SUITABILITY OF SELECTED DROUGHT TOLERANT GRASS SPECIES AS TRAP PLANTS FOR *CHILO PARTELLUS* (SWINHOE) IN KISUMU COUNTY, KENYA

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DECLARATIONS

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

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DEDICATION

This thesis is dedicated to my wife Gladys, my children Onesmus, Alice and my parents Hudson and Alice who were a great source of inspiration.

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ABBREVIATIONS AND ACRONYMS

BIIPM	Biologically Intensive Integrated Pest Management
IARCs	International Agricultural Research Centres
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
ICIPE	International Centre for Insect Physiology and Ecology
NARES	National Agriculture Research and Extension Systems
ANOVA	Analysis Of Variance
KALRO	Kenya Agriculture Livestock Research Organization
IPM	Integrated Pest Management
HPR	Host Plant Resistance
M.a.s.l	Metres above sea level

ABSTRACT

The stem borer, *Chilo partellus* Swinhoe (Lepidoptera: Pyralidae) is a pest that attacks plants in the poacea family in tropical lowland areas of Africa. Yield losses in maize are caused by the borer feeding on plant stems, leaves, grains and tussles. It is difficult to control *C. partellus* since larvae hide in stems. Spraying with insecticides only kills eggs and adults. Other methods used to control *C. partellus* include biological, physical, geneticaland cultural methods. Trap plants are used to control *C. partellus* and they fall under cultural practices. Trap plants are crops grown to attract pests to feed or oviposit on them hence protect target crops from pest attack. Trap plants are eco-friendly and locally available. The purpose of this study was to seek for an alternative control measure by use of trap plants to manage *C. partellus.* The grasses that were selected from 42 grass species at Kenya Agriculture Livestock Research Organization– Kisii for this study included *Pennisetum sphacelatum, P. mezianum, Hypperhania tamba, Hyparrhenia cymbaria, Panicum maximum, Sporobolus pyramidalis, S. consimilis, Chloris gayana, Bracharia brizantha* and *Bracharia mulato II.* These grasses were selected because they can withstand drought. The field experiments were conducted at Nyakach Sub-County in Western Kenya. The grasses were planted in plots measuring 2 m x 2 m with spacing of 30cm by 70cm in a randomized complete block design and there were three replicates. Greenhouse experiments were conducted at KALRO – Kisii. Each grass was transplanted into ten plastic pots measuring 30cm diameter and 60cm depth. The pots were arranged in rows with three replicates. *Sorghum sudanensis* was used as a control trap plant for *C. partellus.* Ten *C. partellus* larvae were introduced onto potted plants two weeks after transplanting. Data on the number of larvae, entry and exit holes, “leaf window”, eggs and tunnel lengths were collected from five grass stems from field and greenhouse experiments one month after planting and transplanting respectvely. The grasses were selected using simple random sampling method. Subsequent data collection was done after every two weeks for 4 months. The data obtained was subjected to ANOVA and analysed using Statistical Analysis System 2010. The means that were significant were separated using the Student-Newman-Keuls test at a significance level of p = 0.05.The results of this study showed that there were significant differences in the mean number of egg batches and eggs in both field and greenhouse experiments. In the field experiments, *Sorghum sudanensis* and *Pennisetum sphacelatum* had the highest mean number of egg batches which significantly differed from those of *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha*, *Bracharia mulato II, Chloris gayana, Pennisetum mezianum, Hyparrhenia cymbaria* and *Panicum maximum*. *Sorghum sudanensis* and *Pennisetum sphacelatum* had the highest mean number of entry holes. *Chloris gayana* had lower mean number of entry holes but this did not significantly differ from those of *Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum* and *Bracharia brizantha. Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum* least attracted *C. partellus* for feeding in both experiments.

CHAPTER ONE

INTRODUCTION

1.1 Background

Stem borers are polyphagous pests and feed on both cultivated and non-cultivated plants belonging to the grass family, Poaceae (Moolman *et al*., 2014, Sylvain *et al*., 2015). Stem borer eggs hatch into larvae which crawl on the plant and congregate in the funnel and feed on the rolled leaves for few days before penetrating into the stem (Mushore, 2005). As the leaves grow out of the funnel, a characteristic pattern of holes and "window panes" can be seen. Larval feeding remove leaf tissue leaving transparent upper cuticle referred to as window panning (CAB International 2006). The leaf damage reduces the photosynthetic area resulting in low crop yield. Further, stem borers causeextensive tunnelling that weakens the plant thus causing breakage (Tefera, 2004). Tunnelled plants are likely to yield lowly and make harvesting more difficult (Hicks, 2004). Yield losses as high as 40% could result from tunnelling (Ransom, 2005). Further, damage to the stems can lead to infection by *Fusarium* stalk rot (Mushore, 2005).

There are five stem borer species found in the Kenyan maize growing areas. They include; spotted stem borer (*Chilo partellus*, Lepidoptera: Pyralidae), the African stem borer, *Busseola fusca* Fuller (Lepidoptera: Noctuidae) (De Groote *et al*., 2003), coastal stem borer, *Chilo orichalcocillielus* Strand (Lepidoptera: Crambidae), pink stem borer, *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and sugarcane borer, *Eldana* *saccharina* Walker (Lepidoptera: Pyralidae) (Kfri *et al*., 2002). *Chilo partellus* and *B. fusca* are the most injurious causing maize yield losses not only in Kenya but also in many African countries (Sylvain *et al*., 2015). Their distribution, relative abundance and pest status vary with environmental conditions (Dejen *et al*., 2014). *Sesamia calamistis* is a native stem borer species that occurs in low densities in all areas in Kenya up to 2400m above sea level (Muhammad and Underwood, 2004). *Chilo partellus* is the dominant and most important species in the lowland and mid-altitude areas in East Africa (Setamou *et al*., 2005).

Several measures are currently used to control and manage stem borers. They include chemical control, host plant resistance, biological control and cultural control methods (Hassanali *et al*., 2008). 'Push–pull' strategy is a cultural method of managing stem borers. It is a cropping system in which specifically chosen companion plants like desmodium are grown in between and around the main crop. The companion plants release semiochemicals that repel insect pests from the main crop ('push') and attract insect pests away from the main crop ('pull') (Cook *et al*., 2007). None of these methods would be effective on their own and are normally used together in an integrated pest management (IPM) system (Kfir *et al*., 2002). Another cultural control method is the use of trap plants. Trap plants are crop strands grown to attract insects or other organisms like nematodes to protect target crops from pest attack (Badenes-Prerez *et al*., 2004). Trap cropping as a pest management tool has received a lot of attention from farmers (Glass *et al*., 2007). In Kenya, some of the gramineous species that are hosts to *Chilo partellus, Busseola fusca* and *Sesamia calamistis* have been tested for their potential to control stem borers (Boucher *et al*., 2003). These species include *Setaria spp. Sorghum* and *Andropogon spp*. (Moolman *et al*., 2014), napier grass (*Pennisetum purpureum),* Sudan grass (*Sorghum vulgare sudanense*), Jaragua grass (*Hyparrhenia rufa)*, Guinea grass (*Megathyrsus maximus*), itch grass (*Rottboellia cochinchinensis*), Johnson grass (*Sorghum halepense*) and Vetiver grass (*Vetiveria zizanioides*). Stem borers are attracted to these trap grasses for either egg laying, feeding or refuge sites. The proposed study will focus on the potential of the drought tolerant grass plantsto control *C. partellus* in the greenhouse at KALRO-Kisii and at Nyakach, in Western Kenya for field experiment.

1.2 Problem statement

Globally, cereal farmers face a big challenge from stem borer attack. Borer damage cause significant yield loss on cereal crops (Afzal *et al*., 2009). In Sub Saharan Africa, stem borers cause 20-40% losses during cultivation and 30-90% during post-harvest and storage (Nyukuri *et al.*, 2014). All stem borer species are reported to have caused average annual losses of 13.5% valued at US$80 million with that of *C. partellus*estimated at US$ 23 million per year (De Groote *et al*., 2003).In Africa, lepidopteran stem borer, *B. fusca* and *C. partellus* are by far the most injurious causing maize yield losses in many African countries (Sylvain *et al*., 2015). Although there are several control methods used by farmers to control stem borers, the control of *C. partellus* has been a challenge among smallholder farmers (Mutyambai *et al*., 2014).

Several control methods and measures have been in use for the management of *C. partellus* but with little success. Use of chemicals has been found ineffective due to cryptic feeding of the larvae (Khan *et al*., 2001). Chemicals are also expensive hence unavailable to smallholder farmers (Bonholf *et al*., 2001). Biological control agents have been in use to manage stem borers. However, the agents are expensive to mass rear and make them available to smallholder farmers. Use of trap plants therefore, could help to manage and control stem borers because they are locally available hence cheap to obtain, eco-friendly to the environment, can be used as fodder and can control soil erosion. For this purpose ten grass species were selected from 42 drought tolerant grasses at KALRO-Kisii for investigation on the ability to attract *Chilo partellus* for oviposition and feeding. The grasses were selected on the basis of their life span and those with a life span of at least six months were selected, ability to withstand drought, narrow leafed and ability to provide fodder in dry periods. Narrow leafed grasses were considered since broad leafed grasses habours a lot of water that could interfere with the feeding of the *C. partellus* larvae.

