EVALUATION OF THE DAMAGE CAUSED BY THE MAIZE STALK BORER, *Busseola fusca* (Fuller), AND SPOTTED STEM BORER, *Chilo partellus* (Swinhoe) AND THEIR MANAGEMENT IN GREEN MEALIES

BY

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ABSTRACT

The maize stem borers, *Busseola fusca* and *Chilo partellus* cause qualitative and quantitative losses on green mealies as they attack maize from the seedling up to harvesting. A study was conducted to evaluate their damage and management in green mealies on maize varieties SC 608, PHB 30B50 and SC 513. Two field trials similar in set-up and treatments were conducted. The first trial was planted on the 4/August/ 2014 and the second was planted on the 4/October/ 2014. The essence of staggering planting was to determine whether *B. fusca* and *C. partellus* were problematic in the first part or second part of the dry season before the onset of the rains. For each variety, four treatments were applied, namely; whorl applications of ammonium nitrate (AN), Bulldock® 0.05 GR, Dipterex® 2.5 GR and an untreated control. The treatments were applied at 6 and 4 weeks after crop emergence (WAE) in the first and second trials, respectively and subsequently at 14 day intervals up to tasseling. The parameters assessed were: plant height, number of plants with windowed leaves, number of plants with dead-hearts, plant biomass, fresh cob weights, number of damaged cobs and stem borer parasitism and predation. Results showed that the October planting was less infested with *B. fusca* and *C. partellus* than the August planting. Dipterex® 2.5 GR and Bulldock® 0.05 GR were effective to manage *B. fusca* and *C. partellus* infestation in green mealies. The effectiveness of the two granular insecticides was not significantly different ($P > 0.05$) on the parameters measured. A stem borer larval parasitoid recorded in the August planting was *Schembria eldana* with 25% parasitism. This parasitoid was recorded from both *B. fusca* and *C. partellus.* For the October planting, the parasitoids that were recovered from both stem borer species were *S. eldana* and *Cotesia sesamiae* with parasitism levels of 18.5 and 29.6% respectively. Recovered species preying on stem borer larvae and pupae included earwigs, wasps and ants. Overall, applying AN in the funnel was not effective in managing *B. fusca* and *C. partellus.* Farmers are therefore encouraged to use Dipterex® 2.5 GR and Bulldock® 0.05 GR with other IPM methods such a planting period manipulation, to manage *B. fusca* and *C. partellus* infestations in green mealies.

DECLARATION

I,……..do hereby declare that this dissertation is my original work accepted at Africa University, Mutare, Zimbabwe in partial fulfillment of the requirements for the degree of Master of Science in Crop Production and has not been submitted to any university for the award of any other degree. All the work that was written by other authors and used in the present thesis is fully acknowledged.

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I would like to dedicate this work to my parents Ntambo Mwafi Fernand and Kimunyi wa Ntambo Sifa, whose guidance and care I first enrolled into primary school. They brought me up and impacted a positive influence on my life.

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CHAPTER 1

INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is an important crop in African countries. The majority of people in Sub-Saharan Africa grow maize as their staple food (Pingali, 2001). In Zimbabwe, maize is an important cereal crop grown by both smallholder and commercial farmers and is the staple food for the majority of the people (Gwara, 2011; GOZ, 2012; Mudita *et al.,* 2014). Maize is grown for different purposes and uses depending on its type. Such uses include; producing stock feeds, producing human food and ethanol for engine fuel (OGTR, 2008).

When freshly harvested, it is referred to as green mealies and is highly valued in Zimbabwe (Masarirambi *et al.,* 2011). Green mealies are more profitable and nutritious than processed maize products such as maize meal since the mealing process removes most of the germ and fibre (Gouse *et al.,* 2006). Green mealies are consumed as a snack; either roasted or boiled and are a rich source of carbohydrates. They also contain fat, proteins and fibre which is a valuable part of human diet because it forms an indigestible bulk against which the muscles of the intestines can exercise and so retain their healthy tone (Mudita *et al*., 2014). In Zimbabwe, smallholder farmers grow green mealies in irrigation schemes during the off-season and get a good price (Goebel, 2005). The price depends largely on the size and quality of the cob and time of supply. Bigger cobs fetch high prices on the market (Mudita *et al.,* 2014).

There are several insect pests that are a constraint to maize production within the smallholder and commercial sectors of Zimbabwe (Chinwada and Overholt, 2001; Chinwada, 2003). The larvae of the lepidopterous stem borers *Busseola fusca* (Fuller), (African maize stalk borer), *Chilo partellus* (Swinhoe) (spotted stem borer) and *Sesamia calamistis* (Hampson) (pink stem borer) contribute significantly to yield losses (Chinwada and Overholt, 2001; Chinwada, 2003; Chinwada *et al.,* 2008).

Relatively high losses can occur at the smallholder level where suppression of stem borers by chemicals is seldom practiced (Chinwada *et al.,* 2001). In sub-Saharan Africa, these pests are responsible for losses ranging between 5-73% of potential yield under different agro-ecological conditions (De Groote *et al.,* 2003). In Zimbabwe, cereal grain yield losses of the order of 10-43% have been estimated (Sithole, 1988).

The distribution of lepidopterous stem borers in Zimbabwe follows a definite pattern with *B. fusca* dominating in the highveld (>1200 m above sea level) while *C. partellus* is the most abundant and widely distributed species, but predominates in the lowveld (< 600 m) and middleveld (600-1,200 m), and *Sesamia calamistis* is found in all agro-ecological zones but in very low proportions compared to the other two (Chinwada *et al,.* 2001, Chinwada, 2003). Farmers use various methods to control stem borers. Several insecticides, formulated as either granules or spray applications are registered for stem borer control in Zimbabwe. The most common ones include carbaryl, endosulfan, Dipterex® (trichlorfon), and carbofuran. Dipterex® 2.5 GR is commonly used throughout Zimbabwe (Chinwada *et al.,* 2001; Chandiposha and Chivende, 2014).

These chemicals have been screened in both maize and sorghum in various agro-ecological regions and found to provide effective control. Cultural practices such as burning crop residues, removal of alternative hosts, intercropping and management of sowing dates have been recommended for pest control (Chinwada *et al.,* 2001; Cugala, 2002).

Some of these control measures have been successful and others have not been successful as the insects continue to cause severe damage on green mealies within the smallholder sector. The aim of this research therefore, was to study the lepidopterous stem borer complex at Africa University farm and find effective solutions to reduce their damage in green mealies production.

1.2 Statement of the problem

In Zimbabwe, production of green mealies is hampered by a number of factors including infestation by larvae of the lepidopterous stem borer complex namely, *B. fusca*, *C. partellus* and *S. calamistis* (Chinwada *et al.,* 2001). Among the three, *B. fusca* and *C. partellus* are the most economically important species in Zimbabwe (Chinwada and Overholt, 2001; Chinwada *et al.,* 2001; Chinwada, 2003). They cause yield losses and quality reduction of green mealies as they attack the maize plants from the seedling stage up to harvesting. Yield losses due to their damage range from 10 to 45% depending on the levels of infestation in a geographical location (Sithole, 1995; Keetch *et al.*, 2005). Foliar damage by the insects results in a reduction in total leaf area and photosynthetic capacity of the maize plant. Stem tunneling by the larvae weakens the

stem and reduces the flow of water, nutrients and metabolites throughout the plant, thereby reducing yields. Stem tunneling also reduces plant vitality and the grain filling process, and promotes breakage and lodging of plants as they mature. Their feeding habit into maize cobs deforms them and these are disliked by consumers (Rice and Davis, 2010). In addition, cob feeding habit creates an environment suitable for infection by fungi such as *Fusarium* spp. leading to the production of mycotoxins (Keetch *et al.,* 2005; Pray *et al.,* 2009).

Mycotoxins are fungal toxins that are known to cause adverse medical problems such as cancer in people and animals consuming contaminated products (Pray *et al.,* 2009). Due to the devastating effects of stem borers, there is need to assess their impact and come up with recommendations to reduce the damage caused by the larvae of *B. fusca* and *C. partellus* in the production of green mealies.

1.3 Justification for the study

The persistent damage of maize at an early stage in green mealies has brought about the need to assess the impact and management of the lepidopterous stem borers in Zimbabwe. Green mealies are more profitable to smallholder farmers if grown in the off-season under irrigation. However, *B. fusca* and *C. partellus* have been causing yield losses in each growing season.

In Zimbabwe, their distribution follows a definite pattern with *B. fusca* dominating the highveld (> 1200 m) and *C. partellus* dominating middleveld (600-1,200 m) and low-veld (< 600 m) Chinwada *et al.,* 2001; Chinwada, 2003). Chinwada and Overholt (2001)

reported that *B. fusca* constitute up to 98% of the stem borer species at some highveld sites in Zimbabwe. High populations of stem borers are encountered in areas of intensive cultivation where crop residues abound in which the resting larvae can survive the dry season (Chabi-Olaye *et al.,* 2005a).

Severe damage is caused by stem borer larvae that feed on the plant from early stage up to maturity causing devastating impact (Bamaiyi and Joan, 2011; Mamudu, 2011). Increased damage in young plants is due to tenderness of leaves and stem since aged and toughened leaves are unsuitable for newly hatched larvae (Nyukuri *et al.,* 2014). As the larvae grow, they invade adjoining plants while others make their way into and down the stalks of the plants they are feeding on as they grow (Keech *et al.,* 2005).

Later, the old larvae tunnel extensively in stems, eating out long frass-filled galleries which may weaken stems and cause breakages. Larvae also tunnel into maize cobs and may seriously affect grain formation. In Kenya *B. fusca* and *C. partellus* caused the means damage of 6.5 and 5.2 on maize respectively (Nyukuri *et al.,* 2014). In Zimbabwe, an estimate cereal grain yield losses of the order 10 – 43% may be reasonable (Sithole, 1988). The highest losses would be expected to occur at the smallholder level where suppression of stem borers by chemicals is generally not practiced.

The control of stem borers is important in order to reduce the populations to levels below economic injury levels. Chemical control using granular and spray insecticides is currently being used by some farmers for stem borer control. Granular formulations are

used extensively by smallholder farmers in some parts of Zimbabwe since they are easy to apply. Some farmers use Ammonium nitrate (AN) in the funnel for stem borer control. It can be argued that smallholder farmers cannot be expected to reduce losses due to stem borers when they have a poor understanding of the biology of the pests and are not aware of other non-chemical alternatives (Chinwada *et al.*, 2001).

Varieties such as SC 608 (medium-late maturing), SC 513 (early maturing) and PHB 30B50 (medium- late maturing) have been reported to have some level of tolerance to the pest. Therefore, there is need to test different maize varieties to establish their levels of tolerance. There is also need to test for effectiveness of different insecticides and come up with appropriate recommendations for managing the stem borer complex on green mealies.

1.4 Objectives of the study

1.4.1 Overall objective

The main objective was to determine methods of reducing damage caused by the larvae of *B. fusca* and *C. partellus* on different maize varieties grown for green mealies through utilization of Integrated Pest Management (IPM) techniques.

