POSTHUMOUS DEFENCE OF TEDDY KAUMA MATAMA

Teddy Kauma Matama passed away on 12th December, 2006 before defending her Ph.D thesis which she had just submitted.

Her defence meeting was held on 26th February, 2007, the Examination Board Members were unanimous that there were no major corrections to be made on the thesis. The supervisor believed that if the candidate had not passed away, she could =have effectively effected the minor corrections which were pointed out and suggested by the examiners in their reports.

The Board therefore recommended that she be awarded a Ph.D degree posthumously with the attached uncorrected thesis that she had submitted.

Jones M. Mueke

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UNIVERSITY SUPERVISOR
FOR AND ON BEHALF OF THE BOARD OF EXAMINERS.

ROLE OF WILD HOST PLANTS IN POPULATION DYNAMICS OF CEREAL STEMBORERS AND THE ASSOCIATED PARASITOIDS IN UGANDA

BY

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DECLARATIONS

This thesis is my original work and has not been presented for a degree in any other University or any award.

Teddy Kauma Matama

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We confirm that the work reported in this thesis was carried out by the candidate under our supervision. We have read and approved this thesis for examination.

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DEDICATION

To my dear husband, Moses Odeke and our daughter, Hannah Sheila.

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ABSTRACT

Lepidopteran stemborers attack several graminaceous and wild host plants. These pests are one of the major constraints to maize production in Africa. However, efforts to control stemborers have aimed at cereal crops and the role of alternative wild hosts has been neglected. Recent reports have indicated that the abundance of wild grass in the maize field surroundings is correlated with lower stemborer incidence. This study was conducted with the aim of elucidating the role of wild grasses in stemborer infestations in maize in Uganda. To achieve this goal, surveys, field and screen house trials were conducted between 2003 and 2005. The study covered four Agroecological zones and these included the Eastern, South eastern, Lake Victoria Crescent and Lake Albert Crescent ecozones.

Results showed that mainly four stemborer species occur on maize in Uganda. *Busseola fusca* Fuller (Noctuidae) and *Chilo partellus* (Crambidae) were the most important across the four Agroecological zones (AEZs). The distribution of these stemborers varied across AEZs with *C. partellus* as the major stemborer species in the eastern AEZ while *B. fusca* was dominant in the Lake Albert Crescent. The major parasitoids of these stemborers were the introduced *Cotesia flavipes* and the indigenous *Cotesia sesamiae* Cameron (Braconidae) attacking the larval stage and *Dentichasmias busseolae* Heinrich (Ichneumonidae) and *Procerochasmias nigromaculatus* Cameron (Ichneumonidae) that attacked the pupal stage.

Surveys of stemborers on the selected grasses revealed that wild sorghum *Sorghum arundinaceum* (Desv.) Stapf. was the major wild host plant for *B. fusca* and *C. partellus* and these stemborers were not common on the wild grasses *Panicum* *maximum* Jacq., *Pennisetum polystachion* (L.) Schult. and *Pennisetum purpureum* Schumach. However, these grasses were hosts of many stemborer species that are confined to the wild grasses. Host plant preference studies showed that all the four selected grasses studied were not preferred over maize for oviposition by both *C. partellus* and *B. fusca*. These grasses did not support larval development to pupation except for *S. arundinaceum,* which had high numbers of *C. partellus* pupating although with reduced weights compared to maize. Therefore, amongst the grasses tested, *S. arundinaceum* was found to be a suitable host for the development of *C. partellus* and *B. fusca,* and may form a reservoir during the off-season for both the pest and parasitoids as several parasitoid species were recovered from this grass species. *C. sesamiae* was also frequently recovered from *P. purpureum* indicating that this grass species also forms a reservoir for this parasitoid and *C. flavipes* to a small extent.

Results further showed that wild grass border rows did not have a consistent effect on reducing stemborer infestations and larval parasitism was independent of the grassy borders. The role of grassy border rows in controlling cereal stemborers in crops is not well understood. Leaving wild grasses intact in the vicinity of crop fields might have a greater effect on stem borer populations in crops than planting grassy border rows around the fields. There is also need to understand better the mechanisms for reduced pest densities when grasses are growing in the vicinity of cereal crops. The role of grasses in maintaining parasitoids need to be further investigated and perhaps grasses that enhance parasitism with out necessarily increasing pest infestation be identified.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Lepidopteran cereal stemborers are destructive insect pests of maize *Zea mays* L., sorghum *Sorghum bicolor* L., millet *Eleusine coracana*, rice *Oryza sativa* and sugarcane *Saccharum officinarum* in sub-Saharan Africa (Kfir *et al.*, 2002). Maes (1998) listed 21 species occurring on cultivated cereals in Africa but only a few of which cause economic damage. Stemborers of economic importance on maize and sorghum in eastern and southern Africa include; *Chilo partellus* Swinhoe (Crambidae), *Chilo orichalciliellus* Strand (Crambidae) and *Eldana saccharina* Walker (Pylaridae), *Busseola fusca* Fuller (Noctuidae) and *Sesamia calamistis* Hampsons (Noctuidae) (Seshu Reddy, 1998; Kfir, 1998). In West Africa, only *S. calamistis*, *E. saccharina* and *B. fusca* are considered the most important (Bosque-Perez and Schulthess, 1998). Generally, the importance of each borer species depends on the region and the cereal in question.

1.2 Stemborer distribution

Stemborers are a problem on cereals through out Africa and their distribution and damage have been widely studied. It is known that *C. partellus* and *B. fusca* are the most damaging stemborers of maize and sorghum in eastern and southern Africa (Kfir, 1997b; Seshu Reddy, 1998). Other known stemborer species are of less economic importance and these include *S. calamistis*, *E. saccharina* and *C. orichalcociliellus*.

Most of the stemborers are indigenous to Africa, except *C. partellus*, which is a recent introduction from Asia. It was first recorded in Malawi in 1930 (Tams, 1932) and later in Uganda (Ingram, 1958). Since its introduction, *C. partellus* has become an important pest of maize and sorghum both at low and high elevations. It now occurs in Ethiopia, Sudan, Somalia, Kenya, Uganda, Tanzania, Mozambique, South Africa, Swaziland, Lesotho, Zimbabwe, Zambia, Malawi, and Botswana (Nye, 1960; Harris, 1990). The two crambids, *C. partellus* and *C. orichalcociliellus* have not been reported in West Africa. However, it is anticipated that *C. partellus* could become established there (Maes, 1998).

Stemborer distribution varies across regions and ecozones within a country. Seasonal fluctuations may also occur depending on how the insects survive during the dry season and if they cannot go through this period successfully, then the population crashes and may take several seasons for it to build-up (Ndemah *et al.*, 2001a). The distribution of stemborers is mainly influenced by elevation. *B. fusca* occurs at medium to high altitudes > 600m above sea level (Nye, 1960) while *C. partellus* occurs at low to mid altitude <600m – 1500m but has also been found at higher elevations of up to 2300m (Zhou *et al.*, 2001b). *S. calamistis* occurs at all elevations from sea level to 2400m (Nye, 1960) and has been reported through out sub-Saharan Africa.

In some eastern and southern African countries, *C. partellus* has proved to be highly competitive often-displacing the indigenous stemborers (Kfir, 1997a; Overholt, 1998). In Kenya, there is evidence that *C. partellus* has partially displaced the indigenous stemborers *C. orichalcociliellus* in the coastal region and *B. fusca* in the Eastern

Province (Overholt, 1998; Zhou *et al.*, 2001b). In South Africa, this borer has partially displaced *B. fusca* in the eastern Highveld region over a period of seven years (Kfir, 1997a). Similarly, in Uganda, *C. partellus* has also been found to increase in abundance relative to the other stemborer species in the eastern part of the country (Matama-Kauma *et al.*, 2001). Predictions by Overholt *et al.* (2000) show that *C. partellus* is likely to increase in abundance in many areas and became an important pest in the new areas of spread.

1.3 Biology and lifecycle of stemborers

Several authors have given accounts of the biology of the various stemborers (Ingram, 1958; Nye, 1960; Harris, 1962, 1990; Girling, 1978). *B. fusca* females lay rounded, flattened eggs under leaf sheaths in batches of 30 - 100 eggs (Harris, 1962). On average the female lays up to 400 eggs, which take 5-8 days to hatch. The larval period lasts 24-45 days with six to eight larval instars while the pupal stage lasts 10-20 days. *S. calamistis* lays eggs in a more regular arrangement and the larvae are pale pink and pupate in 4-5 weeks. On average a female lays 300 eggs in batches of 10-40 eggs. The female of the spotted stemborer, *C. partellus* lays 200-600 flattened, ovoid and scale-like eggs in batches of 10-80 on the under side of leaves, mostly near the midribs or between the leaf sheaths of maize. The eggs are laid within 3-4 days but most of them are laid on the first day after mating (Harris, 1990; Pats, 1992) and hatching takes 4-5 days while the larvae feed on the plant whorl before tunnelling into the stem. Larval development takes 2-4 weeks and the pupal stage lasts 5-12 days. The pest completes its life cycle in 25-50 days during the cropping season, and has 3-4 overlapping generations with a resting period during unfavourable conditions (Harris, 1990). The sugar cane borer, *E. saccharina* lays 400-600 eggs in batches of 50-100 eggs on the plant or on plant debris on the soil (Girling, 1978). Larval development takes 3-5 weeks and the pupae, which are covered by cocoons, made of silk and plant debris can be found in stems and ears. Adults emerge 7-14 days after pupation.

When the stemborer eggs hatch, first instar larvae disperse and migrate into the plant whorl where they feed on young tissue. Others disperse to neighbouring plants. *C. partellus* disperse by spinning silken threads and ballooning to neighbouring plants (Berger, 1989). Other stemborers like *S. calamistis* feed on the leaf sheath and then bore directly into the stem. Larval development takes place in the stem and at pupation; the larvae make exit holes for the emergence of the adult moth. Pupation may also take place in cob husk or outside the stem (Overholt *et al.*, 2001).

1.4 Damage

Stemborer larvae cause damage by feeding on leaves, stems and cobs. First instar larvae feed on the leaf whorls producing “windows”. From the whorl they migrate and tunnel into the stem destroying the tissue, which interferes with the translocation of nutrients and water. Direct feeding from the whorl into the stem causes dead hearts. *Sesamia* spp however, usually feed on the leaf sheath and directly tunnel into the stem that may result in lodging of the plant. *E. saccharina* on the other hand tunnel leaf tissue near the midrib (Overholt *et al.*, 2001). Frass may be found at the entrance of holes chewed by larvae and prior to pupation, an exit hole covered by a transparent stem epidermis is made. The severity and damage symptoms of stemborers depend on the borer species, plant growth stage at the time of attack and the number of larvae feeding on the plant.

Yield loss is mainly as a result of stunted plants, dead hearts, reduced translocation, lodging and direct damage to the cobs. Stem and cob damage may result into the entry of pathogens that also cause further damage (Bosque-Perez and Mareck, 1991). The number of exit holes and percentage stem tunnelling are the main damage parameters that determine yield loss (Songa *et al.*, 2001a). Yield loss of 20-40% has been X reported (~~Wuria~~ Warui and Kuria, 1983; Seshu Reddy and Walker, 1990) and in Uganda, yield loss of 12-31% has been reported (Kalule *et al*, 1998).

1.5 Management of cereal stemborers

Use of insecticides may provide curative control, as Warui and Kuria (1983) demonstrated that chemical treatment timed appropriately reduced stemborer losses in maize by about 20%. However, chemical pesticide use is rarely justified in low input agricultural systems because of high costs (Ingram, 1958; Mathez, 1972; van den Berg and Nur, 1998). Additionally, overlapping generations make the timing of chemical control difficult and the stem-boring habit of the larvae protects them against sprays and therefore regular applications may be required, a practice that the resource poor farmers cannot afford (Sithole, 1990). Besides, the insecticides if used improperly, are hazardous to man and other non-target organisms hence the need for environmentally durable and economically justifiable control options. This demands knowledge of agro-ecosystems and insight into the relationships between natural and agro-ecosystems.

Cultural control of stemborers includes techniques such as sanitation, intercropping, crop rotation and early planting. Several workers have discussed destruction of crop residues, volunteer plants and alternate hosts to reduce stemborers that aestivate during the off-season (Ingram, 1958; Nye, 1960; Kfir, 1990; Seshu Reddy, 1990). This practice effectively reduces first generation infestations on the crop as aestivating larvae in the residues are destroyed. Destruction of volunteer plants, alternate hosts and crop residues serves to reduce the continuous breeding of stemborers that act as a carryover for the next season (Seshu Reddy, 1990; Minja, 1990). However, sanitation has a limitation in that it requires a collective effort from farmers in the area because moths emerging from untreated plots can infest adjacent crops. Besides, destruction of alternate or wild hosts may not be a good option because it disrupts the ecosystem. Early planting to escape first generation stemborer attack is also limited by unreliable rainfall. Farmers will only plant when they are sure of rainfall for the crop growth.

Intercropping is a common practice by small-scale farmers in Africa to reduce the risk of crop failure or unsure market of a single crop, increase unit land productivity and to improve soil fertility (Risch *et al.*, 1983). Farmers may intercrop similar crops or different crops. Where similar host plants are intercropped it results in high infestations, for example intercropping maize and sorghum gave rise to higher incidence of *C. partellus* (Amoako-Atta *et al.*, 1983; Ogwaro, 1983). Intercropping with non-hosts modifies the crop micro environment in a way that may not favour the pest by influencing infestations or oviposition, pest development, spread to other plants and the activity of natural enemies (Root, 1973; Seshu Reddy, 1990; Ampong-Nyarko *et al* 1994a; Khan *et al.*, 1997a; Skovgard and Pats, 1996). The presence of a non-host plant disrupts the ovipisiting female by reducing its ability to find hosts (Root 1973, Schulthess *et al.*, 2004). On the contrary, Pats *et al.* (1997) found that intercropping did not affect the number of eggs oviposited by *C. partellus* and *C. orichalcociliellus* per plant. Similarly, intercropping was found not to significantly affect egg and larval parasitism of stemborers (Pats *et al*, 1997; Chabi-Olaye *et al.*, 2005). However, intercropping cowpeas or cassava with maize/sorghum has been shown to reduce stemborer damage (Amoako-Atta *et al.*, 1983; Ampong-Nyarko *et al.*, 1994b; Schulthess *et al.* 2004; Chabi-Olaye *et al.*, 2005). Ampong-Nyarko *et al.*, (1994a) reported that one of the mechanisms for reduced stemborer damage in intercropping systems is the interruption of stemborer oviposition by non-host plants in the intercrop. They found that although *C. partellus* oviposited on cowpea (non-host), depending on the distance, few neonate larvae reached the host.

Habitat management systems for *C. partellus* and *B. fusca* have been developed in Kenya which is also referred to as the "push-pull systems". It involves the use of trap and repellent plants, enabling stemborers to be simultaneously repelled from the crop and attracted to the trap plants (Khan *et al.*, 1997a; Khan *et al.*, 1997b; Khan *et al.*, 2000; Khan *et al.*, 2001). Several plants have been selected and are of economic importance as they can be used as livestock fodder in eastern Africa. The most promising ones include Napier grass (*Pennisetum purpereum* Schumach), Sudan grass (*Sorghum vulgare sudanenese* Stapf.), molasses grass (*Melinis minutiflora* Beauv.), silver leaf desmodium (*Desmodium uncinatum* Jacq.) and green leaf desmodium (*Desmodium intortum* Urb.). Napier grass and Sudan grass are used as trap plants, whereas the molasses grass and the desmodium repel ovipositing stemborers when intercropped with maize. Molasses grass, was reported not to only reduce infestations on the maize crop, but also increases parasitism by the larval endoparasitoid *Cotesia sesamiae* Cameron (Khan *et al.*, 1997b). Volatile agents produced by the grass repel female moths and attract the foraging female *C. sesamiae*. One of the volatiles released by *M. minutiflora* that attracts parasitoids is also produced by the herbivore-damaged plants and is implicated widely as a cue for stimulatory predation and parasitism (Khan *et al.*, 1997b). The Napier grass is used as trap plants for stemborers while desmodium repels the stemborers. Desmodium is also said to attract natural enemies into the system. The "push-pull" strategy was also found to be economically feasible and it has advantages in areas stricken with the parasitic witch weeds, Striga; the silver leaf desmodium drastically reduces Striga damage on maize (Khan *et al.*, 2000; Khan *et al.*, 2001).

Natural enemies are important mortality factors in the regulation of stemborer populations (Kfir, 2002). Mohyuddin and Greathead (1970), Mohyuddin (1990) and Bonhof *et al.*, (1997) list the natural enemies of cereal stemborers in Africa. Stemborer natural mortality in the field is high and Mathez (1972) estimated that only 5% of eggs laid develop into adult moths.

1.6 Biological control

Attempts to introduce exotic parasitoids in Africa and Indian Ocean Islands for the biological control of exotic and native stemborers have been partially successful; with only the success of *C. flavipes* on the mainland (Kfir *et al.*, 2002). Since 1991 there has been a major effort to introduce exotic parasitoids for the control of *C. partellus* in a number of countries in eastern and southern Africa by the International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with National Progremmes. This programme focused on *Cotesia flavipes* Cameron (Hymenoptera: Braconidae), a gregarious larval endoparasitoid indigenous to South and Southeast Asia (Mohyuddin, 1971). *C. flavipes* was first released in the southern coastal area of Kenya in 1993 (Overholt *et al.*, 1994). The parasitoid established and expanded to other areas but with comparatively low levels of parasitism (Omwega *et al.*, 1995; Overholt *et al.*, 1997). Further releases were made in Kenya (Songa *et al.*, 2001b), Mozambique in

1996 (Cugala *et al.*, 1999), Uganda in 1997-2004 (Matama-Kauma *et al.*, 2001; Ogwang unpublished) and Somalia in 1997 (Overholt, 1998). Establishment has been confirmed in these countries. *C. flavipes* has also spread and established in Tanzania from Kenya (Omwega *et al.*, 1997) and in Ethiopia probably from neighbouring Somalia (Emana *et al.*, 2001). Studies on the impact of the parasitoid at the Kenya coast showed a reduction in stemborer density (Zhou *et al.* 2001a).

One of the reasons for this success could be attributed to compatibility with its old association (*C. partellus*) as well as compatibility with new associations (*S. calamistis* and *C. orichalcoliciellus*). Kfir *et al.* (2002) argue that a parasitoid that exploits more than one host in the target habitat may better colonize a new area than a parasitoid with a narrow host range owing to a more constant availability of hosts and a lack of population growth depression due to the wastage of eggs in attractive but unsuitable hosts. Studies by Ngi-Song *et al.* (1995) showed that *B. fusca* and *E. saccharina* were unsuitable hosts for the development of *C. flavipes*.

Although *C. flavipes* has successfully established in several countries in eastern and southern Africa, there has been no success in the Highveld region in South Africa. Kfir (2001) concluded that the harsh winter, long diapause and the lack of wild host plants in the Highveld might be responsible for the failure of establishment. In the tropical regions where *C. flavipes* originated, stemborers breed continuously on wild grasses adjacent to dry residues harbouring the diapausing larvae (Mbapila, 1997; Polaszek and Khan, 1998). Overholt *et al.* (1997) suggested that *C. flavipes* must locate non-aestivating larvae in wild host plants in order to survive during the non-cropping seasons when the stemborers diapause.

1.7 Justification of the study

Stemborers attack several gramineous and other wild host plants. However, efforts to control stemborers have aimed at the cereals themselves, and the role of alternative wild hosts has been widely neglected. The presence of wild host plants in the vicinity of cereals have been thought to lead to stemborer outbreaks and their destruction would reduce the stemborers carried over the dry season (Ingram, 1958). However, recent reports have indicated that the abundance of wild grasses in the maize field surroundings is correlated with lower stemborer incidence (Schulthess *et al*, 1997) and increases parasitoid diversity (Ndemah *et al.*, 2001c). Additionally, grasses may act as reservoirs for parasitoids during the off-season and increase parasitoid populations during the cropping season. The rates of parasitism have always been found to be low early in the season and peak at the end of the growing season, perhaps because of the inadequate carry over mechanisms. There is no information in Uganda indicating the rates of parasitism in the wild habitat as well as levels of stemborer infestations. Information is generally lacking regarding which grasses are the major alternative hosts for stemborers attacking maize and sorghum.

The use of grass borders in the control of stemborers has yielded variable results (Ndemah, *et al.*, 2002) and in Uganda no studies have been carried out to confirm the usefulness of grasses such as *P. purpureum* as borders in the management of stemborers. It is not also clear if these grasses would be suitable for the major stemborers in Uganda and hence the need for host preference studies. Grasses with positive attributes which can act as trap plants for different stemborer species and those that can support natural enemies for the integration of biological control with other strategies such the "push-pull" strategy in the management of cereal stemborer complex need to be identified and their role evaluated hence the aim of this study.