1.3 Justification of the study

Biological control is the use of parasitoids, predators, nematodes or pathogens to maintain density of a species at a lower level than would occur in their absence (Mushore, 2005). However, it is expensive to mass rear and make biological control agents available to smallholder farmers. Cultural methods and practices used to control stem borers include appropriate crop residue disposal, planting date manipulation, host resistance, use of trap plants, tillage practices, crop rotation and intercropping (Chinwada

2002). Host plant resistance (HPR) is a practical way to overcome the stem borer constraint in maize production (Afzal *et al*., 2009). However, the host resistance plants are expensive to be obtained by smallholder farmers. These control measures do not guarantee 100% control, but help to reduce infestation and enable sustainable maize production (Iowa State University, 2012).

Despite the use of the above discussed methods to controlstem borers, farmers have continually faced a great loss of their produce due to pest attack. It was therefore important to explore other methods that could compliment the ones that are in use in an integrated pest management strategy. One such alternative method is the use of drought tolerant trap plants. Little work has been done on the use of drought tolerant trap plants such as Vetiver (*Vetiveria zizanioides)* on the management and control of stem borer, *C. partellus.* This research, therefore, aimed at investigating which of the 10 drought tolerant grass species found in KALRO-Kisii- station, have the potential to be used in the control of *C. partellus.*

1.4 Research questions

i. What is the suitability of selected grass species in attracting adult *C. partellus* for oviposition in the field and greenhouse?
ii. What is the suitability of selected grass species in attracting *C. partellus* larvae for feeding in the field and greenhouse?

1.5 Hypotheses

1. There is no difference in the suitability of selected grass species in attracting adult *C. partellus* for oviposition in the field and greenhouse.
2. There is no difference in the suitability of selected grass species in attracting *C. partellus* larvae for feeding in the field and greenhouse.

1.6 Objectives of the study

1.6.1 General objective

To determine the suitability of selected drought tolerant grass species astrap plants for *C. partellus* in Kisumu County.

1.6.2 Specific objectives

1. To determine the suitability of selected drought tolerant grass species to attract adult *C. partellus* for oviposition in Nyakach, Kisumu County and in the greenhouse at KALRO-Kisii.
2. To determine the suitability of selected drought tolerant grass species to attract *C. partellus* larvae for feeding in Nyakach, Kisumu County and in the greenhouse at KALRO-Kisii.

1.7 Significance of the study

In sub-Saharan Africa, maize is a staple food crop for about 50% of the population (Ogunniyi, 2011). Its production is hampered by the larvae of the lepidopterous stem borers, B. *fusca* and *C. partellus* (Dejen *et al*., 2014). Borer damage has been reported to affect plant growth and specifically ear development and this impact negatively on grain yield (Afzal *et al*., 2009). In Sub Saharan Africa, stem borers cause losses of between 20-40% during cultivation and 30-90% during harvest and post-harvest period (Nyukuri *et al.,* 2014).

Grain damage by *C. partellus* predisposes maize to pre-and post-harvest infections by storage beetles, infections by *Aspergillus flavus* and *Fusarium verticillioides* (Ndemah and Schulthess, 2002). Use of trap plants has been reported to control stem borers by 52% (Picket *et al*., 2008). Trap plants combines effectiveness with minimal extra labour and cost (Mushore, 2005). Findings from this study would help to reduce *C. partellus* infestations. This will enable sustainable production of cereal crops especially to smallholder farmers who cannot afford chemical pesticides and biological control agents in controlling *C. partellus*.

CHAPTER TWO

LITERATURE REVIEW

2.1 Distribution of *Chilo partellus*

Spotted stem borer, *C. partellus,* originated from India-Pakistan region (CAB International 2007). It is widely distributed in eastern and southern Africa. *Chilo partellus* is found in most eastern andsouthern sub-saharan countries. Its distribution has widened and now it includes countries like Botswana, Cameroon, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Somalia, Sudan, South Africa, Lesotho, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe and Madagascar (CAB International 2007). It is essentially a lowland area pest, seldom found above an altitude of 1500 m.a.s.l (Gupta *et al.,* 2010). Evidence over a period of 30 years indicates that *C. partellus* is gradually replacing the indigenous stem borer, *Chilo orichalcociliellus*, Strand (Lepidoptera: Crambidae) in some regions in Kenya (Ofomata *et al*., 2003). For example, in coastal Kenya, *C. partellus* displaced the indigenous coastal stem borer. Similar observation has been done elsewhere, for example in the eastern region of South Africa; *C. partellus* partially displaced *B. fusca* over a period of seven years (Dejen *et al*., 2014). The first reason for the replacement of the indigenous species is that, hibernating larval populations of *C. partellus* terminate diapause and emerge a month earlier than *B. fusca.* Secondly, the life cycle of *C. partellus* is three weeks shorter than that of *B. fusca,* which gives it a further competitive advantage because of its higher population growth rate (Dejen *et al*., 2014).

2.2 Life cycle of *Chilo partellus*

The stem borer *C. partellus* is the larva of a moth. Adult moths lay eggs on the under or upper sides of maize leaves, often near midribs, but some are laid a long the leaf sheath. After 7-10days, eggs hatch into first instar larvae. The larval period lasts between 28-38 days depending on temperature (Muhammad and Underwood, 2004) and there are 6-8 larval instars. First, second and third instar larvae move to the whorls of the plants where they feed on succulent young tissues while the older larvae bore into the stem where they remain until they pupate (Sylavain *et al*., 2015). The mature larvae form pupal chambers in the tunnels and chew an exit hole through the stem, leaving a thin layer of epidermal tissue for the exit of the adult moth. The pupal period lasts between 7-10 days depending on temperature (Muhammad and Underwood, 2004). Although stem borers oviposit heavily on some grasses, only few species are favourable for them to complete their life cycles (Chabi – Olaye *et al*., 2006).

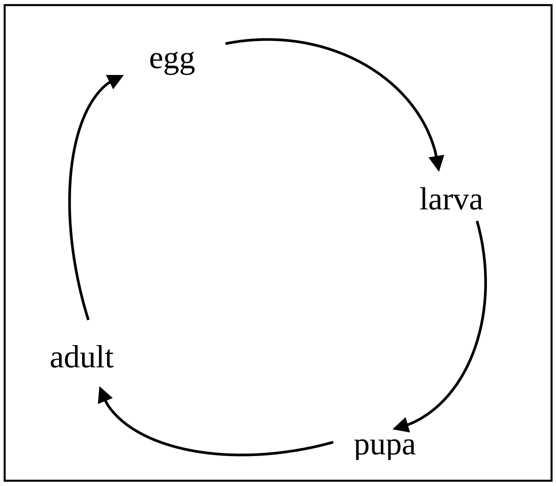

Figure 2.1: Life cycle of *Chilo partellus*

2.3 Damage and losses due to attack by *Chilo partellus*

Chilo partellus is one of the most destructive pests of cereal crops at altitudes below 1500 metres above sea level (Gupta *et al*., 2010; Sylvain *et al*., 2015). Newly hatched larvae of *C. partellus* feed by initially scrapping the leaf whorls of young plants producing characteristic “pinholes” (CAB International 2006). The lesions formed by the scrapping of the epidermis and parenchyma on one side of the leaf are seen as small holes or “windows” on the leaves once the leaf whorls unfold. Foliar damage caused by the first and second instars larvae result in the reduction of total leaf area and a depression in the photosynthetic capacity of the plant. Older larvae make holes and tunnels in stems where they feed for 3 to 5 weeks causing extensive tunnels (Sylvain *et al*., 2015). Yield losses of 12% for every 10% plants infested were reported in Tanzania and Kenya (Klopper, 2008). In South Africa, yield losses in maize and sorghum have exceeded 50% (CIMMYT, 2011).

The feeding habit of *C. partellus* reduces the flow of water and nutrients throughout the plant and can reduce grain weight and kernel number therefore reducing yields (Iowa State University, 2012). The first and second instar larvae of *C. partellus* cause foliar damage, that result in great yield losses particularly if the attack occurs at an early plant growth stage and in high densities. This is because of the tenderness of leaves and stems making the plants suitable for newly hatched larvae (Sylvain *et al*., 2015). The first instar larvae cause more yield loss than the second because they are immobile and feed continuously as they grow into the second instar (Muasya and Diallo, 2006).

Maize and sorghum are the most vulnerable to *C. partellus* causing severe losses to these crops (Arabjafari and Jalali, 2007). Damage by *C. partellus* on maize is due to leaf feeding and subsequent development of “dead hearts” and tunneling within the stalk resulting in disruption of the flow of nutrients to the plant (Tefera, 2004). Older larvae of *C. partellus* make holes and tunnels in stems where they feed for 3 to 5 weeks causing extensive tunnels (Sylvain *et al*., 2015). Stem tunneling has a direct effect on loss in maize grain yield than the effect of leaf feeding (Singh *et al*., 2011).

2.4 Management of *Chilo partellus*

Management of stem borers needs integrated pest management strategies that are environmentally safe, economically feasible and acceptable to smallholder farmers (Pickett *et al*., 2008). Several control measures are currently used and each comes with its own challenges and limitations (Tadele *et al.*, 2010). These methods include cultural, chemical and biological, genetic and physical methods.