1.4.2 Specific objectives

1. To identify the species of stem borers damaging maize crop at Africa University farm
2. To quantify the effects of *B. fusca* and *C. partellus* on yield and quality of green mealies across the commonly grown varieties.
3. To establish the most effective *B. fusca* and *C. partellus* control method that ensures high yield and good quality of green mealies.
4. To determine the occurrence of effective parasitoids and predators that can suppress populations of the associated stem borer complex

1.5 Research questions

1. What are the stem borer species damaging maize crop at Africa University farm?
2. Do infestations by *B. fusca* and *C. partellus* have significant effects on yield and quality of green mealies across the commonly grown varieties?
3. Do registered insecticides vary significantly in their effectiveness against *B. fusca* and *C. partellus* attack?
4. Are there any effective parasitoids and predators that can suppress populations of the stem borer complex associated with green mealies?

CHAPTER 2

LITERATURE REVIEW

2. 1 Maize growth and development

Maize growth and development are dependent on the environment. Variable environments influence growth habit and development on the vast range of maize varieties. It is important to know the different developmental stages of maize because the position at which the eggs of stem borer that are laid correlates with the developmental stages of plant. Insect egg batches are increasingly found higher up on the plant with increasing plant age. The impact of stem borers on maize differs depending with growth stages. Maize growth stages are numbered from 0 to 10. Growth stage 0 lasts from planting of the seed up to when the seedling is just visible above the soil surface. Growth stage 10 is reached when the plant is biologically mature (Du Plessis, 2003). Stage 6 (Figure 2.1) is where green mealies are harvested (soft dough stage).

2.1.1 Growth stage 0: from planting to seed emergence

Once the seed germinates, the growth point and the entire stem are about 25 to 40 mm below the soil surface. Under warm, moist conditions, seedlings emerge after about six to 10 days. Under cool or dry conditions, this may take two weeks or longer. The optimum temperature for germination is from 20 to 30^{o} C, while optimum moisture content of the soil is approximately 60% of soil capacity (Du Plessis, 2003).

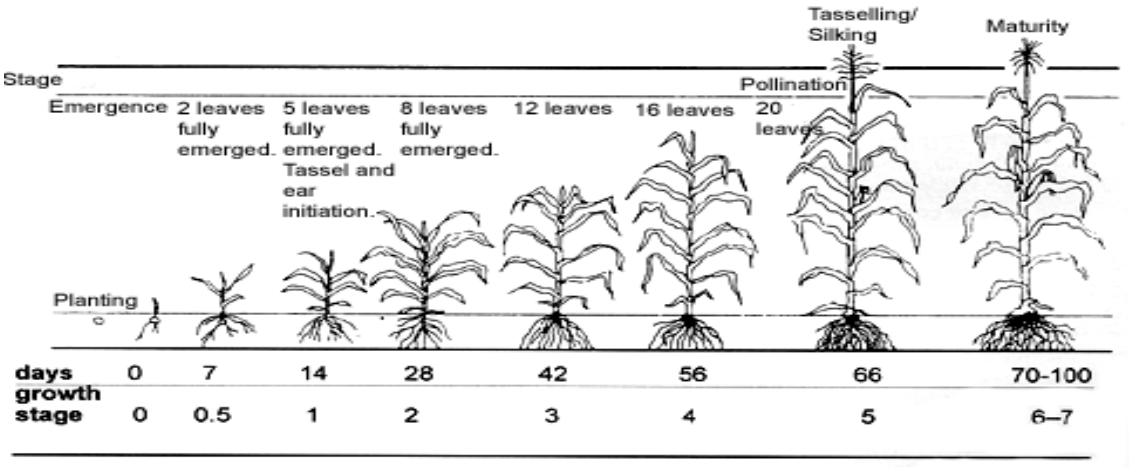

Figure 2.1 Maize growth stages. (Source: Beckingham, 2007)

2.1.2 Growth stage 1: four leaves completely unfolded

The maximum number of leaves and lateral shoots is predetermined and a new leaf unfolds more or less every third day. The growth point is still below the soil surface and aerial parts are limited to the leaf sheath and blades. The tassel will be also initiated during this stage (Du Plessis, 2003). As the leaves unfold, the farmers have to scout for early stem borers and control.

2.1.3 Growth stage 2: eight leaves completely unfolded

The leaf area increases five to 10 times, while stem mass increases 50 to 100 times. Ear initiation has already commenced and tillers begin to develop from nodes below the soil surface. The growth point will be approximately 5.0 to 7.5 cm above the soil surface (Du Plessis, 2003).

2.1.4 Growth stage 3: twelve leaves completely unfolded

The tassel in the growth point begins to develop rapidly. The lateral shoots bearing cobs develop rapidly from the 6 to 8 nodes above the soil surface and the potential number of seed buds of the ear has already been determined. This period is known as the late vegetative growth. The field should be scouted for stem borers and control measures instituted when deemed necessary (Du Plessis, 2003).

2.1.5 Growth stage 4: sixteen leaves completely unfolded

The stem lengthens rapidly and the tassel is almost fully developed. Silks begin to develop and lengthen from the base of the upper ear (Du Plessis, 2003)

2.1.6 Growth stage 5: silk appearance and pollen shedding

All the leaves are completely unfolded and the tassel has been visible for two to three days. The lateral shoot bearing the main ear as well as bracts has almost reached maturity. At this point, demand for nutrients and water by the plant is high. This is called the reproductive growth stage (Du Plessis, 2003).

2.1.7 Growth stage 6: green mealies stage

During this stage, the ear, lateral shoot and bracts are fully developed and starch begins to accumulate in the endosperm. It is during this stage that green mealies are harvested (Du Plessis, 2003).

2.2 Background on biological and ecological behaviour of stem borers and their distribution

The distribution and occurrence of stem borers in Africa is diverse due to a range of factors such as host availability, location and suitability, mate location, success of oviposition, larval survival and establishment, temperature and altitude (Mailafiya *et al.,* 2011).

The cereal stem borer species present in Zimbabwe belong to the Pyralidae and Noctuidae families. The species are *C. partellus, B. fusca* and *S. calamistis* (Chinwada *et al,* 2001; Chinwada and Overholt, 2001; Chinwada, 2003). *Busseola fusca* and *C. partellus* are by far the most important species in Zimbabwe (Chinwada *et al.,* 2001; Chinwada and Overholt, 2001; Chinwada, 2003).

In Zimbabwe, the distribution patterns of the three stem borer species are influenced by climatic factors such as temperature, humidity and altitude, with each species having a preferred ecological zone (Chinwada *et al.,* 2001). *Busseola fusca* and *S. calamistis* originated in Africa and are present in most countries of sub-Saharan Africa, while *C. partellus* is native to Asia and was accidently introduced to Africa through Eastern Africa. These stem borers occur as a complex of species with overlapping spatial and temporal distributions (Chabi-Olaye *et al.,* 2001). Regardless of their different species and damage symptoms, the stem borers generally have similar life cycles and all undergo complete metamorphosis (holo-metabolous) (Chinwada, 2003; ISU, 2012).

2.2.1 *Chilo partellus* (Swinhoe) (Lepidoptera: Pyralidae)

The spotted stem borer, *C. partellus* is found in the family Pyralidae and subfamily Schoenobiinae. In Africa, *C. partellus* is found in most Eastern and Southern African countries, including Botswana, Cameroon, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Somalia, Sudan, South Africa, Lesotho, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe and the Islands, Comoros and Madagascar (De Groote *et al.,* 2003; Tefera, 2004).

Chilo partellus was first recorded in Malawi in 1930 in areas with an altitude below 900m and with high temperatures. The rapid spread of the pest in Africa is enhanced by its ability to competitively displace the native thus becoming the most injurious stem borer (Kfir *et al.,* 2002). For example, in coastal Kenya, it displaced the indigenous *Chilo orichalcociliellus* (Lepidoptera: Crambidae) (Kfir *et al.,* 2002). Similarly, in the eastern highveld region of South Africa, *C. partellus* partially displaced *B. fusca* over a period of seven years. Within two years, it became the predominant borer; constituting of approximately 90% of the total stem borer populations (Kfir *et al.,* 2002). In Zimbabwe, *C. partellus* also showed dominance over *B. fusca* when it accounted for 51.6% and 58.5% respectively for sampling done at the highveld location of Mamina in December 2004 and February 2005 (Mushore, 2005).

One of the possible reasons for the displacement of the indigenous species is that hibernating larval populations of *C. partellus* terminate diapause and emerge a moth earlier than *B. fusca* (Dejen *et al.,* 2014).

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 (Kfir *et al.,* 2002). The pest is reported with high infestation levels on dry-season irrigated maize in the low-veld in Zimbabwe (Chinwada *et al.,* 2001).

In northeastern Ethiopia, *C. partellus* makes up 7 to 100% of the population of stem borer species and cause damage of 1 to 100% in the same zone at an elevation ranging from 1,492m to 2,084 m (Dejen *et al.,* 2014). Degaga *et al.* (2001) recorded *C. partellus* in elevation between 1,030 to 1,900 m in Ethiopia. Gupta *et al.* (2010) reported that *C. partellus,* is one of the most important and destructive pests of maize and sorghum at altitude below 1500 m above sea level in India. In Mozambique, *C. partellus* is reported to be the most abundant stem borer species at lower altitudes (0-200m) and in warm zones with 100% infestation levels (Cugala, 2002).

Chilo partellus and *B. fusca* are important stem borer species in Kenya in the warmer and lower areas and in the cooler and higher altitudes respectively (Odendo *et al.,* 2003). In Eritrea, *C. partellus* and *B. fusca* are important in highlands between 1,450-2,350 m and low lands less than 1,400 m, respectively (Adugna and Hofsvang, 2001). In Pakistan, the highest infestation of *C. partellus* was found at a temperature of 32.5 ° C, low annual rainfall (<1,000 mm) and relative humidity of 68% (Muhammad *et al.,* 2010).

The moths are buff-coloured and nocturnal like the moths of the other stem borer species. Females are generally larger than males and both sexes rest with the wings folded over the abdomen. Mating commences after mid-night on the night of emergence, reaches a peak between 5 am and 7 am then declines (Rebe *et al.,* 2004; Klopper, 2008). The *Chilo partellus* female moths mate soon after emergence from the pupal stage and lay most of the eggs in two to three consecutive nights. The eggs are laid in batches on the upper side of green maize leaves (CABI, 2006). The eggs have an overlapping arrangement upon each other. They are whitish, flattered, scale like and ovoid. A single female can lay a total of 200-600 eggs. The eggs hatch in 4 to 8 days after oviposition (Klopper, 2008).

The emerging larvae move to the whorl where they start to feed on young maize leaves. Some may move to the nearby host plants. They are creamy white and are characterized by dark spots on the body (Klopper, 2008). Young larvae can also feed on low palisade cells leaving a transparent upper cuticle referred to as "window panning". To reduce competition between larvae that hatch from the same egg batch, they spin silken threads which they utilize to "ballon" to neighbouring plants. This instinctive mechanism also increases the chances of survival of the *C. partelus* larvae (Sithole, 1989).

The larvae may only migrate to neighbouring plants as a result of food deterioration, decrease in food quality and overcrowding on individual plants (Rebe *et al.*, 2004). Older larvae tunnel into stems where they feed for a period ranging from 2 - 3 weeks before pupating. The larval period takes 28-35 days (CABI, 2006).

During pupation the full grown larva prepares a circular exit hole for the moth. The pupal period takes 8 - 10 days after which adult moths emerge to complete the cycle. The total life cycle may be completed in about 45 days (CABI, 2006, 2007).

