even if there had been a higher oviposition. If there had been a higher oviposition there would be a correspondingly high mortality, he found.

Ingram (1958), van Rensburg and van Hamburg (1975) found that the just hatched first instar showed a positive phototactic and a negatively geotropic response. Roome and Padgham (1977) found that on reaching the top of the young plant the first instar larvae dispersed with the aid of fine silk threads and the wind. These threads could be of considerable length and thus increased the probability of reaching other plants.

Dogget (1970) and Hill (1975) wrote that after hatching and dispersal of the first instar larvae moved into the plant funnels and fed for a while on the young leaves causing a characteristic "windowing" (with only roughly rectangular strips of epidermis left after the larvae have eaten away the rest of the leaf tissue above or below the strips). This damage, they said,

was the first visible sign of a stalkborer damage. Different authors refer to this damage by different names. Examples of the names include, "short-hole damage" (Ingram, 1958 and van Rensburg and van Hamburg, 1975) and "buck shot" damage (Teetes,1977).

In older plants van Rensburg and van Hamburg (1975) found that the larvae bore directly into the stems. They also found that young larvae may feed for a while on the leaves and then leave the plant for a nother or re-enter the same plant at the base. Both Roome and Padgham (1977) and van Rensburg and van Hamburg (1975) felt that the larvae did not bore down the funnel after invading the young plant. Rather, the larvae feed below the leaf whorl and if the damage is extensive the growing plant is destroyed resulting in "deadhearts".

In older plants, Hill (1975) wrote that the upper part of the stem usually died due to extensive tunnelling by the caterpillars in the pith of the stem. The cavity so formed, he continued, was normally filled with frass. van Rensburg and van Hamburg(1975) noted that all subsequent larval feeding was within the stem and therefore the larvae were well protected from

contact pesticides and from natural enemies. Indeed Girling (1978) found that in Uganda only 0.5% mortality was caused by natural enemies once the larvae had entered the stem. Inspite of the boring activity, Ingram (1958) found older instars could still cause extensive leaf damage as well as in the stem, tassel,and panicle.

Hill (1975) and van Rensburg and van Hamburg (1975) found that there were six larval instars even though additional instars could occur under unfavourable conditions. Mathez (1972) recorded as many as 9 instars in his studies. They also wrote that during the final (sixth) instar the larva prepared a pupal chamber with a characteristic exit hole for the moth covered only by a small disc of epidermal tissue and sometimes a plug of frass between the chamber and the exterior. They found that the pre-oviposition period was 24 hours. Goncalves (1969) found that under suitable conditions, such as in Mozambique, the life cycle was continouos. However, the life cycle in most cases was interrupted by a cold or dry season during which plant growth was impossible (Hill, 1975; Ingram, 1958; Roome and Padgham, 1977). The larvae then entered into diapause in which development was halted until favourable conditions

returned. Van Hamburg (1979) found that C. partellus populations in the field exhibited seasonal and annual changes in numbers, mean size, mass, and fecundity.

Diapause can be referred to as "hibernation" or "aestivation" respectively, depending on whether it occurs during a cold or dry, hot season. Several workers have noted existence of diapause in C. partellus in different regions in the world. These include Butani (1955), Ingram (1958), Moiz and Quresh (1969), Pant and Kalode (1964), Pathak and Pant (1961), Nye (1960), Schmu tterer (1969). Scheltes (1978) looked not only into the existence of diapause in C. partellus but conducted extensive investigations into conditions, causes and even criteria for diapause occurence. Scheltes, in his work, considered climatic conditions, behavioural, physiological, and morphological aspects of the insect and also the condition of the host plant as well as the insect's hormonal rhythm before, during and after diapause. He even considered implications of diapause on C. partellus control.

1.24 Sorghum Resistance to C. partellus

Jepson (1954) and van Emden (1976) have noted that most entomologists in the course of their bionomics studies on stalkborers became aware that some plants were less susceptible to heavy infestation or yielded well inspite of attack. Harber (1980) attributed these differences to plant varietal differences. Plant varieties, he wrote, vary widely in their characteristics , as well as, in intensity of interraction with pests. A "variety" is a term in biology for a closely related group of plants or animals sharing certain characteristics by which they differ from other plants or animals of the same species. Varietal characteristics are inherited. A "variety" is a taxon of subspecific rank. A variety is called a"cultivar" when developed by breeding or selection by man. Varieties under cultivation are therefore called cultivars. In zoology the characteristics of a variety may or may not be inherited and thus the term "variety" has no formal status because it is so vague that it is best avoided.

According to van Emden (1976) the less susceptible varieties, when available, require no extra pest control measures and are thus more

CHAPTER 2

PRELIMINARY EXPERIMENTS ON SOME ASPECTS OF THE BIOLOGY OF CHILO PARTELLUS (SWINHOE) IN MBITA POINT, KENYA

2.10 INTRODUCTION

"Prior to embarking on a plant resistance programme, there must be a significant pool of information on the influence of biotic and abiotic factors on the biology of the pest. This should include information on behaviour, especially in relation to food habits, oviposition, and movement; definition of parameters of growth and fecundity; and the effects of the environment on pest population. These types of information must be available (in order) to design experiments (that are) within the range of the behaviour and activities of the pest. It is critical to design tests that do not preclude the biological expression of important traits or characteristics of the pest of host" (Ortman and Peters, (1980). It is only in such a case that the pests and/or host responses can be categorized according to their conformity or departure from the mean.

The importance of detailed pest biology is especially demonstrated by the resistance studies that

have been conducted for the maize plant to the European corn borer (Ortman and Peters, 1980). According to these authors this pest's feeding location and feeding behaviour have been shown to depend on the development stage of the pest and the host.

General information on Chilo partellus life cycle has been well documented for a long time (as was demonstrated in the literature review). Extensive work on C. partellus ecology and oviposition was also done at the Centre for Overseas Pest Research (COPR) in London, England, by the following authors (Roome, Chadha and Padgham, (1977); Roome and Padgham,(1977); Roome and Padgham, (1980); and Chadha and Roome,(1980). Woodhead et al, (1980), also from the COPR, even reported on the behaviour and host establishment of C. partellus first instar larvae.

However, there were certain major aspects of C. partellus biology for which more information was required for better understanding of the pest's population growth patterns to injurious levels. The most prominent of these deficiencies were the C.partellus adult life span, oviposition pattern and the adult female's fecundity.

The life span or longevity of an insect is the length of time the insect lives from hatching to the time of death due to old age. During this time, three periods can be distinguished in relation to reproduction These are the pre-reproductive, the reproductive, and the post-reproductive periods. The immature stages belong to the pre-reproductive period. This aspect is well covered in the literature and will thus not be included in this study. Adult insects require varying lengths of time to reach sexual maturity, to mate, and to reproduce. This takes from a few hours in some moths and mayfies to much long periods in some beetles and the periodic cicadas.

Likewise, the length of the reproductive period varies among insects. The eggs may all be laid at one time as in the tussock moth, may be laid a few a day for many days as in the bloodsucking lice, or there may be a number of successive egg batches produced at intervals as in the house-fly which lays from two to seven lots at intervals of two to five days each batch consisting of about 25 eggs (Metcalf and Flint, 1967). The length of the post reproductive period is variable but lies with a narrower range than the other periods. Usually it lasts for a few days, although in the meal-worm adults it is as long as the reproductive period.

The knowledge of the relative lengths of these three periods can be very important in the control of the insect pest. In the control of stalkborers like C. partellus the length of the pre-oviposition period is of particular significance since the larvae are vulnerable against pesticides and larval predators only before the larvae enter the stems.

Fecundity of insects is the level of reproduction expressed in terms of the number of eggs (or number of viviparous forms) per female. One of the reasons for the success of insects is their high fecundity. This fecundity is generally fixed for a given species even though it can be influenced by many ecological factors both biotic and abiotic. A single female can lay as few as one egg like the true females of certain aphids, or as many as a million eggs or more in the case of the honeybee queen and the termite queen.

It was in the light of the above considerations that preliminary investigations were initiated on the life span and fecundity of C. partellus in order to better understand how the insect gains its pest status through population build-ups.

b) Plant breeding rarely provides a quick solution for an existing pest problem since it takes 10-15 years from formulation of the problem to dissemination of large quantities of a resistant seed so developed (Woods, 1974).

c) A new variety must compete successfully with established varieties in such respects as yield in the absence of pests, uniformity of germination, flowering and maturation, ease of harvesting (which can be very important where mechanization plays an important role) as well as othe agronomic and aesthetic properties.

d) Entomologist tend to use resistance as a last resort (Woods, 1974). As such less practical use has been made of resistance to insects in agriculture than resistance to pathogens and nematodes. In the past, pest resistance has tended to be eclipsed by such methods as use of synthetic pesticides - whose limitations have now become lengendary.

e) Earlier work on plant resistance did not take into account the importance of understanding underlying plant chemical and morphological bases of resistance. Early emphasis was rather on whether resistance was inherited, genetically manageable and or whether it was reasonably stable in practical uses (Norris and Kogan, 1980).

While recognizing the advantages and weakness of chemical pest control, emphasis, according to some authors, has shifted to integrated pest management (Glass, 1975; Kennedy, 1975; Smith, 1972). Host plant resistance, especially when combined with good cultural practices, is now regarded as the most effective, convenient, economical and environmentally acceptable alternative pest control method to use of pesticides (Waiss et al, 1977).

However, Ortman and Peters, (1980) argued that host plant resistance should be a basic objective of crop improvement programmes conducted by plant breeders and geneticists and "should be an integral part of strategies for insect management"

for entomologists. These authors went on to say that the exact role that plant resistance plays in a breeding programme would vary with each crop and each insect since its importance would be determined by the availability and utility of other control measures. In some cases, they went on, plant resistance would be a contributing feature while in others it would be chief means of controlling a pest. The utility, advantages and economics of usage of resistant cultivars was well demonstrated by Luginbill (1969). Plant resistance is of particular advantage where (1) the insect is exposed for a brief period in its life cycle and therefore requiring critical timing of control measures; (2) the crop is of low economic value; (3) the pest is continuously present and is the single most limiting factor in successful cultivation of the crop in a wide area; (4) other control measures are not available; (5) the pest occurs in unique niches where other control methods are not feasible or are difficult to use (Ortman and Peters, 1980).

1.25 Mechanisms of sorghum resistance to C.partellus

Several workers have looked into resistance of sorghum to damage by several pests. These include: (McMillan and Starks, 1967 (a) and (b); Dickson and

Laird, 1969; Dogget et al., 1970; Fisk, 1978; Woodhead and Bernays, 1978; Fisk, 1980; and Maiti et al., 1980). In some cases several strides have been made in elucidating the mechanisms of resistance. This is particularly true of the work that has been done on resistance of the sorghum shootfly, Atherigona soccata Rond. where presence of trichomes has been demonstrated to play an important role in resistant varieties (Maiti et al., 1980). Specific chemicals such as cyanides, phenolic compounds and related compounds have also been demonstrated to be important against Rhopalogisphum maidis (Fitch), Peregrinus maidis (Ash.), and Lucusta migratoria(L.), (Woodhead and Bernays, 1978; and Fisk, 1980).

Extensive research has also been done on the basis of resistance of sorghum to stemborers by such workers as :Kalode and Pant, (1966); Roome and Padgham (1977); Jotwani et al., (1977); Woodhead and Bernays, (1977); Rao et al., (1978); Singh and Sandhu, (1979); Roome and Padgham (1980); Woodhead et al. (1980) (a) and (c). Although several breakthroughs have been made, a clear picture has not emerged. This is mainly due to the fact that different workers have tended to concentrate on particular aspects. Kalode and Pant (1966) concentrated on field and cage experiments; Roome and Padgham (1977) on the ecology

and behaviour of the first instar, while Woodhead et al.(1977),(1980) (a) and (c) were interested mainly on the chemicals in sorghum that confer resistance. However, sorghum plant resistance is actually on several levels. Some of these are chemical, ecological, due to the physical environment and even on the phenology of the plant. Dabrowski et al. (1981) at ICIPE identified seven levels of interrelation between sorghum and C. partellus. These are:

1. Non-preference for oviposition
2. First larval instar movement and establishment on the sorghum host plant
3. First larval instar leaf damage
4. Whorl feeding of the larvae resulting in "deadhearts"
5. Extensive tunnelling by the larvae
6. Formation of panicles inspite of extensive larval tunnelling, and
7. Seed formation inspite of extensive larval feeding (leaf damage and tunnelling).

This approach has the advantage of considering as many different aspects as possible. This also explains the apparent conflicting reports of resistance in the literature. Resistance of any particular cultivar could be based on any one or some of the seven

relationships. A cultivar that is not preferred for oviposition will not necessarily be resistant to larval tunnelling and hence workers using either criterion could miss potentially resistant lines.

This approach does not necessarily conflict with the traditional basic mechanisms of plant resistance first advocated by Painter (1958). Painter divided mechanisms into three basic types: non-preference, antibiosis and tolerance. Teetes (1980) felt that resistance was usually a result of more than one of these traditional mechanisms. Besides, resistance is a dynamic relationship between the pest and the host plant rather than an absolute phenomenon perculiar to the plant alone. Several references exist to substantiate this (Beck, 1965; Feeny et al. 1977; Kogan, 1975; van Emden and May, 1973; and Waiss et al., 1977). Kogan (1975) in particular has clearly delineated the role of insect-plant interactions in which he covered behavioural and physiological components, plant components, as well as plant stimuli in relation to insect responses. Waiss et al. (1977),on the other hand, pointed out that in order to fully understand the host plant - insect relationships more effort had to be made in understanding the crop plant resistance at chemical and cellular level.

Beck (1965) even excluded tolerance from the definition of resistance because it "implies a biological relationship between the insects and plants that is quite different from resistance in the strict sense". Farrel (1977) also supported this view because tolerance "lies in the response of the plant to a given level of biting or stylet feeding" and went on to give examples drawn from fourteen different workers. Dahms (1972) on the other hand while supporting Painter's definition of plant resistance pointed out the futility of "single factor approaches" to pest control. Thereby he emphasized the integrated pest management approach.

In the light of the considerations covered in the review the objectives of this study were set out as follows:

1.30 OBJECTIVE OF THE STUDY

1) To determine the methods of measuring sorghum resistance to the spotted stalkborer, Chilo partellus (Swinhoe).

2) To explain the role of each of the following aspects of the sorghum - C. partellus relationships:

(a) C. partellus oviposition preference or non-preference on different sorghum cultivars.

(b) C. partellus first instar larval acceptance or non-acceptance of different sorghum cultivars as shown by migration from the host plant, mortality, and or established in the plant.

(c) Larval feeding of the different Chilo partellus instar larvae on the leaves as shown by leaf damage.

(d) Pattern of leaf damage by the larvae and "deadhearts".

(e) Insect-plant biophysical and biochemical factors in relation to plant damage.

(f) Tunnelling in the sorghum stems by C. partellus larvae.

(g) Tolerance and other compensation factors of the sorghum plant to larval Chilo partellus damage.

CHAPTER 2

PRELIMINARY EXPERIMENTS ON SOME ASPECTS OF THE BIOLOGY OF CHILO PARTELLUS (SWINHOE) IN MBITA POINT, KENYA

2.10 INTRODUCTION

"Prior to embarking on a plant resistance programme, there must be a significant pool of information on the influence of biotic and abiotic factors on the biology of the pest. This should include information on behaviour, especially in relation to food habits, ovipposition, and movement; definition of parameters of growth and fecundity; and the effects of the environment on pest population. These types of information must be available (in order) to design experiments (that are) within the range of the behaviour and activities of the pest. It is critical to design tests that do not preclude the biological expression of important traits or characteristics of the pest of host" (Ortman and Peters, (1980). It is only in such a case that the pests and/or host responses can be categorized according to their conformity or departure from the mean.

The importance of detailed pest biology is especially demonstrated by the resistance studies that

have been conducted for the maize plant to the European corn borer (Ortman and Peters, 1980). According to these authors this pest's feeding location and feeding behaviour have been shown to depend on the development stage of the pest and the host.

General information on Chilo partellus life cycle has been well documented for a long time (as was demonstrated in the literature review). Extensive work on C. partellus ecology and oviposition was also done at the Centre for Overseas Pest Research (COPR) in London, England, by the following authors (Roome, Chadha and Padgham, (1977); Roome and Padgham,(1977); Roome and Padgham, (1980); and Chadha and Roome,(1980). Woodhead et al, (1980), also from the COPR, even reported on the behaviour and host establishment of C. partellus first instar larvae.

However, there were certain major aspects of C. partellus biology for which more information was required for better understanding of the pest's population growth patterns to injurious levels. The most prominent of these deficiencies were the C.partellus adult life span, oviposition pattern and the adult female's fecundity.

The life span or longevity of an insect is the length of time the insect lives from hatching to the time of death due to old age. During this time, three periods can be distinguished in relation to reproduction These are the pre-reproductive, the reproductive, and the post-reproductive periods. The immature stages belong to the pre-reproductive period. This aspect is well covered in the literature and will thus not be included in this study. Adult insects require varying lengths of time to reach sexual maturity, to mate, and to reproduce. This takes from a few hours in some moths and mayfies to much long periods in some beetles and the periodic cicadas.

Likewise, the length of the reproductive period varies among insects. The eggs may all be laid at one time as in the tussock moth, may be laid a few a day for many days as in the bloodsucking lice, or there may be a number of successive egg batches produced at intervals as in the house-fly which lays from two to seven lots at intervals of two to five days each batch consisting of about 25 eggs (Metcalf and Flint, 1967). The length of the post reproductive period is variable but lies with a narrower range than the other periods. Usually it lasts for a few days, although in the meal-worm adults it is as long as the reproductive period.

The knowledge of the relative lengths of these three periods can be very important in the control of the insect pest. In the control of stalkborers like C. partellus the length of the pre-oviposition period is of particular significance since the larvae are vulnerable against pesticides and larval predators only before the larvae enter the stems.

Fecundity of insects is the level of reproduction expressed in terms of the number of eggs (or number of viviparous forms) per female. One of the reasons for the success of insects is their high fecundity. This fecundity is generally fixed for a given species even though it can be influenced by many ecological factors both biotic and abiotic. A single female can lay as few as one egg like the true females of certain aphids, or as many as a million eggs or more in the case of the honeybee queen and the termite queen.

It was in the light of the above considerations that preliminary investigations were initiated on the life span and fecundity of C. partellus in order to better understand how the insect gains its pest status through population build-ups.

2.20 MATERIALS AND METHODS

Before C. partellus oviposition preference studies could be initiated some information had to be obtained about the moths' fecundity. In order to obtain this information newly emerged adult moths were obtained from the laboratory colony of C. partellus maintained at the Mbita Point Field Station of the International Centre for Insect Physiology and Ecology (ICIPE). Pairs consisting of male and female freshly emerged moths were put in special oviposition cages (figure 1b) previously lined with wax paper. These cages consisted of 20cm plastic pots (for plants) the insides of which were lined with wax paper. The tops, after caging the moths were covered with fine nylon mesh secured tightly around the mouths with rubber bands. On this nylon mesh was placed cottonwool moistened in 10% sucrose solution.

The C. partellus sexes can be differentiated in that the male is smaller and darker than the females. The female's forewings are pale brown with dark brown scales forming a streak along the costa. The hind wings are a pale straw colour. The female, on the other hand, has much paler forewings while the hind wings are almost white. These are shown in figure 1a.

FIGURE 1 (a)

Male and female Chilo partellus moths

Note that the male is darker and smaller than the female.

FIGURE 1 (b)

Laboratory oviposition cage made up of 20cm pots lined with wax paper and covered by fine nylon mesh.

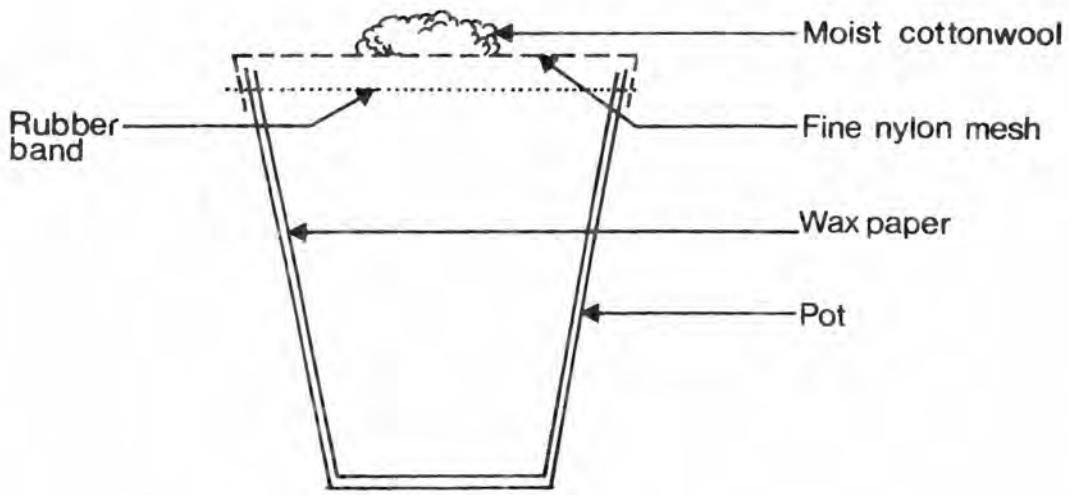


Fig.1(b) Laboratory Oviposition Cage

FIGURE 1 (c)

Chilo partellus glass cages for observation of ovipositing moths on potted sorghum plants. The cages measured 14cm by 14 cm by 58.5cm.

(5.5in x 5.5in x 23.5in)

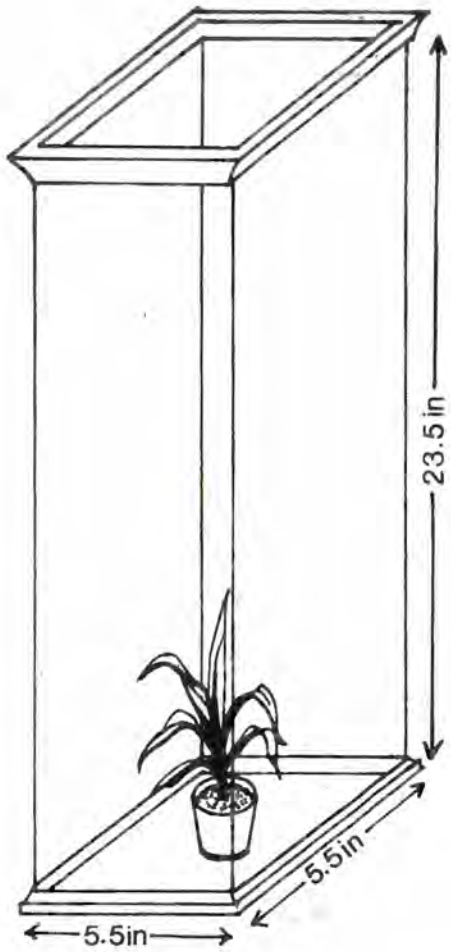


Fig 12 Glass cages for Chilo oviposition on plants

FIGURE 2

Chilo partellus glass cage for observing adult emergence from pupae and adult moth behaviour before, during and after mating The cage measures 37.5cm by 37.5cm by58.5cm.

(15.5 in x 15.5in x 23.5in.)

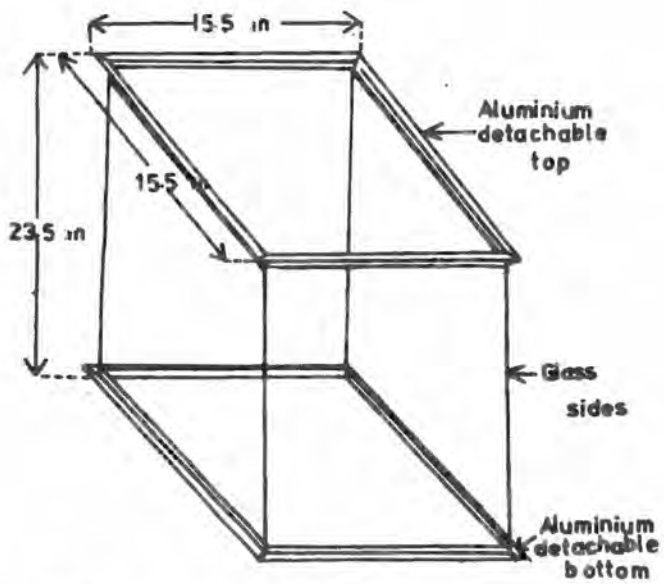


FIG. 2 : OBSERVATION OVIPOSITION CAGE

This experiment was sequentially replicated 80 times. When the caged moths were dead (this took four to six days) the wax paper was removed from the cages and both egg batches and individual eggs counted under a dissecting microscope. The figures so obtained were recorded.

In the second oviposition experiment C.partellus pupae were obtained from the Mbita Field Station colony, put in a 20cm petri dish and covered in a special glass oviposition cage (Figure 2). This cage measured 37.5cm by 37.5cm (15.5 in. x 15.5 in.) and was 58.5cm (23.5 inches) high. This made it possible to observe the emergence of the moths within from every angle. Inside the cage was also placed a smaller petri dish with cottonwool moistened in a 10% sucrose solution. Constant observation was carried out in order to note the moth emergence, the length of time it took the moths to mate and associated behaviour. Immediately after mating the moths were transferred to smaller observation oviposition cages in which sorghum potted plants were provided as oviposition substrates. These smaller cages (Figure 1 (c) measured 14cm by 14cm by 58.5cm (5.5 in. x 5.5 in x 23.5 in.). Constant observation was carried out on the small cages as well in order to determine the

onset of the reproductive phase. Any behavioural perculiarities before, during and after oviposition was recorded.

As already stated, the fecundity of an insect species is the level of reproduction expressed in terms of the number of eggs per female. For. C. partellus, this was determined by counting all the eggs per batch laid by the females. In the second experiment 68 females were used. This count was carried out every day, the moths being transferred to new plants every morning. The recorded counts also revealed the peak oviposition days, the oviposition patterns, the longevity and the frequency distribution of the female moths with different longevities.

The temparature and relative humidity was recorded throughout the duration of these experiments. The temparature varied between 20°C and 29°C (minimum and maximum) while the relative humidity varied between 33% and 69%.

2.30 RESULTS

The emergence of adults from the pupae took place almost always at night and was accomplished relatively quickly (within a few minutes). Males outnumbered the

FIGURE 1 (d)

Mating Chilo partellus moths observed through the glass observation cage

females and emerged before the females. Practically all the males mated on the second day (after 24 hrs) from the time of emergence from the pupae. Females, on the other hand, mated invariably within the first 12 hours from emergence. The calling behaviour by the females started at about 01.00 a.m. This behaviour consisted of movement of the antennae and the abdomen. The antennae would be held upwards and outwards slightly pointed forward. Then the abdomen was moved to and fro first gently and later vigourously. Within time the females became more and more agitated but still remaining on the same spot.

The males, in response to this calling behaviour, got increasingly restless and moved about first on the surface and then flew actively about in the cage. As they neared the calling female they circled it (in flight) a few times before finally approaching. The mating occured back to back (figure 1(d) and lasted as little as 27 minutes to as much as several hours.

The behaviour of both males and females just described coincide with those of Chadha and Roome (1980). However, according to these authors oviposition did not occur within the first 24 hours.

In these experiments a few female did oviposit within the first 24 hours. Others still oviposited without having mated. The egg batches of these moths were different. First of all they were fewer and tended to collapse such that after a few minutes looked flacid.

After mating both males and females remained stationary for the remainder of the day (24 hours). On the second evening both males and females were very active starting at about 5.30 p.m. Initially (earlier in the evening) males were more active and thus very difficult to observe. But when they finally settled (after mating) they did not move again and were invariably dead by the third day or were only moribund. The females moved about actively and restlessly until oviposition started. This occured as early as 5.30 p.m. and as late as 02.30 a.m. on the following day. During oviposition the antennae would be in constant vibrating motion being also moved backwards and forwards. The abdomen would also be moved to and fro until finally the ovipositor, which is reddish in colour and shaped rather like a ship's anchor, was protruded. At first the ovipositor was protruded at regular pulsating intervals. The abdomen was then bent downwards under the body until it was in contact with

the leaf surface. Probing in this fashion continued for a few minutes. The moth would also move orient itself. At times the moth would take off and fly to another part of the plant and continue the probing with the ovipositor. After a while the eggs were then laid. The moths always laid their eggs while moving backwards and the eggs were always laid from left to right and then centre in three rows. The observation was also in agreement with Chadha and Roome's (1980), observations. The eggs were always laid either along the depression between the leaf veins, along the midrib on the adaxial leaf surface, or near and parallel to the midrib on the abaxial surface (Figure 1(e). The oviposition behaviour of different female moths was not always consistent. Some moths oviposited indescriminately and on any surface (even on the glass surface even though plants were available). Others even oviposited some egg batches on top of others. However, the majority oviposited in neat rows always parallel to the leaf venation.

Invariably the moths paused for a few minutes, moved away stopped for a while being stationary only to resume oviposition again. On resuming to oviposit they either moved to a new site or continued from the last position. In most cases pauses separated egg

FIGURE 1 (e)

Chilo partellus egg batches near and parallel to the midrib on the abaxial surface of the leaf.

batches. But large egg batches were laid in several instalments. Different egg batches were invariably laid on different leaves or on different parts of the same leaf.

Oviposition activity continued until about 09.30 p.m. when it would stop only to resume at about 02.35 a.m. on the following day. During the intervening periods the moth would be stationary. By 07.15 a.m. all the moths would be stationary and remained in the same position until dusk when the same cycle would be repeated.

The data on C.partellus fecundity is given in Table 2. According to this table the mean fecundity from both experiments is 305±71.6 eggs per female. The data on longevity, oviposition pattern, number of egg batches per female as well as the number of eggs per batch are given in Table 3. The chi squared value (X^2) according to this table is significant at $p < 0.01$. Table 4 shows the number of moths with different longevities as well as the relative percentages of these moths. None of the female moths lived for one day only. But their longevities varied from 2 days to 7 days with a mean longevity 3.9±1.1 days. The longevities of the male moths was not included because all

FIGURE 3

Chilo partellus overall oviposition pattern showing the peak oviposition period. The number of egg batches was plotted against time in days.

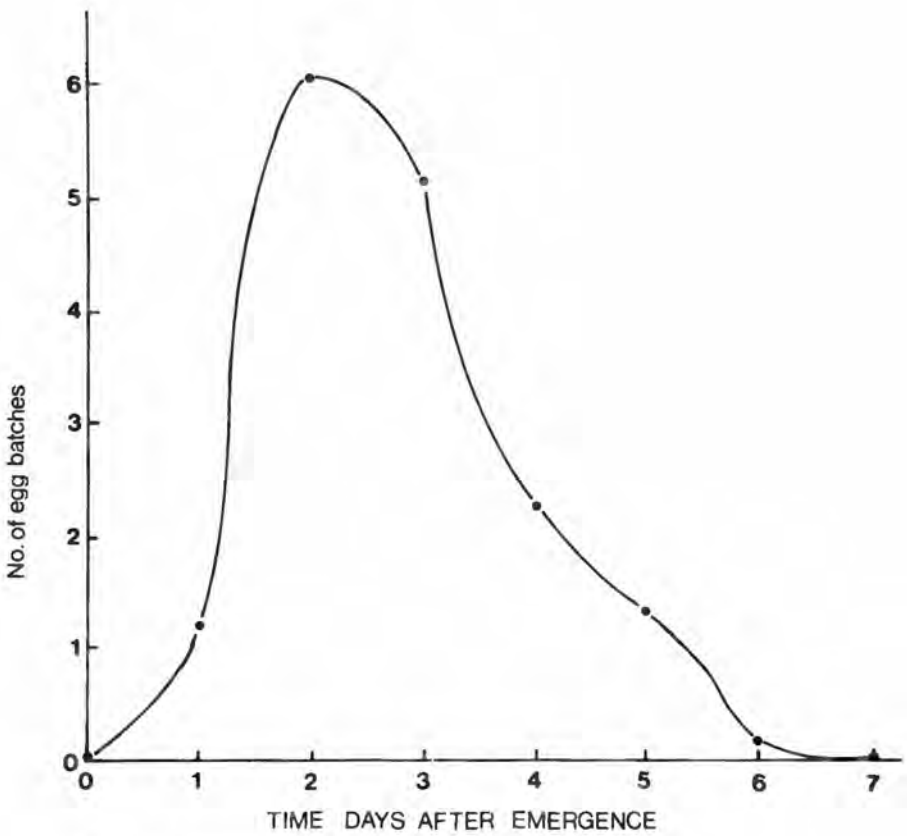


Fig 3. Chilo oviposition duration and peak oviposition

FIGURE 4

Chilo partellus frequency distribution of female moths with different longevities. This follows a normal distribution curve.

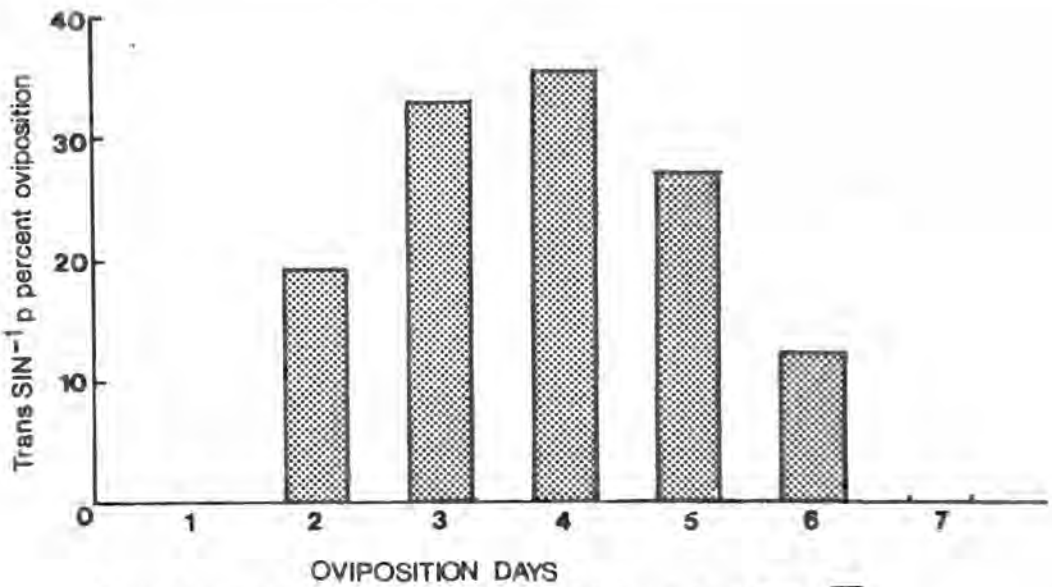


Fig. 4 Frequency distribution of Chilo adult longevity in $SIN^{-}\sqrt{p}$ Transformation of percent dying on different days Mbita Point 1981

FIGURE 5

Relationship between Chilo partellus female longevity and oviposition. Log transformation of egg batches layed on different days was plotted for months with different longevities.

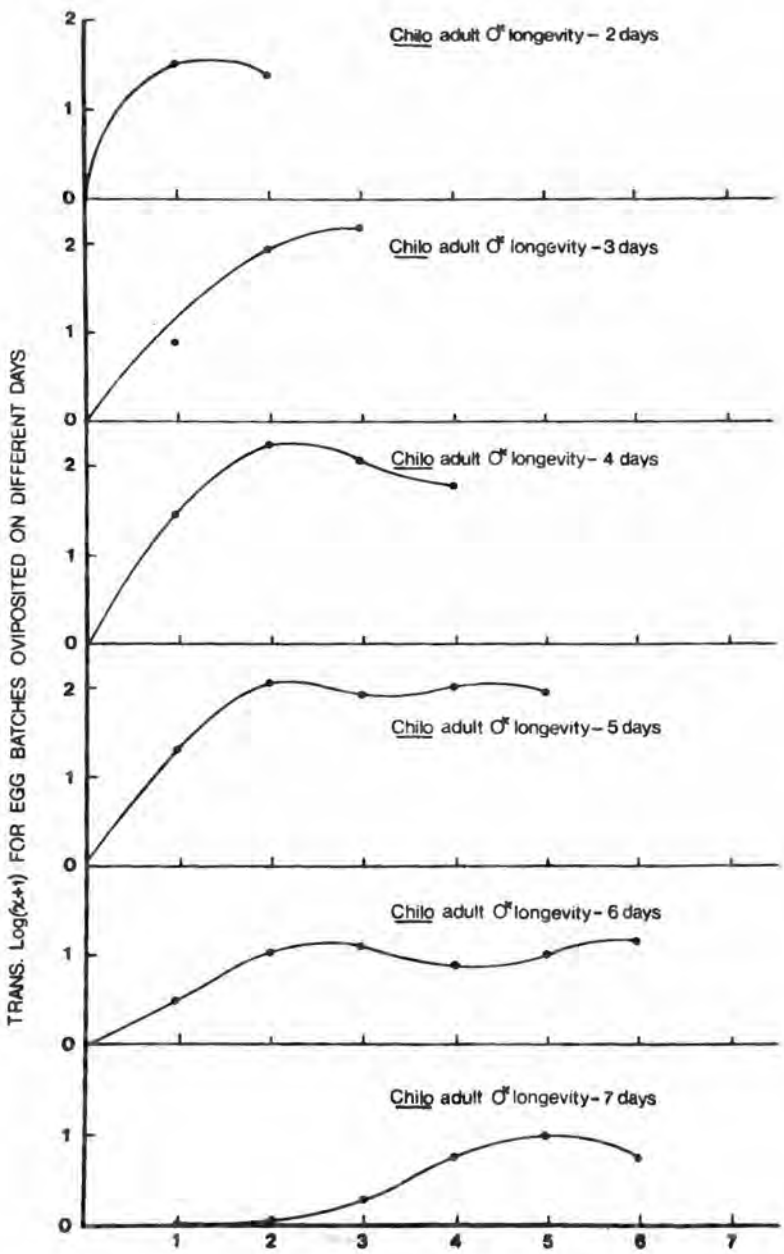


Fig.5 RELATIONSHIP BETWEEN CHILO ♂ LONGEVITY AND OVIPOSITION. MBITA POINT, 1982

males died within 48 hours. The mean number of egg batches per female was 17.2±13.7 batches and the mean number of eggs per batch was 17.5±14.2 eggs. Table 5 shows the total number of eggs laid by moths with different longevities from the first to the seventh day. From this it is quite apparent that most eggs were oviposited on the second day after emergence and thus this was the overall peak oviposition day (figure 3). But when the moths with different longevities are considered separately (figure 5) then a different picture emerged.

(a) when the percentage of moths with different longevities were transformed (using the Arc sine of the squareroot of ρ transformation, where ρ is the percentage expressed as a decimal fraction) then the longevity of the moths followed a normal distribution curve (figure 4).

(b) it also becomes apparent that there were two oviposition peak periods (Figure 5). The moths that lived for 4 days or less had only one peak oviposition period but those that lived for 5 days or more showed two peak oviposition periods. But since those moths that lived for 4 days or less were slightly more (58.2%

according to Table 3), the overall picture that emerged (Figure 3) was that there was only one peak. The moths that lived for seven days showed only the second peak (Figure 5).

(c) the moths that did not oviposit on the first two days lived longest (Figure 5) but were very few (1.5% according to Table 4). But these moths were the least fecund of all.

(d) the moths that oviposited most (the most fecund) were those that lived for 3 to 5 days (88.9%).