2.4.1 Cultural control

Cultural control are practices that make the environment less attractive to pests and less favourable for their survival, dispersal, growth and reproduction and that promote the pest's natural controls(Mushore, 2005). These measures do not guarantee 100% control, but help to reduce infestation and enable sustainable maize production (Iowa State University, 2012). Cultural control is useful because it combines effectiveness with minimal extra labour and cost (Mushore, 2005). Several cultural practices have been implicated in maize and sorghum stem borer control mainly in disrupting or slowing down the population build-up (Khan *et al*., 2000). These cultural practices have little adverse effects on the environment and are the most relevant and economic practices of stem borer control available for smallholder farmers in Africa (Kfir *et al*., 2002). These practices include appropriate crop residue disposal, planting date manipulation, host resistance, destruction of volunteer and alternative host plants, tillage practices, crop rotation and use of trap plants (Sylvain *et al*., 2015).

2.4.1.1 Planting date manipulation

Cultural control of stem borers based on time of planting follows the principles of growing the target crop when the pest is least abundant. Later sowing of maize is less affected by stem borer larvae than earlier sowing as it disrupts their seasonal cycle (Iowa State University, 2012). It is thought that, at the start of the rainy season, borer populations arising from diapausing generation larvae will still be building up, so fewer moths will oviposit on early planted crops (Chinwada *et al*., 2001). In Ethiopia, the infestation of late-sown maize, attacked by the second generation of *B. fusca* was higher (22-100%) than early-sown maize attacked by the first generation (0-22%) (Ebenebe *et al*., 2013).

2.4.1.2 Host plant resistance

Host plant resistance is the ability of the plant to have heritable plant qualities that make the plant to be relatively less damaged than a plant without those qualities. Insect-resistant crop varieties suppress insect pest abundance. The relationship between the insect and plant depends on the kind of resistance, for example, antibiosis, antixenosis or tolerance (Maddonni *et al*., 2006). Antibiosis refers to the ability of the host plant to affect the biology of the insect so that pest abundance and subsequent damage is reduced compared to that which would have occurred if the insect fed on a susceptible crop variety (Maddonni *et al*., 2006). Tolerance is a type of resistance where a plant is able to recover from damage caused by insect pest while avoidance is when host plants escape pest attack by either maturing earlier hence by pass susceptible phenological stages more rapidly (Setamou *et al*., 2005). Leaf toughness also contributes to defence mechanism in plants against stem borers (Afzal *et al*., 2009).

2.4.1.3 Use of trap plants

Trap crops are plant strands grown to attract insects or other organisms like nematodes to protect target crops from pest attack (Glass *et al.*, 2007). They prevent the pests from reaching the crop or concentrating them in a certain part of the field where they can be economically destroyed (Badenes-Prerez *et al*., 2004). Trap cropping as a pest management tool has received a lot of attention from farmers (Glass *et al.*, 2007). It involves habitat manipulation of an agro- ecosystem for the purpose of pest management. Some of the gramineous species which are hosts to *C. partellus, B. fusca* and *S. calamistis* are *Hyparrenia, Pannicum, Pennisetum, Setaria, Sorghum, Sporobolus* s*pp*.

and *Andropogon spp*. (Moolman *et al*., 2014). Trap plants can be classified as conventional and perimeter trap plants.

Conventional trap plants are plants grown next to a high value crop. They are naturally attractive to pests as either source of food or oviposition site as compared to the main crop. They prevent pests from reaching the main crop (Justus *et al*., 2000; Bruce *et al*. 2010) also found that, trap plants leaf exudates attracted *C. partellus* moths to lay eggs on them and this prevented the stem borer from entering into the protected crop plants. Conventional trap plants include napier grass (*Pennisetum purpureum),* Sudan grass (*Sorghum vulgare sudanense)* and Vetiver grass (*Vetiveria zizanioides*). Vetiver grass is attractive to target pest and it allows no or very low larval survival on it (van den Berg, 2006). It is used in IPM system and was stimulated by the development of a novel pest management strategy in East Africa (Midega *et al*., 2005). Napier grass produces wax substances that immobilize the stem borer larvae from moving hence starve to death (Shelton and Nault, 2004). These grasses trap and serve as a sink for pests preventing them from moving from the trap plants to the main crop later in the season (Badenes-Prerez *et al*., 2004). Plant hairs and trichomes in Vetiver grass (*Vetiveria zizanioides*) hindered the proper movement and feeding hence affecting the pest’s growth and development on the host plant (Handley *et al*., 2005).

Perimeter trap plants are plants grown around the border of the main crop and they prevent pests from invading the main field (Boucher *et al.,* 2003). These plants are grown alongside a 'push' and 'pull' plan to repel and draw insect pests from the crop plot (Khan and Pickett, 2007). In East Africa, the "push-pull" system has been used to suppress *C. partellus* with considerable success through manipulation of trophic interactions in the agro-ecosystem (Hassanali *et al*., 2008). Napier grass *Pennisetum purpurem* can be used as perimeter trap plant because it provides limited support for the developing larvae (Midega *et al*., 2010). Elephant grass or Uganda grass is a type of perennial tropical grass native to the African grasslands with low water and nutrient requirements (Strezov *et al*., 2008). Historically the Elephant grass has been used primarily for grazing; however, it has been incorporated into pest management strategy (Wadhams *et al*., 2007). Perimeter trap plants therefore act as repellent plants in this strategy by deterring the entry of stem borers into maize and sorghum fields and they repel the ovipositing stem borers (Maddonni *et al*., 2006).

2.4.2 Chemical control

This is the use of chemicals or mixtures of chemicals to kill, repel, mitigate or reduce pest damage (Gupta *et al*., 2010). This is the most commonly recommended method for stem borer control even though continuous applications have to be made to achieve effectiveness. This is due to the short period that the larvae are exposed and therefore prompt and frequent applications have to be made and this can be uneconomical to smallholder farmers (Bonhof, 2000). Effective chemical control is achieved by having a good understanding of the biology, ecology and population dynamics of the pest**.**

Several insecticides have been screened for the control of maize and sorghum stem borers in different regions in Africa and these include carbofuran, carbaryl, endosulfan, trichlorfon and synthetic pyrethroids (Muhammad and Underwood, 2004). Carbofuran is formulated as liquid or granular. Liquid carbofuran are classified as restricted use pesticides (RUP) because of their acute oral and inhalation toxicity to humans. Granular carbofuran are also classified as RUP's, but for a different reason, their toxicity to birds. Liquid formulations bear the signal word "Danger." Granular formulations bear the signal word "Caution". Endosulfan is formulated as brown granules. Carbaryl is formulated as wettable powder. Most smallholder farmers have adopted granular pesticides because no special application equipment is needed (Khan *et al*., 2001).

2.4.3 Biological control

Biological control is the use of parasitoids, predators, nematodes and pathogens to maintain density of a species at a lower level than would occur in their absence (Mushore, 2005). Under natural conditions, most insect pest populations are controlled by a complex of predators, parasitoids and pathogens (Kfir *et al.*, 2002). Bio control agents of interest in many countries in Africa include; the egg parasitoids such as *Trichogramma spp*. (Hymenoptera: Trichogrammatidae) and *Platytelenomous busseola* (Hymenoptera) contribute to natural mortality of stem borers (Vitale *et al*., 2007). Larval parasitoidsincluding *Cotesia sesamiae* and pupal parasitoids for example, *Pediobiusfurvus*, *Dentichasmias busseolae* and *Psilochalcis sudanensis* (Songa *et al*., 2002), arevaluable components of Integrated Pest Management (IPM).

Ants (Hymenoptera: Formicidae) are the most important predators of stem borers in maize fields (Tounou *et al*., 2013). They attack all stages of stem borers, and are among the few predators preying on stem borer larvae and pupae. *Componotus spp*. (Formicidae) and *Pheidole spp*. (Formicidae) are the most important and common species in Zimbabwe (Mushore, 2005). Pathogens also help to control stem borers. Entomopathogenic viruses, bacteria and fungi can be used as pathogens to control insect pests. *Bacillus thuringiensis* (Bt) lowered stem borer larvae in Kenya with a consequent increase in the yield. *Beauveria bassiana* is known to control *C. partellus* by infecting insect hosts through the skin penetration (Mushore, 2005). This makes them readily able to kill piercing and sucking pests which may not be killed by stomach poisons. High humidity is needed in this case for *Beauveria bassiana* germination (Mushore, 2005).

2.4.4 Genetic control methods

Genetic methods refer to the control of pests by manipulating the genetic make-up of either the pest or the host **(**Alphey, 2014**)**. Various insect species and crop pests are undergoing trials ranging from laboratory experiments to large-scale open releases (Harris *et al.*, 2012; Harvey-Samuel *et al.*, 2015). Some of the methods used to genetically control insect pests include sterile insect technique,use ofengineered strains of agricultural pest species, Mass-release of toxin-sensitive engineered males andtransgenic crops expressing insecticidal toxins.

The sterile insect technique is an area-wide pest control method that reduces agricultural pest populations by releasing mass-reared sterile insects, which then compete for mates with wild insects. Contemporary genetics-based technologies use insects that arehomozygous for a repressible dominant lethal genetic construct rather than being sterilized by irradiation. Sterile insect techniqueinvolves the mass rearing of the pest species on artificial diet, exposing very large batches of individuals to radiation to cause chromosome damage, followed by their release into a target area (Harvey-Samuel *et al.*, 2015). When the released insects mate, the resulting eggs did not hatch because of the damage to genetic material in the parent's germ line (Harvey-Samuel *et al.*, 2014).