Many cereal stem borers have a resting period towards the end of the cropping season, but *C. partellus* can develop continuously all year round in regions where there is sufficient water and an abundance of host plants. It can have up to six generations in a single season (Chinwada, 2003). The larvae may enter a diapause state for up to six months if there are breaks between consecutive growing seasons or any harsh condition by hibernation in stems, low down in the plants and in stem bases beneath the soil (Klopper, 2008). For example, in Kenya, *C. partellus* diapauses for several months in the dry season however, populations without a resting period have also been reported from the coastal regions of Kenya and Uganda (Songa *et al.,* 2002). In South Africa, *C. partellus* moths start to fly from the beginning of September to the end of May and can have up to five overlapping generations, living for approximately four to six days (Van den Berg and Rensburg, 1993).

2.2.2 *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae)

Busseola fusca is native to Africa and considered the most important field pest of cereal crops (maize and sorghum) in sub-Saharan Africa (Belmain *et al.,* 2001; Chinwada and Overholt, 2001; Bok *et al.,* 2006; Mamudu, 2011).

It belongs to the family Noctuidae and subfamily Amphipyrinae. It was first recognized as a pest of maize in South Africa, where much of the early work on its biology and control was done (Harris and Nwanze, 1992; Van den Berg and Rensburg, 1993).

Busseola fusca occurs throughout mainland Africa south of the Sahara and has been recorded from West Africa (Benin, Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Guinea, Mali, Nigeria, and Sierra Leone), from Eastern Africa (Ethiopia, Kenya, Somalia, Tanzania, and Uganda) and from Southern Africa (Angola, Botswana, Lesotho, Malawi, Mozambique, Rwanda, South Africa, Swaziland, DR Congo, Zambia and Zimbabwe) (Harris and Nwanze, 1992).

In West Africa, *B. fusca* is only common on sorghum in the dry hot zones. In Central Africa, it is the predominant pest across all altitudes. The extension of maize cultivation in Africa may have enabled the pest to follow the crop and become established in most African countries. The distributions of *B. fusca* and *C. parellus* are affected by rainfall, temperature and elevations in sub-Saharan countries (Dejen *et al*., 2014).

In Zimbabwe, *B. fusca* is generally dominant in areas with an altitude above 900 metres (Chinwada and Overholt, 2001; Chinwada *et al.,* 2001). In Burundi, *B. fusca* was the only species detected in the high-altitude (2,100 m) location of Gisozi with 80% infestation in maize and sorghum. In the DR Congo, *B. fusca* appears to be the most predominant stem borer species. In the Guinea savanna agro-ecological zone of Nigeria, *B. fusca* is the most predominant borer species in early and late plantings (Okweche *et al.,* 2010).

In Ghana, *B. fusca* is considered the most important pest of maize and its generations occur differently from one region to another. In Ibadan in southern Nigeria, four larval generations have been observed on maize. In Ethiopia, three generations have been recorded with peaks in May-June, July-September and October. In South Africa, the number of generations on maize increases from two in the east to three in the west with peak moth emergences in October-December, January and March. Generations tend to overlap towards the west and seasonal variations in flight patterns are less distinct. In Zimbabwe, two distinct generations emerge in November and January-February and a third generation may develop when conditions are favourable (Sithole, 1989). At all locations, most larvae of the final generation enter diapause and survive in maize stubble or wild grass hosts until the following growing season inside dry maize stems and stubble (Harris and Nwanze, 1992).

The life cycle of *B. fusca* varies mainly because of climatic and seasonal differences of temperature and other parameters. Basically, the adult is a pale brown nocturnal moth with a wingspan of 20-40 mm (CABI, 2006; Le Rü *et al.,* 2006). It emerges after a pupal period of 9 - 14 days. The moth emerges in the afternoon or early evening and is active at night. Its life cycle is completed in 7-8 weeks when conditions are favourable. During the day, adults rest on plants and plant debris and are seldom seen unless disturbed, when they fly briefly (Harris and Nwanze, 1992).

The moth forewings are light to dark brown, with patterns of darker markings, and the hind wings are white to grey-brown. There is much seasonal and geographical variation;

moths developing in colder, wetter conditions tend to be darker in colour, with heavier black markings (Harris and Nwanze, 1992).

The females are generally larger than males and both favour moist conditions. Usually on the night of emergence, the females release a pheromone (Cis-9-tetradecenyl acetate) consisting of a 70:15:15% mixture of (Z)-l l-tetradecyl acetate (main), (E)-1 1-tetradecyl acetate and (Z)-9-tetradecyl acetate (minors) respectively to attract males (Félix *et al*., 2009; Calatayud *et al.*, 2014).

During the 3-4 nights following emergence, they lay eggs on young maize plants. The eggs are laid in a long column stretching up the stem between and under leaf sheaths (Tefera *et al.,* 2010). Some eggs can be laid on the outer ear husks in batches of 30-150 eggs (Ebenebe *et al.,* 2001; Le Rü *et al.,* 2006). On maize, egg laying tends to be concentrated on plants that are less than two months old and the leaf sheath of the youngest unfolded leaf is most attractive to females. The egg hatches after about 7 to 10 days and its exact duration depends on temperature and relative humidity. The female can lay close to 1,000 eggs that are slightly separated from one another. The eggs are creamy-white when laid, but they turn darker before emergence (Harris and Nwanze, 1992). Eggs are globular and about 0.8 to 1 mm in diameter, hemispherical, and slightly flattened with radial ridges (crenulations) on the upper surface of the egg shell (Ebenebe *et al.,* 2001; Le Rü *et al.,* 2006).

The early stages of the larvae feed on the leaves in the whorl and then tunnel into the stalk or burrow into the base of the plant and tunnel up through the centre of the stalk.

Larvae can also feed on maize tassels. Temperatures between 26-30ºC are the most favourable for the development of *B. fusca* larvae. A single larva may attack more than one plant if the first plant does not support as it increases in size (Rice and Davis, 2010). Migration is an important parameter in the proliferation of this pest (Calatayud *et al.,* 2014).

The larval stage undergoes six instars before pupation takes place (CABI 2006). The larvae tunnel inside the stems and before pupation, they cut exit holes (pupation windows) through which the moths emerge. These holes are characteristically covered by a thin remaining layer of epidermis and are visible externally, giving an indication that pupation has occurred or is about to occur. The larval period takes 35 days or more (Le Rü *et al.,* 2006; CABI, 2007).

During dry and/or cold weather, larvae enter a diapause of six months or more in maize stems, stubble and other plant residues before pupating during the next favourable period. In warmer areas like Zimbabwe, *B. fusca* may go into diapause in the lower part of the stem, 25-60 cm above soil surface. Diapausing larvae have a higher survival rate at the base of the stem than in exposed stalks possibly due to protection of larvae from natural enemies and unfavourable conditions. The main factor enabling larvae to survive adverse conditions in diapause seems to be their efficient conservation of water. Diapause is normally terminated as rainfall increases during the subsequent growing season (Harris and Nwanze, 1992).

At the end of the diapause period, the availability of free water, which the larvae drink, facilitates rehydration and stimulates pupation. Contact with water in the vapour state (i.e. higher relative humidity), rather than direct intake, promote diapause termination. The female pupa is about 25 mm long and is brown or shiny yellow-brown. The male pupae are generally slightly smaller than the female (Ebenebe *et al*., 2001). Pupae can be sexed by differences in the positioning of the genital scars, found on sternum 8 in females and on sternum 9 in males (Harris and Nwanze, 1992).

The pupae of *B. fusca* can therefore be distinguished from those of *Sesamia* spp. which have a more complex cremaster with two pairs of thorn-like spines. According to Klopper (2008), the following four aspects on the biology of *B. fusca* are of special significance when control strategies are planned and should be carefully considered: (i) the specific periods within which moth flights occur, (ii) the dependency of neonate larvae on soft plant tissue and the tendency of later instar larvae to remain sheltered in whorls, (iii) the difference in magnitude of the first and second moth flights, and (iv) selective behaviour of moths when plants are selected for oviposition.

2.2.3 *Sesamia calamistis* (Hampson) (Lepidoptera : Noctuidae)

The pink stem borer, *S. calamistis* is found in the family Noctuidae and subfamily Hadeninae. It is distributed in many countries including Angola, Benin, Botswana, Burkina Faso, Cameroon, Comoros, Congo Brazzaville, DR Congo, Ethiopia, Gambia, Ghana, Ivory Coast, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique,

Niger, Nigeria, Reunion, Senegal, South Africa, Sudan, Swaziland, Tanzania, Zambia and Zimbabwe (Nsami *et al.,* 2001).

The specimens from West Africa and Mauritius and Reunion are generally smaller than those from Southern Africa. In a surveys carried out in Benin in the 1990s, *Sesamia* spp. were found to have the widest distribution and were detected in 60% of all maize fields surveyed (Chabi-Olaye *et al.,* 2001). In Zimbabwe, *S. calamistis* is found in all agro-ecological zones but in very low proportions (Chinwada, 2003).

The moths are nocturnal and capable of flying long distances. The forewings are a streaked straw colour with the margin wide, whitish and partly smoky; the rest of the forewing is speckled with dark patches. The hind wings are pearly white with a yellow margin. The male antennae are bipectinate, with the pectinations longer than the width of the antennae shaft.

The adults emerge late in the evening and females release a pheromone consisting of five compounds to attract males for mating. These compounds are (Z)-11 hexadecenyl acetate (60%), (Z)-9 tetradecenyl acetate (14%), (Z)-11 hexadecen- 1-ol (15%), (Z)-9 – tetradecen-l-ol (9%) and tetradecenyl acetate (2%). To prevent interspecies attraction with *B. fusca,* the main components of *S. calamistis* and *C. partellus* sex pheromones are characterized by 16 carbons (Frérot *et al.,* 2006). A blend of the first two compounds is attractive to males. The same blend is also attractive to the adult males of armyworm (*Leucania loreyi*) (Meijerman and Ulenberg, 1996; Zagatti *et al.,* 1988).

Mating of adults takes place as early as the first night after emergence and oviposition begins the same night. The eggs are up to 350 in batches of 10-40. The batches are arranged in 2 - 4 rows and are inserted between the lower leaf sheath and the stems of the host plants (Cugala, 2002). The eggs are thrust within the leaf sheath surrounding the upper internodes and hatch in 7-10 days. Just after hatching, the larvae show a highly aggregated distribution moving from the oviposition site and penetrate directly into stems where they feed. The larvae of *S. calamistis* bore directly into the stem upon hatching, while the first instar larvae of other stem borer species initially feed on the young leaf (Mailafiya *et al.,* 2011). Older larvae create a horizontal hole and move downward, sometimes through several internodes pushing out frass that fills the galleries through openings in the leaf sheath (Mailafiya *et al.,* 2011).

The larva takes 28-35 days to develop, and it is characterized by a pinkish colour and can have a big body similar in size to the *B. fusca* at maturity. Most larvae pupate in stem tunnels after passing through 4-5 instars while others may pupate between the stem and leaf sheaths in 4 -6 weeks (Cugala, 2002; Chinwada, 2003). The newly formed pupa is pale brown and immobile but show wriggling movement of the abdomen when touched (Mengistu *et al.,* 2009). In contrast to *B. fusca, S. calamistis* breeds throughout the year and has no resting stage if conditions are favourable (Chinwada, 2003). Adults of *Sesamia* spp. emerge between 9-13 days after pupation (Mushore, 2005). Adults that emerge at the beginning of the cropping season are smaller and less fecund than those emerging later in the year. The combination effects of smaller numbers of less fecund

adults results in lower incidence of *Sesamia* spp. in first-season maize crops in Ghana (Mamudu, 2011).