1.8 Objectives of the study

1.8.1 General objective

The general objective of the ~~proposed~~ study was to assess the role played by wild host plants in the population dynamics of cereal stemborers and their associated natural enemies, and how to successfully manipulate them in the cereal stemborers management strategies in Uganda.

1.8.2 Specific objectives

i) To determine the distribution and abundance of the most important cereal stemborers and their associated natural enemies.

ii) To study the abundance and diversity of stemborers on selected wild grasses.

iii) To determine the effect of wild host plants on cereal crop~~s~~ infestation and damage levels by stemborers and natural enemy performance.

iv) To assess oviposition and larval feeding preferences of cereal stemborers on selected wild grasses as compared to cultivated hosts.

CHAPTER TWO

LITERATURE REVIEW

2.1 Stemborer host range

Cereal stemborers attack several graminaceous crops and other wild hosts. Hosts mainly belong to Graminae (Poaceae), Cyperaceae and Typhaceae. In Africa stemborers are pests of maize (*Zea mays* L.), sorghum (*Sorghum bicolor*), rice (*Oryza sativa*), millet (*Eleusine coracana*) and sugarcane (*Saccharum officinarum*). Sorghum and millet are native to Africa while maize, rice and sugarcane are new introductions into Africa. Four species of millet are grown, however, pearl millet or bulrush millet (*Pennisetum glaucum*) and finger millet are the most important (Polaszek and Khan, 1998). The less important millets are teff (*Eragrostis tef*) grown exclusively in Ethiopia and fonio (*Digitaria* spp.), which is restricted to a few West African countries.

Maize originated from Central America, probably within the area equivalent to modern Mexico while sugarcane and rice originated from Asia (Polaszek and Khan, 1998). Although maize has existed in Africa for over 300 years, it is still considered a relatively recent introduction in comparison to the more traditional African cereals, such as millet and sorghum in terms of both agro-ecology and insect plant co-evolution (Polaszek and Khan, 1998). The crop was first recorded in Uganda in 1882 as a minor crop (Purseglove, 1988). Because maize is a recent introduction, it suffers the highest damage by native stemborers such as *B. fusca* compared to the native cereals like sorghum. In Ethiopia, Emana (2002) recorded higher *B. fusca* density on maize than on sorghum.

Stemborers are known to have co-evolved with wild host plants. However, with the introduction and cultivation of maize and the extensive planting of sorghum, insects followed the cultivated forms of their host plants. Hence, they become widely distributed and of economic importance although only a few species occur commonly on the cultivated cereals. Sound management practices against the indigenous stemborers can only be devised with an understanding of the interactions between the pests, their cultivated and wild hosts as well as natural fauna of the pests on both types of host plants (Bowden, 1954).

2.2 Wild host plants

Grasses and sedges are the common wild host plants of stemborers and the only limiting factor for their establishment could be the thickness of the stem that must be thick enough to support larval development to maturity (Ingram, 1958; Harris, 1990). In Kenya, surveys by Khan *et al.*, (1997a) yielded 33 species of wild host plants of stem borers. However, recent work at ICIPE indicates over 63 grass species as hosts and a wider range of stemborers of up to 75 species (LeRu *et al.* 2006). In West Africa, 13 grasses and two sedge species were found to harbour larvae of *S. calamistis*, *E. saccharina* and *B. fusca* (Schulthess *et al.*, 1997). Ingram (1958) carried out surveys of host plants of stemborers in Uganda and only recovered 18 stemborer species from maize, sorghum, rice, millet, sugarcane and 14 wild hosts (Table 2.1). Comparing these findings, it appears that the list of wild hosts given by Ingram is far from exhaustive.

Table 2.1 Stemborers and their host plants recorded in Uganda

Host plant	*Busseola fusca*	*Busseola segeta (phaia)*	*Sesamia botanephaga*	*Sesamia calamistis*	*Sesamia oriaula*	*Sesamia peobora (penniseti)*	*Sesamia poephaga*	*Sesamia* sp.n., nr. *Cretica*	*Chilo partellus*	*Chilo* sp.n.	*Eldana saccharina*	*Ematheudes* sp.nr. *helioderma*	*Ematheudes* sp.	*Hypsotropa* sp.nr.*subcostella*	*Maliarpha separatella*	*Pectinigeria* sp.n.	*Gen.*et sp.n.,nr. *Crambus*
Maize	X[1]	X	X[1]	X[1]			X[1]		X[1]		X[1]					X	
Sorghum	X[1]	X	X[1]	X[1]			X[1]		X[1]		X[1]	X					
Rice			X	X[1]					X[1]						X[1]		
Finger millet	X[1]	X	X	X[1]					X[1]			X					
Bulrush millet	[1]								[1]								
Sugar cane	X[1]	X	X	X[1]			X		X		X						
Panicum maximum	X[1]	X[1]		X[1]			X[1]	X	X[1]					X			
Pennisetum purpureum	X[1]	X[1]	X	X[1]	X	X[1]	X	X	X[1]							X	
Pennisetum typhoides	X								X								
Beckeropsis uniseta		X		X										X			
Echinochloa pyramidalis			X		X			X									
Sorghum verticilliflorum	X[1]	X	X[1]	X[1]			X[1]		X[1]		[1]		X				
S. rigidifolium	[1]		[1]				[1]		[1]								
Hyparrhenia rufa	X[1]	X		X					X					X			
Rottboellia compressa		X	X	X			X		X			X					
Vossia cuspidata	X	X	X	X	X		X		X	X				X		X	
Setaria splendida				X													
Cyperus distans			X	X							X						
Cyperus papyrus			X[1]								X						X
Typha australis			X														

Source: Ingram (1958) and Nye (1960); [1]Records by Nye

2.3 Role of wild host plants

Some wild grasses are the natural hosts of lepidopteran stemborers and are more attractive for oviposition compared to cereals such as maize or sorghum (Schulthess *et al.*, 1997; van den Berg *et al.*, 2001; Haile and Hofsvang, 2002). Before the introduction of maize and the extensive farming of sorghum in vast areas of Africa where they did not occur originally, stemborers were of no special consequence (Polaszek and Khan, 1998). Nevertheless, densities in wild hosts do not reach near the levels observed in cultivated grasses due to limited survival and development (Nye, 1960; Mathez, 1972; Schulthess *et al.*, 1997; Gounou and Schulthess, 2004).

Uncultivated lands (wild habitats) are important in maintaining biodiversity in otherwise intensively cultivated areas (van Emden and Dabrowski, 1994). Wild habitats are a food source for many insect species and often encourage insect invasion and outbreaks in neighbouring agroecosystems. On the other hand, wild host plants provide a reservoir for beneficial insects such as predators and parasitoids (van Emden, 1981; van Emden and Dabrowski, 1994; Khan *et al.*, 1997a; Schulthess *et al.*, 1997; Polaszek and Khan, 1998; Landis *et al.*, 2000). Wild host plants basically stabilize the system for both the pest and natural enemies especially during the off-season when the crop is absent (Schulthess *et al.*, 2001). Grasses also harbour stemborers that are only found in the wild habitat hence shielding the cultivated cereals from the attack by these stemborers.

Schulthess *et al.*, (1997) observed an inverse relationship between grass abundance and stemborer incidence in Cote d'Ivoire and Cameroon contradicting a belief that wild grasses are responsible for the pest outbreaks on crops (Bowden, 1976; Ingram, 1958). This phenomenon was attributed to the fact that "grasses harbour natural enemies that prevent stemborers from reaching damaging levels on maize and grasses act as trap plants, or both". Ndemah *et al* (2002) working in West Africa recorded reduced stemborer damage on maize surrounded by grass borders as a result of increased egg and larval parasitism in Benin. In Cameroon, however, *P. purpureum* border reduced borer damage as it acted as a trap plant. Work at ICIPE on the utilisation of wild grasses in the management of stemborers on maize showed that when Sudan grass (*Sorghum vulgare sudanense*) was used as a trap plant, it attracted moths for oviposition; larval survival was high and there was increased efficiency of natural enemies (Khan *et al.*, 1997a).

2.3.1 Stemborer behavioural responses

Insect behavioural and physiological responses largely affect the way they invade plants and these include orientation and settling, feeding, metabolism of ingested food, growth and development and oviposition (Saxena, 1969). And whether the insect is successful in establishment will depend on its response to the characteristics of the host plant. Some wild grasses are more attractive to ovipositing stemborer females than maize but larval development and survival is very low on most of the grasses (Schulthess *et al.*, 1997; van den Berg *et al.*, 2001). Insects choose plants for oviposition where their larvae have the greatest chance of survival for the first 10 days (Ng, 1988; Singer, *et al.*, 1988). However, in Lepidoptera larvae are mobile and can engage in plant selection (Bernays and Chapman, 1994). *C. partellus* is known to oviposit on surfaces of the non-host plants such as Fabaceae and Eurphobiaceae (Ampong-Nyarko *et al.*, 1994a). van den Berg *et al.* (2001) showed that *C. partellus* preferred to oviposit on Napier grass than on maize but larval mortality on Napier grass was very high. Eggs on non-host plants hatch and larvae disperse to adjacent plants in search for hosts. On the other hand, noctuids like *B. fusca* and *S. calamistis* do not oviposit on plant surfaces and hence the oviposition on non-hosts is unlikely. However, studies on oviposition preferences of *B. fusca* are few. Haile and Hofsvang (2002) showed that the wild relatives of sorghum were preferred to maize. In the field, Ndemah *et al.* (2002) working in Cameroon recovered significantly higher number of egg batches laid on maize than on *P. purpureum*. It seems therefore that oviposition responses vary depending on the host plants and stemborer species in question.

2.3.2 Trap plants

Wild grasses may have mechanisms of fighting stemborer infestations, which result into limited population build-up. It appears that wild grasses have antibiotic properties and may lack essential nutrients necessary for optimal stemborer growth compared to cereals. High levels of silica content may increase hardness of plant tissue and hence interfere with larval feeding (McNaughton *et al.*, 1985; Setamou *et al.*, 1993). Sétamou *et al.*, (1993) further found that silica influenced larval survival for the first seven days after infestation while nitrogen increased larval survival. Lack of proper nutritional balance may affect larval development even if all the necessary nutrients are present in the host plant (Soo Hoo and Fraenkel, 1996). The size of the stem also limits larval development (Ingram 1958). Larger larvae often migrate to fresh tillers in search for food and this may expose them to natural enemies. Because of these attributes, grasses have been exploited as trap plants in the 'push-pull' stemborer management strategy. An example for such grass is Napier grass, *P. purpureum* which produces gummy substances when larvae feed on the stem and this result into their eventual death since the larvae get trapped.

Other than trap plants having defence mechanisms which enable them to kill off larvae, the position of the perimeter crop (trap) in the "push-pull" set up also seems to lead some of the adult moths to it, being the first host to be encountered as a component of a trap cropping system (Hokkanen, 1991). The trap crop acts as a buffer since phytophagous insects are attracted to their hosts using both olfactory and visual cues (Cardoza *et al*., 2003).

The use of trap plants or grassy borders has yielded contrasting results in terms of pest reduction. Khan *et al*. (1997b and 2001) reported that maize intercropped with desmodium and surrounded with Napier grass border significantly reduced stemborer damage and increased maize yields. The reduction in stemborer damage was attributed to the Napier grass being attractive for stemborer oviposition and the increased efficiency of natural enemies due to the desmodium. Ndemah *et al.* (2002) observed that grassy borders resulted in an increase of the rate of parasitism and low stemborer damage. However, in the follow-up trials Ndemah (unpublished) indicated that the results derived from the use of grassy borders were the inconsistence.

2.3.3 Seasonal carry over mechanisms

Stemborer populations are sustained during the dry non-cropping periods through two major mechanisms, aestivation as late instar larvae and as non-aestivating larvae in wild grasses and ratoons (Ingram, 1958; Nye, 1960; Usua, 1968; Bowden, 1976; Kfir, 1991). *Stemborers* use crop residues for aestivation as fully-grown larvae during the off-season. The length of the resting period varies from region to region and also depends on the stemborer species and the onset of rains. Reports indicate that some stemborer species do not undergo diapause in some countries, for example in Uganda, *S. calamistis* and *C. partellus* breed through out the year (Ingram, 1958) while in Kenya these stemborers enter diapause for several months in the dry season (Ofomata *et al.*, 1999). Populations of *C. partellus* that do not enter a resting period have also been reported at the Coastal Province of Kenya (Mathez, 1972). Although, *B. fusca* is said to diapauses throughout its distribution range in Africa (Kfir *et al.*, 2002), Nye (1960) found that diapause was facultative in East Africa. LeRu (unpublished) indicates that for the wetter parts of Lake Victoria and Western Kenya (Kakamega), *B. fusca* diapause occurred if only the dry season was for more than two months. Diapause is mainly induced by host plant maturation (Usua, 1973). Hunter and McNeil (1997) working on *Christonuera rosaceana* Harris (Lepidoptera: Tortricidae) found that at constant temperature and photoperiod, larval diapause varied across host species. Factors affecting termination of diapause may vary depending on the geographical location of the area. For example, termination of diapause of *C. partellus* from South Africa is affected by photoperiod while the Kenyan population is not affected by day length (Scheltes, 1978; Kfir, 1993; Kfir *et al*, 2002). Generally, contact with water is an important factor in diapause termination in the tropics.

One of the mechanisms for habitat management is the provision of alternative prey and hosts for arthropod preys and parasitoids (Landis *et al.*, 2000). Non-aestivating stemborer larvae in the wild host plants may act as alternative hosts for parasitoids. Ngi-Song (1995) pointed out that the success of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) as a biological control agent depended on its ability to attack stemborers in the wild grasses throughout the year, and move to cultivated graminaceous plants during the cropping season. One of the reasons suggested for the lack of establishment of *C. flavipes* in South Africa is the lack of wild hosts during winter (Kfir, 2001). It has also been noted that biological control introductions that result in establishment may partly fail to reduce pest densities due to lack of alternative hosts (Gurr and Wratten, 1999). It is also reported that establishment of natural enemies is higher in stable perennial crop systems (Hall and Ehler, 1979). Since the cereals are only present for a limited time, wild host plants may play a role as refugia for stemborers and natural enemies hence stabilizing the ecosystem.

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Surveys

The survey sites were selected from the major maize growing Agroecological zones (AEZs) which were delineated by the National Agricultural Research Organisation (NARO) based on farming systems, vegetation, soils, topography and rainfall. These included Lake Albert Crescent, Lake Victoria Crescent, South-eastern and Eastern AEZs. The AEZs and survey sites are shown in Figure 3.1. The characteristics of the different AEZs are also given in Table 3.1. The rainfall pattern of the four AEZs is bimodal with two rainy seasons here being referred to as the first rains (March-June) and second rains (October-December).

3.2 On-station Experimental sites

The field trials, screen house and laboratory experiments study were conducted at Namulonge Agricultural & Animal production Research Institute (NAARI) in the X Lake Victoria Crescent in ~~c~~Central Uganda. The second site for the field trials was Serere Agricultural & Animal production Research Institute (SAARI) in the Eastern X AEZ in ~~e~~Eastern Uganda.

Namulonge is located 27 km north-east of Kampala (0°31 'N, 32° 35E' and 1150m above sea level) in Wakiso district. The soils are mostly deep tropical red clay loamy types, characteristic of the lower Buganda catena (Yost and Eswaran, 1990). They are heavy but well drained soils with pH 5.0-6.0. Organic matter levels are 2-3% in the surface horizons. It has a tropical climate, with moderate temperatures whose maximum occasionally exceeds 29^0C while the minimum rarely falls below 15^0C. Mean annual rainfall is 1170mm, which is bimodal with a long wet season from March to July and a shorter one from late September to January (Yost and Eswaran, 1990). The vegetation is mainly forest Savannah mosaic.

Serere (SAARI) is located 30 km south west of Soroti town (01° 31'N; 33° 27'E, and 1140 m above sea level). The climate is tropical and the vegetation is grassland savannah. Mean annual rainfall is 1250 mm while maximum temperature is 27.5^0C and a minimum of 22.5^0C. The soils are light mainly sandy-clay loam types.

3.3 Insects

The insects used in the screen house Experiments included *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) and *Busseola fusca* Fuller (Lepidoptera: Noctuidae). *C. partellus* was collected from the different AEZs and were reared on maize stems and tap water at NAARI. The insects did not exceed two generations and every generation had field collected insects infused. *B. fusca* which was used, was laboratory reared on artificial diet at the International Centre of Insect Physiology and Ecology (ICIPE). The insects had gone through six generations.

3.4 Plants

The plants used were collected from the field and raised in plastic pots in the screen house at NAARI and ICIPE. All plants were used only after attaining the age of four weeks for maize and sorghum and five weeks for the grasses. Grasses were established from tufts.

3.5 Statistical analysis

GLM procedures in SAS software (SAS, 2001) were used before subjecting the data to specific analyses. Non-parametric tests were used in the choice Experiments.

Table 3.1 Description of Agroecological zones used

AEZ	Elevation (metres)	Vegetation	Rainfall/ year
Eastern	900-1200 Low plateau	Grass Savanna & Butryospem Savannah, moist *Hyparrhania* and characterized by *Panicum maximum*	1100-1500 mm Pronounced dry season between December and March
South eastern	1000-1300	Forest Savannah Mosaic with remnants of forest cover	1000-1500 mm
Lake Victoria Crescent	1000-1300	Forest Savannah Mosaic and moist thickets; Elephant grass layered.	1000-1500 mm Short dry season
Lake Albert Crescent	900-1300	Dry & moist savannah	1000-1500

Source: J. R. W. Aluma (2001); Jameson (1970)

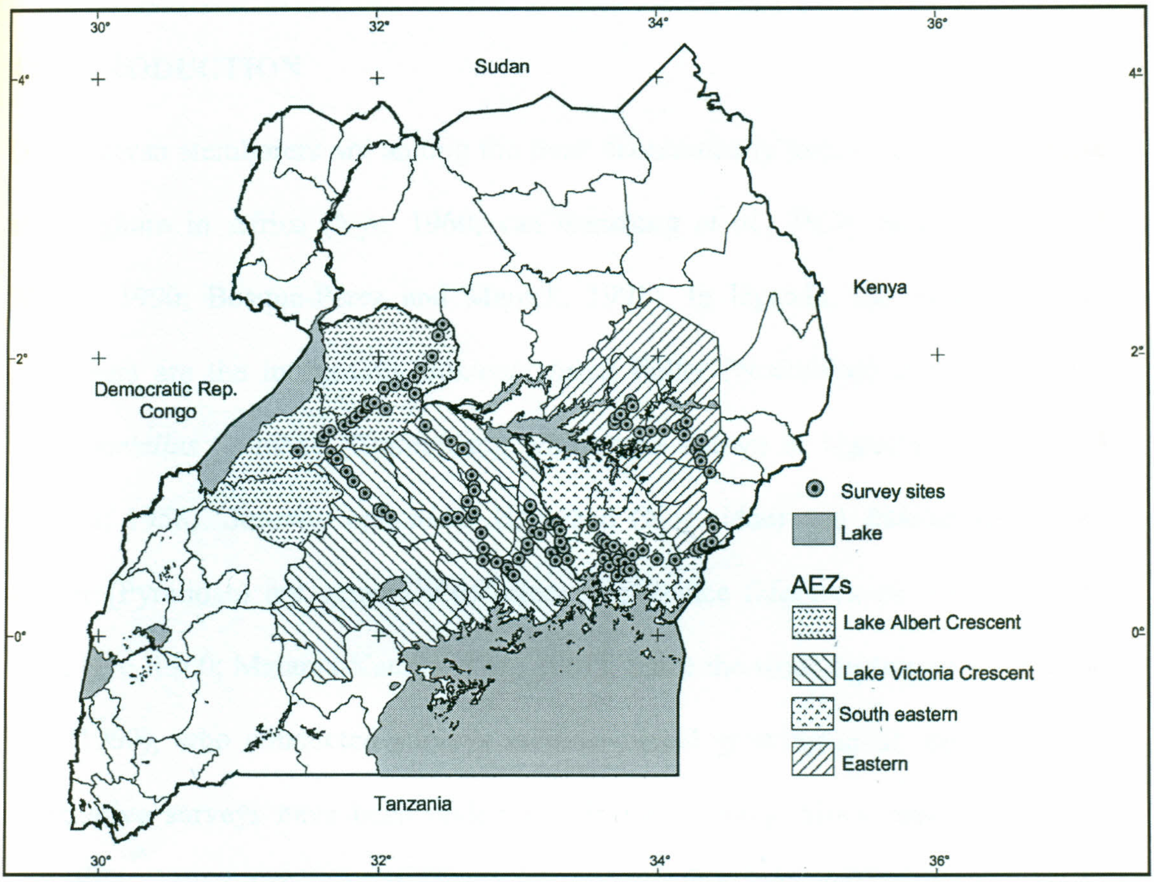

Figure 3.1 Agroecological zones (AEZs) and survey sites of stemborers and wild host plants in Uganda

CHAPTER FOUR

DISTRIBUTION AND RELATIVE IMPORTANCE OF LEPIDOPTERAN CEREAL STEMBORERS AND THEIR PARASITOIDS IN UGANDA

4.1 INTRODUCTION

Lepidopteran stemborers are among the most economically important pests of maize and sorghum in Africa (Nye, 1960; van Rensburg *et al.*, 1988; Seshu Reddy and Walker, 1990; Bosque-Pérez and Mareck, 1991). In Uganda, the most important stemborers are the indigenous *Busseola fusca* Fuller (Noctuidae) and the invasive *Chilo partellus* Swinhoe (Crambidae), which was known in Uganda prior to 1953 (Ingram, 1958). *Sesamia calamistis* Hampson (Noctuidae) and *Eldana saccharina* Walker (Pyralidae) are generally of minor importance (Hargreaves, 1939; Ingram, 1958; Nye, 1960; Matama-Kauma *et al.*, 2001). Since the work by Ingram (1958) and Nye (1960), who conducted surveys in most cereal growing areas, no large-scale quantitative surveys have been undertaken in the country. Since then, the relative importance of the different cereals has changed considerably. For instance, maize is now widely grown in the country including northern and eastern Uganda where millet and sorghum were once the major cereal crops. This might also have changed the relative ecological importance of the individual borer species.

