BIONOMICS OF THE MILLET STEM BORER
CONIESTA IGNEFUSALIS (HAMPSON)
(LEPIDOPTERA: PYRALIDAE)

A Thesis

Presented to the Department of Zoology of the Faculty of Science,

University of Ghana, Legon

in fulfilment of the requirements

for the degree of Doctor of Philosophy

in Zoology (Entomology)

AISSETOU DRAME YAYE

B.Sc. (Forestry), Krakow, Poland

M.Sc. (Entomology), Dakar, Senegal

Zoology Department,
Faculty of Science
University of Ghana,
Legon

November 1998

DECLARATION

I hereby declare that the work herein submitted as a thesis for the Doctor of Philosophy Degree in Zoology (Entomology) is the result of my own investigations and has not been submitted for a similar degree in any other University.

………………………………

Aissetou Drame Yaye

………………………………

Dr O. Youm
ICRISAT Supervisor

………………………………

Dr F. Schulthess
IITA Supervisor

………………………………

Professor J. N. Ayertey
University Supervisor

DEDICATION

To my late parents Idriss and Fatoumata DRAME

whose memories always support me during difficult times.

ABSTRACT

Study conducted from 1993 through 1996 at the ICRISAT Sahelian Centre, Niger, on the millet stem borer *Coniesta ignefusalis* were designed to address larval instar determination and life-fertility table construction, damage and yield loss assessment on pearl millet, *Pennisetum glaucum* (L.) R. Brown, and oviposition preference and larval development on two wild hosts, *Andropogon gayanus* Kunth and *Pennisetum pedicellatum* (Trin.). Biological control studies investigated the suitability of *C. ignefusalis* for the larval endoparasitoids *Cotesia flavipes* Cameron and *Cotesia sesamiae* (Cameron).

The larval instars of *C. ignefusalis* reared on artificial diet in the laboratory were determined based on head capsule widths and colour, body length and age of the larvae. The frequency distribution of head capsule widths gave seven plus one intermediate instar groups. The head capsule widths ranged from 0.2 to 2 mm, and body length from 1.5 to 32 mm. Head capsule colour changed gradually from yellow to brown. Larval age ranged from 1 to 40 days. Mean head capsule widths were significantly different from one instar to another and confirmed Dyar's rule. Body length and age of larvae also differed from one instar to another. The head capsule widths were positively correlated with body length ($r^2 = 0.96$, $P < 0.001$) and larval age ($r^2 = 0.91$, $P < 0.001$). Life-fertility tables showed that on average, 24.41 females were produced per female in a cohort generation time of 65.45 days. The estimated innate capacity of increase (r_c) was 0.0133 and the finite rate of increase (λ_c) was 1.0135. *C. ignefusalis* had a type IV survivorship curve.

Even with natural infestation levels as high as 78.41%, late attack by the millet stem borer caused bored stems to yield more than unbored ones. Artificial infestations with 5 and 10 larvae per plant at two weeks after plant emergence resulted in 50 to 70% plants with dead hearts and 24 to 100% avoidable yield loss. With the same treatments at four weeks after plant emergence, 7% yield increase and 16% yield loss, respectively were recorded.

Andropogon gayanus and *Pennisetum pedicellatum* were non-preferred hosts for oviposition by *C. ignefusalis*. Larvae also partially developed on these hosts without pupae formation. This suggests that these wild hosts could be trap plants rather than reservoirs for *C. ignefusalis* carry-over.

Cotesia flavipes and *C. sesamiae* were equally able to successfully parasitize *C. ignefusalis*. The fourth instar was the most suitable host for both parasitoids. *C. sesamiae* produced significantly more progeny than *C. flavipes*, but progeny development was faster for *C. flavipes* than for *C. sesamiae*. Temperature had no effect on percent parasitism, but for both parasitoid species, progeny developed faster at 26 and 30°C than at18 and 22°C.

ACKNOWLEDGMENTS

I wish to acknowledge Winrock International and the International Institute of Tropical Agriculture (IITA) through the African Women Leaders in Agriculture and Environment (AWLAE) programme for providing the scholarship which allowed me to do this work.

I specially thank my field supervisor, Dr O. Youm, Principal Entomologist (ICRISAT Niamey), who corrected the present work at all stages and helped me make progress through constructive criticisms, suggestions and encouragements. His contribution was not only technical but also administrative.

I am grateful to my IITA supervisor, Dr F. Schulthess, IPM Research Scientist (IITA, Cotonou) for the supply of parasitoids and also for his technical assistance particularly during data analysis and interpretation.

I express my gratitude to my University supervisor, Professor J. N. Ayertey (Crop Science Department, University of Ghana) for reviewing my work at ICRISAT, Niamey and also for providing administrative assistance during my visits to the University of Ghana and for correcting the draft thesis.

I would like to specially thank Dr F. E. Gilstrap, Associate Director (Texas Agricultural Experiment Station, Texas A&M University) who made my two-semester-stay at Texas A&M University a rich experience. I appreciate the teaching and helpful discussions on biological control from Dr J. W. Smith, Dr R. Whorton and Mrs P. Darnell, all of Texas A&M University

Special thanks to Dr E. Owusu (ICRISAT Niger) for his valuable advice and suggestions.

I appreciate the technical contribution of the ICRISAT Niamey Crop Protection Division staff, namely Maliki Yacouba, Idy Saley, Issoufou Manzo, Mamoudou Moussa and Issa Saley during the field and laboratory work.

Special thanks to the Computer Service Unit at ICRISAT, particularly S. Abdou, K. Amany and Mrs B. Mane for sharing their knowledge and experience in using microcomputers, to ICRISAT Niamey for providing the facilities for doing this work, to the Department of Zoology, University of Ghana, for accepting my enrolment as a Ph.D. student and finally to my husband, Seini Yaye, for his constant moral support, and for being so patient.

COPYRIGHT

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

Table Page

LIST OF FIGURES

Figure Page

CHAPTER ONE

INTRODUCTION

Food crops in the West African Sahelian Region are mainly cereals, namely sorghum and millet which constitute over 90% of the total agricultural production (Nwanze, 1981, 1985; FAO and ICRISAT, 1996).

The four major millets grown for food in Asia and Africa are pearl millet, *Pennisetum glaucum* (L.) R. Brown [= *P. americanum* L. = *P. typhoïdes* (Burm.) Staph and Hubb]; foxtail millet, *Setaria italica* Bauv.; proso millet, *Panicum miliaceum* L.; and finger millet, *Eleusine coracana* Gaertn (Nwanze, 1988). The world production of all millet crops is about 28 million t., of which 46.27 % is produced in Africa (FAO and ICRISAT, 1996). Among the different millet species, pearl millet (*Pennisetum glaucum*) occupies 46% of the production area and accounts for nearly 40% of total production (Rachie, 1975; Rachie and Majmudar, 1980). Seventy percent of African pearl millet is grown in West Africa, with an average annual grain yield of 300-650 kg/ha (Nwanze, 1988; FAO and ICRISAT, 1996). The major pearl millet producers in West Africa are Nigeria (31 % of the African prod uction), Niger (12 %), Mali, Chad, Senegal and Burkina Faso (Spencer and Sivakumar, 1987). In Africa, pearl millet is primarily grown for its grain to make couscous, dough (tô), porridge, cakes and beer for human consumption. Other parts like the stalks are used as building material for granaries, fencing, and feed for livestock. In Niger, pearl millet is cultivated on approximately 3.5 million hectares, but average grain yield is low (250 kg/ha) (Jika and Ouendeba, 1985). The low productivity of pearl millet is largely due to the harsh environment in which it is grown (low and erratic rainfall and poor soils) (Maiti and Bidinger, 1981; ICRISAT, 1993), and to biotic factors including insects and diseases.

About a hundred insect species are known to attack millet (Ajayi, 1985). Some major field pests include the millet stem borer (MSB), *Coniesta ignefusalis* Hampson (Lepidoptera: Pyralidae) and the head miner *Heliocheilus (Raghuva) albipunctella* de Joannis (Lepidoptera: Noctuidae) (Nwanze, 1985; Gahukar, 1984, 1992; ICRISAT, 1984, 1988a, 1988 b, 1995).

C. ignefusalis occurs across the Sahel belt of West Africa, from Senegal through Niger and Northern Nigeria to Chad (Risbec, 1950; Harris, 1962; Breniere and Coutin, 1969; Breniere, 1971; Gahukar, 1981, 1992; Dakouo and Lankoande, 1992; Bouchard et al., 1993). Its preferred host plant is pearl millet, but larvae also feed on sorghum (*S. bicolor* (L.)), maize (*Zea mays* L.), sugarcane (*Saccharum officinarum* L.), and on wild grasses like *Panicum maximum* Jacquin and *Andropogon* sp. (Harris, 1962, 1989; ICRISAT, 1983). In Niger, the family Gramineae contains the largest numbers of *C. ignefusalis* alternate host plant species. These are *Pennisetum purpureum* (Schumach), *Andropogon gayanus* Kunth, *Aristida stipoides* Lam., *Pennisetum pedicellatum* (Trin), *Sorghum vulgare* L.) Moench (Youm, 1990; Youm and Gilstrap, 1993). Other common hosts include *Peritrophe bicalyculata* (Retz.) Nees (Acanthaceae), *Corchorus tridens* L.(Tiliaceae) and *Achyranthes aspera* L. (Cyperaceae) (Youm, 1990). Investigations on alternate host plants of the MSB were mainly concerned with the presence or absence of the insect on observed plants. Little is known about oviposition preference, and larval survival on its alternate host plants.

Severe stem borer infestations in pearl millet have been reported from a number of locations, but there are very few reliable quantitative estimates of resultant crop losses

(Taneja and Nwanze, 1989). Assessment of crop losses due to insect attack is essential in determining pest status, economic threshold levels and options for pest control (Bardner and Fletcher, 1974; Taneja and Nwanze, 1989).

Control measures to reduce the losses due to stem borers include chemical control, cultural control, habitat management, host plant resistance, and biological control. Chemical control of stem borers is inefficient due to the boring behavior of the larvae (Harris, 1962). This makes timing insecticide application to coincide with the hatching of larvae a difficult task (Nwanze, 1985). Insecticide applications are also too expensive, thus not economical for low-income West African farmers (Uvah and Ajayi, 1989; Ajayi, 1990).

The main cultural practice against *C. ignefusalis* consists of destroying crop residues after harvest (Sagnia, 1983; Ndoye and Gahukar, 1987). Harris (1962) reported that early stem borer attack is noticeably more severe on crops grown near villages than on those more distant from villages, because of post harvest crop residues stored in these villages. However, crop residue destruction practice is hardly applicable by farmers who need stalks for fencing and for feeding and bedding livestock.

Habitat management through trap plants and soil nutrient management constitute another control option against stem borers. Surveys carried out by the International Institute of tropical Agriculture (IITA) in Ghana, Cameroon and Cote d'Ivoire showed that stem borer incidence in maize field decreased significantly with abundance of wild grasses in the vicinity of a field (Schulthess et al., 1997). It was concluded that many of the most abundant wild grass species act as trap plants rather than being reservoirs for pests. Ajayi (1990) reported that stem borer damage of sole crop dauro millet was low with low rates of fertilizer and increased with an increase in the rate of nitrogen applied.

Results from laboratory and greenhouse experiments suggested that some soil nutrients are either positively (N) or negatively (K, Si, Mg, Na) related to pest infestation in maize (Setamou et al., 1993).

Host plant resistance may reduce *C. ignefusalis* attacks but stem-borer-resistant varieties are not yet available (Leuschner et al., 1985; Ajayi, 1986; Lukefahr, 1990; Nwanze and Harris, 1992). Nwanze (1985) reported that the tillering ability of certain millet varieties could be a tolerance mechanism for minimizing losses due to *C. ignefusalis*.

Biological control has much potential in pest management. The natural enemies which are nowadays used are specific to the target pest or to a small group of related species. They are often capable of providing long term suppression and are unlikely to lose effectiveness through development of resistance in their hosts (Greathead, 1987). Many approaches have been described for biological control. Augmentation biological control may enhance the impact of native natural enemy species by raising their number early or late in the season. This requires breeding of natural enemies in insectaries and carefully-timed releases of sufficient numbers of individuals to prevent an increase in the pest population above the economic threshold (Greathead, 1987). Augmentation biological control has only been successful in large scale organized agriculture and does not appear suitable for scattered small-holder agriculture (Greathead, 1988). Microbial control based on application of pathogens as a pesticide is a form of augmentation biological control where cost factors can be more favorable (Greathead, 1990). Some important pathogens include *Nosema* sp studied at ICIPE, Kenya against *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) (Odindo, 1991; ICIPE, 1992), and *Bacillus thuringiensis* Berlinger used in Kenya against the same borer (Brownbridge, 1991). IITA, Benin, is presently testing some endophytic strains of the fungus *Boveria bassiana* Sandhu (Hyphomycetes) for control of stem borers in West Africa (Schulthess et al., 1997).

Conservation biological control may increase the survival of existing natural enemies by habitat manipulation to provide refuges and food for parasitoids. This can be accomplished by providing facilities that are needed for natural enemy protection, breeding, etc., or by avoiding control measures which adversely affect insect pest abundance (Mohyuddin, 1991). For example, Betbeder-Matibet (1989) showed that soil treatment with pesticides can destroy ants and other predators inhabiting the soil, and subsequently increase damage by *Eldana saccharina* Walker (Lepidoptera: Pyralidae) to sugarcane.

Classical or importation biological control consists of finding a coevolved natural enemy from the aboriginal home of a pest and reuniting the natural enemy with its natural host in the new habitat where the pest has been accidentally introduced (Wiedenmann and Smith, 1993). This biological control approach has been effective against a considerable number of insect pests and weeds (Debach and Rosen, 1991). Natural enemy introductions have been made against stem borers since 1914 (Greathead, 1990). There is also the possibility of natural enemy redistribution or exchange, i.e. the introduction of natural enemies which are present in only part of the distribution area of a native pest (Greathead, 1991; Mohyuddin, 1991; Schulthess et al., 1997). Such intra-regional introductions have been reported by Greathead (1990), and concerned the introduction of *Sturmiopsis parasitica* (Currand) (Diptera: Tachinidae) from South-East and West Africa to East Africa against *E. saccharina* Walker (Lepidoptera: Pyralidae). Other successful examples were *Pediobus furvus* Gahan (Hymenoptera: Eulophidae) introduced from East Africa to Madagascar against *Sesamia calamistis* Hampson (Lepidoptera:

Noctuidae) (Schulthess et al., 1997), and the braconid *Cotesia sesamiae* (Cameron) which has been successful against *S. calamistis* in Mauritius and Reunion (Greathead, 1971 in Greathead, 1987) .

A different approach to classical biological control is the new association strategy, which uses a natural enemy against a host with which it has no coevolutionary history (Wiedenmann et al., 1992). In the case where pest status is not due to pesticide use, but due to the inefficiency of the extant natural enemy fauna to suppress native borer species, introduction of a new association parasite species may be the most fruitful approach to biological control (Smith et al., 1993). One example of successful new association biological control against stem borers is the movement of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) from Asia to control the American sugarcane borer *Diatraea saccharalis* (F.) (Lepidoptera: Pyralidae) (Wiedenmann et al., 1992; Smith et al., 1993; Wiedenmann and Smith, 1995). Classical biological control has proved to be successful especially in areas where a pest is recently introduced (Nwanze, 1981). Both sorghum and millet are indigenous to Africa, and West Africa is a centre of origin of both cereals (Bowden, 1976). *C. ignefusalis* is well adapted to pearl millet which is also its native host (Nwanze, 1981). Youm (1990) studied the impact of natural enemies of the MSB using exclusion cages. He showed that extant natural enemies were not effective in controlling *C. ignefusalis* on millet. Earlier, Ndoye (1980) reported that the predation-parasitism level of *C. ignefusalis* remains low during the crop season, and the efficiency of natural enemies is further lowered during the off season when larvae enter diapause. Thus in West Africa, there is a need for studying a new association biological control against the MSB. *C. flavipes*, which has proved to be efficient against other stem borers in other continents, seems to be an appropriate candidate for such studies. The success of *C. flavipes* in new association biological control results from its capacity of developing ecological races or strains that are also adapted to searching different host plants infested by stem borers and overcoming the host immune system (Mohyuddin et al., 1981). The effectiveness of geographical races of local parasitoids such as *C. sesamiae* (Cameron) (Hymenoptera: Braconidae) should also be examined for possible redistribution in West Africa (Schulthess et al., 1997).

OBJECTIVES OF THE STUDY

The main objective of this work was to investigate *Coniesta ignefusalis* development on artificial diet, its larval infestation and damage on pearl millet and on some alternate hosts, and to study its suitability as a host for the development of *Cotesia flavipes* and *C. sesamiae*.

Specific objectives

1. Study the larval development and life-fertility tables of *C. ignefusalis* reared on artificial diet.

2. Quantify the relationship between *C. ignefusalis* larval infestation and damage on pearl millet.

3. Examine the suitability of two alternate hosts, *Andropogon gayanus* and *Pennisetum pedicellatum* for *C. ignefusalis* adult oviposition and larval development.

4. Investigate the suitability of *C. ignefusalis* for the development of *C. flavipes* and *C. sesamiae*.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Millet Stem Borer (MSB) *Coniesta ignefusalis*

2.1.1 Distribution and Systematics

C. ignefusalis Hampson was first reported as a cereal pest from Mali and Senegal by Risbec (1950) under the name of *Chilo pyrocaustalis* Hampson (Gahukar, 1990 a). Since then, it has been recorded regularly on pearl millet, particularly in the Sudano-Sahelian zone of West Africa where it causes considerable losses in late millet (Harris, 1962; Bhatnagar, 1983, 1984, 1985). Agnew (1987) reported that the species was first placed in the genus *Diatraea* (Hampson), *Proceras* and *Chilo* (Jepson), *Coniesta* (Risbec, 1960), *Haimbachia* (Mohyuddin and Greathead, 1970) and *Acigona*; afterwards it again became *Coniesta ignefusalis* (Hampson) (Youm, 1990).

2.1.2 Life History

Harris (1989) compiled information on sorghum and pearl millet stem borer research published since 1980, and summarized advances in knowledge on the biology, ecology and control of the main lepidopterous pest species including *C. ignefusalis*. Detailed studies on life-histories have been made by Harris (1962), and Bako (1977). The adult is easily distinguished from the other pyralid cereal stem borers by reference to the genitalia and also by the golden-brown forewings. In a caged experiment, most adults emerged from pupae between 19 oo hrs and 23 oo hrs. They mate on the night of emergence or early the following night. Most eggs are laid on the third night after emergence, and oviposition may continue up to the sixth night. Eggs are laid between the leaf sheath and the stem in batches of 20 to 50 and, in captivity, between 100 and 200 eggs are laid per female. The cream-yellow eggs begin to darken between 8 and 11 days and larvae hatch after a further 24 hours. At first, larvae remain clustered under the leaf sheaths but within 24 hours they begin to tunnel in the leaf sheath and underlying stems. Larvae rarely leave the protection of the leaf sheaths to crawl over the exposed surfaces of the plant. Some larval migration occurs between plants but the maximum spread from known oviposition sites is 1.20 m in the insectary and 1.8 m in the field. During the wet season, larvae complete development in 30-40 days. Diapause usually lasts from six to seven months and occasionally more than a year. The termination of diapause is closely associated with increasing rainfall, with its concomitant higher relative humidities and lower temperatures. There are usually six, but sometimes seven, larval instars and in all stages the larvae may be distinguished from the other pyralid stem borers by the setation of the ninth and tenth abdominal segments. A full grown larva measures 15-18 mm (Gahukar, 1989). The pupal stage lasts 7-13 days and three generations develop with an average life cycle of about 42 days under laboratory conditions of 28°C, relative humidity 80% and L:D 12:12. At Samaru (Nigeria), the first generation derives from the diapause larvae and occurs in May, following the onset of rains, while the adults of the second and third generations appear in July and September respectively. Some of the larvae produced by the third generation of adults enter a facultative diapause at the end of the rains (Harris, 1962).

2.1.3 Economic Importance

Among stem borers attacking millet, *C. ignefusalis* is the major species accounting for more than 92% of the total borer population (Gahukar, 1992). It is the most widespread and probably the most damaging insect pest wherever millet is grown (Ajayi, 1990). In 1985, stem borer infestation varied from 30 to 62% in Senegal, with population density of 15-89 larvae per 100 stems (Gahukar, 1989, 1990 b). Ajayi and Labe (1990) found that infestation by the second generation of stem borers was more damaging than infestation by adults emerging from the diapause population. Normally early sown crops are attacked by the first generation of larvae. These larvae, by killing the growing point, cause the production of dead hearts and loss of stand. Early millet is harvested before the adults of the second generation emerge, but late millet is more damaged by this generation. The stems are often so riddled by the feeding galleries of *C. ignefusalis* that the crop is rendered virtually useless (Harris, 1962). Leaf feeding symptoms have not been recorded in this insect species (Nwanze, 1988). Harris (1962) recorded a grain yield loss of 15% due to attack by *C. ignefusalis* on early gero millet at Kano (Nigeria). The late maturing millet species suffered higher levels of attack.

2.1.4 Crop Loss Assessment Methods

Several methods have been used to estimate crop losses due to insect attacks (Taneja and Nwanze, 1989): The incidence ratio technique is a quick and easy method for assessing crop damage by pests. It is usually expressed in percentages derived from actual count of individual insects or damage symptoms. However, it does not give actual loss value sustained by a crop, but an indication of the presence or the frequency of occurrence of a pest in an area. This technique has been used by ICRISAT (1981, 1984) to establish that in Niger both *C. ignefusalis* and *H. albipunctella* incidence were most severe in Niamey, Dosso and Maradi.

The visual score paired analysis method is a modified form of the incidence ratio method and uses the presence of pest attack in a paired analysis for comparing the yield capacity of undamaged samples. It has been used by Harris (1962) to study the effect of stem borer attack on maize, sorghum and millet in northern Nigeria. The assessment of loss at harvest was done by classifying stems into bored and unbored groups and evaluating their yield capacity.