2.40 DISCUSSION

2.41 C. partellus life span (Longevity)

From the experimental observations female moths take a shorter time to reach sexual maturity as indicated by the fact that they invariably mated within 12 hours from emergence. Males tended to mate on the second day after emergence even though exceptions were found. However, male moths tended to emerge earlier than females in a given batch of pupae. As a result, although the different sexes took different periods to reach sexual maturity the time of readiness to mate was well

synchronized. The females lived much longer than males which hardly ever lived for 48 hours. The post-reproductive period in both sexes was, however, the same. The onset of the post-reproductive phase in the males was immediately after mating whereas in the females it was after the last oviposition. This period was hardly ever more than 24 hours. The female longevity was 3.9 1.1 days and the oviposition period was 3.38±1.07 days. On the bases of this knowledge oviposition experiments inthe screenhouses could be initiated. For example, moths could be released into the screenhouses and the egg counts could be done 5 days later.

2.42 C. partellus fecundity

The fecundity data is found in table 3. According to this table, C. partellus oviposits 254.4 204.2 eggs per female, 17.2±13.7 egg batches per female, and the number of eggs per batch were 17.5±14.2. However, on the basis of the 1981 experiment C. partellus laid 13.4 egg batches per female. This is within the confidence limits of the 1982 experiments, namely 17.2±13.7 egg batches per female. It was the 1981 figures that were used for computing the number of moths in each screenhouse. Each screenhouse had a sorghum plant population of about 450 plants and thus approximately

35 female C. partellus moths would be required to lay one egg batch per plant.

Table 2 : CHILO PARTELLUS OVIPOSITION DATA CONDUCTED IN THE LABORATORY AT MBITA POINT, 1981 AND 1982

Experiment	No. of Replications	Temperature	Humidity	Total No. of eggs ovip'd	No. of eggs/ female	Total No. of egg/ batches
1981	80	20-29°c	33-69%	28,449	355.6	1070
1982	68	20-29°c	33-69%	17,297	254.4	1171
Total				45,746	610	2241
$\bar{X}$					305±71.6	15.1

Table 3 : C. PARTELLUS FECUNDITY, FEMALE LONGEVITY, AND PEAK OVIPOSITION, MBITA POINT, 1982

Reps.	♂* Longevity (days)	Total No. of Egg Batches	Total No. of Eggs	No. of Egg Batches on different days							χ^2 (df=1)
				1	2	3	4	5	6	7	
1	3	20	237	0	20	0	-	-	-	-	
2	3	6	26	2	0	4	-	-	-	-	
3	5	30	543	5	6	1	8	10	-	-	
4	7	20	146	0	0	1	5	9	5	0	
5	5	13	178	1	6	6	0	0	-	-	
6	4	24	372	0	18	6	0	-	-	-	
7	3	8	80	0	7	1	-	-	-	-	
8	4	17	230	0	5	11	1	-	-	-	
9	4	15	273	0	10	5	-	-	-	-	
10	5	35	764	2	15	7	11	-	-	-	
11	3	36	737	2	18	16	-	-	-	-	
12	3	14	651	0	10	4	-	-	-	-	
13	4	22	420	0	21	1	-	-	-	-	
14	3	3	115	0	0	3	-	-	-	-	
15	3	4	342	0	3	1	-	-	-	-	
16	6	23	168	0	1	4	2	5	11	-	
17	2	5	20	2	3	0	-	-	-	-	
18	4	11	51	0	0	9	2	-	-	-	

Table 3 (cont'd...)

19	3	4	61	2	2	0	-	-	-	-
20	4	13	74	0	1	12	0	-	-	-
21	2	16	290	0	16	0	-	-	-	-
22	5	27	524	0	9	4	2	12	-	- -
23	3	5	148	0	5	0	-	-	-	-
24	3	4	199	0	4	-	-	-	-	-
25	3	1	14	0	1	-	-	-	-	-
26	3	2	37	0	2	0	-	-	-	-
27	3	21	275	0	2	19	-	-	-	-
28	2	2	15	2	0	-	-	-	-	-
29	3	24	225	0	5	19	-	-	-	-
30	2	4	54	4	0	-	-	-	-	-
31	2	19	452	17	2	-	-	-	-	-
32	3	51	282	0	0	51	-	-	-	-
33	2	6	178	6	0	-	-	-	-	-
34	2	1	21	1	0	-	-	-	-	-
35	2	3	96	0	3	-	-	-	-	-
36	3	16	165	0	0	16	-	-	-	-
37	4	18	159	1	16	1	-	-	-	-
38	4	7	46	6	0	1	-	-	-	-
39	4	6	28	0	3	3	0	-	-	-
40	4	16	528	0	7	9	-	-	-	-
41	4	9	156	0	8	1	-	-	-	-
42	4	6	49	0	3	2	1	-	-	-
43	4	19	102	0	10	5	4	-	-	-
44	4	30	386	3	2	2	23	-	-	-

Table 3 (cont'd...)

45	4	1	6	1	0	-	-	-	-	-
46	4	7	410	0	7	0	-	-	-	-
47	6	13	158	0	0	1	4	5	3	-
48	4	39	740	0	14	5	20	-	-	-
49	4	8	162	0	6	2	-	-	-	-
50	5	10	247	0	10	0	-	-	-	-
51	5	26	484	10	3	7	6	-	-	-
52	4	8	239	2	6	-	-	-	-	-
53	4	44	525	1	11	32	-	-	-	-
54	5	70	336	0	8	7	10	45	-	-
55	4	15	85	0	15	0	-	-	-	-
56	3	3	22	1	2	0	-	-	-	-
57	4	11	27	8	3	0	-	-	-	-
58	3	9	331	0	3	6	-	-	-	-
59	4	30	466	6	11	6	7	-	-	-
60	3	18	519	0	6	12	-	-	-	-
61	5	26	288	0	18	7	1	-	-	-
62	5	31	683	0	15	13	3	-	-	-
63	5	43	154	1	2	7	30	3	-	-
64	5	13	109	1	3	9	-	-	-	-
65	6	18	114	2	9	6	1	-	-	-
66	5	46	409	1	3	6	23	13	-	-
67	5	18	361	0	3	2	4	9	-	-
68	5	28	505	0	18	10	-	-	-	-
Total 68	264	1171	17297	90	420	363	168	111	19	0

Table 3 (cont'd...)

$\bar{X}$	3.9	17.2	254.4	1.32	6.2	5.3	2.5	1.6	0.3	0	321.332***
Standard deviation	1.1	13.7	204.2	2.8	6	8.1	6	6	1.5	0	
Percentage of eggs laid				7.7	35.9	30.9	14.3	9.5	1.6	0	

*** χ^2 Value significant at $p < 0.01$

SUMMARY OF TABLE 3

Total No. of Eggs	$\bar{X}$ No. of Eggs ♂ per moth	Longevity	No. of Egg Laying	$\bar{X}$ No. of Egg Batches/♂	% of Eggs laid in the first 4 days	$\bar{X}$ No. of Eggs per batch
17297	254.4±204.2	3.9±1.1	3.38±1.07	17.2±13.7	88%	17.5±14.

Table 4 : FREQUENCY DISTRIBUTION OF ADULT FEMALE LONGEVITY, MBITA POINT FIELD STATION, 1982

	Days							
	1	2	3	4	5	6	7	Total
No. of moths	0	8	19	23	14	3	1	
Percentage	0	11.8	27.9	33.8	20.6	4.4	1.5	100%
Trans.$\sin^{-1}\sqrt{p}$	0	19.4	33	35.5	27	12.1	7	

Table 5 : RELATIONSHIP BETWEEN C. PARTELLUS FEMALE LONGEVITY AND OVIPOSITON ON DIFFERENT DAYS, MBITA POINT, 1982

Longevity in days	Egg batches on different days							Total
	1	2	3	4	5	6	7	
2	32	24	-	-	-	-	-	56
3	7	90	152	-	-	-	-	349
4	28	177	113	58	-	-	-	376(32.1)
5	21	119	86	98	92	-	-	416(35.5)
6	2	10	11	7	10	14	-	54
7	0	0	1	5	9	5	0	20
Total	9	420	363	168	111	19	0	1171

Chilo Adult Longevity (days)	Trans. log (X+1) for egg batches on different days							Total
	1	2	3	4	5	6	7	
2	1.52	1.4	-	-	-	-	-	2.92
3	0.9	1.96	2.18	-	-	-	-	5.04
4	1.46	2.25	2.06	1.77	-	-	-	7.54
5	1.34	2.08	1.94	2	1.97	-	-	9.33
6	0.48	1.04	1.08	0.9	1.04	1.18	-	5.72
7	0	0	0.30	0.78	1.0	0.78	0	2.86
Total	5.7	8.73	7.56	5.45	4.01	1.96	0	33.41

CHAPTER 3

CHILO PARTELLUS OVIPOSITION PREFERENCE OR NON-PREFERENCE AMONG THE DIFFERENT SORGHUM CULTIVARS

3.10 INTRODUCTION

Resistance of plants to insect attack is defined by Painter (1951) as: "the relative amount of heritable qualities possessed by the plant which influence the ultimate degree of damage done by the insect. In practical agriculture it represents the ability of a certain variety to produce a larger crop of good quality than do ordinary varieties at the same level insect population". However,visiting administrators, entomologists or plant breeders when shown field plots demonstrating the effectiveness of plant resistance often ask, "What is the cause of this resistance?"

There are several ways to answer this question. Mumford (1931), according to Painter (1951), classified plant resistance according to "epiphylaxis" and "endophylaxis". This method was regarded by Painter as being of little practical use. Snelling (1941) identified 15 categories of plant characteristics that

confer resistance. These are as follows:

(1) Early maturity (genetic or ecological)
(ii) Late maturity (genetic or ecological)
(iii) Unattractiveness (feeding or oviposition)
(iv) Repellence
(v) Pubescence
(vi) Hardness of tissue
(vii) Thickness of tissue
(viii) Tightness of tissue
(ix) Growth habit (rate and type)
(x) Incompatible food relations
(xi) Physiological response of plants
(xii) Tolerance to attack
(xiii) Recovery following attack
(xiv) Vigour of plants
(xv) Adaptation to the soil and other conditions of the environment.

Dahms (1972) identified 16 possible criteria to evaluate plant resistance to insects. These are abridged and listed as follows by Ortman and Peters (1980):

1. Visual evaluation of infested cultivars by observing retarded growth, lodging, cutting, discoloration, etc.
2. Determining the number of surviving plants at various intervals following infestation.

3. Determining yield differences between infested and non-infested plots.
4. Determining number of larvae or adults attracted to a cultivar when given a free choice.
5. Observation of comparative effects of forced insect feeding (confinement) on cultivars by measuring length of insect life cycle, mortality, reproductive rates, moulting, etc.
6. Determining weights of insects after definite period on different cultivars.
7. Determining the number of eggs laid.
8. Determining the number of surviving insects and progeny produced.
9. Measurement of food consumed.
10. Measurement of food utilized by the insect.
11. Simulation of insect damage and observation of recovery.
12. Measurement of root damage by the amount of force required to pull out a plant from the ground(This method is indirect).
13. Use of plant leaves or flowers in Olfactometers to determine attractance.
14. Correlation of chemical factors in plants with insect response.

15. Growth and reproduction potential of insects fed on various plant diets containing different plant cultivars.
16. Correlation of morphological factors with injury.

The criteria used in this study, as indicated in the 'objectives', overlap considerably with Dahm's criteria. The bases, mechanisms, or causes of resistance are those classically advocated for by Painter (1951). These interrelated mechanisms are:

(a) Preference or non-preference for oviposition food or shelter.
(b) Antibiosis: adverse effect of the plant cultivar on the biology of the insect.
(c) Tolerance: repair, recovery or ability to withstand infestation.

In this chapter only preference or non-preference for oviposition is covered. The basic "triad of resistance relationships" has been found to be determined by independent genotypes which are interrelated in their effects (Painter, 1951). The possibility of cumulative resistance by combinations of genetic factors for different types of resistance

is thus introduced (Painter, 1951).

According to Painter (1951), preference or non-preference is used to denote those groups of plant characters that lead to or away from the use of a particular plant variety, for oviposition, for food or for shelter, or for combinations of the three. A cultivar or variety that is not preferred may not require the degree of antibiosis or tolerance that must be present in a preferred variety of the same level of resistance. Kogan and Ortman (1978) proposed to substitute "antixenosis" for non-preference because, they argued, this term would be projected as a plant characteristic and thus parallel to the terms "antibiosis and "tolerance". Non-preference,on the other hand, refers more correctly to the insect. But "antixenosis" conveys the idea that the plant is avoided as a "bad host".

In the case of hemimetabolous insects and in many beetles the same plant serves as food for both the young and the adult. As a result, attraction of the adult for food or oviposition may result, at least in part, from the same stimuli (Painter,1951). This is not true of the insects belonging to Orders Lepidoptera, Hymenoptera and Diptera where the adult generally feeds

on nectar and other plant juices, quite different from the food of the larvae.

The existence of preference for oviposition is well documented. Dethier (1947) discussed chemical attractants and repellents taking into account available literature. Larson and Fisher (1938), according to Painter (1951), found the presence of an oviposition stimulus was so important from cowpea weevils, Callosobruchus maculatus (F,) that females died without ovipositing a single egg when a suitable stimulus from cowpeas or beans was not available. Parnell et al. (1949) believed that non-preference alone could cause a decline of the insect pest population, and used resistant cotton to demonstrate their contention. In that example, the susceptible field was "shimmering with adults (leaf hoppers) on the wing" while the non-preferred variety in a field nearby was practically free from adults and nymphs.

However, oviposition preference is difficult to study because unlike antibiosis and tolerance, involves the knowledge of ways in which insects locate plants (Painter, 1951). This in turn, Painter argued, involves a study of the behavior of such insects in the presence of various stimuli derived from the plants.

Behavioural sequences involved in host selection for oviposition are sometimes very complex (Beck and Schoonhoven, 1980). To illustrate this point, these authors referred to Zohren's work in 1968 in which he demonstrated that host selection in the cabbage root fly, Hylemya brassicae, involves nine different steps. Several other references on oviposition preference by different insects for different crops exist. Some of the most important and recent of these include Everson, (1980); Nielson and Lehman (1980); Norris and Kogan (1980); Pathak and Saxena (1980); and Teetes (1980). Other published works include: Behan and Schoonhoven (1978), Blum (1968), Bohn et al. (1972), Claridge and Wilson (1978), Choi et al. (1976), Day et al. (1978), Dickson and Laird (1968), Elsey and McFadden (1980), Everly et al. (1979), Finch (1978), Jermy and Szentesi (1978), Phillips (1978), Rothschild and Schoonhoven (1977), Kennedy (1977), Kennedy (1978), Kishaba (1973), Poston et al. (1979), Saxena (1978), Schalk et al. (1977) Stadelbacher and Scales (1973), Wiklund (1974), and Yamamoto et al. (1969). Only a handful of papers deal specifically with C. partellus oviposition. These include those by Chadha and Roome, (1980), Jotwani (1976), Roome et al. (1977), Roome and Padgham (1976), Roome and Padgham (1980) and Sharma and Chatterji (1971).

3.20 MATERIALS AND METHODS

3.21 C. PARTELLUS OVIPOSITION PREFERENCE AMONG SELECTED SORGHUM CULTIVARS IN A CHOICE SITUATION.

3.211 Screenhouse Experiments

The sorghum cultivars that were used in these experiments were obtained from the International Crops Research Institute for Semi-Arid Tropics (ICRISAT), Hyderabad, India. All the cultivars had already been screened against stalkborer attack, and as such, had been given identifying I.S. numbers for "International Sorghum Stemborer Nursery (I.S.S.B.N.)".

Further screening was carried out in 1979 and 1980 by the Bases of Plant Resistance Programme at the International Centre for Insect Physiology and Ecology (I C I P E). All experiments were conducted at the ICIPE Mbita Point Field Station, South Nyanza, from 1981 to 1983.

For the investigations, Hyderabad sorghum cultivars were used in two experiments, planting nine cultivars each time. The selection was based on how these

FIGURE 10

Nylon mesh screenhouses used for oviposition preference studies in Mbita Point, 1981 and 1982.


STUDIES ON
CHILD

cultivars had performed in 1979 and 1980. The most preferred cultivars were supposed to be IS 18361, IS 18363 and IS 18367 and the least preferred cultivars were supposed to be IS 18479, IS 1082 and IS 4660. Three intermediate cultivars were IS 17739, IS 18319 and IS 18520 ("Serena"). These cultivars would have been used again in 1982 but, after the results of the first field experiment on oviposition, it was decided to include IS 2205 and IS 2122 as the least preferred and drop IS 18367 and IS 18479.

Four parallel screenhouses covered in nylon mesh were used (Figure 10). Each of these sreenhouses were 5 x $10m^2$, 2.5m high at the sides, and 3m high along the middle.

The design used was the randomized complete block, each block in a separate screenhouse. Two rows per cultivar were planted with 60cm interrow distances and 20cm interplant distances as recommended by the Ministry of Agriculture in Kenya. Five seeds were placed in each hole together with a pinch of NPK fertilizer. The fertilizer was first thoroughly mixed with the soil. After germination the seedlings were thinned to one plant per hole. This left 414 plants in each screenhouse.

FIGURE 11

Chilo partellus oviposition in the field, Mbita Point, 1981.


STUDIES ON
CHILO OVIPOSITION
ON SORGHUM

Twenty one days after planting 35 pairs of C. partellus newly emerged male and female moths were introduced, (scattered at random) in each screenhouse. After 5 days egg batches were counted on each plant in each screenhouse. The number of egg batches if any oviposited on each plant, plant height, total number of leaves, the leaf oviposited on (counting from the bottom) and the surface oviposited (abaxial or adaxial) were all recorded. The moth release and subsequent counting were done for six consecutive weeks in the first experiment (in 1981), and for three consecutive weeks in the second (in 1982).

3.212 Field Experiments

In the field experiments, varying numbers of sorghum cultivars and replications were used depending on the availability of space. Either four or six replications were used in a randomized complete block design. The planting procedure was the same as in the screenhouse experiments described above. Figure 11 shows the sorghum stand that was used for the first field oviposition studies.

The first experiment was planted on the first July, 1981, with 15 sorghum cultivars and six replications, the

second on the 24th February, 1982, with 11 cultivars and four replications, the third on the 31st July 1982, with 12 replications and fourth (last) on the 22nd October, 1982, with eight cultivars and six replications. Data on egg batches oviposited on each cultivar were recorded as in the screenhouse experiments.

3.213 Olfactometer Experiments

To demonstrate the difference between preferred and non-preferred sorghum cultivars, cultivars IS 18363 and IS 2205 which in the preceding tests were found to be susceptible and resistant respectively with respect to the preference or non-preference trait for C.partellus were subjected to olfactometer experiments.

The Olfactometers were designed to determine whether preference or non-preference for oviposition by C.partellus on sorghum was affected by odours produced by either cultivar. Each gravid female had to choose between two alternatives. This is shown in a sketch form in the generalized Y-shaped olfactometer (Figure 6). Altogether three different types of olfactometers were used. In the type A, box olfactometer (Figure 7), "resistant" and "susceptible"

FIGURE 6

Generalized Y-shaped olfactometer

This shows alternatives that the moth has between going for the resistant or susceptible sorghum cultivar.

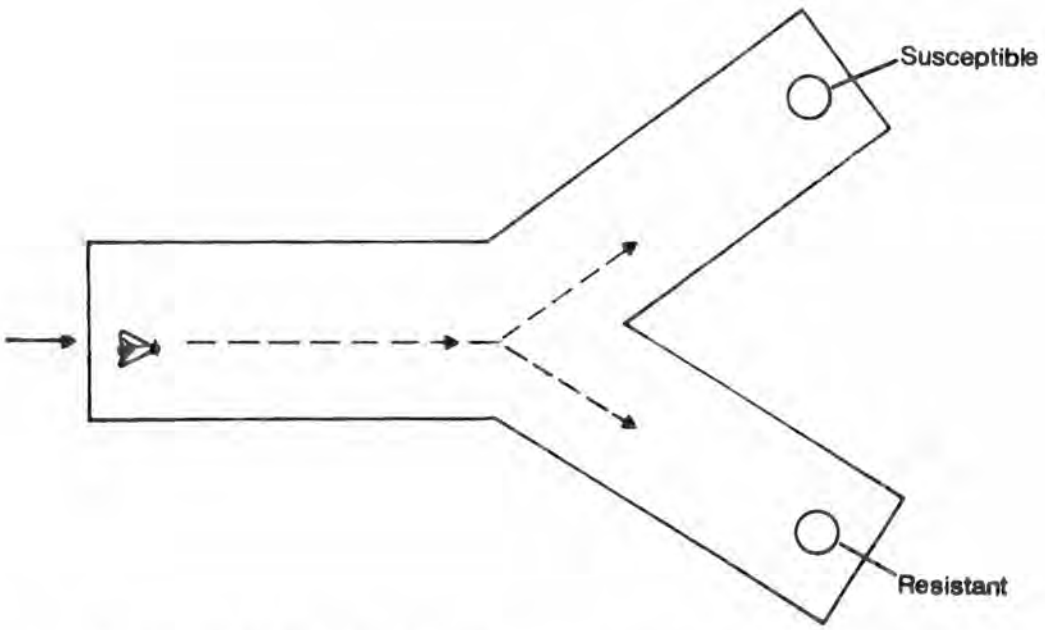


FIG. 6 AN OLFACTOMETER; Y SHAPED (Perspex or glass)

FIGURE 7

Box Olfactometer

Notice that resistant and suceptible cultivars were placed at opposite ends. The moth was released in the middle.

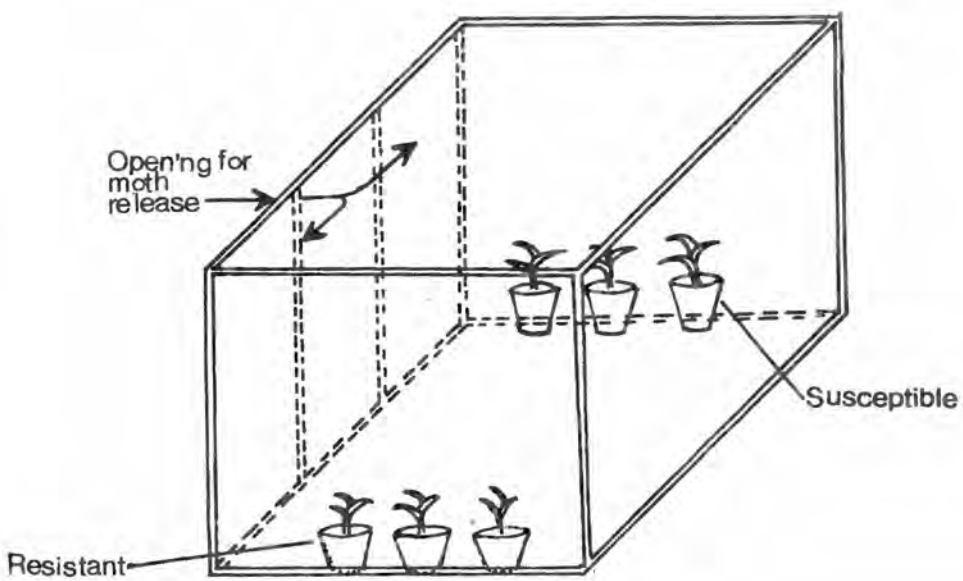


FIG.7 BOX OLFACTOMETER

FIGURE 8

Y-shaped Olfactometer

In this olfactometer the moths could go to the resistant or susceptible cultivar but could escape because the top ends of the cages were open.

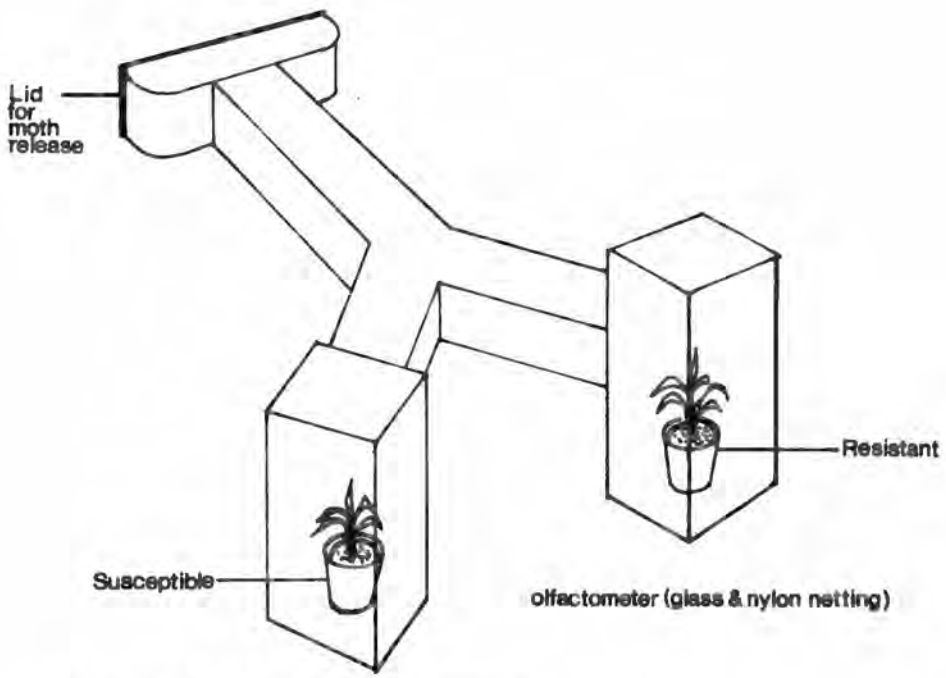


FIG. 8 TYPE B OLFACTOMETER, Y SHAPED

FIGURE 9

Y-Shaped perspex olfactometer

In this olfactometer the moths could be seen through the perspex. All the ends were sealed so that moths could not escape.

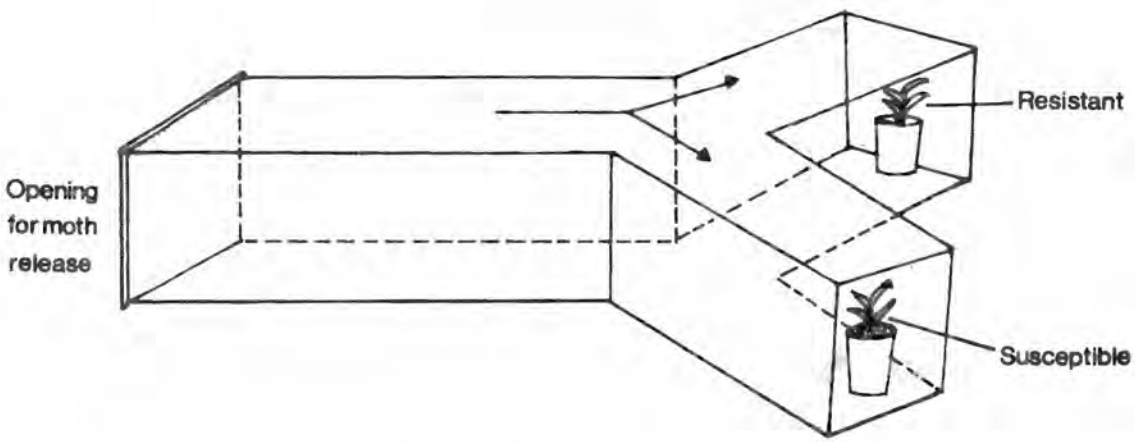


FIG. 9 TYPE 'C' OLFACTOMETER; Y SHAPED

cultivars in pots were placed at either end. The dimensions of the olfactometer were 250x100m^2 and 150cm high. Then five pairs of newly emerged male and female moths were introduced through the centre door and allowed free choice of where to settle for oviposition. They could go to the "resistant" end or the "susceptible" end. After the females had oviposited, the egg batches and the total number of eggs in the batches on the plant as well as in the immediate vicinity of the plants were counted and recorded. Since there were two olfactometers the arrangement of the experiment was always reversed so that where there were "susceptible" plants in one there were "resistant" plants in the other and vice versa. The experiment was replicated sequentially six times.

The other two olfactometers were Y-shaped (Figures 8 and 9). The smaller olfactometer (Type B; Figure 8) was made of glass and the Y part of the olfactometer was 14 x 14cm^2. The ends opened into two non-transparent cages made of wire and nylon mesh containing a "resistant" potted plant and a"susceptible" potted plant, respectively. Again five pairs of newly emerged moths were released into the main stem part of the Y. In this experiment, which was replicated nine

FIGURE 12

Laboratory oviposition glass cages.

FIGURE 13

Oviposition Cage in a non-choice

situation

FIGURE 14

Chilo partellus adult predator

times over three days, the moths could escape on getting to either potted plant. The oviposited egg batches were recorded after three days.

The third olfactometer Figure 9 (type C) was larger than the second type (type B) and was made of perspex. Here the limbs and the main stems were 50cm x 50cm and thus the potted plants could be placed inside. It could also be sealed by nylon mesh so that the moths could not escape and could easily be counted. Egg batches on the plants as well as near the plants could be counted easily. This experiment was also replicated nine times.

3.22 *C. partellus* oviposition on selected sorghum cultivars in a non-choice situation

To determine the effect of confinement of *C. partellus* moths in cages containing either IS 18363 ("susceptible" cultivar) or IS 2205 ("resistant" cultivar) the moths were caged in nylon mesh cages in the field and glass cages in the laboratory (Figure 12). The oviposited egg batches were counted and recorded. The resulting data was again analysed for statistical significance using the analysis of variance method.

In the second experiment the moths were confined in "cages" each of which was constructed by means of two petri dishes (Figure 13). These "cages" did not close tightly. As a result, some predetors such as ants, spiders, etc could go inside but the moths could not escape. Figure 14 shows an example of a spider that was found feeding on C. partellus moths. After noting the number of egg batches and eggs oviposited, the moths' longevity was also noted. All the data was recorded. The egg batches were also ringed in black marking ink in order to monitor their fate. In particular the following aspects were noted:-

(i) whether or not the eggs hatched (if they hatched whether all hatched),
(ii) whether the eggs were parasitized,
(iii) whether the eggs flaked off before hatching, and
(iv) whether they were eaten by predators.

In this experiment the following sorghum cultivars were used: IS 18363, IS 2205, IS 18489, IS 18479, IS 1044 and IS 18520 ("Serena"). Twenty seven newly emerged pairs of moths were used on each cultivar. However, in some cases the "cages" came apart (due to wind forcing the leaves to rub against each other). As a result ended up with different numbers of replications in different cultivars.

3.23 Analysis of results

In each of the preceding experiments the counts (eggs, batches, moths etc.,) were analysed for statistical significance using the analysis of variance method. When a factor was a statistically significant source of variation then the Duncan's Multiple Range Test (Gomez and Gomez, 1976) was used to determine which sorghum cultivars, for instance, had significantly more eggs oviposited on them or which cultivars had significantly less oviposition.

3.30 RESULTS

3.31 C. PARTELLUS OVIPOSITION PREFERENCE AMONG SELECTED SORGHUM CULTIVARS IN A CHOICE SITUATION

3.311 Screenhouse Experiments

The analysis of variance (tables 6(b) and 7(b) show that the variety (sorghum cultivar) was a highly significant factor (affecting the number of egg batches laid by C. partellus (at $\rho<0.01$). In table 6(b) the date of sampling was a very highly significant factor ($\rho<0.001$). The means of numbers of egg batches laid on different varieties were compaired using Duncan's

Multiple Range Test and are given on(tables 6(a) and 7(a). The most favoured varieties were IS 18363, IS 18319, IS 4660, IS 18367 and IS 18361 in the first experiment (table 6 (a), while they were IS 1082 and IS 17739 in the second experiment (table 7(b). Note, however, that cultivar IS 18363 in the second experiment still got more egg batches than IS 2205.

3.312 Field Experiments

The analysis of variance tables for the field oviposition experiments (tables 8(b), 9(b) and 11(b) show that both variety and date of sampling were significant factors affecting the numbers of eggs oviposited by C. partellus (except the date of sampling in table 9(b).

The cultivars of greatest interest (the most susceptible and the most resistant) are compared in table 12. According to this table, the most preferred cultivars by C. partellus for oviposition were IS 18361, IS 18520, and IS 18363. And the least preferred cultivars were IS 2205 and IS 2122. It will be noted,

however, that C. partellus oviposition preference in relation to cultivar IS 18520 ("Serena") was inconsistent Sometimes this cultivar was the most preferred for C. partellus oviposition (tables 9(a) and 11(b) while at other times it was the least preferred (table 8(a).

3.313 Olfactometer Experiments

The results on oviposition studies on the three types of olfactometers are given in tables 13, 14, and 15. In the box olfactometer (figure 7), the results (table 13) suggest that the cultivars were indeed a highly significant source of variation for C.partellus oviposition preference. But that was true only when:

(i) the total number of egg batches (on the plants and near the plants) were counted, or when

(ii) individual eggs on the plants (only) were counted.

Neither the counting of egg batches on the plants (only) nor counting the total number of individual eggs (on the plant and the olfactometer) were advisable for showing differences between the two cultivars.

The Y-shaped perspex olfactometer (Figure 9) showed a significant difference between the two cultivars

only for moth observation but not for egg batch counts or individual egg counts (table14). The third olfactometer (Figure 8) proved completely unsatisfactory. (table 15).

3.32 C. partellus oviposition in a non-choice situation

All the results on C. partellus oviposition in a non-choice situation did not show any significant difference between the two cultivars (tables 16 and 17). Even when other factors (like egg hatchability, parasitism, predation and flaking off) were considered no significant differences were shown to occur between the two cultivars (table 19). Table 18 gives a summarised comparison of what happened to the adults as well as the egg batches in the different cultivars.

3.40 DISCUSSION

3.41 C. PARTELLUS OVIPOSITION IN A CHOICE SITUATION

From the results on C. partellus oviposition studies in the screenhouse and field it can be inferred that:-

(i) There were certain sorghum cultivars that were preferred for oviposition. These cultivars are IS 18361,

IS 18520 and IS 18363; while the least preferred cultivars were IS 2205 and IS 2122. There is a possibility that there were other cultivars in either group but were not selected in these studies. This was because some of these cultivars were used only a few times in these studies.

(ii) Both cultivars and dates of sampling were important sources of oviposition preference variations but there was no interraction between cultivars (A) and date of sampling (B) (AxB was not a significant source of variation). However, when oviposition preference studies in sorghum are conducted the age of plant must also be considered.

(iii) Cultivar IS 18520 ("Serena"),being a locally recommended cultivar, was the only one whose seed was obtained from the Kenya Seed Multiplication Board via the retail stores. The inconsistent nature of C. partellus oviposition preference in relation to this cultivar suggests that the seed is not a pure line.

(iv) Both the box olfactometer (figure 7) and the perspex olfactometer (figure 9) are suitable for C. partellus oviposition preference studies but these olfactometers are suitable for different purposes. The

perspex olfactometer is suitable for moth behaviour studies while the box olfactometer is more suitable for egg counts and egg batch counts studies.

3.42 C. PARTELLUS OVIPOSITION IN A NON - CHOICE SITUATION

The results suggest that when there is a choice C. partellus will show a preference for certain cultivars but any cultivar is acceptable as an oviposition substrate when there is no choice. Factors like egg parastism and adult predation have no significant contribution in the relative susceptibility or resistance of different cultivars.

Table 6(a) : C. partellus oviposition on different Sorghum cultivars in the screenhouse, Mbita Point, 1981.

Cultivar	$\bar{X}$ No. of egg Batches
IS 18363	3.58 a
IS 18319	2.51 ab
IS 4660	2.39 abc
IS 18367	2.32 abc
IS 18361	2.30 abc
IS 17739	1.85 bc
IS 1082	1.62 bc
IS 18520 ("Serena")	1.54 bc
IS 18479	1.44 c

Table 6(b) : Summary of analysis of variance for Chilo partellus oviposition on selected sorghum cultivars in the screenhouse, Mbita, 1981

Source of Variation	df	SS	MS	F ratio
Blocks (T)	3	1.601	0.534	1.534^{ns}
Variety (A)	8	7.368	0.921	1.648**
Dates (B)	5	53.553	10.711	30.779***
A x B	40	11.663	0.291	0.836^{ns}
Error	159	55.398	0.348	
Total	215	129.543		

Note: Figures followed by different letters are significantly different from one another($p<0.05$)

Table 7(a): Chilo partellus oviposition on different sorghum cultivars in the screenhouse, Mbita Point, 1982

cultivar	$\bar{X}$ No. of egg Batches	
IS 1082	2.02	a
IS 17739	1.04	ab
IS 18361	0.81	bc
IS 18520 ("Serena")	0.73	bc
IS 4660	0.72	bc
IS 18363	0.66	bc
IS 2122	0.27	bc
IS 18319	0.22	bc
IS 2205	0.13	c

Table 7(b) : Summary of analysis of variance for C. partellus ovipostion on selected sorghum cultivars in the screenhouse, Mbita, 1982

Source of variation	S S	df	M S	Fratio
Block (T)	0.5298	3	0.1766	1.0425^{ns}
Variety (A)	5.5679	10	0.5568	3.2869^{**}
Date (B)	0.9982	2	0.4991	2.9463^{ns}
A x B	2.7847	20	0.1392	0.8217^{ns}
Error	12.1934	72	0.1694	
Total	22.074	107		

Note: Figures followed by different letters are significantly different ($p < 0.05$)

Table 8 (a) : Chilo partellus oviposition on different sorghum cultivars in the field, Mbita Point, 1981.

Cultivar	$\bar{X}$ No. of Egg Batches		Cultivar	$\bar{X}$ No. of Egg Batches	
IS 2263	2.86	a	IS 18349	1.27	bcdef
IS 2162	2.02	ab	IS 18463 ("Swarna")	1.22	bcdef
IS 18361	1.98	abc			
IS 18427	1.48	abcd	IS 4660	1.2	bcdef
IS 1082	1.46	bcde	IS 18489	1.19	cdef
IS 2122	1.39	bcdef	IS 2205	0.9	def
IS 17739	1.3	bcdef	IS 18520 ("Serena")	0.67	g
IS 1151	2.29	bcdef			
IS 18479	1.28	bcdef			

Table 8(b) : Summary of analysis of variance for Chilo partellus oviposition on selected sorghum cultivars in the field, Mbita, 1981

Source of Variation	df	SS	MS	F ratio
Blocks (T)	5	4.03	0.806	2.839*
Variety (A)	14	18.41	1.315	4.624***
Date (B)	6	5.37	0.895	3.147**
A x B	84	26.451	0.315	1.108^{ns}
Error	520	147.89	0.284	
Total	629	202.146		

Note: Figures followed by different letters are significantly different.