2.3 Host plants

Cereal stem borers are polyphagous and have several gramineous and other non cultivated wild host plants. Host- plant recognition and selection in Lepidoptera is primarily a function of ovipositing females (Konstanto- Poulou *et al.,* 2002) and correct host plant choice is vital for the fitness and survival of progeny (Schoonhoven *et al.,* 2005). The original host plants of all cereal stem borers were wild grasses (Cugala, 2002). However, sorghum and maize are their most important host plants. Stem borers have different preferences in terms of host plants. For instance, *C. partellus* prefers sorghum to maize while *B. fusca* and *S. calamistis* prefer maize to sorghum (Mushore, 2005).

Chilo partellus is a generalist herbivore that feeds on several species of cultivated and wild plants belonging to the family Graminae (Ong'amo *et al.,* 2006; Moolman *et al.,* 2014). For example, it has been observed damaging pearl millet, rice, wheat and sugarcane in the field. According to Mushore (2005), stem borer wild host plants are found in the Graminae, Cyperaceae and Typhaceae families.

Some of these grass hosts include *Hyparrenia, Pannicum, Pennisetum, Setaria, Sorghum, Sporobolus* spp. and *Andropogon* spp. *Busseola fusc*a, *C. partellus* and *S. calamistis* have been recorded on 24 wild plant species in the family Graminae in Kenya (Polaszek, 1998). In Zimbabwe, only maize, sorghum and sugarcane can be mentioned with certainty as hosts (Chinwada *et al.,* 2001). Finger millet (*Eleusine corcacana*) and

bulrush millet (*Pennisetum glaucum*) are widely grown in Zimbabwe but their importance as stem borer host plants has not been investigated (Chinwada *et al*., 2001). In the wild host group, Napier grass, (*Pennisetum purpureum* Schum) was reported to be an important *B. fuca* host in West Africa. This host is more attractive to gravid females than maize plants (Ndemah *et al.,* 2001).

2.4 General stem borer damage and larval behaviour

Most stem borer species produce similar symptoms on maize and sorghum plants. Among cereals, maize is damaged more by stem borers because it has more of amino acids, sugars, than the other gramineous hosts (Souza, 2002). Generally, soon after hatching, stem borer larvae crawl over the plant, congregate in the funnel and feed on the rolled leaves a few days before penetrating into the stalk and stem (Mushore, 2005). As the leaves grow away from the funnel, a characteristic pattern of holes and "window panes" can be seen, leaving transparent upper cuticle referred to as window panning. Window panes refer to early larval feeding in which the larvae do not completely chew through the leaf but leave a thin layer of transparent leaf epidermis (CABI, 2006).

Larvae can also feed on basal meristems of young maize plants resulting in the formation of dead-hearts. Dead-heart is caused by the borers boring into the stalk at the soil level and tunneling upward. Dead hearts cause death of cereals such as maize, while sorghum, millet and rice compensate by tillering (Sithole, 1989). Leaf feeding alone does not cause economic damage, but tunneling into the stalk results in deformed or stunted plants which may not produce an ear (CABI, 2007).

Larval tunneling within the stalk may also predispose plants and ears to infection by fungal pathogens, further compromising the long-term storability, and quality of food products (Kfir *et al.,* 2002). There is an evidence of variation in the lengths of stem tunneling associated with the different stem borer species. *Busseola fusca* and *S. calamistis* larvae produce the largest stem tunneling, followed by *C. partellus*. Mostly, the holes are prepared for pupation. The feeding habit reduces the flow of water and nutrients throughout the plant, and can reduce grain weight, kernel number, therefore reducing yields (ISU, 2012).

The extensive tunneling of stem borers inside the stems weakens the plants causing breakage and lodging (Tefera *et al.,* 2010). On the effect of lodging on the plants, Hicks (2004) reported that lodged plants are likely to yield lower and make harvesting more difficult. Ransom (2005) reported that yield losses as high as 40% could result from lodging. Damage to the stem can lead to infection by *Fusarium* stalk rot. Extensive damage can result in complete death of the plant. After killing the plant, larvae usually migrate to new plants and enter by boring into the stem near the base (Mugo *et al.,* 2000).

Plants damaged by stem borers are often stunted and may die. If they survive the plants may or may not produce harvestable ears. If they do, they are usually smaller than normal plants making them less marketable. In addition, those plants that do not produce ears compete with plants for water, nutrients and sunlight (Bessin, 2010). The magnitude of the damage by stem borers is influenced by soil fertility (Chabi-Olaye *et*

al., 2005a), farming systems (Schulthess *et al.,* 2001; Chabi-Olaye *et al.,* 2005b) and maize cultivars. In the southern lowveld of Zimbabwe, *C. partellus* exhibits a facultative diapause and causes extensive damage to both rain-fed summer crops and off-season irrigated maize crops (Chinwada *et al.,* 2001).

2.5 Yield losses caused by maize stem borers in Africa

Yield loss due to stem borers in Africa vary from 0-100% among ecological zones, regions and seasons. In sub Saharan Africa, they can cause 20-40% losses during cultivation and 30-90% losses postharvest and during storage of dry grain (Nyukuri *et al.,* 2014). The severity and nature of stem borer damage depends upon the borer species, the plant growth stage, the number of larvae feeding on the plant and the plant's reaction to borer feeding. Feeding by borer larvae on maize plants usually result in crop losses as a consequence of death of the growing point (dead-heart), early leaf senescence, reduced translocation of water and nutrients, lodging and direct damage to the ears.

In Zimbabwe, trial-generated data on green mealies yield losses due to the stem borers are scanty because green mealies under smallholder farmers are consumed early in the season and the total grain harvested is not delivered to a buyer where it can be quantified (Gouse *et al.,* 2008). In Zimbabwe yield losses of 10-43% in cereal grain have been estimated.

The highest losses would be expected to occur at the smallholder level where suppression of the pest by chemicals is generally not practiced (Chinwada *et al.,* 2001).

In Zimbabwe, stem borer infestations range from 30 to 70% in fields of resource-poor farmers, and are less than 30% in commercial farms, where insecticides are used for control (Chinwada *et al.,* 2001). In Ghana, yield losses as high as 40% has been attributed to *B. fusca* infestations. In Democratic Republic of Congo, *B. fusca* was reported to occasionally cause yield losses of 8-9% in early planted maize, and 22-25% in late planted maize (Mbenga, 2010). *Chilo partellus* is the most damaging pest in Eastern and Southern Africa (Kfir *et al.,* 2002), and causes significant grain yield losses. Its control has been a challenge among smallholder farmers (Mutyambai *et al.,* 2014).

Busseola fusca larvae can feed on maize kernels at maturity producing higher grain weight reduction as compared to *C. partellus.* In Ethiopia, *B. fusca* and *C. partellus* are considered to be the most damaging insect pests of maize, with reported yield losses of 0 - 100, 39 - 100, 10 - 19 and 2 - 27% from South, North, East and Western Ethiopia, respectively (Melaku *et al.,* 2006).

In Mozambique, Cugala (2002) reported yield losses of over 50% due to *C. partellus* in the smallholder farming sector. In Maputo and Gaza provinces of Mozambique and the Limpopo valley, estimated yield losses of 100% were reported to be caused by *C. partellus*. The larvae of the 3rd generation were reported to infest 87% of cobs of maize planted late and to severely damage 70% of their grain. In Kenya, *B. fusca* accounted for 82% of all maize losses (De Groote, 2002). De Groote *et al.* (2003) reported that all stem borer species caused average annual losses of 13.5% valued at US$80 million. In Kenya, losses to *C. partellus* were estimated at US$ 23 million/year; the majority of other stem

borer losses were attributed to *B. fusca.* This analysis was based on maize prices of $193/ton (De Groote *et al.,* 2003).

In Burundi, *B. fusca* caused yield losses of 30-50% in regions of altitude between 1,500 and 2,100 m. Generally, the magnitude of yield losses vary greatly depending upon the country, season, maize variety, fertilization, severity of damage, stem tunneling and generation of stem borers involved. The first and second generations causes more yield loss than those of the third generation (Kfir *et al.,* 2002; De Groote, 2002).

2.6 Economic importance of green mealies in the smallholder sector

Green mealies are a vital source of income generation for many smallholder farmers in Zimbabwe. It is important for farmers to manage the crop in order to exploit the full potential of the green mealies. One way is to manage stem borer attack during the production process as they affect the size and quality of the cobs. Improvement of yield and quality of green mealies is crucial in guaranting high income for farmers and nourishment for consumers in Zimbabwe (Mudita *et al.,* 2014).

Green mealies are a source of income to smallholder farmers who grow maize in irrigation schemes during the off-season. In Zimbabwe, green mealies production is a horticultural enterprise and markets prices are not controlled by the government as is the case with dry maize grain, the staple food crop. Green mealies are actively marketed in direct marketing channels such as farmer's markets and roadside stands, as fresh, boiled or roasted cobs. The price of green mealies depends largely on the size and quality of the cob and time of supply (Mudita *et al.,* 2014).

2.7 Pest management

Most stem borer attack on cereal crops results from infestation by more than one species and, since there are important differences in biology and ecology that limit the effectiveness of some control techniques, integrated pest management programmes must be devised to meet local conditions and resources (Klopper, 2008). Different chemical and non-chemical control measures have been developed and applied since 1920 in South Africa. The main elements available for inclusion in modern IPM programmes are cultural, biological, chemical controls, as well as host plant resistance.

2.7.1 Cultural control

Cultural control is the practice of modifying the growing environment to reduce the prevalence of unwanted pests (ISU, 2012). Cultural methods and practices that can be used to control stem borers include appropriate crop residue disposal, planting date manipulation, host resistance, destruction of volunteer and alternative host plants, tillage practices, crop rotation and intercropping (Chinwada *et al.,* 2001; Cugala, 2002). These control measures do not guarantee 100% control, but help to reduce infestation and enable sustainable maize production (ISU, 2012).

Cultural control is useful because it combines effectiveness with minimal extra labour and cost. Appropriate disposal of crop residues after harvest can reduce carry-over populations of diapause larvae and so limit initial establishment in the following season's crop. Later sowing of maize is less affected by stem borer larvae than earlier sowings as it disrupts their seasonal cycle (ISU, 2012). In Ethiopia, the infestation of

late-sown maize, 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).

Deep ploughing is effective as it brings the larvae and pupae to the soil surface. The larvae will be then exposed to the heat from the sun and predators like cattle egret (*Bubulcus ibis*). Deep ploughing also controls stem borers by burying, pupae and thus moths fail to emerge from great depths. However, minimum tillage provides insect pests with shelter from plant materials. This may lead to an increase in the number of pests and must be avoided if stem borer numbers are to be reduced. Crop rotations are effective against mono and oligophagous pests. Intercropping reduces pest populations on a crop by reducing the visual and olfactory stimuli which attract pests onto a crop. It also leads to stem borer oviposition on non-host crop plants.