Damage intensity loss ratio method applies the same measurement parameters as the visual score method, but goes one step further by quantifying the degree of infestation or amount of damage and relating this to yield (Nwanze, 1988). Similar techniques have been used by Youm (1990) who compared yield among attacked versus unattacked plants in a plot naturally infested with *C. ignefusalis.* This method is useful in describing rather than forecasting losses (James and Teng, 1979, in Youm, 1990). But it has the advantages of being simple and quick, despite yield variations due to soil fertility, availability of water, nutrients, light and effects of other pests (Walker, 1983).

Insecticide trials for estimating yield losses employ paired plot comparisons with one of each pair of plots being protected by insecticide (Nwanze, 1988; Bosque-Perez and Marek, 1991). This is still the simplest approach to measure crop losses. The results are often exaggerated estimates of actual losses due to insect damage since trials are carried out under well fertilized and monocropped conditions (Nwanze, 1988).

Artificial infestation method involves releasing insects in varying numbers per plant or plot and correlating damage and yield with insect densities. This method has also been used in comparing yield of resistant and susceptible varieties under insect infestations (Taneja and Nwanze, 1989).

For crop loss assessment, pests can be counted directly, or their effects on crop assessed indirectly as injury or damage (Walker, 1987). To estimate stem borer damage, the length of borer tunnel in the stem was frequently used. Counting the number of entry and exit holes, and the percentage of internodes bored were tested as alternatives to the measurement of total tunnel length (Ajayi and Uvah, 1989). The results showed that although both alternative methods take less time and labour, knowing the percentage of internodes bored would be preferred when screening a large number of entries in an epidemic situation.

2.1.5 Life tables

Life tables are basic components in the understanding of the population dynamics of a species (Southwood, 1978). They are a useful means of presenting a concise summary of population statistics such as mortality, survivorship, fecundity and fertility (Southwood, 1980). Fertility estimates allow calculation of the net reproductive rate R_o and the intrinsic or finite rate of natural increase r_c.

2.2 Parasitoids

2.2.1 Successful Parasitization

The sequence of processes leading to successful parasitization include habitat finding, host finding, host selection and acceptance, and host suitability and regulation (Smith et al., 1993). Habitat finding and host finding are based on tritrophic interactions between plants, pests and natural enemies, and are mediated by chemical cues referred to as allelochemicals. Allelochemicals can act as allomones, kairomones or synomones that guide the searching female parasitoid. Physical cues are also exploited by the parasitoids, particularly for stem borer finding. These physical cues can be discolouration or dead heart of stems, host frass, larval tunnel or an emergence window (Smith et al., 1993). Van Leerdam et al. (1985) found that host finding behaviour of *C. flavipes* Cameron is mediated by a water soluble substance present in the fresh frass of *D. saccharalis* F. (Lepidoptera: Pyralidae) larva. Ngi Song (1995) showed that the highest attractiveness to *C. flavipes* of infested maize plants over uninfested ones was the higher quantity of green leaf volatile, and an aldehyde present in the volatile blends of infested maize. Requisites for host selection and acceptance include host species, size, shape, texture, age, odour, behaviour and previous parasitization status (Smith et al., 1993). Mohyuddin (1972) reported that oviposition of the pupal parasite *Dentichasmias busseolae* Heinr. (Hymenoptera: Ichneumonidae) is stimulated by the presence of the frass of *C. partellus* Swinhoe (Lepidoptera: Pyralidae). The importance of host, host plant and parasite strain has been mentioned by Mohyuddin et al. (1981), and Inayatullah (1983). Hailemichael et al., (1994) reported that odour associated with *Diatraea saccharalis* pupae, and sound and/or vibration produced by the host are attractive to the female parasite *Xanthopimpla stemmator* Thunberg (Hymenoptera: Ichneumonidae).

A host is physiologically suitable when it provides adequate protection and food for complete parasitoid development (Smith et al., 1993). In non-coevolved host/parasitoid relationships, the hosts can be acceptable for oviposition, but are not suitable for or can encapsulate the majority of the parasitoid larval progeny (Smith et al., 1993). Encapsulation consists of the complete covering and eventually killing of the enclosed parasitoid by the host's immune system. Death of the encapsulated parasitoid progeny is due to oxygen deprivation or production of toxins within the encapsulation (Smith et al., 1993).

CHAPTER THREE

LARVAL DEVELOPMENTAL STAGES AND LIFE-FERTILITY TABLES OF *C. IGNEFUSALIS* REARED ON ARTIFICIAL DIET.

3.1 Introduction

C. ignefusalis is the only borer causing significant damage and yield loss to pearl millet, *P. glaucum* in Sub-Sahelian West Africa. It was first reported in West Africa by Risbec (1950, 1960). Its life history was described by Harris (1962), Bako (1977) and Betbeder-Matibet (1989). Harris (1962) observed that females lay eggs in batches between the leaf sheath and the stem. After hatching, larvae remain clustered before beginning to tunnel in the leaf sheath. Youm (1990) and Youm and Gilstrap (1994 a) reported that females oviposit mostly within leaf sheath of green millet plants, rarely on green or dry leaves, and almost never on dry millet stems. Host plants, mostly composed of Gramineae, were recorded by Youm (1990). Control methods including cultural, chemical, biological and host plant resistance have been studied by many authors (Ndoye, 1977; Adesiyun, 1983; Guevremont, 1983; Ajayi, 1985, 1990; Markham, 1985, Nwanze, 1985; Lukefahr et al., 1988; Nwanze and Mueller, 1989; Ajayi and Labe, 1990; Mamalo, 1990; Youm, 1990; Gahukar, 1992; Youm et al., 1993; Youm and Gilstrap, 1994 b). The potential for using pheromone to control *C. ignefusalis* has also been reported (Youm et al.,1993; ICRISAT, 1994; Youm and Beevor, 1995; Youm et al., 1997). Recent approach to the control of *C. ignefusalis* is based on the parasitoids of the "*flavipes* complex " (Hailemichael et al. 1997) through new association. Proper evaluation of natural enemies could be enhanced when the appropriate larval instar is used for suitability studies. Although Harris (1962) reported that *C. ignefusalis* has six to seven larval instars, no details were available on how to differentiate one instar from another. The life table which is another basic aspect of *C. ignefusalis* bio-ecology, has also not been investigated. Life tables are useful means of presenting a concise summary of population statistics such as mortality, survivorship and life expectancy (Deevey, 1947, in Youm, 1990). This study was conducted in the laboratory to determine precise larval instars of *C. ignefusalis* and certain life-table parameters such as the intrinsic rate of increase to improve rearing techniques. Before life table construction, male : female ratio was estimated and reproduction studies conducted to determine adult longevity, female fecundity, egg fertility and incubation period. The number of male / female adults to put together for optimizing egg production has also been investigated to improve rearing.

3.2 Materials and Methods

3.2.1 Laboratory rearing of the millet stem borer *Coniesta ignefusalis*.

A laboratory colony of *C. ignefusalis* was established from larvae and pupae collected from stems in millet farms near the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center located at Sadore, 45 km from Niamey (Niger). A hygrothermograph record showed that the laboratory temperature and relative humidity averaged 26 ± 1°C and 60 ± 2%, respectively. The photoperiod was L:D= 12:12. The field-collected larvae and pupae were reared on the tobacco budworm diet (Bioserv inc, NJ / Mix # 9782) (Table 3.1) in 15 ml plastic cups in the laboratory. Freshly emerged

C. ignefusalis adults were placed in a ratio of 5 males : 5 females, in oviposition cages (25 x 25 x 25 cm) covered with a nylon mesh and bottom 1 cm filled with wet sandy soil. Five 20 cm-long green millet stems with leaf sheaths were placed vertically on the wet sandy soil in the cage to simulate natural conditions. Cotton soaked with water was also placed inside the cages to provide additional moisture and high relative humidity. Millet stems were replaced every day and eggs counted, until all females died. Eggs were kept in 36 ml plastic vials inside buckets (32 x 32 cm diameter x height) covered with a lid, and bottom 1-cm filled with water to increase relative humidity. The vials with the eggs were kept above the water level to prevent wetting the eggs. Eggs were observed for hatching at 24 h intervals.

3.2.2 Determination of larval developmental stages

One hundred and seventy one-day-old larvae from the laboratory colony were individually reared in 15 ml plastic cups containing the commercial tobacco budworm diet (Bioserv inc, NJ / Mix # 9782) (Table 3.1). Larvae were transferred into fresh diet on a weekly basis as needed, until pupae formation. Pupae were removed from the diet, sexed and placed in plastic Petri dishes for daily observation of adult emergence. Larval head capsule widths were measured daily with a micrometer at 50 x magnification under a "Wild" stereo microscope, until pupation or death. Body length of first-to-third-instar larvae was also measured using the same equipment. For older larvae, a ruler was used. Molting was observed twice a day, based on cast head capsules, which were recorded. Cast head capsule widths were subsequently measured. The molted head capsules of the last instars could not be measured because they were always split into two along the

Table 3.1. Artificial diet used for rearing *C. ignefusalis* (Bioserv inc. New Jersey, USA, Mix 9782).

	Components	*Quantities*
	Water	831 ml
Pack A	Agar	24.0 g
Pack B	Dry mixture	126.6 g
	grown wheat germ	
	- Sucrose	
	- Cellulose	
	- Salt mixture Wesson	
	- Methyl-parahydroxybenzoate	
	- Sorbic acid	
	- Cholesterol	
	- Aureomycin	
	- Vitamin E Acetate	
	- Casein	
	- Corn oil	
Pack C	Potassium hydroxide solution	4.8 g
Pack D	Vitamins	12.9 g
	- Vitamin fortification mixture	
	- Ascorbic acid	

Directions for preparing 1 litre of diet:

1. Fully boil agar with water for one minute while stirring continuously.
2. Transfer agar solution to blender, cool to 70 °C and add pack B, C and D.
3. Blend for one minute or until mixed thoroughly. Fill plastic rearing cups to about one third their volume.
5. Allow the diet to return to room temperature before introducing the larvae. Store unused diet in refrigerator.

epicranial suture at the time of molting. Head capsule colour and age of larvae were also recorded at the time of molting. The age, body length, head capsule colour, and widths of larvae were used to characterize different instars. Where appropriate, an analysis of variance was performed and the different means separated using the Duncan's multiple range test. The frequency distribution of head capsule widths was plotted to verify the number of larval instars. Scatter diagrams of head capsule widths with body length and larval age were also plotted. The conformity to Dyar's rule was tested using the diagram of the logarithm of the mean head capsule widths against instar numbers. The significance of the difference between observed and calculated head capsule widths was evaluated using a t-test. From the molted head capsule width measurements a histogram of the frequency distributions was drawn.

3.2.3 Life-fertility table of *C. ignefusalis* reared on artificial diet

Sex-ratio determination

The experiment was conducted in 1994/95 at the entomology laboratory (12 hrs light; 26 ± 1°C; 60 ± 2 % Rh) of the International Crop Research Institute for the Semi-Arid Tropics Sahelian Centre (ISC). It consisted of mass rearing a hundred newly emerged larvae from a laboratory colony initiated from field-collected larvae and pupae, in a 1.2 litre plastic rearing cup provided with the artificial tobacco budworm diet (Bioserv inc, NJ / Mix # 9782) (Table 3.1). There were 10 replications. The diet was changed twice a week and the number of surviving larvae recorded until pupation. Pupae were sexed and observed every 24 h until adult emergence. The number of pupae and adults was compared between sex using t-test.

Adult longevity, female fecundity and egg fertility

Six sets of 10 oviposition wire-gauze cages (25 x 25 x 25 cm), and one set of seven cages were used for longevity and fecundity studies. Cages were covered with nylon mesh with the bottom 1 cm filled with wet sandy soil. The first set contained 1 male: female *C. ignefusalis* adult pair per cage, the second set had two pairs per cage, the third set had three pairs per cage, the fourth had four pairs per cage, the fifth and the sixth sets contained five and six male: female pairs per cage. The last set of seven cages had 10 pairs each. All specimens used were newly emerged adults from a laboratory colony initiated from field-collected larvae and pupae, and reared on the artificial tobacco budworm diet (Bioserv inc, NJ / Mix # 9782) as described in section 3.2.1. Mean adult longevity, female fecundity, preoviposition and oviposition periods were computed using the analysis of variance (Proc GLM, Sas Institute, 1987) and separated at 5 % level of probability, using the Least Significant Difference (LSD) test (SAS Institute, 1987).

Fertility was determined using eggs obtained from the set of 10 cages with 1 male: female pair. Eggs laid per cage per day were kept separately in 36 ml plastic cups inside plastic incubation buckets (32 x 32 cm, diameter x height) covered with a lid with the bottom 1-cm filled with water to increase moisture. They were observed for hatching every 24 h, and the number of neonate larvae counted. Egg fertility was estimated as the number of eggs hatched over the number of eggs laid. The egg incubation period was also recorded.

Life tables

Two cohorts of neonate larvae (100 and 70 larvae, respectively) were placed individually in 15 cm^3 plastic rearing cups provided with the artificial tobacco budworm diet (Bioserv inc, NY / Mix # 9782). The diet was changed twice a week using new rearing cups. The number of surviving larvae was recorded every 24 h until pupation and adult emergence. Larval instars were determined from cast head capsules' removal. Mortality and fertility data were summarized in the form of age-specific life fertility-tables according to the procedure described by Southwood (1978). The columns included in the life-fertility tables were:

x, pivotal age (number of days at beginning of each stage),

l_x, number surviving at beginning of age class x,

d_x, number dying in age interval x,

q_x, the apparent mortality during age class x = d_x/l_x,

r_x, the real mortality at age interval x = d_x/l_{x1},

L_x, the survivorship of age class x = l_x/l_{x1}

and m_x, the number of female offspring produced by females in each age class x. m_x was recorded as the number of females in that age class multiplied by the mean fecundity per female per day obtained from the set of 1 male: 1 female adult pair of the reproduction study and by the proportion of females expressed in the sex-ratio calculated above. Since this study was initiated with neonate larvae, the number of eggs (l_{x1}) was estimated by dividing the number of first instar larvae (l_{x2}) by the proportion of egg hatching obtained from the egg fertility study. The column Lxi was used to construct survivorship curves for both cohorts.

From the life fertility tables, the following population reproductive statistics were calculated:

net reproductive rate (R_0), number of females per female = $l_x m_x$,

cohort generation time (T_c) = $x l_x m_x / l_x m_x$, capacity for increase (r_c), number of females per female per unit of time (per day) = $\log_e(R_o)/T_c$,

and finite rate of increase (λ_c), number of times the population multiplies itself per day = $\exp(r_c)$.

The real mortality (r_x) and the net reproductive rate (R_o) were compared between the two cohorts using Kruskal-Wallis test (χ^2, $P = 0.05$) (SAS Institute, 1987).

3.3 Results

3.3.1 Determination of larval developmental stages

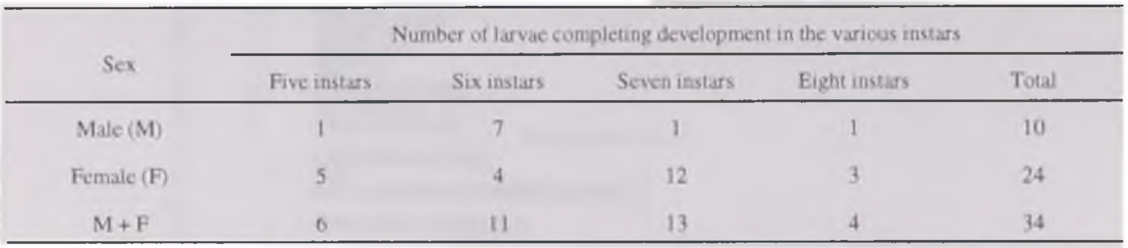
The head capsule width ranged from 0.2 to 2 mm, and body length from 1.5 to 32 mm (Table 3.2). Head capsule colour was initially yellow, and darkened progressively to brown. All means were significantly different from one instar to another, even though there were instances of periodic overlapping in the range values for the head capsule widths, body length, and age of the fifth, sixth and seventh instar larvae (Table 3.2). This indicated that some of the larvae had undergone an intermediate molting, as shown in Table 3.3, where molted head capsule count gave 38.2% of larvae completing development and pupating in seven instars, 32. 4% in six, 17.7% and 11.8% in five and eight instars, respectively. However, 70% of the male pupae completed larval development in six instars, and 50% of the females in seven instars. The frequency distribution of the head capsule widths (Fig. 3.1) showed seven non-overlapping instar groups, and also depicted an intermediate molting. Intermediate molting was also seen in the scatter diagrams of head capsule widths versus body length and larval age (Fig.3.2).

Table 3.2. Larval stage determination for *C. ignefusalis*, based on head capsule width, body length and age

Head Colour	Head capsule width (mm)		Body length (mm)		Age (days)		Instar
	Range	Mean (± SE)	Range	Mean (± SE)	Range	Mean (± SE)	
Yellow-brown	0.2 - 0.3	0.23 ± 0.003 g	1.5 - 3.5	2.19 ± 0.036 g	1 - 10	4.1 ± 0.16 g	first
dark-brown	0.35 - 0.4	0.37 ± 0.003 f	3 - 6	3.80 ± 0.052 f	3 - 17	7.7 ± 0.23 f	second
Orange-brown	0.45 - 0.6	0.51 ± 0.007 e	4 - 11	5.64 ± 0.147 e	7 - 21	11.6 ± 0.31 e	third
Orange-black	0.65 - 0.9	0.79 ± 0.010 d	6.5 - 14	10.08 ± 0.213 d	11 - 30	18.5 ± 0.38 d	fourth
Brown	0.95 - 1.25	1.09 ± 0.010 c	10 - 23	14.62 ± 0.217 c	16 -31	22.3 ± 0.30 c	fifth
Brown	1.3 - 1.5	1.34 ± 0.013 b	14 - 25	18.72 ± 0.499 b	20 - 40	26.7 ± 0.86 b	sixth
Brown	1.4 - 2.0	1.64 ± 0.017 a	15 - 32	22.87 ± 0.268 a	20 - 40	32.6 ± 0.40 a	seventh

Means followed in the column by the same letter are not significantly different ($P < 0.05$), Duncan's multiple range test (SAS Institute, 1987).

Table 3.3. Number of *C. ignefusalis* larvae completing development in the various instars, based on measurements of molted head capsules



Sex	Number of larvae completing development in the various instars				
	Five instars	Six instars	Seven instars	Eight instars	Total
Male (M)	1	7	1	1	10
Female (F)	5	4	12	3	24
M + F	6	11	13	4	34

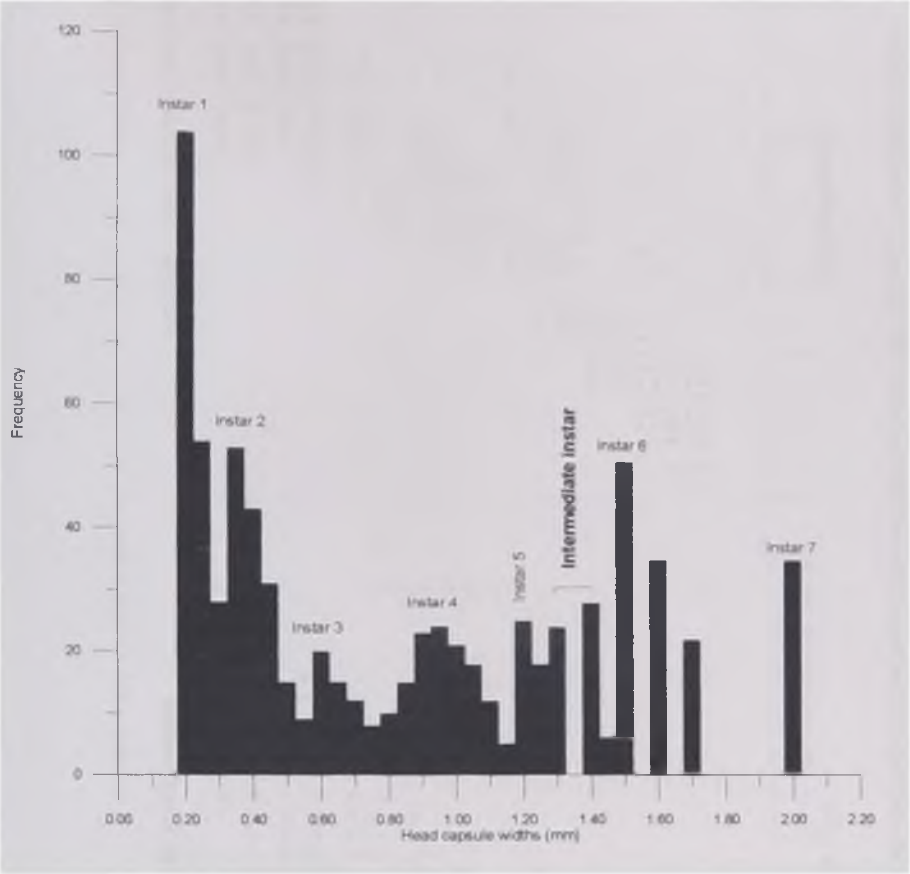


Fig. 3. 1. Frequency distribution of head capsule widths of C. ignefusalis reared on artificial diet