Table 9 (a): Chilo partellus oviposition on selected sorghum cultivars in the field, Mbita Point, 1982

Cultivar	$\bar{X}$ No. of Egg Batches	
IS 8595	1.96	a
IS 18520 ("Serena")	0.94	ab
IS 18363	0.71	b
IS 18361	0.64	b
IS 2146	0.61	b
IS 4660	0.52	b
IS 1082	0.52	b
IS 17739	0.44	b
IS 18319	0.40	b
IS 2205	0.27	bc
IS 2122	0.04	c

Table 9 (b) : Summary of analysis of variance for Chilo partellus oviposition on selected sorghum cultivars in the field, Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Blocks (T)	3	0.8678	0.2893	2.3929^{ns}
Variety (A)	10	3.6548	0.3655	3.0232^{**}
Date (B)	1	0.2739	0.2739	2.2644^{ns}
A x B	10	0.9436	0.0944	0.7808^{ns}
Error	63	7.617	0.1209	
Total	87	13.3571		

Table 10 (a) : Chilo partellus oviposition on different sorghum cultivars in the field. Mbita Point, 1982

Cultivar	$\bar{X}$ No. of Egg Batches	
IS 18361	4.8	a
IS 18363	3.72	ab
IS 18319	3.60	bc
IS 1151	3.3	bcd
IS 18520 ("Serena")	2.71	bcde
IS 1082	2.31	cdef
IS 18479	2.15	efg
IS 4660	1.84	fgh
IS 18489	1.76	fgh
IS 2122	1.52	h
IS 1044	1.26	h
IS 2205	1.16	h

Table 10 (b) : Summary of analysis of variance for Chilo partellus oviposition on selected sorghum cultivars in the field. Mbita, 1982

Source of Variation	df	SS	MS	F ratio
Blocks (T)	11	14.8297	1.3482	4.358**
Variety (A)	11	82.9385	7.5399	25.378**
Date (B)	3	3.3032	10.768	36.244**
A x B	33	24.9108	0.7549	2.541**
Error	517	153.5785	0.2971	
Total	575	279.5607		

Table 11 (a) : Chilo partellus oviposition on different sorghum cultivars in the field. Mbita Point, 1982

Cultivar	$\bar{X}$ No. of Egg Batches	
IS 18361	1.28	a
IS 18520 ("Serena")	1.24	ab
IS 18363	1.03	abc
IS 2205	0.91	bcd
IS 2263	0.7	cd
IS 18489	0.65	cd
IS 2122	0.64	cd
IS 1044	0.59	d

Table 11 (b) : Summary of analysis of variance for Chilo partellus oviposition on selected sorghum cultivars in the field. Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Blocks (T)	5	2.956	0.591	3.36**
Variety (A)	7	4.673	0.668	3.8**
Dates (B)	7	39.184	5.598	31.81**
A x B	49	5.842	0.119	0.67^{ns}
Error	315	55.596	0.176	
Total	383	108.251		

Table 12: Overall ranking of selected sorghum cultivars according to Chilo partellus oviposition. Mbita Point, 1981 to 1982

Sorghum Cultivars	Oviposition Preference Rank in different experiemnts				Overall	
	From Table 7	From Table 9	From Table 10	From Table 11		
IS 18361	1	3	1	1	1.5	Susceptible
IS 18520	2	1	3	2	2	
IS 18363	3	2	2	3	2.8	
IS 2205	5	4	5	4	4.5	
IS 2122	4	5	4	5	4.5	Resistant

(No.1 shows the most preferred cultivar for oviposition and the highest number is the least preferred).

Table 13 : Chilo partellus oviposition preference Assessment using a box olfactometer. Mbita Point. 1982

Egg Batches on the plants

Sorghum Cultivar	$\bar{X}$ No. of Egg Batches	F ratio
IS 18363	14.83	0.6957^{ns}
IS 2205	13.33	
	(Coefficient of varation	= 11.13)

Total Egg Batches (cage + plants)

Cultivar	$\bar{X}$ No. of Eggs	F ratio
IS 18363	43.33	6.7925***
IS 2205	39.33	
	(Coefficient of variation	= 3.22)

Eggs on the plants

Cultivar	$\bar{X}$ No. of Eggs	F ratio
IS 18363	369.67	14.5008***
IS 2205	243.83	

Total No. of Eggs (cage + plant)

Cultivar	$\bar{X}$ No. of Eggs	F ratio
IS 18363	883.50	0.1308^{ns}
IS 2205	840.17	

Table 14 : Chilo partellus oviposition preference assessment using a Y-Olfactometer (Type C). Mbita Point, 1982

Adults (♂+ ♂)

Sorghum Cultivar	$\bar{X}$ No. of Adults (♂+ ♂)	F ratio
IS 18363	4.17	6.855**
IS 2205	2.33	
Main stem (control)	2.33	

♂ Moths

Cultivar	$\bar{X}$ No.of ♂ moths	F ratio
IS 18363	2.7	8.169**
IS 2205	1.33	
Main stem (control)	1.0	

Total Egg Batches

Cultivar	$\bar{X}$ No. of Egg batches	F ratio
IS 18363	16.83	1.023^{ns}
IS 2205	8.67	
Main stem (control)		

Table 15 : Chilo partellus oviposition preference assessment using a Y-Olfactometer (B Type). Mbita Point, 1982

Total No. of Adults (♂+ ♀)

Sorghum Cultivar	$\bar{X}$ No. of Adults	F ratio
IS 18363	1.55	0.885^{ns}
IS 2205	1.09	
Main stem (control)	1.9	

Total No. of ♀ Moths

Cultivar	$\bar{X}$ No. of ♀ moths	F ratio
IS 18363	0.73	0.995^{ns}
IS 2205	0.64	
Main stem (control)	1.18	

Total Egg Batches

Cultivar	♀ No. of Egg batches	F ratio
IS 18363	6.18	1.749^{ns}
IS 2205	3.72	
Main stem (Control)	8	

Table 16: Comparison of Chilo partellus oviposition on two sorghum cultivars in a non-choice situation (Laboratory). Mbita Point, 1982

Adult Longevity

Cultivar	$\bar{X}$ No. of days	F ratio
IS 18363 IS 2205	4.5 4.13	1.151^{ns}

Total Egg Batches

Cultivar	$\bar{X}$ No. of Egg Batches	F ratio
IS 18363 IS 2205	18.13 13.88	1.202^{ns}

Total Eggs on the plant

Cultivar	$\bar{X}$ No. of eggs	F ratio
IS 18363 IS 2205	191.75 134.75	0.683^{ns}

Total Eggs (on the plant + the cage

Cultivar	$\bar{X}$ No. of Eggs	F ratio
IS 18363 IS 2205	354.5 239.25	3.35^{ns}

Table 17 : Comparison of Chilo partellus oviposition on two sorghum cultivars in a non-choice situation (field). Mbita Point, 1982

Adult Longevity

Cultivar	$\bar{X}$ No. of days	F ratio
IS 18363	4.38	o
IS 2205	4.38	

Total Egg Batches

Cultivar	$\bar{X}$ No. of Egg Batches	F ratio
IS 18363	9	1.703^{ns}
IS 2205	12	

Total Eggs on the plant

Cultivar	$\bar{X}$ No. of Eggs	F ratio
IS 18363	255.88	0.007^{ns}
IS 2205	263.5	

Total Eggs (on the plant + the Cage

Cultivar	$\bar{X}$ No. of Eggs	F ratio
IS 18363	298.5	1.13^{ns}
IS 2205	340.88	

Table 18 : CHILO PARTELLUS OVIPOSITION ON SELECTED SORGHUM CULTIVARS IN A NON-CHOICE SITUATION IN THE FIELD. MBITA POINT, 1982

	SORGHUM CULTIVARS						
	IS18363	IS18489	IS18479	IS1044	IS2205	IS18520	Total
Adults							
1.Total No. of Chilo Moths	15	22	22	22	23	27	131 (21.8)
2.Adult removed by predators	6	8	8	8	0	7	37 (6.17)
	36.4%	36.4%	36.4%	36.4%	36.4%	25.9%	28.2%
3.Unexplained Adult Mortality	3	5	7	5	5	3	28(4.7)
	20%	27.7%	31.8%	22.7%	21.7%	11.11%	21.4%
4. Total No of Batches	34	42	18	48	45	48	235 (39.2)
5. No.of Egg Batches hatched	12	12	5	27	19	15	90(15)
	35.3%	28.6%	27.8%	56.3%	42.2%	31.3%	12.3%
6. Total . No. of Eggs	611	809	287	812	775	652	3946 (652.7

Table 18 (cont'd..)

	IS18363	IS18489	IS18479	IS1044	IS2205	IS18520	Total
7. No.of Egg/ Batch	17.97	19.3	15.9	16.9	17.2	13.6	100.9 (16.8)
8. No. of Batches failing to hatch	0	7	4	3	7	8	29(48)
		16.7%	22.2%	6.3%	15.6%	16.7%	12.9%
9. No. of batches parasi- tized	2	0	3	9	1	3	18 (3)
	5.9%	-	16.7%	18.8%	2.2%	6.3%	7.7%
10. No. of Batches removed by preda- tors	14	11	2	1	12	10	50(8.3
	14.2%	26.2%	11.1%	2.1%	26.7%	20.9%	21.5%
11. No. of egg batches that flaked off	6	14	4	6	5	7	42(7)
	17.7	33.3	22.2	12.5	11.1	14.6	17.9
12. No. of days to hatch	6	6	6.5	6.29	6.13	6	36.92 (6.15)

Table 19 : Comparison of Chilo partellus oviposition on six sorghum cultivars in a non-choice situation (Field). Mbita Point, 1982

Egg Batches per plant

Cultivar	$\bar{X}$ No. of Batches	F ratio
IS 18363	2.03	1.109^{ns}
IS 18489	1.81	
IS 18479	0.87	
IS 1044	2.22	
IS 2205	1.78	
IS 18520	1.90	

Hatched Egg Batches per plant

Cultivar	$\bar{X}$ No. of Batches	F ratio
IS 18363	0.03	1.081^{ns}
IS 18489	0.04	
IS 18479	0.036	
IS 1044	0.09	
IS 2205	0.01	
IS 18520	0.07	

Unhatched Egg Batches per plant

Cultivar	$\bar{X}$ No. of batches	F ratio
IS 18363	0.001	2.146^{ns}
IS 18489	0.008	
IS 18479	0.028	
IS 1044	0.001	
IS 2205	0.006	
IS 18520	0.004	

Table 19 (cont'd..)

Parasitised Egg Batches

Cultivar	$\bar{X}$ No. of Batches	F ratio
IS 18363	0.003	-
IS 18489	0.004	
IS 18479	0.01	
IS 1044	0.004	
IS 2205	0.009	
IS 18520	0.001	

Predated Egg Batches

Cultivar	$\bar{X}$ No. of Batches	F ratio
IS 18363	0.036	0.971^{ns}
IS 18489	0.012	
IS 18479	0.08	
IS 1044	0.009	
IS 2205	0.12	
IS 18520	0.02	

Flaked off Egg Batches

Cultivar	$\bar{X}$ No. of Batches	F ratio
IS 18363	0.017	1.045^{ns}
IS 18489	0.04	
IS 18479	0.073	
IS 1044	0.014	
IS 2205	0.01	
IS 18520	0.02	

CHAPTER 4

SORGHUM VARIETAL RESISTANCE TO CHILO PARTELLUS FIRST INSTAR LARVAL ESTABLISHMENT EVIDENCE

4.10 INTRODUCTION

"Even the most susceptible host plant of a given insect species is not defenseless, and only a small percentage of feeding stages of the insect will survive" (Beck and Schoonhoven, 1980). This statement is illustrated by the susceptible maize cultivar WF9 used in many studies to determine resistance of maize to the European corn borer (Ostrinia nubilalis(Hubner) According to Beck and Schoonhoven (1980), Beck and Lilly (1949) found that O. nubilalis first instar larvae when confined exclusively on seedlings of this susceptible cultivar, succumbed within six days. This mortality depended on the age of the plant cultivar.

The duration between hatching of C. partellus and dispersal of these first instar larvae to other sorghum plants has long been identified as a time of high mortality (Roome and Padgham, 1980). Roome(1980) showed that high dispersal rates from the original sorghum plant depended not only on plant age, but also on the sorghum variety used. High dispersal

rates were recorded when within 24 hours of hatching 50-80% of the larvae had migrated from the original plant.

C. partellus first instar larval dispersal from the original plants is not only an ecological means to stop overcrowding but the attendent mortality also ensures a more even distribution. Van Hamburg (1980) showed that mortality occured mainly during the three first larval instars when most of the larvae were still outside the stalk. There was very little mortality that occured once the larvae entered the stalk (after the third week). Consequently, it was decided to confine the present experimental studies to this early period sorghum infestation.

Differences in migration of larvae on different cultivars have been demonstrated to occur in the following cases of resistant and susceptible plant cultivars:- movement of corn earworm (Heliothis zea) larvae on ears of resistant and susceptible maize lines; homoptera species, Rhopalosiphum maidis and Peregrinus maidis on different cultivars and at different stages of sorghum; and the larval red turnip beetle (Entomoscelis americana)on different Brassica ssp (Wiseman et al., 1978)

These differences in larval migration have been attributed, in some cases to differences in food preferences in different cultivars. Documented cases of these include : Ali (1976); Bernays et al. (1976); Bernays and Chapman (1976); Cook (1976); Dethier(1976); Hanson (1976); Hawkes and Coaker (1976); Herrebout et al (1976); Hsiao (1976); Jermy (1976); Karasev (1976); Le Berre and Launois - Luong (1976); Ma (1976); Moreau (1976); Nagy (1976) Norris (1976); Petterson (1976); Scheltes (1976); Schoonhoven (1976); Stadler and Hanson (1976); Tjallingii (1976); Vasetchko (1976); De Wilde (1976); and Wood (1976).

The reasons for these preferences are either biochemical or biophysical or a combination of the two factors (Norris and Kogan, 1980). One of the most dramatic chemicals in insect resistant studies is the aglycone 2, 4-dihydroxy - 7 - methoxy - 2H - 1, 4 Benzoxazin - 3 - one (DIMBOA) in Zea mays which was shown to be a major repellent and feeding inhibitor to first instar larvae of Ostrinia nubilalis (Klun et al., 1967). The morphological (biophysical) resistance factors interfere physically with locomotor mechanisms, feeding ingestion and digestion (Norris and Kogan, 1980). These physical barriers or deterrents include trichomes, surface waxes, silication,

or sclerotization of tissues. These, however, are expressions of, genetically regulated biochemical processes.

Roome and Padgham (1980), Roome (1980) and Woodhead et al., (1980) used blackhead egg batches in their resistance studies in spite of the fact that Singh and Sandhu (1979) had recommended use of first instar larvae rather than egg batches. According to the latter authors use of egg batches "is cumbersome, costly and time consumming". Kalode and Pant (1966) in their studies on susceptibility of different varieties of sorghum, maize and bajra to C. partellus also used just hatched larvae in their caged experiments but used natural infestation in their field experiments. The problem with the latter approach is that it assumes oviposition has been even on different cultivars, a fact which has been demonstrated not to occur (by Roome and Padgham, 1980; Roome, 1980; and Woodhead et al., 1980).

In these investigations the varietal difference in sorghum expressed as high or low dispersal rate of first instar C. partellus larvae was examined with a view to screening and breeding for this trait. This process of selecting sorghum varieties showing low or

high dispersal rates would logically follow from the previous experiments on oviposition preference and would form a second line of defense in sorghum.

4.20 MATERIALS AND METHODS

4.21 Chilo partellus

Two experiments were conducted in screenhouses to determine if there was a difference among the sorghum cultivars with regard to first instar larval dispersal, mortality and seedling leaf damage. These parameters have been used by Roome and Padgham (1980) in their sorghum resistance studies.

The rationale behind the use of these criteria is that: unacceptable sorghum cultivars to the larvae (antixenosis) would be identified by relatively high dispersal (migration) from the artificially infested plants; those cultivars with toxic substance (antibiosis) would be identified by high larval mortality; while high or low leaf damage would indicate presence or absence of antifeedants.

Accordingly twenty sorghum cultivars were selected and planted in pots in five replications in the manner described in chapter three. In the second experiment more replications were used (ten) but only sixteen cultivars had to be selected because of the

limitation in the number of available pots. When the seedlings were three weeks old ten C. partellus newly emerged first instar larvae were introduced into the leaf whorl (leaf funnel) of each plant. The larvae were introduced individually, by means of a fine camel brush moistened with distilled water. This was done from about 0630 hours in the morning. After five days (from infestation) each plant was pulled out, the number of surviving and dead larvae counted, and the sorghum plant leaf damage was recorded using the 0 to 9 scale illustrated in figure 15a, b and c. All this data with respect to each plant in each cultivar was recorded. In the second experiment, where there were ten replications, only half the plants were dissected. The remaining plants were dissected after a further seven days in order to differentiate between first and second instar larval damage. The percentage of larvae succeeding to get established or perishing were computed. In this way a relative high larval establishment rate and low mortality would indicate susceptibility.

4.22 Observation of Chilo partellus first instar larval movement after infestation of selected sorghum cultivars

After the preceding experiments on first instar larval dispersal, mortality and sorghum plant leaf damage, it was decided to conduct two other experiments to demonstrate whether there were any larval movements during the first instar larval colonization of the sorghum plant that were perculiar to either the resistant or the susceptible cultivars.

Fifteen cultivars used in the preceding experiments were planted in the screenhouse in ten pots each in the manner already described. After three weeks the plants were infested with five first instar larvae. Early in the morning at 0700 hours five larvae were placed on the leaves taking care to place the larvae at the horizontal part of the curve of the leaf. The larvae were then observed and timed to see how long they would take to enter the leaf funnels. Cultivars where the larvae took long to enter the funnel, or where the larvae were not able to locate the funnel were regarded as resistant. This experiment was conducted twice.

4.23 Colonization of different selected sorghum cultivars at different stages by *Chilo partellus* first instar larvae.

The following six cultivars were selected and planted in separate blocks of six 10 metre rows: IS 18363, IS 1044, IS 18479, IS 2205, IS 18489 and IS 18520. The method of planting was described in chapter three.

When the plants were three weeks old they were infested with ten first instar larvae. The larvae were individually introduced into the funnel by means of a fine camel brush moisted with distilled water. These larvae were then confined by means of cages (figure 16). In each cultivar five plants were infested and caged. After five days these plants were pulled out, the number of larvae recovered recorded as well as their position in the plant. This procedure was repeated for five consecutive weeks in order to see whether there was a difference in larval establishment at different plant stages among the cultivars. Each time the plant was infested it was ensured that there was no prior infestation.

4.24 *Chilo partellus* first instar larval establishment through the nodes and internodes of different selected sorghum cultivars.

When all the six selected sorghum cultivars in the above experiment were either at the booting stage or already begining to flower (depending on the cultivar) ten newly emerged *C. partellus* first instar larvae were caged and confined either at the node or internode of the stems. In each cultivar five plants were used. The object of the experiment was to compare the different cultivars with respect to *C. partellus* larval establishment at a later stage. At an earlier sorghum stage infestation was through the funnel but later when plant developed a panicle infestation was either through the nodes or internodes. After five days, the plants were pulled out, dissected and the number of surviving larvae recorded. Even the position of the larvae was noted and recorded (whether the larvae were able to gain entry into the plant or not).

4.25 Analysis of the results

The results were expressed as percentages (for example, percent dispersal, mortality etc.). These percentages were transformed using the arc sine

transformation before being analysed using the analysis of variance method. The leaf damage scores (ranks one to nine) were transformed to ranked scores. This transformation is illustrated in the legend and was described by Sarup et al., (1978). The conversion tables are found in Fisher and Yates (1963). After transformation, the damage scores were also analysed using the analysis of variance method.

4.30 RESULTS

4.31 Chilo partellus first instar larval dispersal, survival and plant leaf damage.

Results on larval survival, dispersal and plant damage are given in Tables 20, 21 and 22. In cultivars IS 18520, IS 18319, IS 17739 and IS 18363 more than 50% of the larvae survived while in cultivars IS 2162, IS 18367, IS 18349, IS 18489 and IS 1044 less than 20% of the larvae survived. On the other hand, more than 80% of the larvae migrated (dispersed) from IS 1044, IS 18489 and IS 18349 while less than 40% migrated from IS 17739, IS 2122, IS 18363 and IS 18520. The results on larval survival and dispersal however, did not show a statistically significant difference

among the cultivars.

According to Table 22(b) differences in cultivars were a significant source of variation for plant damage at $p<0.05$. Cultivar IS 18349 was significantly the least damaged by first instar larvae. All other cultivars displayed varying degrees of mean plant damage ranging from 1.8 to 2.8 in the damage ranking scale.

The results of the second experiment on first instar larval dispersal (migration), survival, and plant leaf damage are given in Tables 23, 24, and 25. These experiments included both the first and second instar larvae because the damage caused by the first instar larvae in the first experiment was rather limited. In the results on larval survival, it will be noted, the varieties were a significant source of variation ($p<0.05$) while dispersal and leaf damage were not significantly different from cultivar to cultivar. There was significantly less survival on IS 2205 which would mean the C. partellus larval population in this cultivar would be much lower. All the other cultivars were not significantly different from one another. Cultivars IS 2205 and IS 18479 had a larval

dispersal (migration) of more than 80%. Cultivars IS 2205, IS 18489 and IS 4660 showed the least amount of damage while IS 18520 and IS 1044 showed the most extensive damage.

4.32 Observation of Chilo partellus first instar larval movements after infestation of selected sorghum cultivars.

When the first instar larvae were timed to see how long after infestation they took to locate and enter the leaf funnel, it was found that they took on the average from one minute 12 seconds to two minutes 54 seconds in all the cultivars used. There were,however, two exceptions. In IS 18520 the larvae took as little as 53 seconds to disappear into the leaf whorl while in IS 1044 some larvae still had not located the funnel after five minutes. In IS 18361 some larvae took three minutes 51 seconds.

4.33 Colonization of different selected sorghum cultivars at different plant stages by Chilo partellus first instar larvae.

The results of the Chilo partellus larval colonization at different plant stages are given in Tables 26, 27 and 28. The analysis of variance

(Tables 26 (b), 27 (b)) show that larval mortality and survival in different cultivars was not significantly different but larval dispersal (migration) cultivars were a significant source of and variation at $\rho<0.01$. Dispersal on different dates was also a significant source of variation at the same level. There was significantly more dispersal in IS 1044, IS 18479, IS 18489, IS 2205 and IS 18520 than in IS 18363.

4.34 Chilo partellus first instar larval establishment through the nodes and internodes of different selected sorghum cultivars.

The results on larval establishment and dispersal (migration) are given in Tables 29 and 30. In both larval establishment (survival) and dispersal the cultivar is a highly significant source of variation ($\rho<0.01$). There were significantly more larvae that got established in IS 18363 than any other cultivar. Cultivar IS 18479 had the least number of larvae established. On the other hand, there was significantly more dispersal from cultivars IS 1044 IS 18489, IS 2205 and IS 18520. The cultivar with least migration was IS 18363. Establishment through

the node and internode as well as on different dates was also a significant source of variation ($\rho<0.05$ and $\rho<0.01$ respectively). Dispersal on different dates, but not according to whether from the node or internode, was also a significant source of variation.

4.40 DISCUSSION

The summary of all the results is given in Table 31. According to this Table the most susceptible cultivar was IS 18363 because wherever it was used, irrespective of the criteria, it was found to be susceptible. The cultivars that were resistant, however, were not resistant in all aspects. Cultivar IS 2205 was resistant with respect to larval survival and larval dispersal but not with regard to a leaf damage. The most resistant cultivars in this respect were IS 18349 and IS 1044. From this set of data it can be inferred that cultivar IS 2205 is resistant through both antixenosis and antibiosis but the larvae have to feed on plants before these factors can be apparent.

LEGEND FOR C. PARTELLUS SORGHUM PLANT DAMAGE ON A O TO 9 SCALE RATING INCLUDING THE TRANSFORMATION TO RANKED SCORES - FISHER AND YATES(1963)

Transformation (underlined)

Class O = -1.54

-No visible leaf injury

Class 1 = -1.00

-Small amount of pin or fine short-type of injury on a few leaves.

Class 2 = -0.66

-Small amount of shot-hole lesions on a few leaves.

Class 3 ± -0.38

-Shot-hole injury common on several leaves.

Class 4 = -0.12

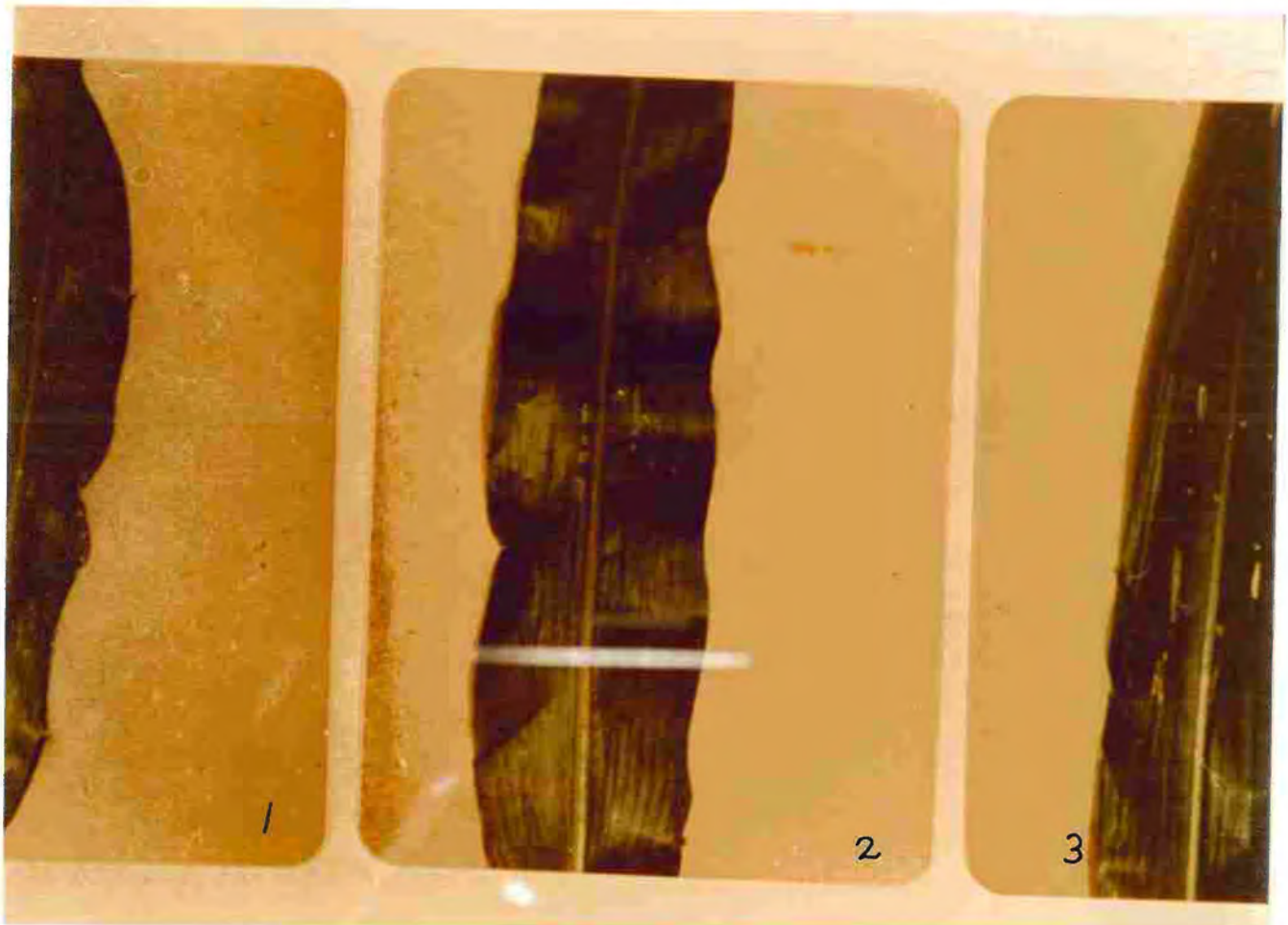
-Several leaves with shot-hole and elongated lessions.

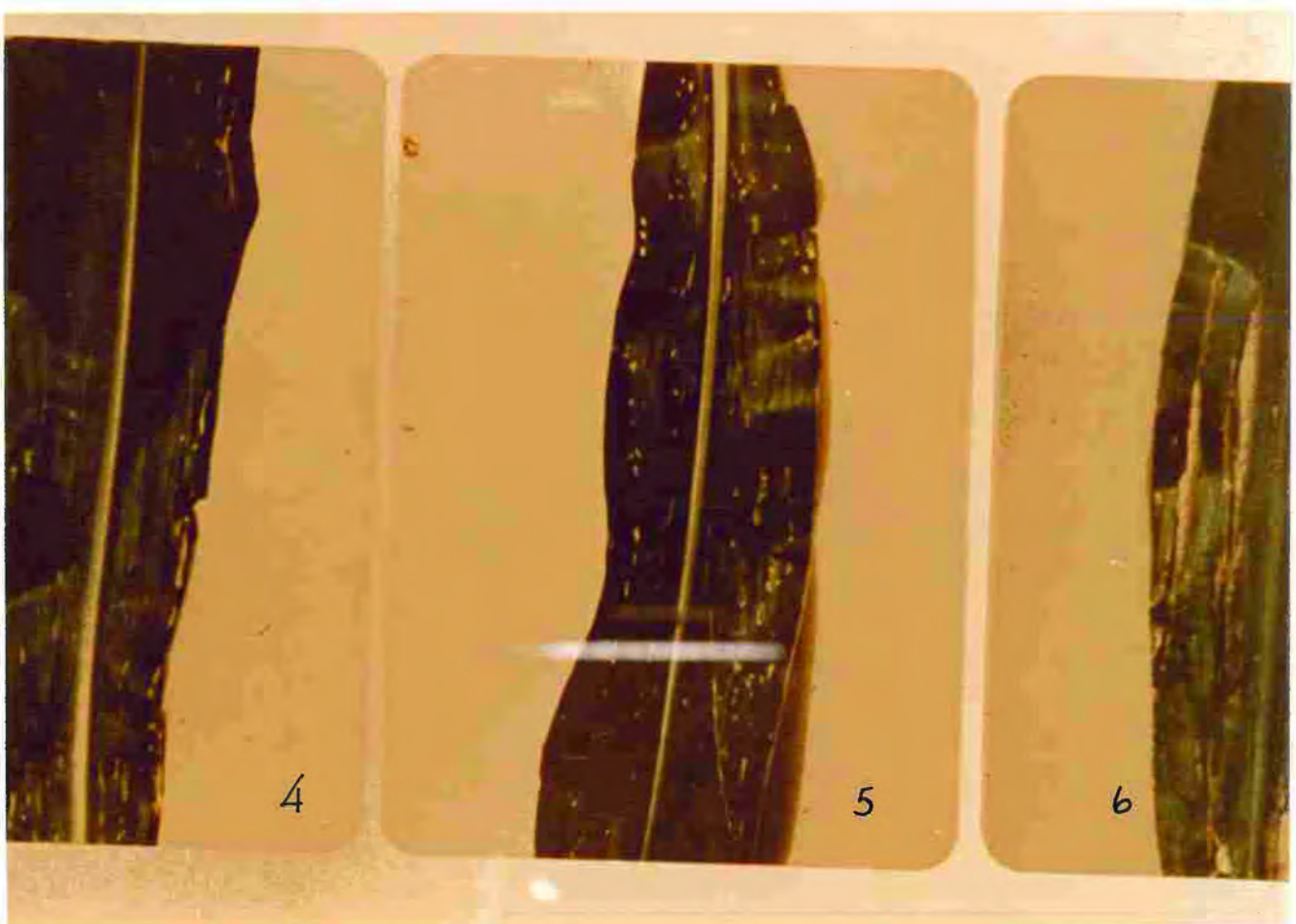
Class 5 = +0.12

- About 50% of leaf damage (pin holes, shot-holes, slits, streaks and lessions) and midrib damage (if any).

Class 6 = +0.38

+Varied type of leaf injury in about two-thirds of the total number of leaves.


1
2
3


4
5
6

Class 7 = +0.66

Every type of leaf injury and almost all leaves damaged.

Class 8 = +1.00

Entire plant showing maximu leaf injury and likely to form dead-heart (such plants usually show stunted growth).

Class 9 = +1.54

Deadheart

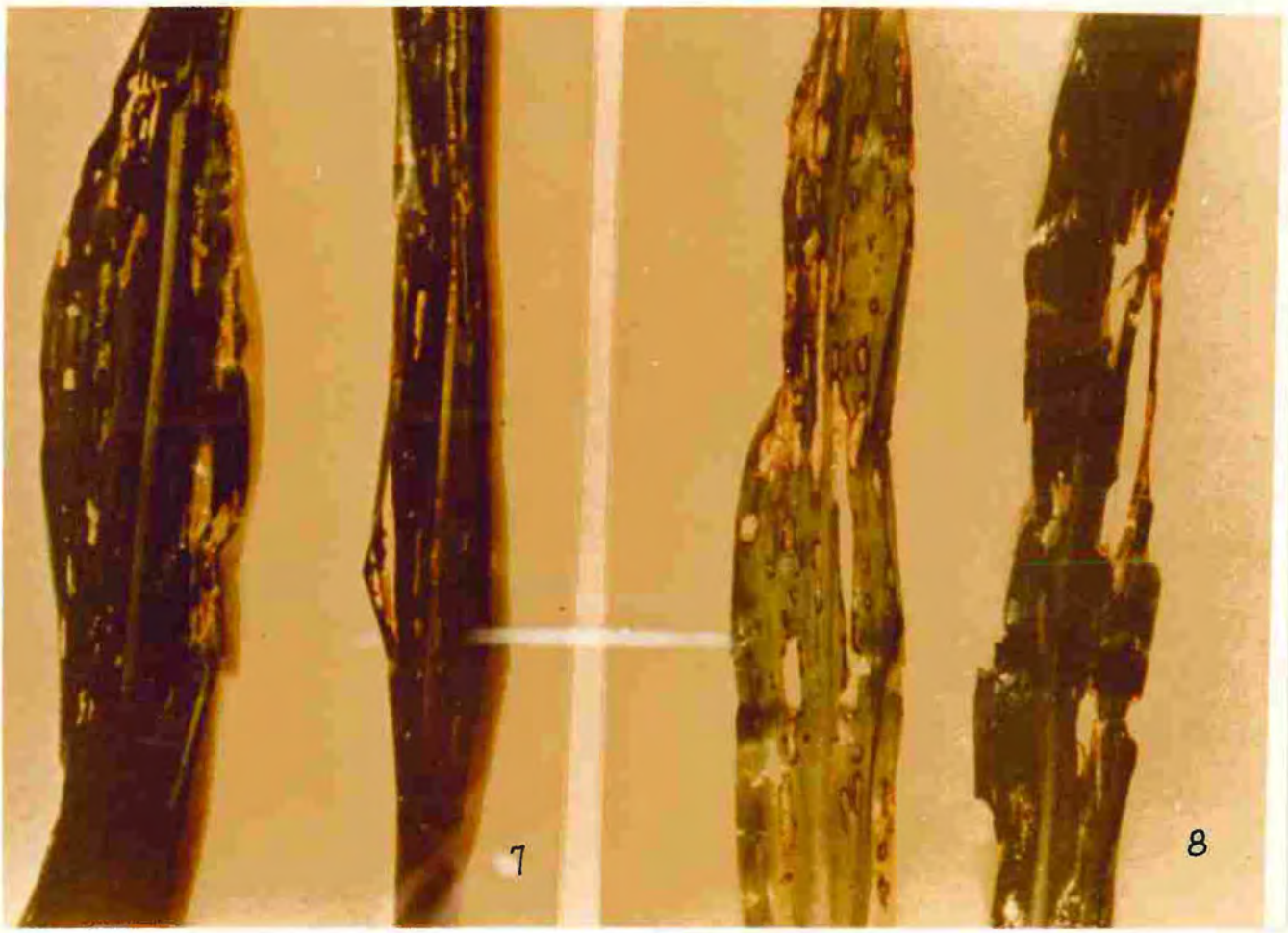

7
8

FIGURE 16

Cage for confining first instar larvae

to a particular plant after infestation.

Table 20 (a) : *Chilo partellus* first instar larval survival on selected sorghum culitvars Mbita Point, 1981

Sorghum Cultivars	$\bar{X}$ % Survival
IS 18520 ("Serena")	64.5
IS 18319	59.2
IS 17739	56
IS 18363	52.6
IS 2122	49.7
IS 1151	46.5
IS 2205	46
IS 1082	42.9
IS 18328	40.6
IS 18427	36.7
IS 18676	36
IS 18479	34.8
IS 14660	33.9
IS 2263	30
IS 18361	28.9
IS 18390	28.1
IS 18463 ("Swarna")	27
IS 2162	18.4
IS 18367	18
IS 18349	14.3
IS 18489	12.4
IS 1044	5.3

Table 20(b): Summary of analysis of variance of Chilo partellus first instar larval survival on sorghum. Mbita Point, 1981.

Source of Variation	df	SS	MS	F
Cultivar	21	11422.13	543.91	0.5725^{ns}
Residual (Error)	88	83600.24	950.003	
Total	109	95022.37		

Table 21(a): Chilo partellus first instar larval dispersal from selected sorghum cultivars. Mbita Point, 1981

Sorghum Cultivar	$\bar{X}$ % Dispersal	Sorghum Cultivar	$\bar{X}$ % Dispersal
IS 1044	91.5	IS 18427	56.4
IS 18489	85.6	IS 18328	49.5
IS 18349	83.7	IS 1082	45.8
IS 2162	79.8	IS 2205	45.6
IS 2263	70	IS 4660	43.9
IS 18367	69.4	IS 1151	43.6
IS 18390	69.4	IS 18319	40.8
IS 18463	62.9	IS 17739	38.8
IS 18676	62.8	IS 2122	36.6
IS 18479	58.7	IS 18363	34.2
IS 18361	58.5	IS 18520	32.9

Table 21 (b): Summary of analysis of variance of Chilo partellus larval dispersal on sorghum. Mbita Point, 1981.

Source of Variation	df	SS	MS	F ratio
Cultivar	21	12683.88	603.99	1.0441^{ns}
Residual (Error)	88	51086.71	580.53	
Total	109	63770.59		

Table 22 (a) : Sorghum plant damage by Chilo partellus first instar larvae. Mbita Point, 1981

Sorghum Cultivar	$\bar{X}$ Plant Damage		Sorghum Cultivar	$\bar{X}$ Plant Damage	
IS 18479	2.8	a	IS 4660	2.2	bcd
IS 1151	2.8	a	IS 18520	2.2	bcd
IS 18363	2.6	ab	IS 2122	2.2	bcd
IS 18676	2.6	ab	IS 18328	2.2	bcd
IS 17739	2.4	abc	IS 18390	2.2	bcd
IS 2205	2.4	abc	IS 18489	2.0	cd
IS 2263	2.4	abc	IS 18361	2.0	cd
IS 2162	2.4	abc	IS 18437	1.8	d
IS 1082	2.4	abc	IS 18463	1.8	d
IS 18367	2.4	abc	IS 1044	1.8	d
IS 18319	2.4	abc	IS 18349	1.	e

Note: Damage was expressed ina scale of 0-9 where 0 is no damage and 9 is extensive damage resulting in "deahearts".
Figures followed by different letters are significantly different from one another ($p<0.05$)

Table 22 (b): Summary of analysis of variance of Sorghum plant damage by Chilo partellus first instar larvae. Mbita Point, 1981

Source of Variation	df	SS	MS	F ratio
Cultivar	21	2.217	0.105	1.940*
Error	88	4.788	0.054	
Total	109	7.005		

Table 23 (a) : Chilo partellus first and second instar larval survival in 12 days on selected sorghum cultivars. Mbita Point, 1982

Sorghum Cultivars	Overall % Survival Over 12 days	
IS 1151	60.40	a
IS 1044	46.38	a
IS 1082	44.4	a
IS 18361	42.15	a
IS 18319	40.5	a
IS 18363	39.56	a
IS 18479	38.9	a
IS 4660	36.6	a
IS 18489	36.31	a
IS 18677	35.62	a
IS 2122	34.92	a
IS 18427	34.38	a
IS 18367	33.72	a
IS 18520	32.78	a
IS 2205	16	b

Note: Figures followed by different letters are significantly different.