As a result, larvae emerging from eggs on non hosts die due to starvation and this reduces the number migrating to host plants (Ampong- Nyarko *et al.,* 1995). Studies in Kenya suggested that intercropping maize and/or sorghum with cowpeas may reduce damage caused by *B. fusca* (Abate, 2002). Stubble and old stems of maize and sorghum constitute an important reservoir for stem borer infestation. Therefore, managing crop residues by exposing old stems to the sun and heat reduced carryover of infestation and has proved to be suitable for both commercial and subsistence farmers because of the low input of labour and money (ISU, 2002).

2.7.2 Host plant resistance

Host resistance to insects is the genetic property that enables a plant to avoid, minimize, tolerate or recover from injury caused by the pests. These plants have genetic traits which manifest as antibiosis, in which the biology of the pest is adversely affected after feeding on the plant. Furthermore, they can have genetic traits which manifest as antixenosis (non preference) where the plant is not desirable as a host and the pest seeks alternative hosts.

They can also be tolerant and able to withstand or recover from the pest damage (Mugo *et al.,* 2001). Reduced preference for oviposition, reduced feeding due to the presence of some chemicals in the plants, reduced ability to be tunneled and plant's tolerance to leaf damage, dead heart and stem tunneling are some of the mechanisms of host plant resistance. Destruction of volunteer and alternative host plants reduce overwintering and hibernation of stem borer species. Stubble is probably the main source of initial stem borer infestation in subsequent seasons (Klopper, 2008).

2.7.3 Biological control

Natural enemies play an important role in the control of lepidopterous borers in Africa. Biological control is the use of parasitoids, predators, nematodes and/or pathogens to maintain density of a species at a lower level than would occur in their absence. The main attraction of this control technique is that it lowers the need for using chemicals and there is limited environmental pollution, which may affect non-targeted flora and

fauna (Mushore, 2005). It usually offers a lasting solution of stem borer control from one introduction and hence is beneficial to both smallholder and commercial farmers.

Some parasitoids attack eggs, others attack larvae, while some attack pupae. *Trichogramma* spp. (Hymenoptera: Trichogrammatidae) and *Platytelenomous busseola* (Gahan) (Hymenoptera: Scelionidae) are egg parasitoids, that contribute to natural mortality of stem borers in South Africa. Hymenopteran parasitoids such as *Cotesia* spp. have highly specialized ovipositors for stinging and depositing eggs in the host. The sting causes permanent paralysis in the host body (Mushore, 2005). *Cotesia* spp. parasitize larvae of stem borer species (Cugala, 2002).

Egg parasitism offers good control in that it stops the emergence of the damaging larval stage. Thus damage to the crop is avoided. *Dentichasmiasis busseolae* (Heinrich) (Hymenoptera: Ichneumonidae), *Pediobus furvus* (Gahan) (Hymenoptera: Eulophidae), *Lepidoscelio* spp. (Hymenoptera: Scelionidae) and *Xanthopimpla stemmator* (Thunberg) (Hymenoptera: Ichneumonidae) are parasitoids of stem borers in Southern Africa. In South Africa, *Procerochasmiasis nigromaculatus* Cameron (Hymenoptera: Ichneumonidae) was recorded with up to 100% pupal parasitism on *B. fusca*. In addition, in South Africa, the parasitoid *Cotesia sesamiae* (Cameron) (Hymenoptera: Braconidae) accounted for up to 90% of parasitized *B .fusca* larvae, but has not yet been able to maintain populations below economic threshold levels (Klopper, 2008).

Parasitoids of hosts which feed in exposed situations usually pupate in protective silken cocoons produced by the larvae themselves. Some parasitoids can pupate within the

eaten out body of the host. Parasitoids of hosts which feed in exposed situations usually pupate in protective silken cocoons produced by the larvae themselves (Mushore, 2005).

In Ghana, exotic species of *Trichogramma* showed high fecundity and helped to control stem borers, including *B. fusca*. In Southern Benin, *Telenomus busseolae* (Gahan) and *Telenomus isis* (Polaszek) (both Hymenoptera: Scelionidae) are the most important egg parasitoids of over 90% of *B. fusca* and *S. calamistis* in maize (Schulthess *et al.,* 2001; Chabi-Olaye *et al.,* 2001). In Ethiopia, the braconid, *Dolichogenidea fuscivora* was found to be a major larval parasitoid of *B. fusca* with parasitism as high as 71% being recorded in the dry season and 18% in the wet season (Worku *et al.,* 2011).

Cotesia sesamiae is the most important larval parasitoid of *B. fusca* with 20 to 25% parasitism recorded in Ethiopia (Worku *et al.*, 2011). It also parasites *S. calamistis* larvae. *Pediobius furvus* is a gregarious primary pupal parasitoid of *B. fusca* in maize and sorghum in Ethiopia. *Stenobracon rufus* is a solitary pupal parasitoid of *B. fusca* attacking maize and sorghum in Ethiopia with parasitism of 14% having been recorded (Worku *et al.,* 2011).

In Zimbabwe, many natural enemies associated with maize stem borers have been recorded in the highveld region and outside (Chinwada and Overholt, 2001). These include the egg-larval braconid parasitoid *Chelonus curvimaculatus* Cameron, braconid larval parasitoids such as *C. sesamiae, Bracon sesamiae* Cameron and *Dolichogenidea polaszeki* Walker, *Sturmiopsis parasitica* (Curran) (Diptera: Tachinidae) and the

ichneumonid pupal parasitoids *D. busseolae* and *P. nigromaculatus* (Chinwada and Overholt, 2001; Chinwada *et al.,* 2001).

In Zimbabwe, both *C. sesamiae* and *S. parasitica* seem to play a significant role in stem borer larval population regulation. During the 1996-1997 season, Chinwada and Overholt (2001) reported *C. sesamiae* parasitism fluctuating from a low of 4.9% in January, peaking at 25.8% in April and declining to 13.8% by May. During the same period, the study revealed parasitism by *S. parasitica* at a peak of 18.5 % in January, declining to 9.6% in February and there after declining sharply to end at 1.3 % in May.

It was hypothesized that the observed fluctuations in larval parasitism patterns by the two parasitoids species could be a pupative niche-partitioning mechanism which is brought about mainly by differences in life history and host attack strategies of the two parasitoids (Chinwada and Overholt, 2001).

Predators are valuable components of IPM. Ants (Hymenoptera: Formicidae) are the most important predators of stem borers in maize fields (Bonhof, 2000). They attack all stages of stem borers and are among the few predators preying on stem borer larvae and pupae. Some ant species that have been recorded as stem borer natural enemies include *Componotus, Pheidole* and *Lepisiota* spp. (Bonhof, 2000). In Ethiopia, earwigs (Dermaptera: Forficulidae) and ants were commonly seen preying on *B. fusca* (Wale *et al*., 2006).

Entomopathogenic viruses, bacteria and fungi can also be used to control insect pests. *Bacillus thuringiensis* (Bt) lowered stem borer larvae in Kenya with a consequent

increase in crop yield. *Beauveria bassiana* is known to control *C. partellus* by infecting insect hosts through the skin. This enables such pathogens to kill piercing and sucking pests which may not be killed by stomach poisons. High humidity is, however needed for *Beauveria bassiana* germination (Sithole, 1990).

2.7.4 Insecticidal control

Chemical insecticides are used in some sub-Saharan countries for the control of lepidopterous borers. These chemicals insecticides fall under different chemical groups namely, methyl and dimethyl carbamates of heterocyclic compounds, organochlorines, pyrethroids, organophosphates and carbamates such as carbofuran.

However, the majority of African farmers cannot afford to buy insecticides, which are also seldom available on time. These farmers also have limited knowledge on the safe use of the insecticides. In addition, insecticides have negative impact on the environment as they are a health hazard to humans and may not be compatible with other means of control such as biological control (Brown, 2013). In Zimbabwe, stem borer control using chemicals dates back to the beginning of the last century. Some of the earliest chemicals recommended on maize included carbolic and arsenic cattle dips (Arnold, 1928).

Currently, several insecticides, formulated as either granules or spray applications, are registered for stem borer control in Zimbabwe (Chinwada *et al.,* 2001). The most common ones include carbaryl, endosulfan, trichloforn, carbofuran and synthetic pyrethroids. These chemicals have been screened in both maize and sorghum crops in

various agro-ecological regions of Zimbabwe and found to provide effective control (Chinwada *et al.,* 2001).

In Zimbabwe under the smallholder sector, granular insecticides like Dipterex® 2.5 GR (trichloforn) are the most widely used as whorl-applied granular insecticides because of their ease of application and lack of the requirement for special application equipment. They are also easy and safe to handle and can be applied accurately in a controlled manner by hand.

In South Africa and Nigeria, insecticide such as carbofuran at 1.0-2.5 kg/ha gave good stem borer control up to seven weeks after emergence. Bulldock® 0.05 GR (beta-cyfluthrin) has been found to be effective for the control of *B. fusca* in Burundi. In Cote d'Ivoire, deltamethrin as an emulsifiable concentrate at 15 g active ingredient/ha and carbofuran as granules at 200 g active ingredient/ha gave economical control of *S. calamistis* and other stem borers in maize. However, borers found in the ear could not be controlled by endosulfan, chlorpyrifos, phoxin, carbofuran, deltamethrin, cypermethrin and *B. thuringiensis* (Moyal, 1989).

A single application of endosulfan against *C. partellus* was found to be beneficial when applied shortly before tasselling in maize and before panicle emergence in grain sorghum in South Africa. In Mozambique, it was shown that when insecticides are applied against *C. partellus* in maize, yield can increase two - to four - fold. The recommendation is to apply diazinon twice into the whorl when the plants are three and five weeks old. Placement of granular dusts of endosulfan, carbaryl, trichloforn, beta-

cyfluthrin, malathion, or fenvalerate in maize leaf whorls is effective in controlling stem borers. For example, Bulldock® 0.05 GR and Dipterex® 2.5 GR were the most frequently used granular insecticides in Kenya and gave good control of stem borers (Bonhof *et al.,* 2001).

However, soil systemic insecticides are not suitable for use in borer control if the maize crop is intended for consumption as green mealies. Green mealies are harvested much earlier than grain maize, and residues of the chemical may still be higher than desired within the plant. In addition, chemical control may also result in low population levels of parasitoids and possibly other natural enemies (Kfir, 2002).

The time of application of any kind of spray is crucial because stem borers are difficult to control with insecticides (Vitale *et al.,* 2007). The reason presumably being that, existing spray-based practices have been found ineffective against internal feeders and are costly and hazardous (ICIPE, 2000; James, 2003). Spraying should be done before the moths lay their eggs or when larvae are at their most vulnerable stage (feeding at the base of the leaves) than when they have started tunneling into stalks and thus cannot be controlled with insecticides (ISU, 2012)

2.7.5 Stem borer control by whorl applications of ammonium nitrate

Some commercial farmers in Zimbabwe claim that ammonium nitrate in the funnel helps to control stalk borer in maize. When the maize is knee high, the ammonium nitrate (AN) is applied with a rotary fertilizer spreader ‘vicon’, and in the process some of the ammonium nitrate granules fall into the funnels. This control method is considered

adequate if the stalk borer infestation is light. Heavier infestations are controlled using chemical means (Mbenga, 2010). Farmers without vicon, apply AN in the funnel through placing few granules in maize funnel with the expectation that the stem borers are killed by the fertilizer. Due care should be taken when applying AN in the funnel as leaf burning can occur if applied in excess (Nelson *et al.,* 2003).