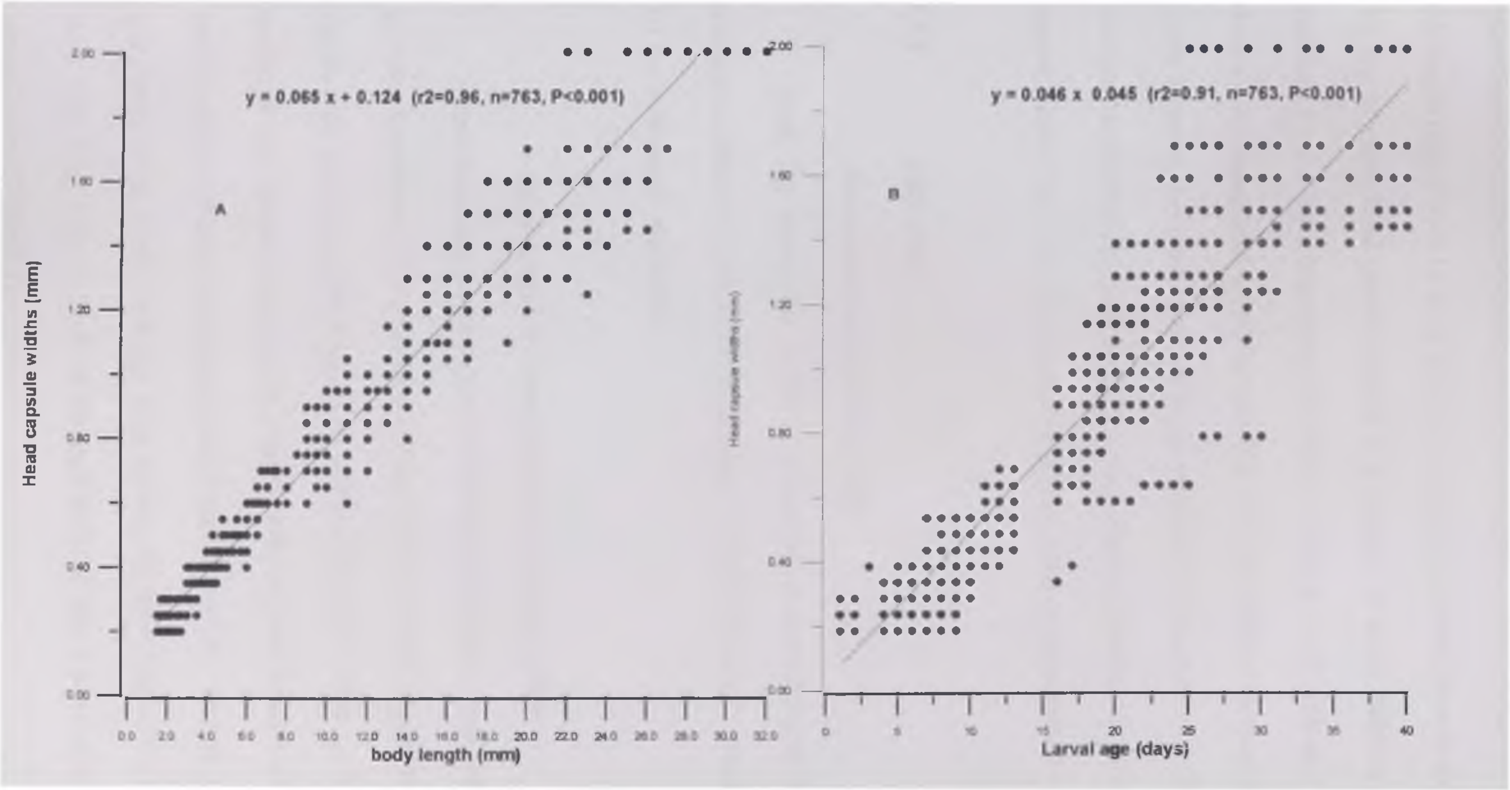


Fig. 3. 2. Scatter diagrams of head capsuie widths with body lengths (A) and age (B) of C. ignefusalis larvae

Higher dispersion of head capsule values was obtained for sixth to seventh instars which body length ranged from 15 to 32 mm (Fig. 3.2A) and age from 20 to 40 days (Fig. 3.2B). The log of mean head capsule widths as a function of instar numbers was very well described by the linear regression equation $y = 0.14x - 0.73$ with an r^2 value of 0.99 where $y = \log$ (mean head capsule width) (Fig. 3.3). The ratio of increase in head capsule widths in successive instars indicated a geometrical progression in larval growth which conformed to Dyar's rule (Table 3.4). From the frequency distribution of the molted head capsule widths (Fig. 3.4), seven non-overlapping instar groups could be separated.

3.3.2 Life table

Determination of adult sex-ratio

Table 3.5 shows that 31.5% of reared larvae formed pupae but only 16.1% emerged as adults (51.11% of the total pupae formed). The male : female sex-ratio was 1:1 for both pupae and adults.

Adult Longevity, female fecundity and egg fertility

Adult longevity was not significantly different between male and female and did not vary significantly due to variation in the number of male: female pairs (Table 3.6). Significantly more eggs per female were laid in cages with 1 male : 1 female pairs. The number of eggs laid per female was not significantly different in cages with 2 to 10 male: female pairs. For all adult pairs, oviposition began the second day after adult emergence, and continued up to the sixth day, with significantly more eggs laid on the second and third days (Fig. 3.5); 65.38 % of the eggs hatched after a mean incubation period of almost 7 days (Table 3.7).

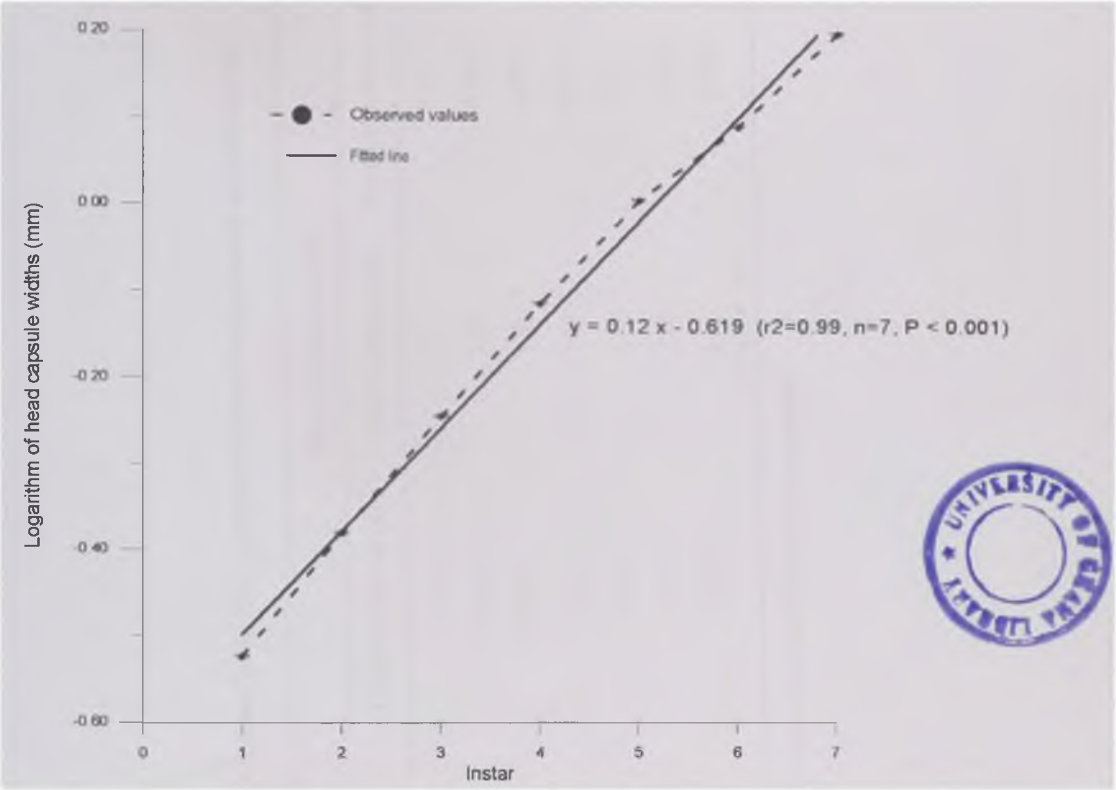


Fig. 3. 3. Growth progression of the head capsule widths of C. ignefusalis reared on artificial diet

Table 3.4. Conformity to Dyar's rule for *C. ignefusalis* larval instars reared on artificial diet.

Larval instars	Head capsule widths		
	Observed mean (mm)	Ratio of increase	Predicted mean (mm)[1]
First	0.230	-	0.257
Second	0.372	1.62	0.355
Third	0.512	1.38	0.490
Fourth	0.790	1.54	0.676
Fifth	1.090	1.38	0.933
Sixth	1.342	1.23	1.288
Seven	1.637	1.22 Average = 1.39	1.778

[1] $y = 0.14\ x - 0.73$ where $y = \log(\text{mean head capsule width})$, x = instar number.

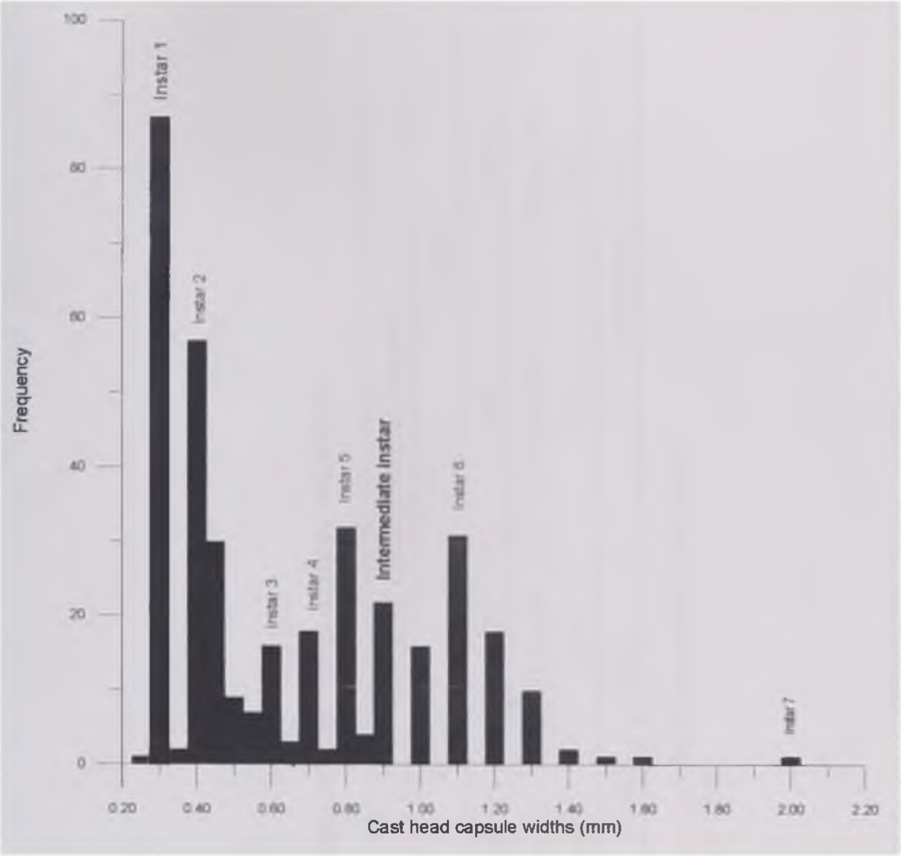


Fig. 3.4. Frequency distribution of molted head capsule widths of C. ignefusalis reared on artificial diet

Table 3.5. Sex-ratio for pupae and adults of *C. ignefusalis* reared on artificial diet.

No of replications	Percentage of individuals obtained (Mean ± SE)			
	Pupae		Adults	
	male	female	male	female
10 (1000)	14 ± 2.10 a (140)	17.5 ± 1.78 a (175)	8.5 ± 1.71a (75)	10.5 ± 1.45 a (86)
	Sex-ratio = 1 : 1.25		Sex-ratio = 1 : 1.09	

Pupae or adult means followed by the same letter are not significantly different (P > 0.05, t test).
Numbers in parentheses indicate total number of larvae.

Table 3.6. Fecundity and longevity of *C. ignefusalis* reared on artificial diet

No of male: female pairs	Mean ± SE (range)					
	Total No of eggs per female	No of eggs per female per day	Pre-oviposition period in days	Oviposition period in days	Female longevity in days	Male longevity in days
1	163.5 ± 40.92 a (36 - 382)	36.33 ± 9.33 a (0 - 71.2)	1.4 ± 0.16 a (1 - 2)	1.80 ± 0.36 b (1 - 4)	4.5 ± 0.27 a (3 - 6)	4.9 ± 0.38 a (3 - 7)
2	96.65 ± 24.81 b (11 - 280)	21.48 ± 5.5 b (0 - 50.1)	1.2 ± 0.15 ab (1 - 2)	2.33 ± 0.33 ab (1 - 4)	4.5 ± 0.17 a (4 - 5)	4.6 ± 0.16 a (4 - 5)
3	65.2 ± 16.67 b (9 - 180)	15.90 ± 4.13 b (0 - 41.44)	1.3 ± 0.15 ab (1 - 2)	1.70 ± 0.3 b (1 - 4)	4.2 ± 0.39 a (3 - 7)	4.2 ± 0.39 a (3 - 7)
4	62.87 ± 9.5 b (21 - 110)	15.34 ± 3.91b (0 - 29.7)	1.3 ± 0.15 ab (1 - 2)	1.80 ± 0.25 b (1 - 4)	4.1 ± 0.28 a (3 - 6)	4.2 ± 0.29 a (3 - 6)
5	59.68 ± 9.57 b (15 - 130)	12.70 ± 3.4 b (0 - 33.9)	1.2 ± 0.13 ab (1 - 2)	2.10 ± 0.15 ab (2 - 4)	4.8 ± 0.29 a (4 - 6)	4.5 ± 0.27 a (4 - 6)
6	82.75 ± 13.28 b (20 - 149)	17.61 ± 3.73 b (0 - 44.97)	1 b (1 - 1)	2.80 ± 0.29 a (1 - 3)	4.7 ± 0.3 a (3 - 6)	4.5 ± 0.22 a (3 - 5)
10	60.59 ± 6.51 b (39 - 79)	13.68 ± 4.03 b (0 - 47.79)	1 b (1 - 1)	2.43 ± 0.3 ab (1 - 3)	4.4 ± 0.3 a (3 - 5)	4.4 ± 0.3 a (3 - 5)

Means in the same column followed by the same letter are not significantly different ($P > 0.05$) (LSD test).
Longevities followed in the same row by the same letter are not significantly different at $P = 0.05$

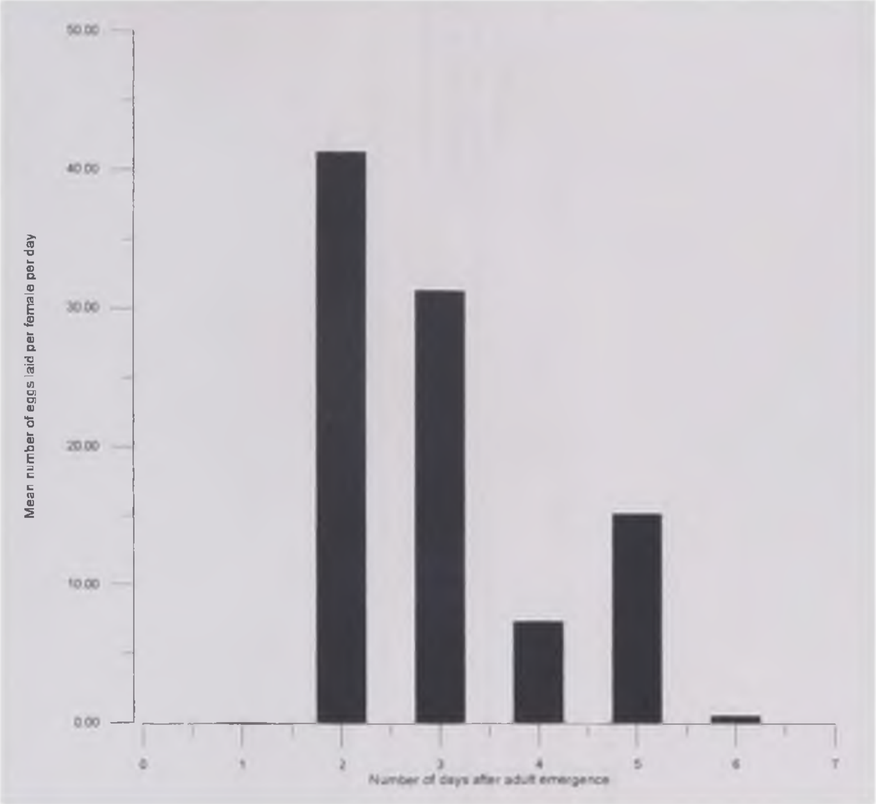


Fig. 3.5. Variation in the mean number of eggs laid per day by C. ignefusalis female reared on artificial diet

Table 3.7. Egg fertility and incubation period for *C. ignefusalis* reared on artificial diet.

Mean ± SE (range)		
Total fecundity	Egg fertility (%)	Incubation period (days)
163.5 ± 40.92 (36 - 382)	65.38 ± 6.79 (45.45 - 100)	6.89 ± 0.31 (6 - 9)

Parentheses indicate the range of the mean values

Life-fertility tables

Life tables (Table 3.8) and the derived survivorship curves (Fig. 3.6) showed high egg survival of 65%. The survivorship curves for cohorts 1 and 2 presented the same pattern, with heavy mortality acting at the early larval stages (first to third stages), corresponding to a type IV curve (Southwood, 1978). The real mortality was not significantly different between cohorts 1 and 2 ($\chi^2 = 1.3423$; df = 1; P = 0.2466). The population reproductive parameters calculated from the life tables are summarized in Table 3.9. The net reproductive rate (R_0) was not significantly different between cohorts 1 and 2 ($\chi^2 = 0.\ 239119$; DF = 1; P = 0.5895). Therefore values were pooled together and the mean R_0 was 24.41 females / female. The finite rate of increase λ_c was 1.0833 and the capacity for increase r_c was 0.07 females / female per day in a cohort generation time of 62.95 days.

3. 4 Discussion

The results obtained in the present study showed that head capsule width, colour, body length and age can be successfully used for *C. ignefusalis* larval instar determination. The range of *C. ignefusalis* larval instars (5 to 7) obtained in the present study was greater than the numbers (6 to 7) reported by Harris (1962). This difference might result from the artificial diet used in the present study, which might be less suitable than the millet plants used by Harris (1962), and thus resulted in some individuals with prolonged development time passing through an intermediate molt between the fifth and the sixth instars.

Table 3.8. Life-fertility tables for *C. ignefusalis* reared on artificial diet.

Stage	x	lx	dx	qx	rx	Lx	mx	Lx mx	x Lx mx
					Cohort 1				
Egg	0	153	53	0.35	0.35	1.00			
1st	8	100	2	0.02	0.01	0.65			
2nd	11	98	72	0.73	0.47	0.64			
3rd	15	26	3	0.12	0.02	0.17			
4th	19	23	1	0.04	0.01	0.15			
5th	22	22	0	0.00	0.00	0.14			
6th	24	22	0	0.00	0.00	0.14			
7th	31	22	3	0.14	0.02	0.14			
Pupa	42	19	1	0.05	0.01	0.12			
Adult	56	18	0	0.00	0.00	0.12	36.33	4.27	239.36
	57	18	0	0.00	0.00	0.12	27.25	3.21	182.74
	58	18	0	0.00	0.00	0.12	24.34	2.86	166.09
	59	18	2	0.11	0.01	0.12	24.34	2.86	168.95
	60	16	1	0.06	0.01	0.10	18.17	1.9	114.01
	61	15	0	0.00	0.00	0.10	11.99	1.18	71.71
	62	15	1	0.07	0.01	0.10	18.17	1.78	110.45
	63	14	0	0.00	0.00	0.09	0.00	0.00	0.00
	64	14	0	0.00	0.00	0.09	0.00	0.00	0.00
	65	14	0	0.00	0.00	0.09	0.00	0.00	0.00
	66	14	0	0.00	0.00	0.09	11.99	1.10	72.41
	67	14	0	0.00	0.00	0.09	11.99	1.10	73.51
	68	14	1	0.07	0.01	0.09	11.99	1.10	74.60
	69	13	0	0.00	0.00	0.08	0.00	0.00	0.00
	70	13	0	0.00	0.00	0.08	0.00	0.00	0.00
	71	13	0	0.00	0.00	0.08	0.00	0.00	0.00
	72	13	13	1.00	0.08	0.08	0.00	0.00	0.00
								21.36	1273.82

Table 3.8. Continued

Stage	x	lx	dx	qx	rx	Lx	mx	Lx mx	x Lx mx
Cohort 2									
Egg	0	107	37	0.35	0.35	1.00			
1st	8	70	19	0.27	0.18	0.65			
2nd	11	51	22	0.43	0.21	0.48			
3rd	15	29	7	0.24	0.07	0.27			
4th	19	22	2	0.09	0.02	0.21			
5th	21	20	1	0.05	0.01	0.19			
6th	24	19	2	0.11	0.02	0.18			
7th	28	17	1	0.06	0.01	0.16			
Pupa	47	16	0	0.00	0.00	0.15			
Adult	58	16	0	0.00	0.00	0.15			
	59	16	0	0.00	0.00	0.15	18.17	2.72	160.30
	60	16	0	0.00	0.00	0.15	18.17	2.72	163.02
	61	16	1	0.06	0.01	0.15	18.17	2.72	165.74
	62	15	1	0.07	0.01	0.14	24.34	3.41	211.56
	63	14	1	0.07	0.01	0.13	18.17	2.38	149.77
	64	13	0	0.00	0.00	0.12	24.34	2.96	189.27
	65	13	0	0.00	0.00	0.12	27.25	3.31	215.21
	66	13	1	0.08	0.01	0.12	21.80	2.65	174.81
	67	12	1	0.08	0.01	0.11	24.34	2.73	182.89
	68	11	1	0.09	0.01	0.10	18.17	1.87	127.02
	69	10	0	0.00	0.00	0.09	0.00	0.00	0.00
	70	10	0	0.00	0.00	0.09	0.00	0.00	0.00
	71	10	0	0.00	0.00	0.09	0.00	0.00	0.00
	72	10	1	0.1	0.01	0.09	0.00	0.00	0.00
	73	9	0	0.00	0.00	0.08	0.00	0.00	0.00
	74	9	9	1.00	0.08	0.08	0.00	0.00	0.00
								27.46	1739.58

x, pivotal age (number of days at beginning of each stage); l_x, number surviving at beginning of age class x; d_x, number dying in age interval x; q_x, the apparent mortality during age class x = d_x / l_x;
r_x, the real mortality at age interval x = d_x / l_x. L_x, the survivorship of age class x = l_x / l_{x1};
m_x, the number of female offspring produced by females in each age class x.