Table 23 (b) : Summary of analysis of variance for *Chilo partellus* first and second instar larval survival in 12 days. Mbita Point, 1982.

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	14	12027.890	859.135	1.941*
Dates (B)	1	0.101	0.101	0.000^{ns}
A X B	14	7816.293	558.520	1.262^{ns}
Error	120	52096.988	442.474	
Total	149			

Table 24 (a) Chilo partellus first and second instar larval dispersal in 12 days on selected sorghum cultivars. Mbita Point, 1982

Sorghum Cultivars	Overall % Dispersal over 12 days
IS 2205	91.1
IS 18479	86.2
IS 18520	68.9
IS 18427	67
IS 18367	65.3
IS 2122	64.8
IS 18677	63.9
IS 4660	60.4
IS 1151	58.9
IS 18363	58.5
IS 18489	58.5
IS 18319	57.6
IS 18361	56.4
IS 1082	51
IS 1044	47

Table 24 (b): Summary of the analysis of variance of Chilo partellus first and second instar larval survival. Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	14	8558.351	611.310	1.695^{ns}
Dates (B)	1	1799.201	1799.201	4.989*
A X B	14	7869.527	562.109	1.558^{ns}
Error	120	53270.888	360.590	
Total	149			

Table 25 (a) : Sorghum leaf damage by Chilo partellus first and second instar larvae in selected sorghum cultivars in 12 days. Mbita Point, 1982.

Sorghum Cultivar	Overall leaf damage in 12 days
IS 18520	5.3
IS 1044	5.3
IS 1151	4.4
IS 18677	4.4
IS 18361	4.2
IS 18319	4.2
IS 18427	4.0
IS 18479	3.6
IS 1082	3.5
IS 18363	3.4
IS 2122	3.3
IS 18367	3.0
IS 4660	2.8
IS 18489	2.0
IS 2205	1.8

Table 25 (b) : Summary of analysis of variance of sorghum leaf damage by *Chilo partellus* first and second instar larvae. Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	14	2.065	0.147	0.846^{ns}
Date (B)	1	0.000	0.000	0.000^{ns}
A X B	14	4.754	0.339	1.948*
Error	110	19.168	0.174	
Total	139			

Table 26 (a) : Chilo partellus first instar larval survival on selected sorghum cultivars at different plant stages. Mbita Point 1982

Sorghum Cultivar	Overall % Survival
IS 18363	70.2
IS 18479	64.6
IS 18520	64.2
IS 18489	63.7
IS 1044	62.7
IS 2205	58.5

Table 26 (b): Summary of analysis of variance of Chilo partellus first instar larval survival at different sorghum stages, Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	5	643.65	128.730	1.537^{ns}
Dates (B)	4	2861.135	715.283	8.545**
A X B	20	2819.845	140.992	1.684
Error	120	10044.680	83.705	
Total	129			

Table 27 (a) : Chilo partellus first instar larval mortality on selected sorghum cultivars at different plant stages. Mbita Point, 1982

Sorghum Cultivar	Overall % Mortality
IS 18363	13.2
IS 18520	7.8
IS 2205	6.8
IS 1044	6.3
IS 18479	4.7
IS 18489	4.3

Table 27 (b) : Summary of analysis of variance of Chilo partellus first instar larval mortality at different plant stages. Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	5	1302.921	260.584	1.897^{ns}
Dates (B)	4	3871.285	967.821	7.045**
A X B	20	1824.175	91.208	0.66^{ns}
Error	120	16483.024	137.358	
Total	129			

Table 28 (a): Chilo partellus first instar larval dispersal from selected sorghum cultivars at different plant stages. Mbita Point, 1982

Sorghum Cultivar	$\bar{X}$% Dispersal over five weeks	
IS 1044	32.2	a
IS 18479	26.9	a
IS 18489	25.5	a
IS 2205	25.3	a
IS 18520	22.9	a
IS 18363	10.6	b

Table 28 (b): Summary of analysis of variance of Chilo partellus first instar larval dispersal at different sorghum stages. Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	5	2905.181	581.036	5.727**
Dates (B)	3	990.950	330.950	3.255*
A X B	15	1194.771	79.651	0.785^{ns}
Error	96	9739.696	101.455	
Total	119			

Table 29 (a) : Chilo partellus first instar larval establishment (Survival) through sorghum nodes and internodes. Mbita Point, 1982

Sorghum Cultivar	Overall % Survival Node	Internode	$\bar{X}$	
IS 18363	71.9	62.3	67.1	a
IS 18489	48.4	48.3	48.4	b
IS 2205	44.9	51.7	48.3	b
IS 18520	56.4	37.1	46.8	b
IS 18479	9.7	44.9	27.3	c

Table 29 (b): Summary of analysis of variance of Chilo partellus larval establishment through nodes and internodes

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	5	1516.266	303.253	4.022**
Node/Internode(B)	1	309.590	309.590	4.107*
Date (C)	2	1502.660	751.330	9.967**
A x B	5	473.480	94.696	1.256^{ns}
A x C	10	2228.974	222.897	2.956**
B x C	2	162.455	81.227	1.077^{ns}
A x B x C	10	358.526	35.852	0.475^{ns}
Error	36	2713.685	75.380	
Total	71	9265.638		

Table 30 (a) : Chilo partellus first instar larval dispersal from selected sorghum cultivars. Mbita Point, 1982

Sorghum Cultivar	Overal % Dispersal (Migration) Node	Internode	$\bar{X}$	
IS 1044	45.6	43.3	44.5	a
IS 18489	44.9	35.7	40.3	ab
IS 2205	41.4	30.6	36	ab
IS 18520	6	58.6	32.3	ab
IS 18479	27.6	32.3	30	b
IS 18363	16.1	23.2	19.7	c

Table 30 (b): Summary of analysis of variance of Chilo partellus larval dispersal from selected sorghum cultivars. Mbita Point, 1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	5	1929.066	385.813	5.145**
Node/Internode (B)	1	71.003	71.003	0.946^{ns}
Date (C)	2	1098.840	549.420	7.327**
A x B	5	876.607	175.321	2.33^{ns}
A x C	10	1472.554	147.255	1.963^{ns}
B x C	2	303.511	151.755	2.024^{ns}
A x B x C	10	489.329	48.932	0.652^{ns}
Error	36	2699.205	74.977	
Total	71	8940.118		

Table 31 : Summary of Chilo partellus resistance with respect to larval survival, dispersal and sorghum leaf damage

Resistance Criteria	Resistant	Susceptible	Evidence
1. Larval Survival			
(a)	IS 2205	All Other Cultivars	Table 23
(b)	IS 2205 IS 18489 IS 18520 IS 18479	IS 18363	Table 26
2. Larval Dispersal (Migration)	IS 1044 IS 18489 IS 2205 IS 18520	IS 18363	Table 28
3. Leaf Damage (by larvae)	IS 18349 IS 1044	IS 18363 IS 2205 IS 18479	Table 22

CHAPTER 5

ASSESSMENT OF SORGHUM VARIETAL RESISTANCE AGAINST *CHILO PARTELLUS* BY PLANT DAMAGE AND 'DEADHEARTS'

5.10 INTRODUCTION

Lepidopterous stemborers are very important pests in East Africa and as such there are many entomologists who have devoted a lot of time and efforts to their study. These include: Anderson (1962), Hargreaves (1939), Duerden (1953), Jepson (1954), Coaker (1956), Swaine (1957), Ingram (1958), Nye (1960), Wheatley (1961), Walker (1961), Mohyuddin and Greathead (1970), Mathez (1972), and Scheltez (1978). Stemborers are considered as major pests of many gramineae all over the world (Jepson, 1954; Metcalf and Flint, 1967; Hill, 1975 and Van Hamburg, 1980). *C. partellus* is an important pest of rice, maize, and sugarcane in India (Sharma *et al*. 1967) and in Japan, Taiwan, Ceylon, Pakistan, Afghanistan and Iran (Rao, 1965). In South and East Africa it is thought to have originated from India because early records do not show this pest (Van Hamburg, 1979 and Mohyuddin and Greathead, 1970 respectively).

Because of a similarity in behaviour of the first instar larvae of Busseola fusca and C. partellus the plant damage is "exactly similar" (Duerden, 1953). Besides they often "exist side by side in the same field" even "in the same plant" according to Duerden (1953). The presence of the larvae in the funnel of the plant can be "noticed by a speckled appearance of the leaves" (Taylor, 1952) caused by feeding of the larvae on the young succulent leaves that have not unfolded. In this manner the larvae burrow their way into the succulent growing point which if destroyed, the centre of the plant dies and no further growth occurs. This dead growing point is referred to as a "deadheart" (Roome and Padghan, 1977).

The leaf damage causing a corresponding drop in sorghum yield has been unequivocally demonstrated. Haraki and Horino (1981) used leaf removal and measured the corresponding effect on yield. In their study they found that leaf removal decreased grain yield but increased the number of grains per hill. Removing the first and second leaves reduced yield to 85.6% of the control. Removal of the first four leaves reduced the yield to 65.9%. Removal of all 10 leaves of this cultivar reduced the yield to 14.3%. In their studies Wang et al. (1981) used both the techniques of defoliation and covering portions of leaves with aluminium

foil. In these studies they found that the leaves at the top and middle supplied 80-90% of the assimilate that is translocated to grain during grain formation. The third leaf from the top was the largest and contributed most of the assimilate.

In assessing leaf damage several leaf damage ranking methods have been used. Guthrie et al.,(1960) used a 9-class visual injury method (where 0 is equivalent to no injury while nine indicates "extensive damage"). Singh and Sandhu (1979) used a one to nine leaf damage grading system. Roome (1976) on the other hand, used a complex ranking system based on the number of cultivars used (for example, he used a one to 45 ranking where there were 45 cultivars.). Sarup et al, (1974) used a scale of one to nine (where one represents no apparent leaf damage and nine represents a deadheart). Kalode and Pant (1966) used a zero to three grading scale (where zero represents no damage and three represents a deadheart). The scale used at the International Centre of Insect Physiology and Ecology (ICIPE), which was used for grading sorghum leaf damage in these experiments, was a modification of Guthrie et al. (1960) and Sarup et al.,(1974). This scale is illustrated in Figure 15 a, b and c. It is described in the legend

facing these figures.

5.20 MATERIALS AND METHODS

Twenty sorghum cultivars obtained from the ICRISAT germplasm were used. These cultivars had originated from India, Uganda, and United States. They were sown between July 1981 and October 1982 in a randomized complete block design in the field and screenhouses. Altogether seven experiments were planted in three, four, five, six or ten replications depending on the available space in the screenhouses. Some of the experiments were planted in pots. The seeds were planted in the manner described in Chapter three.

When the plants were three weeks or four weeks they were infested with ten C. partellus first instar larvae using a fine camel brush for counting the larvae. Subsequent plant damage was monitored and recorded. Different periods of plant damage assessment were used. In some cases damage was assessed for four weeks since this is the minimum time it takes for the larvae to pupate while in other cases only the first and second instar larval damage was assessed. Plant damage (leaf damage) was scored in the manner described and illustrated in Figure 15 a, b, and c. These scores were transformed into ranked

scores as described by Sarup et al.(1978) The conversion tables are found in Fisher and Yates (1963). These transformations are also given in the legend.

The deadhearts were also recorded in each experiment. Because of the problem of uncontrolled natural infestation by C. partellus, as well as by Busseola fusca, Eldana saccharina, and Sesamia calamistis, all field experiments were discarded (mixture of the stemborers in Figure 17).

The experiments whose results follow were planted during the following periods in the screenhouses (only the last experiment was planted in the field).

(a) The first experiment was planted on the 25th of February, 1982, with three replications, infested at three weeeks and assessed after 26 days. Nine cultivars were used.

(b) On the 9th April 1982, the second experiment was planted in pots infested at three weeks, and assessed after 35 days. There were ten replications and fifteen sorghum cultivars.

(c) In the third experiment fifteen sorghum cultivars were used, replicated three times in three different screenhouses, each cultivar with twelve plants per screenhouse. It was infested at four weeks and assessed after 31 days. It was planted on the 22nd of April, 1982.

(d) The fourth experiment was planted on 29th of June 1982, in pots replicated five times, infested at three weeks, and assessed five days and twelve days thereafter. Again fifteen cultivars were used.

(e) The fifth experiment had twelve sorghum cultivars in ten replications, infested at three weeks, assessed after 19, 26 and 33 days from the time of infestation. It was planted on 28th of July 1982.

(f) The sixth experiment had fifteen sorghum cultivars, ten replications, infested at three weeks and assessed 28 days thereafter.

(g) The last experiment was planted on the second of August, 1982. It was infested at three, four, five and six weeks and assessed five days after each infestation.

5.30 RESULTS

The results of the experiments are given in Tables 32, 33, 34, 35, 36, 37, and 38. From the analysis of variance Tables it will be noted that where damage was assessed only once (at the end of the experiment) there was no statistically significant plant damage difference from cultivar to cultivar (Tables 32, 33, 34 and 37). But where damage assessment was taken several times the cultivar was a significant source of variation ($\rho<0.05$). In Table 35 the only damage that was assessed was that caused by the first two instar larvae and as such the cultivar differences did not appear statistically significant. The interaction between date of sampling and cultivar (A x B) was, however, highly significant at $\rho<0.01$. According to Table 36 cultivars IS 18361, IS 2205, IS 18363, and IS 18319 were significantly the most damaged (leaf damage) by C. partellus larvae while the least damaged cultivars were IS 18489, IS 4660, IS 1082 and IS 1044. Table 38, where only six cultivars were selected, is in perfect agreement with Table 36 with respect to cultivars IS 18363, IS 18489, IS 18520, and IS 1044. The damage caused by different instar larvae on different dates (B) in Table 36 was a highly significant source of variation at $\rho<0.01$ while the damage caused

by first instar larvae only on different dates (B) in Table 38 was not significantly different from cultivar to cultivar. Even in Tables 32, 33, 34, 35, and 37 where cultivars were not a significant source of variation cultivar IS 18363 was consistently one of the most damaged while cultivars IS 1044, IS 4660 and IS 1082 were consistently some of the least damaged.

In Table 39 six selected cultivars were compared with respect to their tendency to form deadhearts. According to this Table the cultivars more inclined to form deadhearts were IS 2205 and IS 18520 and the least likely were IS 18489 and IS 18363 (probably as well as IS 1044). It is worth noting that although cultivar IS 18363 was the most susceptible to leaf damage (Tables 36 and 38) (Figure 18) it was relatively less susceptible for deadhearts even though the leaf damage scale included deadhearts (refer score nine in Figure fifteen).

5.40 DISCUSSION

The most susceptible cultivars to leaf damage were IS 18361, IS 2205, IS 18363, and IS 18319 (Table 36). The most resistant cultivars were IS 1044, IS 18489, IS 1082, and IS 4660 (Table 36). However, the fact

that there was no direct correlation in all cultivars between leaf damage and deadhearts, suggests that deadhearts should not be included in the damage rating scale since cultivars with high incidence of deadhearts would tend to appear as necessarily susceptible to leaf damage, which fact has been demonstrated not to be necessarily true (refer to the last paragraph in RESULTS). The suggestion is that deadhearts should be assessed separately. The damage scale could then be modified to (0 to 8 instead of 0 to 9 which includes deadhearts as 9).

Table 32 (a): *Chilo partellus* plant damage in sorghum infested at three weeks and assessed 26 days thereafter. Mbita Point, 1982

Sorghum Cultivar	$\bar{X}$ Plant damage score	Deadhearts %	Rank
IS 18363	7.9	-	
IS 18520	7.2	-	
IS 2205	6.0	-	
IS 2122	5.3	-	
IS 18479	4.7	-	
IS 1082	4.3	-	
IS 18319	4.3	-	
IS 18361	3.7	-	
IS 4660	2.1	-	

Table 32 (b) : Summary of analysis of variance for plant damage in sorghum infested at three weeks and assessed 26 days thereafter.

Source of Variation	df	SS	MS	F ratio
Cultivars	8	4.218	0.527	1.848^{ns}
Error	18	5.134	0.285	
Total	26	9.352		

Table 33 (a) : Chilo partellus plant damage in sorghum infested at three weeks and assessed 35 days thereafter. Mbita Point, 1982

Sorghum Cultivar	$\bar{X}$ Plant damage score	Deadhearts %	Rank
IS 18367	6.3	30	3
IS 18361	6.1	40	1
IS 18363	6.0	10	7
IS 18520	6.0	30	3
IS 18676	5.8	10	7
IS 18479	5.7	20	6
IS 17739	5.3	30	3
IS 18437	5.2	10	7
IS 2122	5.1	10	7
IS 2205	5.0	40	1
IS 18319	4.6	10	7
IS 1044	4.5	10	7
IS 18328	3.7	0	13
IS 18677	3.6	0	13
IS 1082	3.6	0	13

Table 33(b): Summary of analysis of variance for plant damage in sorghum infested at three weeks and assessed 35 days thereafter

Source of Variation	df	SS	MS	F ratio
Cultivars	14	7.723	0.551	0.892^{ns}
Error	128	79.077	0.617	
Total	142	86.801		

Table 34 (a) : Chilo partellus plant damage in sorghum infested at four weeks and assessed 31 days thereafter. Mbita Point, 1982

Sorghum Cultivar	$\bar{x}$ Pland damage score	Deadhearts %	Rank
IS 18520	8.0	31.9	1
IS 18367	7.3	15.5	5
IS 17739	7.1	20.1	2
IS 18363	7.0	9.9	12
IS 18361	6.7	14	8
IS 2122	6.7	18.5	3
IS 18319	6.5	11.7	9
IS 18479	6.1	5.2	15
IS 2205	6.1	14.6	7
IS 18677	6.0	14.8	4
IS 18328	5.9	6.4	14
IS 1082	5.6	15.5	5
IS 18489	5.6	8	13
IS 18676	5.5	11.3	10
IS 18427	5.3	9.9	11

Table 34 (b) : Summary of analysis of variance for plant damage of plants infested at four weeks and assessed 31 days thereafter.

Source of Variation	df	SS	MS	F ratio
Cultivars	14	2.062	0.147	0.146^{ns}
Error	30	30.191	1.006	
Total	44	5.253		

Table 34 (c) : Summary of analysis of variance for deadhearts of plants infested at four weeks and assessed 31 days thereafter.

Source of Variation	df	SS	MS	F ratio
Cultivars	14	1183.499	84.535	0.627^{ns}
Error	30	4041.140	134.704	
Total	44	5224.640		

Table 35(a): Chilo partellus plant damage in sorghum infested at three weeks and assessed five days and 12 days thereafter. Mbita Point, 1982.

Sorghum Cultivar	$\bar{x}$ Pland damage score 5 days	12 days	Deadhearts %	Rank
IS 18520	5.3	6.7	-	
IS 2122	3.2	4.4	-	
IS 18363	3.5	4.2	-	
IS 18427	4.3	4.0	-	
IS 2205	1.7	3.8	-	
IS 18489	1.8	3.8	-	
IS 1082	3.5	3.8	-	
IS 18319	4.3	3.7	-	
IS 1151	4.4	3.5	-	
IS 18677	4.4	3.4	-	
IS 4660	2.8	3.3	-	
IS 18361	4.2	2.9	-	
IS 18479	3.6	2.8	-	
IS 18367	3	2.5	-	
IS 1044	5.3	2.4	-	

Table 35(b): Summary of analysis of variance for plant damage assessed after five days and 12 days.

Source of Variation	df.	SS	MS	F ratio
Cultivar (A)	14	2.251	0.160	1.063^{ns}
Dates (B)	1	0.058	0.058	0.389^{ns}
A x B	14	5.044	0.360	2.383**
Error	110	16.628	0.151	
Total	139	23.981		

Table 36 (a): Chilo partellus plant damage in sorghum infested at three weeks and assessed 19, 26, and 33 days thereafter. Mbita Point, 1982

Sorghum Cultivar	$\bar{x}$ Plant Damage score		Deadhearts %	Rank
IS 18361	7.8	a	60	1
IS 2205	7.6	a b	60	1
IS 18363	7.4	a b	40	3
IS 18319	6.9	a b	40	3
IS 18479	6.8	b	40	3
IS 1151	6.2	b c	30	6
IS 2122	5.5	c	20	7
IS 18520	5.3	c	10	9
IS 18489	5.0	d	20	7
IS 4660	4.8	d	10	9
IS 1082	4.7	d	10	9
IS 1044	4.5	d	10	9

Table 36 (b) : Summary of analysis of variance for plant damage in sorghum assessed after 19, 26 AND 33 days thereafter. Mbita Point,1982

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	11	24.732	2.248	2.570**
Dates (B)	2	11.065	5.532	6.324*
A xB	22	20.459	0.929	1.063^{ns}
Error	324	283.417	0.874	
Total	359	339.675		

Note: Figures followed by different letters are significantly different from one another ($\rho<0.05$)

Table 37 (a) : Chilo partellus plant damage in sorghum infested at three weeks and assessed 28 days thereafter. Mbita Point,1982

Sorghum Cultivar	$\bar{x}$ Plant Damage	Deadhearts %	Rank
IS 18367	8.7	90	1
IS 1151	8.3	80	2
IS 1082	8.1	80	2
IS 18520	8.1	70	4
IS 18363	7.8	60	9
IS 2122	7.4	70	4
IS 18319	7.4	60	9
IS 18677	7.2	70	4
IS 18479	7.1	70	4
IS 2205	6.9	70	4
IS 4660	6.9	40	11
IS 18427	6.8	40	11
IS 1044	6.2	30	14
IS 18361	5.7	40	11
IS 18489	3.9	0	15

Table 37 (b) : Summary of analysis of variance for damage after 28 days

Source of Variation	df	SS	MS	F ratio
Cultivar	14	19.391	1.385	1.376^{ns}
Error	135	135.806	1.005	
Total	149	155.198		

Table 38 (a): Chilo partellus first instar larval plant damage in sorghum infested at three, four, five and six weeks and assessed five days after at each infestation.

Sorghum Cultivar	$\bar{x}$ Plant damage score		Deadhearts %	Rank
IS 18363	3.7	a	-	
IS 18489	2.6	b	-	
IS 18520	2.6	b	-	
IS 2205	2.5	b	-	
IS 1044	2.2	b	-	
IS 18479	2.2	b	-	

Table 38 (b): Summary of analysis of variance for plant damage at three, four, five and six weeks.

Source of Variation	df	SS	MS	F ratio
Cultivar (A)	5	1.719	0.343	2.414*
Date (B)	3	0.511	0.170	1.196^{ns}
A x B	15	3.462	0.230	1.620^{ns}
Error	96	13.676	0.142	
Total	119			

Table 39 : Comparison of selected sorghum cultivars on their tendencies to form deadhearts.

Sorghum Cultivar	Deadheart ranking in different Experiments			Total	$\bar{x}$
	Table 34	Table 36	Table 37		
IS 18363	12	3	9	24	8
IS 18489	8	7	15	30	10
IS 18520	1	9	4	14	4.7
IS 2205	7	1	4	12	4
IS 1044	-	9	14	21	10.5
IS 18479	15	3	4	22	7.3

Figure 17

A mixture of stalkborer moths. The larvae were often found in the same field and even in the same plant.

(a) Chilo partellus

(b) Eldana saccharina and

(c) Busseola fusca

The fourth stalkborer, Sessamia calamistis, is not shown in the figure.

Figure 18

Extensive leaf damage in cultivar

IS 18363

CHAPTER 6

ASSESSMENT OF SORGHUM VARIETAL RESISTANCE AGAINST *CHILO PARTELLUS* USING LARVAL TUNNELLING

6.10 INTRODUCTION

The importance of lepidopterous stem borers in graminaceous crops in East Africa is underscored by the time and effort different entomologists have devoted to these pests. The most relevant include: Hargreaves (1939), Coaker (1956) and Ingram (1958) in Uganda; Duerden (1953), Swaine (1957) and Walker (1961) in Tanzania: Wheatley (1961), and Mathez (1972), in Kenya: Nye (1960) undertook a comprehensive study in all three countries, while Scheltez (1976 and 1978) looked into the ecological and physiological aspects of Pyralid stem borers in Kenya.

C. partellus is a major pest of maize and sorghum in India, East Africa and it is not unimportant in other countreis where it occurs (Hill, 1975). It also affects other cereals. After feeding for a while in the funnel, usually gregariously, a large proportion of *C. partellus* larvae disperse by means of slender threads (Van Hamburg, 1980). The surviving

larvae bore into the stems where they are relatively protected so that very little mortality occurs. Van Hamburg (1980) found that most of the larvae move into the stem during the third instar. Since the larvae of other stemborers also invade the sorghum plants it is essential that the larvae can be reliably differentiated.

At Mbita the stem borer complex consists of four species, C. partellus (87-99%), Eldana saccharina (8-32%), Busseola fusca, and Sesamia calamistis (ICIPE, 1982). The last two are noctuids, while the first two are pyralids. On the basis of the arrangement of crochets on the abdominal prolegs it is easy to tell the noctuid larvae from the pyralids (Jepson, 1954). The two pyralids cannot be easily confused with each other because E. saccharina is dark (almost black) and without any conspicuous markings while C. partellus is spotted (Figure 19). C. partellus, however, is not easily distinguishable from C. orichalcociliella. But Mathez (1972) devised a practical, easy and reliable method of distinguishing between the two borers. This problem in the present study did not arise since C. orichalcociliella is not found around Mbita.

Trehan and Butani (1950) estimated grain sorghum losses caused by C. partellus while Mohyuddin and Attique (1978) estimated the loss in maize. Several control measures against the borer have been tried without much success.

But Adesiyun and Ajayi (1980) found that even partial burning of sorghum stems(to cure them for use as firewood immediately after harvest), killed 95% of the diapausing Busseola fusca larvae inside the stalks. This chapter reports on effects of boring by C. partellus larvae in different sorghum cultivars as one of the means of determining mechanisms sorghum plants use to resist the stalk-borer.

6.20 MATERIALS AND METHODS

Between February and November, 1982, six experiments were conducted at the ICIPE Mbita Point Field Station in order to compare the activities of C. partellus larvae in the stems of 15 selected cultivars. The sorghum cultivars were planted in the manner described in chapter three either directly into three

screenhouses or, when these were not available, into pots. Three experiments were planted in the screenhouses, each screenhouse being a replication. There were four potted plant experiments each experiment with ten replications. At three to four weeks each plant was individually infested with ten C. partellus first instar larvae. The method of infestation was described in chapter four. In the last experiment the method of infestation was changed in order to find out the most effective way of infestation. Twelve potted plants were used of which: four were infested with equal size blackhead stage egg batches, four were infested with ten first instar larvae (in the normal way described in chapter four), and the last two plants were infested with five first instar larvae. In each case the larvae or egg batches were introduced into the leaf funnel.

After about four to five weeks from the time of infestation, the plant heights were measured and the plants pulled out with the roots in order to also measure the tunnel lengths made by the larvae. The percentage of the stem tunnelled was then calculated. To compute the percentage tunnelling the total length of the stem tunnelled was divided by the plant height

(stem length) and then multiplied by a hundred.

The tunnelling percentages were transformed to arc sine the square root of ρ(where ρ is the percentage expressed as a fraction) being analysed using the analysis of variance method. Where the results were significant Duncan's Multiple Range Test was used as in chapters three, four and five.

6.30 RESULTS

The tunnelling results are given in Table 40, 41, 42, 43, 44 and 45. The analysis of variance results in these experiments show no significant differences among the different cultivars in their resistance of susceptibility to C. partellus tunnelling. The only exception is in Table 43 where the analysis of variance of tunnelling among different cultivars (Table 43) shows sorghum cultivars to be a highly significant source of variation. According to these results a large number of cultivars (IS 1044, IS 18361, IS 1082, IS 18479, IS 18363, IS 18367, IS 2122, IS 2205, IS 18520, and IS 18677 are equally resistant to C. partellus tunnelling.

6.30 DISCUSSION

The results imply that cultivars are not significantly different in their susceptibility or resistance to tunnelling. Indeed, there is no pattern in the order or degree of tunnelling (ranking of the cultivars according to degree of tunnelling). However, cultivars IS 2122 appeared at the bottom of ranking order in most experiments. It can thus be inferred that this was less susceptible to tunnelling.

The reason for this apparent lack of difference could be because the period of assessment was too short in relation to the period of sorghum growth. Alternatively, the cultivars are genuinely not significantly different. The latter explanation is most probably correct. Indeed, Mohyuddin and Attique (1978) found that in maize the loss of grain yield was due to deadhearts and stunting of growth rather than tunnelling by C. partellus larvae. In the field normally several waves of infestation occur leading to a much higher C. partellus population.

Table 40 (a): Chilo partellus larval tunnelling in different selected sorghum cultivars infested at three weeks and assessed 26 days thereafter.

SORGHUM CULTIVARS	$\bar{x}$ Percent tunnelling
IS 18363	33.4
IS 18319	19.9
IS 2205	19.2
IS 1082	15.1
IS 18520	14.4
IS 2122	8.1
IS 18361	7.6
IS 18479	6.3
IS 4660	4

Table 40 (b) : Summary of analysis of variance for larval tunnelling after 26 days.

Source of Variation	df	SS	MS	F
Cultivar	8	1312.474	164.059	1.701^{ns}
Error	18	1735.220	96.401	
Total	26	3047.694		

Table 41 (a): Chilo partellus larval tunnelling in different selected sorghum cultivars infested at three weeks and assessed 35 days thereafter.

Sorghum Cultivar	$\bar{x}$ Percent tunnelled
IS 18361	24.7
IS 18520	23.9
IS 17739	23.5
IS 18363	18.7
IS 1044	10.7
IS 18677	6.3
IS 18367	3.3
IS 1082	3.1
IS 18427	3.0
IS 2205	2.5
IS 18319	2.2
IS 18328	1.5
IS 18676	1.3
IS 18479	0.8
IS 2122	0.8

Table 41 (b) : Summary of Analysis of variance for Chilo partellus larval tunnelling in different sorghum cultivars after 35 days.

Source of Variation	df	SS	MS	F
Cultivar	14	9565.514	683.251	1.556^{ns}
Error	120	52669.966	438.916	
Total	134	62235.481		

Table 42 (a) : Chilo partellus larval tunnelling in different selected sorghum cultivars infested at four weeks and assessed 31 days thereafter.

Sorghum Cultivars	$\bar{x}$ Percent tunnelled
IS 18520	24.1
IS 18361	19.8
IS 17739	19.6
IS 18328	19.5
IS 1082	19.1
IS 18367	18.8
IS 18319	18.5
IS 18479	17.7
IS 18676	16.9
IS 18363	16.7
IS 18677	16.7
IS 18489	15.8
IS 2205	13.6
IS 18427	12.5
IS 2122	9.4

Table 42 (b): Summary of Analysis of variance for Chilo partellus larval tunnelling in different sorghum cultivars after 31 days.

Sorghum Cultivars	df	SS	MS	F
Cultivar	14	320.925	22.923	0.816^{ns}
Error	30	842.546	28.084	
Total	44	1163.472		

Table 43 (a) : Chilo partellus larval tunnelling in different selected sorghum cultivars infested at three weeks and assessed 28 days thereafter.

Sorghum Cultivars	$\bar{x}$ Percent tunnelled	
IS 4660	22.5	a
IS 18427	15.	a b
IS 18319	13.4	a b c
IS 18489	12.6	a b c
IS 1151	12.5	a b c
IS 1044	11.5	b c d
IS 18361	10	b c d
IS 1082	8.3	b c d
IS 18363	6.9	b c d
IS 18367	6.6	b c d
IS 2122	3	c d
IS 2205	2.8	c d
IS 18520	2.7	c d
IS 18677	1.5	d

Table 43 (b) : Summary of analysis of variance for larval tunnelling after 28 days.

Source of Variation	df	SS	MS	F
Cultivar	14	4487.835	320.559	3.084**
Error	130	13512.223	103.940	
Total	144	18000.058		

Note: Figures followed by different letters are significantly different from one another ($p<0.05$).

Table 44 (a) : Chilo partellus tunnelling in different selected sorghum cultivars infested at three weeks and assessed 36 days thereafter.

Sorghum Cultivars	$\bar{x}$ Percent tunnelling
IS 18361	27.8
IS 18489	27.5
IS 18520	26.6
IS 18479	21.3
IS 4660	17.4
IS 18363	17.2
IS 18319	17.1
IS 1151	13.7
IS 2122	10.8
IS 1082	9.9
IS 1044	3.0
IS 2205	3.0

Table 44 (b): Summary of analysis of variance for tunnelling in sorghum infested at three weeks and assessed after 36 days

Source of Variation	df	SS	MS	F
Cultivar	11	2536.234	230.475	1.435^{ns}
Error	108	17338.839	160.544	
Total	119	19874.073		

Table 45 (a): Chilo partellus tunnelling in different selected sorghum cultivars infested at three weeks and assessed after 36 days. Mbita Point, 1982

Sorghum Cultivars	Trans $\sin^{-1}\sqrt{p}$ (Black heads) Replications			
	I	II	III	IV
IS 18479	11.2	14.3	0	20.7
IS 18349	15.2	-	-	20.4
IS 1151	-	-	9.8	17.6
IS 18677	14.5	-	24.1	23
IS 18361	30	-	16,4	-
IS 18676	-	9.8	-	21.6
IS 2205	24.1	-	-	37,1
IS 4660	14.3	19.5	-	-
IS 18520	40.5	18.4	-	24.1
IS 18319	23.2	-	19,7	23,1
IS 1044	23.5	-	-	-
IS 1082	22.2	29.6	-	-
IS 18363	-	14.7	22,9	9.6
IS 18489	-	-	22.2	-
IS 2122	26	15.2	-	43.5

(Table 45 (a) Cont'd..)

Sorghum Cultivars	Trans $\sin^{-1}\sqrt{p}$ (10 First instar larvae) Replications I	II	III	IV
IS 18479	DH	-	-	24.6
IS 18349	-	-	16,4	15.3
IS 1151	17.5	-	-	8.5
IS 18677	-	-	17.8	16.7
IS 18361	18.4	22	15	63.4
IS 18676	-	30.4	22.2	21.5
IS 2205	13.1	-	-	-
IS 4660	10.3	15.1	22.8	-
IS 18520	-	-	-	-
IS 18319	18.4	-	9.8	14.5
IS 1044	23.7	-	15.5	-
IS 1082	15.5	15.8	15.9	-
IS 18363	15.8	22.5	-	26.3
IS 18489	15.9	16.1	-	-
IS 2122	9.2	17	-	35.2

(Table 45 (a) cont'd..)

Sorghum Cultivars	Trans $\sin^{-1}\sqrt{p}$ (Five First Instar larvae Replications I	II
IS 18479	30	15,8
IS 18349	30	15
IS 1151	20,1	31,7
IS 18677	-	30,2
IS 18361	18,9	-
IS 18676	25,9	18,4
IS 2205	-	15,8
IS 4660	-	21
IS 18520	24,7	34,8
IS 18319	12,4	11,7
IS 1044	13,7	14,9
IS 18363	26	27,6
IS 18489	-	24,3
IS 2122	9,6	-

Table 45 (b) : Summary of analysis of variance for tunnelling after 36 days. Mbita Point 1982.

Source of Variation	df	SS	MS	F :
Variety/ Cultivar (A)	14	727.737	51.981	0.642^{ns}
Egg Batches/ Larvae (B)	2	102.018	51.009	0.630^{ns}
A x B	28	2513.067	89.752	1.108^{ns}
Error	49	3966.975	80.952	
Total	93			

FIGURE 19

Chilo partellus sixth instar larva

in the stem

CHAPTER 7

BIOPHYSICAL AND BIOCHEMICAL FACTORS IN SORGHUM IN RELATION TO *CHILO PARTELLUS* LARVAL DAMAGE

7.10 INTRODUCTION

According to Norris and Kogan (1980),"resitance, in its broadest sense, ranges from the temporal escape mechanisms that result from phenological asynchronies to the biosynthesis of lethal complex organic molecules. Between is a vast array of phytochemical and morphological characteristics that more or less disrupt the behaviour or metabolic processes involved in the herbivore utilization of a plant as a host."

Some of the most dramatic chemicals that have been implicated for plant resistance include: the aglycone, 2, 4-dihydroxy-7-methoxy-2H-1, 4-benzoxazin -3-one (DIMBOA) in *Zea mays*, which was shown to be a major repellent and feeding inhibitor to first instar larvae of the European corn borer, *Ostrinia nubilalis* (Hubner)(Klun *et al.*, 1967); the dimeric sesquiterpene gossypol which was found to be a feeding deterrent in some cotton pests (Maxwell *et al.*,

1965; and the aglycone 5-hydroxy-1, 4-naphthroquinone (juglone) in hickory trees, which was shown to be a repellent to the elm bark beetle, Scolytus multistriatus (Fabricius)(GiDeci et al., 1967). Working out the chemical bases for plant-pest interractions in plant resistance work has become a very important aspect in scientific inquiry (Norris and Kogan, 1980). The latter workers have listed the following chemical groups as imparting resistance to plants: isoprenoids, acetogenins, aromatics derived from shikimic acid and acetate, alkaloids, protease inhibitors and non-protein amino acids, and glucosides.

A number of morphological factors have also been implicated as contributors to plant resistance. These include: thickening of cell walls and rapid proliferation of plant tissues, solidness and other stem characteristics, trichomes, effect of pubescence on feeding and digestion, effect of pubescence on oviposition, pubescence as a mechanical barrier to locomotion, attachment and related behaviour, pubescence associated with allelochemical factors, incrustrations of minerals in cuticles, surface waxes, and anatomical adaptation of organs (Norris and Kogan, 1980).

Several biochemical and biophysical studies have been conducted on sorghum in order to link certain characteristics with pest feeding deterrence. Woodhead et al., (1982), for example, found p-hydroxybenzaldehyde in concentrations of up to 30% in sorghum wax, was a feeding deterrent to locusts, reducing their normal feeding by 90%. Earlier Woodhead et al.,(1980) found that high cyanide concentration in sorghum was correlated with a reduction in feeding by grasshoppers and by first instar C. partellus larvae, while high concentration of phenolic acids was correlated with reduced feeding by various grasshoppers and by the planthopper Peregrinus maidis (Ashm.). As early as 1939 Franzke et al., found that certain varieties had high hydrocyanic acid but this depended on the environment. However, these workers also found that some resistant sorghum cultivars to grasshoppers and to P. maidis had low levels of these chemicals, which implied that some other factor or factors were involved in their unpalatability. Other workers, such as Blom (1978) have looked into correlation between sensory activity and behavioural response when using specific chemical stimuli.

Maiti et al., (1980)have looked into the nature and occurrence of trichomes in sorghum cultivars with resistance to the sorghum shootfly, (Atherigona soccata). Blum (1968), on the other hand, found positive correlation between the degree of lignin and silica deposition and shootfly resistance in certain sorghum varieties. Before that Djamin and Pathak (1966) had found a negative correlation between silica content in the rice stems and susceptibility to the Asiatic rice borer, Chilo suppressalis (Walker). Waxy coating of leaves also function in insect pest interference even though they can be inhibitory in some plants and excitatory in others (Norris and Kogan, 1980). Thus the waxy leaves of sprouting braccoli are more resistant to the cabbage flea beetle,Phyllotreta albionica than the glossy-leaved mutant (Anstey and Moore, 1954). On the other hand, the cabbage aphid, Brevicoryne brassicae (Linne') and the whitefly, Aleurodes brassicae (Walk.), develop large colonies on normal narrow-stem kale, Brassica oleracea var acephala but do not colonize non-waxy plants (Thomson, 1963). Woodhead et al., (1982) found that epicullicular wax of sorghum contained up to 30% of p-hydroxybenzaldehyde which they demonstrated to be a feeding deterrent in locusts.