2.7.6 Integrated Pest Management

Integrated Pest Management refers to a broad-based approach to pest management that integrates biological, cultural and chemical control of pests with the aim of suppressing pests below the Economic Injury Level (EIL) (Bajwa and Kogan, 2002; Ehler, 2006) while reducing negative impacts on the environment (Jean-Pierre *et al.,* 2013). Integrated Pest Management protects crops based on specific field information, using both preventive and curative tactics to manage pests. It places emphasis on scouting and thorough record keeping.

The benefit of IPM is the management of pests economically, with minimal use of pesticides and reduced insecticide resistance (ISU, 2012). Farmers can obtain higher yields and increase green mealies profitability through IPM. In Zimbabwe many natural enemies have been recorded attacking both larvae and pupae of stem borers (Chinwada *et al.,* 2001) and their activity needs to be enhanced through appropriate conservation techniques.

The utilization of cultural practices such as appropriate crop residue disposal, planting date manipulation, destruction of volunteer and alternative host plants, host resistance,

tillage practices, crop rotation and intercropping must be considered too (Chinwada *et al.,* 2001). Where biological and cultural controls fail to suppress stem borers below the EIL (10%), chemical control can be used concurrently with biological/and/ or cultural practices if possible. A "push-pull" strategy can also be used by farmers to control the pests. One form of a "push-pull" strategy is whereby a farmer plants Napier grass around the field and *Desmodium* legume (silverleaf and Greenleaf *Desmodium*) as intercrops. The legume will repel "push away" the insect pest from the field, while the Napier will attract it away "pull" from the crop. The pest will oviposit on the Napier grass instead of the crop (Uwumukiza *et al.,* 2012).

2.8 Determination of threshold values and scouting of maize fields

The Economic Threshold Level (ETL) is that level of damage at which control measures should be implemented to prevent an increasing pest population from reaching the EIL (ISU, 2012). The ETL for control of *B. fusca* in commercial maize farming systems in South Africa is when 10% of plants in a field showing whorl damage symptoms (Van den Berg and Rensburg, 1993). In Zimbabwe, an ETL of 16% was determined by Sithole (1995) for *B. fusca* in maize and sorghum. These ETL values are only applied to commercial farming systems where the cash value of the crop is high (Polaszek, 1998).

Stem borer oviposition patterns are not linked to planting dates but remain constant in relation to plant age. An ETL of 5% oviposition, was determined based on the incidence of *B. fusca* egg batches on maize plants. However, this ETL is not commonly used due to its being labour intensive (Polaszek, 1998).

The control of *C. partellus* in commercial maize in South Africa is recommended when 40% of plants show symptoms of larval feeding in the whorls. This difference between the ETL of *B. fusca* and *C. partellus* is due to lower comparative injuriousness of *C. partellus* on maize in South Africa (Van den Berg and Rensburg, 1993).

An economic threshold value can also be based on the percentage whorl damage found in a maize field. It is important to scout the inner (youngest) leaves of whorls since this will indicate the most recent damage symptoms. Scouting efforts should be concentrated between two to seven weeks after crop emergence to ensure that producers have ample time to react (Klopper, 2008).

CHAPTER 3

MATERIALS AND METHODS

3.1 Description of the study site

A set of trials to evaluate the effect of maize stem borers and their management in green mealies was conducted at Africa University farm (18º53'70, 3'' S: 32º 36'27.9'' E, 1,131 m above sea level), Mutare, Zimbabwe during the 2014-2015 farming season. The area falls under Natural Farming Region II. Average day length is 14 hours in summer and 11 hours in winter and annual rainfall ranges from 750 mm to 1,200 mm. Rain falls mostly in the months December to February although heavy showers are possible before and after this period. The average maximum temperature ranges from 18 º C in July to 32 º C in October (World Weather Online, 2014). The soils are classified as sandy clay loam of the red Fersiallitic 5E series under Zimbabwe soil classification (Nyamapfene, 1991).

3.2 Experimental design and treatments

Three maize varieties, SC 513 (maturing maturing), SC 608 (medium to late maturing) and PHB 30B50 (medium to late maturing) were evaluated for their responses to stem borer infestation in a field experiment laid out in a Randomized Complete Block Design (RCBD) with three replicates. The distance between the blocks was 1.5m and the distance between plots in a block was 1 m. Each plot was 4m x 3.6 m with five rows. Each row had 13 plant stations spaced 30 cm apart. For each variety, four treatments were applied: (1) placing ammonium nitrate (AN) (34.5% N) in the maize funnel,

(2) funnel applications of Bulldock® 0.05 GR granules (a.i. beta-cyfluthrin 0.5 g/kg) at 3-4 kg/ha, (3) funnel applications of Dipterex® 2.5 GR granules (a.i. trichloforn 2.5 g/kg) at 3-4 kg/ha and (4) untreated control. The two chemicals used in the experiment are commonly used for stem borer control in Zimbabwe. The difference treatments were applied at 42 and 28 days after planting in the first and second trials, respectively and subsequently at 14 day intervals up to tasseling.

3.3 General trial management

The experimental site was ploughed to a depth of 25 cm, disked and harrowed to ensure a fine soil tilth. The site was leveled manually and divided into three blocks and 36 plots. Two trials were prepared with a total land area of 1,152 m^2 (0.1152 hectare). The first trial was planted in August 2014 and the second in October 2014. The reason for having two plantings was to determine whether stem borers were a problem in the first part or the second part of the dry season before the rains. Maize seeds were sown manually. Two seeds were planted per station at a spacing of 90 cm between rows and 30 cm within rows. After emergence, thinning was carried out so as to remain with one plant per station for the net plot rows. The seeds were sown at a depth of 3-5 cm. As the seedlings were emerging, Lambda- cyhalothrin® 2.5 EC insecticide was applied within the rows to control cutworms. N:P_2O_5:K_20 compound D 8-14-7 was applied as a basal fertilizer in each planting station at a rate of 300 kg per hectare in all treatments. For both trials, top dressing with AN was conducted at 49 days after planting at the rate of 300 kg/ha and applied at 63 days after planting at the rate of 150 kg/ha. Sprinkler irrigation was applied at 48 mm/12 hr as a net discharge per cycle. Weeding was carried

out at three, six and nine weeks after crop emergence. The common weeds were gallant soldier, wandering jew, couch grasses, upright starbur, black jack and nutsedge. Harvesting for both trials was done manually at 16 weeks after crop emergence.

3.4 Insect pest identification

Correct recognition and identification of insect pests is an important first step to making a proper management decision regarding any insect species found in maize (ISU, 2012). Visual examination for symptoms of funnel feeding, presence of dead- hearts and/or stem tunneling was done to establish whether crops have been attacked. Samples of affected stems were removed and dissected to retrieve larvae and pupae from which adults were reared for identification using the protocol developed by Polaszek (1998). Stem borer larvae were collected and put in glass vials. The larvae were fixed by immersing them in hot water. The fixed specimens were then placed in 70% alcohol in glass vials and viewed under a stereo microscope. Larval chaetotaxy was used to distinguish between the larvae of *B. fusca* and *C. partellus. Busseola fusca* larvae have the crochets arranged in a semicircle while the crochets in a *C. partellus* larva are arranged in a complete circle (Harris and Nwanze 1992; Meijerman and Ulenberg 1996 Hutchison *et al.* 2008).

However, these features cannot distinguish between *B. fusca* and *S. calamistis* as the larvae are very similar in morphology. They can only be distinguished in the adult stages. To distinguish *B. fusca* from *S. calamistis* pupae were collected from infested stems and placed in plastic vials and reared to the adult stage. Positive identification of

the species was then made based on protocols developed by Polaszek (1998) and Le Rü *et al*. (2006). All stem borer life stages were incubated individually in vials under ambient conditions in the laboratory for at least two weeks to observe the emergence of any parasitoids or the pupation of non-parasitized larvae.

3.5 Identification of associated parasitoids

Samples of infested stems were obtained from the trials and dissected to retrieve stem borer larvae and pupae. The larvae and pupae were collected from the trials were put into one vial and covered using a lid. They were reared under ambient conditions in the laboratory for at least two weeks. Stem borer egg batches were also collected and placed in the glass vials and reared in the laboratory under ambient temperature for their development. Vials were monitored regularly to observe possible emergence of any parasitoids. The parasitoid clutches that emerged from stem borer larvae and pupae were kept separately in glass vials and preserved in 70% alcohol. Vials were appropriate labeled to show the location from which they were collected, date of collection, date of parasitoid emergence and the name of the collector. Emerging parasitoids were identified using taxonomic keys outlined by Polaszek (1998).

3.6 Collection of field data

Data was collected on a weekly basis starting from week 5 and 3 after crop planting when infestations started to build up in the first and second trials respectively. The following data were recorded: number of infested plants, number of plants with windowed leaves, number of plants with dead-hearts, number of completely dead plants,

plant height, cob yields (in terms of weights of marketable cobs), plant biomass weight and weekly percentage parasitism.

Cob damage scores was assessed based on a 1 – 5 scale (where 1 was 1 hole on the cob and 5 more than 7 holes on the cob) (Table 3.1). An average of less than one was considered as none

Table 3.1 Damage scores key

Damage intensity	Score	Description of score
Least damage score	1 =	1 hole on the cob
↕	2=	1 but not more than 2 holes on the cob
Moderate damage	3=	3 but not more than 4 holes on the cob
↕	4=	5 but not more than 7 holes on the cob
Severe damage	5=	more than 7 holes on the cob

Plant height was determined by measuring three randomly tagged plants every week from ground level to the tip of the terminal emerging leaf. The measurements were taken from sixth and third week after crop emergence of the first and second trials respectively, up to 10^{th} week when the plants tasseled. As the cob was maturing, the heights and diameters of three randomly tagged plants were measured every week from week 12 after emergence with the aid of ruler and a rope up to harvesting at week 16.

Plant biomass weight was recorded by weighing plants from the net plot together with the cob(s) on an electronic weighing balance.

3.7 Data analysis

The data were analyzed using Genstat 5 statistical package. The data were subjected to analysis of variance (ANOVA) and the means of the parameters were separated using the least significance difference (LSD) at P= 0.05.

CHAPTER 4

RESULTS

4.1 Identity of stem borer species

Busseola fusca (Plate 4.1) and *C. partellus* (Plate 4.2) were the two stem borer species that were recorded damaging the green mealies.

Plate 4.1 Adult of *Busseola fusca* Fuller

Plate 4.2 Adult of *Chilo partellus* Swinhoe

4.2 Plant heights (cm) of yellow maize variety SC 608 for the August and October plantings

In the August planting, at week 6 there was no significant difference ($P > 0.05$) across all the treatments on plant heights. At weeks 7-10 Dipterex® 0.05 GR and Bulldock® 0.05 GR were not significantly different ($P > 0.05$) from each other on plant heights and AN in the funnel and the control were also not significantly different from each other on plant heights. There were significant differences ($P < 0.05$) between Dipterex® 2.5 GR , AN in the funnel and the control and also between Bulldock® 0.05 GR, AN in the funnel and the control on plant heights (Table 4.1).