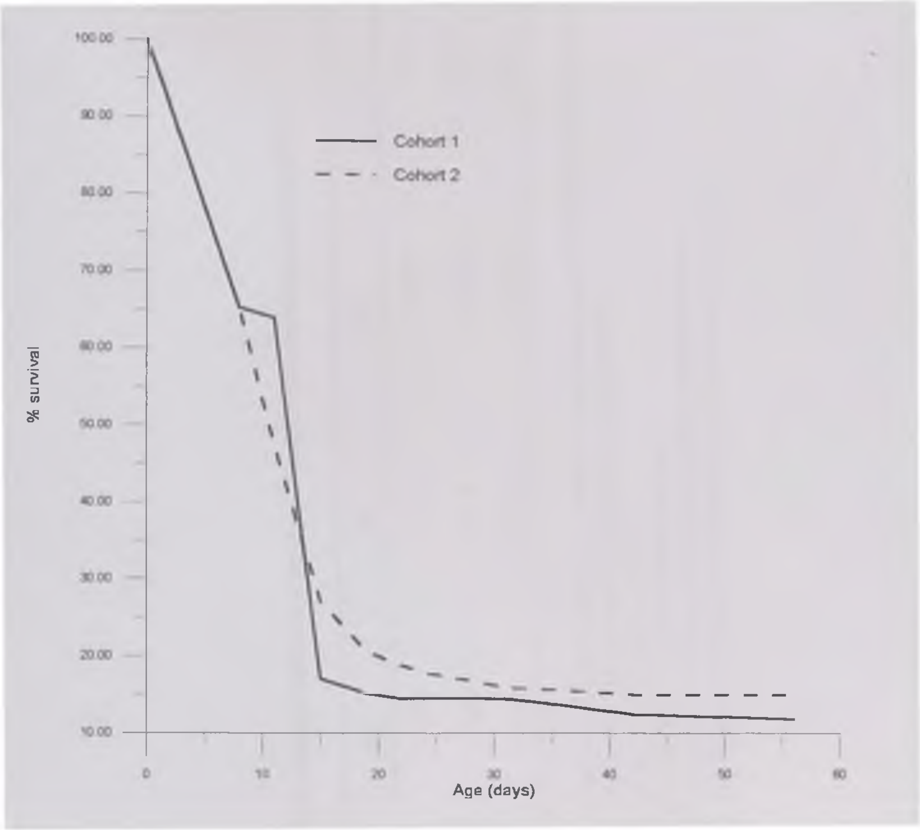


Fig. 3.6. Survivorship curves of two cohorts of C. ignefusalis reared on artificial diet

Table 3.9. Population reproductive statistics for *C. ignefusalis* reared on artificial diet.

Cohort	R_o	T_c	r_c	λ_c
1	21.36	61.4	0.0109	1.0110
2	27.46	63.5	0.0158	1.0159
Pooled values	24.41	62.95	0.0133	1.0135

R_o = net reproductive rate, the sum of the products L_x m_x, where L_x represents the proportion of individuals alive at age x, and m_x the number of female offspring produced by females in the age interval x.

T_c = cohort generation time = $\sum_x L_x m_x / \sum L_x m_x$ (in days).

r_c = capacity for increase = $\log_e R_o / T_c$ (female / female per day),

λ_c = finite rate of increase = exp (r_c) (number of times the population multiplies per day).

Values are not significantly different between cohorts 1 and 2 ($P > 0.05$, Kruskall Wallis test).

Intermediate molting due to poor nutritive food value was also reported for *E. saccharina* Walker (Lepidoptera: Pyralidae) by Girling (1978) and Atkinson (1980). Another explanation of the above mentioned difference could be that larvae were disturbed too frequently due to the necessity for measurements and for changing the diet. As a result, larvae may have fed more slowly, requiring longer time to complete the larval period. Longer development time caused by frequent disturbance of larvae was also suggested by Shanower et al. (1993) for *S. calamistis* (Hampson) (Lepidoptera: Noctuidae) and *E. saccharina* reared on maize plants. Kishi (1971) explained the variation in the numbers of larval instars reported for *Pissodes nitidus* Roelofs (Coleoptera; Curculionidae) by the use of the frequency distribution of head capsule widths. He concluded that it is necessary, for more reliable determination of larval instars, to count the molted head capsules in the larval gallery. The frequency distribution of head capsule width measurements was successfully used by Bal (1988) to determine the number of larval instars for *E. saccharina*. In the present study, the frequency distribution of the daily measurements of head capsule widths gave a clear separation of *C. ignefusalis* instar groups, which were confirmed by molted head capsule count. Dyar's rule states that the discontinuous or step-like increase in the dimensions of the sclerotized parts of insects during larval development usually takes the form of a geometrical progression (Gaines and Campbell, 1935). Although Gaines and Campbell (1935) did not recommend the use of Dyar's rule for confirming the number of instars observed, they pointed out that a perfect geometrical progression of head capsule widths can be represented by a straight line if the logarithm of the head capsule measurements are plotted against the numbers of instars. In the present study, a straight line gave the best fit to the observed values, and corroborated Dyar's rule. The conformity to Dyar's rule was also seen in the high correlation between the head capsule width and the age of larvae. A similar significant relationship between the size of the head capsule and the period of development or larval age was reported by Odebiyi (1981) for *Maruca vitrata (*previously *M. testulalis)* Geyer (Lepidoptera: Pyralidae), and by Alghali (1985) for *C. partellus.*

Adult sex ratio was approximately 1:1. Harris (1962) obtained significantly more females than males of *C. ignefusalis* by rearing field collected eggs, larvae and pupae on potted plants in the laboratory and on plants grown under natural conditions. Sampson and Kumar (1985) also found a 1:1 sex ratio for *E. saccharina* reared in the laboratory and a sex ratio in favor of females for field collected larvae. The difference may be caused by the artificial diet used in the present study, or by the controlled laboratory conditions which allowed equal development rate between male and female individuals compared to naturally growing plants as hosts.

In the present study, males and females showed the same lifespan which averaged 4.5 days and rarely exceeded 6 days. Kaufmann (1983) reported adult longevity averaging 7 days for *S. calamistis* and 5 and 6 days for *E. saccharina* and *Busseola fusca* Fuller (Lepidoptera: Noctuidae), respectively. Unnithan (1987) obtained an overall average longevity of 8.7 days for males and 6.9 days for females *B. fusca* reared from different sources. Although mean fecundity was significantly higher when 1 female was paired with 1 male, and not significantly different between the other groups of pairs, there was a decrease in the maximum number of eggs laid by a female as the density of adult pairs increased. This suggests that high adult density could cause lack of mating or disruption of oviposition. However, more studies including observation of virgin females and ovary dissections would be required to confirm this suggestion. The fecundity of *C. ignefusalis* obtained in this study (36 to 382) was higher than that reported by Harris (1962) for the same insect (a maximum of 210 eggs) reared on host plant material instead of on artificial diet as in the present study. Nevertheless, these values were very low compared with those reported for other stem borer species such as *B. fusca* which laid a maximum of 1790 eggs with an overall mean fecundity of 723 egg per female (Unnithan, 1987); *S. calamistis* and *E. saccharina* with mean fecundity of 454.3 and 621.3, respectively at 30 °C (range- 21-1062 and 187-1265 eggs, respectively) (Shanower et al., 1993). The high variability in egg fertility (45.45% to 100%) observed could result from oviposition by virgin females. However this needs to be confirmed with more detailed experiments. A type IV survivorship curve was obtained, indicating high mortality during the young stage. A similar survivorship curve was obtained by Islam (1994) for the rice stem borer *Scirpophaga incertulas* Walker (Lepidoptera: Pyralidae). The net reproduction rate R_o was not significantly different between cohorts 1 and 2. Birch (1948) showed that the comparison of two or more populations by means of their R_o may be quite misleading unless the mean lengths of the generations T_c are the same. In the present study, the values of T_c were not different between cohort 1 and 2. The potential rate of increase r_p ($r_p = \ln R_m/T_c$, where R_m, maximum rate of reproduction = mean maximum fecundity / female x proportion of females in the population) assumes a maximum fertility and zero mortality (Southwood 1969). Although this situation would never arise under natural conditions, this theoretical concept is useful to compare the potential growth rate of different species (Rodriguez-Del-Bosque, 1988). The maximum value of r_p estimated for *C. ignefusalis* in this study was 0.04. This value was smaller than the range of 0.105 to 0.154 calculated by Southwood (1969, in Setamou et al. 1993) for sugarcane stalk borers. It was also smaller than the r_p of 0.115 reported by Rodriguez-Del-Bosque (1988) for *Diatraea lineolata* or the 0.116 obtained by Setamou et al. (1993) for *S. calamistis*. This smaller

r_p value obtained for *C. ignefusalis* in this study was probably because the fecundity was much lower than that of other cereal stem borers. Another explanation could be that since *C. ignefusalis* is the only important stem borer on millet and does not attack other cereals, it does not experience competition and thus does not need to lay a great number of eggs to ensure progeny survival.

The results reported here gave parameters for *C. ignefusalis* larval instar determination. This information will be a useful tool for rapid instar determination, particularly in the laboratory, and for testing the suitability of parasitoids. *C. ignefusalis* lived shorter, laid fewer eggs and presented lower potential rate of increase than other cereal stem borers. In laboratory experiments, adult density was inversely related to female fecundity, with 1 male: 1 female per cage giving significantly more eggs than 2 to 10 pairs per cage. Results presented here provide further knowledge on *C. ignefusalis* and can be used to improve rearing. However, field data are needed to undestand what happens in nature.

CHAPTER FOUR

CONIESTA IGNEFUSALIS LARVAL ESTABLISHMENT AND DAMAGE ON PEARL MILLET *PENNISETUM GLAUCUM* (L.) R. BROWN.

4.1 Introduction

Pearl millet, *Pennisetum glaucum* (L.) R. Brown is an important food crop in the Sahelian zone of West Africa. *Coniesta ignefusalis* Hampson (Lepidoptera: Pyralidae) is a major pest of pearl millet in West Africa (Taneja and Nwanze, 1989). Gahukar (1990 a) reported that *C. ignefusalis* accounted for 90% of the total stem borer population of locally improved pearl millets in Senegal. Early season attack of *C. ignefusalis* results in the destruction of the growing points of plants, thus prematures plant death called 'dead-hearts'. Attack on older plants by larval tunneling results in disruption of nutrient flow, stem lodging and poor or no grain formation (Harris, 1962; NRI, 1993; Youm and Gilstrap, 1993). The severity and nature of damage depends on the planting date (Ajayi and Uvah, 1989; Ajayi, 1990) and the time of infestation (Taneja and Leuschner, 1985). However, crop damage may not always result in yield loss (Nwanze 1988). Yield loss assessment methods have been discussed by several authors (Chiarappa, 1981; Teng, 1987; Walker, 1981, 1983; Nwanze, 1988; Seshu Reddy, 1988; Seshu Reddy and Walker, 1990; Youm, 1990). Yield loss due to an insect pest can be expressed as avoidable loss and indirect loss. Avoidable loss is best expressed as the reduction in the maximum potential or attainable yield in the absence of the causal pest, expressed as a percentage of that attainable yield (Walker, 1981). Indirect losses are due to dead hearts and non-harvestable heads (NRI, 1993). The relationship between stem borer infestation and damage and yield losses in millet is important in determining economic threshold levels. It is also essential in developing efficient management strategies.

The objective of the present study was to quantify the relationship between larval infestation, damage and grain yield on millet using both artificial and natural infestations.

4.2 Materials and Methods

4.2.1 Trap Monitoring

Two light traps and five pheromone-baited traps similar to that described by Youm et al. (1993), Youm and Beevor (1995), and located at the ISC research station, were used in 1996. Light traps consisted of a 250 w mercury-vapour bulb mounted on top of a 3 x 3 x 3 m screen cage with a screen door on one side for access to moths attracted to it. Moths attracted by light were drawn into the cage through a plastic tube. The light bulb was switched on / off by an automatic photosensitive cell at dusk and dawn. Water-oil pheromone traps were made of aluminum trays (32-cm diameter) filled with water to a depth of 2 cm and containing 17 ml Total Rubia S-40 oil (SIFAL, RCI) as a surfactant. The tray was supported at 50 cm above ground level on a wooden shelf (40 x 40 cm) fixed to a wooden stake. Traps were baited with pheromone dispensers which consisted of polythene vials 32 x 15 x 2 mm thick (Agrisense-BCS) impregnated with the optimum pheromone blend prepared at the Natural Resources Institute (NRI), U. K. Pheromone traps were 300 500 m from the nearest light trap. Light and pheromone traps were inspected every morning to record the number of stem borer moths caught and to monitor moth generation time and population build up. Rainfall records were obtained from meteorological equipment located close to the light traps at ICRISAT-Niger research station.

4.2.2 Natural Infestation

During the 1996 rainy season, a plot was planted with the millet variety "Ex-Bornu." It consisted of 29 rows each 29 m long and 50 cm wide. Planting was done on July 07, 1996, at an intra-row spacing. Sowing consisted of placing three or more seeds in an open pocket (hill) which was afterwards covered with soil. Plants were thinned to one per hill one week after plant emergence. The plot was weeded two times before harvest. No fertilizer was applied. One week after plant emergence (WAE), 10 hills were randomly selected from each row and tagged. Plants were selected using a table of random numbers with each random number representing the position of a hill in a given row. First date of dead-heart formation on each selected plant was recorded by observing plants once a week starting one WAE. At harvest, the number of infested and non-infested stems per hill, and the number of harvestable and non-harvestable heads per hill were recorded for tagged hills. No distinction was made between main stem and tillers. Harvestable heads were defined as relatively well filled with grains and neither attacked by any disease nor by the millet head miner *Heliocheilus albipunctella* de Joanos (Lepidoptera: Pyralidae) or any other head pests. Stems showing feeding galleries, entry holes or exit holes were considered as infested. Stems infested and non-infested with harvestable heads from tagged hills, and non-infested stems with harvestable heads from the whole plot were cut from the base and transported to the laboratory where their leaves and leaf sheaths were removed and the number and length of internodes recorded. The numbers of entry and exit holes, and the number of larvae and pupae were counted for each internode after dissecting stems. From these data, the mean number of stems and infested stems per hill, the mean number of heads and harvestable heads per hill, the mean number of entry and exit holes, the mean number of larvae per stem and the percentage of bored internodes per stem were determined.

Harvestable heads were cut and placed individually in labelled white cloth bags. They were sun-dried for about ten days. Each dried head was weighed and the net grain yield determined by weighing the threshed grains to the nearest 0.01 g. A sample of 1,000 grains was taken at random from each threshed head, using an automatic grain counter, and weighed to the nearest 0.01 g. Pearson's correlation analysis was done to examine the relationship between grain weight and number of larvae per plant, grain weight and number of entry and exit holes, grain weight and percent internodes bored. Data were analyzed using an analysis of variance (ANOVA). The ANOVA was done using the SAS/PC package procedure GLM (SAS Institute, 1987). Means among infested and non-infested stems were separated at the 5% level of significance using the LSD test (SAS Institute, 1987).

4.2.3 Artificial Infestation

The experiment was conducted in a total of twelve 9 x 3 x 3 m field screen cages, covered with fine mesh wire gauze to exclude other insects. The millet variety "Ex-Bornu" was planted in plastic pots (16 cm in diameter and height) in a glasshouse and thinned to one plant per pot. One week after emergence, potted plants were transferred to the screen cages. Each cage contained four rows of potted plants with 14 pots per row. The distance between rows and between pots in a row was 60 cm. Cages were arranged in a completely randomized block design with infestation date representing the block and replicated twice. The two infestation dates were 2 and 4 WAE, i.e. 17 and 32 days after sowing (DAS), respectively. Larvae for infestation were obtained from the laboratory colony described in section 3.2.1. To ensure better larval establishment, plants were artificially infested after 6:00 pm. Neonate larvae were transferred to plants using a soft camel hair brush. Treatments consisting of 0, 5, and 10 larvae per plant, corresponding to densities of 0, 280 and 560 larvae per cage, respectively, were randomly assigned to blocks in each of the two replications. The numbers of plants showing dead hearts were counted for three consecutive weeks after infestation, starting from the first week. Percentage dead hearts was estimated as the number of plants with dead hearts over the total number of plants. At harvest, the total number of harvestable and non-harvestable heads per pot was counted. Stems with harvestable heads were cut at their bases and the heads brought to the laboratory where they were placed individually in labeled cloth bags and sun-dried for about ten days. Yield was evaluated by weighing threshed grains to the nearest 0.01 g. Percent avoidable loss in yield (w%) was calculated using the formula given by Walker (1983): $w\% = (m - y)/m \times 100$, where m = yield obtained in control plots and y = yield obtained in a particular treatment. In this trial, m = yield of non-infested plants.

Means were computed using the General Linear Model Procedure (Proc GLM SAS Institute, 1987) and separated at 5% level of significance by Least Significant Difference (LSD) test (SAS Institute, 1987). Mean values of the two infestation dates were compared using a t- test (P = 0.05). Before analysis, percentages were subjected to arcsine square root transformations.

4.3 RESULTS

4.3.1 Trap monitoring

The first adults appeared in late June (Fig. 4.1A), two weeks after the first rain on May, 31 (Fig.4.1B). At that time, planting had already started in farmers' fields and in some experimental plots at the ISC. Millet plants in the trial plots were at the early vegetative stage. Three generations of moths of unequal sizes could be distinguished from both light and pheromone trap catches. The first and smallest generation lasted for about seven weeks. It started in late June and lasted until end of July. The second generation had the highest peak. It began in the second week of August and also lasted for about seven weeks. The third generation was intermediate in size, occurring from mid September to almost the end of November. There was a clear influence of rainfall on *C. ignefusalis* catches, with peak catches always following peak rainfall in a time lag of 2 weeks. The first and second generations peaked about three weeks after their first moths appeared, while the third generation peaked two weeks after moth appearance. Moth catches started when wild grasses surrounding millet plots were still dry.

4.3.2 Natural Infestation

The first dead hearts were observed on plants at 5 WAE (August 16, 1996). At harvest, the mean number of stems per hill was 3.41 (range = 1 10), with an average of 2.73 infested by *C. ignefusalis* (Table 4.1). There was an average of 0.41 harvestable heads per hill, corresponding to 16.18 ± 1.62% of the total heads produced per hill. The

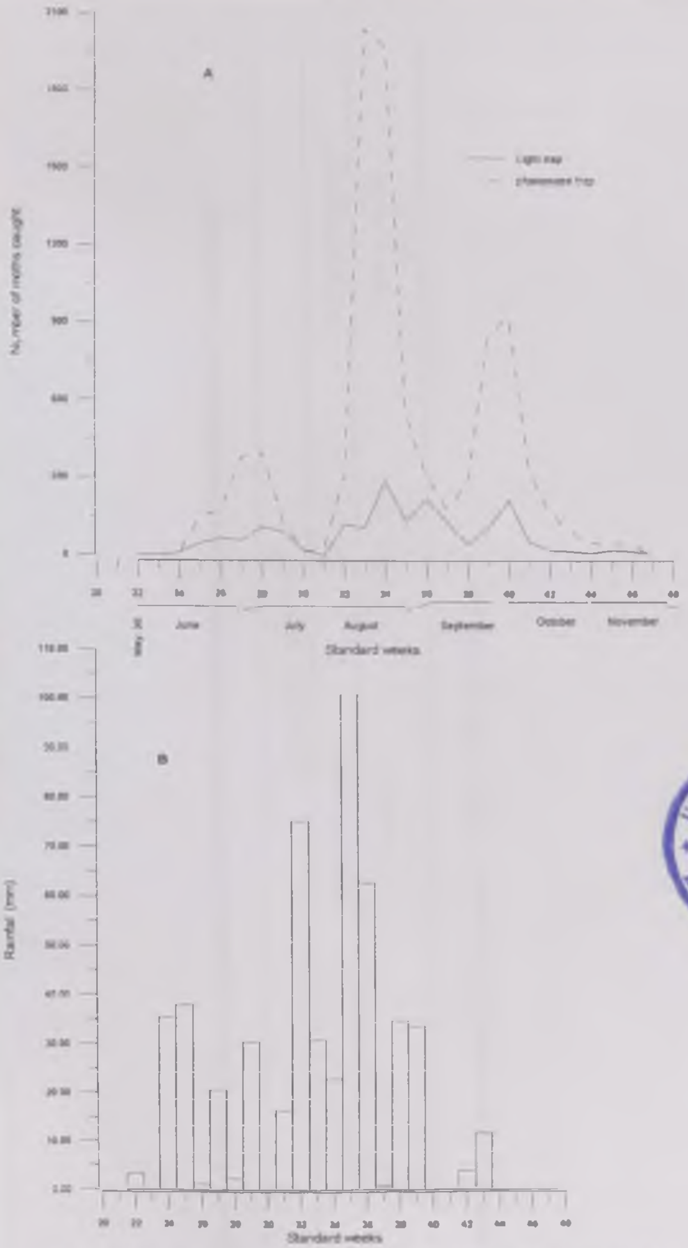


Figure 5. 1. Light and pheromone trap catches of C. ignefusalis at ISC (A) in relation to rainfall (B), in 1996.

Table 4.1. Count of infested plants and harvestable heads following natural infestation by *C. ignefusalis*.

Mean ± SE number of *			
stems/hill	infested stems/hill	heads/hill	harvestable heads/hill
3.41 ± 0.073 (1 - 10)	2.73 ± 0.092 (0 - 10)	2.77 ± 0.072 (0 - 10)	0.41 ± 0.038 (0 - 4)

* Parentheses indicate the range of the values. n = 290 (= 10 plants x 29 rows).

mean percentage of infested stems was 78.41%. A mean of 20.08 entry holes was counted per infested stem but only 3.14 exit holes and 4.09 larvae were seen per stem (Table 4.2). Although there was no difference in thousand-grain weight between infested and non-infested stems, net grain yield per stem was significantly higher for infested stems. Thousand-grain weight of infested stems was negatively correlated with number of entry holes (r = -0.23, P = 0.04) (Table 4.3). Other correlations measured were not significant.