Slight variations in anatomical structure of plants may result in altered fitness to herbivore feeding. Norris and Kogan (1980) and Mathes and Charpentier (1963) found that the amount of leaf sheath in different sugarcane varieties resulted in different suitabilities of those varieties to sugarcane borer (Diatraea saccharalis (Fabr.) colonization. This was attributable to differing amounts of water accumulation in the leaf axis. Several other examples of plant morphological adaptation exist in cotton (Jenkins and Parrot, 1971; Leigh et al., 1972), in corn (Luckmann et al., 1964; Link and Rossetto, 1972).

7.20 MATERIALS AND METHODS

7.21 Oviposition Preference or Non-Preference

7.211 Crude Extracts From Selected Sorghum Cultivars.

Since in the oviposition preference experiments (Chapter three) the most preferred and the least preferred cultivars were, respectively, IS 18363 and IS 2205, these cultivars were selected for further comparison. An intermediate cultivar, IS 4660, was

also included. Leaves of three week sorghum plants of each of the three cultivars were rubbed vigorously on wax paper. This was crude since no attempt was made to separate only the cuticle, the wax, or the chlorophyll imbedded in the leaf tissue. The wax paper was labelled according to the cultivar used. These wax papers were kept separate until required for the test later on the same day. They were then suspended inside the observation cages (Figure 2) in such a way that each cage contained all three cultivar extracts on the three sides, the fourth side being left without any wax paper. In each cage newly emerged pairs of male and female C. partellus moths were released at 5.00 p.m. and left in the cages until the next day. On the following day they were transferred to different cages similarly lined with wax paper. Each day the wax papers were removed and the egg batches as well as individual eggs were counted and recorded in such a way that the totals for each cultivar were added together for each pair. This was replicated 46 times. The final totals for each pair were transformed to $\sqrt{x+0.5}$ (where x is the number of egg batches laid by each female). These figures were then analysed for variance using the analysis of variance method.

7.212 Solvent Extracts from Selected Sorghum Cultivars.

The Cultivars that were selected for this experiment were once again IS 18363 and IS 2205. In each case 250 gm of leaves were extracted with 250 mls of solvent. Leaves of three-week old plants were cut to small pieces and then extracted with methyl alcohol, ethyl alcohol, chloroform and hexane each in a different labelled bottle for two days. The resulting extract was then rubbed on wax paper, by means of cotton wool. IS 18363 and IS2205 extracts were suspended at opposite ends of the oviposition cages. Again moths were released in the same manner as in the previous experiment. The resulting egg batches and eggs were counted and recorded. The resulting figures were again transformed to $\sqrt{x+0.5}$ as in the previous experiment and then analysed for variance. Both egg batches and individual egg counts were analysed.

7.22 Sucrose, Fructose, Galactose and Fibre Content

Seven selected sorghum cultivars were planted in the normal manner described in Chapter three and after ten weeks (when most of the cultivars had flowered) they were cut and then transported to the

Kibos Sugar Research Station, near Kisumu for sucrose, fructose, galactose and fibre content determination. Ten plants of each cultivar were used. The stems were crushed to extract the juice using the Laboratory Mill Cane Crusher. The sucrose content was determined by using a polarimeter (Bellingham and Stanley). This is the standard method used for determining sucrose content in sugarcane. The total amount of solutes was determined by means of the Abbne 60 Refractometer (Bellingham and Stanley Ltd.), which is also a standard method used for sugarcane. Reducing sugars which result from hydrolysis (inversion) of sucrose were chemically determined. These are a mixture of glucose and galactose. Fibre content was determined by cutting portions of the stems, weighing , crushing and then dehydrating at 100^{o}C for 48 hours in the oven.

7.23 Lignification in the Stems

Seven selected sorghum cultivars were planted and then at ten weeks were cut into sections on to labelled slides. The sections were stained with phloglucin stain in the manner described by Blum (1968) and were then photographed for later comparison under the microscope. Photographs were then taken through the

dissecting microscope in order to compare the manner and degree of lignification. The phloglucin stain gives a bright red colour in the presence of lignin. The darkness of the colour is proportional to the amount of lignin.

7.24 Examination of Leaves, Stems and Roots

7.241 Leaf Examination

All the cultivars that were used for all the studies were planted in the manner described in Chapter three. Then some leaves of seven selected cultivars were cut at three weeks and prepared for trichome examination using the method by Maiti *et al.*, (1980). At flowering the total number of leaves of all the cultivars were counted and recorded. The lengths and widths of the longest leaves of all the cultivars were also measured and recorded. At this stage the amount of wax from live plants of each of six selected cultivars was collected with a fine camel paint brush into ten dram vials for comparison. In these cultivars note was taken of the leaf sheaths, nature of leaf blades and ligules. In order to give a rough but fair comparison of wax in different cultivars, wax was collected from an equal number of plants in each cultivar.

7.242 Stem Examination

During the leaf examinations in 7.221 the following stem examinations were also made:

(i) Plant heights were determined in the manner described by House (1980).

(ii) Stem thicknesses were measured as well as the total number of internodes.

7.243 Root Examination

In seven selected sorghum cultivars the roots were labelled and compared in size and number of side roots. Photographs of these were taken for later comparisons.

7.25 Bioassay for Antibiosis Studies

7.251 Laboratory Bioassay

Twenty selected sorghum cultivars were planted in the manner described in Chapter three. Every week for seven weeks 30 plants were selected from each cultivar and dissected for C. partellus larvae. The larvae were then reared in labelled laboratory jars containing pieces of stems of the same cultivars; as they were collected from stem, changes were made every two days. On pupation they were sexed and

weighed. Note was taken of how long pupation lasted, mortalities, parasitization, and the adult emergence were also noted and recorded. The resulting adults were paired and the fecundity determined. Fecundity was calculated by determining the mean number of egg batches per female. All the data was recorded.

7.252 Field Bioassay

In 1982 four screenhouse experiments were conducted in which nine to fifteen selected cultivars were planted, infested with five to ten C. partellus first instar larvae and then after a certain period an assessement of larval survival, pupation, larval weights and pupal weights was done.

In February, 1982 nine sorghum cultivars in the field were infested at the booting stage and then assessed 32 days later. The object was to see if antibiosis builds up or declines with age. For comparison all the three other screenhouse experiments were infested at three weeks and assessed after 21, 30 and 36 days, respectively.

7.30 RESULTS

7.31 Oviposition Preference or Non-Preference

7.311 Crude Extracts from Selected Sorghum Cultivars

The results of this experiment are given in Table 46(a). The mean number of Chilo partellus egg batches on cultivars IS 18363, IS 2205 and IS 4660 were, respectively, 78.61, 78.77 and 75.27. According to the analysis of variance for the oviposition count the results (Table 46(b) are not significant at p 0.05. But what was puzzling was that more egg batches were deposited on the IS 2205 extract than on either IS 4660 or IS 18363 extracts. (The cultivar IS 2205 had been selected as the least preferred, while IS 4660 was selected as intermediate between IS 18363 and IS 2205)

7.312 Solvent Extracts from Selected Sorghum Cultivars

The results of the oviposition preference of the moths is given in Tables 47 to 50. The solvents had been selected according to polarity. Ethyl and methyl alcohols are both slightly polar and would therefore tend to extract polar compounds such as aliphatic and aromatic acids, alcohols, and aldehydes. Hexane and choloroform, on the other hand, are completely non-polar. They would thus be expected to

extract non-polar compounds and high molecular weight compounds which would include waxes and esters. Polarity in solvents is caused by the oxygen atom in the hydroxyl (-OH) group. Thus hexane and chloroform are relatively non-polar because they do not have the hydroxyl group.

In these experiments all the results were statistically not significant. But there was a striking difference between the polar solvent extracts (Table 47(a) and Table 48(a) from the non-polar solvent extracts (Table 49(a) and Table 50(e). In the polar solvents there was a slight preference for the IS 18363 extracts over the IS 2205 extracts. But in the non-polar solvent extracts there was a reversal. More egg batches were deposited on IS 2205 than on IS 18363. However in both cases the number of the actual eggs deposited was more on the IS 18363 (refer to Tables 49 and 50).

7.32 Fibre Content and Amounts of Sucrose, Fructose and Galactose

The results of the chemical and physical analysis of selected sorghum cultivars is given in Table 51. IS 18520 ("Serena") had the lowest fibre content and a relatively high sucrose content. The Cultivar IS 2122 had a high fibre content and an intermediate

amount of sucrose. This would explain why it was relatively less susceptible to larval tunnelling, (refer to Tables 41, 42 and 43). Cultivar IS 17739 had a high fibre content and the lowest sucrose content. The total sugar content (Sucrose + Fructose + Galactose) corresponded with the amount of sucrose. Cultivar IS 18676 had a low fibre content but also had a low sucrose content.

7.33 Lignification on the Stems

The photographs of the stained stem sections are given in figures 20 to 25. All the stems of different cultivars showed presence of lignin in the rind of the stem. Differing amounts of lignin also occured around the vascular bundles. Cultivar IS 18363 had very little lignin as shown by very little red colouring. IS 1044 had a distinct pith where there were neither vascular bundles nor any lignification. The cultivars IS 18489 and IS 18520 and to some extent IS 2205, all had a lot of lignin deposition. These cultivars would thus all be expected to have hard stems and therefore not so easily tunnelled by young stemborer larvae. Cultivars IS 18363, IS 1044, and to some extent, IS 2146 (Figures 23, 24, and 25) would be expected to be relatively susceptible compared with the other cultivars

(Figures 20, 21 and 22). This, however, is not the case (Tables 40 to 45). According to these tables cultivars are not a significant source of variation (except Table 43).

7.34 Examination of Leaves, Stems and Roots

7.341 Leaf Examination

Maiti et al (1980) showed that the number of trichomes are not related to shootfly resistance. Since C. partellus larvae are even larger than shootfly larvae it was assumed that trichomes (which are smaller than plant cells) could not affect the first instar larvae or the ovipositing moth. The detailed structures of the different trichomes are illustrated in Figures 26, 27, 28, 29, 30, 31 and 32. The magnification was 157.5x. IS 2205 has glandular trichomes (Figure 32). The exudate from the grandular base can be seen at the tip of the trichome. This exudate is viscous. After secretion it forms threads that do not dissolve in hot water, lactic acid, or even boiling alcohol. Table 52 gives the dimensions of the largest leaf (second from the flag leaf). Figure 33 shows the relative amount of wax from different selected cultivars. The nature of the leaf blade, leaf sheath and ligule is shown in Figures 34 and 35. IS 18363 has wide

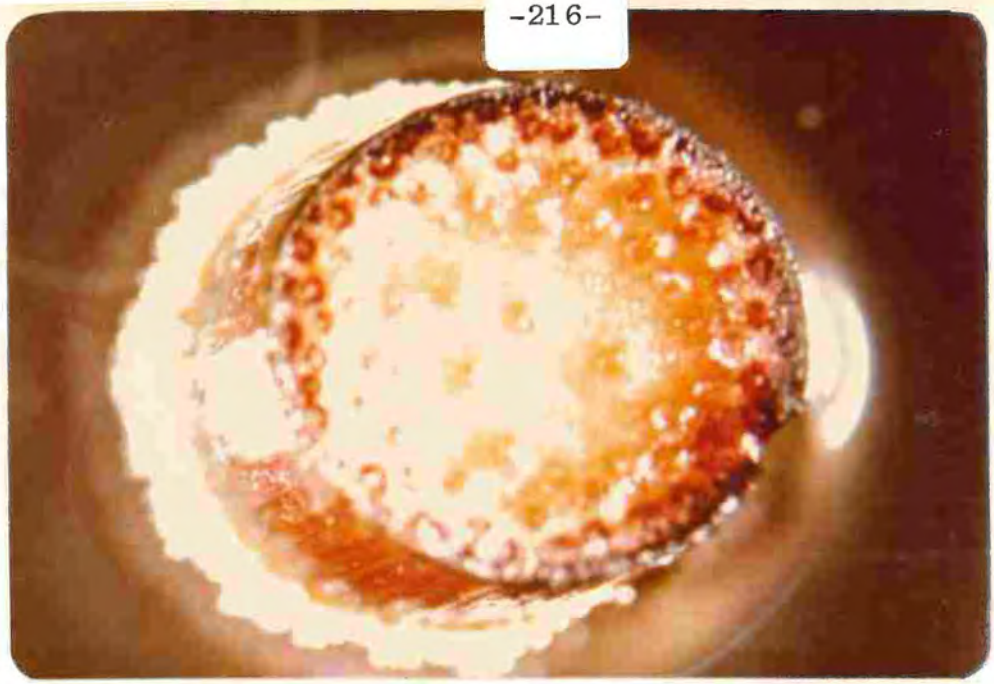
leaves and leaf sheath wraps around the stem several times making it difficult for first instar larvae to get to the growing point or into the stem. In IS 18489 the ligule has several hard bristly hairs. These make an effective barrier for first instar larvae moving down the leaf to the stem. The first instar larvae were actually observed to be trapped in these. The dimensions of the leaves are given in Table 52.

Cross sections of stems stained with phloglucin. Dark red colour indicates high concentration of lignin. These cultivars would therefore be expected to be relatively resistant to Chilo partellus larval tunnelling.

FIGURE 20 - IS 2205

FIGURE 21 - IS 18489

FIGURE 22 - IS 18520



IS2205

IS18489

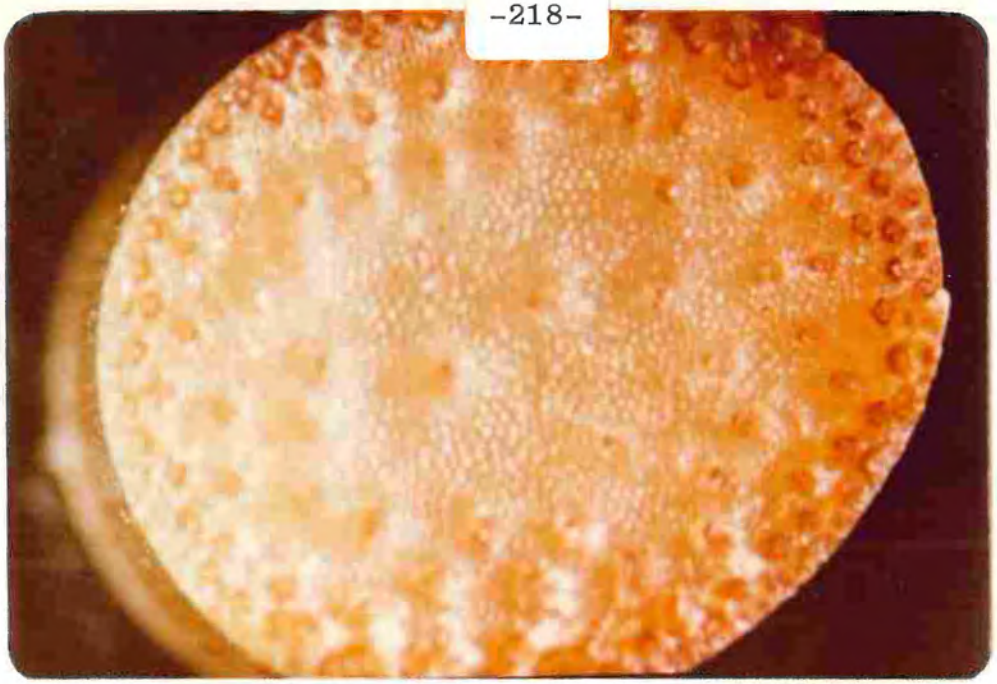
IS18520

Cross sections of stems stained with phloglucin. Although lignin is present as indicated by the red colour, in these cultivars there were relatively lower concentrations of lignin. These cultivars would be expected to be relatively susceptible to C. partellus larval tunnelling.

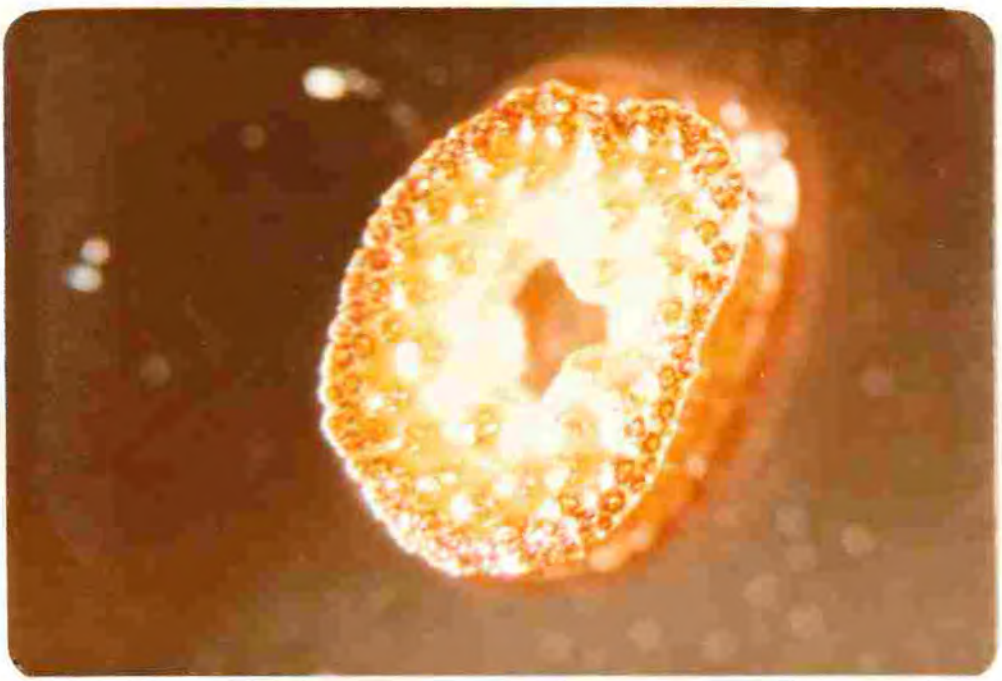
FIGURE 23 - IS 18363

FIGURE 24 - IS 1044

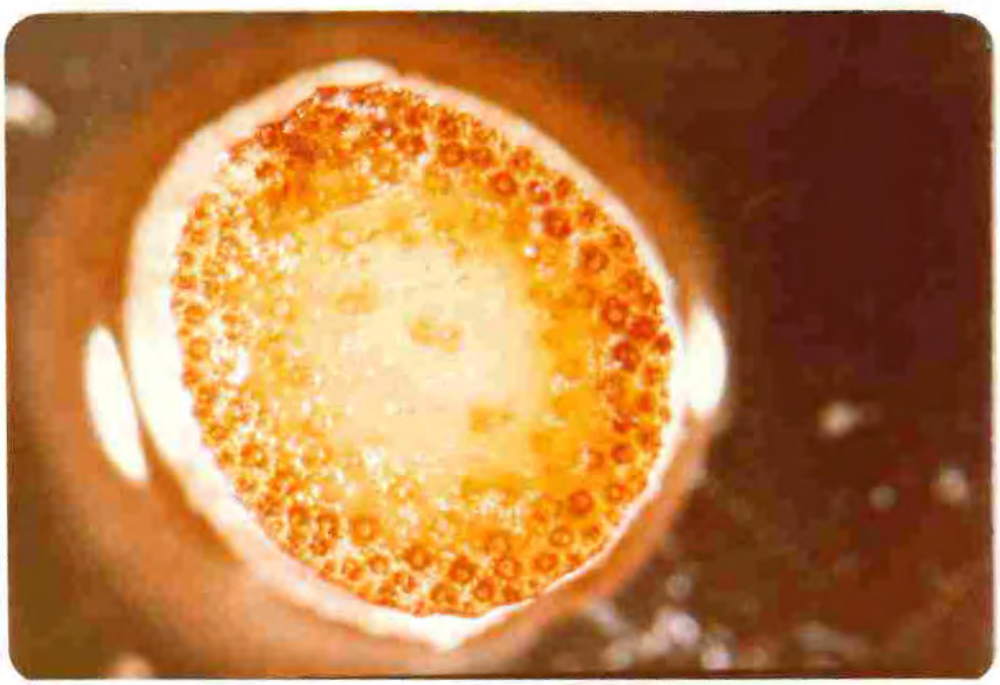
FIGURE 25 - IS 2146



IS18363

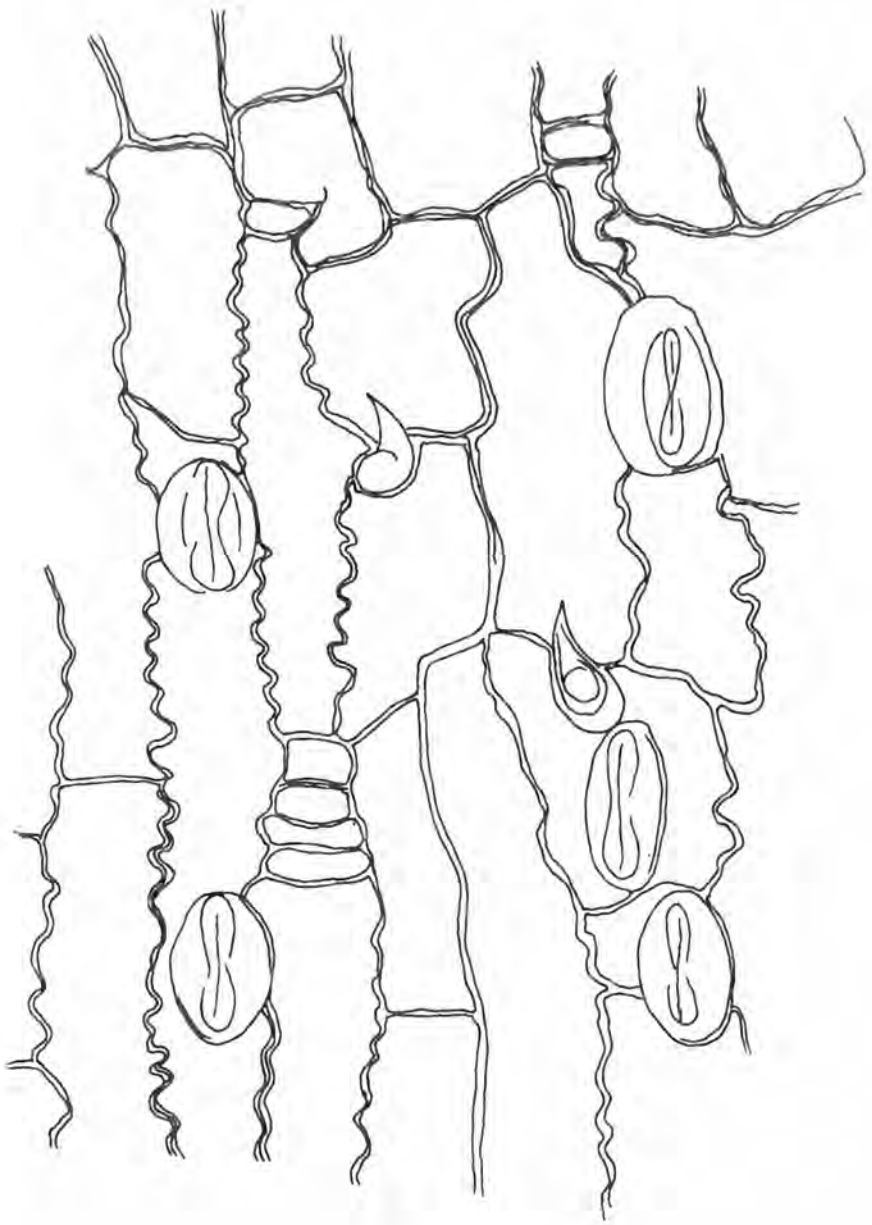


IS1044



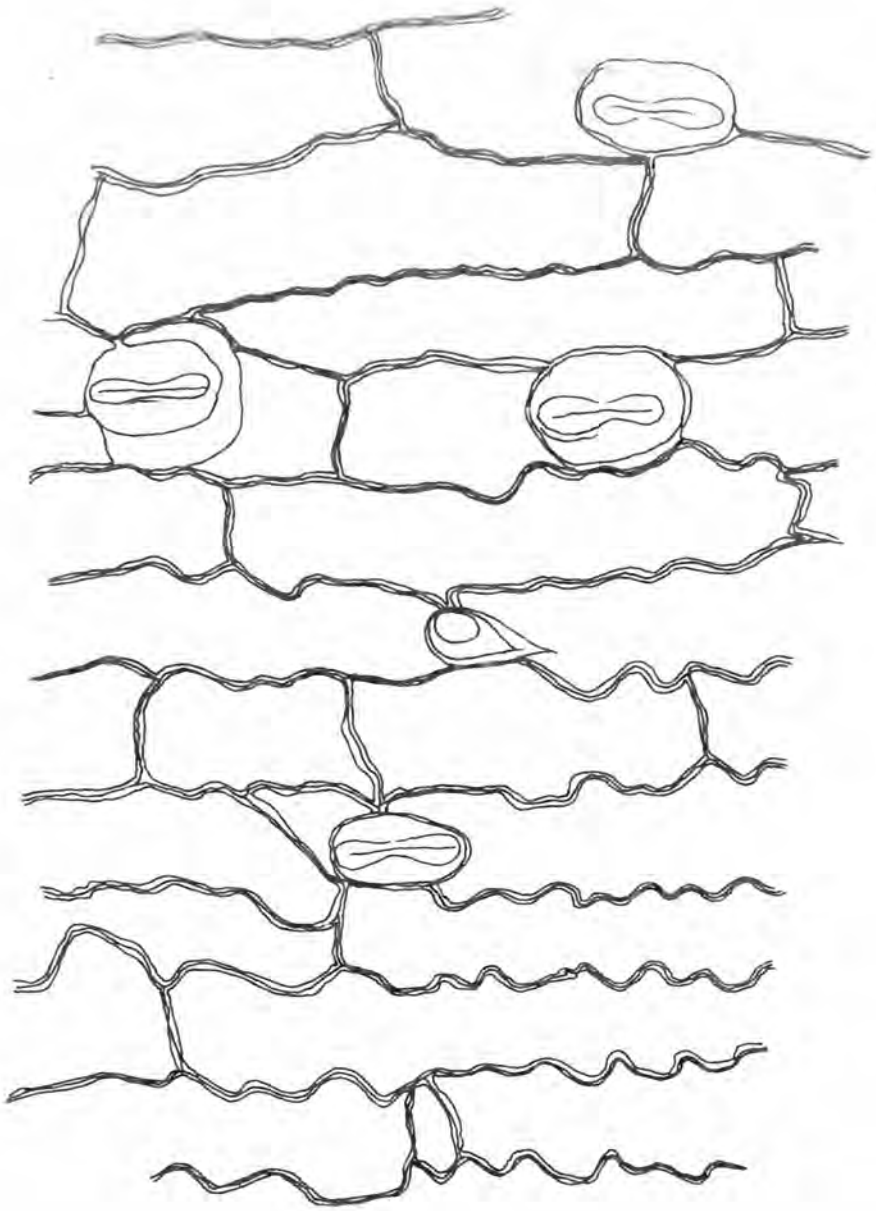
IS2146

FIGURE 26 - IS 18363



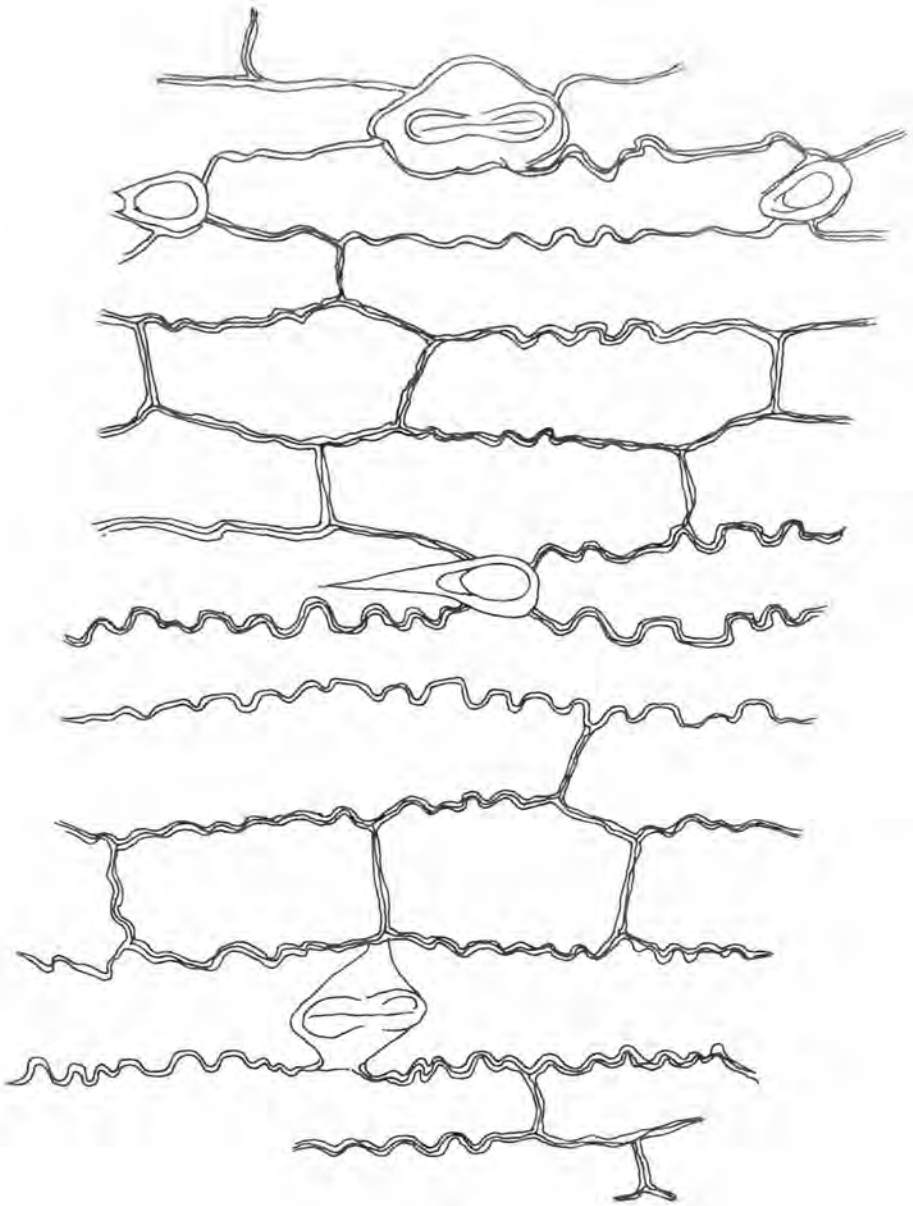
IS 18363

FIGURE 28 - IS 18479



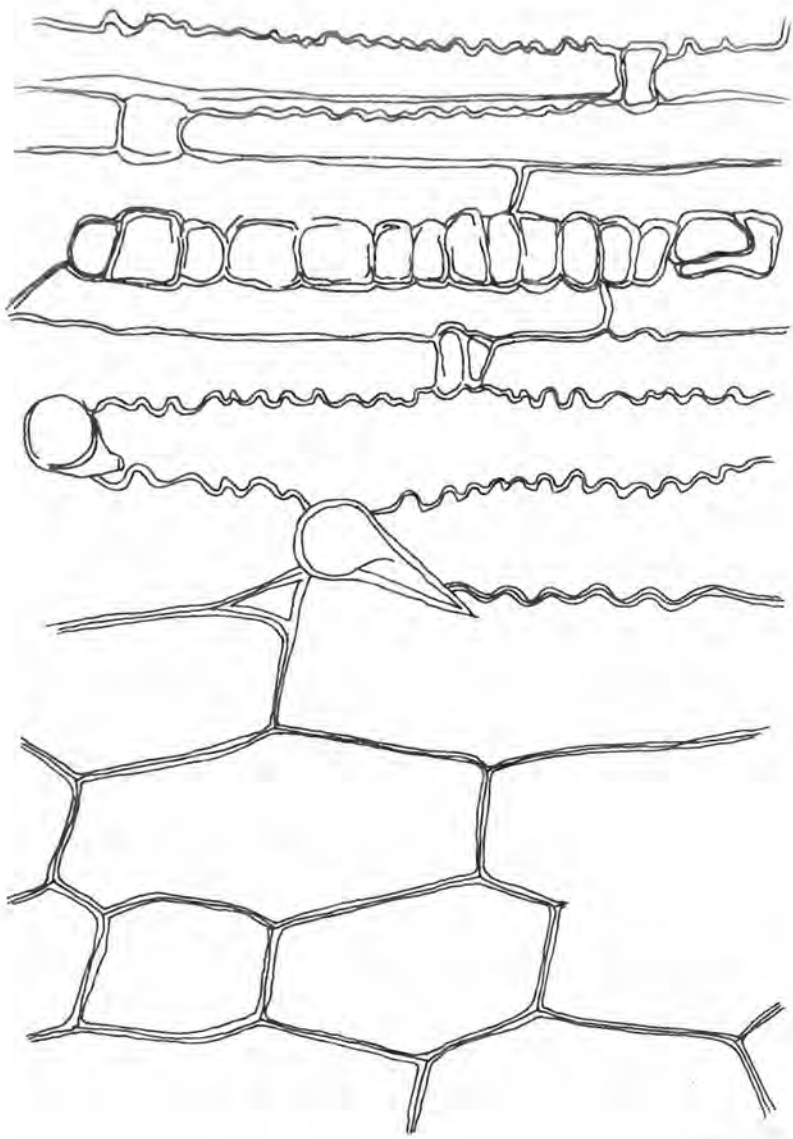
IS 18479

FIGURE 29 - IS 18489



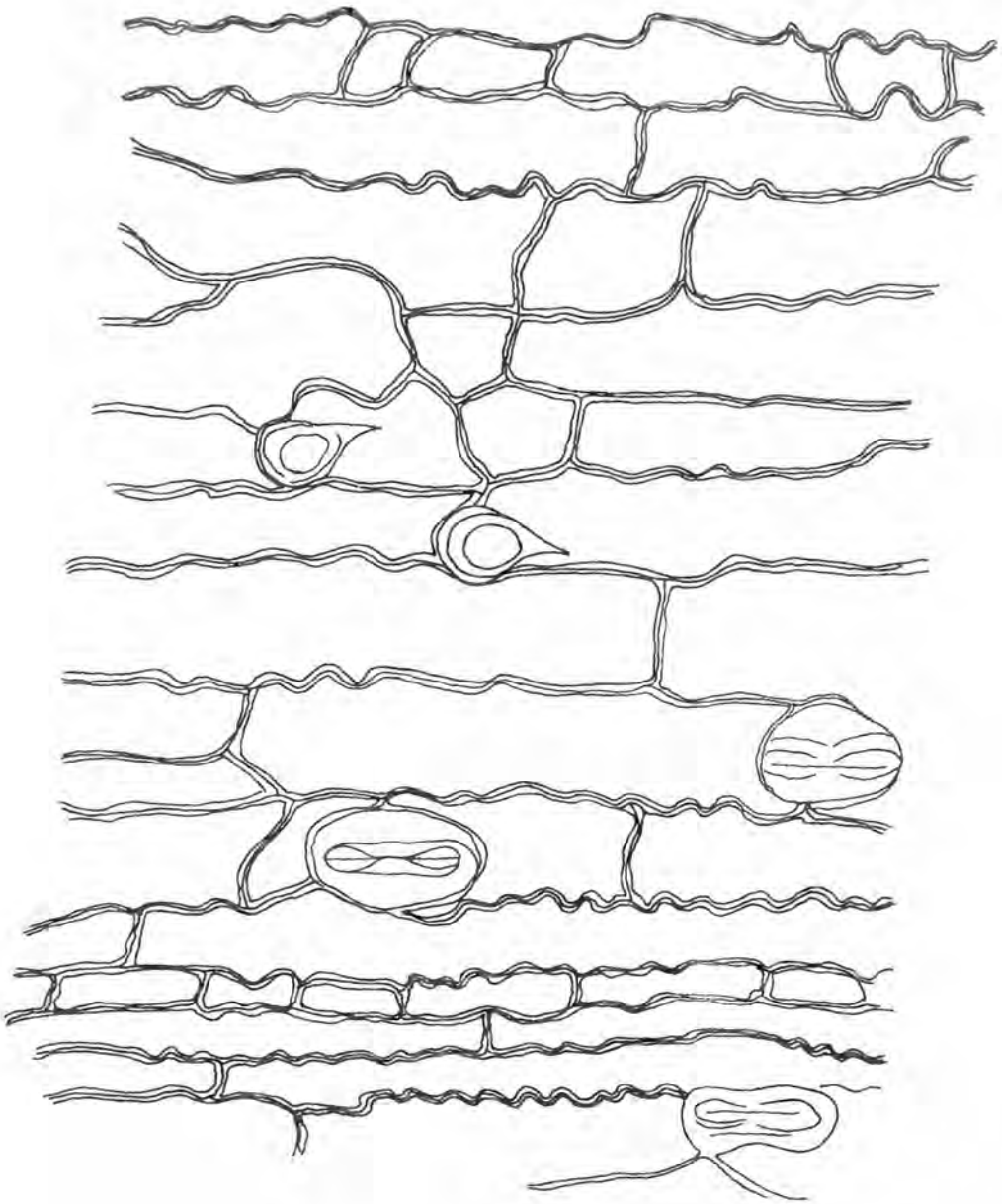
IS 18489

FIGURE 30 - IS 1044



IS 1044

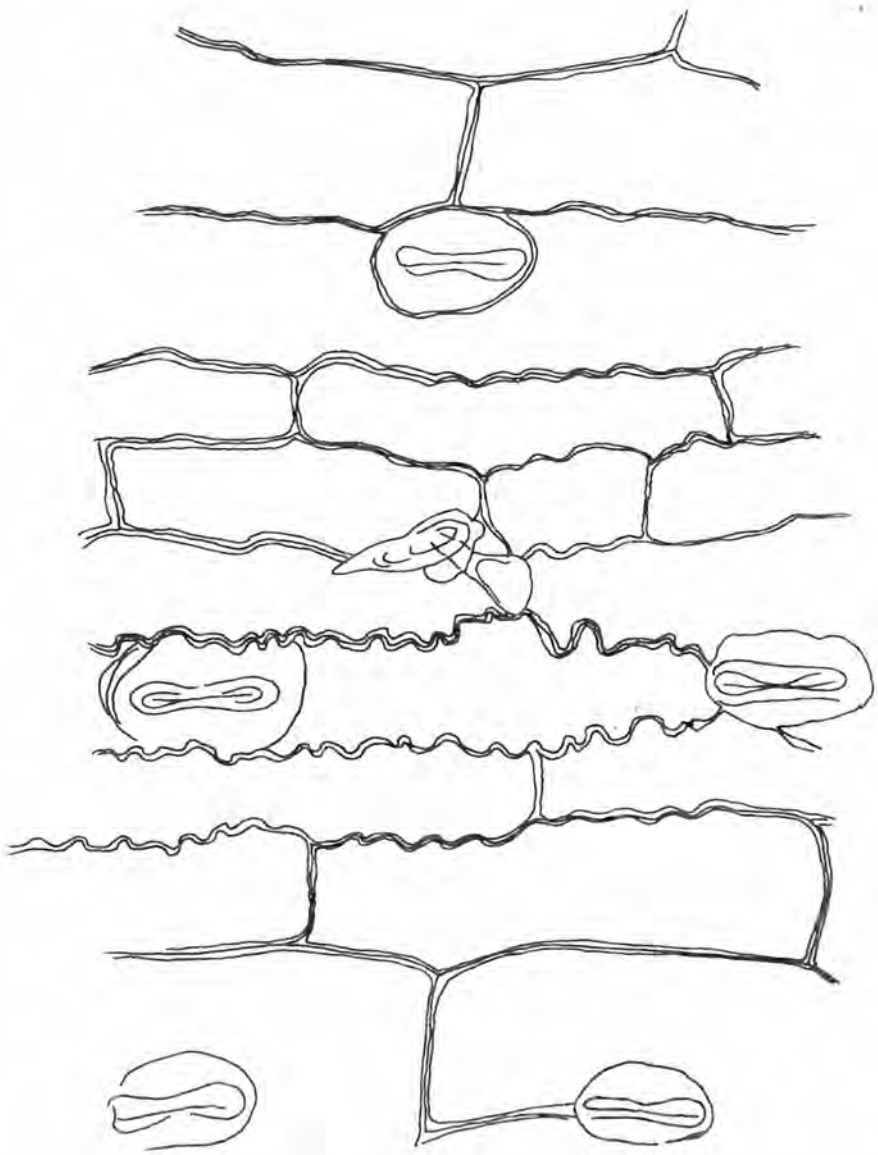
FIGURE 31 - IS 2122



IS 2122

FIGURE 32 - IS 2205

Notice that the trichomes are glandular and the exudate secreted from the tip is clearly discernible.