During 1968-72 the Commonwealth Institute for Biological Control (CIBC) introduced the larval endoparasitoid *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) from Pakistan into Uganda and the other East African countries for the control of *C. partellus*. In spite of multiple releases the parasitoid did not get established (CIBC, 1968-72). In the early 1990s the International Centre of Insect

Physiology and Ecology (ICIPE) initiated a new attempt at bringing the pest under natural control. *C. flavipes* was first released at the Kenyan Coast, where it got established and reduced pest densities by 70% (Zhou *et al.* 2001a; Jiang *et al.*, in press). The parasitoid was released in eleven countries, among them Uganda, where it got established in the original release sites in eastern Uganda (Matama-Kauma *et al.*, 2001). The objective of this study therefore was first, to assess the distribution and relative importance of the different stemborer species and associated natural enemies and, secondly, to establish performance and spread of C. *flavipes* in the different Agroecological zones (AEZ) in the country.

4.2 MATERIALS AND METHODS

The distribution and ?

Variations in the infestation levels of the different stemborer species and their associated natural enemies on maize were evaluated in four selected major AEZs (Figure 3.1) during the second rains of 2003 and both the first and second rains of 2004. Destructive samplings were conducted three times during the cropping season. In each AEZ, 2-4 districts, where maize is the main cereal crop ~~production~~ were selected. In each AEZ, sampling sites were selected at 5-10 km intervals along the major and minor roads in the selected districts. A total of 20-25 maize fields of 0.25-1 ha were sampled per AEZ.

The first sampling for stemborer eggs and egg parasitoids was carried out when maize plants were at the 4-6 leaves stage. Sampling for egg infestation was conducted only in the first and second rains of 2004. Each field was divided into four quadrants, and 10 plants were randomly selected from each. Plants were uprooted and checked for egg infestation. The number of plants with egg batches as well as egg batch size was recorded. The egg batches were kept in the laboratory at room temperature until larval

? do you mean quarters

or parasitoid emergence. Stemborer species were determined from eggs observation and from the emerged larvae. Parasitoids were counted per egg mass and identified. Parasitism per field was computed as average percentage of eggs parasitized in an egg batch (egg parasitism) and the "discovery efficiency" as the percentage of egg batches with parasitoids. Egg parasitism is an estimate of the number of eggs parasitized while egg batches parasitized is a measure of the "discovery efficiency" of the parasitoid.

The second sampling was conducted in the same fields at taselling stage using the same protocol as above. Plants were dissected and assessed for stemborer incidence and the number of borers per plant. All larvae were identified and reared on fresh maize stem pieces in the laboratory until adult or parasitoid emergence. Maize stem pieces used in the rearing were replenished every 2 to 3 days. Pupae collected from the field were kept singly in clean plastic containers and observed for any parasitoid or adult emergence. Emerged parasitoids were identified in the laboratory where possible and if not were sent to ICIPE for identity confirmation.

The third survey was conducted at the maturity stage of maize for assessment of borer densities and ear damage. Five plants were randomly sampled per quadrant and the same sampling procedures as for the second survey were used. In addition, ear weight and grain damage were recorded. Grain damage was expressed as percentage of the total grain per ear using a visual scoring of percentage of ear damaged. Data for the second rains of 2004 was not taken for these parameters since data from previous two seasons showed that single plant analysis was not appropriate measure for estimating yield loss due to stemborers.

4.3 Statistical analysis

The general linear model procedure (SAS, 2001) was used to analyse differences in borer, plant damage variables, and ear weight by season across AEZs. Counts of borer variables were log x +1, and percentage data were arcsine square root transformed before analyses. Stepwise multiple regressions were used to plot the role of different stemborer species to stem tunnelling, ear damage and their effect on ear weight.

4.4 RESULTS

4.4.1 Abundance of stemborers

Four stemborer species belonging to the families Noctuidae, Crambidae and Pyralidae were recorded. *C. partellus* and *B. fusca* were the most abundant species. Other species occasionally encountered were *S. calamistis* and *E. saccharina*. *C. partellus* was the predominant species in the Eastern AEZ while *B. fusca* was dominant in the other three AEZs accounting for 60-79% of the stemborers across seasons (Table 4.1).

4.4.2 Stemborer egg infestations

Of the 139 fields sampled 29.7% were found infested with egg batches. The mean number of infested plants per field was less than 2% while the mean number of egg batches per plant varied with AEZ and was found at between 0 and 0.02 (Table 4.2). Overall one *S. calamistis*, seven *C. partellus* and 55 *B. fusca* egg batches were collected. Egg infestations did not vary between AEZs except for the Lake Albert Crescent where no eggs were found during the long rains 2004. Parasitized eggs were found in 36.6% of the infested fields. Discovery efficiency did not vary significantly between AEZs (Table 4.2). Only *B. fusca* eggs were found parasitized and only by *Telenomous busseolae* Gahan (Hymenoptera: Scelionidae). Egg parasitism did not significantly vary between AEZs and seasons (df = 5, 46; F = 0.89; P = 0.4946). Mean egg parasitism per field ranged between 0 and 46% (Table 4.2) but didn't vary significantly between EAZs and seasons (df = 5, 46; F = 0.89; P = 0.4946).

Table 4.1 Relative abundance (%) of stemborers in the different agro-ecological zones (AEZ) across seasons

AEZ	N	*C. partellus*	*B. fusca*	*S. calamistis*	*E. saccharina*
Eastern	983	77.2 ± 4.2	21.9 ± 4.2	0.8 ± 0.4	0.1 ± 0.1
L. Albert Crescent	318	19.4 ± 6.2	79.0 ± 6.3	1.6 ± 0.9	0.9 ± 0.9
L. Victoria Crescent	471	32.8 ± 7.3	66.6 ± 7.4	0.6 ± 0.6	0.1 ± 0.1
South eastern	1164	37.8 ± 4.0	60.3 ± 4.1	2.0 ± 0.7	0.1 ± 0.1

N = Total borers collected

Table 4.2 Mean percentages of plants infested with eggs (± SE), number of egg batches per plant, egg batches parasitized and percentage egg parasitism at the whorl stage of maize in four Agroecological zones during 2004[1]

AEZ	% plants with batches	Egg batches/ plant	Discovery efficiency (%)	% egg parasitism
		1st rains 2004		
Eastern	0.98 ± 0.46 ab	0.010 ± 0.005 a	9.8 ± 6.0 a	39.4 ± 16.9a
South eastern	1.63 ± 0.50 a	0.016 ± 0.005 a	9.6 ± 4.8 a	17.7 ± 8.4 a
L. Albert Crescent	0.00 b	0.00 b	Nil	Nil
L. Victoria Crescent	-	-	-	-
Df	2, 62	2, 62	1, 47	1, 19
F- value	4.09	4.11	1.05	1.32
P- value	0.0214	0.0211	0.3465	0.2642
		2nd rains 2004		
Eastern	0.69 ± 0.34 a	0.007 ± 0.003 a	5.6 ± 5.6 a	27.8 ± 22.0 a
South eastern	1.96 ± 0.52 a	0.020 ± 0.005 a	18.8 ± 7.4 a	46.0 ± 11.7 a
L. Albert Crescent	1.53 ± 0.61 a	0.015 ± 0.006 a	1.4 ± 1.4 a	7.4 ± 5.9 a
L. Victoria Crescent	0.42 ± 0.22 a	0.004 ± 0.002 a	0.0 a	0.0a
Df	3, 73	3, 73	3, 73	3, 25
F- value	2.48	2.48	3.01	2.24
P- value	0.0680	0.0680	0.0354	0.1082

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[1] Egg parasitism on *Busseola fusca*; Means within a column followed by the same letter are not significantly different at $P \leq 0.05$ (SNK); - Data not collected; Nil = No host found.

4.4.3 Distribution and densities of stemborers

The infested plants ranged between 16.4 and 45.8 percent with significantly higher infestation and borer density in the Eastern AEZ, except during the first rains 2004 when the borer density recorded was very low (Table 4.3). In this AEZ, *C. partellus* was consistently the predominant stemborer species across all the seasons. The incidence of *C. partellus* and *B. fusca* varied across years in the Lake Victoria Crescent with a higher density of *C. partellus* recorded in the second rains 2003 than in the second rains 2004.

4.4.4 Stem damage and ear weight

The impact of individual larvae of the different stemborer species to stem damage at harvest is shown in Table 4.4. *B. fusca* caused the highest stem damage in both seasons in all AEZs, except the Eastern AEZ where *C. partellus* caused comparatively higher stem damage. Although incidence of *S. calamistis* was low, it contributed significantly to stem damage during the first rains of 2004. There was no significant relationship between stem damage and ear weight in any of the AEZs (df = 3, 576; F = 1.50; P = 0.2136) (data not shown). A weak relation ship was also observed for ear damage and ear weight (b = -1.37; F = 4.48; p = 0.0348; intercept = 155.0; $R^2 = 0.01$).

Table 4.3 Mean number of borers per plant (± SE) according to species and percentage of infested plants at the reproductive stage of maize in four Agroecological zones during the first and second seasons of 2003 and 2004

AEZ	Total borers	*C. partellus*	*B. fusca*	*S. calamistis*	% infested plants
		Second rains 2003			
Eastern	1.02 ± 0.03 a	0.91 ± 0.03a	0.10 ± 0.01 a	0.00	45.8 ± 4.2 a
L. Albert Crescent	0.34 ± 0.02 d	0.07 ± 0.01 d	0.27 ± 0.02 a	0.00	18.6 ± 3.8b
L. Victoria Crescent	0.84 ± 0.04 b	0.55 ± 0.03 b	0.29 ± 0.02 a	0.01± 0.00	26.6 ± 3.4b
South eastern	0.46 ±0.02 c	0.25 ± 0.01 c	0.20 ± 0.01 a	0.01± 0.00	34.2 ± 7.5ab
df	3, 1635	3, 1635	3, 1635	3, 1635	3, 39
F- value	25,43	51.06	2.03	1.19	7.25
P- value	0.0001	0.0001	0.1076	0.3110	0.0006
		First rains 2004			
Eastern	0.19 ± 0.01 b	0.12 ± 0.01	0.06 ± 0.01 b	0.00	29.9 ± 2.7 a
South eastern	0.45 ± 0.01 a	0.14 ± 0.01	0.30 ± 0.01 a	0.01 ± 0.00	31.2 ± 2.9 a
df	1, 1797	1, 1797	1, 1797	1, 1797	1, 40
F- value	42.33	0	67.77	0.86	0.15
P- value	0.0001	0.9617	0.0001	0.3527	0.6982
		Second rains 2004			
Eastern	0.53 ± 0.02 a	0.42 ±0.02 a	0.09 ± 0.01 c	0.00	30.4 ±5.0 a
L. Albert Crescent	0.26 ± 0.01 b	0.08 ± 0.01 bc	0.18 ± 0.01 ab	0.00	20.5 ± 4.0 ab
L. Victoria Crescent	0.33 ± 0.01 b	0.05 ± 0.01 c	0.26 ± 0.01 a	0.00	17.8 ± 3.7 b
South eastern	0.27 ± 0.01 b	0.10 ± 0.01 b	0.16 ± 0.01 b	0.00	16.4 ± 2.2 b
df	3, 4715	3, 4715	3, 4715	3, 4715	3, 70
F- value	42.11	117.26	10.50	1.21	2.97
P- value	0.0001	0.0001	0.0001	0.3031	0.0377

For each season, means within a column followed by the same letter are not significantly different at $P \leq 0.05$ (SNK)

Table 4.4 Assessment of the relative importance of stemborer species to percentage of stem tunnelled by stemborers at harvest using stepwise multiple regressions during the second rains 2003 and first rains 2004

AEZ		b	F	P	Mean ± SE
		Second rains 2003			
Eastern	Y %stem tunnelling				
	X_1 no. of *C. partellus*	2.82	12.52	0.0008	0.22 ± 0.07
	X_2 no. of *B. fusca*	3.43	7.51	0.0082	0.07 ± 0.05
	Intercept =2.60, $R^2 = 0.27$, N = 59				
Lake Albert Crescent	Y %stem tunnelling				
	X_1 no. of *B. fusca*	2.37	4.79	0.0001	0.08 ± 0.04
	Intercept =1.59, $R^2 = 0.06$, N = 79				
South eastern	Y %stem tunnelling				
	X_1 no. of *B. fusca*	3.85	29.18	0.0001	0.09 ± 0.03
	Intercept =1.12, $R^2 = 0.18$, N = 139				
			First rains 2004		
South eastern	Y %stem tunnelling				
	X_1 no. of *B. fusca*	5.08	74.42	0.0001	0.04 ± 0.02
	X_2 no. of *C. partellus*	2.14	15.78	0.0001	0.03 ± 0.02
	X_3 no. of *S. calamistis*	7.20	23.88	0.0001	0.01 ± 0.01
	Intercept =0.43, $R^2 = 0.35$, N = 239				

4.4.5 Larval and pupal parasitism

In the course

During the duration of this study only four larval and three pupal parasitoid species were recovered (Table 4.5). Among the larval parasitoids, *Cotesia sesamiae* Cameron (Hymenoptera; Braconidae) and *C. flavipes* were the most common species. Some of the parasitoids such as *Dolichogenidae polaszeki* Walker and the Mermithidae nematodes were recovered only a few times. Parasitism by *C. flavipes* and *C. sesamiae* on *C. partellus* and *B. fusca* are shown in Table 4.6. Mean parasitism by *C. flavipes* ranged between 0 and 30.5% while that of *C. sesamiae* was between 0 and 29.4%. Levels of parasitism were generally higher during the second than the first rains. The Eastern AEZ had significantly higher levels of parasitism than the other zones though the results were not consistent for all seasons. *C. flavipes* was also recovered from *B. fusca* in two out of three seasons, with parasitism ranging between 0 and 12% during 2004. However, higher levels of parasitism for each of the *Cotesia* spp were recorded on their co-evolved host (i.e. *C. flavipes* on *C. partellus*, and *C. sesamiae* on *B. fusca*). Pupal parasitism was low ranging between 0 and 20% (Table 4.7). *Dentichasmias busseolae* Heinrich (Hymenoptera: Ichneumonidae) attacking *C. partellus* was the most common among pupal parasitoids.

Correlation analysis showed that percentage parasitism by *C. flavipes* was positively associated with *C. partellus* densities in the Lake Victoria Crescent AEZ (n = 13, P = 0.0045, r = 0.73). A significant positive relationship was also observed for *C. sesamiae* on *C. partellus* in the Eastern AEZ (n = 39, P = 0.0460, r = 0.32). The relationship between *C. flavipes* and *B. fusca* was negative and not significantly different for all the AEZs (n = 93, P = 0.4273, r = 0.08).

Table 4.5 Parasitoid species of stemborers recovered during 2003and 2004 in four Agroecological zones in Uganda

Species	Family	Host	Host stage	AEZ
Cotesia flavipes Cameron	Braconidae	*Cp, Bf,*	Larvae	En, LAC, LVC, Sen
Cotesia sesamiae Cameron	Braconidae	*Cp, Bf*	Larvae	En, LAC, LVC, Sen
Dolichogenidae polaszeki Walker	Braconidae	*Bf*	Larvae	LVC, Sen
Mermithidae	Mermithidae	*Cp, Bf*	Larvae	LVC, Sen, En, LAC
Pediobius furvus Gahan	Eulophidae	*Cp, Bf*	Pupae	En, LAC
Dentichasmias busseolae Heinrich	Ichneumonidae	*Cp*	Pupae	LVC, Sen
Procerochasmias nigromaculatus Cameron	Ichneumonidae	*Bf*	Pupae	LVC
Hyperparasitoid				
Aphanogmus fijiensis Ferrière	Ceraphronidae	*Cotesia* spp.	Pupae	En, LAC, LVC, Sen

Cp, Chilo partellus; Bf, Busseola fusca; En, Eastern; LAC, Lake Albert Crescent; LVC, Lake Victoria Crescent; Sen, South eastern

Table 4.6 Mean percentage parasitism of *Chilo partellus* and *Busseola fusca* by *Cotesia flavipes* and *C. sesamiae* across Agroecological zones (AEZs) during 2003 and 2004

AEZ	2nd rains 2003			1st rains 2004			2nd rains 2004		
	n	*C. flavipes*	*C. sesamiae*	n	*C. flavipes*	*C. sesamiae*		*C. flavipes*	*C. sesamiae*
					C. partellus				
Eastern	381	15.2 ± 5.0 a	6.4 ± 1.4 a	55	5.4 ± 2.9 a	0.0 a	126	30.5 ± 4.1 a	4.1 ± 2.7 a
South eastern	115	11.1 ± 3.9 a	13.1 ± 8.9 a	124	8.2 ± 5.4 a	1.7 ± 1.7 a	52	5.2 ± 3.8 b	1.2 ± 1.2 a
L. Albert Crescent	45	23.1 ± 6.4 a	5.9 ± 5.9 a	-	-	-	23	0.0 b	0.0 a
L. Victoria Crescent	156	10.0 ± 6.4 a	8.1 ± 6.5 a	-	-	-	28	0.9 ± 0.9 b	7.3 ± 5.6 a
df		3, 26	3, 26		1, 30	1, 30		3, 39	3, 39
F- value		0.71	0.03		1.02	0.59		18.26	0.92
P- value		0.5562	0.9913		0.8823	0.4366		0.0001	0.4379
					B. fusca				
Eastern	28	0.0	17.7 ± 8.4 a	31	0.0 a	16.7 ± 16.7 a	25	3.3 ± 3.3 a	29.4 ± 13.3 a
South eastern	66	0.0	4.6 ± 4.6 a	134	12.0 ± 5.4 a	5.1 ± 2.2 a	81	0.0 ± 0.0 a	4.4 ± 3.1 b
L. Albert Crescent	90	0.0	12.8 ± 7.2 a	-	-	-	46	5.0 ± 3.3 a	7.5 ± 5.3 b
L. Victoria Crescent	71	0.0	7.6 ± 4.1a	-	-	-	120	1.3 ± 0.9 a	2.2 ± 1.1 b
df			3, 28		1, 28	1,28		3, 46	3, 46
F- value			1.18		0.28	0.97		1.82	4.84
P- value			0.3369		0.6192	0.3324		0.1576	0.0052

- Data not collected; for each stemborer species, means within a column followed by the same letter are not significantly different at P≤0.05 (SNK)

Table 4.7 Percentage parasitism of *Chilo partellus* (*Cp*) and *Busseola fusca* (*Bf*) by pupal parasitoids across Agroecological zones (AEZs) during 2003 and 2004

Host	AEZ	2nd rains 2003			1st rains 2004				2nd rains 2004		
		n	*D. busseolae*	*P. furvus*	n	*D. busseolae*	*P. nigromaculatus*	*P. furvus*	n	*D. busseolae*	*P. nigromaculatus*
Cp	En	1	0	0	9	0	0	11.1	6	0	0
	Sen	12	8.3	8.3	29	10.3	0	0	19	5.2	0
	LAC	5	20.0	0	-	-	-	-	6	0	0
	LVC	10	10.0	0	-	-	-	-	0	0	0
Bf	En	2	Nil	0	3	Nil	0	0	7	Nil	0
	Sen	13	Nil	7.7	126	Nil	7.9	1.6	55	Nil	0
	LAC	5	Nil	0	-	-	-	-	37	Nil	0
	LVC	8	Nil	0	-	-	-	-	28	Nil	3.6

- Data not collected; Nil, *B. fusca* not a recognised host of *D. busseolae*; En = Eastern; LAC = Lake Albert Crescent; LVC = Lake Victoria Crescent; Sen = South eastern.