Table 4.2 Plant heights (cm) of yellow maize variety SC 608 from week 6 to week 10 for the August planting

Treatments	Weeks				
	6	7	8	9	10
Control	57.00	65.78[a]	86.11[a]	139.33[a]	176.33[a]
Dipterex® 2.5 GR	59.11	77.55[b]	88.99[b]	145.66[b]	179.89[b]
Bulldock® 0.05 GR	58.77	76.66[b]	89.33[b]	146.00[b]	181.55[b]
AN in the funnel	57.89	68.78[a]	87.33[a]	141.22[a]	175.33[a]
Significance of F	N.S.	***	**	**	**
$L.s.d_{(0.05)}$	-	3.024	1.727	3.309	3.417
CV%	1.9	2.2	1.0	1.2	1.0

Means followed by the same letter in a column are not significantly different from each other at $P = 0.05$.

Key of significance (** at $P < 0.01$; *** at $P < 0.001$; N.S: No significant difference).

For the October planting, at weeks 4-10, Dipterex® 2.5 GR and Bulldock® 0.05 GR had plants of similar size but these were significantly larger ($P < 0.01$) than those in the AN control treatments. Plants in the latter two treatments were of similar size (Table 4.2).

Table 4.3 Plant heights (cm) of yellow maize variety SC 608 from week 4 to week 10 for the October planting

Treatments	Weeks						
	4	5	6	7	8	9	10
Control	13.88[a]	29.00[a]	53.33[a]	63.44[a]	88.44[a]	142.88[a]	179.22[a]
Dipterex® 2.5 GR	15.22[b]	30.33[b]	54.55[b]	67.88[b]	93.44[b]	146.33[b]	182.44[b]
Bulldock® 0.05 GR	15.55[b]	30.44[b]	54.33[b]	67.88[b]	93.55[b]	147.77[b]	181.66[b]
AN in the funnel	14.33[a]	29.22[a]	53.44[a]	62.77[a]	87.66[a]	143.55[a]	178.11[a]
Significance of F	***	**	***	***	***	**	***
$L.s.d_{(0.05)}$	0.6253	0.920	0.5073	1.306	0.884	2.034	1.715
CV%	2.3	1.6	0.5	1.1	0.5	0.7	0.5

Means followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001).

4.3 Plant heights (cm) of yellow maize variety PHB 30B50 for the August and October plantings

In the August planting, at week 6 there was no significant difference (P > 0.05) on plant heights across all the treatments. At weeks 7 – 10 there were no significant differences (P > 0.05) between Dipterex® 2.5 GR and Bulldock® 0.05 GR and also between AN in the funnel and the control on plant heights. There were significant differences (P < 0.05) between Dipterex®, AN in the funnel and the control and also between Bulldock® 0.05 GR, AN in the funnel and the control on plant heights (Table 4.3).

Table 4.4 Plant heights (cm) for PHB 30B50 from week 6 to week 10 for the August planting

Treatments	Weeks				
	6	7	8	9	10
Control	58.88	71.66[a]	86.00[a]	139.88[a]	175.66[a]
Dipterex® 2.5 GR	57.44	75.22[b]	88.99[b]	146.66[b]	183.44[b]
Bulldock® 0.05 GR	58.88	75.11[b]	89.11[b]	148.78[b]	182.11[b]
AN in the funnel	58.88	70.11[a]	87.22[a]	140.77[a]	177.11[a]
Significance of F	N.S.	**	**	***	***
$L.s.d_{(0.05)}$	-	2.528	1.650	2.126	2.492
CV%	1.5	1.8	1.0	0.8	0.7

Means followed by the same letter in the column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001; N.S: No significant difference).

For the October planting, at week 4 there was no significant differences (P > 0.05) in plant heights among the treatments. At weeks 5 – 10, there were no significant differences (P > 0.05) among treatments Dipterex® 2.5 GR and Bulldock® 0.05 GR and also among AN in the funnel and the control. Significant differences (P < 0.05) were observed between Bulldock® 0.05 GR, AN in the funnel and the control and also between Dipterex® 2.5 GR, AN in the funnel and the control on plant heights (Table 4.4).

Table 4.5 Plant heights (cm) of yellow maize variety PHB 30B50 from week 4 to week 10 for the October planting

Treatments	Weeks						
	4	5	6	7	8	9	10
Control	14.11	28.33[a]	49.11[a]	63.33[a]	88.40[a]	143.66[a]	175.00[a]
Dipterex® 2.5 GR	14.11	30.88[b]	50.88[b]	67.77[b]	92.22[b]	146.99[b]	177.88[b]
Bulldock®0.05 GR	14.11	30.77[b]	50.66[b]	69.11[b]	94.11[b]	148.99[b]	177.77[b]
AN in the funnel	14.00	29.21[a]	48.66[a]	63.66[a]	88.00[a]	144.77[a]	173.77[a]
Significance of F	N.S.	***	**	**	***	**	**
$L.s.d_{(0.05)}$	-	0.6284	1.355	2.954	2.304	2.759	1.803
CV%	1.2	1.1	1.4	2.4	1.3	1.0	0.5

Means followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001; N.S: No significant difference).

4.4 Plant heights (cm) of white maize variety SC 513 for the August and October plantings

For the August planting, at weeks 6 - 10 there were no significant differences (P > 0.05) between Dipterex® 2.5 GR and Bulldock® 0.05 GR and also between AN in the funnel and the control on plant heights. There were significant differences (P < 0.05) between Dipterex® 2.5 GR, AN in the funnel and the control and also between Bulldock® 0.05 GR, AN in the funnel and the control on plant heights (Table 4.5).

Table 4.6 Plant heights (cm) of white maize variety SC 513 from week 6 to week 10 for the August planting

Treatments	Weeks				
	6	7	8	9	10
Control	55.89[a]	68.77[a]	89.11[a]	142.22[a]	172.00[a]
Dipterex 2.5 GR	59.66[b]	77.44[b]	92.77[b]	148.44[b]	179.11[b]
Bulldock 0.05 GR	59.44[b]	77.33[b]	93.33[b]	148.22[b]	178.55[b]
AN in the funnel	56.88[a]	70.11[a]	89.66[a]	141.44[a]	174.77[a]
Significance of F	**	***	**	**	***
$L.s.d_{(0.05)}$	2.034	2.124	2.120	4.271	2.897
CV%	1.9	1.5	1.2	1.6	0.9

Means followed by the same letter in the column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001).

For the October planting at week 4 there was no significant difference (P > 0.05) on plant heights across all the treatments. At weeks 5 - 10 there were no significant differences (P > 0.05) between Dipterex® 2.5 GR and Bulldock® 0.05 GR and also between AN in the funnel and the control on plant heights. Significant differences (P < 0.05) were observed between Bulldock® 0.05 GR, AN in the funnel and the control and also between Dipterex® 2.5 GR, AN in the funnel and the control on plant heights as indicated in table 4.6.

Table 4.7 Plant heights (cm) of white maize variety SC 513 from week 4 to week 10 for the October planting

Treatments	Weeks						
	4	5	6	7	8	9	10
Control	12.44	30.11[a]	53.66[a]	64.11[a]	88.99[a]	142.00[a]	172.00[a]
Dipterex® 2.5 GR	13.22	32.88[b]	59.11[b]	69.22[b]	94.11[b]	149.00[b]	179.11[b]
Bulldock® 0.05 GR	12.99	32.22[b]	58.44[b]	68.66[b]	93.88[b]	148.55[b]	178.55[b]
AN in the funnel	12.88	29.99[a]	54.44[a]	64.00[a]	89.44[a]	143.78[a]	174.77[a]
Significance of F	N.S.	**	***	***	**	***	***
$L.s.d_{(0.05)}$	-	1.631	0.993	1.318	2.584	2.729	2.897
CV%	3.7	2.8	0.9	1.1	1.5	1.0	0.9

Means followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001; N.S: No significant difference).

4.5 Windowed leaves on yellow maize variety SC 608 for the August and October plantings

For the August planting at weeks 6 there was no significant difference (P > 0.05) on windowed leaves across all the treatments. At weeks 7 - 10 Bulldock® 0.05 GR and Dipterex® 2.5 GR were not significantly different (P > 0.05) from each other and also AN in the funnel and the control were not significantly different from each other on windowed leaves. Significant differences (P < 0.05) were noted between Bulldock® 0.05 GR, AN in the funnel and the control and also between Dipterex® 2.5 GR, AN in the funnel and the control on windowed leaves (Table 4.7).

Table 4.8 Windowed leaves on SC 608 from week 6 to week 10 for the August planting

Treatments	Weeks					% inf
	6	7	8	9	10	10
Control	2.00	4.00[b]	5.00[b]	10.67[b]	11.33[b]	29.6
Dipterex® 2.5 GR	1. 33	2.67[a]	3.67[a]	3.67[a]	3.67[a]	11.1
Bulldock® 0.05 GR	1.67	2.00[a]	2.00[a]	2.00[a]	2.00[a]	7.4
AN in the funnel	1.67	4.67[b]	5.33[b]	7.33[b]	8.67[b]	24.4
Significance of F	N.S.	**	***	***	***	
$L.s.d_{(0.05)}$	-	1.215	0.769	1.631	0.941	
CV%	30.0	19.4	10.2	14.6	7.8	

Mean followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001; N.S: No significant difference; % inf: Percentage infestation).

For the October planting at weeks 4 - 6 there was no significant difference (P > 0.05) across all the treatments on windowed leaves. At weeks 7 - 10 there were no significant differences (P > 0.05) between AN in the funnel and the control and also between Bulldock® 0.05 GR and Dipterex® 2.5 GR on windowed leaves. There were significant differences (P < 0.05) between Dipterex® 2.5 GR, AN in the funnel and the control and also between Bulldock® 0.05 GR, AN in the funnel and the control on windowed leaves as shown in table 4.8. There was more damage in the August planting as opposed to the October planting (Tables 4.7 and 4.8).

Table 4.9 Windowed leaves on SC 608 from week 4 to week 10 for the October planting

Treatments	Weeks							% inf
	4	5	6	7	8	9	10	10
Control	1.00	1.33	2.67	2.67[b]	3.00[b]	3.67[b]	5.00[b]	18.5
Dipterex® 2.5 GR	1.00	1.00	1.33	1.33[a]	2.00[a]	2.00[a]	2.00[a]	7.4
Bulldock® 0.05 GR	1.00	1.00	1.33	1.33[a]	1.33[a]	1.33[a]	1.33[a]	3.7
AN in the funnel	1.333	1.33	3.00	3.33[b]	7.33[b]	7.67[b]	10.67[b]	15.3
Significance of F	N.S.	N.S.	N.S.	*	***	***	****	
$L.s.d_{(0.05)}$	-	-	-	1.438	0.769	0.941	0.769	
CV%	26.6	35.0	48.0	35.3	11.9	13.6	8.6	

Mean followed by the same letter in a column are not significantly different from each other at P = 0.05.
Key of significance (* at P < 0.05; *** at P < 0.001; N.S: No significant difference; % inf: Percentage infestation).

4.6 Windowed leaves on yellow maize variety PHB 30B50 for the August and October plantings

For the August planting at week 6 there was no significant difference (P > 0.05) across all the treatment on windowed leaves. At week 7 the control, Dipterex® 2.5 GR and Bulldock® 0.05 GR were not significantly different (P > 0.05) from each other. AN in the funnel was significantly different (P < 0.05) from the control, Dipterex® 2.5 GR and Bulldock® 0.05 GR (Table 4.9).