IS 2205

FIGURE 33

Relative amounts of wax from selected cultivars. Notice that IS 1044, which show the greatest larval dispersal (migration), had the greatest amount of wax while IS 18363 and IS 18520 ("Serena") had almost no wax. These cultivars also had the least larval dispersal (migration).


IS 1044
IS 18479
Serena
IS 18363

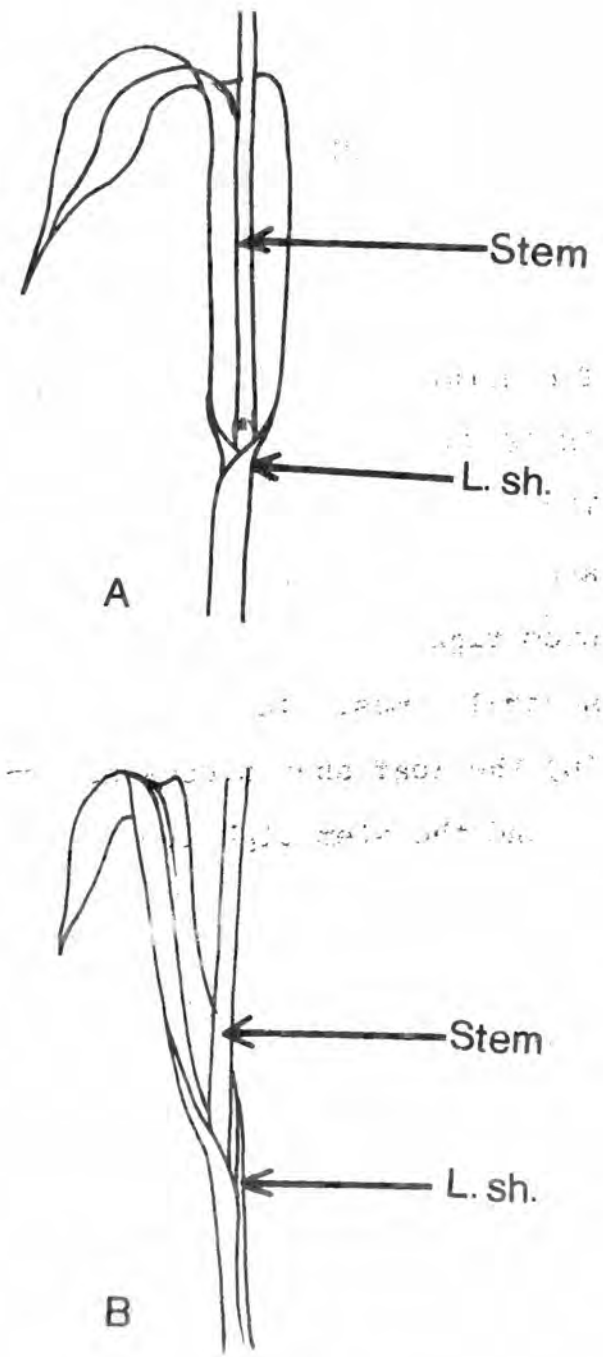
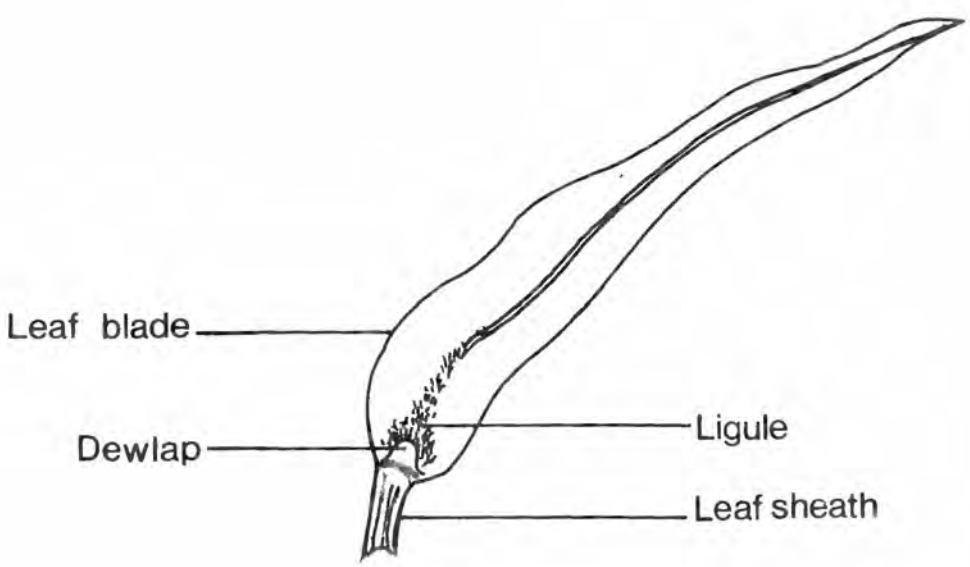

Stem
L. sh.
A
Stem
L. sh.
B

FIGURE 35

Leaf blade in IS 18489

At the base of the leaf blade in IS 18489 there is a bristly ligule which traps the C. partellus first instar larvae. A number of larvae are killed in this way before they go past the dewlap into the stem.


Leaf blade
Dewlap
Ligule
Leaf sheath

A comparison of the root systems of resistant and susceptible cultivars.

FIGURE 36

Strong long and profuse root system in IS 2205 and a poor root system in IS 18363.

FIGURE 37

Poor root system in IS 18520 and a stong and long root system in IS 18489.


IS 2205
IS 18363


IS 18520
IS 18489

FIGURE 38

Root systems in IS 2205 and IS 2122 are both long and are comparable.


IS 2205
IS 2122

7.342 Stem Examination

The mean plant heights, total number of inter-nodes are given in Table 53. The tallest cultivars were IS 17739, IS 2122, IS 2263, and IS 18489 while the shortest were IS 3954 and CK60B. These cultivars also had the highest and lowest number of internodes, respectively.

7.343 Root Examination

On comparing the roots of different cultivars labelled cultivar pictures were taken at the same magnification and distance. (Figures 36, 37, and 38). A comparison of their relative size and number of side roots is thus shown. From the photographs it will be noticed that IS 18363 and IS 18520 had the smallest roots when compared with IS 18489, IS 2122 and IS 2205. These cultivars happen to be the most susceptible and the most resistant respectively. There is nothing, however, to suggest a link between size of roots and resistance.

7.35 Bioassays for Antiobiosis Studies

7.351 Laboratory Bioassays

The pupation periods, pupal weight scores, adult

emergence data, sex ratio and the female fecundity are given in Tables 54, 55 and 56. The pupation periods most affected were for those larvae reared in IS 1082, IS 18479, IS 2205, IS 17739 and IS 2122. The least affected pupae were from IS 18367, IS 18677. IS 18361 and IS 18363. The least pupal weights came from IS 2205, IS 18520, and IS 2122. The number of larvae collected from and reared in IS 18520 was, however, high. The low pupal weight might therefore be due to larval congestion and competition. The lowest percentages of adults that emerged were IS 18363 IS 2263, IS 1082 and IS 18489. However, the number of larvae collected per plant were much higher in IS 18363. The low percent emergence could be due to this factor. The least fertile moths were those reared in IS 2122, IS 18676, IS 18361, IS 2162 and IS 18427.

7.352 Field Bioassays

The results of the field bioassays are given in Table 57 to Table 62. The analysis of variance is insignificant in all experiments at $\rho<0.05$. They are, however, significant at $\rho<0.1$. The only exception was in Table 58 (c) where the analysis of variance for larval weights was highly significant (at $\rho<0.01$).

7.40 DISCUSSION

7.41 Oviposition Preference or Non-Preference

In this experiment only the eggs deposited on the wax paper were counted. An improvement on the methodology would be to count the eggs and egg batches near the wax paper with selected extracts. The components in which moths had to make a choice were so small that if either cultivar produced volatile chemicals these would mix and make it difficult for the moths to make a choice. Finally, even the method of extraction (rubbing leaves on the wax paper) might have been such that the most important compounds were masked by other compounds that would not be normally secreted by the plant.

Oviposition preference in difference extracts suggests that the compounds that attract the moths are polar. Using a very polar solvent (like water) would probably be more fruitful.

7.41 Sucrose, Fructose, Galactose and Fibre Content

The results did not demonstrate if any relationship exists between sorghum cultivar resistance, on one hand, and the amounts of sugars (sucrose, fructose and galactose) as well as fibres, on the other hand. Some other factors are probably responsible.

7.43 Lignification in the Stems.

From the photographs showing the relative amounts of lignin it can be inferred that:-

(a) Lignin occurs in all cultivars in the rind and in those vascular bundles nearest the rind.

(b) Different amounts occur in different cultivars. The resistant cultivars contain more lignin.

(c) Some cultivars, like IS 1044, have a pith that has no vascular bundles. As such, tunnelling in this region would not interfere with the transport of water, minerals and photosynthates.

7.44 Examination of Leaves, Stems and Roots

All leaves, stems and roots have an important role to play. The number of trichomes *per se* have no role to play in resistance to *C. Partellus.* However, the type of trichomes are important. IS 2205 was the only cultivar with glandular trichomes that give a secretion. This leads to the interference that

they have an important role to play in oviposition. However, the spinelike hairs at the base (ligule) of the leaves of IS 18489 definately affect the movement of first instar larvae. Rather unfortunately these hairs only occur in older leaves and not in the whorl where first instar larvae enter the plant at the early stages.

The amounts of wax differ in different cultivars. They seem important in interferring with C. partellus first instar larval infestation. It can be noted that the least resistant cultivars (IS 18520 and IS 18363) also had the least amount of wax. Examination of the stem anatomy did not reveal any characters that enhance plant resistance. Resistance, it seems, occured among both tall and short cultivars.

7.45 Bioassays for Antibiosis Studies

From the results in the laboratory bioassays it can be noted that there was no cultivar that was resistant in all aspects. Indeed, some cultivars were resistant in one aspect and completely susceptible when different criteria were used. IS 2122, for example, gave very low pupal scores but the resulting moths had

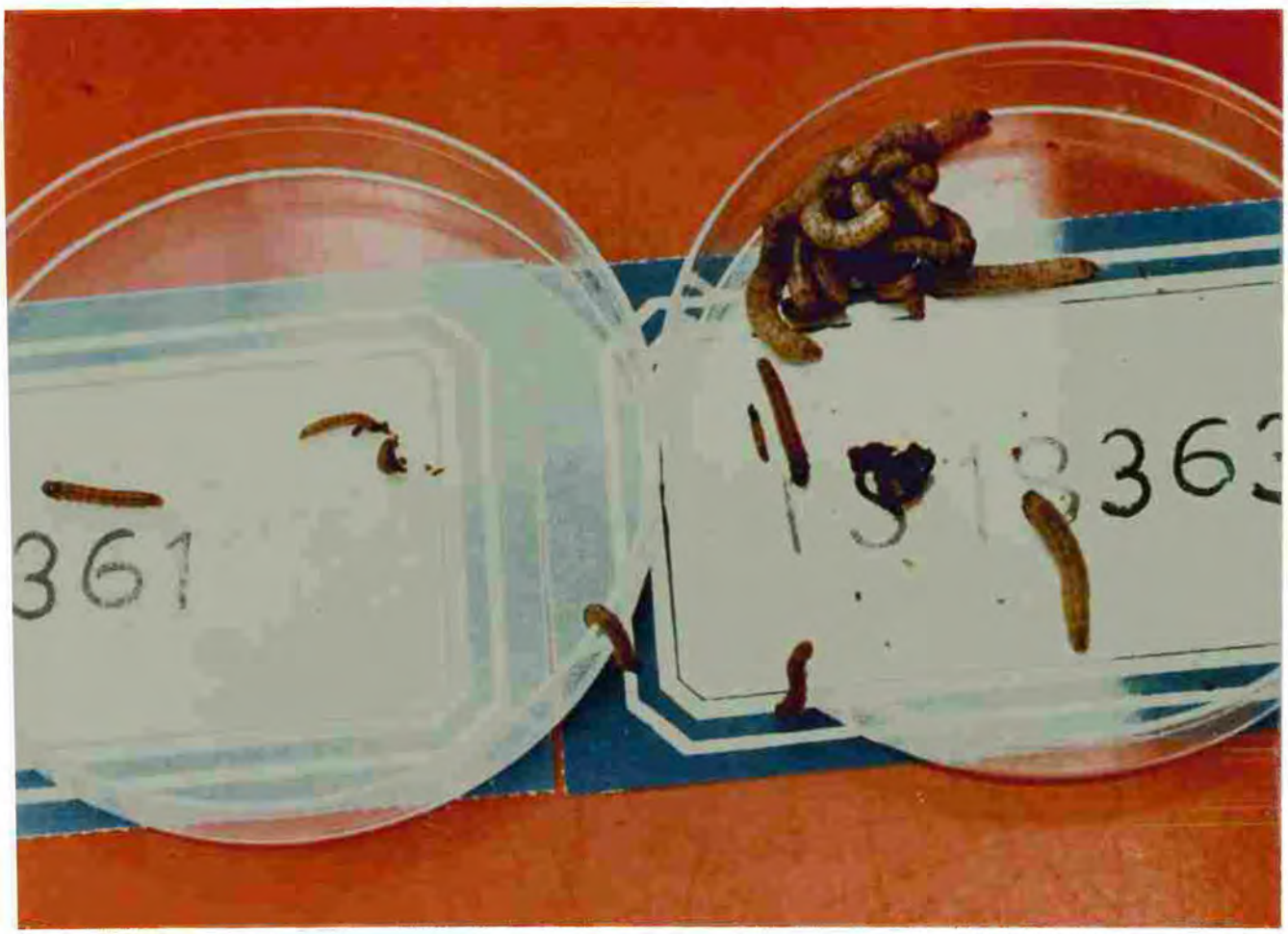
the highest fecundity. This could be because the different factors are determined by different genes. It could also be explained by a low level of resistance. According to House (1980) sorghum resistance to insect pests in general and to stemborers in particular is polygenic and thus not at a very high level.

There was slightly more consistency in the field bioassays. IS 2122 seemed to have the highest antibiosis. Comparison of the larval weights at different plant stages seemed to indicate that some cultivars were initially resistant but lost this resistance at a later stage. IS 1861 was relatively resistant at the early stage (Figure 39 and 40), but when infested at the booting stage (Table 57) it turned out to be susceptible. Other cultivars that had a marked effect on larval weight were IS 18479, IS 1082 and IS 18427 (Table 58). However, the analysis of variance of the results are insignificant and this suggests either a low level of resistance or insufficient replication in the performance of the experiments.

FIGURE 39

Comparison between IS 18361 and IS 18363

Larvae reared on IS 18361 at three weeks were fewer and smaller than those reared on IS 18363 at the same age.



IS 18361 IS 18363

FIGURE 40

Comparison between IS 18479 and IS 18363

Larvae reared on IS 18479 were fewer but of comparable size with those reared on IS 18363.


18479
IS 18363

Table 46 (a) : Chilo partellus oviposition behaviour to crude sorghum extracts from three selected sorghum cultivars: Mbita, 1982.

	EGG BATCH (TRANS.$\sqrt{x+0.5}$)		
REPLICATIONS	IS 18363	IS 2205	IS 4660
1	1.22	2.35	1.8
2	1.22	0.71	2.74
3	3.08	2.12	1.87
4	0.71	2.12	1.58
5	1.87	2.12	2.55
6	2.35	2.55	3.08
7	0.71	0.71	1.58
8	2.74	2.12	2.92
9	1.87	3.24	3.24
10	0.71	1.58	0.71
11	0.71	1.87	0.71
12	1.87	0.71	0.71
13	3.54	1.87	1.22
14	0.71	2.12	0.71
15	0.71	1.22	0.71
16	1.22	0.71	0.71
17	1.22	1.58	1.58
18	2.12	2.35	2.12
19	1.58	1.58	2.35
20	2.55	1.12	1.87

Table 46 (a) (cont'd...)

	EGG BATCH (TRANS. $\sqrt{x+0.5}$)		
REPLICATIONS	IS 18363	IS 2205	IS 4660
21	3.08	2.12	2.12
22	3.24	2.12	1.58
23	1.87	2.74	1.22
24	1.87	2.12	2.12
25	2.35	1.22	2.74
26	0.71	2.12	0.71
27	2.55	0.71	0.71
28	2.35	1.58	1.58
29	3.08	2.74	3.08
30	1.58	1.58	1.22
31	2.35	2.55	2.12
32	2.12	1.58	1.87
33	1.22	0.71	0.71
34	3.39	2.92	1.87
35	1.22	0.71	1.22
36	0.71	1.22	1.22
37	1.22	1.58	0.71
38	0.71	1.22	0.71
39	1.58	2.92	2.74
40	1.58	1.22	2.55
41	1.22	0.71	0.71
42	0.71	2.12	0.71

Table 46 (a) (cont'd...)

REPLICATIONS	EGG BATCH (TRANS.$\sqrt{x+0.5}$) IS 18363	IS 2205	IS 4660
43	2.55	1.87	2.35
44	0.71	0.71	1.58
45	1.22	0.71	1.58
46	0.71	1.22	0.71
Total	78.61	78.77	75.27
$\bar{X}$	1.71	1.71	1.44

Table 46 (b) : Analysis of variance for C. partellus oviposition on wax paper with crude sorghum leaf extracts.

Source of Variance	df	SS	MS	F
Treatment	2	0.169	0.0845	0.133^{ns}
Expl Error	135	85.599	0.634	
Total	137			

Table 47 (a): Chilo partellus oviposition response to methyl alcohol extracts of two selected sorghum cultivars. Mbita Point , 1982.

EGG BATCHES

Cultivar	$\bar{X}$ Trans. $\sqrt{x+0.5}$	$\bar{X}$
IS 2205	0.83	0.19
IS 18363	1.04	0.58

EGGS

IS 2205	0.98	0.46
IS 18363	1.9	3.11

Table 47 (b) : Analysis of variance for Chilo partellus oviposition on wax paper with methyl alcohol extracts.

EGG BATCHES

Source of Variation	df	SS	MS	F
Cultivars	1	0.268	0.268	1.99^{ns}
Error	22	2.957	0.134	
Total	23	3.336		

Table 47 (b) (cont'd.....)

EGGS

Source of Variation	df	SS	MS	F
Cultivars	1	5.078	5.078	3.584^{ns}
Error	22	31.171	1.416	
Total	23	36.249		

Table 48 (a): Chilo partellus oviposition response to ethyl alcohol extracts of two selected sorghum cultivars. Mbita Point, 1982.

EGG BATCHES

Cultivar	$\bar{X}$ Trans.$\sqrt{X+0.5}$)	$\bar{X}$
IS 2205	0.71	0.64
IS 18363	0.71	0.85

EGGS

IS 2205	0.71	4.17
IS 18363	0.71	6.8

Table 48 (b): Analysis of variance for Chilo partellus oviposition on wax paper with ethyl alcohol extracts.

EGG BATCHES

Source of Variation	df	SS	MS	F
Cultivar	1	0.067	0.067	0.159^{ns}
Error	28	11.801	0.421	
Total	29	11.868		

Table 48 (b) (cont'd.....)

EGGS

Source of Variation	df	SS	MS	F
Cultivars	1	2.241	2.241	0.206^{ns}
Error	28	303.968	10.856	
Total	29	306.210		

Table 49 (a) : Chilo partellus oviposition response to chloroform extracts of two selected sorghum cultivars. Mbita Point, 1982.

EGG BATCHES

Cultivar	$\bar{X}$ Trans.$\sqrt{X+0.5}$)	$\bar{X}$
IS 2205	0.71	0.42
IS 18363	0.71	0.29

EGGS

IS 2205	2.04	3.67
IS 18363	2.12	3.99

Table 49 (b): Analysis of variance for Chilo partellus on wax paper with chloroform extracts.

EGG BATCHES

Source of Variation	df	SS	MS	F
Cultivars	1	0.047	0.047	0.318^{ns}
Error	32	4.763	0.148	
Total	33	4.810		

Table 49 (b) (cont'd....)

EGGS

Source of Variation	df	SS	MS	F
Cultivars	1	0.056	0.056	0.009^{ns}
Error	32	190.322	5.947	
Total	33	190.378		

Table 50 (a) : Chilo partellus oviposition response to hexane extracts of two selected sorghum cultivars. Mbita Point, 1982.

EGG BATCHES

Cultivar	$\bar{X}$ Trans. $(\sqrt{X+0.5})$	$\bar{X}$
IS 2205	0.84	0.21
IS 18363	0.82	0.17

EGGS

IS 2205	1.2	0.94
IS 18363	1.27	1.11

Table 50 (b): Analysis of variance for Chilo partellus oviposition on wax paper with hexane extracts.

EGG BATCHES

Source of Variation	df	SS	MS	F
Cultivars	1	0.003	0.003	0.034^{ns}
Error	24	2.261	0.094	

EGGS

Cultivar	1	0.032	0.032	0.016^{ns}
Error	24	47.072	1.961	
Total	25	47.105		

Table 51: Chemical and Physical Analysis of Selected Sorghum Cultivars for Sucrose, Fructose, Galactose and Fibre Content (21°C)

Sorghum Cultivars	CHEMICAL ANALYSIS				Physica Analysi
	% Sucrose	% Sucrose Purity	%Reducing Sugars (Fructose + Galactose)	%Total Solutes	%Fibre Content
IS 17739	2.68	28.69	4.3	9.34	14
IS 1082	6.8	42.51	3.87	13.05	12
IS 2122	4.29	40.9	3.99	10.45	15.5
IS 18520	5.86	51.98	3.37	10.97	9.0
IS 18479	3.86	31.3	3.63	12.4	9.5
IS 18363	3.16	33.1	4.24	11.45	11.0
IS 18676	3.02	33.77	3.91	9.56	9.5
IS 4660	7.26	-	3.70	1.47	16.5

Table 52 : Dimensions of leaves of sorghum cultivars used for plant resistance studies to *Chilo partellus*, Mbita Point, 1983

Sorghum Cultivar	Leaf length (cm) (the plant's largest)	Leaf width (cm) (the plant's largest
IS 18520	68.4	8.5
IS 18677(E303)	70.7	8.5
IS 17739	57.4	8.2
IS 1044	78.5	9.0
IS 6504	55.1	8.1
IS 18427	68.4	8.5
IS 4764	56.3	7.1
IS 18361	57.1	10.0
IS 1082	54.9	8.8
IS 18363	56.5	9.5
IS 2122	46.7	7.6
IS 18328	63.3	7.0
IS 18319	58.9	8.6
IS 1151	64.8	8.2
IS 18349	48.5	7.5
IS 5072	49.3	7.4
CK 60B	58.2	7.1
IS 18676	73.8	8.6
IS 5629	53.6	8.1

Table 52:(cont'd...)

Sorghum Cultivar	Leaf length(cm) (the plant's largest)	Leaf width(cm) (the plant's largest
IS 2263	52.0	8.7
IS 5016	61.4	8.3
IS 4383	65.9	8.7
IS 2162	60.7	8.1
IS 4307	63.2	6.3
IS 18489	59.7	7.7
IS 18467("Swarna")	73.0	6.9
IS 18390	55.2	9.0
IS 18432	64.2	7.9
IS 18479	81.5	7.6
IS 4776	57.8	7.4
IS 5200	57.4	7.4
IS 8595	79.9	7.7
IS 2205	47.7	7.9
IS 2146	50.6	7.9
IS 3954	71.1	8.8
IS 18367	51.2	9.5
IS 4660	66.0	9.7

Table 53 : Dimensions of stems of sorghum cultivars used for plant resistance studies to Chilo partellus, Mbita Point, 1983

Sorghum Cultivars	Number of Internodes	Plant Height (cm.)
IS 18520	9.9	137.3
IS 18677	8.8	218.4
IS 17739	15.3	290.2
IS 1044	7.7	187.9
IS 5604	13.8	271.6
IS 18427	10.4	222.4
IS 4764	9.3	183.6
IS 18361	12.5	231.5
IS 1082	12.6	216.7
IS 18363	12.2	187.3
IS 2122	14.9	281.0
IS 18328	9.1	248.3
IS 18319	11.3	241.3
IS 1151	9.6	212.8
IS 18349	12.7	272.8
IS 5072	15.4	247.0
CK60B	4.9	73.6
IS 18676	8.8	220.1
IS 5629	12.7	248.9

Table 53 (cont'd....)

Sorghum Cultivars	Number of Internodes	Plant Height (cm)
IS 2263	13.2	269.9
IS 5016	10.8	199.9
IS 4383	8.2	198.1
IS 2162	14.9	253.9
IS 4307	10.9	232.4
IS 18489	13.0	266.5
IS 18467	8.0	145.3
IS 18390	12.0	214.1
IS 18432	13.0	229.8
IS 18479	6.9	118.9
IS 4776	8.8	203.1
IS 5200	9.9	227.4
IS 8595	7.6	146.5
IS 2205	14.0	248.0
IS 2146	12.2	211.6
IS 3954	3.3	52.2
IS 18367	14.0	257.7
IS 4660	12.3	239.8

Table 54: Chilo partellus pupation period in different Sorghum cultivars, Mbita Point, 1981.

Sorghum Cultivar	Total No of Pupae ♂ + ♂	MALE PUPAE			FEMALE PUPAE			Rank of Mean Period
		Total No.	Pupation Period (days)	Rank	Total No.	Pupation period	Rank	
IS 18361	342	159	5.80	16	183	6.06	15	16
IS 18349	131	67	7.65	14	64	7.87	12	14
IS 18489	85	37	9.58	6	48	8.22	9	8
IS 18520	229	127	9.56	7	102	8.06	10	10
IS 1151	139	63	8.52	11	76	7.54	13	12
IS 2162	64	29	9.07	9	35	9.16	7	6
IS 4660	188	103	9.15	8	85	8.61	8	9
IS 18427	166	74	8.70	10	92	7.29	14	13
IS 18479	162	78	12.94	1	84	11.63	2	2
IS 2263	128	54	8.25	12	74	8.00	11	11
IS 2205	98	48	10.92	3	58	11.56	4	3
IS 18467	76	30	8.17	13	46	10.02	6	7
IS 2122	73	39	9.69	5	34	11.60	3	5
IS 1082	227	114	12.03	2	113	13.57	1	1
IS 17739	218	99	10.17	4	119	10.18	5	4
IS 18328	34	12	-	-	22	-	-	-
IS 18367	138	59	4.61	17	69	5.34	18	18
IS 18363	252	98	6.84	15	154	5.48	17	15
IS 18677	8	2	4.37	18	6	5.84	16	17
IS 18676	29	11	-	-	18	-	-	-
IS 18319	146	69	-	-	77	-	-	-

Table 55: Chilo partellus pupal weights of the insects reared in different sorghum cultivars. Mbita Point,1981.

Sorghum Cultivars	Total No. of pupae	Weight of male pupae(mgm)	Weight of Female pupae(mgm)	Pupal wt. (both sexes) (mgm)	Overall Rank
IS 18361	342	51	107	79	12
IS 18349	131	53	102	77.5	16
IS 18489	85	51	107	79	12
IS 18520	229	48.7	101	74.9	20
IS 1151	139	54	104	79	12
IS 2162	64	50	149	99.5	2
IS 4660	188	55	111	83	10
IS 18427	166	51	104	77.5	16
IS 18479	162	52	106	79	12
IS 2263	128	54	114	84	8
IS 2205	98	49	89	69	21
IS 18467	76	48	104	76	18
IS 2122	73	49	101	75	19
IS 1082	227	53	109	81	11
IS 17739	218	57	110	84	8
IS 18328	34	59	123	91	4
IS 18367	138	62	112	92	3
IS 18363	252	59	120	89.5	5
IS 18677	8	70	130	100	1
IS 18676	26	55	120	87.5	6

Table 56: Chilo partellus Adult emergence, sex ratio and female fecundity in different sorghum cultivars. Mbita Point, 1981.

Sorghum Cultivars	% Adult Emergence	Rank	Sex Ratio (♂ : ♀)	Fecundity (No of egg Batches)	Rank
IS 18361	63	12	48:52	23.4	3
IS 18349	75	5	50:50	18.9	14
IS 18489	58.3	17	29:71	20.0	12
IS 18520	60.9	14	35:65	19.1	13
IS 1151	69.2	8	38:62	21.2	9
IS 2162	77.8	4	39:61	22.4	4
IS 4660	61.1	13	44:56	21.1	10
IS 18427	79.2	3	21:79	22.1	5
IS 18479	60.6	15	48:52	18.5	17
IS 2263	55	19	20:80	22.1	5
IS 2205	66.7	10	28:72	20.1	11
IS 18467	60	16	20:80	21.5	8
IS 2122	66.7	10	42:58	27.8	1
IS 1082	55.7	18	50:50	18.2	19
IS 17739	68.7	9	28:72	21.9	7
IS 18328	100	1	38:62	18.8	15
IS 18367	70	7	34:66	18.5	17
IS 18363	50	20	50:50	18.6	16
IS 18677	83.3	2	17:83	13	20
IS 18676	75	5	25:75	23.8	2

Table 57 (a): Chilo partellus larval survival in selected sorghum cultivars infested at booting and assessed after 32 days. Mbita Point, 1982.

Chilo Larval Survival

Sorghum Cultivars	$\bar{X}$ Trans. $\sqrt{X+0.5}$	$\bar{X}$
IS 18361	2.77	7.17
IS 18520	3.05	8.8
IS 1082	2.62	6.36
IS 2205	2.38	5.16
IS 2122	1.92	3.34
IS 4660	2.83	7.51
IS 18319	3.02	8.62
IS 18363	3.18	9.61
IS 17739	2.72	6.9

Chilo Larval Weight (mgm)

Sorghum Cultivar	$\bar{X}$
IS 18361	98.0
IS 18520	52.0
IS 1082	59.5
IS 2205	67.3
IS 2122	39.3
IS 4660	64.5
IS 18319	65.8
IS 18363	57.8
IS 17739	82.3

Table 57 (b): Summary of analysis of variance for Chilo partellus larval survival in different Sorghum Cultivars after 32 days, Mbita Point, 1982.

Source of Variation	df	SS	MS	F
Cultivars	8	4.536	0.567	1.38^{ns}
Error	27	11.186	o.414	
Total	35	15.723		

Table 57 (c) : Summary of analysis of variance for Chilo partellus larval weights in different sorghum cultivars after 32 days, Mbita, 1982.

Source of Variation	df	SS	MS	F
Cultivars	8	4639.500	579.937	0.791^{ns}
Error	27	19784.500	732.579	
Total	35	24424.00		

Table 58 (a): Chilo partellus Larval survival in selected sorghum cultivars infested at three weeks and assessed after 21 days. Mbita Point, 1982.

Chilo Larval Survival

Sorghum Cultivars	Trans. $\sqrt{X+0.5}$	$\bar{X}$	Rank
IS 18479	1.02	0.54	13
IS 18520	1.63	2.16	5
IS 1082	1.88	3.03	2
IS 2205	1.62	2.12	6
IS 2122	0.88	0.27	14
IS 18319	1.39	1.43	11
IS 18363	2.36	5.07	1
IS 17739	1.53	1.84	8
IS 18427	1.41	1.49	10
IS 18676	1.58	2.00	7
IS 1044	1.72	2.46	4
IS 18367	1.87	3.0	3
IS 18328	1.42	1.52	9
IS 18677	1.32	1.24	12

Table 58 (a) - cont'd....

Chilo Larval Weight (mgm)

Sorghum Cultivars	$\bar{X}$	Rank
IS 18479	11.7	11
IS 18520	16.8	9
IS 1082	16.4	10
IS 2205	55.8	1
IS 2122	21.2	6
IS 18319	7.8	13
IS 18363	41.4	3
IS 17739	17.4	8
IS 18427	5.0	14
IS 18676	27.0	4
IS 1044	15.2	7
IS 18367	26.2	5
IS 18328	8.2	12
IS 18677	44.3	2

Table 58 (b): Summary of analysis of variance for Chilo partellus larval survival in different sorghum cultivars after 21 days, Mbita Point, 1982

Source of Variation	df	SS	MS	F
Cultivars	13	8.788	0.676	1.548^{ns}
Error	56	24.453	0.436	
Total	69	33.241		

Table 58 (c): Summary of analysis of variance for Chilo partellus larval weights in different sorghum cultivars after 21 days, Mbita Point, 1982.

Source of Variation	df	SS	MS	F
Cultivars	13	14702.373	1130.951	3.553**
Error	56	17821.372	318.228	
Total	69	32523.745		

Table 59 (a): Chilo partellus survival in potted different selected sorghum cultivars infested at three weeks and assessed after 36 days. Mbita Point, 1982.

Sorghum Cultivars	$\bar{X}$ Trans. $\sqrt{X+0.5}$	$\bar{X}$	Rank
IS 1151	1.15	0.82	9
IS 18479	1.37	1.38	4
IS 1082	0.95	0.4	11
IS 2122	0.86	0.34	12
IS 1044	1.16	0.85	8
IS 4660	1.02	0.54	10
IS 18319	1.28	1.14	6
IS 18363	1.42	1.52	2
IS 18489	1.41	1.49	3
IS 18520	1.66	2.26	1
IS 18361	1.36	1.35	5
IS 2205	1.17	0.87	7

Table 59 (b) : Summary of analysis of variance for *Chilo partellus* larval survival in different sorghum cultivars after 36 days, Mbita Point, 1982.

Source of Variation	df	SS	MS	F
Cultivars	11	13.039	1.185	1.191^{ns}
Error	108	107.419	0.994	
Total	119	120.459		

Table 60 (a): Chilo partellus larval weights in different selected sorghum cultivars after 36 days. Mbita Point, 1982.

Sorghum Cultivars	Replications 1	2	3	4	5	6	7	8	9	10	11	12
IS 1151	77	60	46	21	-	-	-	-	-	-	-	-
IS 18479	100	44	80	31	26	-	-	-	-	-	-	-
IS 1082	32	-	-	-	-	-	-	-	-	-	-	-
IS 2122	75	83	-	-	-	-	-	-	-	-	-	-
IS 1044	49	71	65	56	-	-	-	-	-	-	-	-
IS 4660	34	78	68	-	-	-	-	-	-	-	-	-
IS 18319	82	51	18	-	-	-	-	-	-	-	-	-
IS 18363	36	42	44	51	66	91	104	15	-	-	-	-
IS 18489	21	67	67	31	81	34	-	-	-	-	-	-
IS 18520	72	65	62	63	105	98	72	-	-	-	-	-
IS 18361	68	69	102	129	-	-	-	-	-	-	-	-
IS 2205	54	57	54	44	102	-	-	-	-	-	-	-

Table 60(a) cont'd....

Chilo partellus pupal weights in different selected sorghum cultivars after 36 days. Mbita Point, 1982

Sorghum	Replications													
Cultivars	1	2	3	4	5	6	7	8	9	10	11	12	13	14
IS 1151	112	44	41	85	54	-	-	-	-	-	-	-	-	-
IS 18479	81	104	44	62	62	34	72	18	-	-	-	-	-	-
IS 1082	30	15	35	52	-	-	-	-	-	-	-	-	-	-
IS 2122	94	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 1044	131	78	73	45	45	54	49	56	-	-	-	-	-	-
IS 4660	99	57	110	57	-	-	-	-	-	-	-	-	-	-
IS 18319	49	59	34	34	40	33	33	38	-	-	-	-	-	-
IS 18363	65	91	51	53	52	40	-	-	-	-	-	-	-	-
IS 18489	84	53	74	59	74	50	74	70	45	-	-	-	-	-
IS 18520	113	104	82	44	77	78	30	53	82	53	64	48	29	22
IS 18361	52	86	52	99	106	54	122	106	69	8	27	-	-	-
IS 2205	106	61	62	80	63	55	38	-	-	-	-	-	-	-

No. of Larvae pupated

Cultivars	IS 1152	IS 18479	IS 1082	IS 2122	IS 1044	IS 4660
No.of pupae	5	10	4	1	3	5

Cultivars	IS 18319	IS 18363	IS 18489	IS 18520	IS 18361	IS 2205
No.of pupae	9	6	11	17	12	7

Table 60(b): Summary of analysis of variance for Chilo partellus larval survival in different sorghum cultivars after 36 days, Mbita Point, 1982.

Source of Variation	df	SS	MS	F
Cultivars	11	8792.519	799.319	1.286^{ns}
Error	40	24852.153	621.303	
Total	51	33644.673		

Table 60(c): Summary of analysis of variance for Chilo partellus pupal weights in different sorghum cultivars after 36 days, Mbita Point, 1982.

Source of Variation	df	SS	MS	F
Cultivars	11	11172.633	1015.693	1.571^{ns}
Error	40	47178.260	646.277	
Total	51	58350.984		

Table 61(a): Chilo partellus survival in potted sorghum of different selected cultivars infested at three weeks and assessed after 30 days. Mbita Point, 1982

Sorghum Cultivar	Infested with Five larvae Replications I	II	III	IV
IS 18479	0.71	1.22	1.58	1.22
IS 18349	0.71	0.71	1.87	1.22
IS 1151	0.71	0.71	1.22	1.22
IS 18677	1.58	0.71	1.22	1.58
IS 18361	0.71	0.71	1.22	1.87
IS 18676	2.55	0.71	0.71	1.22
IS 2205	0.71	0.71	0.71	1.58
IS 4660	1.22	1.22	0.71	0.71
IS 18520	1.22	1.22	1.22	1.87
IS 18319	0.71	0.71	1.22	0.71
IS 1044	1.58	0.71	0.71	0.71
IS 1082	0.71	1.22	0.71	0.71
IS 18363	1.58	0.71	0.71	1.22
IS 18489	0.71	1.22	1.58	0.71
IS 2122	0.71	0.71	0.71	1.22

Table 61(a) cont'd....