4.5 DISCUSSION

The results obtained for the stemborer species abundance in this study corroborate results by Ingram (1958) and Matama-Kauma *et al.* (2001). In contrast, Girling (1978) reported *E. saccharina* to be very common at Kawanda in central Uganda (Lake Victoria Crescent) while Kalule *et al.* (1997) indicated that at Namulonge in the same AEZ and Masaka in south-western Uganda, *E. saccharina* accounted for 20-24% versus 12% *S. calamistis*. This indicates that the importance of these minor species might change locally with season and year but *C. partellus* and *B. fusca* still remain the key-pests.

Results also showed that although egg infestation was low, egg parasitism by *T. busseolae* was moderate. In Kenya, parasitism by this parasitoid had a similar range of 4 and 49.2% (A. Bruce, ICIPE, unpublished). In West Africa, *T. busseolae* is a major species of egg parasitism on *S. calamistis* in the forest-savanna transition zone of Benin (Sétamou and Schulthess, 1995; Schulthess *et al.*, 2001) and on *B. fusca* in the forest zone of Cameroon (Ndemah *et al.*, 2001b; Ndemah *et al.*, 2003). It is known that mean regional parasitism in W. Africa can reach 95%. However, *T. busseolae* is complimented by *Telenomous isis* Polaszek (Hymenoptera: Scelionidae) in West Africa and its introduction in Uganda is proposed in order to further reduce the number of *B. fusca* eggs surviving to become larvae.

Seasonal fluctuations in stemborer densities were observed in the Eastern AEZ where densities were considerably low in the first rains. First rains are characteristic of higher levels of rainfall which may cause a temporary decline in egg batches laid (Schulthess *et al.*, 2001) and reduced larval establishment (Bernays *et al.*, 1983;

Ndemah *et al.*, 2003). The relatively high percentage of plants infested with larvae when compared with those infested with eggs, probably indicates high dispersal of young larvae. This was observed for both *C. partellus* and *B. fusca* (Smithers, 1960; Harris, 1962; Bernays *et al.*, 1983; Chapman *et al.*, 1983; van Rensburg *et al.*, 1987; Pats and Ekbom, 1992). It can be expected that larval dispersal is density dependent. Since the economic injury level of cereal stemborers is exceedingly low (Usua 1968; Bosque-Pérez and Mareck, 1991), a single larva can cause considerable yield loss especially on maize, which is unable to compensate for stem loss by production of tillers, prevention of larval dispersal via increased mortality of eggs by egg parasitoids therefore should contribute considerably to prevention of yield loss.

In West Africa, stem damage caused by borers such as *S. calamistis* and *E. saccharina* has often been described as the most important damage parameter in relation to yield loss (Bosque-Pérez and Mareck, 1991; Gounou *et al.*, 1994; Sétamou *et al.*, 1995). Thus, stem tunnelling together with ear damage was often used in survey work to estimate yield loss. The lack of relationship between the percentage stem tunnelled and yield in the present study could be attributed to the migratory nature of older *B. fusca* larvae (van Rensburg *et al.*, 1987; Ndemah *et al.*, 2001a). Thus, one may encounter older plants with relatively short tunnels but large larvae. Furthermore, *B. fusca* is reported to selectively choose plants with larger stems for oviposition (van Rensburg *et al.*, 1989). Thus, it is recommended to use insecticide exclusion methods for yield loss estimation in Uganda.

Parasitism by *C. flavipes* on *C. partellus* was low compared to the previous levels of up to 10 - 32.9% in 1999 eastern Uganda reported by Matama-Kauma *et al.* (2001).

Further work conducted in 2002-03 at the same release sites indicated 18.8 - 34.8% parasitism (Rwomushana *et al.*, 2005). In Kenya where *C. flavipes* was released in 1993, it took about 5 years to register a decrease in stemborers densities (Zhou *et al.*, 2001a) and even then data show that the parasitoid has not attained an equilibrium (Jiang *et al.*, in press). The wider the geographical expanse of the suitable habitat, the longer it will take the parasitoid to reach a characteristic density (Overholt *et al.*, 1997). It is however, important to conduct impact assessment studies to evaluate the impact of *C. flavipes* on stemborer populations in Uganda. The low parasitism by *C. sesamiae* on *C. partellus* compared to that of *C. flavipes* can be attributed to its lower searching efficiency and progeny production (Sallam *et al.*, 1999). In the present study, *B. fusca* was found being parasitized by *C. flavipes* in two out of three seasons. Ngi-song *et al.* (1995) showed that *C. flavipes* was unable to develop in *B. fusca* and it was only possible in cases of multiple-parasitism by both *C. sesamiae* and *C. flavipes* (Ngi-song *et al.*, 2001). Studies by Cugala *et al.* (2001) showed that *B. fusca* was partially suitable for the development of *C. flavipes* with 6.7% of the larvae stung producing cocoons compared to 29.4% in *C. partellus* laboratory. Being a new association, it is not clear if *C. flavipes* will evolve to evade the *B. fusca* immune of egg encapsulation.

CHAPTER FIVE

ABUNDANCE AND DIVERSITY OF LEPIDOPTERAN STEMBORERS ON SELECTED WILD GRASSES IN UGANDA

5.1 INTRODUCTION

In Africa, cereal stemborers pests are reported to attack a wide range of wild hosts belonging to Poaceae, Cyperaceae and Typhaceae (Polaszek and Khan, 1998). These wild hosts have long been considered as a reservoir of stemborers pests during the off-season and therefore supposedly are responsible for stemborer attacks of crops in the following season (Ingram, 1958; Bowden, 1976). Some grasses have however, been found to act as trap plants because they are highly attractive to ovipositing female moths, though larvae are unable to develop to maturity (Khan *et al.*, 2000; Schulthess *et al.*, 1997; van den Berg *et al.*, 2001). In general, stemborer densities on wild hosts are much lower than in maize and sorghum (Schulthess *et al.,* 1997; Gounou and Schulthess, 2004).

Studies on the host range of stemborers have been conducted in the different regions of Africa and in Uganda by Ingram (1958), Kenya by Randriamananoro (1996) and Khan *et al.* (1997b), Eritrea by Haile and Hofsvang (2001) South Africa by Atkinson (1980) and West Africa by Schulthess *et al.* (1997) and Gounou and Schulthess, 2004. Nye (1960) conducted surveys in the three East African countries while LeRu *et al.* (2006) covered eastern and Southern Africa.). In Uganda, Ingram (1958) and Nye (1960) described 17 species of stemborers from 14 wild host plant species. Recent surveys in several countries in Eastern and Southern Africa yielded 136 stemborer species from 75 wild host species (LeRu *et al.*, 2006) indicating that the list of borer and host plant species in eastern Africa is far from being exhaustive. The present study was designed to explore the host range of stemborer pests in wild habitats in Uganda. The incidence and associated parasitism of stemborers were further studied on selected grass species in order to elucidate their role in the invasion of crop fields.

5.2 MATERIALS AND METHODS

5.2.1 Wild host survey

Surveys of stemborer wild hosts were conducted in four agro-ecological zones (AEZs) where maize and sorghum are widely grown. Two surveys were carried out, one during the dry season (February - March) and the other during the cropping season (May – July) of 2003. The AEZs and the districts surveyed are shown in Figure 3.1. Survey routes were established in each AEZ and wild host plants were sampled at 10-15 km intervals along the major and minor roads using the transect and quadrat methods (William, 1996; Songa *et al.*, 2002). For each survey, 20-25 sites were sampled per AEZ. At each site a 100m tape measure was stretched perpendicular to the road and three 1x1m quadrats taken at 0-10m, 40-60m and 70-100m. The grasses found were scored at the 1-4 scale for the percentage area occupied by each grass species (1 = 1 - 29%, 2 = 30 - 49%, 3 = 50 - 69%, 4 = over 70%) and then cut at ground level to check for stemborer damage and immature stages. In addition 50 tillers of the potential wild grasses within a 25m radius from either side of the transect line were sampled at random and dissected. Potential grasses were sampled based on the work by Ingram (1958) who recovered the major stemborers (*C. partellus* and *B. fusca*) on wild grasses species and for this reason there was no emphasis on Cyperaceae and Typhaceae. Stemborer larvae and pupae found were collected, the numbers recorded, and reared at ambient conditions on maize stems in glass vials of 3 x 5 cm for individual borers per tiller or plastic vials of 8 x 15 cm for stemborers which were more than one per tiller until parasitoid or moth emergence. The stems were replenished after every two to three days. Parasitoids that emerged were recorded and in the case of *Cotesia* spp. the progeny were counted according to sex. Adult moths that emerged were preserved in absolute alcohol or pin-mounted. In some situations the stemborers rejected the maize stems. These were preserved at the larval stage. The grass species were taken to the Makerere University Herbarium for identification, while the parasitoids and moths were later sent to the International Centre of Insect Physiology and Ecology (ICIPE) for identification.

5.2.2 Stemborer abundance on selected grasses

Surveys were conducted between January and February 2004 (dry season) and between June and August 2005 (wet season) to assess the abundance of stemborers on selected wild grasses. The grasses sampled included *Panicum maximum* Jacq., *Pennisetum purpureum* Schumach., *Pennisetum polystachion* (L.) Schult. and *Sorghum arundinaceum* (Desv.) Stapf. The grasses were selected based on their abundance and distribution determined in the above surveys. Furthermore, these grasses, with the exception of *P. polystachion*, were reported to constitute a large reservoir of stemborers near cultivated fields (Ingram, 1958). Sampling sites were established at 10-15 km intervals along the major roads within an AEZ (Figure 3.1). During the dry season 100 tillers of each grass species per site were randomly chosen according to Ndemah *et al.* (2001b). However, due to low stemborer density the tillers sampled were increased to 200 during the wet season (Gounou and Schulthess, 1994). The tillers were checked for stemborer damage, and dissected for assessment of numbers of larvae and pupae. Immatures were recorded per grass species and site and provided with pieces of maize stems in the same rearing conditions previously reported

5.3 Statistical analyses

Analysis of variance (ANOVA) was used to analyse differences in stemborer infestation and density across grass species and AEZ. Data on insect counts were log transformed (x+1) and proportions were arcsine-square-root-transformed before analyses. Significance level was set at $P < 0.05$ and means compared with Students-Newman-Keuls multiple range test (SNK). Back transformed means were presented.

5.3.1 Dispersion of stemborers on grasses

Taylor's (1961) power law was used to describe the dispersion of stemborer larvae and pupae on the different selected host plant species. This law postulates a consistent relationship for a species between variance S^2 and the mean m:

$$S^2 = am^b$$

Where b is the measure of dispersion of the species, with $b > 1$ indicating an aggregated distribution, $b = 1$ randomness, and $b < 1$ regular distribution, while a, is considered a mere scalar factor without biological meaning. These coefficients were computed by regressing the natural logarithm of the between plant variance ($\text{In}S^2$) against the natural logarithm of mean density ($\text{In}m$) for each field or sampling occasion. Student's t-test was used to compare b with unity. To minimize errors, data for the noctuids were pooled because underdeveloped larvae that suffered mortality in the laboratory could not be fully identified.

5.4 RESULTS

5.4.1 Abundance and distribution of wild host plants

Many grasses showed stemborer damage, but only eight yielded stemborer larvae and pupae (Table 5.1). The most abundant and widely distributed grass species was *P. maximum* followed by *Hyparrhenia rufa* (Nees) Stapf. and *S. arundinaceum*. Six stemborer genera were found and these included *Busseola* spp., *Chilo* spp., *Sesamia* spp., *Eldana* sp., *Manga* sp. and *Poeonoma* sp. (Table 5.2). *Sesamia* spp had a wider range of hosts compared to the other stemborer species.

5.4.2 Incidence of stemborers on selected grasses

Levels of infestation were low varying between 0.31 and 10.8% infested tillers and mean borer densities were between 0 and 0.07 borers per tiller (Table 5.3). Highest borer incidence and densities were found on *S. arundinaceum* across all AEZs. The percentage of infested tillers of *P. maximum* varied significantly across AEZ (df = 3, 133; F = 5.55; P = 0.0002) with the highest recorded in the Eastern AEZ. The same trend was observed for the borer density (df =3, 133; F = 4.77, P = 0.0013) (Table 5.3).

Table 5.1 Abundance (average scores) and distribution of wild grasses infested by stemborers in various Agroecological zones (AEZs) in Uganda.

Grass species	AEZs				
	Lake Victoria Crescent	Lake Albert Crescent	South- Eastern	Eastern	Average
Hyparrhenia rufa (Nees) Stapf	1.6 ± 0.2	2.2 ± 0.2	2.0 ± 0.4	1.8 ± 0.1	1.9 ± 0.1
Hyparrhenia filipendula (Hochst.) Stapf	0	2.9 ± 0.5	0	0	1.1 ± 0.5
Panicum maximum Jacq	2.8 ± 0.6	2.2 ± 0.2	2.3 ± 0.2	2.0 ± 0.1	2.3 ± 0.1
Pennisetum purpureum Schumach	1.0	1.6 ± 0.2	1.0	1.0 ± 0	1.3 ± 0.1
Pennisetum polystachion Schult	2.3 ± 0.8	1.0	1.7 ± 0.5	2.0 ± 0.3	1.3 ± 0.2
Pennisetum trachyphyllum Pilg.	0	1.6 ± 0.4	1.0	1.0	1.2
Sorghum arundinaceum (Devs.) Stapf	1.6 ± 0.2	2.4 ± 0.2	1.6 ± 0.3	1.6 ± 0.4	1.7 ± 0.1
Sporobolus pyramidalis P. Beauv,	1.5 ± 0.5	1.0 ± 0.0	1.0 ± 0.0	1.0 ± 0.0	1.3 ± 0.2

* Abundance scores 1 = 1-29%, 2 = 30- 49, 3 = 50-69, 4 = over 70%

Table 5.2 Wild hosts and stemborer genera recorded in Uganda between February and July 2003

Plant species	*Busseola spp.*	*Sesamia* spp.	*Manga* spp	*Poenoma* sp.	*Chilo* spp.	*Eldana sp.*
H. rufa	-	+	-	-	+	-
H. filipendula.	-	-	-	-	-	+
P. maximum	+	+	+	-	+	-
P. purpureum	+	+	+	+	+	+
P. polystachion	+	+	-	-	+	-
P. trachyphyllum	+	-	-	-	-	-
S. arundinaceum	+	+	+	-	+	+
S. pyramidalis	-	+	-	-	-	-

+, Stemborer species recorded from a host plant; -, stemborer species not recorded from a host plant

Table 5.3 Mean (± S.E) percentages of the infested tillers and mean densities of larvae and pupae per tiller on selected grasses in four Agroecological zones (AEZs) in Uganda

Grass species	AEZs			
	Eastern	Lake Victoria Crescent	Lake Albert Crescent	South eastern
		Percentage of infested tillers		
P. maximum	5.8 ± 0.95 abA	4.14 ± 0.85 bB	3.02 ± 0.67 bB	1.39 ± 0.33 bC
P. polystachion	2.0 ± 0.43 b	0.79 ± 0.31 b	0.50 ± 0.29 b	1.09 ± 0.38 b
P. purpureum	3.2 ± 0.92 b	3.31 ± 0.41 b	2.58 ± 0.58 b	2.38 ± 0.78 b
S. arundinaceum	10.8 ± 2.42 a	8.31 ± 1.48 a	8.69 ± 1.85 a	8.53 ± 1.71 a
df	3, 103	3, 92	3, 92	3, 93
F	6.41	7.84	6.46	8.12
P	0.0005	0.0001	0.0005	0.0001
		Mean stemborer/ tiller		
P. maximum	0.050 ± 0.017A	0.009 ± 0.003B	0.005 ± 0.001 abB	0.006 ± 0.004 bB
P. polystachion	0.001 ± 0.001	0.001 ± 0.001	0 b	0.001 ± 0.001 b
P. purpureum	0.014 ± 0.006	0.009 ± 0.001	0.009 ± 0.003 ab	0.015 ± 0.005 ab
S. arundinaceum	0.070 ± 0.028	0.014 ± 0.005	0.029 ± 0.009 a	0.041 ± 0.012 a
df	3, 103	3, 92	3, 92	3, 93
F	2.49	1.48	4.26	4.16
P	0.0641	0.2261	0.0073	0.0082

For each damage parameter, means within rows followed by the same uppercase letters and means within columns followed by the same lower case letters are not significantly different at $P \leq 0.05$ (Students Newman Keuls)

5.4.3 Stemborer diversity

A total of 1,388 larvae and pupae belonging to 11 species, 7 genera and 4 families were collected from the four grass species. The families included Noctuidae, Crambidae, Pylaridae and Cossidae (Table 5.4). Pylarids and cossids were rarely ~~only~~ recovered ~~rarely.~~ Of the stemborers collected 64% were noctuids, however, in the Lake Albert Crescent the noctuids accounted for up to 82%. *Sorghum arundinaceum* yielded both crambids and noctuids, while from *P. maximum, P. polystachion* and *P. pennisetum*, 88% of the borers recovered were noctuids (Table 5.4). Among the stemborers collected, were known pests of maize and sorghum, namely *B. fusca, C. partellus*, *Sesamia calamistis* Hampson (Noctuidae) and *Eldana saccharina* Walker (Pylaridae). *B. fusca, C. partellus* and *S. calamistis* were principally recovered from *S. arundinaceum* and were not common on *P. maximum* and *P. purpureum* (Table 5.4). Of the other stemborers found in the wild, *Busseola phaia* Bowden (Noctuidae) was very common in all the four AEZs accounting for 17.4% of the stemborers and was found on all the four grasses species. The second most widely spread species was *Manga melanodonta* Fletcher (Noctuidae). *B. phaia* and *M. melanodonta* were the major stemborers commonly recovered from *P. maximum*. *P. maximum* also seemed to be the major host for *Sesamia poephaga* Tams and Bowden (Noctuidae). *Sesamia penniseti* Tams and Bowden (Noctuidae) was the most common stemborer on *P. purpureum* and was not found on any other host. In order of abundance, *C. partellus* was the most common stemborer (46%) on the selected grasses followed by *B. phaia* (17.4%), *B. fusca* (13.1%), *M. melanodonta* (9.8%) and *S. penniseti* (5.7%) (Table 5.4). The abundance of the other stemborers was less than 5%. *P. purpureum* had higher stemborer diversity than the other grass species.

Table 5.4 Stemborer species diversity and numbers collected on four selected grasses during 2004 and 2005 in Uganda

Stemborer species	*Panicum maximum*	*Pennisetum polystachion*	*Pennisetum purpureum*	*Sorghum arundinaceum*	% of all stemborers collected	Agro-ecological Zone
Noctuidae						
Busseola fusca Fuller	2	-	1	96	13.1	En, LAC, LVC, Sen
Busseola phaia Bowden	107	1	16	8	17.4	En, LAC, LVC, Sen
Manga melanondonta Fletcher	72	-	1	1	9.8	En, LAC, LVC, Sen
Peonoma serrata Hampson	-	-	1	-	0.1	En
Sesamia calamistis Hampson	4	-	3	20	3.6	En, LAC, LVC, Sen
Sesamia penniseti Tams & Bowden	-	-	41	-	5.7	En, LAC, LVC
Sesamia poephaga Tams & Bowden	9	-	2	-	1.5	En, LVC
Sesamia sp.	-	7	1	1	1.2	En, LVC
Crambidae						
Chilo partellus Swinhoe	1	1	1	349	46.4	En, LAC, LVC, Sen
Chilo sp.	4	-	-	-	0.5	En, LVC
Pylaridae						
Eldana saccharina Walker	-	-	1	1	0.1	LVC
Cossidae	-	-	4	-	0.5	LAC
% of all stemborers	27.4	1.2	10.2	65.5		

- Stemborer species not recorded; En, Eastern; LAC, Lake Albert Crescent; LVC, Lake Victoria Crescent; Sen, South eastern.