4.3.3 Artificial Infestation

Before harvest, more than 90% of the plants infested at 2 WAE had dead hearts, against less than 50% for infestations at 4 WAE (Table 4.4). Early attacks caused 50-70% dead-hearts in the stems, compared to 15 - 25% for infestations at 4 WAE. Harvestable heads and threshed grain per head were significantly heavier in cages infested at 4 WAE than those infested at 2 WAE (Table 4.5). Subsequently, cages infested at 4 WAE yielded more grain than those infested at 2 WAE. No harvestable head was obtained in cages infested at 2 WAE with 10 larvae per plant. Within infestation dates, treatments with 0 and 5 larvae per plant did not show significant differences in the weight of their harvestable heads, while 10 larvae per plant gave significantly lower weight. In cages infested at 2 WAE, grain weight per head was not significantly different between treatments with 0 and 5 larvae per plant. Infestations at 4 WAE had significantly higher grain weight in control cages (0 larva per plant) than in cages with 10 larvae per plant. However, there was no significant difference in grain weight per head between treatments with 5 and 10 larvae per plant. At 2 WAE, 24.07% and 100% avoidable yield loss was

Table 4.2. Damage on stems and grain yield at harvest of pearl millet following natural infestation by *C. ignefusalis*

Stem	Mean ± SE per stem						
	Height (cm)	Number of entry holes	Number of exit holes	Bored internodes (%)	Number of larvae / stem	Net grain yield (g)	1000-grain weight (g)
Infested	212.09 ± 3.1a	20.08 ± 2.01	3.14 ± 0.4	42.87 ± 2.81	4.09 ± 0.43	29.33 ± 1.23a	7.62 ± 0.2 a
Non-infested	194.99 ± 5.92b	-	-	-	-	23.19 ± 2 b	7.03 ± 0.3 a

Average percent infested stems = 78.41 ± 1.76%

Average percent harvestable heads per hill= 16.18 ± 1.62%

Means in the same column followed by the same letter are not significantly different at P= 0.05 (LSD test).

Table 4.3. Correlations between *C. ignefusalis* damage (percent of internodes bored,number of larvae, and entry and exit holes) and grain weight in naturally infested plot

Parameters	Net grain weight[1]	Thousand grain weight[2]
% of internodes bored	0.06 ($P = 0.59$) NS	- 0.20 ($P = 0.07$) NS
No of entry holes	0.05 ($P = 0.64$) NS	- 0.23 ($P = 0.04$) S
No of exit holes	0.19 ($P = 0.07$) NS	- 0.10 ($P = 0.38$) NS
No of larvae	0.21 ($P = 0.06$) NS	- 0.14 ($P = 0.22$) NS

[1] n = 89

[2] n = 86

NS: not significant; S: significant at 5%.

Table 4.4. Percentages of dead hearts on caged millet plants artificially infested at two infestation dates.

	Infestation dates					
	Two weeks after plant emergence			four weeks after plant emergence		
No of larvae/ plant	Hills with dead heart (%)	Hills with all stems dead (%)	Stems with dead heart (%)	Hills with dead heart (%)	Hills with all stems dead (%)	Stems with dead heart (%)
0	0	0	0	0	0	0
5	94.5	10.81	50.25	16.84	0	16.66
10	99.08	51.35	71.96	43.54	0	25

Table 4.5. Head weight, grain weight and avoidable yield loss from millet plants artificially infested at 2 and 4 weeks after emergence with 0, 5 or 10 larvae per plant.

Time of Infestation[2]	Mean ± SE weight / harvestable head (g) after infestation with[1]			Mean ± SE grain weight/ harvestable head (g)			Net grain weight per plot (g)			Avoidable yield loss per plot (%)		
	0 (control)	5 larvae/plant	10 larvae/plant	control	5 larvae/ plant	10 larvae/plant	control	5 larvae/plant	10 larvae/plant	control	5 larvae/plant	10 larvae/plant
2 WAE	18.18 ± 1.15 (55) b A	15.82 ± 1.1 (48) b A	0 (0) b B	12.75 ± 1.01 bA	10.85 ± 0.91 b A	0 b B	1000	759.3	0	-	24.07	100
4 WAE	21.61 ± 1.23 (49) a A	18.74 ± 1.08 (61) a AB	17.55 ± 1.23 (51) a B	16.31 ± 1.16 a A	13.3±0.92 a BC	12.87 ±1.01 a C	1058.9	1143	894.8	-	-7.94	15.9

Means within column followed by the same lowercase letter are not significantly different (P > 0.05, LSD test).
Means within row followed by the same uppercase letter are not significantly different (P > 0.05, LSD test)

[1] Parentheses indicate numbers of harvestable heads per plot.

[2] WAE = Weeks after emergence.

calculated for cages with 5 and 10 larvae per plant, respectively. Infestation at 4 WAE gave a negative avoidable yield loss of -7.94% for 5 larvae per plant, and 15.9% for 10 larvae per plant.

4.4 Discussion

There was a two-week delay between the first rains and the first moth catch. This time was necessary for diapausing larvae inside old millet stalks to pupate and emerge as adults. The number of adults caught varied with the age of millet. The first generation of moths had the smallest peak . This is related to the low number of larvae that survived in diapause and produced the adults that started the first generation. The second generation, which was the largest, coincided with the period when millet was fully grown. The third generation was small because plants were old and did no longer offer enough oviposition sites.

A natural *C. ignefusalis* infestation of 78.41 % was obtained. Nwanze (1988) reported field surveys conducted from 1980-1983 in different regions in Burkina Faso and Niger where 44.6 to 72 % infested stems were obtained in Burkina Faso and 35.2 to 69.1 % in Niger. Despite the high infestation level, infested stems were taller and yielded more than non-infested ones in this study. This could indicate that infestations concerned more vigorous plants. Harris (1962) reported that many crop loss assessments based on counts of percentage bored stems showed that correlation of these counts with yield sometimes fails to demonstrate any reduction in yield and may even show that highly attacked plants give more yield. In Nigeria, Harris (1962) assessed the yielding capacities of bored and unbored early millet stems. He found that bored stems yielded less than unbored stems in three cases and more in two cases. He also noticed that in the latter case borer attack was associated with better plant growth and hence higher yields. Flattery (1982), while estimating *C. partellus* damage on grain sorghum in Botswana, explained the observed increase in the yield of bored stems by the selective infestation of more vigorous plants. At ICRISAT India, it was found that 60 % tunneling by *C. partellus* in any part of the stem did not reduce the grain yield of the susceptible sorghum variety CSH1 (Taneja and Leuschner, 1985). The low effect of attack on yield might also result from good plant growth conditions. Association of high stem borer infestations with better plant growth was also reported by Setamou et al. (1993), who showed that nitrogen fertilizer not only increased yield but also survival and, thus, final densities of *S. calamistis* on maize. Increase in yield may also result in attack having a growth hormonal effect (Walker, 1983).

Young plants infested artificially were more sensitive to dead heart formation than were older ones. Similar results were obtained by Taneja and Nwanze (1989) who showed, by artificially infesting resistant and susceptible sorghum genotypes with 0, 4, 8, and 12 larvae per plant at 15, 20, 30, 40 and 50 days after emergence (DAE), that early infestation at 15 days after plant emergence (DAE) resulted in maximum damage and yield reduction for both genotypes. Seshu Reddy and Sum (1991) studied the relationship between *C. partellus* infestation and grain yield under artificial infestations. They found that grain yield loss was higher in the young plants (21 DAE) when subjected to the same kind of treatment than older plant, stages, irrespective of cultivars and larval densities. Seshu Reddy (1989) reported studies conducted at the International Centre for Insect Ecology and Physiology (ICIPE) field station in Western Kenya, where *C. partellus* caused 74.4% grain yield losses in plants artificially infested with 5 larvae per plant at 10

DAE; 87.8% in plants infested with 10 larvae at 10 DAE, and 2-13% at 60 DAE. The high avoidable yield loss in millet infested at 2 WAE in this study was attributable to the development, in the same plants, of successive generations of the *C. ignefusalis*; the latter generations attacked the young new tillers formed from the same plants. Plants infested at 4 WAE were strong enough to support new infestations without big losses.

The present study confirmed results reported by other workers that early infestations result in higher damage and yield loss, and that yield loss in late infestations is not always correlated with the intensity of damage. For pest resistance or economic injury level studies, it is suggested that infestation levels of more than 5 larvae per plant should be used.

CHAPTER FIVE

OVIPOSITION PREFERENCE AND LARVAL SURVIVAL OF *C. IGNEFUSALIS* ON COMMON HOST PLANTS.

5.1 Introduction

Pearl millet *P. glaucum*, is the preferred host plant of the millet stem borer *C. ignefusalis*, but larvae also feed on wild grasses like *Andropogon* sp. and *P. maximum* Jacquin (Harris, 1962, 1989). Investigations in Niger showed that important alternate host plants of the MSB include *A. gayanus* Kunth and *P. pedicellatum* (Trin.) (Youm, 1990; Youm and Gilstrap, 1993). Although newly hatched larvae were collected from *Pennisetum* sp. by Youm (1990), and one pupa was collected from *A. gayanus*, there is no evidence that these plant species are suitable for oviposition and for completion of larval development. To investigate this, oviposition preference and larval development of *C. ignefusalis* were studied in the laboratory on the wild hosts, *A. gayanus* and *P. pedicellatum*.

5.2 Materials and Methods

5.2.1 Oviposition preference

P. pedicellatum and *A. gayanus* were compared with *P. glaucum* for oviposition preference by *C. ignefusalis* in the laboratory, under ambient environmental conditions.

P. pedicellatum and *A. gayanus* were collected in weedy areas in nearby millet plots at the ISC research station. Pearl millet variety ex-Bornu was grown from seeds in 8-cm diameter plastic pots in the glasshouse. Plants were selected before the panicule initiation stage described for pearl millet by Maiti and Bidinger (1981). In a three-choice test, replicated nine times (nine buckets), freshly-cut-30 cm-long tillers with leaf sheaths from A. *gayanus, P. pedicellatum* and *P. glaucum* were arranged vertically, randomly alternating species, in a circle in a plastic bucket (40 cm high and 30 cm diameter) containing wet sandy soil and covered with a sleeve cloth. Each plant species was replicated three times within a bucket. The same plant species were tested in a no choice situation, using nine buckets per plant species. Each bucket containing nine freshly cut tillers of the same species arranged in a circle. Five newly emerged male: female pairs of *C. ignefusalis* from the laboratory colony were released into each bucket. Cotton soaked with water was introduced in the buckets to maintain high humidity. Every two days, the number of stems with eggs and the number of eggs laid on them were counted, and the stems were replaced until all females died. The relative preference for a host plant species was calculated using the method developed by Nylin and Niklas (1993), as the ratio of the total number of eggs laid by all females on this host over the number of eggs laid on pearl millet which was used as a reference. The number of eggs per plant species per replication, n, was transformed using natural logarithm as $n_t = \log(n+1)$, where n_t was the transformed value of n. Percentages of plants with eggs, and species' relative preference were arcsin square root transformed. Transformed data were analyzed using an analysis of variance (ANOVA). The ANOVA was done using the SAS/PC package procedure GLM (SAS Institute, 1987). Means were separated at 5% level of significance using the LSD test (SAS Institute, 1987). The choice and non-choice tests were compared using t test.

Replications with no oviposition on any of the plant species were excluded from the analysis.

5.2.2 Larval survival

Survival of first to fifth instar larvae of *C. ignefusalis* on *P. pedicellatum* and *A. gayanus* was compared to survival on *P. glaucum* from September to November 1995 at the ISC, using two experiments, each replicated three times. In the first experiment, a mixture of 27 young (first and second instar) larvae from a laboratory colony was used to artificially infest nine 10-cm-long stem sections of each plant species. In the second experiment, a mixture of 36 older (third to fifth instar) larvae from the laboratory colony and twelve 10-cm-long stem sections were used per plant species. Stem sections were infested by placing three larvae of about the same age into a 2-cm hole drilled in the stems using strong forceps. Infested stems were kept individually in 30 ml plastic cups. Plants were obtained as described in the preceding section. The number of surviving larvae per plant species was counted every 3 days after infestation, for 15 days. The stems were changed every 3 days. After 15 days, observations were made weekly until all larvae died, pupated or entered diapause. Mean larval mortality and longevity were computed using an analysis of variance (SAS Institute, 1987). Means were compared between plant species using the LSD test (SAS Institute, 1987). Percenta.ges were arcsin square root transformed before analysis.

5.3 Results

5.3.1 Oviposition preference

In both choice and no-choice tests, the proportion of stems with eggs and the mean number of eggs were significantly higher on *P. glaucum*, but there was no significant difference between *A. gayanus* and *P. pedicellatum* (Table 5.1). Over 88% and 98% of the total eggs obtained in the choice and the no-choice tests, respectively, were laid on pearl millet. However, the total number of eggs laid in the choice test was three times higher than that obtained in the no-choice test.

5.3.2 Larval survival

On all plant species tested, larval mortality increased with time (Fig. 5.1). Young larvae reared on *A. gayanus* and *P. pedicellatum* were all dead 9 and 12 days after infestation, respectively, while 37.04% were still alive on *P. glaucum* 15 days after infestation. 96.3% and 88% of the older larvae on *A. gayanus* and *P. pedicellatum*, respectively, were dead 15 days after infestation, compared with 55% on *P. glaucum*. Although older larvae survived significantly better than young larvae, larval survival was not significantly different between *A. gayanus* and *P. pedicellatum* (Table 5.2). No pupae

Table 5.1. Comparative oviposition by *C. ignefusalis* on *A. gayanus*, *P. pedicellatum* and *P. glaucum* in choice and no-choice laboratory tests.

Test	Plant species	Mean ± SE Percent plants with eggs/species [1]	Total number of eggs per plant species *	Mean ± SE number of eggs per plant species [2]	Mean ± SE percent relative preference (%)[1]
Choice test	*P. glaucum*	72.22 ± 6.17 (64.12 ± 5.31) a	4076 (88.36%)	75.48 ± 12.17 (3.09 ± 0.29) a	100 ± 0.00 (90.00 ± 0.00) a
	A. gayanus	12.96 ± 6.11 (11.08 ± 5.12) b	443 (9.6%)	8.20 ± 3.98 (0.48 ± 0.18) b	15.54 ± 7.79 (8.51 ± 4.70) b
	P. pedicellatum	5.56 ± 3.01 (5.88 ± 3.19) b	94 (2.04%)	1.74 ± 1.11 (0.18 ± 0.11) b	4.16 ± 2.90 (4.54 ± 2.86) b
Non-choice test	*P. glaucum*	34.44 ± 6.30 (33.99 ± 4.90) a	1427 (98.89%)	15.86 ± 3.66 (1.19 ± 0.18) a	100 ± 0.00 (90.00 ± 0.00) a
	A. gayanus	1.11 ± 1.11 (1.95 ± 1.95) b	9 (0.62%)	0.10 ± 0.10 (0.03 ± 0.03) b	0.93 ± 0.93 (1.86 ± 1.86) b
	P. pedicellatum	1.11 ± 1.11 (1.95 ± 1.95) b	7 (0.47%)	0.08 ± 0.08 (0.02 ± 0.02) b	0.19 ± 0.19 (0.84 ± 0.84) b

Means in the same test, followed in the same column by different letters are significantly different ($P<0.050$)± (LSD test, SAS Institute, 1987).

[1] Means were based on 18 observations (9 replications x 2 observation dates) for the choice test and 10 observations (5 replications x 2 observation dates) for the no-choice test. Number in parentheses indicate transformed mean values.

[2] Means were based on 54 observations (9 replications x 3 plants x 2 observation dates) for the choice test and 90 observations (5 replications x 9 plants x 2 observation dates) for the no-choice test. Number in parentheses indicate transformed mean values.

* Number in parentheses indicate the ratio of the total number of eggs laid on the species over the overall number of eggs on all plant species.

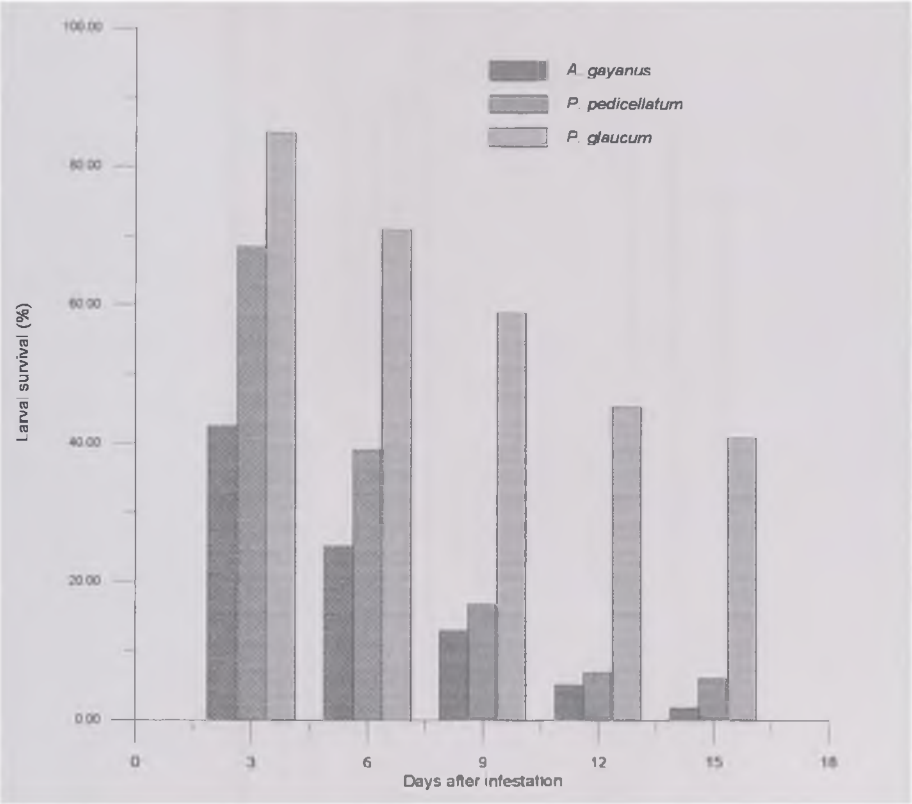


Fig. 5.1. Overall larval survival of C. ignefusalis reared on A. gayanus, P. pedicellatum and P. glaucum

Table 5.2. Survival of *C. ignefusalis* reared on *A. gayanus, P. pedicellatum* and *P. glaucum* stems in the laboratory, 15 days after infestation.

Host plant	Mean ± SE percent larval survival 15 days after infestation with [a]		Total number of pupae from [b]	
	Young larvae (1st and 2nd instars)	Older larvae (3rd to 5th instars)	Young larvae (1st and 2nd instars)	Older larvae (3rd to 5th instars)
A. gayanus	0 b	3.70 ± 1.35 (0.01 ± 0.003) b	0	0
P. pedicellatum	0 b	12.04 ± 2.70 (0.03 ± 0.005) b	0	0
P. glaucum	37.04 ± 3.104 (0.11 ± 0.006) a	45.37 ± 2.19 (0.10 ± 0.004) a	5 (6.17%)	12 (22.22%)

Means followed in the same column by different letters are significantly different ($P<0.050$)± (LSD test, SAS Institute, 1987).

[a] Number in parentheses indicate transformed mean values.

[b] Number in parentheses indicate percentages pupae formed = (number of pupae/total number of infested larvae)x 100.

were formed from larvae reared on *A. gayanus* and *P. pedicellatum* since there were no larvae alive on these species 20 days after infestation. On *P. glaucum*, however, 6% of the young and 22% of the older larvae, pupated, respectively.

5.3 Discussion

The possibility for C. ignefusalis to oviposit on alternate hosts was investigated. The results showed that pearl millet was a highly preferred host while *A. gayanus* and *P. pedicellatum* were not preferred for oviposition by *C. ignefusalis*. Three-fold more eggs were obtained in the choice test than in the no-choice one, suggesting that oviposition should be higher on millet grown in the vicinity of wild grasses than on millet plants without grasses around. The lack of preference (less than 1%) for *A. gayanus* and *P. pedicellatum* in the no-choice test, compared to the 16% and 4%, respectively, in the choice test, suggests that oviposition on these wild hosts was induced by the presence of pearl millet. The dissection of females would have probably showed high egg retention in ovaries, as noticed earlier by Adesiyun (1983) after he dissected *B. fusca* females that did not oviposit on millet. The suppression of oviposition on wild hosts was also reported by Nylin and Niklas (1993) for the Comma Butterfly, *Polygonia c-album* L. The mechanisms of host plant resistance and host selection by phytophagous insects have been described by Thorsteinson (1960) and Ukwungwu (1990). The non-preference for oviposition on *A. gayanus and P. pedicellatum* could be explained by the aspect of their leaf-sheaths which are hairy and tightly attached to the stems (in the case of *A. gayanus*); The leaf sheaths in ex-Bornu is non-hairy and loose. It could also be explained by the presence of some undetermined oviposition-stimulating and inhibiting chemicals as suggested by several authors (Beck, 1965; Ampofo, 1985; Balidawa, 1985; Kumar and Saxena, 1985; Saxena, 1985). There could probably also be an influence of plant age as seen after presenting sorghum plants of different ages for oviposition to *C. partellus* (Alghali, 1985). Ampofo (1985) reported that young maize plants (3-4 weeks after planting) were more preferred for oviposition by *C. partellus* than older plants (7-8 weeks after planting). Therefore, this could influence the results obtained in the present study since the wild host plants collected from the field could be of different ages, and older than the millet plants.