Engineered strainsof moths and fruit flies such as the Mediterranean fruit fly *Ceratitiscapitata* have been developed with lethality that operates in both sexes (Harris *et al.*, 2012). Male insects tha tare homozygous for that transgene are released to mate with wild females, whose progeny inherit the dominant lethal and so are unable to survive to reproductive maturity. The population-level outcome is then identical to sterile insect technique hence a reduction in population size (Harvey-Samuel *et al.*, 2014).

Mass-release of toxin-sensitive engineered maleinsects carry female-lethal genes aswell as suppressing populations which could substantially delay or reverse the spread ofresistance (Alphey *et al.*, 2007). These transgenic insect technologies could form an effective resistancemanagement strategy. Daughters of homozygous transgenic males are not viable andthis sex-specificity can be exploited to enablemale-only release (Tan *et al.*, 2013).Transgenic crops expressing insecticidal toxins are widely used; the economic benefits of these crops would be lost if toxin resistance spread through the pest population. The primary resistance management method is a high-dose/refuge strategy.It also requires toxinfree crops as refuges near the insecticidal crops, as well as toxin doses sufficiently highto kill wild-type insects and insects heterozygous for a resistance allele (Matten *et al.*, 2012). Genetically modified (GM) insecticidal crops express Bt toxins to protect plants from target pests. *Bacillus thuringiensist* crops have been reported to defend the crops againstlepidopteran attack (Furlong *et al.*, 2013).

2.4.5 Physical control method

Physical pest control is a method of getting rid of insects and small rodents by removing, attacking, or setting up barriers that will prevent further destruction of one's plants (Meers and Scott, 2011). These methods are used primarily for crop growing, but some methods can be applied to homes as well. Some of these physical methods include mechanical traps, change in temperature, hand picking and burning. Mechanical traps or physical attractants are used in three main ways: to efficiently trap insects, to kill them or to estimate how much many insects there are in the total land mass using sampling method (Mahr and Ridgway, 2011). However, some traps are expensive to produce and can end up benefiting insects rather than harming them.

Temperature extremes are fatal to insects. This method is used against stored grain pest. Low temperaturers that are enough to dormancy can prevent damage. Low temperatures are utilized for the control of insect in flour mills and warehouses. Exposure to sub-zero temperatures for 24 hours is lethal to most of the insects (Meers and Scott, 2011). This method is applicable to stored product pests. Drying of grain reduces moisture content and results in lower infestation rates especially when pest insects are in vulnerable stages (Meyer and John, 2010).

Handpicking, as the name implies, is simply to pick and destroy an insect by hand. Hand destruction also includes picking larval forms or egg masses from a plant and destroying them by some physical means. The use of human hands to remove harmful insects or other toxic material is often the most common action by gardeners (Meers and Scott, 2011). It is also classified as the most direct and the quickest way to remove clearly visible pests. However, it also has equal disadvantages as it must be performed before damage to the plant has been done and before the key development of insects (Mahr and Ridgway, 2011).

Controlled burning is sometimes recommended to control certain pests. Weeds harbouring pest insects can be burnt to destroy all the stages of the pest.Stem borers in dry stalks of maize and other crops are collectedand burnt (Meyer and John, 2010). This method is recommended after harvesting time andduring land preparation forplanting. However this method can lead to soil erosion, killing of beneficial soil organisms and can easily burn farm structurers if not carefully done (Meers and Scott, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study areas

Field experiments were conducted in Kasano village, Nyakach Sub-County; Kisumu County, Kenya. The study area is situated 500’14’59.5’, E 034’58’36.7’S and has an altitude of 1,166 m.a.s.l, (Figures 3.1). It receives low amount of rainfall ranging between 250 to 300 mm per year and has a mean temperature of 33^{o}C. The vegetation in the area is predominantly *Acacia* and *Euphorbia*. The area has black clay cotton soil. Greenhouse experiment was conducted at Kenya Agriculture Livestock Research Organisation (KALRO) - Kisii Centre situated -0^{0} 40’ 59” N 34^{0} 47’ 13” E.

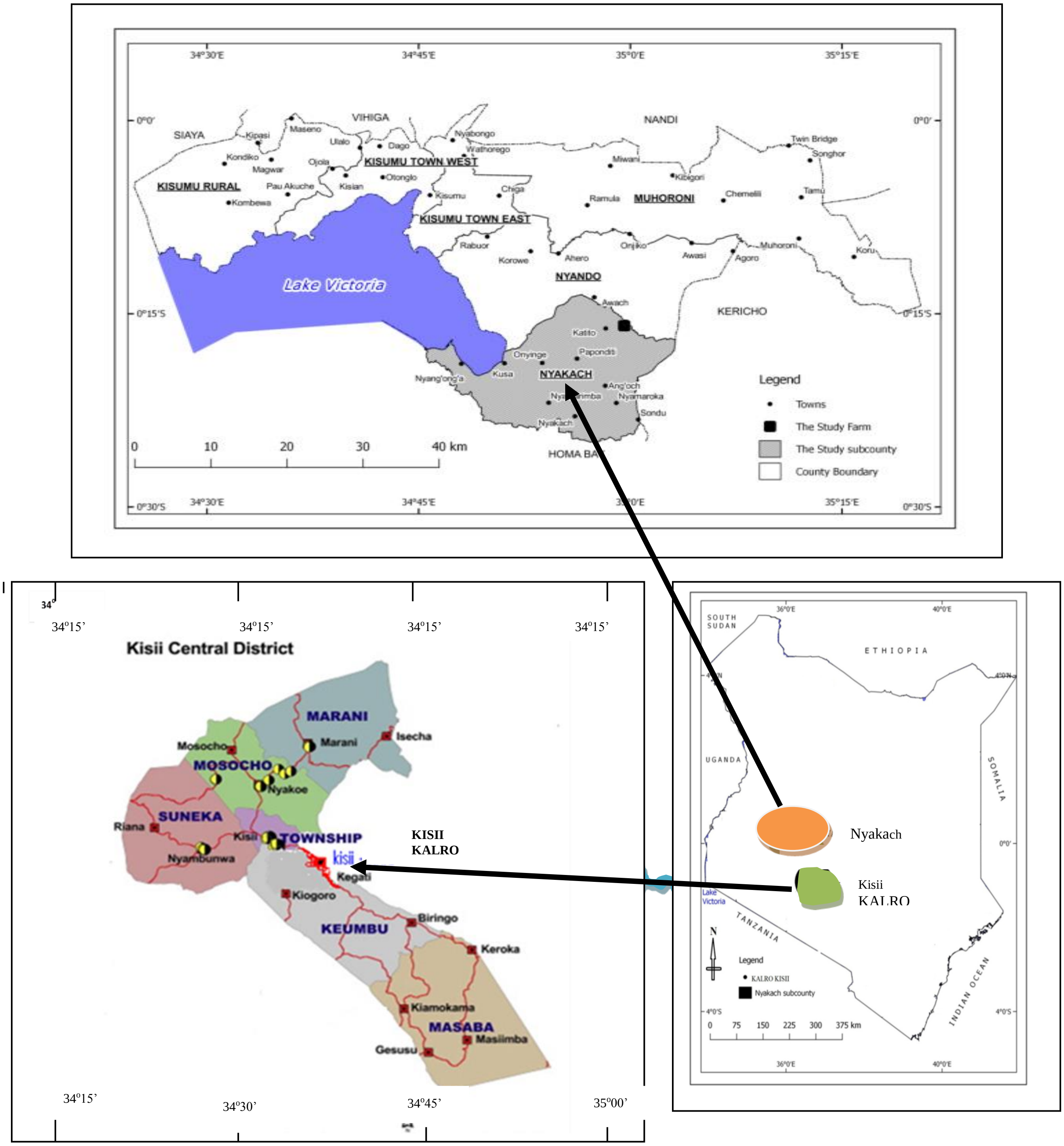

Figure 3.1: Map of Kenya showing study sites (Source: Government of Kenya, 2013)

3.2 Experimental layout in the field

Ten screened drought tolerant grass species from Kenya Agricultural Livestock Research Organisation (KALRO) - Kisii Centre were used in the study. *Sorgum sudanensis* was used as a control grass. Each grass species was planted in small plots measuring 2m x2 m having five rows with spacing of 30 cm by 70 cm. There were three replicates planted in a randomized complete block design. Agronomic practices were done in field experiments throughout the growing season.

Five stems from five grass plants were selected using simple random sampling (SRS) method and cut for the study. To randomize the selection of stems, all the grass plants in each plot were assigned a unique number. The numbers were placed in a bowl and mixed thoroughly. Five numbers were selected while the eyes were closed. The grass plants with the selected numbers were included in the sample. The data which was collected from the five selected stems include numbers of egg batches, eggs, “leaf windows,” entry and exit holes and length of tunnels made by *C. partellus* larvae. This was done after every two weeks and continued for a period of four months. The eggs oviposited on the grass plants were collected every two weeks by cutting the section of the grass containing the eggs. The sections were then put into plastic containers and transferred to the insectory and allowed to hatch at 26-27^{o}C and a relative humidity of 70-78%. After 7-10 days, the eggs hatched into larvae. The eggs were incubated in the laboratory at KALRO-Kisii to confirm the emergence of *C. partellus* larvae. The larvae were reared in the plastic containers containing artificial diet. The diet comprised 25.2g of 30% casein and 70% *Zea mays* stem tissue powder mixed with 22.7g yeast, 2.5g ascorbic acid, 1.3g sorbic acid, 2.0g methyl-p- hydroxyl benzoate, 2.1g vitamin E capsules, 35.3g sucrose, 403.1 ml of water, 12.6g agar powder and 2.0 ml (40%) of formaldehyde.