5.4.4 Dispersion

Table 5.5 gives Taylor's coefficients for *C. partellus* and the noctuids (pooled data). *Chilo partellus* yielded a regression slope greater than 1 on *S. arundinaceum*, indicating an aggregated distribution. The noctuids showed high aggregation on *P. maximum*, while on *P. purpureum* and *S. arundinaceum* the dispersion was random. The dispersion of noctuids on *P. polystachion*; and of *C. partellus* on both *P. maximum* and *P. purpureum* could not be calculated due to very low densities of these stemborer species.

Table 5.5 Taylor's power coefficients for Chilo partellus and noctuids on selected grass species

Grass species	N^1	Log a	b	r^2	p
			Noctuidae		
P. maximum	33	2.94	1.76	0.88	0.0001
P. purpureum	20	0.33	1.08*	0.94	0.0001
S. arundinaceum	37	0.20	1.04*	0.93	0.0001
Across grass species	95	1.75	1.44	0.85	0.0001
			Chilo partellus		
S. arundinaceum	36	0.60	1.15	0.91	0.0001

*slope not different from 1 following t-test, $P \leq 0.05$; [1]Number of data points (sampling occasions).

5.4.5 Larval and pupal parasitism

Ten parasitoids species belonging to Hymenoptera and one Diptera were recovered from larvae and pupae from the four grass species (Table 5.6). The most abundant larval parasitoids were the braconids, *Cotesia sesamiae* Cameron, *Cotesia flavipes* Cameron, and *Bracon* sp. and the tachinid fly, *Sturmiopsis* sp. Pupal parasitoids namely *Dentichasmias busseolae* Heinrich, *Pediobius furvus* Gahan (Eulophidae) and *Brachymeria* sp. were only recovered from *C. partellus* in *S. arundinaceum* (Table 5.6). The other three grass species did not yield any pupal parasitoids.

Cotesia flavipes parasitised 0 - 9.7% of *C. partellus* while parasitism of noctuids was exceedingly low during both seasons (Table 5.7). The indigenous *C. sesamiae* was recovered from all the four grasses with very low parasitism levels on *C. partellus* and parasitism of between 0 and 18.8% on the noctuid larvae (Table 5.7). Other larval parasitoids, *Bracon* sp. and *S. parasitica* also had low levels of parasitism and were only recovered during the dry season from *P. maximum*. Pupal parasitoids were scarce with parasitism levels ranging between 0 and 40% on *C. partellus*. The mean number of progeny and sex ratio (females to males) of *C. flavipes* on *C. partellus* was 28.5 ± 5.2 (± SE) and 0.69 ± 0.08 respectively, while on the noctuids, the number of progeny was 20.2 ± 4.0 with a sex ratio of 0.59 ± 0.09. Due to very low parasitism levels, the numbers of progeny and sex ratios for *C. flavipes* on the noctuids and *C. sesamiae* on *C. partellus* were not computed.

Table 5.6 Parasitoid species of stemborers recovered on the four selected wild grasses during 2004 and 2005 in four Agroecological zones in Uganda

Species	Order: Family	Host plant	Host	Host stage	AEZ found
Cotesia flavipes Cameron	Hym: Braconidae	*S.aru, P.purp*	*Cp, B, S,*	Larvae	En, LAC, LVC, Sen
Cotesia sesamiae Cameron	Hym: Braconidae	*S.aru, P.purp, P.poly, P.max*	*Cp, Bf, B, S*	Larvae	En, LAC, LVC, Sen
Bracon sp.	Hym: Braconidae	*P.max*	*Manga* sp.	Larvae	En
Dolichogenidae sp.	Hym: Braconidae	*P.max*	*B*	Larvae	LAC
Sturmiopsis sp.	Diptera: Tachinidae	*P.max*	*Manga* sp.	Larvae	En
Brachymeria sp	Hymn: Chalcididae	*S.aru*	*Cp*	Pupae	En
Pediobius furvus Gahan	Hym: Eulophidae	*S.aru*	*Cp*	Pupae	En, LAC
Dentichasmias busseolae Heinrich	Hym: Ichnuemonidae	*S.aru*	*Cp*	Pupae	LVC, Sen
Grambroides numbipennis Seyrig	Hym: Ichnuemonidae	*S.aru*	?	?Pupae	LVC
Unknown species	Hymenoptera	*P.max*	B	Larvae	En
Aphanogmus fijiensis Ferrière	Hym: Ceraphronidae	*S.aru*	*Cotesia* spp	Hyper	En, LAC, LVC, Sen

Hym, Hymenoptera; *S.aru, Sorghum arundinaceum; P.purp, Pennisetum purpuruem; P.poly, Pennisetum polystachion; P.max, Panicum maximum; Cp, Chilo partellus; Bf, Busseola fusca; B, Busseola* sp.; Hyper, Hyperparasitoid; En, Eastern; LAC, Lake Albert Crescent; LVC, Lake Victoria Crescent; Sen, South eastern.

Table 5.7 Parasitism of stemborers recovered from the selected grass species during the dry season (Jan-Feb) of 2004 and wet season (May-Aug) of 2005 in four Agroecological Zones (AEZs) in Uganda

Location	Grass species	Host and Parasitoids species	% and number ( ) parasitized	
			Dry season	Wet season
		***C. partellus* larvae & pupae**		
Eastern	*S. arundinaceum*	*C. flavipes*	9.7 (7)	5.1 (5)
		C. sesamiae	1.4 (1)	1.0 (1)
		P. furvus	14.3 (1)	0
		Brachymeria sp.	0	10.0 (1)
LAC	*S. arundinaceum*	*P. furvus*	0	33.3 (1)
LVC	*S. arundinaceum*	*C. flavipes*	0	4.4 (4)
		D. busseolae	-	33.3 (1)
Sen	*S. arundinaceum*	*C. flavipes*	0	3.7 (2)
		C. sesamiae	0	1.9 (1)
		D. busseolae	-	40.0 (2)
		Noctuidae larvae		
Eastern	*P. maximum*	*C. sesamiae*	1.8 (1)	0.6 (1)
		Bracon sp.	5.5 (3)	0.0
		Sturmiopsis sp.	3.6 (2)	0.0
	P. purpureum	*C. sesamiae*	-	18.8 (3)
	S. arundinaceum	*C. flavipes*	0	5.0 (1)
LAC	*P. maximum*	*Dolichogenidae sp.*	0	14.3 (1)
	P. purpureum	*C. flavipes*	-	2.4 (1)
		C. sesamiae	-	2.4 (1)
LVC	*P. purpureum*	*C. flavipes*	-	4.0 (1)
		C. sesamiae	-	4.0 (1)
Sen	*P. purpureum*	*C. sesamiae*	-	6.3 (1)
	S. arundinaceum	*C. sesamiae*	0	5.0 (1)

Number of parasitised larvae or pupae in parenthesis, -No host found; En, Eastern; LAC, Lake Albert Crescent; LVC, Lake Victoria Crescent; Sen, South eastern.

5.5 DISCUSSION

The stemborer and host plant species diversities obtained in this study were low ✓ compared to reports by Ingram (1958) and Nye (1960) in ~~from~~ Uganda, and LeRu *et al.* (2006) in East and Southern Africa. In the present study, the surveys mainly covered major roads in the maize growing regions, however, special ecologies like river banks, forests and swamps were not considered. As shown by Ndemah *et al.* (2001a) for the humid forest zone of Cameroon, road-side fields constitute special ecologies and are not comparable with those inside the forests. The grasses of major emphasis in the study tolerate disturbed areas, and are common in dry open areas.

Stemborer infestations on grasses were much lower than those recorded on crops corroborating findings from western Africa (Schulthess *et al.*, 1997; Gounou and Schulthess, 2004; Ndemah *et al.*, 2002). Laboratory studies have shown low larval survival and development on several wild grasses (Shanower *et al.*, 1993; Ofamata *et al.*, 2000; van den Berg *et al.*, 2001), which may be attributed to high silica contents in the epidermis of leaves (McNaughton *et al.*, 1985; Sétamou *et al.*, 1993). Among the grasses studied, *S. arundinaceum* had the highest stemborer infestation followed by *P. maximum* corroborating findings by Ingram (1958), who hypothesized that these two grasses constitute a large reservoir of stemborers near cultivated fields. *Sorghum arundinaceum* was the principal host for *B. fusca* and *C.* partellus, while other grass species were of minor importance or non-hosts. This corroborates results by LeRu *et al.* (2006), who concluded that the wide range of host plants reported for the two pests was the result of misidentification of the stemborer species. Similarly, in West Africa, Gounou and Schulthess (2004) reported a narrow host range for *B. fusca* which was recovered from *S. arundinaceum* and *P. purpureum* only. However, recent surveys indicate that the borers found on the latter were not *B. fusca* (R. Ndemah, ICIPE, Yaoundé, Cameroon). They also found highest incidence of *S. calamistis* on *S. arundinaceum* and *P. maximum* while *E. saccharina* was common on *S. arundinaceum* only, besides other host plants such the sedges.

According to some authors, *Busseola fusca* undergoes an obligatory diapause (Harris, 1962; Usua, 1973; Kfir, 1991; Kfir *et al.*, 2002) while others (Nye, 1960) reported a facultative diapause. According to LeRu (unpublished results), diapause occurs only if the dry season is more than 2 months as is the case for the wet parts of Lake Victoria and Western Kenya (Kakamega). In Uganda, *C. partellus* undergoes a facultative diapause (Ingram, 1958). In regions in South Africa (mainly Kwazulu Natal and Eastern regions), where host plants are abundant and the climate is warm, *C. partellus* develops continuously all year round (Kfir *et al.*, 2002; LeRu unpublished). Therefore, *S. arundinaceum* appears to be an important carryover mechanism for both non-aestivating and aestivating borers of *B. fusca* and *C. partellus*, when maize and sorghum are not available.

Most stemborers species recorded in this study have been reported by previous workers in Uganda (Tams and Bowden, 1953; Ingram, 1958; Nye, 1960 and Fletcher, 1963). *Manga melanodonta* which were found to be wide-spread, was however, not recorded by Ingram (1958) and Nye (1960) who conducted surveys in most parts of the country. Similarly, the cossids on *P. purpureum* were not reported by these authors. Although *M. melanodonta* was recorded on *P. purpureum* and *S. arundinaceum* these seem not to be true hosts and in both cases they were recovered where *P. maximum,* its principal host was growing in close proximity. *P.*

maximum was also the principal host for *B. phaia* and *S. poephaga*. On *P. purpureum*, *S. penniseti* was the major borer although *B. phaia* was regularly found. *P. serrata* was only recovered once but LeRu (unpublished data) frequently recovered it in Uganda on *P. purpureum*. The major stemborers recovered from *P. polystachion* were *Sesamia* sp. which was never identified to species level because of high larval mortality during rearing on a sub-optimal diet.

A wide range of larval and pupal parasitoids were recovered during the present study but parasitism was low (Table 5.7). *Cotesia sesamiae and C. flavipes* were mainly recovered from *S. arundinaceum* and *P. purpureum* in both the dry and wet seasons. Sétamou *et al.* (2005) showed that in the laboratory the performance of *C. flavipes* parasitising *C. partellus* larvae feeding on stems of *S. arundinaceum* and *P. purpureum* was poor compared to the maize and cultivated sorghum. In the present study progeny and sex ratios of *Cotesia* spp. were in the range of those observed from *C. partellus* collected from maize and sorghum (Omwega and Overholt, 1997; Cugala *et al.*, 2001). Therefore, stemborers in the wild would be important in maintaining parasitoid populations. The parasitoid diversity was higher in the grasses studied than that recorded on maize and sorghum (Matama-Kauma *et al*, 2001; Rwomushana *et al.*, 2005). Ndemah *et al.* (2001c) similarly, reported a higher parasitoid diversity on *P. purpureum* than on maize in Cameroon. In coastal Kenya, after release of *C. flavipes* it took four years for parasitism to increase substantially and exert control of *C. partellus* (Zhou *et al.*, 2001a). Seven years later, the system is still not yet at an equilibrium as shown by still increasing parasitization rates (Jiang *et al.*, in press). It is suspected that alternate borer hosts in wild habitats, which may be acceptable but vary in their degree of suitability, may be responsible for it. Laboratory studies have shown that some stemborers in the wild are acceptable to *C. flavipes* but are not suitable for development and therefore form a reproductive sink (Obonyo, 2005). There is a need for further studies on the suitability of alternate borer species found on wild host plants to the most common parasitoid species found in both cultivated and wild habitats to understand the role of these habitats in the population dynamics of the introduced and indigenous natural enemy species.

CHAPTER SIX

EFFECT OF WILD GRASSES PLANTED AS BORDER ROWS ON STEMBORER INFESTATIONS IN MAIZE IN UGANDA

6.1 INTRODUCTION

A complex of seven lepidopteran stemborer species is reported to cause economic losses to cereals in Africa. In Uganda, *Busseola fusca* Fuller (Noctuidae) and *Chilo partellus* Swinhoe (Crambidae) are the most important species on maize and sorghum (Ingram 1958; Matama-Kauma *et al.*, 2001). Other species commonly found are *Sesamia calamistis* Hampson (Noctuidae) and *Eldana saccharina* Walker (Pylaridae). All the stemborer species are indigenous to Africa except for *C. partellus*, which was introduced from Asia into Southern Africa sometime before 1930s (Tams, 1932). It was not recorded in East Africa until 1953 (Ingram, 1958). Several indigenous parasitoids attack these stemborers but the rates of parasitism are low. *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) was recently introduced into Uganda for the control of *C. partellus* and is fully established with parasitism rates ranging from 4 to 32% in eastern Uganda (Matama-Kauma *et al.*, 2001).

Stemborers attack wild host plants besides cereals. However, on the wild host plants, their densities are not as high as those observed in crops, mostly as a result of low survival of young instars (Nye, 1960; Mathez, 1972; Schulthess *et al.*, 1997; Shanower *et al.*, 1993; Gounou & Schulthess, 2004). Schulthess *et al.* (1997) working in Côte d'Ivoire and Cameroon found that the presence of wild hosts in the vicinity of the field reduced stemborer incidence in the crop. They concluded that wild grasses either act as trap plants or they stabilized the system for both the pest and natural enemies (Schulthess *et al.*, 2001). Trials that used grasses as trap plants for stemborers have been carried out in Kenya (Khan *et al.*, 1997b; 2001), Benin and Cameroon (Ndemah *et al.*, 2002). The results were variable. Such studies have not been conducted in Uganda. The present study investigated the effect of planting grass border rows on stemborer infestations and parasitism.

6.2 MATERIALS AND METHODS

6.2.1 Experimental site

Field trials were conducted at Namulonge Agricultural Research Institute and Serere Agricultural Research Institute in central and eastern Uganda, respectively. Both sites are characterised by a bimodal rainfall distribution, which allows for two cropping seasons, the first lasting from March to mid-July and the second from September to December. Further descriptions of the sites are given in Chapter three.

6.2.2 Experimental procedures and layout

Four grass species were used to test the effect of wild grasses on stemborer infestations. The grasses were selected based on a survey of abundance of stemborers on wild grasses conducted in 2003 (Chapter 5 of this thesis). The grass species included *Pennisetum purpureum* Schumach, *Pennisetum polystachion* (L.) Schult., *Panicum maximum* Jacq. and *Sorghum arundinaceum* (Desv.) Stapf. The trials were conducted from May to September and September to January for the first and second rains 2004, respectively. For the first rains 2005 the trial was carried out from April to August. The trials were laid in a randomised complete block design with split plots, replicated three times. The main plot treatments were maize pure and maize with grassy borders and these were divided into two sub plots, one treated with an insecticide and the other was untreated. The grassy borders were established as three rows of grass tufts planted at the spacing of 75 x 50cm. The open pollinated 110-days maize variety Longe 4 was planted at the same spacing with three seeds per hill, which was thinned down to two plants at 2 weeks after plant emergence (WAE). Main plots measured 14m x 20m for pure maize, and 11m x 17m for maize with grassy borders, while the subplot size was 14m x 10m and 11m x 9m, respectively. The distance between plots was 3m and between blocks 5m. In the insecticide subplot, Furadan granules (i.e carbofuran 5G, 50g/kg a.i) were applied into the whorls at 3WAE.

6.2.3 Data collection

Each maize sub plot was divided into four quadrants of four by five metres each. At 3WAE, ten plants were randomly uprooted per quadrant and assessed for stemborer egg batches. After counting, the collected eggs were reared in the laboratory until larvae or parasitoids emerged. A second sampling was conducted at tasselling stage to assess borer infestation and larval parasitism. Five plants were randomly selected per quadrant and assessed for infestation. The number of plants infested and number of larvae and pupae per plant were recorded. All the larvae collected were reared in the laboratory on maize stems and cobs, which were replenished every 2-3 days until pupation or parasitoid emergence. The pupae obtained from the field were kept singly in Petri dishes until parasitoid or adult moth emergence. The emerged parasitoids were preserved in 70% alcohol and identified, where possible and the difficult to identify were sent to the International Centre of Insect Physiology and Ecology (ICIPE) for identification.

At maturity, plant height with tassel, tunnel length, number of exit holes, number of borers and cob weights were measured on five plants per quadrant. All cobs of plants of two middle rows in each quadrant (i.e 2 m^2) were harvested and weighed. The sampling procedures were the same for all seasons and both locations except for the first season 2004, when there was no insecticide treatment.

6.3 Statistical analyses

Analysis of variance (ANOVA) in SAS was used to assess any treatment differences in pest infestation, plant damage and yield variables. Data was analysed separately for each season and location. Where necessary, data that involved counts were log transformed (x+1) and proportions were arcsine square root transformed before analyses. Significance level was set at $P < 0.05$ and the back transformed means are presented.

6.4 RESULTS

6.4.1 Effect of grass borders on stemborer infestations on maize

Four stemborer species were found namely *C. partellus, B. fusca, S. calamistis* and *E. saccharina.* Egg infestation was very low and the data were not analyzed. *C. partellus* and *B. fusca* were the dominant species accounting for over 90% of all the species (Figures 6.1 & 6.2). There were seasonal variations in stemborer species abundance and density. At Namulonge *C. partellus* and *B. fusca* occurred in equal proportions except for the second rains of 2004 when *C. partellus* became the most abundant (Figure 6.1). While at Serere, with the exception of the first rains of 2004, *C. partellus* was the dominant species representing 74-100% of the stemborers.

Stemborer infestations varied across locations and seasons but there were no significant differences between treatments in the first season, as a result of poor grass establishment (Figure 6.1 & 6.2). At Namulonge, in the following seasons, *P. purpureum* and *P. maximum* grassy borders significantly reduced percent plants infested (Figure 6.1). However, for maize with *P. maximum* border, this result was not consistent. There were significant differences in the number of stemborers per plant at Namulonge (Figure 6.1). Similarly, at Serere, *P. purpureum* is the only grass border that significantly reduced percent plants infested in two consecutive seasons (Figure 6.2). Stemborer densities were lower during both seasons of 2004 at this location. In the second rains 2004 and first rains 2005, maize with the *P. purpureum* border had significantly reduced stemborer densities compared to the pure maize (Figure 6.2). The entire maize crop surrounded by the grass borders had significantly lower borer density than the pure maize.