There was partial development of *C. ignefusalis* larvae on *A. gayanus* and *P. pedicellatum*. No larvae reached the pupal stage although a few survived for up to 20 days. Several workers have collected *C. ignefusalis* larvae in wild hosts (Harris, 1962; Markham, 1985; Ajayi, 1990; Youm, 1990). However no reports mentioned *C. ignefusalis* developing completely in those alternate hosts. Collected larvae probably migrated from adjacent millet fields to these hosts. Feeding symptoms were not observed during this study, and the failure of larvae to develop in *A. gayanus* and *P. pedicellatum* could be due to an inadequate food intake resulting from non-preference of the larvae for feeding on these hosts. The idea of non-preference for feeding was defended by Saxena (1985), who reported some behaviour-controlling plant chemicals which differ between host and non-host plant genera and between insect species. Oviposition experiments using maize and various wild grass species and carried out in the greenhouse at the IITA-Benin station showed that *S. calamistis* and *E. saccharina* females had equal oviposition preference for most grass species and maize although both borer species had a high preference for *Pennisetum polystachion* (Sekloka, 1996, in Schulthess et al., 1997). On the other hand, life-table studies on *S. calamistis* and *E. saccharina* conducted at IITA-Benin on the same grass species showed that for both insects, the only grass species suitable for larval development to adult was *Sorghum arundinaceum* (Shanower et al., 1993). Surveys from the forest zone of Cameroon, Côte d'Ivoire and Ghana showed that borer incidence in maize fields decreased significantly when wild grasses were abundant in the vicinity of a field (Schulthess et al., 1997). From these IITA studies, Schulthess et al. (1997) concluded that grasses, although attractive to ovipositing moths, act as trap plants and cause high mortalities. The non-preference for oviposition and the high larval mortalities obtained in the present study seem to support the hypothesis by Schulthess et al. (1997) that alternate hosts could be trap hosts rather than reservoirs for stem borers. In the Sahel, the scarcity of wild grasses around millet fields, due to erratic rainfall, and the use of these grasses for roofing and animal bedding explain why *C. ignefusalis* is such an important pest on millet. Field studies are, however, necessary to confirm these results.

CHAPTER SIX

SUITABILITY OF THE MILLET STEM BORER *CONIESTA IGNEFUSALIS* AS A HOST FOR *COTESIA FLAVIPES* AND *C. SESAMIAE*

6.1. Introduction

Cotesia flavipes and *C. sesamiae* are gregarious larval endoparasitoids of pyralid and noctuid (Lepidoptera) stem borers of gramineous plants (Beg and Inayatullah, 1980). They belong to the Family Braconidae and the Subfamily Microgastrinae. The Microgastrinae are probably the single most important group of parasitic Hymenoptera with regard to the biological control of Lepidopterous pests (Greathead, 1987). *Cotesia flavipes* and *C. sesamiae,* previously placed in the genus *Apanteles,* are now members of a three-species complex that also includes *C. chilonis* (Matsumura)(Sigwalt and Pointel, 1980; Walker, 1994). All three species are ecologically similar and are thought to be phylogenetically closely related (Omwega et al., 1995). *C. sesamiae* and *C. chilonis* which are morphologically indistinguishable, can be separated from *C. flavipes* by the form of the male genitalia (Polaszek and Walker, 1991).

Cotesia flavipes is native to South-East Asia where it attacks *Chilo sacchariphagus* (Bojer). It has been introduced into more than 42 countries in the Ethiopian and neotropical regions including the USA (Inayatullah, 1987; Polaszek and Walker, 1991; Walker, 1994). In the USA, it gave excellent control of the sugarcane borer, *D. saccharalis* (Fuchs et al., 1979). In Madagascar, it is reported to control *C. sacchariphagus* in sugarcane (Omwega et al., 1995). In South Africa, *C. flavipes* was introduced and established to control *C. partellus* (Skoroszewski and Van Hamburg, 1987 in Omwega et al., 1995). There have been several attempts to introduce *C. flavipes* into East Africa (Kenya, Tanzania and Uganda) against the maize stem borer *C. partellus* and in West Africa, particularly, in Ghana against *C. partellus* (Scheibelreiter, 1980), and in Cote D'Ivoire and Senegal against the rice stem borer *C. zacconius* Bleszynski (Bal, 1981; Breniere and Bordat, 1982). All these attempts have failed (Breniere and Bordat, 1982; Overholt et al., 1994 in Walker, 1994). Recently, Omwega et al. (1995) recovered cocoon masses of *C. flavipes* from south-western Kenya where the parasitoid was never released. They hypothesized that *C. flavipes* became established in this region from individuals escaping from a laboratory colony maintained in south-western Kenya.

Cotesia sesamiae (Cameron), of African origin, is said to be widely distributed in Tropical Africa and has been established in Mauritius against *S. calamistis* Hampson (Lepidoptera: Noctuidae) (Mohyuddin, 1971). In South Africa, *C. sesamiae* was reported to be the most abundant larval parasitoid of *B. fusca* (Kfir, 1995). In East Africa, *C. sesamiae* is a common parasitoid of *S. calamistis* and *B. fusca* (Ingram, 1958). In Western Africa, C. *sesamiae* is very scarce (Schulthess et al., 1991). Markham (1985) and Youm (1990) did not record the species from their field investigations of natural enemies of the millet stem borer in Niger. The species has also not been found in Ghana nor in Guinea Conakry (Schulthess et al., 1997). The scarcity of *C. sesamiae* in West Africa suggests that the local strains are either not adapted to or do not breed successfully on known pests, or they do not recognize the host habitats (Schulthess et al., 1997). Therefore there should be a biological strain of *C. sesamiae* existing in East Africa or South Africa, that could successfully attack west African stem borers. To address this issue, and to evaluate the three species of the *flavipes* complex for possible introduction against West African gramineous stem borers, a large project was initiated at the International Institute of Tropical Agriculture (IITA), Benin (Schulthess et al., 1997; Hailemichael et al., 1997). This study is a small part of that project and concentrated on the millet stem borer, *C. ignefusalis* and two parasitoid species, *C. flavipes* and *C. sesamiae*. *C. ignefusalis* is a factitious host for *C. flavipes* and a natural host for *C. sesamiae*. The objective of the study was to examine the suitability of *C. ignefusalis* as a host for *C. flavipes* and *C. sesamiae*.

6.2 Materials and Methods

6.2.1 Rearing of the parasitoids *Cotesia flavipes* and *C. sesamiae*

The *C. flavipes* used originated from *C. partellus* in Rawalapindi, Pakistan, while *C. sesamiae* was reared from field-collected *S. calamistis* from the coastal zone of Kenya (Ngi-Song et al., 1995). Laboratory colonies of *C. flavipes* and *C. sesamiae* were maintained on *C. partellus* and *S. calamistis*, respectively, for several generations at the International Centre of Insect Physiology and Ecology (ICIPE), Kenya. Individuals from the Kenyan colonies were imported into IITA-Benin laboratory in 1994 and the parasitoids were subsequently cultured on locally collected *S. calamistis* (Hailemichael et al., 1997). Individuals from the IITA colony were imported into the entomology laboratory of the ISC, Niger, and reared on *C. ignefusalis*. A laboratory colony of *C. ignefusalis* was established as described in section 4.1. In order to spread parasitoid adult emergence over time, received cocoons were stored in the refrigerator (15°C) in glass shell vials and taken out progressively as needed over a maximum of ten days. Emerging adult parasitoids were fed on a 1:2 solution of honey: water and released for mating into 3.8 l Fonda^{R} paper containers, each about 16 cm in diameter. The lid of each container was replaced with a fine mesh screening, consisting of polyester organza secured to the paper ring portion of the original lid. To allow access to cages without parasite escape, a 10 cm diameter hole was cut on one side of each container and then covered with a sleeve cloth. Five mated females were placed in 16 cm-diameter plastic cups with five millet stem sections (8 cm long) each infested with one millet stem borer larva (4th-to-6th instar) for 24 h. The millet stem sections were infested by placing larvae into a 2-cm hole drilled in stem sections 4 to 24 hours prior to exposure to the parasitoids. Infested stem sections were replaced every 24 h after exposure to parasitoids,, until all female parasitoids died. Exposed larvae were removed from millet stems and reared in individual 15 ml cups containing artificial diet. Formed parasitoid cocoons were transferred into 20-ml plastic vials plugged with cotton, where they were held until parasitoid adult emergence.

6.2.2 Experimental procedure

Mated females of *C. flavipes* and *C. sesamiae* from the laboratory colony were exposed to second-to-fifth instars and diapausing *C. ignefusalis* larvae in incubators maintained at 18, 22, 26 or 30°C under constant photoperiod (L:D) 12:12 and 70% relative humidity. The treatment consisted of exposing, under each temperature regime, one mated female parasitoid to one host larva of a given instar, in a millet stem as described in section 6.2.1. A new larva of the same instar was offered to the female parasitoid every 24 h, until it died. Ten females were used per host instar per temperature regime. After 24 h exposure at a given temperature, host larvae were removed and reared individually at the same temperature in 15 ml plastic cups provided with the artificial diet Bioserv. They were observed twice a day until death, pupation or emergence of parasitoid larvae. Formed cocoon masses were removed and placed in empty glass vials (110 mm long and 35 mm diameter). Honey solution droplets were later sprayed on the walls of the vials. After parasitoid cocoon removal, parasitoid larvae that exited the host body but failed to pupate were counted, and host larvae dissected in distilled water to record the number of parasitoid larvae remaining in them. Dead hosts without parasitoid larval emergence and hosts in diapause were also dissected to determine the presence and number of parasitoid larvae. The parameters recorded were the percent of host larvae killed, pupating or entering diapause, the proportion of hosts parasitized, hosts successfully parasitized, the total brood size, the total progeny and female progeny produced per parasiting female, and the progeny developmental times. The proportion of hosts parasitized was defined as the percentage of hosts from which parasitoid larvae emerged plus hosts that contained dead immature parasitoids divided by the total number of hosts exposed. Hosts successfully parasitized were those from which parasitoid larvae emerged. The sum of the adult progeny plus immature stages (parasitoid adults that did not emerge from cocoons, emerged larvae that did not form cocoons, and larvae that did not exit host body) was used to estimate the total brood size. Development times included the larval period (the time from first day of exposure to first cocoon formation) and the pupal period (from cocoon formation to adult emergence).

Data were analyzed using the general linear models procedure (PROC GLM, SAS Institute, 1987). Means were separated using LSD test. Percentages were arcsin square root transformed before analysis.

6.3 RESULTS

The overall percentage of hosts pupating, dying or diapausing was not significantly different between *C. flavipes* and *C. sesamiae* (Table 6.1). At least 50% of the hosts exposed at each temperature to both species died, while an overall mean of less than 10% pupated. The percentage of hosts parasitized and successfully parasitized was not significantly different between *C. flavipes* and *C. sesamiae* (Table 6.2). Less than 30% of the hosts exposed to either parasitoid species were parasitized, but successful parasitization was less than 15% for both parasitoid species at all temperatures. Temperature had no effect on the percentage of hosts successfully parasitized within and between species (Table 6.2). *C. flavipes* parasitized significantly more fifth, fourth and third instar larvae than diapausing and second instar larvae (Table 6.3). *C. sesamiae* parasitized significantly more fourth instar larvae than second, third or fifth instar and diapausing larvae; the differences between the latter were not significant (Table 6.3; Appendix 1). The highest level of successful parasitism among instars was also less than 30% (i.e. 19.05% for the fifth instar exposed to *C. flavipes* at 22°C, and 31.03% for the fourth instar exposed to C. *sesamiae* at 22°C (Table 6.3; Appendix 1). The second instar larvae were successfully parasitized only by *C. sesamiae*. The fifth instar larvae were almost not parasitized by *C. sesamiae* (Table 6.3). Successful parasitism of diapausing larvae was not significantly different between *C. flavipes* and *C. sesamiae* (Table 6.3).

The total number of parasitoid larvae and adults, and also the female ratio were significantly higher for *C. sesamiae* than for *C. flavipes*. However, larval and total parasitoid developmental periods were significantly shorter in hosts exposed to *C. flavipes* (Table 6.4). Developmental times were also significantly shorter in old (fourth and fifth

Table 6.1. Overall percentage (mean ± SE) of *C. ignefusalis* hosts pupating, dying or diapausing after exposure to *C. flavipes* and *C. sesamiae* at 18, 22, 26 and 30°C.

Temperature (°C)	Host pupating		Host dead		Host diapausing	
	C. flavipes	*C. sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*
18	12.9±2.70aA	18.95±3.18aA	59.35±3.95aA	49.67±4.06aA	17.42±3.056aB	15.69±2.950aB
22	1.99±1.14aB	2.03±1.19aB	53.64±4.07aA	56.94±4.14aA	22.52±3.410aA	28.47±3.77aA
26	8.076±2.45aB	0.75±0.75aB	61.29±4.39aA	61.94±4.05aA	18.55±3.50aA	25.37±3.77aA
30	16.24±3.42aA	11.48±2.9aA	52.14±4.64aA	56.56±4.51aA	16.24±3.424aB	18.03±3.5aB
Mean	9.51±1.26a	8.5±1.19a	56.67±2.12a	56.06±2.11a	18.83±1.67a	21.88±1.76a

Means within a column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).
Means followed by the same lowercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

Table 6.2. Overall percentage (mean ± SE) of *C. ignefusalis* hosts parasitized and successfully parasitized after exposure to *C. flavipes* and *C. sesamiae* at 18, 22, 26 and 30°C.

Temperature (°C)	Hosts parasitized [1]		Hosts successfully parasitized [2]	
	C. flavipes	C. sesamiae	C. flavipes	C. sesamiae
18	10.26 ± 2.44 a B	15.69 ± 2.95 a A	5.77 ± 1.87 a A	7.19 ±2.1 a A
22	21.85 ± 3.37 a A	12.5 ± 2.77 a A	13.25 ± 2.77 a A	8.33 ± 2.31 a A
26	12.1 ± 2.94 a B	11.94 ± 2.81 a A	9.68 ± 2.67 a A	5.22 ± 1.93 a A
30	15.38 ± 3.35 a AB	13.93 ± 3.15 a A	7.69 ± 2.47 a A	7.26 ± 2.34 a A
Mean	14.96 ± 1.53 a	13.51 ± 1.45 a	9.14 ± 1.23 a	7.05 ± 1.09 a

Means within column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

Means followed by the same lowercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

[1] host parasitized = host from which parasitoid emerged or were observed after dissection .

[2] Host successfully parasitized n= host from which parasitoid larvae emerged.

Table 6.3. Overall percentage of larval instars of *C. ignefusalis* successfully parasitized by *C. flavipes* and C. *sesamiae*

Parasitoid species	Mean ± SE percent successful parasitism of larval instars (range)				
	Second	Third	Fourth	Fifth	Diapausing
C. flavipes	1.82* b B (0 - 1.82)	11 ± 3.14 a A (7.69 - 11.54)	12.39 ± 3.11 a B (5.56 - 16)	13.64 ± 2.77 a A (3.57 - 19.05)	2.38 ± 1.36 b A (0 - 3.57)
C. sesamiae	8.64 ± 3.14 b A (4.35 - 16)	7.79 ± 3.07 b A (3.7 - 13.33)	22.92 ± 4.31 a A (11.54 - 31.03)	1.14 ±0.81 b B (0 - 2.56)	1.59 ±1.12 b A (0 - 3.33)

Means within row followed by the same lowercase letter are not significantly different ($P>0.05$, LSD test, SAS Institute, 1987).
Means within column followed by the same uppercase letter are not significantly different ($P>0.05$, LSD test, SAS Institute, 1987).
* Only one of all exposed hosts was successfully parasitized.

Table 6.4. Mean (± SE) number and developmental time of progeny of *C. flavipes* and *C. sesamiae* reared on *C. ignefusalis* at 18, 22, 26 and 30°C.

Temp (°C)	No of larvae		No of adults		Female ratio (%)		Larval period (days)		Total developmental time (days)	
	C. flavipes	*C. sesamiae*	*C. flavipes*	*C.sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C.sesamiae*	*C. flavipes*	*C.sesamiae*
18	36.1±3.93 b A	49.4±5.66 a A	15.6±4.08 b A	35.6±4.06 a A	50.76±13.28 b A	69.92±5.04 a A	23.5±2.49 b A	25.1±1.68 a A	31.7±2.4 b A	32.9±1.68 a A
22	31.3±5.6 b A	52.75±6.68 a A	19.4±4.97 b A	34.83±6.0 a A	53.09±9.32 b A	78.07±3.63 a A	19.6±1.26 b A	26.42±1.68 a A	28.1±1.05 b A	33.08±1.76 a A
26	37.3±4.65 a A	37.67±8.92 a A	24.2±5.38 b A	34.67±8.73 a A	50.38±11.78 b A	67.06±7.67 a A	15.7±1.12 b B	18.67±1.75 a B	22.1±1.2 b B	24.67±1.73 a B
30	34.63±7.32 b A	43.33±9.44 a A	18.13±4.84 b A	23.33±5.4 a A	46.73±11.37 b A	51.95±13.37 a A	14.75±1.94 b B	17.33±1.20 a B	20.13±1.75 b B	22±0.86 a B
Mean	34.92±2.58 b	47.44±3.64 a	19.39±2.39 b	33±3.0 a	50.4±5.51 b	69.12±3.52 a	18.58±1.02 b	23.06±1.06 a	25.79±1.10 b	29.59±1.17 a

Means within column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).
Overall means followed by the same lowercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987)
* Female ratio = (number of females/number of adults)x 100.

instars) than in young (second and third instars) host larvae (Table 6.5, 6.6). For both *C. flavipes* and C. *sesamiae*, the number of progenies produced per female was not significantly different between temperatures, but the progeny developed significantly faster at high (26 and 30°C) than at low (18 and 22°C) temperatures (Table 6.4). Comparison of progeny production and development within species (Appendix 2) showed that the most suitable host for both parasitoid species, in terms of higher progeny production and shorter developmental times, was the fourth instar (Table 6.4, 6.5). Diapausing larvae seemed to be promising.

6.4 Discussion

The average percentage of hosts successfully parasitized by either parasitoid species was less than 20%. On the other hand, more than 50% of the hosts exposed died. Even though acceptability was not estimated in this study and host dissection occurred too late to show parasitoid eggs, it could be that most of the dead hosts were actually parasitized and could not survive. High host mortality and low parasitism rate might also result from exposure of non-healthy hosts. The absence of successful parasitism of the fifth instar by *C. sesamiae* could be due to diapause-induction in older larvae by exposure to the parasitoid. In all cases, the percent of hosts successfully parasitized was probably significantly lower in this study than it should be. Hailemichael et al. (1997) compared the host acceptability and suitability of the noctuids *S. calamistis, S. poephaga*, and *B. fusca,*

Table 6.5. Suitability of larval instars of *C. ignefusalis* for the development of *C. flavipes*

Suitable larval instars	Number of adult progeny	Female progeny ratio (%)*	Progeny larval period (days)	Progeny total developmental period (days)
Third	19 ± 3.476 A	56.19 ± 10.861 A	24.56 ± 2.261 A	31.22 ± 2.172 A
Fourth	22.55 ± 5.211 A	25.29 ± 9.055 B	17 ± 1.607 B	23.73 ± 1.931 B
Fifth	14.93 ± 2.978 B	68.54 ± 6.656 A	16.73 ±1.089 B	24.67 ± 1.446 B

Means within column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

* Female ratio = (number of females/number of adults)x 100

Table 6.6 Suitability of larval instars of *C. ignefusalis* for the development of *C. sesamiae*

Suitable larval instars	No of adults progeny	Female progeny ratio (%) *	Progeny larval period (days)	Progeny total developmental period (days)
Second	47.43 ± 4.466 B	74.94 ± 3.04 A	28.71 ± 2.067 A	35.71 ± 2.388 A
Third	31 ± 6.663 C	68.86 ± 10.619 A	25.4 ± 2.561 B	32.2 ± 3.231 A
Fourth	50.05 ± 5.161 A	72.24 ± 3.622 A	21.35 ± 1.122 C	27.75 ± 1.176 B

Means within column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

* Female progeny ratio = (number of females/number of adults)x 100

and the pyralids *C. ignefusalis*, *E. saccharina* and *Mussidia nigrivenella* to *C. flavipes*, *C. sesamiae* and *C. chilonis* in the laboratory. They found that *C. ignefusalis* was almost equally accepted and suitable to all *Cotesia* species. In contrast, the present study showed that host suitability, in terms of brood size and number of emerged adults, was significantly higher for *C. sesamiae* than for *C. flavipes* in spite of the almost equal percent of hosts successfully parasitized by both parasitoids. Lower progeny production by *C. flavipes* than *C. sesamiae* is understandable since *C. ignefusalis* is a factitious host for *C. flavipes* and a coevolved host for *C. sesamiae*. Similar results were reported by Overholt (1992) who found in Kenya that the Asian *C. flavipes* produced approximately three-fold more progeny per host than did *C. sesamiae* when the introduced Asian stem borer *C. partellus* was used as a host. However, the difference between the results reported by Hailemichael et al. (1997) and those obtained here is striking since both studies used *Cotesia* spp. originating from the Kenyan Coast. There should also not be any difference in both ecological and physiological equivalence of the host used (Wiedenmann and Smith, 1997), since in both studies, colonies of *C. ignefusalis* were initiated from individuals collected from millet fields in Parakou (Benin) and Niamey (Niger) in the dry sahelian region. Differences might result from the parasitoid colonies since the *Cotesia* colony used by Hailemichael et al. (1997) was reared on the suitable host *S. calamistis*, while in this study, the parasitoid colonies were maintained on *C. ignefusalis*. Equal parasitism rate but faster progeny development of *C. flavipes* compared to *C. sesamiae* suggests that the former would control *C. ignefusalis* better than the native *C. sesamiae* in sahelian western Africa. The progeny developmental times found in this study were longer than the 16 and 18.5 days reported by Mohyuddin (1971) for *C. flavipes* and *C. sesamiae*, respectively, when reared on *C. partellus* at 30°C. Due to the novel association (Wiedenmann and Smith, 1997) between *C. flavipes* and *C. ignefusalis,* larval development in *C. flavipes* took much longer in this study than the 12.7 13.1 days reported for *C. flavipes* reared on *C. partellus* (Inayatullah, 1987). It was also longer than the average 13.8 days and 13.1 days reported for the same parasitoid by Wiedenmann et al. (1992), and Wiedenmann and Smith (1995), respectively on *D. saccharalis.*

C. flavipes successfully parasitized third to fifth instar hosts, while *C. sesamiae* parasitized the fourth instars. During host acceptance study of *C. flavipes* on *D. saccharalis* larvae, Van Leerdam (1981) found that first and second instars having a mass of less than 20 mg not accepted by the females. Wiedenmann et al. (1992) also found that *C. flavipes* accepted and developed in third to sixth instar *D. saccharalis.* Ngi-Song (1995) and Ngi Song et al. (1995) reported that third to sixth instar larvae of *C. partellus* were acceptable and suitable for parasitization by *C. flavipes.* A striking finding in the present study was the attack and successful parasitization of diapausing *C. ignefusalis* larvae by both parasitoid species. By contrast, Mbapila and Overholt (1997), while studying in the laboratory and in cages the suitability of aestivating versus non-aestivating larvae of *Chilo* spp. for *C. flavipes* and *C. sesamiae*, found that none of the aestivating larvae was parasitized. Host finding by *C. flavipes* and *C. sesamiae* is induced by the frass produced by stem borers (Smith et al., 1993). But diapausing *C. ignefusalis,* easily distinguishable from the non-diapausing larva by its creamy whitish body not marked with black spots is not active and does not feed. An explanation for the parasitism of diapausing larvae in this study could be that given by Mbapila and Overholt (1997), that larvae were about to break, or just entered diapause when their exposure to the parasitoids occurred. Alternatively, many of parasitized diapausing larvae might only be in quiescence and became active once introduced in fresh millet stems.