Sorghum Cultivars	Infested with blackheads Replications I	II	III	IV
IS 18479	0.71	0.71	0.71	1.87
IS 18349	0.71	0.71	1.22	1.22
IS 1151	1.22	0.71	0.71	1.22
IS 18677	1.22	0.71	3.39	0.71
IS 18361	0.71	0.71	1.22	2.35
IS 18676	0.71	1.87	1.58	0.71
IS 2205	0.71	0.71	0.71	0.71
IS 4660	0.71	0.71	1.22	0.71
IS 18520	0.71	0.71	1.22	0.71
IS 18319	0.71	0.71	0.71	1.22
IS 1044	1.58	1.58	0.71	0.71
IS 1082	0.71	0.71	1.22	0.71
IS 18363	0.71	1.22	0.71	0.71
IS 18489	1.22	1.22	1.22	0.71
IS 2122	0.71	1.12	0.71	0.71

Table 61(a) cont'd.....

Sorghum Cultivars	Replications I	II
IS 18479	1.58	0.71
IS 18349	1.58	0.71
IS 1151	1.22	1.74
IS 18677	1.22	1.22
IS 18361	1.58	0.71
IS 18676	1.58	1.87
IS 2205	0.71	1.22
IS 4660	0.71	1.22
IS 18520	1.22	1.58
IS 18319	1.58	0.71
IS 1044	1.58	1.22
IS 1082	0.71	0.71
IS 18363	0.71	1.22
IS 18489	0.71	2.35
IS 2122	1.22	0.71

Table 61(b) : Summary of analysis of variance for Chilo partellus larval survival in different sorghum cultivars after 30 days.

Source of Variation	df	SS	MS	F
Cultivars (A)	14	4.009	0.286	1.155^{ns}
No. of Larval/ Egg (B)	2	0.997	0.498	2.010^{ns}
A x B	28	3.254	0.116	0.468^{ns}
Error	105	26.032	0.247	
Total	149	34.292	1.147	

Table 62 (a): Chilo partellus larval weights in different selected sorghum cultivars infested at three weeks and assessed after 30 days. Mbita Point, 1982.

Sorghum Cultivars	Infested with five larvae replications									
	1	2	3	4	5	6	7	8	9	10
IS 18479	50	40	40	50	-	-	-	-	-	-
IS 18349	60	40	90	70	-	-	-	-	-	-
IS 1151	50	60	-	-	-	-	-	-	-	-
IS 18677	60	60	50	50	60	-	-	-	-	-
IS 18361	130	20	40	20	-	-	-	-	-	-
IS 18676	70	30	40	60	20	70	40	-	-	-
IS 2205	30	50	-	-	-	-	-	-	-	-
IS 4660	20	40	-	-	-	-	-	-	-	-
IS 18520	60	50	128	51	10	90	-	-	-	-
IS 18319	31	-	-	-	-	-	-	-	-	-
IS 1044	104	45	-	-	-	-	-	-	-	-
IS 1082	62	-	-	-	-	-	-	-	-	-
IS 18363	56	13	-	-	-	-	-	-	-	-
IS 18489	67	21	-	-	-	-	-	-	-	-
IS 2122	0	-	-	-	-	-	-	-	-	-

Table 62(a) cont'd.....

Sorghum Cultivars	Infested with ten larvae replications						
	1	2	3	4	5	6	7
IS 18479	60	90	-	-	-	-	-
IS 18349	80	100	-	-	-	-	-
IS 1151	70	90	100	120	80	70	120;110
IS 18677	40	70	-	-	-	-	-
IS 18361	90	110	-	-	-	-	-
IS 18676	80	50	100	60	70	-	-
IS 2205	20	-	-	-	-	-	-
IS 4660	31	-	-	-	-	-	-
IS 18520	44	20	70	-	-	-	-
IS 18319	106	45	-	-	-	-	-
IS 1044	26	5	-	-	-	-	-
IS 1082	0	-	-	-	-	-	-
IS 18363	56	-	-	-	-	-	-
IS 18489	52	45	55	38	-	-	-
IS 2122	20	-	-	-	-	-	-

Table 62 (a) - cont'd...

Sorghum Cultivars	Infested with "Blackhead" *Chilo* eggs Replications															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
IS 18479	20	40	50	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 18349	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 1151	110	130	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 18677	20	20	40	40	20	30	30	60	40	40	20	30	-	-	-	-
IS 18361	90	30	100	50	10	20	-	-	-	-	-	-	-	-	-	-
IS 18676	140	80	50	80	90	70	40	-	-	-	-	-	-	-	-	-
IS 2205	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 4660	60	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 18520	17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 18319	55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 1044	107	81	7	86	-	-	-	-	-	-	-	-	-	-	-	-
IS 1082	24	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 18363	58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 18489	37	36	-	-	-	-	-	-	-	-	-	-	-	-	-	-
IS 2122	22	7	4	2	-	-	-	-	-	-	-	-	-	-	-	-

Table 62 (b) : Summary of analysis of variance for Chilo partellus larval heights in different selected sorghum cultivars after 30 days. Mbita Point, 1982.

Source of Variation	df	SS	MS	F
Cultivars (A)	14	104079.775	7434.269	0.838^{ns}
No. of Larvae/ Egg (B)	2	40334.713	20167.356	2.273^{ns}
A x B	28	121330.480	4333.231	0.488^{ns}
Error	85	754001.523	8870.606	

CHAPTER 8

SORGHUM TOLERANCE TO *CHILO PARTELLUS* DAMAGE

8.10 INTRODUCTION

The oldest most widely accepted approach to the study of plant mechanisms in response to insect attack is that which was proposed by Painter (1951). This empirical approach suggests three categories of mechanisms:

Preference or non-preference (antixenosis, according to Kogan and Ortman (1978),

Antibiosis and Tolerence.

Antixenosis and antibiosis were dealt with in Chapters three and seven, respectively, and will thus not be covered in this chapter. Tolerance according to Painter (1951) differs from the other two mechanisms in that the plant plays the most important role. The other two "require an active insect response or lack of response". According to Ortman and Peters (1980) "tolerance includes all plant responses resulting in the ability to withstand infestation and to support insect populations that would severely damage susceptible plants".

Unfortunately, tolerance is more subject to variation as a result of environmental conditions, than are preference and antibiosis (Painter, 1951). As a result tolerance is more difficult to identify. Consequently, a number of workers, such as Beck (1965) and Farrel (1977), exclude tolerance from the definition of resistance. These workers gave different reasons for disagreeing with Painter (1951). Beck (1965) maintained that tolerance "implies a biological relationship between insects and plants that is quite different from resistance in the strict sense". Farrel (1977), on the other hand, argued that tolerance "lies in the response of the plant to a given level or biting or stylet feeding". It is not uncommon to hear some workers saying, "This cultivar is not resitant but merely tolerant". According to Painter's definition of plant resistance, this statement would be contradictory because tolerance is a kind of plant resistance. In this chapter Painter's definition (quoted in Chapter one) has been followed. Four different aspects have been considered:

(i) Effect of C. partellus on plant height (stunting effect). This aspect has been considered because Mohyuddin and Attique

(1978) established that stemborer yield loss in maize was due to the stunting effect as well as deadhearts, rather than to tunnelling.

(ii) Tillering in infested versus non-infested sorghum plants. The object of this study was to find out whether tillering is a means of compensating for damage and to see what extent tillering compensates in different sorghum cultivars.

(iii) Effect of C. partellus on the plants' ability to form side shoots, multiple panicles or offshoots. Jotwani (1977) has described this aspect in sorghum and he also found that offshoots formed because of damage to the main plant compensated to the extent of giving a higher yield in the infested plant than the non-infested.

(iv) Damage to sorghum plants resulting in: failure to flower due to damage, failure to form seed by those plants that have flowered, or formation or broken heads.

The two latter aspects were suggested by Dabrowski et al.(unpublished manuscript).

Formation of tillers and multiple heads are both mechanisms for compensation or replacement of damaged parts. "The insects with chewing mouthparts, as a rule, destroy the plant part attacked so completely that the only type of tolerance that can be developed is that concerned with replacement or growth." (Painter, 1951).

Painter's empirical approach (i.e. that of classifying mechanisms of resistance into three categories) is criticized by Horber (1980) as "arbitrary and vaguely delineated" since not all resistance phenomena "can unequivocally be assigned to one of the three categories". However, Horber (1980) also made a strong case for inclusion of tolerance as a distinct resistance mechanism since, unlike antixenosis and antibiosis, it does not exert a selection pressure on the insect pest.

8.20 MATERIALS AND METHODS

8.21 Effect of C. partellus Larvae on Sorghum Height

In 1982 sixteen sorghum cultivars were selected and planted in the manner already described in Chapter three. They were planted in four replications, each

replication in a different screenhouse in a randomized complete block design. At three weeks half the screenhouse was infested with ten C. partellus first larvae in the manner described in Chapter four. Every week thereafter the plant height of both infested and non-infested plants was taken until most of the cultivars were at the booting stage.

In 1983 another set of eight cultivars was selected and planted into pots in the screenhouse. Twelve pots were used for each cultivar. At 21 days five pots of each cultivar were infested with ten C. partellus first instar larvae. After 14, 21 and 35 days the plant heights of both infested and non-infested plants were measured and recorded.

8.22 Tillering in Infested versus Non-Infested Sorghum Plants

In 1983 an experiment was set up to find out whether :

(a) Tillering in different cultivars was affected by plant damage (i.e. whether plant damage stimulated tiller formation) and,

(b) Whether plants with deadhearts form more tillers than non -infested plants and slightly damaged plants.

Eight cultivars selected, were planted in 17 pots in the screenhouse, and at three weeks given three different treatments. Seven plants in each cultivar were left uninfested, five plants in each cultivar were infested with ten C. partellus first instar larvae and the last five plants in each cultivar were damaged artificially so as to produce deadhearts but not to kill the plants. After 14 days the tillers were counted and recorded. This was repeated after 21 and 35 days.

8.23 Formation of Multiple Heads in Infested versus Non-infested Plants.

Sixteen cultivars were selected and planted in four randomized complete blocks each replication in a different screenhouse. When they were ready to harvest (this is indicated by general plant senescence) the mature heads were cut, labelled according to cultivars, main plants, tillers or offshoot, and placed in the sun to dry over a number of days. Then the dimensions of the heads were taken (i.e. length of each

head, the girth and the dry weight indicated by no further weight drop after successive weighings). After this each head was threshed and the grain again weighed.

8.24 C. partellus Resulting in Sorghum Plant Failure to Flower or and to Form Seed

Eighteen sorghum cultivars were selected and planted in the field as described in Chapter three. These were planted in six replications in a completely randomized block design. When the plants were ready to harvest they were assessed according to the numbers that had failed to flower as well as those that had flowered but failed to form seed (chaffy heads). Included in this group were the broken heads due to feeding in the peducle.

8.30 RESULTS

8.31 Effect of C. partellus Larvae on Sorghum Plant Height

The results of this experiment are given in Table 63. From Table 63(b) it will be noted that cultivar differences in height were highly significant ($\rho<0.01$). The differences due to treatment (i.e. height

of infested versus non-infested plants) were even more significant. This means that C. partellus had a highly significant effect on sorghum plant height. Cultivar differences in height were also significant as would be expected since different cultivars have different genotypes. Height differences on different days would also be expected since all plants become taller as they grow.

In practically all cases infested plants were shorter than non-infested plants. In IS 1044 and IS 2122 this trend was reversed (i.e. infested plants were taller than non-infested plants). However, potted plants did not show this anomally (Figure 42,43 and 51).

8.32 Tillering in Infested versus Non-infested Sorghum Plants

The results of the tillering assessment experiments are given in Tables 65 and 66. In all cases plant damage caused more tillers to be formed. But the pattern of tiller formation was different in different cultivars. Three distinct patterns can be noted.

(a) In some cultivars plant damage caused more tiller formation and artificial deadheart

resulted in an even higher number of tillers. These cultivars were : IS 1044, IS 2205, IS 18489, IS 18363 and IS 2122.

(b) In some cultivars plant damage caused more tillers to be formed but there were fewer tillers when there were deadhearts than when the plants were merely damaged. Examples were IS 18479 and IS 18520.

(c) In the remaining cultivars the degree of tillering was the same whether the plants were merely damaged or whether there were deadhearts. Examples here was IS 2146 (Ref:-Table 65(a))

The highest tillering cultivar when plants were infested was by far IS 18520 ("Serena"). Each plant had an average of 4.38 tillers. But when there were deadhearts the highest tillering cultivar was IS 2122 with an average of 3.38 tillers.

However, IS 18520 ("Serena") was also the highest tillering non-infested cultivar with an average of 2.16 tillers. Cultivar IS 18479 did not tiller at all when not infested. Cultivar IS 18363 was the highest tillering with an average of 1.32 tillers when not

infested.

8.33 Formation of Multiple Heads in Infested versus Non-infested Plants

The results of the multiple head and tillering contribution experiment are given in Table 67. Multiple head contribution to the yield was found to be rather low. It ranged between 0% and 9.8%. The highest contribution was in IS 2122. In IS 1082 the contributions were only in the non-infested plants, while in IS 18349 the contributions were both in infested and non-infested plants.

When IS 18676 was heavily attacked the main plants all succumbed so that all the yields came from the tillers (i.e. 100% contribution by the tillers). Other cultivars with high tiller contribution were IS 18363 (62.49%) and IS 18349 (50.09%). In a few cultivars there was no tiller contribution at all. IS 18520 although with the highest number of tillers whether infested or not had the highest contribution only when not infested. When infested the tillers contributed only 37.62%.

Table 68 gives the relative sizes of heads when plants were infested and also when not infested. In all cases the size of the heads was smaller in the infested plants.

The least drop in yield due to C. partellus larval feeding occured in IS 4660, IS 18489, IS 2122, IS 18349, IS 1082 and IS 18520. All cultivars had low but varying degrees of tolerance. Cultivars IS 18676 and IS 1151 had no tolerance at all since heavily damaged plants produced no seed at all.

8.34 C. partellus Damage Resulting in Sorghum Failure to Flower or to Form Seed

The experiments on flowering and seed formation are given in Tables 69 and 70. The pattern of flowering in different sorghum cultivars was highly significant ($\rho<0.01$) as shown in Table 69 (b). The pattern of seed formation was very significant ($\rho<0.05$). The cultivars most affected by C. partellus during flowering were IS 18363, IS 18361 and IS 18367 (refer to Table 69). In these cultivars about 50% of the plants failed to flower. The least affected cultivars were IS 18676, IS 1151 and IS 18520.

But some of those plants that flowered failed to form seeds either because there was no grain or because the peducles were so tunnelled that the heads broke off. The most affected cultivars (in Table 70) were IS 18361, IS 1151, IS 2205 and IS 18479. And the least affected cultivars were IS 18677, IS 18520 and IS 18328.

8.40 DISCUSSION

8.41 Effect of C. partellus Larvae on Plant Height

Table 63 demonstrates unequivocally that the borer has a significant effect on sorghum plant height irrespective of the cultivar involved. Since Mohyuddin and Attique (1978) have demonstrated that the stunting effect of the stem borer attack results in the lowering of yield it can be inferred that C. partellus depresses the yield in all the sorghum cultivars used. In comparing the depression in plant height and the depression in yield it will be noted that these are not directly correlated (refer Table 64). In IS 1044 and IS 2122, for example, the plant height increased but the yield did not increase accordingly. This indicated that plant height was not the only factor related to yield drop. However, in general C. partellus

attack stunted the plants (Figure 41, 42, 43 and 50) and lowered the yield. Potted plants showed the difference much clearer since in all cultivars (including IS 1044) infested plants were shorter (Figure 42, 43 and 51).

8.42 Tillering in Infested versus Non-infested Sorghum Plants

The formation of tillers in sorghum is illustrated in Figure 44. As indicated before, the highest tillering cultivar when plants were damaged was IS 18520 ("Serena"). The advantage this cultivar had is illustrated in Figure 45 and 46 where it was compared with a low tillering cultivar (IS 1151) both in the field and in the screenhouse. The highest tillering cultivar when there were deadhearts in all the plants was IS 2122. Tillering, however, is affected by external conditions. Harrock and Jorgensen (1981) showed that tillering was affected not only by temperature conditions but also by the age of the plant when temperature variations occured. As such it could not be predicted how a given cultivar would tiller. These workers found that even a change in temperature affects different cultivars in different ways.

However, the fact that tillering was highly significant implies that it was a dependable characteristic of the sorghum plant. Accordingly low tillering cultivars could not compensate much for yield loss due to stemborer attack. IS 18363 was such an example since it was the least tillering when attacked by the stemborer.

8.43 Formation of Multiple Heads in Infested versus Non-infested Plants

Formation of offshoots or multiple heads is another mechanism that has been demonstrated to compensate for stemborer attack (Jotwani, 1977). This is illustrated in Figure 47. In these experiments offshoots did not contribute appreciably to total yield of any particular cultivar. The highest contribution was in IS 2122 where it was 9.8%. This could also be much higher in the field where sorghum grows much more vigorously. Tillering on the other hand contributed as much as 100% when the main plants had been killed by stemborer damage. This was the case in IS 18676. The size of the heads were, however, smaller in the tillers than in the main plants (refer Tables 67 and 68).

8.44 *C. partellus* Damage Resulting in Sorghum Failure to flower or to Produce Seed

The failure to form flowers due to stemborer attack is illustrated by Figure 48 where in the cultivar IS 18363 the plant ended up by drying before flowers were formed. Even where flowering did occur seed did not form, resulting in chaffy heads (Figure 49) or some of the peduncles were so heavily tunnelled that the head broke before seeds were formed (Figure 50).

Table 63(a) : Effect of Chilo partellus damage on Plant Height of a Few selected Sorghum Cultivars in the screenhouse (potted plants) Mbita, 1983.

Sorghum Cultivars	$\bar{X}$
Height of Non-infested Plants (cm)	
14 days	
IS 1044	91.4
IS 2205	93.7
IS 18479	76.4
IS 14489	47.3
IS 18363	44.1
IS 2122	95.1
IS 18520	73.3
IS 2146	117.0
Height of Infested Plants (cm)	
14 days	
IS 1044	122.6
IS 2205	58.2
IS 18479	28.2
IS 18489	28.2
IS 18363	35.8
IS 2122	100.8
IS 18520	57.8
IS 2146	82.6

Table 63(a) cont'd.....

Sorghum Cultivars	$\bar{X}$
Height of Non-infested Plants (cm)	
21 days	
IS 1044	137.6
IS 2205	133.4
IS 18479	105.9
IS 18489	68.7
IS 18363	53.9
IS 2122	107.4
IS 18520	89.0
IS 2146	133.0
Height of Infested Plants (cm)	
21 days	
IS 1044	156.6
IS 2205	90.0
IS 18479	28.8
IS 18489	32.4
IS 18363	40.8
IS 2122	118.8
IS 18520	75.0
IS 2146	109.0

Table 63(a) cont'd.....

Sorghum Cultivars	$\bar{X}$
Height of Non-infested Plants (cm)	
35 days	
IS 1044	168.0
IS 2205	190.4
IS 18479	122.3
IS 18489	97.9
IS 18363	72.9
IS 2122	138.7
IS 18520	216.0
IS 2146	172.4
Height of Infested Plants (cm)	
35 days	
IS 1044	184.4
IS 2205	120.8
IS 18479	30.8
IS 18489	28.0
IS 18363	63.8
IS 2122	155.8
IS 18520	87.4
IS 2146	143.4

Table 63(b): Summary of analysis of variance for Effect of Chilo partellus damage on plant height in different sorghum cultivars. Mbita Point, 1983.

Source of Variation	df	SS	MS	F
Cultivar (A)	7	294953.234	42136.176	8.638***
Treatment(B)	1	54701.205	54701.205	11.214***
Time (C)	2	5757.340	28786.670	5.901**
A x B	7	82912.231	11844.604	2.428^{ns}
A x C	14	82565.595	5897.542	1.209^{ns}
B x C	2	4937.130	2868.565	0.506^{ns}
A x B x C	14	41643.754	2974.553	0.609^{ns}
Error	243	1185302.003	4877.786	
Total	290			

Table 64: Comparison between Plant Height Compensation and Yield Compensation among selected Sorghum Cultivars.

Sorghum Cultivar	Sorghum plant height Compensation %	Sorghum yield Compensation %
IS 2122	112.3	55.7
IS 1044	109.8	27.4
IS 18363	87.5	34.7
IS 2146	83.2	-
IS 2205	63.4	60.8
IS 18520	40.5	47.5
IS 18489	28.6	63.4
IS 18479	25.2	46.9

Table 65(a): Comparison of Tillering in Chilo partellus damaged plants and artificial deadhearts of a few selected sorghum cultivars, (Screenhouse Experiments).Mbita, 1983

Sorghum Cultivars	$\bar{x}$ No. of tillers in infested Plants (Trans$\sqrt{X+0.5}$)
14 days	
IS 1044	1.16
IS 2205	1.26
IS 18479	1.78
IS 18489	1.52
IS 18363	1.09
IS 2122	1.19
IS 18520	1.89
IS 2146	1.32

Sorghum Cultivars	$\bar{x}$ No.of tillers in artificial deadheart Plants(Trans$\sqrt{X+0.5}$)
14 days	
IS 1044	1.62
IS 2205	1.57
IS 18479	1.75
IS 18489	1.73
IS 18363	1.44
IS 2122	1.63
IS 18520	1.72
IS 2146	1.72

Table 65 (a) cont'd.....

Sorghum Cultivars	$\bar{x}$ No. of tillers in infested Plants (Trans. $\sqrt{X+0.5}$)
21 days	
IS 1044	1.26
IS 2205	1.26
IS 18479	1.85
IS 18489	1.62
IS 18363	1.23
IS 2122	1.19
IS 18520	2.16
IS 2146	1.36

Sorghum Cultivars	$\bar{x}$ No.of tillers in artificial deadheart plants(Trans.$\sqrt{X+0.5}$)
21 days	
IS 1044	1.62
IS 2205	1.57
IS 18479	1.81
IS 18489	1.73
IS 18363	1.60
IS 2122	1.86
IS 18520	1.75
IS 2146	1.72

Table 65 (a) cont'd.....

Sorghum Cultivars	$\bar{x}$ No.of tillers in infested plants (Trans $\sqrt{X+0.5}$)
35 days	
IS 1044	1.33
IS 2205	1.42
IS 18479	1.85
IS 18489	1.68
IS 18363	1.39
IS 2122	1.26
IS 18520	2.21
IS 2146	1.49

Sorghum Cultivar	$\bar{x}$ No. of tillers in artificial deadhearts plants (Trans$\sqrt{X+0.5}$)
35 days	
IS 1044	1.73
IS 2205	1.49
IS 18479	1.81
IS 18489	2.68
IS 18363	1.54
IS 2122	1.97
IS 18520	1.8
IS 2146	1.49

Table 65 (b): Summary of analysis of Variance for comparison of tillering in infested and artificially damaged plants. Mbita, 1983.

Source of Variation	df	SS	MS	F
Cultivar (A)	7	8.103	1.157	10.701***
Treatment (B)	1	2.213	2.213	20.463***
Time (C)	2	0.490	0.245	2.267***
A x B	7	4.098	0.585	5.412***
A x C	14	0.291	0.020	0.192^{ns}
B x C	2	0.211	0.105	0.975^{ns}
A x B x C	14	0.499	0.035	0.329^{ns}
Error	192	20.770	0.108	
Total	239			

Table 66(a): Comparison of tillering in Chilo partellus damaged plants, and non-infested plants of a few selected sorghum cultivars, (Screenhouse Experiment)Mbita Point, 1983.

Sorghum Cultivars	$\bar{x}$ No. of tillers in Non-infested plants (Trans. $\sqrt{X+0.5}$)
14 days	
IS 1044	0.98
IS 2205	0.96
IS 18479	0.71
IS 18489	0.83
IS 18363	1.08
IS 2122	1.20
IS 18520	1.42
IS 2146	0.98

Sorghum Cultivars	$\bar{x}$ No. of tillers in Infested Plants (Trans. $\sqrt{X+0.5}$)
14 days	
IS 1044	1.16
IS 2205	1.26
IS 18479	1.78
IS 18489	1.52
IS 18363	1.09
IS 2122	1.19
IS 18520	1.89
IS2146	1.32

Table 66 (a) cont'd.....

Sorghum Cultivars	$\bar{x}$ No. of tillers in Non-infested Plants (Trans. $\sqrt{X+0.5}$)
21 days	
IS 1044	0.98
IS 2205	1.03
IS 18479	0.71
IS 18489	0.85
IS 18363	1.31
IS 2122	1.20
IS 18520	1.81
IS 2146	0.98

Sorghum Cultivars	$\bar{x}$ No. of tillers in Infested Plants (Trans. $\sqrt{X+0.5}$)
21 days	
IS 1044	1.26
IS 2205	1.26
IS 18479	1.85
IS 18489	1.62
IS 18363	1.23
IS 2122	1.19
IS 18520	2.16
IS 2146	1.32

Table 66 (a) cont'd.....

Sorghum Cultivars	$\bar{x}$ No. of tillers in Non-infested Plants (Trans.$\sqrt{X+0.5}$)
35 days	
IS 1044	0.91
IS 2205	1.03
IS 18479	0.71
IS 18489	0.83
IS 18363	1.32
IS 2122	1.13
IS 18520	1.63
IS 2146	0.98

Sorghum Cultivars	$\bar{x}$ No. of tillers in Infested Plants (Trans.$\sqrt{X+0.5}$)
35 days	
IS 1044	1.33
IS 2205	1.42
IS 18479	1.85
IS 18489	1.68
IS 18363	1.39
IS 2122	1.26
IS 18520	2.21
IS 2146	1.49

Table 66 (b): Analysis of Variance for Tillering in Infested and Non-infested Sorghum plants. Mbita Point, 1983.

Source of Variation	df	SS	MS	F
Cultivar (A)	7	12.576	1.796	10.579***
Treatment (b)	1	12.456	12.456	73.343***
Time (C)	2	0.516	0.258	1.520***
A x B	7	7.756	1.108	6.524***
Ax C	14	0.573	0.040	0.241^{ns}
B x C	2	0.204	0.102	0.602^{ns}
A x B x C	14	0.093	0.006	0.039^{ns}
Error	237	40.250	0.169	
Total	284			

Table 67: Comparison of grain mass from Infested and Non-infested Sorghum Cultivars. Mbita Point, 1982 (Screenhouse Experiment).

Sorghum Cultivars	GRAIN FROM INFESTED PLANTS		GRAIN FROM NON-INFESTED PLANTS		
	Total Grain Mass(gm)	% Grain fr. Tillers	Total Grain Mass(gm)	% Grain fr. Tillers	Grain from Offshoot (Percentage
IS 18363	250.12	62.49	527.67	14.64	
IS 1082	283.41	10.60	612.96	7.47	6.08**
IS 18489	412.98	4.53	621.52	0	
IS 2122	257.57	13.79	456.14	0	9.8*
IS 4660	409.67	12.33	652.49	2.85	1.25*
IS 1044	58.82	0	214.44	0	
IS 18479	48.95	0	177.47	0	2.09*
IS 18520	204.32	37.62	482.53	23.68	
IS 18319	311.37	28.77	542.25	9.36	
IS 18427	80.55	20.01	521.48	0	
IS 1151	0	0	480.68	16.31	
IS 2205	335.99	7.25	530.47	3.38	
IS 18677	19.47	0	171.67	22.62	
IS 18361	298.73	12.47	675.48	0	2.04**
IS 18676	9.66	100.0	594.87	0	
IS 18349	375.81	50.09	416.59	0	2.0*;4.25

** Percentage of grain from offshoot in infested plants

* Percentage of grain from offshoot in non-infested plants

Table 68: Comparison between Sorghum heads from Infested and Non-infested plants by Chilo partellus. Mbita Point, 1982 (Screenhouse Experiment)

Sorghum Cultivars	HEADS FROM INFESTED PLANTS			HEADS FROM NON-INFESTED PLANTS			% Infested/ Non-Infested
	Length (cm)	Girth (cm)	Mass (gm)	Length (cm)	Girth (cm)	Mass (gm)	
IS 18363	9.66	6.0	31.28	10.52	7.9	90.09	34.72
IS 1082	15.9	6.36	47.28	18.17	8.3	94.53	49.96
IS 18489	14.08	5.6	65.65	15.22	6.4	103.59	63.37
IS 2122	7.75	4.17	38.21	8.3	5.2	68.58	55.7
IS 4660	14.84	6.9	71.83	16.17	8.17	104.29	68.88
IS 1044	21.98	5.13	14.71	24.25	7.75	53.61	27.43
IS 18479	24.5	3.6	16.3	24.3	6.2	34.75	46.91
IS 18520	16.95	6.95	31.87	23.04	8.4	67.16	47.45
IS 18319	10.67	4.97	35.63	13.02	6.75	96.01	37.11
IS 18427	16.0	5.45	32.22	16.13	7.83	86.91	37.07
IS 1151	0	0	0	14.33	7.28	67.05	0
IS 2205	16.83	6.67	51.94	17.33	8.33	85.42	60.81
IS 18677	20.0	6.0	19.47	18.17	6.67	44.28	43.97
IS 18361	16.4	6.06	51.07	17.08	8.27	112.58	45.26
IS 18676	0	0	0	20.72	9.3	99.15	0
IS 18349	15.7	5.4	34.32	17.75	7.33	68.04	50.54

Table 69 (a): Failure to Flower due to stemborer attack in selected Sorghum Cultivars. Mbita Point, 1981.

Sorghum Cultivars	$\bar{X}$ Percentage of Plants Failing to Flower	Rank
IS 18361	51.2	2
IS 18349	47.0	4
IS 18489	32.9	17
IS 18520	28.0	18
IS 1151	25.0	19
IS 2162	38.8	12
IS 4660	39.0	11
IS 18427	36.3	13
IS 18479	28.1	16
IS 2263	42.1	7
IS 2205	39.9	10
IS 18467	36.2	14
IS 2122	41.6	8
IS 1082	42.3	6
IS 17739	43.1	5
IS 18328	40.7	9
IS 18367	47.2	3
IS 18363	51.8	1
IS 18677	43.1	15
IS 18676	13.0	20

Table 69 (b): Summary of analysis of variance for sorghum cultivars failing to produce flowers due to infestation. Mbita Point, 1981.

Source of Variation	df	SS	MS	F
Cultivar	19	7332.325	385.911	4.528***
Error	93	7925.996	85.225	
Total	112	15258.322		

Table 70(a): Failure to produce seed due to stemborer attack (chaffy heads) in selected Sorghum Cultivars. Mbita Point, 1981

Sorghum Cultivars	$\bar{X}$ Percentage of Plants Failing to produce Seed	Rank
IS 18361	27.1	1
IS 18349	10.4	13
IS 18489	6.3	15
IS 18520	1.9	17
IS 1151	25.7	2
IS 2162	17.3	8
IS 4660	21.3	5
IS 18427	16.2	9
IS 18479	23.0	4
IS 2263	10.9	12
IS 2205	24.1	3
IS 18467	21.1	6
IS 1082	14.5	10
IS 17739	18.8	7
IS 18328	2.8	16
IS 18363	13.7	11
IS 18677	0	18
IS 18676	8.9	14

Table 70 (b): Summary of analysis of variance for Sorghum cultivars failing to produce seed due to Infestation, Mbita, 1981

Source of Variation	df	SS	MS	F
Cultivar	17	6077.651	357.508	2.311*
Error	84	12990.976	154.654	
Total	101	19068.628		

FIGURE 41

Sorghum Plants in the Screenhouse

Half the screenhouse (on the right) was infested with Chilo partellus larvae. Notice that in some cultivars the infested plants were killed.

FIGURE 42

Comparison between infested (on the left) and non-infested potted plants. Notice that infested plants are stunted.

Comparison of tillering in cultivars IS 18520 ("Serena") and IS 1151. "Serena" is a better tillering cultivar both in the field and in the pots in the screenhouse.

FIGURE 45

Cultivars IS 1151 and IS 18520 ("Serena") in the field.

FIGURE 46

Cultivars IS 18520 ("Serena") and IS 1151 in pots.


IS 1151
SERENA


IS 1151

FIGURE 47

Multiple Heads (Offshoots)

FIGURE 48

Effect of Chilo partellus infestation on Sorghum plants. In this illustration the plants dried so that there was no flowering. Notice that the cultivars on either side of IS 18363 were not similarly affected.


IS 18363


IS 104

FIGURE 43

Comparison between infested (on the right) and non-infested potted plants. Notice that infested plants are stunted.


IS 2205

FIGURE 44

Tiller formation in young sorghum

plants

FIGURE 49

Comparison between a normal sorghum head (left) and a chaffy head (right). In the latter the plant fails to form seed.


IS 18361

FIGURE 50

Comparison between a normal sorghum head (left) and a broken (chaffy) head (right) Notice that the head breaks off as a result of extensive tunnelling in the peduncle.

FIGURE 51

Tiller formation for damage compsetion

In cultivar IS 2146 as soon as the main plant formed a deadheart, there was a profusion of tillers to compensate for the dead plant. But the non-attacked plant on the right did not tiller at all.


LS 2146

CHAPTER 9

GENERAL DISCUSSIONS AND CONCLUSIONS

Chilo partellus oviposition preference or non-preference studies indicated that there were genuine differences among sorghum cultivars in relation to this trait. The most preferred sorghum cultivars for oviposition were IS 18361, IS 18520 and IS 18363 while the least preferred cultivars were IS 2205 and IS 2122. Olfactometer experiments, as well as the solvent extract tests indicated that the cause for oviposition preference among the cultivars was chemical and that the active ingredient was probably a volatile polar compound. As a result, extraction with non-polar solvents, such as chloroform and ether, did not only not show differences between the preferred and non-preferred cultivars but even caused a reversal in preference. The listed cultivars (IS 18361, IS 18520, IS 18363, IS 2205 and IS 2122) can therefore be used for any further comparisons on C. partellus oviposition preference studies and would also be good candidates for extraction of active ingredients. In these studies IS 18363 and IS 2205 were selected as susceptible and resistant, respectively. These

studies also revealed that any cultivar comparisons have to be conducted over a period of several weeks since both cultivar differences and different dates of sampling were significant sources of variation. Olfactometer studies revealed that both Box olfactometers (Figure 7) and Y-shaped olfactometers (Figure 9) were suitable for cultivar comparisons provided that both are large enough for egg batches and individual eggs to be counted. The oviposition behaviour studies are best done in the large Y-shaped perspex olfactometer.

C. partellus first instar larval acceptance or non-acceptance of different sorghum cultivars as shown by migration from the host plant, larval mortality, and sorghum plant damage showed cultivar IS 18363 to be the most acceptable for colonization. The least acceptable cultivars were IS 1044, IS 18489, IS 18520 and IS 2205. The last cultivar was also extensively damaged. From this it can be inferred that the cultivar was not preferred for colonization (as shown by high migration) and it had antibiosis (this was indicated by high larval mortality) but the larvae fed before they were killed and hence the cultivar showed extensive leaf damage. It can thus be inferred

that this cultivar probably contains a repellent but not an antifeedant.

Larval feeding of the different C. partellus instar larvae on the leaves as shown by leaf damage, indicated that the most susceptible cultivar was once again IS 18363. But this cultivar had one of the lowest incidences of deadhearts. This was attributed to the fact that leaves of this cultivar, as well as the leaf sheaths were large and thus larvae did not easily locate the growing point. Cultivars IS 18361, IS 2205 and IS 18319 were also extensively damaged. The least damaged cultivars were IS 18489, IS 4660, IS 1082 and IS 1044. These results are in agreement with those on first instar larval damage (Chapter four). These results, although in general agreement with those of Roome and Padgham (1980), differ in that these authors found IS 2205 to be resistant to leaf damage.

The pattern of leaf damage and the incidence of deadhearts suggest that these two aspects are not necessarily related. Cultivar IS 18363, for example, was found to be very susceptible to leaf damage but

not to deadhearts. It is thus suggested that the plant damage scale rating should not include deadhearts.

The results on C. partellus larval tunnelling imply that varietal differences are not a significant source of variation. Cultivar IS 2122, however, was consistently the least damaged whenever it was planted and compared with other cultivars. From this it can be inferred it was the most resistant cultivar to tunnelling.

From the biophysical and biochemical studies the following inferences can be made:

(a) While the sugar content and fibre content ratio may be important factors in resistance, they are not decisive on their own. They are augmented or nullified by other factors.

(b) The amount of lignifcation in the stem is an important factor in resistance to C. partellus larval damage.

(c) Glandular trichomes have an important role to play in cultivar IS 2205. This is probably both in oviposition and colonization by larvae.

(d) The spiny bristles forming the ligule in IS 18489 form an effective barrier to first instar larve.

(e) The amounts of wax (or a substance it contains) may be an important factor in C. partellus colonization of the sorghum plant. In those cultivars with a lot of wax there was a high larval migration.

(f) The nature of the leaf sheath can protect the plant from deadhearts. Cultivar IS 18363 is very susceptible to leaf damage but its leaf sheath wraps around the stem several times. As a result the cultivar is not prone to deadhearts.

The most important aspect of sorghum resistance is that which is concerned with compensation for damage. Tillering in response to plant damage in particular, plays an important role. In this aspect, the most resistant cultivars were IS 18520 and IS 2146 (Figures 45, 46, and 51). Formation of multiple heads is another aspect that compensates for damage. Among the cultivars used none compensated to any appreciable extent. The cultivars that were able to compensate in this manner were IS 1082, IS 18349 and IS 18363. Even then, the compensation ranged between 2.04 to 6.08%. Tillering, on the other hand, compensated up 100% when the main plant was damaged (Cultivar IS 18676 in Table 67).

Another important aspect of tolerance is that which is concerned with flowering and seed formation Some cultivars fail to flower when heavily infested (IS 18363 in Table 69 and Figure 48).

Table 71: Summary of results on sorghum resistance to Chilo partellus damage. Mbita Point, 1981-1983.

Resistance - Criteria used	Resistant	Susceptible	Notes
1. Oviposition preference or non-preference (antixenosis)	IS 2205 IS 2122	IS 18363 IS 18361 IS 18520	Refer Table 12
2. First instar larval dispersal(migration)	IS 1044 IS 18489 IS 2205	IS 18363	Refer Table 28
3. First instar larval mortality	IS 18489 IS 2205	IS 18363	Refer Tables 23 and 26
4. First instar larval damage	IS 18349 IS 1044	IS 2205 IS 18363	Refer Table 22
5. Sorghum leaf damage by C.partellus larvae	IS 18489 IS 4660 IS 1082 IS 1044	IS 18361 IS 18363 IS 2205 IS 18319	Refer Table 36

Table 71 cont'd..

Resistance Criteria used	Resistant	Susceptible	Notes
6. Sorghum plant(stem) tunnelling by C. partellus larvae	IS 2122	All other cultivars	Refer Table 43 and Table 40 to 45
7. Biochemical and biophysical factors (a) oviposition preference or no-preference in response to extracts	IS 2205	IS 18363	Refer Tables 46 to 50
(b) Sucrose, and fibre content	IS 17739 IS 2122	IS 18676 IS 18363 IS 18520	Refer Table 51
(c) Lignin content	IS 2122 IS 2205 IS 18489	IS 18363 IS 1044 IS 2146	Refer Figures 20 to 25
(d) Trichome structure	IS 2205	IS 18520 and all other cultivars	Refer Figures 26 to 32

Table 71 cont'd

Resistance Criteria used	Resistant	Susceptible	Notes
7(e) Leaf anatomy (i) Nature of the ligule	IS 18489	All other cultivars tested	Refer Figure 35
(ii) Nature of the leaf sheath	IS 18363	All other cultivars tested	Refer Figure 34
(iii) Wax	IS 1044 IS 18489	IS 18520 IS 18363	Refer Figure 33
(f) Type of root system	IS 2205	IS 18363 IS 18520	Refer Figures 36 to 38
8. Tolerance (a) C. partellus stunting effect	IS 2122 IS 1044 IS 18363 IS 2146	IS 18479	Refer Table 64
(b) Compensation by tillering	IS 18520 IS 2146 IS 18489 IS 2122	IS 1151	Refer Table 67

Table 71 cont'd.