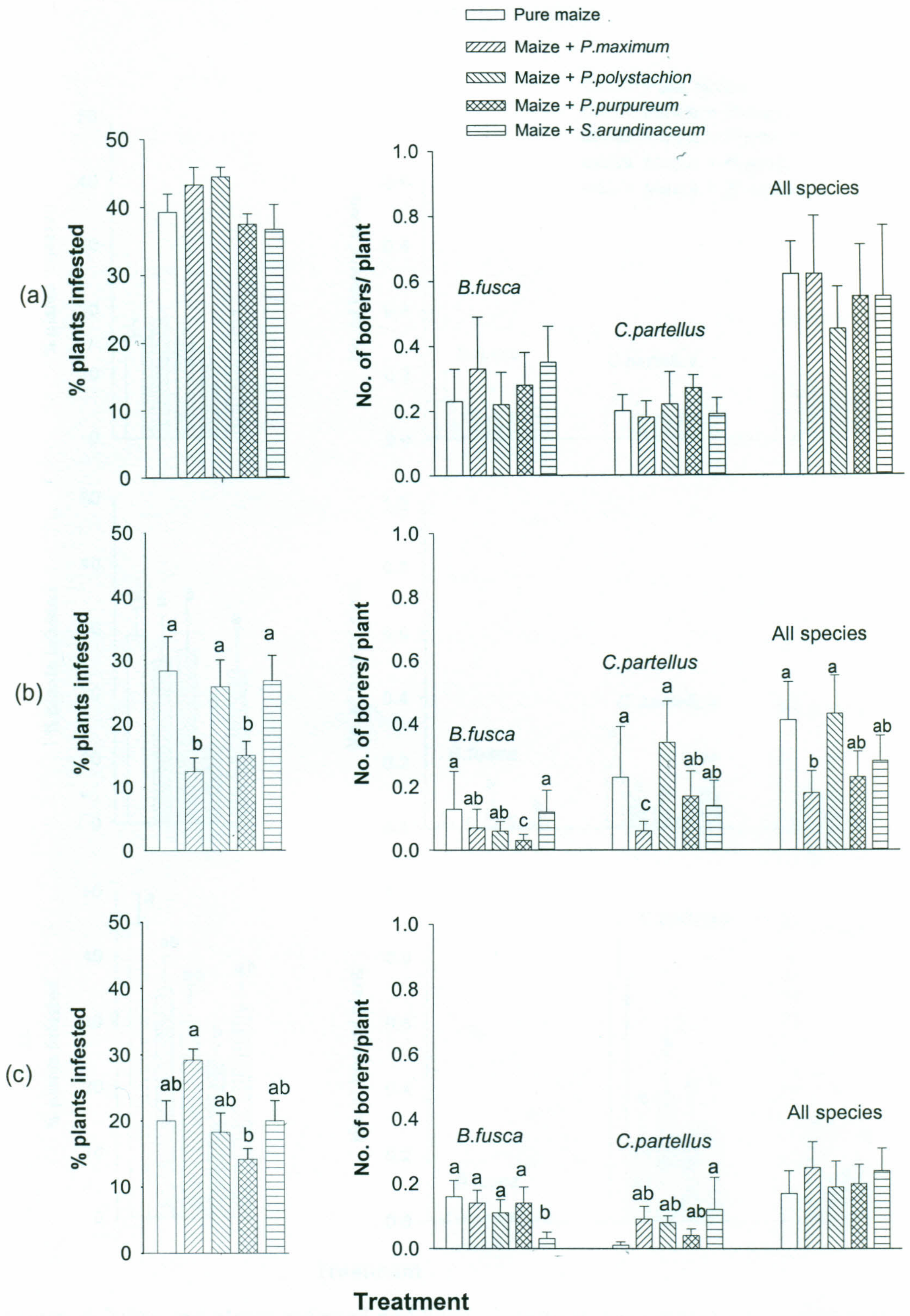

Figure 6.1 Percent plants infested and borer density in pure maize and maize with grassy borders at Namulonge uganda during the first (a) and second rains (b) of 2004, and first rains 2005 (c). Columns followed by the same lower case letter were not significantly different at $P \leq 0.05$.

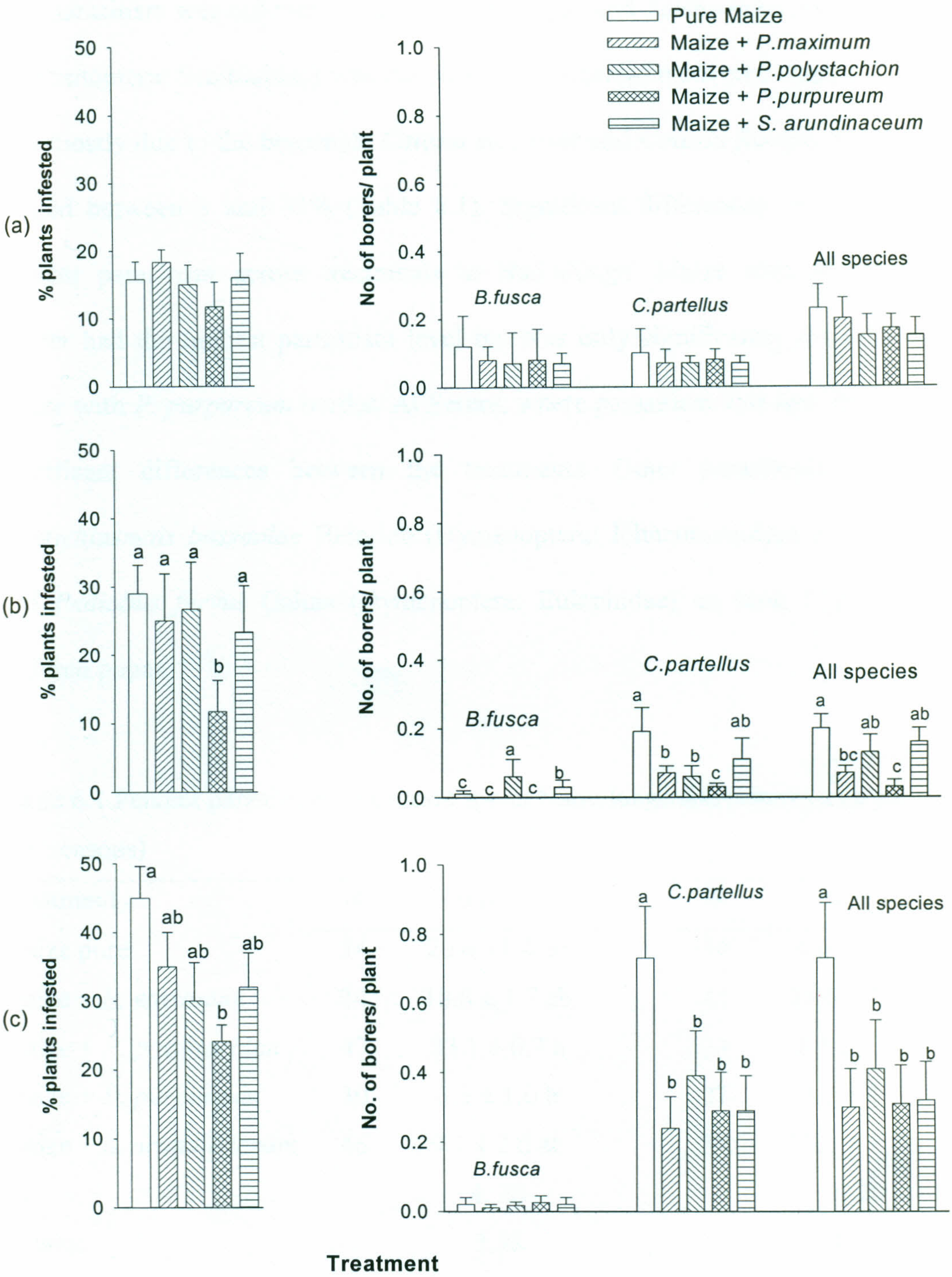

Figure 6.2 Percent plants infested and borer density in pure maize and maize with grassy borders at Serere Uganda during the first (a) and second rains (b) of 2004, and first rains of 2005 (c). Columns followed by the same lower case letter were not significantly different at P ≤ 0.05.

6.4.2 Effect of grass borders on parasitism

Egg parasitism was only recorded on *B. fusca* eggs and *Telenomous busseolae* Gahan (Hymenoptera: Scelionidae) was the only egg parasitoid recovered. Larval parasitism was mostly due to the braconids *Cotesia sesamiae* and *Cotesia flavipes* Cameron and ranged between 3 and 33% (Table 6.1). Significant differences were observed in percent parasitism across treatments at Namulonge. Maize with *P. polystachion* border had the highest parasitism level but was only significantly different that on maize with *P. purpureum* border. At Serere, where parasitism was low, there were no significant differences between the treatments. Other parasitoids found were *Dentichiasmais busseolae* Heinrich (Hymenoptera: Ichneumonidae) on *C. partellus* and *Pediobus furvus* Gahan (Hymenoptera: Eulophidae) on both *C. partellus* and *B. fusca* pupae.

Table 6.1 Percent parasitism by *Cotesia* spp at Namulonge and Serere, Uganda (data pooled for two seasons)

Treatment	N	Namulonge	N	Serere
Maize pure	54	20.4 ±1.4 ab	34	4.6 ± 1.7 a
Maize + *P. maximum*	34	18.6 ± 1.7 ab	44	25.6 ± 1.2 a
Maize + *P. polystachion*	47	33.1 ± 0.7 a	24	8.3 ± 1.4 a
Maize + *P. purpureum*	30	3.3 ± 1.0 b	27	13.3 ± 1.7 a
Maize + *S. arundinaceum*	46	9.4 ± 2.0 ab	35	15.8 ± 1.7 a
Df		4, 20		4, 20
F-value		3.58		1.76
P<0.05		0.0233		0.1758

Means within columns followed by the same lowercase letters are not significantly different at $P \leq 0.05$ (SNK)

6.4.3 Effect of grass borders and insecticide treatment on plant damage and yield

At Namulonge, percentage stem tunnelled was not significantly different across grass border treatments while insecticide treatment significantly reduced percentage stem tunnelled in one of the two seasons under the different grass borders (Table 6.2). Significantly higher cob weight per plant was recorded in maize with grass borders compared to pure maize in the first rains 2005. Insecticide treatment was found to increase cob weight per plant significantly in maize with *P. maximum* and *P. polystachion* grass borders but the result was not consistent. Cob weight per plot was significantly higher in pure maize plots than in plots with grass borders in both treated and untreated plots in the second rains of 2004. In the same season insecticide treatments had increased yield compared to the untreated maize in the maize pure plots and maize bordered by *P. maximum* (Table 6.2). In the first rains 2005, there was no trend in the cob weight per plot between the grass border treatments and the insecticide treatment did not lead to an increase in yield per plot.

At Serere, similarly, results of stem damage and yield were not consistent across seasons and the grass border treatments (Table 6.3). There were no significant differences in the percentage stem tunnelled and cob weight during the first rains 2004. In the following two seasons, percentage stem tunnelled tended to be significantly lower in maize with the *P. purpureum* grass border and the insecticide treated maize plots. Insecticide treatment and grass borders generally did not have a significant effect on cob weight per plant. Cob weight per plot was significantly higher in pure maize than all the maize bordered by grasses (Table 6.3).

Table 6.2 Effect of grass border rows and the insecticide treatment interaction on % stem tunnelled and cob weight (± SE) in the second rains 2004 and first rains 2005 at Namulonge[1], Uganda

Grass border	2nd rains 2004		1st rains 2005	
	Untreated	Treated	Untreated	Treated
		% stem tunnel		
Pure Maize	0.7 ± 0.2 A	0.3 ± 0.2 A	2.0 ± 0.5 A	0.4 ± 0.2 B
Maize + *P.max*	0.8 ± 0.3 A	0.2 ± 0.2 A	2.5 ± 0.7 A	0.6 ± 0.2 B
Maize + *P.Poly*	1.0 ± 0.4 A	0.3 ± 0.2 A	1.4 ± 0.6 A	0.1 ± 0.1 B
Maize + *P.Purp*	0.9 ± 0.4 A	0.3 ± 0.1 A	1.9 ± 0.8 A	0.4 ± 0.2 B
Maize + *S.aru*	1.8 ± 0.6 A	0.8 ± 0.3 A	1.4 ± 0.5 A	0.8 ± 0.4 A
df	4, 295	4, 294	4, 295	4, 295
F-value	1.32	1.34	0.91	1.17
P-value	0.2641	0.2540	0.4558	0.3255
		Cob weight/ plant (g)		
Pure Maize	176.3 ± 6.1 A	188.9 ± 5.6 A	137.7 ± 9.2 A	122.3 ± 7.8 b A
Maize + *P.max*	163.0 ± 7.9 A	196.9 ± 7.7 B	156.9 ± 10.1 A	164.0 ± 9.8 aA
Maize + *P.Poly*	157.0 ± 9.1 A	170.5 ± 9.0 A	123.3 ± 8.5A	158.8 ± 9.1 aB
Maize + *P.Purp*	157.0 ± 8.3 A	170.8 ± 8.1 A	127.8 ± 9.9 A	133.0 ± 10.1 abA
Maize + *S.aru*	174.7 ± 8.4 A	172.8 ± 8.2 A	139.5 ± 9.3 A	135.9 ± 9.0 abA
df	4, 295	4, 294	4, 295	4, 295
F-value	1.06	2.37	1.91	3.75
P-value	0.3777	0.0526	0.1080	0.0054
		Cob weight/plot (kg)		
Pure Maize	221.9 ± 3.2 aA	241.3 ± 6.0 aB	118.0 ± 7.3 A	117.6 ± 5.9 aA
Maize + *P max*	131.3 ± 5.4 bA	165.6 ± 5.4 bB	112.7 ± 6.4 A	112.7 ± 6.6 aA
Maize + *P.Poly*	137.6 ± 7.8 bA	143.2 ± 5.5 bA	100.5 ± 5.8 A	114.2 ± 7.7 aA
Maize + *P.Purp*	131.9 ± 8.1 bA	146.2 ± 13.8 bA	97.4 ± 7.7 A	104.2 ± 4.1 abA
Maize + *S.aru*	146.7 ± 4.0 bA	145.1 ± 10.9 bA	94.3 ± 7.4 A	87.2 ± 6.8 bA
df	4, 10	4, 10	4, 55	4, 55
F-value	40.66	21.52	2.17	3.70
P-value	0.0001	0.0001	0.0847	0.0097

[1] Data for first rains not collected due to drought; within a season, means within rows followed by the same uppercase letters and means within columns followed by same lowercase letters are not significantly different at P ≤ 0.05 (SNK)

Table 6.3 Effect of grass border rows and the insecticide treatment interaction on % stem tunnelled and cob weight (± SE) in the second rains 2004 and first rains 2005 at Serere / Uganda.

Grass border	1st rains 2004[1]	2nd rains 2004		1st rains 2005	
	Untreated	Untreated	Treated	Untreated	Treated
			% stem tunnel		
Pure Maize	0.4 ± 0.2	2.4 ± 0.7 aA	0.5 ± 0.3 bB	3.3 ± 1.0 aA	1.0 ± 0.4 B
Maize + *P.max*	1.4 ± 0.4	1.4 ± 0.4 abA	0.4 ± 0.3 B	2.6 ± 0.6 bA	1.3 ± 0.5 A
Maize + *P.Poly*	0.8 ± 0.3	2.3 ± 0.8 aA	0.4 ± 0.3 B	1.8 ± 0.5 bA	2.0 ± 0.6 A
Maize + *P.Purp*	1.0 ± 0.4	0.3 ± 0.1 bA	0.2 ± 0.1 A	1.6 ± 0.4 bA	1.1 ± 0.4 A
Maize + *S.aru*	1.4 ± 0.4	1.2 ± 0.4 abA	0.4 ± 0.2 B	1.6 ± 0.5 bA	1.8 ± 0.7 A
df	4, 290	4, 295	4, 295	4, 255	4, 251
F-value	1.75	2.62	0.12	1.45	0.81
P-value	0.1389	0.0352	0.9744	0.2193	0.5186
			Cob weight/ plant (g)		
Pure Maize	144.8 ± 10.1	82.2 ± 5.4 aA	76.9 ± 6.7abA	116.1 ± 6.5abA	127.9 ± 4.6 A
Maize + *P.max*	130.8 ± 9.7	90.9 ± 5.5 aA	65.9 ± 4.3 bB	122.8 ± 6.3aA	122.1 ± 5.6 A
Maize + *P.Poly*	143.0 ± 7.6	51.7 ± 4.5 bA	43.4 ± 4.5 cA	122.8 ± 7.8aA	111.9 ± 5.7A
Maize + *P.Purp*	151.4 ± 8.0	62.9 ± 5.4 abA	84.0 ± 6.1 abB	114.9 ± 6.4abA	112.7 ± 5.6 A
Maize + *S.aru*	153.8 ± 10.2	77.3 ± 5.0 abA	87.2 ± 6.4 aA	92.5 ± 7.2bA	121.9 ± 11.5 B
df	4, 290	2, 294	4, 294	4, 244	4, 196
F-value	0.95	9.12	9.59	2.64	1.22
P-value	0.4346	0.0001	0.0001	0.0350	0.3047
			Cob weight/plot (kg)		
Pure Maize	97.5 ± 19.5	118 ± 5.5 a	115.4 ± 8.8 a	134.1 ± 13.2 a	147.8 ± 10.8 a
Maize + *P. max*	80.9 ± 15.0	79.2 ± 6.5 b	61.0 ± 5.6 b	83.2 ± 8.1 b	78.6 ± 6.1 b
Maize + *P.Poly*	67.8 ± 6.5	50.2 ± 6.2 b	50.5 ± 3.6 b	84.3 ± 9.4 b	75.4 ± 6.4 b
Maize + *P.Purp*	71.0 ± 13.8	53.1 ± 8.7 b	70.6 ± 11.1 b	78.3 ± 6.9 b	74.3 ± 5.7 b
Maize + *S.aru*	64.4 ± 11.8	65.0 ± 8.9 b	70.1 ± 11.8 b	64.6 ± 1.4 b	80.9 ± 6.8 b
df	4, 10	4, 10	4, 10	4, 21	4, 21
F-value	0.92	8.00	14.42	7.52	16.97
P-value	0.4900	0.0037	0.0004	0.0006	0.0001

[1] No insecticide treatment used in this season; within a season, means within rows followed by the same uppercase letters and means within columns followed by same lowercase letters are not significantly different at P ≤ 0.05 (SNK).

6.4 DISCUSSION

In the present study, grassy border rows around maize fields showed no consistent effect on *B. fusca* and *C. partellus* infestations, stem damage and on yields of maize. In western Africa, incidence of stemborers such as *B. fusca*, *S. calamistis* and *E. saccharina* in maize crops decreased with abundance of grasses around the field (Gounou *et al*., 1994; Schulthess *et al*., 1997). In subsequent trials in the humid forest in Cameroon in 1996/97 by Ndemah *et al*. (2002), border rows with grasses reduced pest densities in maize, in the second and third season after planting the borders, but not during the first, indicating that the borders have to be well-established to have an effect. In similar trials in the forest-savannah mosaic of Benin in 1998/99, one set of trials showed a decrease in pest densities, while another set showed no effect. In the Cameroon trials during the second cropping season of 1997, when there was a prolonged drought, Ndemah *et al*. (2002) observed less wilting and more vigorous plants in crops surrounded by *P. purpureum*. Thus, they hypothesized that the main effect of grassy border rows was due to changes of soil chemical and physical properties in plots surrounded by the tall grasses rather than due to lower pest densities. Follow-up trials in 2002 indicated a higher soil water retention capacity in plots surrounded by grasses compared to plots with sole maize. It was concluded that grassy border rows had only a beneficial effect if the crop was affected by spells of drought, which is crucial during the tasseling of maize (R. Ndemah unpublished).

Ndemah *et al*. (2002) showed that the presence of wild grasses increased egg and larval parasitism on maize. Again, follow-up trials in 2002 showed no effect on parasitism. ~~corroborating~~ These findings corroborate the results of the present experiments where there was no difference in larval parasitism by *Cotesia* spp. except for plots surrounded by *P. polystachion* at one site only.

What are the reasons for the variability in the effects of grassy border rows? First, borer species compositions vary greatly with regions in Africa. In West Africa, the major species *S. calamistis* and *E. saccharina* do not diapause and are forced to spend the off-season on wild hosts. So they evolutionarily never developed an oviposition preference for maize, which guarantees a much higher survival of offspring than wild ?? grasses (Shanower *et al.*, 1993). This was corroborated by oviposition preference studies by Schulthess *et al.* (1997). *B. fusca* and *C. partellus*, on the other hand, do diapause during the off-season thus they do not depend on alternative wild hosts for perennation of their populations. Probably as a result, their host plant range is much narrower than that of *S. calamistis* and *E. saccharina* (Gounou and Schulthess, 2004; LeRü *et al.*, 2006). This suggests that grassy border rows would be more effective against non-diapausing than diapausing species. In fact, the diversity of borers and parasitoids and differences in parasitism levels between treatments were greater in the Benin trials, where *S. calamistis* and *E. saccharina* were the main species, than in the Cameroon trials, where *B. fusca* was the predominant pest. The question also arises if grasses act as trap plants for diapausing species such as *B. fusca* and *C. partellus* or if rather they form a barrier. This could explain the variable results of the border rows; if the borders are not well established, the moths have easy access to and oviposits on the crop; if crop residues are not removed, they form a refuge for diapausing larvae and adults emerging at the onset of the season will be "arrested" inside the border rows and attack the new crop rather than disperse. The barrier hypothesis is partly supported by findings by Calatayud (unpublished data) and van den Berg *et al.* (in press) who found that ovipositing *B. fusca* did not prefer *P. purpureum* over maize. As shown by LeRü *et al.* (2006) and in Chapter 5 (this thesis), *B. fusca* and *C. partellus* attack very few wild host plant species, with over 90% found on wild sorghum. This suggests that borers on wild host plants have been widely misidentified in the past. Concerning *C. partellus*, why should an insect species oviposit on a plant species that causes a 100% of mortality of offspring? According to Singer et al. (1988) and Ng (1988) oviposition preference and larval performance may be correlated such that females prefer the plant species on which their larvae have the greatest chance of surviving during their first 10 days of growth. Two reasons are proposed for the preference of an unsuitable host plant by *C. partellus*; (a) *C. partellus* is exotic to Africa and *P. purpureum* is a relatively recent addition to its habitat (b) *C. partellus* does not have a preference for *P. purpureum* over maize. In fact, field evidence, which would consist of higher number of eggs laid on *P. purpureum* compared to maize, is lacking. Thus, existing data do not support either of the hypotheses.