Entry and exit holes were counted and recorded. Entry holes were differentiated from exit holes using their sizes. Entry holes were smaller than the exit holes. This was because the larvae were still thiny in size when they chewed to enter the stems. While inside the stems, they fed and enlarged in size, so on coming out as moths, they were to make larger exit holes. The entry holes also had faecal materials produced by the lodged larvae while the exit holes were clear and open. “Leaf windows” were scored using Zhou’s 1-9 scale. Scale value of 1-2 indicated no leaf damage; 3-5 indicated some damage while that of 6-9 indicated severe damage (Zhou, 2012). Tunnel lengths were measured in centimetres using a ruler.

3.3 Experimental layout in the greenhouse

The grass species that were used in the field experiment were used in the greenhouse experiment. Each grass species was transplanted in ten plastic pots arranged in a row with each pot having a single grass species (Plate 3.11). The pots were 30 cm diameter and 60 cm depth. Two weeks after transplanting, ten second-instar *C. partellus* larvae were introduced onto each potted plant using a Carmel brush. The soil that was used in greenhouse experiment was obtained from the ground where field experiment was set. The grasses were watered every two days with 150 ml of water per pot. The data which was collected from the five selected stems was as in section 3.2 above in the field experiment.

Plate 3.1: Experimental layout in the greenhouse at KALRO- Kisii. Photo taken 3/1/2015

3.4 Data analysis

Data on number of egg batches, eggs, “leaf windows,” entry and exit holes and tunnel length from different grass species were analyzed by ANOVA using SAS (2010). The means that were significant were separated using the Student-Newman- Keuls (SNK) test at a significance level of *p* = 0.05.

CHAPTER FOUR

RESULTS

4.1 Suitability of selected grass species in attracting adult*Chilo partellus* for Oviposition in the field and greenhouse experiments

4.1.1 Field experiments

There were significant differences in the mean number of egg batches in the eleven grass species that were studied (F 3.77; df =10, 18; P<0.0001). *Sorghum sudanensis* and *Pennisetum sphacelatum* had the highest mean number of egg batches which significantly differed from those of*Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha*, *Bracharia mulato II*, *Chloris gayana, Pennisetum mezianum, Hyparrhenia cymbaria* and *Panicum maximum* which also showed no significant differences (Table 4.1). *Sporobolus consimilis* had the lowest mean number of egg batches.

Table 4.1: Mean number ± SE of egg batches of adult *Chilo partellus* laid on different grass species in the field experiments

Grass species	Mean number of egg batches
Sorghum sudanensis	3.00 ± 0.14^a
Pennisetum sphacelatum	3.00 ± 0.12^a
Sporobolus pyramidalis	2.00 ± 0.19^b
Hyparrhenia tamba	2.00 ± 0.19^b
Bracharia brizantha	2.00 ± 0.23^b
Bracharia mulato II	2.00 ± 0.17^b
Chloris gayana	2.00 ± 0.16^b
Pennisetum mezianum	2.00 ± 0.15^b
Hyparrhenia cymbaria	2.00 ± 0.13^b
Panicum maximum	2.00 ± 0.14^b
Sporobolus consimilis	1.00 ± 0.13^c

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 3.77).

There were significant differences in the mean number of eggs in the eleven grass species that were studied (F 3.46; df =10, 801,128; P<0.0001).*Sorghum sudanensis* had the highest mean number of eggs but this did not significantly differ from those of*Pennisetum sphacelatum* and *Sporobolus pyramidalis* (Table 4.2). *Hyparrhenia tamba* had a significantly lower mean number of eggs than *Sorghum sudanensis* but did not significantly differ from those of Pennisetum *sphacelatum*, *Sporobolus pyramidalis*, *Bracharia brizantha*, *Bracharia mulato II*, *Chloris gayana* and *Pennisetum mezianum* (Table 4.2). *Sporobolus consimilis* had lowest mean number of eggs though this was not significantly different from those of *Panicum maximum*, *Hyparrhenia cymbaria*, *Pennisetum mezianum*, *Chloris gayana*, *Bracharia mulato II*, *Bracharia brizantha* and *Hyparrhenia tamba* (Table 4.2).

Table 4.2: Mean number ± SE of eggs of adult *Chilo partellus* laid on different grass species in the field experiments

Grass species	Mean number of eggs
Sorghum sudanensis	178.00 ± 2.54^{a}
Pennisetum sphacelatum	147.00 ± 1.00^{ab}
Sporobolus pyramidalis	131.00 ± 0.70^{ab}
Hyparrhenia tamba	111.00 ± 3.70^{bc}
Bracharia brizantha	111.00 ± 3.00^{bc}
Bracharia mulato II	111.00 ± 1.30^{bc}
Chloris gayana	111.00 ± 3.30^{bc}
Pennisetum mezianum	111.00 ± 4.80^{bc}
Hyparrhenia cymbaria	96.00 ± 4.30^{c}
Panicum maximum	87.00 ± 3.00^{cd}
Sporobolus consimilis	81.00 ± 0.46^{cd}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 3.46).

4.1.2 Greenhouse experiments

There were significant differences in the mean number of egg batches in the eleven grass species that were studied (F=2.95; df =10, 80; P = 0.0006). *Bracharia brizantha*, *Sporobolus pyramidalis*, *Chloris gayana* and *Pennisetum sphacelatum* had highest mean number of egg batches which showed no significant differences (Table 4.3). *Hyparrhenia tamba*, *Hyparrhenia cymbaria*, *Bracharia mulato II*, *Pennisetum mezianum*, *Sorghum sudanensis*, *Panicum maximum* and *Sporobolus consimilis* had lower mean number of egg batches that were significantly different from those of *Bracharia brizantha*, *Sporobolus pyramidalis*, *Chloris gayana* and *Pennisetum sphacelatum* (Table 4.3).

Table 4.3: Mean number ± SE of egg batches of adult *Chilo partellus* laid on different grass species in the greenhouse experiments

Grass species	No. of egg batches
Bracharia brizantha	2.00 ± 0.92^a
Sporobolus pyramidalis	2.00 ± 0.67^a
Chloris gayana	2.00 ± 0.26^a
Pennisetum sphacelatum	2.00 ± 0.22^a
Hyparrhenia tamba	1.00 ± 0.25^b
Hyparrhenia cymbaria	1.00 ± 0.22^b
Bracharia mulato II	1.00 ± 0.21^b
Pennisetum mezianum	1.00 ± 0.21^b
Sorghum sudanensis	1.00 ± 0.20^b
Panicum maximum	1.00 ± 0.28^b
Sporobolus consimilis	1.00 ± 0.21^b

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 2.95).

There were significant differences in the mean number of eggs in the eleven grass species that were studied (F=3.27; df=10, 367,140; P=0.0001). *Pennisetum sphacelatum* had the highest mean number of eggs but this did not significantly differ from those of *Sporobolus pyramidalis* and *Bracharia brizantha.* The mean number of eggs of *Chloris gayana* was lower than that of *Pennisetum sphacelatum* and did not significantly differ from those of *Sporobolus pyramidalis* and *Bracharia brizantha* (Table 4.4). *Bracharia mulato II* had the lowest mean number of eggs though this did not significantly differ from those of *Hyparrhenia tamba, Sorghum sudanensis, Pennisetum mezianum, Panicum maximum, Sporobolus consimilis* and *Hyparrhenia cymbaria* (Table 4.4).

Table 4.4: Mean number ± SE of eggs of adult *Chilo partellus* laid on different grass species in the greenhouse experiments

Grass species	No. of eggs
Pennisetum sphacelatum	137.00 ± 3.91^{a}
Sporobolus pyramidalis	108.00 ± 4.22^{ab}
Bracharia brizantha	101.00 ± 2.68^{ab}
Chloris gayana	98.00 ± 3.68^{b}
Hyparrhenia tamba	84.00 ± 3.32^{c}
Sorghum sudanensis	82.00 ± 4.5^{c}
Pennisetum mezianum	82.00 ± 5.68^{c}
Panicum maximum	76.00 ± 3.32^{c}
Sporobolus consimilis	64.00 ± 3.28^{c}
Hyparrhenia cymbaria	56.00 ± 4.42^{bc}
Bracharia mulato II	47.00 ± 3.82^{c}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 3.27).

4.2Suitability of selected grass species in attracting*Chilo partellus*larvae forfeeding in the field and greenhouse experiments

4.2.1 Field experiments

There were significant differences in the mean number of entry holes in the eleven grass species that were studied (F=11.85; df=10, 382; P<0.0001). *Sorghum sudanensis* and *Pennisetum sphacelatum* had the highest mean number of entry holes which did not show any significant difference. *Chloris gayana* had lower mean number of entry holes but this did not significantly differ from those of *Sporobolus pyramidalis*, *Bracharia mulato II*, *Hyparrhenia tamba*, *Panicum maximum* and *Bracharia brizantha* (Table 4.5). *Sporobolus consimilis*, *Hyparrhenia cymbaria* and *Pennisetum mezianum* had lowest mean number of entry holes with no significant differences among them (Table 4.5).