The results obtained in the present study showed that both *C. flavipes* and *C. sesamiae* were able to parasitize the millet stem borer *C. ignefusalis*. Despite longer developmental times, *C. sesamiae* produced much more adult and female progeny than *C. flavipes*, indicating that the East African strain of *C. sesamiae* could be used in the Sahelian region of West Africa. However, the faster-developing novel association parasitoid, *C. flavipes*, would probably give better control of *C. ignefusalis* than *C. sesamiae* in the region.

CHAPTER SEVEN

GENERAL DISCUSSION AND CONCLUSIONS.

Coniesta ignefusalis is the only stem borer causing significant damage and yield loss in pearl millet *P. glaucum* in the Sahelian belt of West Africa. Damaged young plants develop dead-hearts while older plants suffer from stem tunneling and breakage. So far, the most efficient practice for *C. ignefusalis* management is cultural control, although the use of pheromones holds much promise and potential. However, farmers are reluctant to destroy old millet stems for economic reasons. Because indigenous natural enemies are inefficient against the majority of the West African stem borers, there is a resurgence of interest for two biological control tactics:

a) Redistribution of efficient biological races of African natural enemies existing in Eastern and Southern Africa.

b) Novel association, in which natural enemies are introduced, that have had no previous association with the pest, but that attack pests having the same ecological niche in another part of the world.

As part of a project initiated by IITA to introduce *C. flavipes*, *C. sesamiae* and *C. chilonis* into West Africa, the present study investigated in the laboratory suitability of *C. ignefusalis* as a host for *C. flavipes* and *C. sesamiae*. Before that, experiments were conducted to assess larval developmental stages and life table parameters for *C. ignefusalis*. The role of wild hosts in stem borer maintenance in the field was also investigated by testing the acceptability and suitability of *A. gayanus* and *P. pedicellatum* for oviposition and development of *C. ignefusalis*.

The frequency distribution of the daily measurements of head capsule widths gave seven plus one intermediate *C. ignefusalis* larval instar groups, which were confirmed by the molted head capsule observation. A straight line gave the best fit to observed values and indicated that there was a geometrical progression of head capsule widths. Life-fertility studies showed that *C. ignefusalis* female fecundity was very low when compared with values reported for other stem borers. A type IV survivorship curve was obtained indicating high mortality during the young stages.

There was a clear relationship between rainfall and adult *C. ignefusalis* trap catches, with peaks always following high rainfall. This is logical since diapausing larvae need high relative humidity to pupate and emerge as adults. Rainfall is also related to better plant growth and subsequently more oviposition and feeding substrate for moths and their progenies. As a consequence, the absence of suitable host plants was partly responsible for the low first generation population early in the rainy season. Despite a natural infestation of 78.41%, infested stems yielded more than non-infested ones. This confirmed what was already reported by many authors that late infestations may result in more yield of infested than non-infested stems because more vigorous plants are attacked. Artificial infestations at 2 WAE resulted in more damage and yield reduction than infestations at 4 WAE. The 100% avoidable yield loss obtained in cages infested at 2 WAE with 10 larvae per plant was attributable to the development in the cages of successive generations of *C. ignefusalis* causing a kind of 'pest saturation' in the cages. The same phenomena occurred in cages infested at 4 WAE, but plants were strong enough to cope with heavy infestations. There were some yield variations in cages with the same treatment, due to the small number of replications. This should be corrected during future studies to get better results.

The wild hosts *A. gayanus* and *P. pedicellatum* were non-preferred hosts for oviposition but were partially suitable for the development of *C. ignefusalis*. This raised the question of knowing if these wild hosts are reservoirs or trap plants for *C. ignefusalis*. To answer this important question, field studies are necessary, during which the age of plants used should be taken into account.

Studies on the suitability studies of *C. ignefusalis* as a host for the development of the parasitoids *C. flavipes* and *C. sesamiae* showed high host mortality and low parasitism rate. This suggests that there was some problem with the quality of the hosts or the parasitoids used. The exposure of non-healthy hosts may cause them to die or to enter diapause. On the other hand, the experimental procedure used, consisting of exposing successively the same female to several hosts in stems may cause the parasitoids to be exhausted by their host-searching effort and thus reduce the parasitism rate. Although *C. ignefusalis* was only partially suitable in this study, the appreciably high number of progeny produced per *C. sesamiae* female, and the fast development of *C. flavipes* support the use of *C. sesamiae* and *C. flavipes* for redistribution and novel association, respectively against *C. ignefusalis*. There is however a need to confirm the partial suitability obtained in the present work, aswell as a host acceptability study.

From the present study, the following conclusions can be drawn:

1) In the laboratory and on artificial diet, *C. ignefusalis* passed through 7 to 8 larval instars and presented a type IV survivorship curve.

2) Larval instar determination using head capsule frequency distribution should be investigated under natural conditions in the field.

3) In 1996, three adult generations of *C. ignefusalis* were present in the field at Sadore, Niger. Late-occurring natural and artificial infestations caused infested stems to yield more than non-infested stems. Early artificial infestation at 2 WAE with 10 larvae per plant

resulted in a total crop failure.

4) Appropriate methods of yield loss assessment need to be developed for cereal stem borers, including *C. ignefusalis*.

5) *A. gayanus* and *P. pedicellatum* are probably trap plants rather than reservoirs for *C. ignefusalis*. Additional field studies on wild hosts will provide better insight into their real status in the millet environment.

6) *C. ignefusalis* was partially suitable for both *C. sesamiae* and *C. flavipes*. The introduction of *C. sesamiae* and *C. flavipes* for redistribution and novel association, respectively against *C. ignefusalis* in Niger and other Sahelian regions should be feasible. Before host suitability studies of *C. ignefusalis* for *C. flavipes* and *C. sesamiae*, parasitoid colonies need to be well established, with a stable progeny production. Better results may be obtained if *S. calamistis* is used as a host in establishing the parasitoid colonies.

REFERENCES CITED

Adesiyun, A. A. 1983. Some effects of intercropping of sorghum, millet and maize on infestation by lepidopterous stalk-borers, particularly *Busseola fusca*. *Insect Science and its Application* **4** (4): 387-391.

Agnew, C. W. 1987. Status of *Acigona* Hubner (sensu Bleszynski) (Lepidoptera: Pyralidae: Crambinae) with changes in nomenclatur. *Proceedings of the Entomological Society of Washington* **89** (1): 100-102.

Ajayi, O. 1985. A checklist of millet insect pests and their natural enemies in Nigeria. *Samaru Miscellaneous Paper* **108**. 16 pp.

Ajayi, O. 1986. The effects of planting date and varieties on stem borer infestation and damage of pearl millet. *Nigerian Journal of Entomology* **6**(1-2): 71-77.

Ajayi, O. 1990. Possibilities for integrated control of the millet stem borer *Acigona ignefusalis* Hampson (Lepidoptera: Pyralidae) in Nigeria. *Insect Science and its Application* **11** (2): 109-117.

Ajayi, O. and Uvah, I. I. 1989. Review of research on millet entomology in Nigeria:1977-1987. Pages 21-30 *in* Proceedings of Regional Pearl Millet Workshop held at the Kongo Conference hall, 14-19 August 1988.

Ajayi, O. and Labe, D. A. 1990. The effect of sowing date and planting method on stem borer damage in Daura millet. *Annals of Applied Biology* **117**: 487-494.

Alghali, A. M. 1985. Larval instars determination for *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) reared on sorghum. *Insect Science and its Application* **6** (6): 677-679.

Ampofo, J. K., O. 1985. *Chilo partellus* (Swinhoe) oviposition on susceptible and resistant maize genotypes. *Insect Science and its Application* **6** (3): 323-330.

Atkinson, P. R. 1980. On the biology, distribution and natural host-plants of *Eldana saccharina* Walker (Lepidoptera: Pyralidae). *Journal of the Entomological Society of South Africa* **43** (2): 171-194.

Bako, O. 1977. Etude biologique et écologique de *Haimbachia ignefusalis* (Hampson) (Lepidoptera: Pyralidae, Crambinae) en vue d'une lutte biologique. Université Laval, Montréal. 55 pp.

Balidawa C. W. 1985. Insect behaviour and host plant resistance. *Insect Science and its*

Application **6** **(30)**:337-340.

Bal, A. B. 1981. Observations sur le superparasitisme d'*Apanteles flavipes* CAM. (Hymenoptera: Braconidae) parasite de *Chilo zacconius* BLESZ. (Lep., Pyralidae). Mémoire-Thèse, Ecole Nationale d'Ingénieurs des Travaux Agricoles de Bordeaux, section de protection des végétaux, 33 pages.

Bal, A. B. 1988. Nombre de stades larvaires d'*Eldana saccharina* Walker (Lepidoptera: Pyralidae) et facteurs de variation. *Revue Sénégalaise des Recherches Agricoles et Halieutiques* **1**: 1-14

Bardner, R. and Fletcher, K. E. 1974. Insect infestations and their effects on the growth and yield of field crops: a review. *Bulletin of Entomological Research* **64**: 141-160.

Beck, S. D. 1965. Resistance of plants to insects. *Annual Review of Entomology* **10**: 207-232.

Beg, M. N. and Inayatullah C. 1980. Studies on Apanteles flavipes, a parasite of graminaceous borers. *Pakistan Journal of Agricultural Research* **1**: 50-53

Betbeder-Matibet, M. 1989. Biological control of sorghum stem borers. International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India, pp. 89-93.

Bhatnagar, V. S. 1983. Rapport d'activité (juin - octobre 1982). Projet CILSS Lutte Intégrée, Composante Nationale du Sénégal. Institut Sénégalais de Recherches Agricoles (ISRA), pp.28.

Bhatnagar, V. S. 1984. Rapport d'activité (Nov. 1982 - Oct. 1983). Projet CILSS Lutte Intégrée, Composante Nationale du Sénégal. Institut Sénégalais de Recherches Agricoles (ISRA), pp. 78.

Bhatnagar, V. S. 1985. Rapport technique (Nov. 1983 - Dec. 1984). Projet CILSS Lutte Intégrée contre les ravageurs des cultures vivrières dans le Sahel. Institut Sénégalais de Recherches Agricoles (ISRA), 58 pp.

Birch, L. C. 1948. The intrinsic rate of natural increase of an insect population. *Journal of Animal Ecology* **17**: 15-26

Bosque-Pérez, N. A. and Marek, J. H. 1991. Effect of the stem borer *Eldana saccharina* (Lepidoptera: Pyralidae) on the yield of maize. *Bulletin of Entomological Research* **81**: 243-247.

Bouchard, D., Quedraogo, A. and Boivin, G. 1993. Impact de la coupe des tiges de mil sur les larves diapausantes de *Coniesta (Acigona) ignefusalis* (Lepidoptera: Pyralidae). *Insect*

Science and its Application **14**: 31-37.

Bowden, J. 1976. stem borer ecology and strategy for control *in Annals of Applied biology* **84**: 107-111.

Breniere, J. and Coutin, R. 1969. Observations entomologiques sur les insectes du mil au Sénégal Oriental. Institut de Recherches Agronomiques Tropicales et des Cultures vivrières (IRAT). 30 pp.

Breniere, J. 1971. Les problèmes des Lépidoptères foreurs des graminées en Afrique de l'Ouest. *Annales de Zoologie et Ecologie Animale* **3**: 287-296.

Breniere, J. And Bordat D. 1982. Intêrets et difficultés de la lutte biologique par introduction d'entomophages: cas des foreurs du riz en Afrique. *Agronomie Tropicale* **40**: 203-206.

Brownidge, M. 1991. Native *Bacillus thuringiensis* isolates for the management of Lepidopteran cereal pests. *Insect Science and its Application* **12** (1/2/3): 57-61.

Chiarappa L. (Ed.) 1981. Crop loss assessment methods. Supplement 3. Rome, FAO, 123 pp.

Dakouo, D. and Lankouande, A. 1992. Les Lépidoptères foreurs de tiges de sorgho: fluctuations saisonnières, importance économique et perspectives de lutte Intégrèe. *Sahel PV Info* **42**: 16-22.

Debach, P. and Rosen, D. 1991. Biological control by natural enemies, second Edition. Cambridge University Press, 440 pp.

Deevey, E.S. 1947. Life tables for natural populations of animals. *Quart. Review of Biology* **22**: 283-314.

FAO (Food and Agriculture Organization of the United Nations) and **ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)** 1996. The world sorghum and millet economies. Facts, trends and outlook. 68 pp.

Flattery, K. E. 1982. An assessment of pest damage on grain sorghum in Botswana. *Expl. Agric.* **18**: 319-328.

Fuchs T. W., Huffman F. R. and Smith, W. W. Jr 1979. Introduction and establishment of *Apanteles flavipes* (Hym.: Braconidae) on *Diatraea saccharalis* (Lep.: Pyralidae) in Texas. *Entomophaga* **24**: 109-114.

Gahukar, R. T. 1981. Biological control of insect pests of sorghum and pearl millet in West Africa, pp.69-91 *in* Proceedings of the Conference on Biological Control of pests: its potential in West Africa, Dakar, Sénégal.

Gahukar, R. T. 1984. Insect pests of pearl millet in West Africa: a review. *Tropical Pest Management* **30**: 142-147.

Gahukar, R. T. 1989. Pest and disease incidence in pearl millet under different plant density and intercropping patterns. *Agriculture, Ecosystems and Environment* **26**: 69-74.

Gahukar, R.T. 1990 a. Population ecology of *Acigona ignefusalis* Hampson (Lepidoptera: Pyralidae) in Senegal. *Environmental Entomology* **19** (3): 13-19.

Gahukar, R. T. 1990 b. Reaction of locally improved pearl millets to three insect pests and two diseases in Senegal. *Journal of Economic Entomology* **83** (5): 2102- 2106.

Gahukar, R. T. 1992. Effect of various fertilizers and rates on insect pest / pearl millet relationship in Senegal. *Tropical Agriculture* **69** (2): 149-152.

Gaines, J. C. and Campbell, F. L. 1935. Dyar's rule as related to the number of instars of the corn ear worm, *Heliothis obsoleta* (Fab.), collected in the field. *Annals of Entomological Society of America* **XXVIII**: 445-461.

Girling, D. J. 1978. The distribution and biology of *Eldana saccharina* Walker (Lepidoptera: Pyralidae) and its relationship to other stem-borers Uganda. *Bulletin of Entomological Research* **68**: 471-488.

Greathead, D. J. 1971. *A Review of Biological Control in the Ethiopian Region*. Technical Communication no. 5, Commonwealth Agricultural Bureaux, Farnham Royal, U.K.

Greathead, D. J. 1987. Prospects for biological control in the tropics. *Insect Science and its Application* **8** (4/5/6): 787-789.

Greathead, D. J. 1988. Crop protection without chemicals: *Pest control in the Third World. Aspect of Biology* **17**:19-28.

Greathead, D. J. 1990. Utilization of natural enemies of *Chilo* spp. for management in Africa. *Insect Science and its Application* **11** (4/5): 749-755.

Greathead, D. J. 1991. Biological control in the Tropics: present opportunities and future prospects. *Insect Science and its Application*, **12** (1/2/3): 3-8.

Guevremont, H. 1983. Recherche sur l'entomofaune du mil: Rapport Annuel de Recherches pour 1982. Maradi, Niger (Centre National de Recherches Agronomiques de Tarna, INRAN (Institut national de Recherches Agronomiques du niger.

Hailemichael, Y., Smith, Jr. J. W. and Wiedenmann, R. N. 1994. Host-finding, behavior, host acceptance, and host suitability of the parasite *Xanthopimpla stemmator*. *Entomol. exp.*

appl. **71**: 155-166.

Hailemichael, Y., Schulthess, F., Smith, Jr. J. W. and Overholt, W. A. 1997. Suitability of West African gramineous stemborers for the development of *Cotesia* species (Hymenoptera: Braconidae). *Insect Science and its Application* **17** (1): 89-95.

Harris, K. M. 1962. Lepidopterous stem borers of cereals in Nigeria.*Bulletin of Entomological Research* **53**: 139-171.

Harris, K. M. 1989. Bioecology of sorghum stem borers. ICRISAT Conference Paper 495: 63-71. (International Workshop on Sorghum Stem Borers, Patancheru (India), 17-20 Nov. 1987).

ICIPE (International Centre of Insect Physiology and Ecology) 1992. Annual Report. 149 pp.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1981. Upper volta cooperative Programme. Annual Report 1980. Entomology, pp. F1-f36. Quagadougou, Upper Volta.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1983. Manuel d'identification des insectes nuisibles au sorgho. Bulletin d'Information no. 12.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1984. ICRISAT Sahelian Center Annual Report, 1983, pp. 31-37, Niamey, Niger.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1988 a. Proceedings of the Regional Pearl Millet Improvement Workshop, Institute for Agricultural Research Ahmadu Bello University, International Crops Research Institute for the Semi-Arid Tropics, 15-19 August 1988, Zaria, Nigeria.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1988 b. Insect and other animal pests of millet. Sorghum and Millets Information Center, ICRISAT, Patancheru, 502 324, Andhra Pradesh, India.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1994. *ICRISAT Now: Sowing for the Future.* A.P. 502 324, ICRISAT, india.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1995. ICRISAT Report 1994. A.p. 502 324, ICRISAT, India.

Inayatullah, C. 1983. Host selection by *Apanteles flavipes* (Cameron) (Hymenoptera: Braconidae): influence of host and host plant. *Journal of Economic Entomology* **76**: 1086-

1087

Inayatullah, C. 1987. Development and survival of *Apanteles flavipes* (Cam.) (Hymenoptera: Braconidae) on *Chilo partellus* (Swinh.) (Lepidoptera: Pyralidae) larvae reared on grain-flour diet. *Insect Science and its Application* **8** (1): 95-97.

Ingram W. R. 1958. The lepidopterous stalk borers associated with gramineae in Uganda. *Bulletin of Entomological Research* **49**: 67-83.

Islam Z. 1994. Key factors responsible for fluctuations in rice yellow stemborer populations in deepwater rice ecosystems. *Insect Science and its Application* **15** (4/5): 461-468.

Jika, N. and Quendeba, B. 1985. Programme de selection du mil au Niger. INSORTMIL-INRAN, 13-15.

James, W. C. and Teng, P. S. 1979. the quantification of production constrainsts associated with plant diseases. *Applied biology* **4**: 201-267.

Kaufmann, T. 1983. Behavioral biology, feeding habits, and ecology of three species of maize stem-borers: *Eldana saccharina* (Lepidoptera: Pyralidae), *Sesamia calamistis* and *Busseola fusca* (Noctuidae) in Ibadan, Nigeria, West Africa. *J. Georgia Entomol. Soc.* **18** (2): 255-259.

Kfir R. 1995. Parasitoids of the African stem borer, *Busseola fusca* (Lepidoptera: Noctuidae) in South Africa. *Bulletin of entomological research* **85**: 369-377.

Kishi, Y. 1971. Reconsideration of the method to measure the larval instars by use of the frequency distribution of head-capsule widths or lengths. *Canadian Entomologist* **103**: 1011-1015.

Kumar, H. and Saxena K. N. 1985. Ovipositional responses of *Chilo partellus* (Swinhoe) to certain susceptible and resistant maize genotypes. *Insect Science and its Application* **6** (3): 331-335.

Leuschner, K., Taneja, S. L. and Sharma, H. C. 1985. The role of host plant resistance in pest management in sorghum in India. *Insect Science and its Application* **6**: 453-460.

Lukefahr, M. J. 1990. Considerations in the development of a host plant resistance program against the pearl millet stem borer. International; Workshop on sorghum stem borers, 17-20 Nov. 1987. ICRISAT.

Lukefahr, M. J., Mamalo, A. K. and Klaij, M. C. 1988. Survival of the millet stem borer (*Coniesta (Acigona) ignefusalis*) during the non-growing season. Pages 31-34 *in* The

Regional Millet Workshop, ICRISAT-IAR/ABU, Samaru, Zaria, Nigeria, 15-19 August 1988.

Maiti, R. K. and Bidinger, F. R. 1981. Growth and development of the pearl millet plant. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Center, India, Patancheru, A. P. 502 324, India: ICRISAT. *ICRISAT Research Bulletin* **6**.