Resistance Criteria used	Resistant	Susceptible	Notes
8(c) Compensation by formation of multiple heads	IS 1082 IS 18349	-	Refer Table 67
.(d) Effect of C.partellus on flowering and seed formation	IS 18520 IS 1151 IS 18489	IS 18363 IS 18361 IS 18367	Refer Table 69
(e) General ability to yield inspite of infestation	IS 18489 IS 2205 IS 2212 IS 4660	IS 18676 IS 1151	Refer Table 68

Table 72: Information on all sorghum cultivars used (1981 - 1983).

IS NO.	Pedigree	Country of Origin	50% Flower (Days)	Plant Height
1044	PJ-1k(Parbhani)	India	59;58	187.8 (cm)
1082	Barshi 3-8-2	India	71.67;68	216.7 "
1151	Aispuri	India	83;86.3	212.8 "
2122	Pl 195682	U.S.A.	74;73	281 "
2162	Pl 221615 Fara-fara	U.S.A.	81.0;84.7	253.9 "
2205	Jaglur	India	70;76	248.8 "
2263	Agyin AD11 Q/2/2/50	Sudan	74.7;76.7	269.9 "
4283	Dura-Medium Boregaon; Betuli;Mp	India	-	-
4307	Mehra Sonthia	India	61;62	232.4 "
4660	Tomri Jogri Heevargaon	India	70.8;75	239.8 "
4764	Desi Khiyaria	India	54;64	183.6 "
4776	Majevari	India	56;58.7	203.1 "
5016	Jagdhan Chandra Bagor	India	67;71.7	199.9 "
5200	Patcha Jonna	India	59;66	227.4 "

Table 72 (cont'd...)

IS NO.	Pedigree	Country of Origin	50% Flower (days)	Plant Height
5604	Allu Jola	India	96;74	271.6 (cm)
5629	Gund Bili Jola	India	66.7;68	248.9 "
17739	Nala Voosa Jonna	India	74	290.2 "
18319	N-1	India	71.5;89.3	241.3 "
18328	N-10	India	92;92	248.3 "
18349	G-1	India	92;96.8	272.8 "
18361	PJ-8 R	India	68; 72.5	231.5 "
18363	PJ-10 R	India	72.3;75.5	187.3 "
18367	PJ-14 R	India	73	257.7 "
18427	Nialo	India	64	222.4 "
18463	Swarna	India	59.5	145.3 "
18479	772	India	61.3;61.5	118.9 "
18489	PS-13	India	76;81.7	266.5 "
18520	Serena	Uganda	65.7	137.7 "
18676	E302	India	55;59.7	220.1 "
18677	E303	India	56;57.3	218.4 "
3954	-	India	59.3;62	52.2 "
4383	-	India	58;62	198.1 "
-	CK 60B (Kafir B)	-	65.6;69.7	73.6 "

Table 72 (cont'd....)

IS NO.	Pedigree	Country of Origin	50% Flower (days)	Plant Height
18390	-	-	67;67.3	214.1 (cm)
18432	BP 53	India	76;80	229.8 "
5072	Tella Jonna	Bramhan, India	70;80.7	247 "
8595	-	-	57;59	145.5 "
2146	Pl 221569	U.S.A.	69	211.6 "

R E F E R E N C E S

ADESIYUN, A.A. and Ajayi, O. (1980)
Control of the sorghum stem borer, Busseola fusca, by partial burning of the stalks. Tropical Pest Management 26(2) : 113-117

AHMED, S.M. and Young, W.R. (1969)
Field observations on the susceptibility of sorghum, maize, and bajra to Chilo zonellus (Swinhoe). Indian Journal of Entomology 31 : 235-238

ALI, M. (1976)
Studies on the induction of food preference in alfalfa ladybird, Subcoccinella 24-punctata L. (Coleoptera: Coccinellidae) in Jermy, T. (Ed) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

ANDERSSEN, E.E. (1946)
Controlling the maize stalk-borer with DDT. Fmg in S. Afr.

ANONYMOUS (1926)
Farming in the Springbork Flats. Fmg S. Afr. 1 : 1-9

ANONYMOUS (1975)

Progress report of All Indian Co-ordinated Sorghum Improvement Project: Part III Sorghum Entomology 1973-75 33 pp INDIAN COUNCIL FOR AGRICULTURAL RESEARCH.

ANSTEY, T.H. and Moore, J.F. (1954)

Inheritance of glossy foliage and cream petals in green sprouting braccoli. J. Hered 45: 39-41

BECK, S.D. (1965)

Resistance of plants to insects A. Rev. Ent. 10: 207-32

BECK, S.D. and Lilly, J.H. (1949)

Report on European corn borer resistance investigations Jowa State Coll J. Sc. 23: 249-259

BECK, S.D. and Schoonhoven, L.M. (1980)

Insect behaviour and plant resistance from Maxwell, F.G. and Jennings, P.R. (Ed.) Breeding plants resistant to insects.

BEHAN, M. and Schoonhoven, L.M. (1978)

Chemoreception of an oviposition deterrent associated with eggs in Pieris brassicae. Ent. Exp. & Appl. 24: 163-179.

BERNAYS, E.A. and Chapman, R.F. (1976)
Antifeedant properties of seedling grasses in Jermy, T. (Ed). The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

BERNAYS, E.A., Blaney, W.M., Chapman, R.F. and Cook, A.G. (1976)
The ability of Locusta migratoria L. to perceive plant surface waxes in Jermy, T. (Ed.) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

BLESZYNSKI, S. (1970)
A revision of the world species of Chilo zicken (Lepidoptera : Pyralidae) Bull of the British Museum (Natural History) Entomology 25(4) : 99-195

BLESZYNSKI, S. and Collin, R.J. (1962)
A short catalogue of the World species of the family Crambidae (Lepidoptera). Acta Zool. Cracov. 1 : 197-389

BLOM, F. (198)
Sensory input behaviour output relationships in the feeding activity of some lepidopterous larvae. Ent. Exp. & Appl. 24 : 58-63

BLUM, A (1968)

Anatomical phenomena in seedlings of sorghum varieties resistant to the sorghum shoot fly (Atherigona varia soccata) Crop. Sc. 8 : 388-390

BLUM, N.S., Hughes, R.D., Mittler, T.E. and Norris, D.M. (1978) (Eds)

Entomologia Experimentalis et Applicata 24 (3) pp. 258-766

BOHN, G.W., Kishaba, A.N. and Toba, H.H. (1972)

Mechanisms of resistance to melon aphid in a muskmelon line Hortscience 7 (3): 281-2

BUTANI, D.K. (1955)

The influence of temperature on the development of Insects, with special reference to Chilo zonellus Indian J. Ent. 17 : 280-282

CHADHA, G.K. and Roome, R.E. (1980)

Oviposition behaviour and sensilla of the oviposition of Chilo partellus and Spodoptera littoralis (Lepidopt: Noctuidae) J. Zool, London (1980) 192: 169-178

CHATTERJI, S.M., Bhamburkar, M.W., Marwaha, K.K., Panwar, V.P.S., Siddiqui, K.H. and

Young, W.R. (1971)
Relative susceptibility of some promising exotic maize material to Chilo zonellus Swinhoe under artificial infestation Indian J. Ent. 33 : 209-213

CHATTERJI, S.M., Sarup, P., Bhamburkar, M.W., Marwaha, K.K., Panwar, V.P.S., and Siddiqui, K.H. (1972)
Screening some promising exotic maize germplasm for resistance to Chilo zonellus Swinhoe Indian J. Ent. 34(2): 185-6

CHATTERJI, S.M., Sarup, P., Panwar, V.P.S., Siddiqui, K.H., Marwaha, K.K., Bhamburkar, M.W. and Young, W.R. (1973)
Studies on insect-plant relation - performance of some exotic maize germ plasms with particular reference to their susceptibility to Chilo partellus (Swinhoe) under artificial infestation Indian J. Ent. 35(1) : 63-66

CHUI, S.F. (1942)
Fukien J. Agric. (In Chinese with an English summary) (R.A.E. (A) 34 : p.152) 66pp.

CHOI, S.Y., Lee, H.R., Lee, J.O. and Park, J.S. (1976)

Varietal differences in ovipositional preference of the stripped rice borer (Chilo suppressalis W.) Kor. J. Pl. Prot. 15(1) : 23-27

CLARIDGE, M.F. and Wilson, M.R. (1978)
Oviposition behaviour as an ecological factor in woodland canopy leafhoppers. Ent. Exp. & Appl. 24 : 101-109

COAKER, T.H. (1965)
An experiment on stemborer control on maize E. Afr. J. 21 : 220-1

COOK, A.G. (1976)
A critical review of the methodology and interpretation of experiments designed to assay the phygostimulatory activity of chemicals to phytophagous insects in Jermy, T. The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

DABROWSKI, Z.T., Kidiavai, E. and Arwa, M.O. (1981)
Sorghum resistance to stemborers. 1980 Annual Report, ICIPE, Nairobi.

DAHMS, R.C. (1972)
Role of host plant resistance to integrated insect control. From Jotwani, M.G. and Young, W.R. (Ed) Control of

Sorghum Shootfly Oxford and ibh Publishing Co., New Delhi.

DAVID, V.B., Sivagami, R., Janagarajan, A. (1969) A schedule treatment against stemborer and earhead but pests of Vellai Cholam Madras Agricultural Journal 56: 785-789

DAY, A., Nugent, P.E., and Robinson, J.F. (1978) Variation of picklerworm and oviposition on muskmelon and cucumbers. Hortscience 13(3) : 286-287

De WILDE, J. (1976) Olfactory component in hostplant selection in the adult Colorado beetle (Leptinotarsa decemlineata say) in Jermy, T. (Ed) The host plant in relation to insect behaviour and reproduction. Plenum Press New York.

DELOBEL, A. (1975) Une population hivernante de Chilo partellus (Lepidoptera, Pyralidae) sur la cote ouest de Madagascar Cah Orstom, ser Biol X(1) : 17-23

DETHIER, V.G. (1947) Chemical insect attractions and repellents. Blakinston's Son & Co. Philadelphia.

DETHIER, V.G. (1976)

The importance of stimulus patterns for host-plant recognition and acceptance in Jermy, T. The host-plant in relation to insect behaviour and reproduction Plenum Press New York

DICK, J. (1945)

Some data on the biology of the sugar-cane borer (Eldana saccharina Wlk.) Proc. S. Afr. Sug. Technol. Ass. 19 ; 75-79

DICKSON, R.C. and Laird, E.F. (1969)

Crop host preferences of greenbug biotype attacking sorghum J. Econ. Entomol. 62(5):: 1241

DJAMIN, A. and Pathak, M.D. (1967)

The role of silica in resistance to Asiatic rice borer Chilo suppressalis (Walker) in rice varieties J. Econ. Entomol. 60 : 347-351

DODDS, H.H. (1939)

The cane borer pest in Zululand S. Afr. Sug. J. 23 : 565-576

DOGGET, H. (1970)

Sorghum. Longmans Green, London 403pp.

DOGGET, H., Starks, K.J. and Eberhart, S.A. (1970)

Breeding for resistance to the sorghum shootfly Crop Sc. 10 : 528-531

DUERDEN, J.C. (1953)

Stemborer of Cereal crops at Kongwa, Tanganyika 1950-1952 E. Afr. Agric. J. 19 : 105-119

DUERDEN, J.C. (1953)

Stemborers of cereal crops at Kongwa, East Afr. Agric. Jour. Tanganyika 19(2): 105-119

ELSEY, K.D. and McFadden, T.L. (1980)

Pickworm: Oviposition on an artificial surface treated with cucurbit extract. J. Econ. Entomol. 74(A) 473-474

EVERLY, R.T., Guthrie, W.D., Dickie, F.F. (1979)

Attractiveness of con genotypes to ovipositing European corn borer moths. Agricultural Reviews and Manuals. Science and Education Administr. U.S.D.A.

EVERSON, E.H. and Gallun, R.L. (1980)

Breeding approaches in wheat in Maxwell, F.G. and Jennings, P.R. (Eds) Breeding plants resistant to insects. John Wile & Sons New York

F.A.O. (1980)

F.A.O. production yearbook Rome pp.4-11

FARREL, J.A.K. (1977)

Plant resistance to insect and selection

of resistant lines N.A. Entomologist 6(3) : 244-261

FEENY, P. (1976)

Plant apparency and chemical defence. From Wallace, J.W. and Mansell, R.L. (Ed) Recent Advances in Phytochemistry 10 : 1-40

FINCH, S. (1978)

Volatile plant chemicals and their effect on host plant finding by the cabbage root fly (Delia brassicae). Ent. Exp. & Appl. 24 : 150-159

FISK, J. (1978)

Resistance of Sorghum bicolor to Rhopalosiphum maidis and Peregrinus maidis as affected by diffences in the growth stage of the host Ent. Exp. & Appl. 23 : 227-236

FISK, J. (1980)

Effects of HCN, Phenolic acids and related compounds in Sorghum bicolor on the feeding behaviour of the plant-hopper Preregrinus maidis. Ent. Exp. and Appl. 27 : 211-222

FRANZKE, C.J., Purh, L.F. and Hume, A.N. (1939)

A study of sorghum with reference to

the content of HCN S. Dak Agr. Expt. Sta. Tech. Bull 1 51pp

GAHUKAR, R.T., Jotwani, M.G. (1980)
Present status of field pests of sorghum and millets in India. Tropical Pest Management 28(2) : 138-151

GALUN, R.L. and Khush, G.S. (1980)
Genetic factors affecting expression and stability of resistance in Maxwell, F.G. and Jennings, J.R. (Eds) Breeding plants resistant to insects. John Willey & Sons Inc New York

GLASS, E.H. (1975)
Integrated pest management : Rationale, potential, needs and implementation Entomological Soc. Amer. Baltimore, MD.

GIRLING, D.J. (1978)
The distribution and biology of Eldana saccharina Walker (Lepidoptera : Pyralidae) and its relationship to other stemborers in Uganda Bull Ent. Res. : 471-488

GOMEZ, K.A. and Gomez, A.A. (1976)
Statistical proceedings for agricultural research with emphasis on rice. International Rice Research Institute Los

Banos, Manila, Philippines.

GONCALVES, L. (1970)

A broca do milho Chilo partellus Swinhoe (Lepidoptera : Crambidae) em Mozambique contribuicao para o seu estudo. Agron Mozamb. Lourenco Marques 4(4) : 239-246. (Summary in English & French)

GUTHRIE, W.D., Dickie, F.F. and Neiswander, C.R. (1960)

Leaf and sheath feeding resistance to the European corn borer in eight inbred lines of dent corn. Ohio Agric. Exp. Stn. Res. Bull. 860 : 38pp.

HANSON, F.E. (1976)

Comparative studies on induction of food choice in lepidopterous larvae in Jermy T. The host-plant in relation to insect behaviour and reproduction Plenum Press New York

HARAKI, T. and Horino, T. (1981)

Effect of leaf removal on yield and its components in grain sorghum Japanese Journal of Crop Science 50(2) : 231-242

HARGREAVES, H. (1939)
Notes on some pests of maize and millets in Uganda East African Agricultural Journal

HARRIS, K.M. (1962)
Lepidopterous stem borers of cereals in Nigeria Bull. Ent. Res. 53 ; 139-171

HARRIS, K.M. (1970)
Biology and breeding for resistance to Arthropods and pathogens in agricultural plants. Proceedings of short course entitled "International Short Course in Host Plant Resistance". Texas A. & M. Univ. College State Texas.

HAWKES, C. and Coaker, T.H. (1976)
Behavioural responses to host-plant odours in adult cabbage root fly (Erioschia brassicae) (Bouce)) in Jermy T. The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

HERREBOUT, W.M., Kurjten, P.J. and Wiebes, J.T. (1976)
Small ermine moths of the genus Yponomeuta and their host relationships (Lepidoptera : Yponomeutidae) in Jermy T. The host-plant in relation to insect

behaviour and reproduction. Plenum Press New York.

HILL, D.S. (1975)
Agricultural insect pests of the tropics and their control.

HORBER, E. (1980)
Types and classification of resistance in Maxwell, F.G. and Jennings, P.R. (Eds) Breeding plants resistant to insects John Wiley & Sons. New York.

HORROCKS, R.D. and Jorgensen, M.E. (1981)
Tillering of Sorghum bicolor under various temperature regimes. American Society of Agronomy 106 Brigham Young Univ. Prov. U.T.

HOUSE, L.R. (1980)
A guide to sorghum breeding. Patancheru, Andhra Pradesh, India ICRISAT 238 pp.

HSIAO, T.H. (1976)
Chemical behavioural factors influencing food selection of Lepti-notarsa beetle in Jermy, T. The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

HULSE, Joseph H., Liang, E.M. and Pearson, O.E. (1980)
Sorghum and millets: Their composition and nutritive value. Academic Press London N.Y. 997.

INDIAN Council for Agricultural Research (1975)
Progress report of All India Co-ordinated Sorghum Entomology 1973-75 New Delhi. 33 pp.

INGRAM, W.R. (1958)
The Lepidopterous stalk borers associated with Gramineae in Uganda Bull. Ent. Res. 49 : 367-383

IVANYUKOVICH, L.K. (1980)
History and origin of sorghum Botanicheskii Zhrnal 65 (7) : 1014-1020

JENKINS, J.N. and Parrot, W.L. (1971)
Effectiveness of frego bract as a boll weevil resistance character in cotton. Crop Sc. 11 : 739-743

JEPSON, W.F. (1954)
A critical review of the world literature on the lepidopterous stalk borers of tropical graminaccous crops. Commonwealth Institute of Entomology, London. 128 pp.

JERMY, T. (1976)

Insect-host-plant relationship-co-evolution or sequential evolution in Jermy, T. (Ed) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

JERMY, T. and Szentesi, A. (1978)

Role of inhibitory stimuli in the choice of oviposition site by phytophagous insects Ent. Exp. & Appl. 24 : 258-271

JOTWANI, M.G. (1972)

Insect pests - Major limitation in producing higher yields of sorghum. Ent. Newslet. 2(12) : 75

JOTWANI, M.G., Sharma, G.C., Kundu, G.G., T.R., Verma, K.K., Singh, S.P., and Samarjit Rai (1978)

Investigations on insect pests sorghum and millets with special reference to host plant resistance. Research Bull. of the Div. of Entomol. Indiana Agricultural Research Institute (New Series, No.2) pp. 1-115

JOTWANI, M.G., Srivastava, K.P., Kundu, G.G. Kishore, P., & Kushani, T.R. (1978) Management of stemborer, Chilo partellus (Swinhoe)

infesting sorghum through the use of resistant varieties and chemical control. J. Entomol. Res. 2(2) : 203-5

JOTWANI, M.G. and Young, W.R. (1971)
Sorghum insect control. Wild. Emg. 13(9) 6-11

KALODE, M.E. and Pant, N.C. (1966)
Studies on the susceptibility of different varieties of sorghum, maize and bajra to Chilo zonellus (Swin) under field and cage conditions and methods of determining it. Indiana J. Ent. 28 : 448-464

KAPUR, A.P. (1950)
The identity of some Crambianae associated with sugar-cane in India and a certain species related to them (Lepidoptera : Pyralidae). Trans. Ento. Soc. Lond. 101: 389-439, 10 pp.

KARASEV, V.S. (1976)
The role of volatile oil composition for trunk pest resistance in coniferous plants. Experiments on lumber in Jermy , T. (Ed) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

KENNEDY, J.S. (1977)

Olfactory responses to distant plants and other odour sources in Shorey, H.H. and McKelvey, J.J. (Eds.) chemical control of insect behaviour. John Wiley and Sons New York.

KENNEDY, J.S. (1978)

The concepts of olfactory 'arrestment' and 'attraction'. Physiological Entomol. 3 : 91-98

KISHABA, A.N., Whittaker, T.W., Vail, P.V. and Toba, H.H. (1973)

Differential oviposition of cabbage loopers on lettuce. J. Amer. Soc. Hort. Sci. 98(4) : 367-370

KLUB, J.A., Tipton, C.L. and Brindley, T.A. (1967)

2,4 dihydroxy-7-methoxy-1,4 benzoxazin-3-one-(DIMBOA), an active agent in the resistance of maize to the European corn borer. J. Econ. Entomol. 60 : 1529-1533

KOGAN, M. (1976)

Resistance in soybean to insect pests In Expanding the use of soybeans. Godman, R.M. (Ed) Proceedings of a conference for Asia and Oceania, Chiang Mai, Thailand University of Illinois, Urbana, Insoy

KOGAN, M. and Ortman, E.E. (1978)
Antixenosis - a new term proposed to replace Painters "Non-preference" modality of resistance E.S.A. Bull. 24

LA CROIX, E.A.S. (1967)
Maize stalk borers in the Coast Province of Kenya. E. Afr. Agric. J. 33 : 49-54

LE BERRE, J.R., and Launois-Luong, H. (1976)
Finding of feeding and egg-laying sites by migratory locust, Locusta migratoria L. in Jermy T. (Ed) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York

LEIGH, T.F., Hyer, A.H. and Rice, R.E. (1972)
Frego bract condition of cotton in relation to insect populations. Environ. Entomol. 1 : 390-391

LARSON, A.O. and Fisher, C.K. (1938)
The bean weevil and the southern cowpea in California USDA Tech. Bull No.59

LINK, D. and Possetto, C.J. (1972)
Relacao entre fissura na casca do arroz e infestacao de Sitotroga cerealella (Oliver) (Lepidoptera : Gelechiidae). Rev. Paruana Entomol. (An. ler. Cong. Lationam Entomol.) 15 : 255-327

LUCKMANN, W.H., Rhodes, A.M., Wann. E.V. (1964)
Silk balling and other factors associated with resistance of corn earworm. J. Econ. Entomol. 57 : 778-779

MA, W. (1976)
Mouth parts and receptors involved in feeding behaviour and sugar perception in the African armyworm, Spodoptera exempta (Lepidoptera, Noctuidae). Symp. Biol. Hung 16 : 139-151

MAITI, R.K., Bidinger, F.R., Seshu Reddy, K.V., Gipson, P, and Davies, J.C. (1980)
Nature and occurence trichomes in sorghum lines with resistance to sorghum shoot fly. Joint Progress Report Sorghum Physiol. - sorghum - Entomology 3 : 40pp

MATHES, R. and Charpentier, L.J. (1963)
Some techniques and observations in studying the resistance of sugar-cane varieties to the sugarcane borer in Louisiana. Proc. Int. Soc. Sugarcane Technol. 11 : 594-603

MATHEZ, F.C. (1972)
Chilo partellus (Swinh.) C. orichalcociliella Strand (Lep., Crambidae) and Sesamia calamistis Hmps. (Lep., Noctuidae)

on maize in the Coast Province, Kenya. Mitt. Scweiz. Ent. 45 : 267-289

McMILLAN, W.W. and Starks, K.J. (1967)
Greenhouse and Laboratory screening of sorghum lines for resistance to Fall Armyworm larvae J. Econ. Entoml. 59(5): 1211-4

METCALF, C.L. and Flint, R.L. (1967)
Destructive and useful insects. Their habits and control. McGraw-Hill Book Company New York

MOHYUDDIN, A.I. and Attique, M.R. (1978)
An assessment of loss caused by Chilo partellus to maize in Pakistan. PANS 24(2) : 111-113

MOHYUDDIN, A.I. and Greathead, D.J. (1970)
An annoted list of the parasites of graminaceous stem borers in East Africa, with a discussion of their potential in biological control. Entomophaga 15(3) : 241-274

MOIZ, S.A. and Quereshi, M.S. (1969)
Life history of maize stem borer (Chilo zonellus Swinhoe) at Tandojam. Agriculture Pakistan XIX(2) : 130-149

MOREAU, J.P. (1976)

Distribution of adult insects in relation to the host-plants in Jermy T. (Ed) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

MUMFORD, E.P. (1931)

Studies in certain factors affecting the resistance of plants to insects

NAGY, B. (1976)

Host selection of European corn borer (Ostriani nubilalis Hbn.) population in Hungary, Symp. Biol. Hung. 16 : 191-195

NIELSON, M.W. and Lehman, W.F. (1980)

Breeding approaches in alfalfa in Maxwell, F.G. and Jennings, P.R. (Eds.) Breeding plants resistant to insects. John Wiley and Sons, New York.

NORRIS, D.M. (1976)

Physico-chemical aspects of the effects of certain Phytochemicals on insect gustration in Jermy, T.(Ed). The host plant in relation to insect behaviour and reproduction. Plenum Press New York.

NORRIS, D.M. and Kogan, M. (1980)

Biochemical and morphological bases of

resistance from F.G. Maxwell and P.R. Jennings (Ed.) Breeding plants resistant to insects. Wiley & Sons, New York

NYE, I.B.W. (1960)
The insect pest of Graminaceous crops in East Africa Colon. Res. Stud.

ORTMAN, E.E. and Peters, D.C. (1980)
Plant resistance to insects - Introduction from F.G. Maxwell and P.R. Jennings. Breeding plants resistant to insect. Wiley and Sons, N.Y.

PAINTER, R.H. (1951)
Insect resistance in crop plants Univ. Press of Kansas, Lawrence.

PAINTER, R.H. (1958)
Resistance of plants to insects. Ann. Rev. Entomol. 3 : 267-290

PANT, N.C. and Kalode, M.B. (1964)
Pests of wheat, maize, and millets in: Entomology in India, Silver Jubilee number of the Indian J. Ent., 279-292

PANT, N.C., Pathak, M.D. and Pant, J.C. (1961)
Resistance to Chilo zonellus (Swinhoe) in different host plants. Development of larvae on different hosts. Indiana J. Entomol. 23 : 128-136

PARNELL, F.R., King, H.E. and Ruston, D.F. (1949)
Jassid resistance and hariness of the cotton plant. Bull. Entomol. Res. 39: 539-575

PATHAK, M.D. (1968)
Ecology of common insect pests of rice. A. Rev. Ent. 13 : 257-294

PATHAK, M.D. and Saxena, R.C. (1980)
Breeding approaches in rice in Maxwell, F.G. and Jennings, P.R. (Eds.) Breeding plants resistant to insects. John Wiley and Sons, New York

PETTERSSON, J. (1976)
Ethology of Dasyneura brassicae Winn. (Dipt. Cecidomyidae) I Laboratory studies of olfactory reactions to the host plant in Jermy T. (Ed.). The host-plant in relation to insect behaviour and reproduction. Plenum Press, New York

PHILLIPS, W.M. (1978)
Sensilla types from the ovipositor of the flea beetle Altica lythri (Coleoptera): Chrysomelidae). Ento. Exp. & Appl. 24: 399-400

POSTON, P.L., Whitworth, R.J., Loera, J. and Safford, H.B. (1979)

RAO, V.B. (1965)

Natural enemies of rice stemborers and allied species in various parts of the world and possibilities of their use in biological control of rice stemborers in Asia Tech. Bull.

RAO, N.G.P. (1975)

Sorghum production programme. Indian Farming 25 : 71-4

RAO, N.G.P., Rana, B.S. and Jotwani, M.G. (1978)

Host plant resistance to major insect pests of sorghum. Proceedings of an advisory group meeting on the use of induced mutations for resistance of crop plants to insects, International Atomic Energy Agency, Vienna : pp 63-78.

RAO, N.G., Rana, B.S. and Jotwani, M.G. (1979)

Host plant resistance to major insect pests of sorghum. All India Co-ordinated Sorghum Improvement Project. IARI - Regional Station. pp. 63-78

RIPLEY, L.B. and Hepburn, G.A. (1931)

Fmg in S. Afr. Reprint No. 63, 2pp.

ROOME, R.E. (1976)

Resistance in sorghum varieties to attack by larvae of Chilo partellus

(Swinhoe) Sorghum stalk borer. Crop Protection in Botswana Biennial Report 1971-73. Min. of Agr. Div. of Agric. Research, Gaberone, Botswana. pp. 1-39.

ROOME, R.E. (1980)
Dispersal of newly hatched Chilo partellus (Swinhoe) larvae from sorghum cultivars. Zeitschrift Fur Anewandte Entomologie Sonderdruk Aus. Bd. 90, H.2, S: 174-180.

ROOME, R.E,, Chadha, G.K., and D. Padgham, D. (1977)
Choice of oviposition site by Chilo the sorghum stemborer. Bulletin SROP 1977: 115-121

ROOME, R.E. and Padham, D.E. (1977)
Sorghum stemborer ecology and behaviour: Report of field study period July - November, 1976 COPR/ICRISAT Collaborative Project. pp. 1-55

ROOME, R.E. and Padgham, D.E. (1980)
Report on second Chilo field study period June-November 1978 COPR/ICRISAT Collaborative Project pp. 1-114

ROTCSCHILD, M. and Schoonhoven, L.M. (1977)
Assessment of egg load by Pieris brassicae (Lepidoptera : Pieridae). Nature 266 (5600) : 352-355

SARUP, P., Marwaha, K.K., Panwar, V.P.S. and Siddiqui, K.H. (1978)
Evaluation of some exotic and indigenous maize germplasms for resistance to Chilo partellus (Swinhoe) under artificial Infestation. J. Ent. Res. 2(1) : 98-105

SARUP, P., Panwar, V.P.S., Marwaha, K.K. and Siddiqui, K.H. (1977)
Exploitation of polyphagy for the control of Chilo partellus (Swinhoe) infesting maize crop. J. Entomol Res. 1(2) : 184-182

SARUP, P., Panwar, V.P.S., Marwaha, K.K. and Siddiqui, K.H. (1978)
Management of maize pests with particular reference to salkborer, Chilo partellus (Swinhoe) under resource constraints. J. Entomol. Res. 2(1) : 5.14

SAXENA, K.N. (1978)
Role of certain environmental factors in determing the efficiency of host plant by an insect Ent. Exp. & Appl. 24 : 464-478

SCHALK, J.M. and Ratchliffe, R.H. (1977)
Evaluation of the United States Department of Agriculture Programme on alternative methods of insect control : Host plant resistance to insects. FAO Plant Protection Bulletin.

SCHELTES, P. (1976)
The role graminaceous host plants in induction aestivation-diapause in the larvae of Chilo zonellus (Swinhoe) and Chilo argyrolepia (Hmps.) Symp. Biol. Hung. 16 : 247-253.

SCHELTES, P. (1978)
Ecological and Physiological aspects of aestivation-diapause in the larvae to two Pyralid stalkborers of maize in Kenya. Modeling No. 298 pp. 1-110. Laborotorium Voor Entomologie, Wageningen.

SCHMUTTERER, H. (1969)
Pests of crops in Northeast and Central Africa. Gustav Fisher Verlag. Stutgart.

SCHOONHOVEN, L.M. (1976)
On the variability of chemosensory information in Jermy, T. (Ed). The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

SESHU REDDY, K.V. and Davies, J.C. (1979)
Pests of sorghum and pearl millet, and their parasites and predators recorded at ICRISAT Centre, India up to August, 1979. Progress Report No. 2 Central Entomology ICRISAT. 23 pp.

SESHU REDDY, K.V. and Davies, J.C. (1980)
Sorghum stemborer Chilo partellus Swinh. Recent findings at ICRISAT Centre. All India Co-ordinated Sorghum Improvement Project Workshop held at Coimbatore, 12-14th May, 1980. ICRISAT.

SHARMA, K.A., Saxena, J.D. and Subba Rao, B.R. (1967)
A catalogue of the hymenopterous and dipterous parasites of Chilo zonellus (Swinhoe)(Crambidae : Lepidoptera). Indian J. Ent. 28 : 511-541

SHARMA, V.K. and Chatterji, S.M. (1971)
Preferential oviposition and antibodies in different maize germplasms against Chilo zonellus (Swinh.) under cage conditions. Indian J. Ent. 33(3) : 299-311

SHIRAKI, T. (1977)
Paddy borer Schoenobius incertellus Wlk 256 pp. Taihoku, Agric. Exp. Sta., Formosa.

SIDDIQUI, S.A. (1972)
Graminaceous stemborers in the Northern Province of Sudan. Z. Angew. Ent. 71 : 376-381

SINGH, B., Dhaliwal, J.S. and Atwal, A.S. (1974)
The effect of simulated rain on the survival of first instar of Chilo partellus (Swinhoe). Current Science 43 : 422-423

SINGH, G. and Sandhu, G.S. 1979)
Testing for resistance to Chilo partellus (Swinhoe) under cage infestation. Indian J. Ent. 41(1) : 43-46

SMITH, E.H. (1972)
Pest control strategies for the future National Academy of Sciences, Washington D.C.

STARKS, K.J. and Doggett, H. (1969)
Resistance to stemborer, Chilo partellus in sorghum and maize Crop Science 9 : 197-211

SNELLING, R.O. (1941)
Resistance of plants to insect attack. Bot. Review 7 : 543-586

STADELBACHER, E.A. and Scales, A.L. (1973)
Technique for determining oviposition preference of the boolworm and tobacco budworm for varieties and experimental sticks of cotton. J. Econ. Entomol. 66(2) : 418-421

STADLER, E., and Hanson, F.E. (1976)
Influence of induction of host preference on chemoreception of Monduca sexta : behavioural and electrophysiological studies in Jermy, T. (Ed.) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

SWAINE, G. (1957)
The maize and sorghum stalkborer, Busseola fusca (Fuller), in peasant agriculture in Tanganyika territory. East African Agricultural Journal.

SZENTESI, A. (1976)
The effect of emputation of head appandages on the oviposition of the bean weevil, Acanthoscelides obteclus Say (Coleoptera : Brucidae) in Jermy, T. (Ed.) The host plant in relation to insect behaviour and reproduction Plenum Press, New York

TAYLOR, F. (1952)
The maize stalkborer in the Eastern Orange Free State. Fmg. in S. Afr.

TEETES, G.L. (980)
Breeding sorghums resistant to insects in Maxwell, F.G. and Jennings, P.R.

(Ed.) Breeding plants resistant to insects. John Wiley & Sons New York.

THOMSON, F.K. (1963)
Resistance to the cabbage aphid (Brevicoryna brassicae) in Brassica plants. Nature 198-209.

TJALLINGII, W.F. (1976)
A preliminary study of host selection and acceptance behaviour in the cabbage aphid Brevicoryne brassicae L. in Jermy, (Ed.) The host plant in relation to insect behaviour and reproduction. Plenum Press, New York.

TREHAN, K.N. and Butani, D.K. (1949)
Bionomics and control of Chilo zonellus Swinhoe in Bombay Province. Indian J. Ent. 2 : 57-59

USUA, F.J. (1968)
Temperature and relative humidity effects on the development of the immature stages of the maize of the maize stem-borers Busseola fusca and Sesamia calamistis J. Econ. Ent. 61 : 1091-1093.

VAN EMDEN, Helmut F. (1976)
Pest control and its ecology (Studies in Biology N.50). Edward Arnold

(Publishers) Ltd. Camelol Press Ltd., Southampton 60 pp.

VAN EMDEN, H.F. and May, M.J. (1963)
Insect-plant relationships (From Van Emden, H.F. (Ed.) Wiley, N.Y.

VANHAMBURG, H. (1979)
The grain-sorghum stalkborer Chilo partellus (Swinhoe) (Lepidoptera : Pyralidae) : Seasonal changes in adult populations in grain sorghum in the Transvaal. J. Ent. Soc. Sth. Afr. 42(1): 1-9.

VAN HAMBURG, H. (1980)
The grain-sorghum stalk-borer Chilo partellus (Swinhoe) (Lepidoptera : Pyralidae) : survival and location of larvae at different infestation levels in plants of different ages. J. Ent. Soc. Sth. Afr. 43(1) : 71-76

VAN RENSBURG, N.J. and Van Hamburg, H. (1975)
Grain sorghum pests : an integrated control approach. Proc. 1st Congr. Ent. Soc. Sth. Afr. : 151-162

VASETECHKO, G.I. (1976)
Host selection and colonization by some spruce bark beetles in Jermy, T. (Ed.)

The host plant in relation to insect behaviour and reproduction. Plen Press New York.

WAISS, A.C., Chan, B.G. and Elliger, C.A. (1977) Host plant resistance to insects from Hedin, P.A. (Ed.) Host plant resistance to pests A.C.S. Symp. Series No. 62 pp. 115-128.

WAIYAKI, J.N. (1968)
The biology and control of the principal lepidopterous borers associated with sugarcane at the Tanganyika Planting Company, Arusha-Chini. Tropical Research Institute, Arusha Tanzania.

WALKER, F.T. (1961)
Insecticide studies on the maize stalk-borer, Busseola fusca (Fuller), in East Africa. Ann. Appl. Biol. 48(4) : 321-351

WANG, C.Y., Chen, H.Y. and Chu, T.M. (1981)
Studies on source sink relationships in sorghum. The effect of defoliation or wrapping portion of leaves on yield. National Science Council Monthly 9(11): 975-982.

WHEATLEY, P.E. (1961)
Insect pests of agriculture in the coast

province of Kenya. Part 5 Maize and sorghum E. Afr. Agr. J. 27(2) : 105-107

WIKLUND, C. (1974)
Oviposition preference in Papillo machaon in relation to the host plants of larvae. Ent. Exp. Appl. 17 : 189-198

WOODHEAD, S. and Bernays, E.A. (1977)
Changes in release rates of cyanide in relation to paatability of sorghum to insects. Nature 270(5634) : 235-6

WOODHEAD, S. and Bernays, E.A. (1978)
The chemical basis of resistance of Sorghum bicolor to attack by Locusta migratoria. Ent. Exp. & Appl. 24 : 123-144

WOODHEAD, S., Bernays, E., Chapman, E., Padgham, D. and Leather, E. (1980)
Report on a study of newly hatched larvae of Chilo partellus on different cultivars of sorghum bicolor. COPR/ICRISAT COLL. PROJ. COPR. pp. 1.33

WOODHEAD, S., Galeffi, C., and Bettolo, G. (1982)
p-Hydroxybenzaldehyde as a major constituent of the epicuticular wax of seedling. Sorghum bicolor. Biochemistry 21(2) : 455-6

WOODHEAD, S., Padgham, D.E. and Bernays, E.A. (1980)
Insect feeding on different sorghum cultivars in relation to cyanide and phenolic content. Ann. Appl. Biol. 95: 151-157

WOODHEAD, S., Padgham, D., and Leather, E. (1978)
Insect feeding preferences and plant chemistry in sorghum cultivars, July-October 1978 COPR/ICRISAT COLL. PROJ., COPR. pp. 1-36

WOOD, D.L. (1976)
Host selection by bark beetles in the mixed-confer forests of California in Jermy, T. (Ed.) The host-plant in relation to insect behaviour and reproduction. Plenum Press New York.

WOODS, Arthur (1974)
Pest Control. A survey. McGraw-Hill Book C. (UK) Ltd. Fakenhum & Reading.

YAMAMOTO, R.T., Jenkings, R.Y. and McClusky, R.K. (1969)
Factors determing the selection of plants for oviposition by the tobacco hornworm Manduca sexta. Ent. Exp. & Appl. 12 : 504-508

YOUNG, W.R. and Teetes, G.L. (1977)
Sorghum entomology. Ann. Rev. Entomol. 22 : 193-218