Table 4.5: Mean number ± SE of entry holes of *Chilo partellus* larvae on different grass species in the field experiments

Grass species	Mean number of entry holes
Sorghum sudanensis	2.00 ± 0.09^{a}
Pennisetum sphacelatum	2.00 ± 0.04^{a}
Sporobolus pyramidalis	1.00 ± 0.03^{b}
Bracharia mulato II	1.00 ± 0.08^{b}
Hyparrhenia tamba	1.00 ± 0.04^{b}
Panicum maximum	1.00 ± 0.09^{b}
Bracharia brizantha	1.00 ± 0.09^{b}
Chloris gayana	1.00 ± 0.06^{b}
Sporobolus consimilis	0.00 ± 0.18^{c}
Hyparrhenia cymbaria	0.00 ± 0.06^{c}
Pennisetum mezianum	0.00 ± 0.07^{c}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 11.85).

There were significant differences in the mean number of exit holes in the eleven grass species that were studied (F=4.27; df=10, 31; P<0.0001). *Sorghum sudanensis* and *Pennisetum sphacelatum* had the highest mean number of entry holes which did not show any significant difference (Table 4.6). *Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana* and *Sporobolus consimilis* had no exit holes (Table 4.6).

Table 4.6: Mean number ± SE of exit holes of *Chilo partellus* larvae on different grass species in the fieldexperiments

Grass species	No. of exit holes
Sorghum sudanensis	1.00 ± 0.06^{a}
Pennisetum sphacelatum	1.00 ± 0.01^{a}
Sporobolus pyramidalis	0.00 ± 0.09^{b}
Bracharia mulato II	0.00 ± 0.02^{b}
Hyparrhenia tamba	0.00 ± 0.03^{b}
Panicum maximum	0.00 ± 0.02^{b}
Bracharia brizantha	0.00 ± 0.05^{b}
Chloris gayana	0.00 ± 0.06^{b}
Sporobolus consimilis	0.00 ± 0.01^{b}
Hyparrhenia cymbaria	0.00 ± 0.07^{b}
Pennisetum mezianum	0.00 ± 0.08^{b}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 4.27).

There were significant differences in the mean tunnel length in the eleven grass species that were studied (F=10.04; df=10, 1313; P<0.0001). *Sorghum sudanensis* and *Pennisetum sphacelatum* had the longest tunnel length which did not show any significant difference (Table 4.7). *Bracharia mulato II*, *Sporobolus pyramidalis*, *Hyparrhenia tamba*, *Bracharia brizantha*, *Panicum maximum* and *Chloris gayana* had shorter tunnel length which also showed no significant difference (Table 4.7). *Hyparrhenia cymbaria*, *Pennisetum mezianum* and *Sporobolus consimilis* had the shortest tunnel length which showed no significant difference (Table 4.7).

Table 4.7: Mean tunnel length (cm) ± SE made by *Chilo partellus*larvae in different grasses in thefield experiments

Grass species	Mean tunnel lengths (cm)
Sorghum sudanensis	4.00 ± 0.19^{a}
Pennisetum sphacelatum	4.00 ± 0.12^{a}
Bracharia mulato II	3.00 ± 0.20^{b}
Sporobolus pyramidalis	3.00 ± 0.18^{b}
Hyparrhenia tamba	3.00 ± 0.48^{b}
Bracharia brizantha	3.00 ± 0.28^{b}
Panicum maximum	3.00 ± 0.22^{b}
Chloris gayana	3.00 ± 0.14^{b}
Sporobolus consimilis	1.00 ± 0.43^{c}
Pennisetum mezianum	1.00 ± 0.12^{c}
Hyparrhenia cymbaria	1.00 ± 0.17^{c}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 10.04).

There were significant differences in the mean number of “leaf windows” in the eleven grass species that were studied (F=9.55; df=10,427; P<0.0001). *Pennisetum sphacelatum* and *Sorghum sudanensis* had the highest mean number of “leaf windows” though this was not significantly different from that of *Sporobolus pyramidalis* and *Bracharia mulato II*. *Sporobolus pyramidalis* and *Bracharia mulato II* had lower mean number of “leaf windows” which did not significantly differ. *Hyparrhenia tamba, Panicum maximum, Bracharia brizantha*, *Chloris gayana*, *Sporobolus consimilis, Hyparrhenia cymbaria* and

Pennisetum mezianum had lowest mean number of “leaf windows” which showed no significant differences (Table 4.8).

Table 4.8: Mean number ± SE of “leaf windows” made by *Chilopartellus* larvae on leaves of different grass speciesin the field experiments

Grass species	Mean number of “leaf windows”
Pennisetum sphacelatum	4.00 ± 0.16^{a}
Sorghum sudanensis	4.00 ± 0.11^{a}
Sporobolus pyramidalis	3.00 ± 0.12^{a}
Bracharia mulato II	3.00 ± 0.14^{a}
Hyparrhenia tamba	2.00 ± 0.17^{b}
Panicum maximum	2.00 ± 0.30^{b}
Bracharia brizantha	2.00 ± 0.20^{b}
Chloris gayana	2.00 ± 0.17^{b}
Sporobolus consimilis	2.00 ± 0.10^{b}
Hyparrhenia cymbaria	2.00 ± 0.11^{b}
Pennisetum mezianum	2.00 ± 0.40^{b}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 9.55).

4.2.2 Greenhouse experiments

There were significant differences in the mean number of entry holes in the eleven grass species that were studied (F=4.69; df 10, 31; P<0.0001). *Sorghum sudanensis* had the highest mean number of entry holes which differed significantly from those of *Pennisetum sphacelatum, Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana, Sporobolus consimilis,* *Hyparrhenia cymbaria* and *Pennisetum mezianum* (Table 4.9). *Pennisetum sphacelatum, Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha* and *Chloris gayana* had lower mean number of entry holes which showed no significant difference among them (Table 4.9). *Sporobolus consimilis*, *Hyparrhenia cymbaria* and *Pennisetum mezianum* had no entry holes (Table 4.9).

Table 4.9: Mean number ± SE of entry holes of *Chilo partellus* larvae on different grass species in the greenhouse experiments

Grass species	Mean number of entry holes
Sorghum sudanensis	2.00 ± 0.19^{a}
Pennisetum sphacelatum	1.00 ± 0.10^{b}
Sporobolus pyramidalis	1.00 ± 0.11^{b}
Bracharia mulato II	1.00 ± 0.10^{b}
Hyparrhenia tamba	1.00 ± 0.11^{b}
Panicum maximum	1.00 ± 0.10^{b}
Bracharia brizantha	1.00 ± 0.20^{b}
Chloris gayana	1.00 ± 0.10^{b}
Sporobolus consimilis	0.00 ± 0.10^{c}
Hyparrhenia cymbaria	0.00 ± 0.11^{c}
Pennisetum mezianum	0.00 ± 0.30^{c}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 4.69).

There were significant differences in the mean number of exit holes in the eleven grass species that were studied (F=1.35; df 10, 4; P=0.1870). *Sorghum sudanensis* had the highest mean number of exit holes (Table 4.10). *Pennisetum sphacelatum, Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana, Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum* had no exit holes (Table 4.10).

Table 4.10: Mean number ± SE of exit holes of *Chilo partellus* larvae on different grass species in the greenhouse experiments

Grass species	Mean number of exit holes
Sorghum sudanensis	1.00 ± 0.11^{a}
Pennisetum sphacelatum	0.00 ± 0.05^{b}
Sporobolus pyramidalis	0.00 ± 0.07^{b}
Bracharia mulato II	0.00 ± 0.07^{b}
Hyparrhenia tamba	0.00 ± 0.07^{b}
Panicum maximum	0.00 ± 0.07^{b}
Bracharia brizantha	0.00 ± 0.09^{b}
Chloris gayana	0.00 ± 0.07^{b}
Sporobolus consimilis	0.00 ± 0.07^{b}
Hyparrhenia cymbaria	0.00 ± 0.07^{b}
Pennisetum mezianum	0.00 ± 0.07^{b}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 1.35).

There were significant differences in the mean tunnel length in the eleven grass species that were studied (F=4.72; df=10, 211; P<0.0001). *Sorghum sudanensis*,*Pennisetum sphacelatum* and *Bracharia mulato II* had longest tunnel length with no significant difference but significantly differed from those of *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha*, *Panicum maximum, Chloris gayana, Sporobolus consimilis*, *Pennisetum mezianum* and *Hyparrhenia cymbaria* (Table 4.11). *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha*, *Panicum maximum*, *Chloris gayana*, *Sporobolus consimilis* and *Pennisetum mezianum* had shorter mean tunnel length that were not significantly different (Table 4.11). *Hyparrhenia cymbaria* had the shortest mean tunnel length (Table 4.11).