Mamalo, A. K. 1990. Perspectives pour une approche integree de lutte contre *Coniesta* (*Acigona*) *ignefusalis* Hampson (Lepidoptera: Pyralidae) borer de tige de mil en zone sahelienne. These, Universite de Quagadougou, Burkina faso, 119 pp.

Markham, R. H. 1985. Natural enemies of *Acigona ignefusalis* and *Raghuva albipunctella* in Niger and Burkina Faso and possibilities for development of a biological control strategy. Report of a consultancy for ICRISAT Sahel Centre, Niamey.

Mbapila, J. C. and Overholt, W. A. 1997. Oviposition, development and searching behaviour of *Cotesia flavipes* (Hymenoptera: Braconidae) in relation to aestivating and non-aestivating *Chilo* spp. (Lepidoptera: Pyralidae) larvae in maize. *African Entomology* **5** (1): 35-39.

Mohyuddin, A. I. 1971. Comparative biology and ecology of *Apanteles flavipes* (Cam.) and *A. sesamiae* as parasites of graminaceous borers. *Bulletin of Entomological Research* **61**: 33-39.

Mohyuddin, A. I. 1972. Distribution, biology and ecology of *Dentichasmias busseolae* Heinr. (Hym.: Ichneumonidae), a pupal parasite of graminaceous stem borers (Lep., Pyralidae). *Bulletin of Entomological Research* **62**: 161-168.

Mohyuddin, A. I. 1991. Utilization of natural enemies for the control of insect pests of sugar-cane. Insect *Science and its Application* **12** (1/2/3): 19-26.

Mohyuddin, A. I. and Greathead, D. J. 1970. An annotated list of the parasites of graminaceous stem borers in East Africa, with a discussion of their potential in biological control. *Entomophaga* **15**: 241-274.

Mohyuddin, A. I., Inayatullah, C. and King, E. G. 1981. Host selection and strain occurrence in *Apanteles flavipes* (Cameron) Hymenoptera: Braconidae) and its bearing on biological control of graminaceous stem borers (Lepidoptera: Pyralidae). *Bulletin of Entomological Research* **71**: 575-581.

Moutia, L. A. and Courtois, C. M. 1952. Parasites of the moth borers of sugarcane in Mauritius.

Bulletin of Entomological Research **43**: 325-359.

Ndoye, M. 1977. Synthèse de quelques résultats sur les insectes foreurs des mils et sorgho au Sénégal. Bambey, Sénégal: Centre de Recherches Agronomiques, pp. 15.

Ndoye, M. 1980. *Goniozus procera* Risbec (Hymenoptera: Bethylidae) ectoparasite larvaire d'*Acigona ignefusalis* (Hampson) (Lepidoptera: Pyralidae, Crambinae). Institut Sénégalais de Recherches Agricoles (ISRA), 6 pp.

Ndoye, M. and Gahukar, R. 1987. Insect pests of pearl millet in West Africa and their control. Pages: 195-205 *in* Proceedings of the International Pearl Millet Workshop, 7-11 April 1986, ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Center, India, Patancheru, A. P. 502 324, India: ICRISAT.

Ngi-Song, A. J. 1995. Parasitization of selected African stemborers by *Cotesia flavipes* (Cameron) and *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) with emphasis on host selection and host suitability. Ph.D Thesis (Entomology), 200 pp. Department of Crop Science, Faculty of Agriculture, University of Ghana, Legon.

Ngi-Song, A. J., Overholt, W.A. and Ayertey, J. N. 1995. Suitability of African gramineous stem borers for development of *Cotesia flavipes* and *C. sesamiae* (Hymenoptera: Braconidae). *Environmental Entomology* **24**: 978-984.

NRI: Natural Resources Institute 1993. Millet crop-loss assessment methods. Bulletin 62.

Nwanze, K. F. 1981. Stem borers of cereals in Sahelian West Africa. Distribution, relative importance and control. Projet Conference on "Biological Control of pests: its potential in West Africa". 16 pp.

Nwanze, K. F. 1985. Some aspects of pest management and host plant resistance in pearl millet in the Sahel. *Insect Science and its Application* **6** (3): 461- 465.

Nwanze, K. F. 1988. Assessment of on-farm losses in millets due to insect pests. *Insect Science and its Application* **9** (6): 673-677.

Nwanze, K. F. and Harris K. M. 1992. Insect pests of pearl millet in West Africa. *Review of Agricultural entomology* **80**: 1133-1155. 97 ref..

Nwanze, K. F. and Mueller, R. A. E. 1989. Management options for sorghum stem borers for farmers in the semi-arid tropics. Pp. 105-116 *in* International Workshop on Sorghum Stem Borers, 17-20 Nov 1987, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crop Research Institute for the Semi-Arid Tropics. 33 ref.

Nylin, S. and Niklas, J. 1993. Oviposition preference and larval performance in *Polygonia-c-album* (Lepidoptera: Nymphalidae): the choice between bad and worse. *Ecological Entomology* **18**: 394-398.

Odebiyi, J. B. 1981. Studies on the biology of the cowpea pod-borer *Maruca testulalis* in Kenya-1. Determination of the larval instars. *Insect Science and its Application* **1** (4): 339-341.

Odindo, M. O. 1991. Management of cereal stem borers, especially *Chilo partellus*, using microsporidia. *Insect Science and its Application* **12** (1/2/3): 51-55.

Omwega, C. O., Kimani, S. W., Overholt, W. A. and Ogol, C. K. P. O. 1995. Evidence of the establishment of *Cotesia flavipes* (Hymenoptera: Braconidae) in continental Africa. *Bulletin of Entomological Research* **85**: 525-530.

Overholt, W. A. 1992. Classical biological control of *Chilo partellus*. ICIPE Annual Report 1992, pp. 51-54.

Overholt, W., Ngi-Song, A. J., Kimani, S. K., Mbapila, J., Lammers, P. and Kioko, E. 1994. Ecological considerations of the introduction of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) for biological control of *Chilo partellus* (Swinhoe) (lepidoptera: Pyralidae).

Polaszek, A. and Walker, A. K. 1991. The *Cotesia flavipes* species complex: Parasitoids of cereal stem borers in the Tropics. Fourth European Workshop. Perugia 3-4 April 1991, *Redia* **LXXIV** (3): 335-341.

Rachie, K. O. 1975. The millets: importance, utilization and outlook. ICRISAT India.

Rachie, K. O. and Majmudar, J. V. 1980. Pearl millet. The Pennsylvania State University Press. 307 pp.

Risbec, J. 1950. La faune entomologique des cultures au Sénégal et au Soudan Français. Paris, Gouvernement Général de l'Afrique Occidentale Française. Jouve, Paris.

Risbec, J. 1960. Les parasites des insectes d'importance économique en Afrique Tropicale et à Madagascar. *Agronomie Tropicale* **XV** (6): 624-656.

Rodriguez-Del-Bosque, L. A. 1988. Population ecology of corn stalk borers (Lepidoptera: Pyralidae) in Northern Mexico. Ph.D. dissertation. Texas A & M University. 160 pp.

Sagnia, S. B. 1983. Possible integrated pest management tools for the effective control of cereal stem borers in the Gambia. *Insect Science and its Application* **4**: 217-219.

Sampson, M. A. and Kumar, R. 1985. Life history, development and behaviour of *Eldana saccharina* Walker on suggar-cane in southern Ghana. *Insect Science and its Application*

6 (2): 135-143.

SAS Institute 1987. SAS/STAT guide for personal computers; version 6 ed. SAS Institute, Cary. N.C.

Saxena, K. N. 1985. Behavioural basis of plant resistance or susceptibility to insects. *Insect Science and its Application* **6** (3): 303-313.

Scheibelreiter G. K. 1980. Sugar-cane stem borers (Lep.:Noctuidae and Pyralidae)in Ghana. *Zeitschrift fur Angewandte Entomologie* **89**: 87-99.

Schulthess, F., Bosque-Pérez, N. A. and Gounou, S. 1991. Sampling lepidopterous pests on maize in West Africa. *Bulletin of Entomological Research* **81**: 297-301.

Schulthess, F., Bosque-Perez, N. A., Chabi-Olaye, A., Gounou, S., Ndemah, R. and Goergen, G. 1997. Exchange of natural enemies of lepidopteran cereal stem borers between african regions. *Insect Science and its Application* **17** (1): 97-108.

Sekloka, S. 1996. Contribution à l'étude bioécologique de *Eldana saccharina* Walker (Lepidoptera: Pyralidae) sur *Zea mays* L. et les plantes hotes alternatives. Memoires Ing. Agr. UNB, Benin

Seshu Reddy, K. V. 1988. Assessment of on farm yield loss in sorghum due to insect pests. *Insect Science and its Application* **9** (6): 679-685.

Seshu Reddy, K. V. 1989. Sorghum stem borers in eastern Africa. International Workshop on Sorghum Stemborers. Patancheru, India 17-20 November 1987. Pp. 33-40.

Seshu Reddy, K. V. and Sum, K. O. S. 1991. Determination of economic injury level of the stem borer, Chilo partellus (Swinhoe) in maize, Zea mays L. *Insect Science and its Application* **12** (1/2/3): 269-274.

Seshu Reddy, K.V. and Walker, P. T. 1990. A review of the yield losses in graminaceous crops caused by *Chilo* spp. *Insect Science and its Application* **11** (4/5): 563-569.

Setamou, M., Schulthess, F., Bosque-Perez, N. A. and Odjo, T. 1993. The effects of plant nitrogen and silica on the bionomics of *Sesamia calamistis* (Lepidoptera: Noctuidae). *Bulletin of Entomological Research* **83**: 405-411.

Shanower, T. G., Schultess, F. and Bosque-Perez, N. 1993. Development and fecundity of *Sesamia calamistis* (Lepidoptera: Noctuidae) and *Eldana saccharina* (Lepidoptera: Pyralidae). *Bulletin of Entomological Research* **83**: 237-243.

Sigwalt, B. and Pointel, J. G. 1980. Statut spécifique et séparation des *Apanteles* du sous-groupe *flavipes* (Hym: braconidae) utilisés en lutte biologique. *Annales de la Société Entomologique de France* **16** (1): 109-128.

Skoroszewski, R. W. and Van Hamburg, H. 1987. The release of *Apanteles flavipes* (Cameron) (Hymenoptera: Braconidae) against stalk-borers of maize and grain-sorghum in South Africa. *Journal of the Entomological Society of Southern Africa* **50**: 249-255.

Smith, Jr. W. J., Wiedenmann, R. N. and Overholt, W.A. 1993. Parasites of lepidopteran stem borers of tropical graminaceous plants. ICIPE (International Center of Insect Physiology and Ecology), Science Press, Nairobi, Kenya, 89 pp.

Southwood, T. R. E. 1969. Population studies of insects attacking sugar cane, pp. 428-459 *in* Williams J. R., Metcalfe, R. W., Mungomery R. W. and Mathes, R. (eds), Pests of sugar cane, Elsevier, New York.

Southwood, T. R. E. 1978. Ecological methods. Wiley, New York. 524 pp.

Southwood, T. R. E. 1980. Ecological methods with particular reference to the study of insect populations. 2nd edn. 524 pp. London, Chapman and Hall.

Spencer, D. S. C. and Sivakumar, M. V. K. 1987. Pearl millet in African agriculture. Pages 19-31 *in* Proceedings of the International Pearl Millet Workshop, 7-11 April 1986, ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Center, India, Patancheru, A. P. 502 324, India: ICRISAT.

Taneja, S. L. and Leuschner, K. 1985. Methods of rearing, infestation, and evaluation for *Chilo partellus* resistance in sorghum. Pages 175-188 *in* Proceedings of the International Sorghum Entomology Workshop, 15-21 July 1984, Texas A&M University, College Station, Texas, USA. Patancheru, A.P. 502 324, India. International Crops Research Institute for the Semi-Arid Tropics.

Taneja, S. L. and Nwanze, K. F. 1989. Assessment of yield loss of sorghum and pearl millet due to stem borer damage. ICRISAT (International Crop Research Institut for the Semi-Arid Tropics). International Workshop on Sorghum Stem Borers, 17-20 Nov. 1987, 6 pp.

Teng, P. S. (Ed) 1987. Crop loss assessment and pest management. APS Press. *The American Phytopatological Society*. 270 p.

Thorsteinson, A. J. 1960. Host selection in phytophagous insects. *Annual Review of Entomology* 5: 193-218.

Ukwungwu, M. N. 1990. Host plant resistance in rice to the African striped borer, *Chilo* *zacconius* Blesz. (Lepidoptera: Pyralidae). *Insect Science and its Application* **11** (4/5): 639-647.

Unnithan, G. C. 1987. Development and reproductive biology of the maize stem borer *Busseola fusca* fuller (Lepidoptera: Noctuidae). *Journal of Applied entomology* **104**: 172-179.

Uvah, I. I. and Ajayi, O. 1989. Chemicals for control of stem borers of pearl millet in the Nigerian savanna. Pages 16-22 *in* proceedings of the Regional Pearl Millet Improvement Workshop, 4-7 Sep 1989, ICRISAT Sahelian Center, Sadore (Fussell, L. K. and Werder, J., eds.). Niamey, Niger.

Van Leerdam, M. B. 1981. Parasitism of *Diatraea saccharalis* (F.) infesting Johnson grass, by the braconid parasite *Apanteles flavipes* (Cameron). M.S. Thesis. Texas A&M University, College station. 91 pp. ICRISAT (International Crop Research Institut for the Semi-Arid Tropics). 10 ref.

Van Leerdam, M. B., Smith, Jr. J. W. and Fuchs, T.W. 1985. Frass-mediated, host-finding behavior of *Cotesia flavipes*, a Braconid parasite of *Diatraea saccharalis* (Lepidoptera: Pyralidae). *Annals of the Entomological Society of America* **78**: 647-650.

Walker, A. K. 1994. Species of microgastrinae (Hymenoptera: Braconidae) parasitizing lepidopterous cereal stem borers in Africa. *Bulletin of Entomological Research* **84**: 421-434.

Walker, P. T. 1981. The relation between infestation by lepidopterous stem borers and yield in maize: methods and results. *Eppo bulletin* **11** (2): 101-106.

Walker, P. T. 1983. Crop losses: the need to quantify the effects of pests, diseases, and weeds on agricultural production. *Agriculture Ecosystems and Environment* **9**: 119-158

Walker, P.T. 1987. Methods of studying the relation between different insect population levels, damage and yield in experiments and surveys. *The American Phytopathological Society*. 270 pp.

Wiedenmann, R. N., Smith, Jr. J. W and Darnell, P. O. 1992. Laboratory rearing and biology of the parasite *Cotesia flavipes* (Hymenoptera: Braconidae) using *Diatraea saccharalis* (Lepidoptera: Pyralidae) as a host. *Environmental Entomology* **21** (5): 1160-1167.

Wiedenmann, R. N. and Smith, Jr. J. W. 1993. Functional response of the parasite *Cotesia flavipes* (Hymenoptera: Braconidae) at low densities of the host *Diatraea saccharalis* (Lepidoptera: Pyralidae). *Environmental Entomology* **22** (4): 849-858.

Wiedenmann, R. N. and Smith, Jr. J. W. 1995. Parasitization of *Diatraea saccharalis* (Lepidoptera: Pyralidae) by *Cotesia chilonis* and *C. flavipes* (Hymenoptera: Braconidae). *Environmental Entomology* **24** (4): 950-961.

Wiedenmann R. N. and Smith, W. W. Jr 1997. Novel association and importation biological control: The need for ecological and physiological equivalences. *Insect Science and its Application* **17** (1): 51-60.

Youm, O. 1990. Evaluation of natural enemies associated with the millet stalk borer *Haimbachia ignefusalis* (Hampson) (Lepidoptera: Pyralidae) in Niger. PH.D. dissertation, 145 pp. Texas A & M University. College station, Texas, USA.

Youm, O., Mamalo, A. K. and Nwanze, K. F. 1993. Bioecology and integrated management of the millet stem borer (Lepidoptera : Pyralidae): A review and highlights of current research at the ICRISAT Sahelian Center. Proceedings of the Regional Pearl Millet Workshop, 19-21 Sep. 1990, ICRISAT, Niger.

Youm, O. and Gilstrap, F. E. 1993. A note on the bioecology of the millet stem borer *Coniesta* (=*Haimbachia*) *ignefusalis* (Lepidoptera: Pyralidae) in Niger. *Samaru Journal of Agricultural Research* **10**: 97-104.

Youm, O. and Gilstrap, F. E. 1994 a. Habitat site selection, crop damage and oviposition preference by *Coniesta* (= *Haimbachia*) *ignefusalis* (Lepidoptera: Pyralidae). *International Journal of Pest Management* **40** (3): 231-236.

Youm, O. and Gilstrap, F. E. 1994 b. Population dynamics and parasitism of *Coniesta* (= *Haimbachia) ignefusalis, Sesamia calamistis*, and *Heliocheilus albipunctella* in millet monoculture. *Insect Science and its Application* **14** (4): 419 - 426.

Youm, O. and Beevor, P. S. 1995. Field evaluation of pheromone-baited traps for *Coniesta ignefusalis* (Lepidoptera: Pyralidae) in Niger. *Journal of Economic Entomology* **88** (1): 65-69.

Youm, O., Harris, K. M. and Nwanze, K. F. 1996. *Coniesta ignefusalis* (Hampson) the millet stem borer, a handbook of Information. *ICRISAT Information Bulletin* **46.** ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) 1996. India.

Youm, O., Beevor, P. S., Hall, D. R. and Mc Veigh, L. J. 1997. The potential use of pheromones for the management of the millet stem borer, *Coniesta ignefusalis* (Hampson). *Insect science and its Application* **17** (10): 169-173.

APPENDICES

Appendix 1. Parasitism of the second-to-fifth instars and diapausing larvae of *C. ignefusalis* exposed to *C. flavipes* and *C. sesamiae* at 18, 22, 26 and 30°C.

Host instar	Mean ± SE parasitism (%)									
	18°C		22°C		26°C		30°C		All instars	
	C. flavipes	C. sesamiae	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*
second	5.56±5.56 b* B	24±8.72a AB	7.14 ±7.14a* B	4.35±4.35a* B	0a B	5.35 ±5.35a* C	0a B	7.14 ±7.14* a B	3.64± 2.55b B	11.11±3.51a B
Third	8.33 ± 5.76a B	3.70 ±3.7a * C	11.54±6.39a B	10.0±6.88a B	15.38 ± 7.22a B	6.67 ±6.67b* C	16.67±7.77 A	13.33± 9.09a B	13.0±3.38a AB	7.79±3.07a B
Fourth	3.03 ±3.03b B	36.84 ±11.37a A	21.88 ± 7.42 a A	34.48±8.98b A	13.04±7.18b A	31.82±10.16a A	20.0±8.17a A	34.62±9.51a A	14.16±3.29b AB	34.38± 4.87a A
Fifth	17.65±5.39a A	12.77±4.92a B	42.86±7.73a A	7.32±4.12b B	21.21±7.23a A	4.17±2.92b C	17.86±7.37a A	7.69±4.32b B	25.97±3.52 a A	8.0±2.06b B
Diapause	10.34±5.76a B	11.43±7.73a B	10.81±5.17a B	6.45 ±7.23a B	3.23±3.23b B	16.67±7.37a B	14.29±6.73a A	7.14± 4.96a B	9.6 ± 2.65a B	10.48±2.76a B
All instars	10.32±2.45a	15.69± 2.95a	21.85 ± 3.36 a	12.5± 2.77 b	12.10±2.94 a	11.94±2.81a	15.38±3.35a	13.93 ± 3.15a	14.99 ± 1.53a	13.56±1.46a

* Only one female parasitoid was concerned; not included in statistical analyses.

Mean within column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

Means of the different temperatures followed for each instar by the same lowercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).

Appendix 2. Number and developmental time of progeny obtained from *C. flavipes* and *C. sesamiae* exposed to second to fifth and diapausing larvae of *C. ignefusalis*.

Host instar	Mean ± SE									
	No of larval progeny		No of adult progeny		Female progeny ratio (%)[1]		Larval period (days)		total developmental time (days)	
	C. flavipes	*C. sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*	*C. flavipes*	*C. sesamiae*
second	33* (1)	47.43±4.47 (7) B	32*	41.14±5.29 A	71.88*	74.94 ±3.04 A	*	28.71±2.07 A	*	35.71±2.39 A
Third	33.89 ±6.18 (9) a A	31±6.66 (5) a B	19±3.48 a A	21.8 ±7.55 a B	56.19 ±10.86 b B	68.86 ±10.62 a A	24.56±2.26 a A	25.4±2.56 a B	31.22 ±2.17 a A	32.2±3.23 a A
Fourth	35.91±4.14 (11) b A	50.05 ±5.16 (20) a A	22.55 ±5.21 b A	32.85 ±4.19 a AB	25.29±9.06 b C	72.24±3.62 a A	17.0±1.61 b B	21.35±1.12 a C	23.73 ±1.93 b B	27.75 ±1.18 a B
Fifth	32.93 ±3.85 (15) A	86* (1)	14.93 ±2.98 B	35*	68.54 ±6.66 A	*	16.73±1.09B	*	24.67 ±1.45 B	*
Diapausing	50±23 (2) A	39* (1)	31±27 A	33*	25 ±25 C	36.36*	19.5±5.5 B	*	26.00±7.00 B	0
All instars	34.92±2.58b	47.44±3.64a	19.39±2.39b	33±3.0 a	50.41±5.51a	61.12±3.52a	18.58±1.02b	23.06±1.06a	25.79±1.10b	29.59±1.17a

*** Only one female parasitoid concerned; not included in statistical analyses.**
Parentheses indicate the number of female parasitoids that parasitized the hosts with progeny production.
[1] (number of females/number of adults) x 100.
Mean within column followed by the same uppercase letter are not significantly different (P>0.05, LSD test, SAS Institute, 1987).
Means of the different parameters followed for each instar by the same lowercase letter are not significantly different (P > 0.05, LSD test, SAS Institute, 1987).