The main reason for the variable results of the grassy border studies, however, might be that the area planted with grasses is too small to have an effect. The surveys carried out in Côte d'Ivoire and Cameroon showed that borer densities on maize steeply decreased with grass abundance around the field (Schulthess *et al.*, 1997). Moreover, these grassy habitats very likely have been well established for many years, therefore, harbouring stable populations of both pests and parasitoids. Those grassy habitats might have had a much more crucial effect on the population dynamics of pests and beneficials than the grassy border rows. In the use of grass borders, these borders are trimmed at the beginning of every season to make them attractive to the moths hence they themselves are not a stable system as compared to the wild habitat. It can be concluded that the role of grassy border rows in controlling cereal stemborers in cereal crops is questionable and that, moreover, the mechanisms are not understood at all. As proposed by Ndemah *et al.* (2002), leaving wild habitats in the vicinity of crop fields intact rather than burning them every dry season might have more effect on pest populations in crops than planting grassy border rows around fields.

CHAPTER SEVEN

OVIPOSITION PREFERENCE AND LARVAL DEVELOPMENT OF *CHILO PARTELLUS* SWINHOE AND *BUSSEOLA FUSCA* FULLER ON SELECTED GRASSES

7. 1 INTRODUCTION

The lepidopteran stemborers *Chilo partellus* Swinhoe (Crambidae) and *Busseola fusca* Fuller (Noctuidae) are the most important stemborers on maize and sorghum in Uganda. *B. fusca* is indigenous to Africa while *C. partellus* is an introduced species from Asia. This pest was not known in Uganda before 1953 (Ingram, 1958). Both species have been recovered from several wild grasses in eastern Africa including Uganda (Ingram, 1958; Nye, 1960; Khan *et al.*, 1997b; Haile and Hovsfang, 2002; LeRu *et al.*, 2006).

According to Ingram (1958) and Bowden (1976), wild grasses harbour stemborers during the off season, from where they attack cereals in the following cropping season. Ingram (1958) reported that in Uganda the most important reservoirs among wild hosts were *Sorghum arundinaceum* (Desv.) Stapf., *Panicum maximum* Jacq. and *Pennisetum purpureum* Schumach. Studies elsewhere have, however, indicated that stemborer survival on wild grasses is very low and that some of these grasses species instead act as trap plants for some stemborer species (Shanower, *et al.*, 1993; van den Berg *et al.*, 2001; van den Berg, 2006). In Uganda, the attractiveness of these wild grasses and their ability to support the development of *C. partellus* and *B. fusca* has not been evaluated. The objective of this study therefore was to assess the oviposition preference, larval growth and development of these stemborers on selected grasses in Uganda.

7.2 MATERIALS AND METHODS

7.2.1 Plants and insects used

The test plants included Maize (*Zea mays* L)., sorghum (*Sorghum bicolor* L. Moench), wild sorghum (*S. arundinaceum*), Napier grass (*P. purpureum)*, *Pennisetum polystachion* Schult. and Guinea grass (*P. maximum)*. With the exception of *P. polystachion,* the grasses chosen were the ones indicated to be major stemborer reservoirs in Uganda (Ingram, 1958). *P. polystachion* was included because during preliminary surveys (Chapter 5), this grass was found to harbour *Chilo* sp. pupae while *S. bicolor* is a major cereal in Uganda and indigenous to Africa. The grasses were grown from root splits planted in plastic pots in an insect proofed screen house at Namulonge Agricultural Research Institute (NAARI) and at the International Centre of Insect Physiology and Ecology (ICIPE). All plants used in the experiments were 4 - 7 weeks old after planting. Each pot was thinned to 3-4 tillers.

The test insects included *Chilo partellus* and *Busseola fusca. C. partellus* was reared in the laboratory at NAARI for 1-2 generations on natural diet of fresh maize stems and young cobs, which were replenished every 2-3 days. The founder insects were collected from maize and sorghum in farmers' fields. *B. fusca* used was obtained from the insectary at ICIPE and was reared on artificial diet for 6-8 generations. For the oviposition experiment, one-day old mated adults were used while first instar larvae were used in the larval growth and development experiments.

7.2.2 Oviposition response

The oviposition response of *C. partellus* and *B. fusca* on the different test plants was studied in a no-choice situation in 30 x 30 x 100cm cages. The cages were made of light transparent nylon cloth with a glass door. Newly emerged moths were allowed one day to mate and one gravid female paired with a male was released into an oviposition the cage containing the test plant and left to oviposit for 48 hours. The plants were then removed and dissected and examined for infestation and numbers of egg batches and eggs per batch. The experiment was replicated six times.

7.2.3 Oviposition preference

To assess the oviposition preference of *B. fusca* and *C. partellus* on selected grasses, two-choice and multiple-choice tests were used. One mated female paired with one male was used in each test. For the two- choice tests, maize was compared with one test plant at a time in cages of 0.5 x 1 x 1m and one pair of moths (female and male) released per cage. For the multiple choice tests, potted plants of each test plant were arranged in a circle in a cage of 2 x 2.5 x 2.5 metres and one pair of moths was released in the centre. The plants were dissected 48 hours after the release of moths and examined for infestation and numbers of egg batches and eggs per batch. The experiment was replicated six times.

7.2.4 Larval development

Maize, sorghum and the four selected wild grasses were evaluated for larval growth and development of *B. fusca* and *C. partellus*. In total 14 pots were used for each test plant. When maize was four weeks old and the grasses at five weeks after transplanting, ten (10) first instar larvae were introduced per tiller/plant of the potted plants in the screen house. The experiment was replicated six times. The plants were left to grow normally and watered regularly. To determine larval growth over time, six stems of each test plant were dissected at the intervals of 7, 14, 21, 28, 35, 42 and

49 days after infestation (DAI) and to record their weights. Larval weights for 7 and 14 days after infestation were not taken owing to their small size. The number of larvae pupating and pupal weight was recorded for each DAI.

7.3 Data analysis

Data from the no choice tests and larval growth and development were subjected to analysis of variance (ANOVA) using PROC GLM in SAS (SAS, 2001) and where significant, means were separated by Tukey's studentized test. In the no choice tests, count data of egg batches and total eggs were log transformed (log + 1) before analyses. Due to lack of independence of treatments, non- parametric tests were used to test for the oviposition preferences between the test plants (treatments). The Wilcoxon test was used for the two choice tests and Friedman's test for multiple choice tests (Zar, 1999).

7.4 RESULTS

7.4.1 *BUSSEOLA FUSCA*

7.4.1.1 Oviposition response of *B. fusca*

All the test plants evaluated were acceptable for oviposition by *B. fusca* with the mean number of egg batches laid per pot ranging between 0.17 and 5.50 in a no choice situation (Table 7.1). The number of egg batches, egg batch size and total number of eggs were lowest on *P. maximum* and similar among the other grass species.

Table 7.1 Ovipositional response per *Busseola fusca* female moth to the different test plants in a no choice tests

Test plant	Number of egg batches/ pot	Egg batch size	Total number of eggs laid/ pot
Maize	3.83 ± 0.31 ab	52.3 ± 10.4 a	201.5 ± 36.8 a
Sorghum bicolor	3.67 ± 0.71 ab	48.8 ± 12.9 a	201.7 ± 60.7 a
Sorghum arundinaceum	2.33 ± 0.49 b	36.3 ± 10.4 a	71.2 ± 15.2 a
Pennisetum purpureum	5.50 ± 1.09 a	27.8 ± 2.1 a	152.2 ± 32.8 a
Panicum maximum	0.17 ± 0.17 c	15	2.5 ± 2.5 b
df	4, 25	3, 20	4, 25
F value	19.66	1.33	25.89
P value	0.0001	0.2931	0.0001

Means within columns followed by the same letter are not significantly different at P<0.05 by Tukey's Studentized Range test.

7.4.1.2 Oviposition preference of *B. fusca*

In the two choice tests, observations of the number of egg batches, egg batch size and total number of eggs showed that *S. bicolor* was preferred over maize and maize was preferred over *P. maximum* while *S. arundinaceum* and *P. purpureum* were equally attractive as maize (Table 7.2). In a multiple-choice situation, the number of egg batches and total eggs laid were significantly higher on *S. bicolor* than on *P. maximum* on which no eggs were recovered but differences among the other grass species were not significant. The egg batch size on maize and sorghum was similar and only one egg batch was recovered from *P. maximum*.

Table 7.2 Mean number (± SE) of eggs laid per *Busseola fusca* female moth on maize and different grasses in the two-choice tests for oviposition preference[1]

Combination of test plants	Number of egg batches per pot	Egg batch size	Total number of eggs laid per pot
Maize	1.00 ± 0.52	10.8 ± 8.8	30.3 ± 26.7
Sorghum bicolor	2.50 ± 0.43	37.9 ± 7.8	85.2 ± 17.8
χ^2	3.55	4.39	3.74
P-value	0.0595	0.0360	0.0530
Maize	1.00 ± 0.52	19.6 ± 10.4	32.2 ± 14.4
Sorghum arundinaceum	1.33 ± 0.42	23.3 ±11.8	46.3 ± 25.8
χ^2	0.44	0.17	0.54
P-value	0.5050	0.6836	0.4624
Maize	1.33 ± 0.49	25.2 ± 11.1	52.8 ± 26.3
Pennisetum purpureum	2.83 ± 1.10	29.6 ± 8.9	94.2 ± 35.3
χ^2	0.80	0.23	0.65
P-value	0.3700	0.6285	0.4201
Maize	2.00 ± 0.26	52.5 ± 15.4	118.7 ± 41.8
Panicum maximum	0.33 ± 0.33	7.8 ± 7.8	15.7 ± 15.7
χ^2	6.70	7.06	7.06
P-value	0.0096	0.0096	0.0079

[1] Chi-squares by Wilcoxon test $P \leq 0.05$

Table 7.3 Mean (± SE) number of egg batches, batch size and total eggs laid per *Busseola fusca* female on the selected host plants in a multiple-choice tests[1]

Test plant	Mean number of egg batches/ pot	Mean egg batch size	Mean number of eggs/ pot
Maize	0.75 ± 0.31 ab	39.8 ± 14.5 a	19.9 ± 10.1 ab
Sorghum bicolor	0.88 ± 0.35 a	64.8 ± 19.9 a	40.5 ± 16.8 a
Sorghum arundinaceum	0.25 ± 0.25 ab	47.0	11.8 ± 11.8 ab
Pennisetum purpureum	0.25 ± 0.25 ab	26.5	6.6 ± 6.6 ab
Panicum maximum	0.0 b	0	0.0 b
df	4, 35	1, 7	4, 35
F value	3.66	4.67	3.88
P value	0.0136	0.0676	0.0103

[1]Within columns, means followed by the same letter are not significantly different at P≤0.05, Tukey's Studentized Range test after Friedman's test.

7.4.1.3 Larval growth and development of *B. fusca*

B. fusca larvae were recovered from all the plants tested for larval growth (Figure 7.1). The test plants significantly influenced the number of larvae recovered at the different days after infestation (7DAI – 35DAI: df = 4, 25; 42DAI and 49DAI: df = 3, 20; 7DAI: F = 3.31, P = 0.0262; 14DAI: F = 15.42, P = 0.0001; 21DAI: F = 5.87, P = 0.0018; 28DAI: F = 3.59, P = 0.0191; 35DAI: F= 6.55, P = 0.0009; 42DAI: F = 7.13, P = 0.0019; 49DAI: F = 4.41, P = 0.0155). Maize and *S. bicolor* tended to have similar number of larvae recovered except at 14 days after infestation (DAI) when the number of larvae on *S. bicolor* was significantly higher (df = 4, 25; F = 24.26; P = 0.0001). The number of larvae recovered on maize was not significantly different from that on *S. arundinaceum*. Significantly fewer numbers of larvae were recovered from *P. maximum* and *P. purpureum* than from maize on most sampling dates (Figure 7.1).

Larval weights did not vary significantly on the different test plants over days after infestation (Table 7.4). Very few larvae were recovered from *P. purpureum* and *P. maximum*; they were not therefore included in the analysis. Larval development on *S. arundinaceum* did not go beyond 35 DAI due to infestation by aphids which destroyed by the plants. On maize and *S. bicolor* larvae developed to the pupal stage but not on *P. purpureum* and *P. maximum*. Per cent larvae that pupated on maize and *S. bicolor* and their pupal weights and did not vary significantly (Table 7.4).

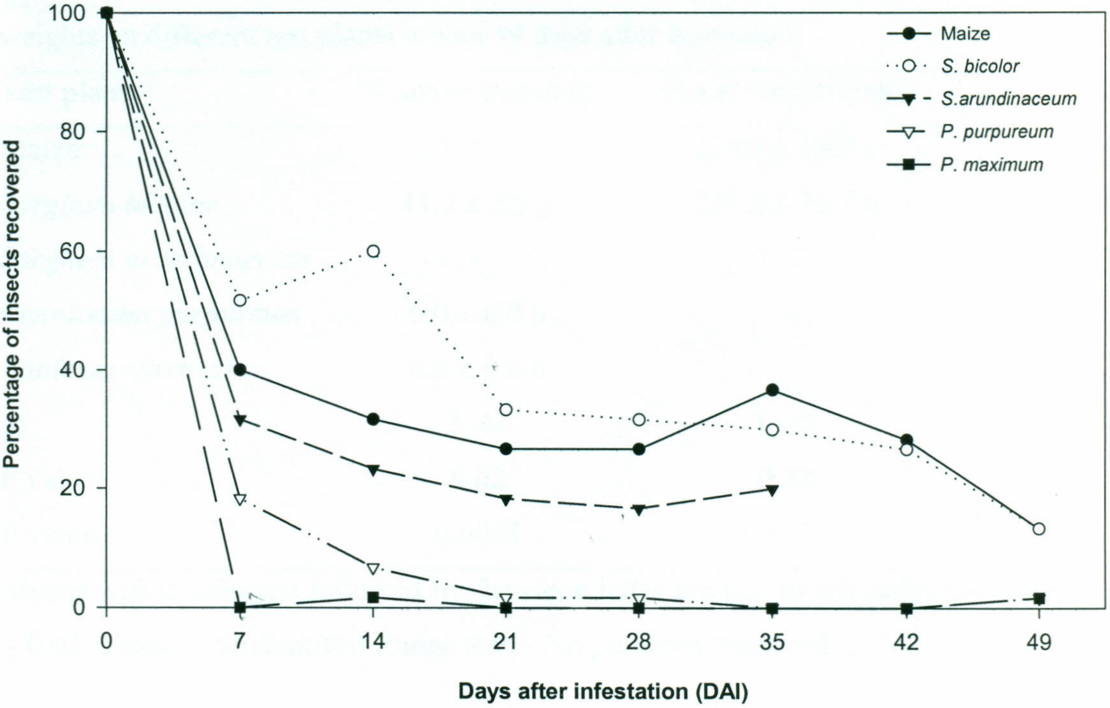

Figure 7.1 Percentage of *Busseola fusca* recovered on maize, *Sorghum bicolor* and three selected grasses over different time intervals after infestation

Table 7.4 Mean larval weights (± SE) of *Busseola fusca* larvae recovered on each test plant at the different days after infestation (DAI)[1]

Test plant/	Larval weight (mg)				
DAI	21	28	35	42	49
Maize	39.7 ± 6.3	89.7 ± 5.2	107.8 ± 15.2	222.3 ± 43.0	48.6
S. bicolor	37.5 ± 6.4	90.6 ± 8.1	116.1 ± 26.3	173.6 ± 26.3	211.8 ± 74.2
S. arundinaceum	35.2 ± 1.5	68.9 ± 2.1	88.5 ± 11.7	-	-
P. purpureum	8.0	-	10.3	146.7	40.7
P. maximum	-	-	-	-	124.0
df	2, 51	2, 40	2, 56	1, 11	-
F value	0.04	1.68	0.59	1.02	-
P value	0.9576	0.1990	0.5569	0.3337	-

[1] Means not significantly different at $P \leq 0.05$

Table 7.5 Percentage (± S.E) of *B. fusca* larvae successfully pupating and their pupal weights on different test plants within 49 days after infestation

Test plant	% larvae pupating	Pupal weight (mg)
Maize	15.8 ± 4.2 a	224.9 ± 19.7 a
Sorghum bicolor	11.7 ± 3.5 a	227.6 ± 18.7 a
Sorghum arundinaceum	-	-
Pennisetum purpureum	0.0 ± 0.0 b	-
Panicum maximum	0.0 ± 0.0 b	-
df	3, 44	1, 12
F value	9.02	0.33
P value	0.0001	0.5754

Means within columns followed by the same letter are not significantly different at $P \leq 0.05$, Tukey's Studentized Range test; - No pupation observed

7.4.2 *CHILO PARTELLUS*

7.4.2.1 Oviposition response of *C. partellus*

All the test plants were acceptable for oviposition by *C. partellus* in no-choice tests. No significant differences were observed among the test plants in the number of egg batches, batch size and eggs laid in a no-choice situation (Table 7.6).

7.4.2.2 Oviposition preference of *C. partellus*

In the two-choice tests, there were no significant differences between the number of eggs laid by *Chilo partellus* on maize and any of the tested host plants (Table 7.7). In the multiple-choice experiments, significantly higher numbers of egg batches and total eggs were laid on maize and sorghum than on *P. polystachion* and *P. maximum* (Table 7.8). The number of egg batches and total eggs recorded on maize, *S. bicolor, S. arundinaceum* and *P. purpureum* were significantly different from each other.

Table 7.6 Oviposition response per *Chilo partellus* female to the different test plants in a no choice tests

Test plant	Number of egg batches	Egg batch size	Total number of eggs laid
Maize	1.50 ± 0.62 a	20.1 ± 4.9 a	34.3 ± 16.6 a
Sorghum bicolor	2.17 ± 1.28 a	20.5 ± 0.8 a	43.7 ± 25.1 a
Sorghum arundinaceum	2.50 ± 1.09 a	13.3 ± 1.8 a	34.3 ± 15.8 a
Pennisetum purpureum	2.17 ± 1.08 a	16.3 ± 2.3 a	29.3 ± 11.4 a
Pennisetum polystachion	1.17 ± 0.47 a	21.4 ± 0.5 a	25.2 ± 10.5 a
Panicum maximum	1.00 ± 0.52 a	22.6 ± 4.0 a	24.8 ± 14.3 a
df	5, 30	5, 16	5, 30
F value	0.46	1.54	0.19
P value	0.7999	0.2318	0.9643

Means within columns followed by the same letter are not significantly different at P ≤ 0.05 by Tukey's Studentized Range test.

Table 7.7 Mean number of eggs batches and total eggs laid per *Chilo partellus* female moth on maize and on different grasses in the two-choice tests for oviposition preference[1]

Combination of test plants		Number of egg batches per pot	Total of eggs laid per pot
Maize		1.33 ± 0.49	25.33 ± 8.7
Sorghum bicolor		2.33 ± 1.05	52.7 ± 27.4
	χ^2	0.17	0.03
	P-value	0.6809	0.8705
Maize		1.00 ± 0.63	45.7 ± 32.5
Sorghum arundinaceum		0.83 ± 0.40	23.5 ± 11.8
	χ^2	0.01	0.01
	P-value	0.9312	0.9319
Maize		1.33 ± 0.42	34.5 ± 10.7
Pennisetum purpureum		2.17 ± 0.54	75.2 ± 19.1
	χ^2	1.53	2.84
	P-value	0.2164	0.0921
Maize		1.17 ± 0.48	37.3 ± 28.8
Pennisetum polystachion		0.50 ± 0.34	10.8 ± 9.9
	χ^2	1.26	1.05
	P-value	0.2617	0.3051
Maize		0.67 ± 0.49	20.8 ± 13.9
Panicum maximum		0.83 ± 0.48	27.5 ± 19.5
	χ^2	0.21	0.13
	P-value	0.6517	0.7210

[1] Chi-squares (χ^2) by Wilcoxon test $P \leq 0.05$

Table 7.8 Mean number of egg batches and eggs laid by *Chilo partellus* female moths on the selected host plants in a multiple-choice tests

Test plant	Mean number of egg batches/pot	Mean number of eggs/ pot
Maize	2.17 ± 0.31 a	56.3 ± 11.8 a
Sorghum	1.83 ± 0.48 a	56.3 ± 12.9 a
Sorghum arundinaceum	1.00 ± 0.36 ab	27.7 ± 10.7 ab
Pennisetum purpureum	1.33 ± 0.33 ab	34.5 ± 7.8 a
Pennisetum polystachion	0.50 ± 0.22 b	11.7 ± 5.3 b
Panicum maximum	0.33 ± 0.21 b	6.3 ± 4.1 b
df	5, 30	5, 30
F	5.96	6.33
$P \leq 0.05$	0.0006	0.0004

Means within columns followed by the same letter are not significantly different at $P \leq 0.05$, Tukey's Studentized Range test (comparison performed on ranks after Friedman's test).