Table 4.11: Mean tunnel length (cm) ± SE (cm) made by *Chilo partellus* larvae on different grasses in the greenhouse experiments

Grass species	Mean tunnel length(cm)
Sorghum sudanensis	3.00 ± 0.36^{a}
Pennisetum sphacelatum	3.00 ± 0.27^{a}
Bracharia mulato II	3.00 ± 0.25^{a}
Sporobolus pyramidalis	2.00 ± 0.27^{b}
Hyparrhenia tamba	2.00± 0.27^{b}
Bracharia brizantha	2.00 ± 0.27^{b}
Panicum maximum	2.00 ± 0.24^{b}
Chloris gayana	2.00 ± 0.27^{b}
Sporobolus consimilis	2.00 ± 0.22^{b}
Pennisetum mezianum	2.00 ± 0.27^{b}
Hyparrhenia cymbaria	1.00 ± 0.29^{c}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 4.72).

There were significant differences in the mean number of "leaf windows" in the eleven grass species that were studied (F=6.61; df= 10, 82; P<0.0001). *Pennisetum sphacelatum* had highest mean number of "leaf windows"which significantly differed from those of *Sorghum sudanensis, Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana, Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum* (Table 4.12). *Sporobolus consimilis* had lower mean number of "leaf windows" with no significant difference (Table 4.12).

Hyparrhenia cymbaria and *Pennisetum mezianum* had the lowest mean number of “leaf window” (Table 4.12).

Table 4.12: Mean number ± SE of “leaf windows” made by *Chilo partellus* on different grass species in the greenhouse experiments

Grass species	Mean no.of “leaf window”
Pennisetum sphacelatum	3.00 ± 0.14^{a}
Sorghum sudanensis	2.00 ± 0.70^{b}
Sporobolus pyramidalis	2.00 ± 0.15^{b}
Bracharia mulato II	2.00 ± 0.15^{b}
Hyparrhenia tamba	2.00 ± 0.14^{b}
Panicum maximum	2.00 ± 0.14^{b}
Bracharia brizantha	2.00 ± 0.14^{b}
Chloris gayana	2.00 ± 0.12^{b}
Sporobolus consimilis	2.00 ± 0.14^{b}
Hyparrhenia cymbaria	1.00 ± 0.15^{c}
Pennisetum mezianum	1.00 ± 0.13^{c}

Means followed by the same letter within the column are not significantly different at P= 0.05 (df=10, F= 6.61).

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Results from the field experiments showed that all the grass species were able to attract adult *C. partellus* for oviposition because egg batches were recorded in all of them. This agrees with the findings of (Moolman *et al*., 2014) who worked on *Hyparrenia, Pannicum, Pennisetum, Setaria, Sorghum, Sporobolus* and *Andropogon spps*. and found that these gramineous plants species were suitable hosts of *C. partellus* for oviposition. Result from the field experiments indicated that *Sorghum sudanensis* and *pennisetum sphacelatum* were most suitable hosts for adult *C. partellus* for oviposition since more egg batches were recorded on them than on others. These grass plants could be containing plant exudates that acted as cues to attract adult *C. partellus* to oviposit on them. This agrees with the findings of (Bruce *et al*., 2010) who also found that, trap plants leaf exudates attracted *C. partellus* moths to lay eggs on them and this prevented the stem borer from entering into the protected crop plants.

Results from the field experiments showed that, *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha, Bracharia mulato II, Chloris gayana, Pennisetum mezianum, Hyparrhenia cymbaria* and *Panicum maximum* formed the second most suitable host plantsin attracting adult *C. partellus* for ovipsition. These grass species were likely to contain plantexudates that attracted the adult *C. partellus* for oviposition although not as much as in the *Sorghum sudanensis* and *pennisetum sphacelatum.* This agrees with the findings of (Justus *et al*., 2000; Bruce *et al*., 2010) who found that, trap plants leaf exudates attracted *C. partellus* moths to lay eggs or feed on them. Results from the field experiments further revealed that *Sporobolus consimilis* least attracted adult *C. partellus* for oviposition becauseof low mean number of egg batches and eggs that were recorded on them. *Sporobolus consimilis* was not able to attract adult *C. partellus* for oviposition probably due to the grass species containing plant volatiles that repelled adult *C. partellus* thus preventing them from ovipositing on it as it was in the case of *Sorghum sudanensis* and *pennisetum sphacelatum* that were heavily oviposited on. This agrees with the findings of Khan *et al.* (2000) who worked on host plants of stem borers and reported that plant volatiles like (*E*)-β-ocimene and (*E*)-4, 8-dimethyl-1, 3, 7-nonatriene were able to repel stem borers and the plants with these volatiles were found with few egg batches. The same observation was reported by Maddonni *et al*. (2006) who worked on perimeter trap plants which acted as repellents and deterred the ovipositing stem borers from entering into maize and sorghum fields.

Results from greenhouse experiments showed that *Bracharia brizantha, Sporobolus pyramidalis, Chloris gayana* and *Pennisetum sphacelatum* most attracted adult *C. partellus* for oviposition since more mean number of egg batches and eggs were recorded in them. This could be due to some chemical substances in these grasses that were discussed in the field experiments above. *Hyparrhenia tamba, Hyparrhenia cymbaria, Bracharia mulato II, Pennisetum mezianum, Sorghum sudanensis* and *Panicum maximum* formed the second most suitable host plants to attract adult *C. partellus* for oviposition.

This was because of moderate mean number of egg batches and eggs which were recorded in them. The reason for this could be due to the plant exudates which were discussed in the field experiments above.

Results from the field experiments showed the presence of entry and exit holes on the stems of the grasses. This was an indication that the borer burrowed into the stem for feeding and exited probably as adults. Tunnelling by *C. partellus* larvae is one way of feeding of this stem borer. This pest feeds more on host plants with soft plant tissues since the tissues are more nutritious and easy to bore by the feeding borer. Exit holes were made by the developing pupae in readness for theadult moth to exit from the tunnelled stems. Entry and exit holes in the field experiments were more in *Sorghum sudanensis* and *Pennisetum sphacelatum* due to their soft stem tissues that allowed the larvae to continue feeding on them. This is a further confirmation that *C. partellus* not only laid more eggs on *P. sphacelatum* but also the former's larvae fed on it. This would make this grass species a better trap plant since once the young larvae lands on it; it would not leave to seek another host to feed on. This agrees with the findings of (Sylvain *et al*., 2015) who worked on maize and sorghum as host plants of stem borers and reported that older larvae made holes and tunnels in stems where they feed for 3 to 5 weeks causing extensive tunnels. They also reported that larvae of *C. partellus* fed on basal meristems of young maize and sorghum plants with soft tissues resulting in the formation of "dead hearts."

Results from the field experiments revealed that *Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha* and *Chloris gayana* had relatively more mean number of entry holes but had no exit holes**.** Entry holes were small and were not easily noticed. They also had faecal matter in the entrance. Exit holes were bigger than entry holes because the exiting moths were bigger in size than the entering larvae. Exit holes also had no faecal matter at the entrance as the entry holes. Lack of exit holes indicated that, these grasses did not attract as more *C. partellus* larvae as in *Sorghum sudanensis* and *Pennisetum sphacelatum* for feeding. Tough stem tissues in *Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha* and *Chloris gayana* led to this observation.

Although these grasses attracted adult *C. partellus* for oviposition, only few eggs were able to hatch into larvae. The grasses could be containing some traits which never allowed most of the eggs to hatch. This agrees with findings of Chabi – Olaye *et al*. (2006) whow worked on host grass plants reported that, stem borers were able to oviposit heavily on some host grasses, but only few species were favourable for them to complete their life cycles. Research done by Maddonni *et al*. (2006) also validated this study in that, they found some host plants with the ability to affect the biology of the insects so that pest abundance and subsequent damage was reduced compared to that which would have occurred if the insects fed on a susceptible crop variety.

Hyparrhenia cymbaria, Sporobolus consimilis and *Pennisetum mezianum* had no entry and exit holes. The grasses had tough stems which did not allow the larvae of *C. partellus* to feed and make holes on them and they starved to death or moved to alternative hosts. This agrees with the findings of Midega *et al*. (2010) who worked on napier grass, *Pennisetum purpurem*, as a perimeter trap plant reported that, the grass was able to attract *C. partellus* for feeding but it provided limited support for the developing larvae. The exit holes were not recorded in *Hyparrhenia cymbaria, Sporobolus consimilis* and *Pennisetum mezianum* since the larvae never had an access into their stems.

Results from the greenhouse experiments further showed that *Sorghum sudanensis* was the most suitable host grass plant for *C. partellus* larval feeding because more entry and exit holes were recorded in it. *Sorghum sudanensis* was able to attract adult *C. partellus* for oviposition and more entry hole in it tells that, the grass was able to sustain the eggs until they hatched into larvae which then fed on it as they grow. The soft stem tissues on *Sorghum sudanensis* discussed in the field experiments above explains why this grass was having more enry and exit holes. *Pennisetum sphacelatum, Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha* and *Chloris gayana* formed the second most suitable host grass plants because a number of entry holes were recorded in them. Like in the field experiments these grasses had tough tissues hence attracted afew number of *C. partellus* larvae for feeding as reflected by few entry holes. Like in the field experiments*Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum* had no entry and exit holes.

Although *Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum* attracted adult *C. partellus* for oviposition, the eggs never hatched into larvae which could have fed on the grasses. Larvae from other grasses in the greenhouse also never fed on these grasses indicating that *Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum* completely could not attract *C. partellus* larvae for feeding. Tough tissues and white powder like substance could have hindered the feeding process of the *C. partellus* larvae. This agrees with findings of Midega *et al*. (2010) who worked on napier grass, *Pennisetum purpurem,* as a perimeter trap plant and reported that, the grass was able to attract *C. partellus* for feeding but it provided limited support for the developing larvae. These findings validated the observation made in this research.