7.4.2.3 Larval growth and development of *C. partellus*

Chilo partellus larvae were recovered from the entire six test plants however; *P. maximum P. purpureum* and *P. polystachion* had significantly lower percentage of larvae surviving compared to the other test plants at all sampling dates after infestation (df = 5, 30 in all cases; 7 DAI: F = 24.32, P = 0.0001; 14 DAI: F = 25.29, P = 0.0001; 21 DAI: F = 17.03, P = 0.0001; 28 DAI: F = 14.10, P = 0.0001; 35 DAI: F = 7.39, P = 0.0002; 42 DAI: F = 29.41, P = 0.0001; 49 DAI: F = 3.89, P = 0.0078) (Figure 7.2). A marked decline in the number of larvae surviving was observed within the first week after infestation on *P. purpureum, P. maximum* and *P. polystachion.* At 7, 21 and 42 days after infestation (DAI), *S. bicolor* had significantly higher number of larvae recovered compared to maize. No significant differences were observed in the number of insects recovered at 14, 28 and 49 DAI from maize, *S. bicolor* and *S. arundinaceum*.

Larval weight did not vary significantly across test plants over the different DAI except at 21 DAI when larval weight was lowest on *P. polystachion* (Table 7.9). Larvae on this host plant were not recovered beyond 21 DAI. *C. partellus* larvae were able to develop to the pupal stage on maize, *S. bicolor* and *S. arundinaceum.* No pupae were recovered on the wild grasses *P. polystachion*, *P. purpureum* and *P. maximum* (Table 7.10). Pupation started at 28 DAI and was the per cent number of larvae pupating on maize, *S. bicolor* and *S. arundinaceum* was similar. However, maize had significantly higher pupal weights than *S. bicolor* and *S. arundinaceum*. After 49 DAI, not all larvae had pupated on all the host plants indicating that the larval development exceeded 7 weeks even on suitable host plants. Significantly lower pupation (df = 74, F = 5.39, P = 0.0020) occurred at 28 DAI (47.6%) compared to 80.7%, 69.7% and 71.8% for 35, 42 and 49 DAI respectively.

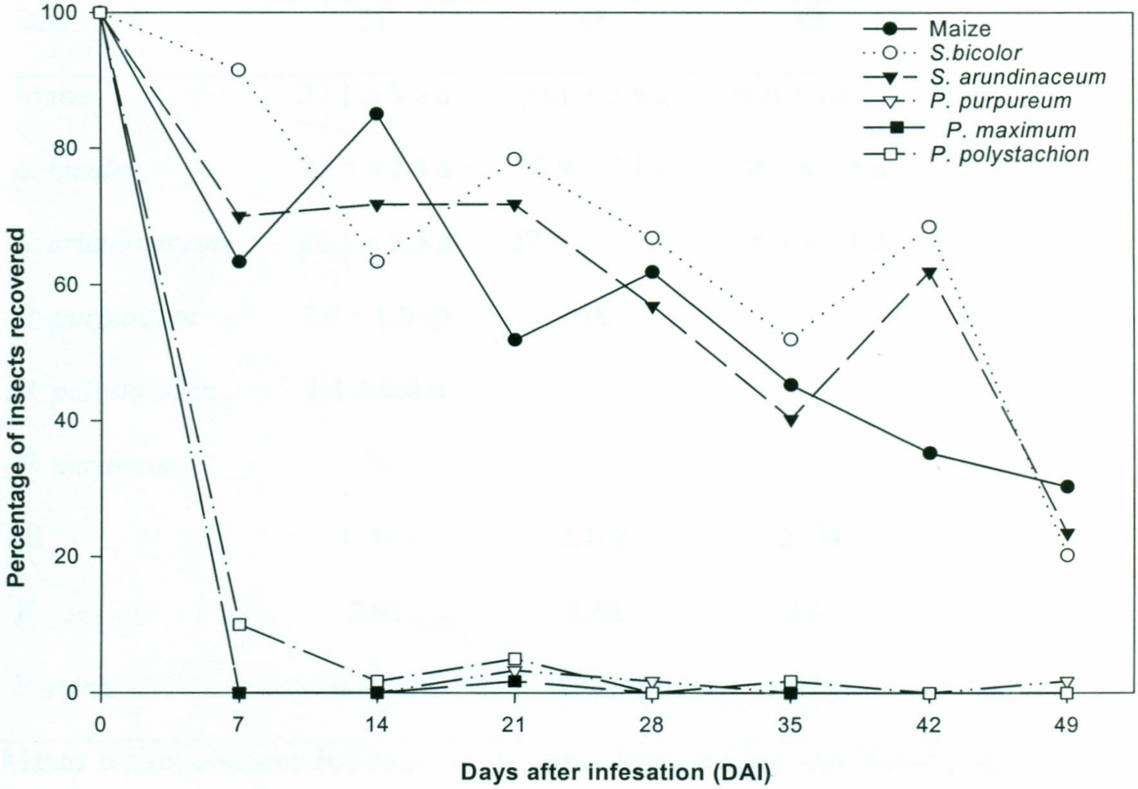

Figure 7.2 Percentage number of *Chilo partellus* recovered on maize, *S. bicolor* and four selected wild grasses over different time intervals after infestation

Table 7.9 Mean larval weights (± SE) of *Chilo partellus* larvae recovered on each test plant at the different days after infestation (DAI)

Test plant/	Larval weight (mg)			
DAI	21	28	42	49
Maize	27.1 ± 3.0 a	70.1 ± 5.6 a	76.6 ± 10.1 a	105.2 ± 17.4 a
S. bicolor	27.5 ± 2.4 a	75.9 ± 7.1 a	78.3 ± 7.8 a	97.0 ± 15.0 a
S. arundinaceum	28.1 ± 2.5 a	57.8 ± 11.5 a	78.5 ± 7.8 a	62.7 ± 13.4 a
P. purpureum	7.0 ± 1.0 ab	58	-	53
P. polystachion	1.1 ± 0.4 b	-	-	-
P. maximum	26	-	-	-
df	4, 109	2,108	2, 34	2, 11
F	2.91	2.68	0.01	2.10
P value	0.0250	0.0734	0.9864	0.1690

Means within columns followed by the same letter are not significantly different at P<0.05, Tukey's Studentized Range test; - no larvae recovered.

Table 7.10 Percentage (± S.E) of *C. partellus* larvae successfully pupating and their pupal weights on different test plants within 49 days after infestation

Test plant	% larvae pupating	Pupal weight (mg)
Maize	13.8 ± 3.1 a	87.92 ± 6.96 a
Sorghum bicolor	24.6 ± 4.9 a	69.11 ± 4.37 b
Sorghum arundinaceum	20.0 ± 4.9 a	55.85 ± 4.00 b
Pennisetum purpureum	0.0 ± 0.0 b	-
Panicum maximum	0.0 ± 0.0 b	-
Pennisetum polystachion	0.0 ± 0.0 b	-
df	4, 120	2, 74
F value	25.75	9.00
P value	0.0001	0.0003

Means within columns followed by the same letter are not significantly different at $P<0.05$, Tukey's Studentized Range test; - No pupae obtained.

7.5 DISCUSSION

Results from the no choice tests showed that all the plant species tested in the present study were acceptable for oviposition by *B. fusca* but *P. maximum* was less acceptable. And maize was preferred for oviposition to *P. maximum* in choice tests. *B. fusca* has been observed to selectively oviposit on plants with thick stems (van Rensburg *et al*., 1989; Randriamananoro, 1996) and also the firmness of the leaf sheath may influence oviposition (Randriamananoro, 1996). The two-choice test showed that *S. bicolor* is a preferred host to maize for oviposition as reflected in the egg batch size. *S. bicolor* is indigenous to Africa just like *B. fusca* while maize is an introduced species and therefore *S. bicolor* could be preferred possibly due to evolutionary factors.

Compared to the wild grasses tested, *B. fusca* did not show oviposition preference of these grasses to maize. In South Africa, van den Berg *et al.*, (in press) found no differences in the oviposition of *B. fusca* on maize and on several varieties of Napier grass in two choice situations. Randriamananoro (1996) however, found that under the two choice situations, susceptible maize varieties were preferred to *P. purpureum* for oviposition; and *S. arundinaceum* was preferred to maize but reported no differences under multiple choice situations. The differences in preferences could be attributed to the differences in insect populations and the use of more than one gravid female per test (Thompson and Pellmyr, 1991). The number of generations through which insects have been reared may also lead to differences in acceptance and preference. Wild insects are likely to behave differently from the laboratory reared insects and in the present study, the *B. fusca* used was in the sixth generation and one female was used at a time.

Wild grasses such as *P. purpureum* and *P. maximum* which did not support larval development to pupation were acceptable for oviposition perhaps also because *B. fusca* larvae are capable of dispersing from one plant to another in search for suitable hosts (van Rensburg *et al.*, 1987). Field studies have also shown that *P. purpureum* and *P. maximum* were not major host plants of *B. fusca* in Uganda (part of this thesis). The absence of differences in weights of larvae recovered from *P. purpureum* and *P. maximum* compared to those on maize and sorghum may indicate that larval establishment on these two grasses was the limiting factor and not the nutrition. On *P. purpureum*, van den Berg *et al.* (in press) attributed *B. fusca* larval migration away from the plants to the hairiness of the grass. Gummy substances that are produced by *P. purpureum* when larvae feed on the stem have been reported to arrest larval movement resulting into death. In this study, *P. maximum* was also observed to produce a sticky substance which limited larval feeding and movement.

C. partellus did not show oviposition preference to any of the host plants in the two-choice situation, but in the multiple-choice experiment, *P. polystachion* and *P. maximum* the were less preferred hosts. In contrast, other workers (van den Berg *et al.,* 2001; van den Berg, 2006; Mohammed *et al.*, 2004) working found that *C. partellus* preferred *P. purpureum* for oviposition over maize. In the present study, it was common for *C. partellus* to oviposit eggs on the glass doors and walls of the cages. Mohammed *et al.* (2004) however, did not find differences between maize and *P. purpureum* the multiple-choice tests. In the field, *C. partellus* has been reported to oviposit on non-hosts plants like cowpeas and cassava when they were intercropped with *Sorghum bicolor* (Ampong-Nyarko *et al.*, 1994a). One of the reasons for oviposition on non hosts is the ability of larvae to migrate (Roome *et al.*, 1977; Thompson and Pellmyr, 1991; Bernays and Chapman, 1994). Päts (1992) found that on maize and sorghum, *C. partellus* chose smooth lower sites with a crease for oviposition which may protect the eggs from desiccation and dislodgement. It was suggested that the choice of oviposition sites depended on egg survival rather than larval survival. Young larvae of *C. partellus* are able to disperse to other plants for a distance of 30-70 cm and only about 20% of larvae were reported to remain on the plant of oviposition and 25% dispersed to other plants successfully (Päts and Ekbom, 1992). The larvae disperse by ballooning on silky threads (Berger, 1989). It appears therefore, that *C. partellus* may not be selective of hosts for oviposition.

Larval growth and development of *C. partellus* was highest on the cultivated cereals maize and *S. bicolor*; and on *S. arundinaceum*. Only a few larvae were recovered from *P. purpureum, P. polystachion* and *P. maximum*. Similar screen house studies in West Africa showed that although grasses such as *P. purpureum, P. polystachion, P. maximum* and *S. arundinaceum* were preferred for oviposition to maize by *Sesamia calamistis* (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae), they did not support borer development to adulthood except for *S. arundinaceum* (Shanower *et al.*, 1993; Schulthess *et al.*, 1997). van den Berg (2006) also found very high mortality of *C. partellus* on several varieties of *P. purpureum* in South Africa. In the present study, the number of borers that pupated on *S. arundinaceum* and their pupal masses were not different from that on maize and *S. bicolor*. This indicates that, of the grasses tested, *S. arundinaceum* is a suitable host for the development of *C. partellus* and hence may act as a reservoir during the off-season. The results also concur with those of the field surveys (part of this thesis) where this grass was found to have the highest infestations and borer density of *C. partellus*. In contrast, Ofomata *et al.* (2000) recorded very low larval survival to the pupation of *C. partellus* (0-5.6%) reared on cut pieces of *S. arundinaceum* at different temperature regimes compared to 20% pupating in the present study. Perhaps the high mortality they observed was due to handling during the stem replenishment.

The other grass species in this study caused high mortality with less than 3% of the larvae surviving and no pupation was observed by 49 days. Rebe *et al.* (2004) similarly recorded no pupation of *C. partellus* reared on *P. purpureum*. This grass has been reported to be a trap plant for *C. partellus* where by it produces gummy substances that arrest larval survival (Khan *et al.*, 2000; 2001). *P. maximum* was also observed in this study to produce sticky substances that interfered with larval feeding and the few medium sized larvae recovered were mainly in the leaf sheath. Plant waxes are also said to affect larval movement (Saxena, 1985; Bernays and Chapman, 1994) and were usually observed on *P. maximum* and may have affected larval establishment. Other than the plant physical characteristics, larval growth is also affected by the lack of nutrients or presence of toxins or deterrents which influence food intake and its digestion (Soo Hoo and Frankel, 1966). High silica content in plants has been reported to limit stemborer larval feeding (McNaughton *et al.*1985; Sétamou *et al.*, 1993).

The poor growth and development of *C. partellus* and *B. fusca* on the wild grasses viz *P. purpureum, P. polystachion* and *P. maximum* would render them good trap plants, however, they were found not to be preferred to maize for oviposition. One of the major characteristic for a trap plant is that it should be highly preferred for oviposition compared to the crop being protected (Hokkanen, 1991).

CHAPTER EIGHT

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

8.1 GENERAL DISCUSSION

Busseola fusca Fuller (Noctuidae) and *Chilo partellus* Swinhoe (Crambidae) were the most important stemborers in all the Agroecological zones (AEZs) surveyed. *C. partellus* was the predominant species in the Eastern AEZ while *B. fusca* was dominant in the other three AEZs. The prevalence of *C. partellus* in the Eastern AEZ may be attributed to differences in the temperature where by *C. partellus* tolerates higher temperature compared to *B. fusca* (Ingram, 1958; Nye, 1960). However, stemborer densities were moderate in all AEZs.

Among the parasitoids collected, the most common were the egg parasitoid *Telenomus busseolae* Gahan (Scelionidae) parasitizing *B. fusca* eggs which contributed up to 46% egg parasitism. *Cotesia sesamiae* and *Cotesia flavipes* Cameron (Braconidae) were the major larval parasitoids recovered through out the study. The larval parasitoids accounted for up to 30% parasitism with higher parasitism rate occurring on their respective co-evolved hosts. *C. flavipes* was recovered in all the districts. However, the rates of parasitism did not seem to have increased from the rates reported earlier when the parasitoid became established (Matama-Kauma *et al.*, 2001; Rwomushana *et al.*, 2005). In this study, surveys covered a much wider geographical area than the release sites and hence the results may not be comparable to those of Matama-Kauma *et al.* (2001) and Rwomushana *et al.* (2005) due to the colonising effect which has a counteracting effect on population build up (Overholt *et al.*, 1997). The parasitoid populations were much lower in the first rains compared to the second rains an indication of the influence of the non cropping dry season that precedes the first rains. Paucity of hosts during the dry season may explain the low parasitism rates in the first cropping season in the cultivated cereals. Natural enemies have to re-colonise the habitat compared to where there is continuous presence of wild hosts which harbour stemborers year round (Conlong, 1994; Ndemah *et al.*, 2003). It is also speculated that parasitism is likely to be higher in perennial grass habitats than in the cultivated cereals (Hall and Ehler, 1979; Smith, *et al.*, 1993; Conlong, 1994; Zhou *et al.*, 2003).

Results obtained in this study showed that stemborer densities were low on wild grasses compared to the cultivated cereals and this corroborated earlier work in West Africa (Schulthess *et al.*, 1997; Gounou and Schulthess, 1994). A wide range of stemborer species was were? found on the selected grasses including the stemborers that damage maize and sorghum. However, only *Sorghum arundinaceum* was the major host for *B. fusca* and *C. partellus*. *Panicum maximum*, *Pennisetum purpureum* and *Pennisetum polystachion* were minor hosts of these two stemborer species but principal hosts of other stemborers which are not cereal pests. Large numbers of *B. fusca* and *C. partellus* were reported on these wild grasses previously and LeRu *et al.* (2006) attributed it to misidentification.

Earlier work indicated that wild grasses served as reservoir for stemborers that attack crops (Ingram, 1958; Bowden, 1976). However, Schulthess *et al.* (1997) reported that wild host plants in the vicinity of cultivated maize crop resulted in a reduced stemborer attack on the maize crop. Similarly, in the management of stemborers, grass borders have been reported to reduce stemborer attack on maize and increase natural enemy efficiency (Khan *et al.*, 1997a, 1997b, 2001; Ndemah *et al.*, 2002). The results have sometimes been variable. In the present study, stemborer infestation tended to be low in the maize surrounded by grass borders but the results were not consistent. The present work shows that the effect of wild habitat cannot be generalised but it must be serving to stabilise the ecosystem as it shields the cereals from stemborers that specialize on grasses. The grasses studied were important as reservoirs for parasitoids and a wider parasitoid guild was found compared to the maize crop (Chapter 4).

Schulthess *et al.* (1997) speculated that the reduced stemborer infestation in the presence of wild grasses could be due to: (a) increased natural enemy activity which prevents stemborers from reaching damaging levels on maize, (b) act as trap plants, or (c) both. The cutting back of grass borders at the beginning of the season to make them attractive for oviposition, does not serve to stabilise the ecosystem as the natural enemy fauna is destroyed in the process. Therefore, grass borders can at this point only act as trap plants. However, in the oviposition tests, none of the grasses tested was preferred for oviposition by either *C. partellus* or *B. fusca* over maize. A good trap plant must be highly preferred for oviposition to the crop being protected (Hokkanen, 1991) in order to divert adult moths. It therefore appears that the other mechanism for the reduced stemborer infestation in maize with grass borders could be that the grasses form a barrier to ovipositing moths (Hokkanen, 1991). Larval development was only successful on *S. arundinaceum* supporting the field results where most of the *C. partellus* and *B. fusca* were recovered on this grass. Thus *S. arundinaceum* forms a major reservoir for these two stemborers among the grasses tested as also shown in Chapter 5.

8.2 CONCLUSIONS

In conclusion, the studies which were carried out have shown that wild grasses are important in agricultural ecosystems as they serve both as reservoir for both stemborers and their natural enemies. They also shield cereals from stemborers specialized on these grasses and their elimination may lead to more stemborers becoming pests on cereals. The use of grass borders to control stemborers is questionable since stemborers did not prefer the grasses to maize for oviposition and may not be cost effective for farmers. Having wild host plants left intact in the farm surroundings might have more stabilizing effect on pest densities and parasitoids than planting the borders. There is also need to understand better the mechanisms for reduced pest densities when grasses are growing in the vicinity of cereal crops. The role of the grasses in maintaining parasitoids need to be further investigated and perhaps grasses that enhance parasitism with out necessarily increasing pest infestation identified.

8.3 RECOMMENDATIONS

Based on the results obtained from the studies conducted, the following can be recommended;

i) To use cohort studies with more frequent sampling regimes in order to fully document egg parasitoids of stemborers in Uganda and the release of *Telenomous isis* Polaszek (Hymenoptera: Scelionidae) to compliment *T. busseolae*.

ii) Evaluate the impact of *C. flavipes* on stemborers in Uganda.

iii) Evaluate the importance of other wild host plants which are common in the maize growing areas including the sedges and Typhaceae (the major hosts of *S. calamistis* and *E. saccharina*) in order to understand their role in regulating these stemborer species.

iv) Carry out intensive studies with proper taxonomy of the parasitized larvae and pupae on the different wild host plants and the prevalence of the parasitoids through out the year. It would be important to evaluate the effect of *S. arundinaceum* (one of the major wild host plants) when left intact on stemborer infestation and their parasitoids.

v) Studies on the oviposition preference of wild *B. fusca* (freshly collected from the field) on the different wild grasses. This is under way at ICIPE by the IRD.

vi) Evaluate the effect of maintaining natural wild host habitats in the surrounding of cereal crops on stemborer attack and parasitoid efficiency other than planting grassy borders.

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