Results on tunnel length in the field experiments revealed that *Sorghum sudanensis* and *Pennisetum sphacelatum* were the most suitable host plants for *C. partellus* larval feeding through tunnelling. This is because longest tunnel length was recorded in them. As in the case of entry and exit holes, *Sorghum sudanensis* and *Pennisetum sphacelatum* had soft stem tissues that attracted the borer for stem tunnelling. As the *C. partellus* fed, they made extensive tunnels a long the stems hence weakening the grasses. This also disrupted the smooth translocation of materials in the grass species. (Kfir *et al*., 2002; Singh *et al*., 2011) worked on host plants to *C. partellus* and found that, *C. partellus* fed by stem tunnelling inthe stems of host plants and this had a direct effect on the host.

Bracharia mulato II, *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha*, *Panicum maximum* and *Chloris gayana* formed the second suitable host plants for the *C. partellus* larvae to feed on. This is because the grass species had tunnel lengths that were slightly shorter than those from *Sorghum sudanensis* and *Pennisetum sphacelatum.* This is likely due to toughness of tissues in these grasses which did not allow the *C. partellus* larvae to feed on them as in the case of *Sorghum sudanensis* and *Pennisetum sphacelatum.Bracharia mulato II*, *Sporobolus pyramidalis, Hyparrhenia tamba*, *Bracharia brizantha*, *Panicum maximum* and *Chloris gayana*could be containing anti-feedants which made them unattractive to *C. Partellus* larval feeding. *Hyparrhenia cymbaria*, *Pennisetum mezianum* and *Sporobolus consimilis* formed the least suitable host plants in attracting *C. Partellus* larval feeding. This is because the shortest tunnel lengths were recorded in them. This could bedue to the presence of plant volatiles that discouraged feeding of the *C. Partellus* larvae.

Greenhouse results showed that *Sorghum sudanensis*, *Pennisetum sphacelatum* and *Bracharia mulato II* were most suitable for feeding in form of tunnel making. This is because of thelongest tunnel lengththat was recorded in them. These grasses most likely contained plant volatiles with cues that attracted the *C. partellus* to feed more on these grasses. Soft plant tissues also contributed to the longest tunnel lengths that were recorded in them. *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha*, *Panicum maximum*, *Chloris gayana, Sporobolus consimilis* and *Pennisetum mezianum* formed the second most suitable hot plants for the attraction of *C. partellus* for feeding. This was because the grasses were able to attract some *C. partellus* for feeding. Since some tunnel lengths were recorded in the grasses. *Hyparrhenia cymbaria* had the shortest tunnel length suggesting that it only attracted a mall number of *C. partellus* larvae for feeding. This could be due to tough tissues in this grass.

Results from the field experiment on “leaf windows” showed that *Pennisetum sphacelatum* and *Sorghum sudanensis* formed the most suitable host plants for attracting *C. partellus* larvae for feeding.*Pennisetum sphacelatum* and *Sorghum sudanensis* had tender leaves which encouraged *C. partellu*s to eat more on soft leaves. This is due to a more mean number of “leaf windows” that was recorded in them. This was concentrated on the young leaves with soft tissues than on the old leaves with tough tissues. This observation was validated by the findings of Mushore (2005) who reported that soon after hatching, stem borer larvae congregate on the funnel and feed on the rolled soft leaves resulting to the development of “leaf windows” as the leaves unfold. *Sporobolus pyramidalis* and *Bracharia mulato II* formed the second suitable for the attraction of *C. partellus* for feeding. The plant volatiles that could be present in the grasses attracted C. *partellus* larvae for feeding than in *Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana, Sporobolus consimilis, Hyparrhenia cymbaria* and *Pennisetum mezianum.*

Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana, Sporobolus consimilis, Hyparrhenia cymbaria and *Pennisetum mezianum* were least suitable for feeding by *C. partellus.* The presence of wax materials on leaf surfaces limited the movement of larvae inorder to feed and the larvae starved to death. The leaf hairs also trapped some water which also made it difficult for the larvae to move and feed. This observation was also reported by (Shelton and Nault, 2004) who worked on napier grass and found that, this grass produced wax substances that immobilized the stem borer hence starved to death.

Greenhouse experiment results showed that *Pennisetum sphacelatum* formed the most suitable host plant in attracting *C. partellus* for feeding. This was because of more mean number of "leaf windows" that were recorded in this grass species. The *C. partellus* larvae fed on the leaf whorls which were soft and produced characteristic "pinholes." The soft leaf tissues were likely the contributing factor of *Pennisetum sphacelatum* having more mean number of "leaf windows". This observation agrees with findings of CAB International (2006) which worked on young host plants and reported that, newly hatched larvae fed by initially scrapping the leaf whorls of young plants producing "leaf windows."

Sorghum sudanensis, Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha, Chloris gayana and *Sporobolus consimilis* formed the second most suitable host plants for the attraction of *C. partellus* larvae for feeding. This was because some "leaf windows" were recorded in them. Leaf toughness in these grass species contributed to low leaf damage hence low mean number of "leaf windows" in this grass species.This observation was also recorded by Afzal *et al*. (2009) who found that leaf toughness which increases as the leaves mature contributed to a defence mechanism in plants against stem borer attack. *Hyparrhenia cymbaria* and *Pennisetum mezianum*least attracted *C. partellus* larvae for feeding which had the lowest mean number of "leaf windows." The presence of hairs on leaf surfaces could have hindered the feeding process of C. *partellus* larvae. This observation was also recorded by Handley *et al*. (2005) who found that leaf hairs and trichomes hindered the feeding of *C. partellus* larvae hence affecting the growth and development of the pest on the plant species.

5.2 Conclusions

i. All the grasses in the field and greenhouse experiments attracted adult *C. partellus* for oviposition. However, in the field experiments, Sorghum *sudanensis* and *Pennisetum sphacelatum* were the most suitable host plants of adult *C. partellus* for oviposition. *Sporobolus pyramidalis, Hyparrhenia tamba, Bracharia brizantha, Bracharia mulato II, Chloris gayana, Pennisetum mezianum, Hyparrhenia cymbaria* and *Panicum maximum* formed the second most suitable host plants for the oviposition of adult *C. partellus*. *Sporobolus consimilis* least attracted adult *C. partellus* for oviposition. In the greenhouse experiments *Chloris gayana, Sporobolus pyramidalis, Bracharia brizantha* and *Pennisetum sphacelatum* were the most suitable host plants of adult *C. partellus* for oviposition. *Hyparrhenia tamba, Hyparrhenia cymbaria, Bracharia mulato II, Pennisetum mezianum, Sorghum sudanensis, Panicum maximum* and *Sporobolus consimilis* least attracted *C. partellus* larvae for oviposition.

ii. Most grass species in the field and greenhouse experiments attracted *C. partellus* for feeding. However, *Sorghum sudanensis* and *Pennisetum sphacelatum* were the most suitable host plants in attracting *C. partellus* larvae for feeding. *Sporobolus pyramidalis, Bracharia mulato II, Hyparrhenia tamba, Panicum maximum, Bracharia brizantha* and *Chloris gayana* formed the second most suitable host plants for *C. partellus* larval feeding in both field and greenhouse experiments. *Hyparrhenia cymbaria, Pennisetum mezianum* and *Sporobolus consimilis* least attracted *C. partellus* larvae for feeding in both field and greenhouse experiments.

5.3 Recommendations

i. All the grasses that were research on were able to attract adult *C. partellus* for oviposition in both field and greenhouse experiments. The grasses that had least mean number of egg batches and eggs could form the best trap plants that can be used to control *C. partellus* especially when the grasses are used as perimeter trap plants. Results from the greenhouse experiments indicated that *Sorghum sudanensis, Hyparrhenia tamba, Pennisetum mezianum, Panicum maximum, Sporobolus consimilis, Hyparrhenia cymbaria* and *Bracharia mulato II* had least mean number of egg batches and eggs. In the field experiments, *Sporobolus consimilis* had least mean number of egg batches and eggs. These grasses therefore should be included in the IPM for the control of *C. partellus.*

ii. The grass species that least attracted *C. partellus* larvae for feeding could form the best trap plants to control the pest since *C. partellus* could not complete their life cycles in these grasses. The results indicated that *Hyparrhenia cymbaria*, *Pennisetum mezianum* and *Sporobolus consimilis* were least fed by *C. partellus* in both field and greenhouse experiments. These grasses therefore should be included in the IPM for the control of *C. partellus.*

5.4 Suggestions for further research

i. In this research drought tolerant grass species were used in a dry area. These grasses attracted *C. patellus* for oviposition and feeding. These grasses should be tested on the ability to attract *C. paetellus* for oviposition and feeding in areas with enough rainfall.

ii. This research focused on whether the selected grasses could be able to attract *C. partellus* for oviposition and feeding. The results indicated that most of them were able to do so. Research should be done to find out whether these grasses could attract *Busseola fusca*, *Chilo orichalcocillielus*, *Sesamia calamistis* and *Eldana saccharina* for oviposition and feeding. The preference of oviposition and feeding of these stem borers on these grasses to other host plants should also be researched on.

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