At weeks 7 - 10 Bulldock® 0.05 GR and Dipterex® 2.5 GR were not significantly different (P > 0.05) from each other and AN in the funnel and the control were also not significantly different from each other on windowed leaves. Dipterex® 2.5 GR was significantly different (P < 0.05) from AN in the funnel and the control and Bulldock® 0.05 GR was also significantly different from AN in the funnel and the control on

windowed leaves (Table 4.9). There was more damage in the August planting as compared to the October planting (Tables 4.9 and 4.10).

Table 4.10 Windowed leaves on PHB 30B50 from week 6 to week 10 for the August planting

Treatments	Weeks					% inf
	6	7	8	9	10	10
Control	1.33	2.67[a]	6.00[b]	10.00[b]	11.00[b]	40.7
Dipterex® 2.5 GR	1.33	2.33[a]	2.33[a]	3.00[a]	3.67[a]	11.1
Bulldock® 0.05 GR	1.67	1.67[a]	1.67[a]	1.67[a]	2.00[a]	7.4
AN in the funnel	2.67	4.00[b]	5.33[b]	8.33[b]	10.00[b]	37
Significance of F	N.S.	**	*	***	***	
$L.s.d_{(0.05)}$	-	0.941	2.824	0.769	1.719	
CV%	43.6	18.8	39.1	7.1	13.7	

Means followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (* at P < 0.05; ** at P < 0.01;*** at P < 0.001; N.S: No significant difference; % inf: Percentage infestation).

For the October planting as indicated in table 4.10, there was no significant difference (P > 0.05) on windowed leaves across all the treatments at weeks 4 - 7. At weeks 8 - 10 Bulldock® 0.05 GR and Dipterex® 2.5 GR were not significantly different (P > 0.05) from each other and AN in the funnel and the control were also not significantly different from each other on windowed leaves. There were significant differences (P < 0.05) between Bulldock® 0.05 GR, AN in the funnel and the control and also between Dipterex® 2.5 GR, AN in the funnel and the control on windowed leaves.

Table 4.11 Windowed leaves on PHB 30B50 from week 4 to week 10 for the October planting

Treatments	Weeks							% inf
	4	5	6	7	8	9	10	10
Control	1.00	1.33	1.33	1.33	2.00[a]	2.00[a]	6.67[a]	22.2
Dipterex® 2.5 GR	1.00	1.00	1.00	1.00	1.00[b]	1.00[b]	1.33[b]	3.7
Bulldock® 0.05 GR	1.00	1.00	1.00	1.00	1.00[b]	1.00[b]	1.00[b]	3.7
AN in the funnel	1.33	1.33	1.33	1.33	3.33[a]	3.33[a]	3.67[a]	11.1
Significance of F	N.S.	N.S.	N.S.	N.S.	**	**	***	
$L.s.d_{(0.05)}$	-	-	-	-	1.087	1.087	0.941	
CV%	26.6	35.0	35.0	35.0	31.5	31.5	15.8	

Mean followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001; N.S: No significant difference; % inf: Percentage infestation).

4.7 Windowed leaves on white maize variety SC 513 for the August and October plantings

For the August planting at weeks 6 - 10 no significant differences (P > 0.05) were observed between AN in the funnel and the control and also between Bulldock® 0.05 GR and Dipterex ® 2.5 GR on windowed leaves (Plate 4.3). There were significant differences (P < 0.05) between Bulldock® 0.05 GR, AN in the funnel and the control and also between Dipterex® 2.5 GR, AN in the funnel and the control on windowed leaves (Table 4.11). There was more damage on the August planting than the October planting (Tables 4.11 and 4.12).

Table 4.12 Windowed leaves on SC 513 from week 6 to week 10 for the August planting

Treatments	Weeks					% inf
	6	7	8	9	10	10
Control	3.67[b]	4.33[b]	7.33[b]	9.00[b]	10.33[b]	29.6
Dipterex® 2.5 GR	1.00[a]	1.00[a]	2.33[a]	2.67[a]	2.67[a]	17.2
Bulldock® 0.05 GR	1.33[a]	1.33[a]	1.33[a]	1.33[a]	1.33[a]	16.9
AN in the funnel	2.00[b]	3.67[b]	4.33[b]	5.67[b]	8.00[b]	21.8
Significance of F	***	***	***	***	***	
$L.s.d_{(0.05)}$	0.769	1.331	1.438	2.306	1.331	
CV%	20.4	27.4	19.9	26.2	12.7	

Means followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (*** at P < 0.001; %inf: percentage infestation).

For the October planting at weeks 4 - 6 there was no significant difference (P > 0.05) across all the treatments on windowed leaves (Plate 4.3). At weeks 6 - 10 there were no significant differences between Bulldock® 0.05 GR and Dipterex® 2.5 GR and also between AN in the funnel and the control. There were significant differences (P < 0.05) between Dipterex® 2.5 GR, AN in the funnel and the control and also between Bulldock® 0.05 GR, AN in the funnel and the control on windowed leaves (Table 4.12).

Table 4.13 Windowed leaves on SC 513 from week 4 to week 10 for the October planting

Treatments	Weeks							%inf
	4	5	6	7	8	9	10	10
Control	1.00	1.33	1.33	2.33[a]	3.00[a]	4.00[a]	4.00[a]	14.8
Dipterex® 2.5 GR	1.00	1.00	1.00	1.00[b]	1.67[b]	1.67[b]	1.67[b]	0.8
Bulldock® 0.05 GR	1.00	1.00	1.00	1.00[b]	1.33[b]	1.33[b]	1.33[b]	0.4
AN in the funnel	1.67	1.67	2.00	2.00[a]	2.67[a]	2.67[a]	3.33[a]	13.1
Significance of F	N.S.	N.S.	N.S.	*	*	**	**	
$L.s.d_{(0.05)}$	-	-	-	1.087	1.331	1.331	1.33	
CV%	49.5	51.6	43.3	36.5	32.6	29.3	27.4	

Mean followed by the same letter in a column are not significantly different from each other at P = 0.05.
Key of significance (* at P < 0.05; ** at P < 0.01; N.S: No significant difference; % inf: percentage infestation).

Plate 4.3 Windowed leaf caused by stem borer larvae

4.8 Dead hearts on SC 608, PHB 30B50 and SC 513 for the August and October planting

In both the August and October plantings, whorl applications of Bulldock® 0.05 GR and Dipterex® 2.5 GR significantly reduced dead-heart formation compared to the AN application which did not differ from the untreated control. In general there was more dead- hearts (Plate 4.4) in the August planting than the October planting (Tables 4.13 and 4.14).

Table 4.14 Dead hearts for SC 608, PHB 30B50 and SC 513 for the August planting

Treatments	SC 608	PHB 30B50	SC 513
Control	3.00[b]	3.33[b]	3.13[b]
Dipterex® 2.5 GR	1.67[a]	1.67[a]	1.43[a]
Bulldock® 0.05 GR	1.23[a]	2.33[a]	1.67[a]
AN in the funnel	3.33[b]	4.00[b]	2.67[b]
Significance of F	***	*	**
$L.s.d_{(0.05)}$	0.804	1.631	0.934
CV%	18.5	30.6	22.3

Mean followed by the same letters in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (* at $P < 0.05$; ** at $P < 0.01$; *** at $P < 0.001$).

Plate 4.4 Dead-heart caused by stem borer larvae

Table 4.15 Dead hearts for SC 608, PHB 30B50 and SC 513 for the October planting

Treatments	SC 608	PHB 30B50	SC 513
Control	2.73[b]	2.00[b]	2.57[b]
Dipterex® 2.5 GR	1.10[a]	1.00[a]	1.00[a]
Bulldock® 0.05 GR	1.07[a]	1.00[a]	1.00[a]
AN the in funnel	2.33[b]	3.33[b]	3.67[b]
Significance of F	**	*	**
L.s.d$_{(0.05)}$	0.863	1.438	1.190
CV%	25.3	41.7	30.7

Means followed by the same letter in a column are not significantly different from each other at P = 0.05.

Key of significance (* at P < 0.05; ** at P < 0.01).

4.9 Plant biomass (t/ha) for SC 608, PHB 30B50 and SC 513 for the August and October plantings

In both the August and October plantings, whorl applications of Bulldock® 0.05 GR and Dipterex® 2.5 GR significantly increased plant biomass compared to the AN application which did not differ from the untreated control. In general, the October planting yielded more biomass than the August planting (Tables 4.15 and 4.16).

Table 4.16 Plant biomass (t/ha) for SC 608, PHB 30B50 and SC 513 for the August planting

Treatments	SC 608	PHB 30B50	SC 513
Control	52.02[a]	53.07[a]	51.14[a]
Dipterex® 2.5 GR	62.91[b]	62.72[b]	54.37[b]
Bulldock® 0.05 GR	68.65[b]	59.18[b]	54.86[b]
AN in the funnel	51.86[a]	49.69[a]	49.54[a]
Significance of F	***	***	**
L.s.d$_{(0.05)}$	4.055	1.087	2.178
CV%	3.7	1.0	2.8

Means followed by the same letter in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001).

Table 4.17 Plant biomass (t/ha) for SC 608, PHB 30B50 and SC 513 for the October planting

Treatments	SC 608	PHB 30B50	SC 513
Control	66.53[a]	53.75[a]	53.06[a]
Dipterex® 2.5 GR	69.43[b]	58.72[b]	60.91[b]
Bulldock® 0.05 GR	68.94[b]	64.35[b]	62.32[b]
AN in the funnel	62.33[a]	54.34[a]	51.14[a]
Significance of F	*	***	***
$L.s.d_{(0.05)}$	4.484	4.060	1.087
CV%	3.6	3.7	1.0

Mean followed by the same letter in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (* at P < 0.05; *** at P < 0.001).

4.10 Fresh cob weights (t/ha) for SC 608, PHB 30B50 and SC 513 for the August and October plantings

In both the August and October plantings, whorl applications of Dipterex® 2.5 GR and Bulldock® GR significantly increased fresh cob weights (t/ha) as compared to the whorl application of AN which did not differ from the untreated control. In general there was an increase in fresh cob weights in the October planting as compared to the August planting (Tables 4.17 and 4.18).

Table 4.18 Fresh cob weights (t/ha) for SC 608, PHB 30B50 and SC 513 for the August planting

Treatments	SC 608	PHB 30B50	SC 513
Control	17.35[a]	16.87[a]	16.35[a]
Dipterex 2.5 GR	20.06[b]	19.76[b]	17.83[b]
Bulldock 0.05 GR	19.50[b]	18.35[b]	17.83[b]
AN in the funnel	16.39[a]	15.90[a]	16.39[a]
Significance of F	**	***	**
$L.s.d_{(0.05)}$	1.537	0.788	0.788
CV%	4.5	2.4	2.4

Means followed by the same letter in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (** at P < 0.01; *** at P < 0.001).

Table 4.19 Fresh Cob weights (t/ha) for SC 608, PHB 30B50 and SC 513 for the October planting

Treatments	SC 608	PHB 30B50	SC 513
Control	19.16[a]	18.32[a]	19.16[a]
Dipterex 2.5 GR	23.14[b]	20.25[b]	23.14[b]
Bulldock 0.05 GR	24.10[b]	19.61[b]	24.10[b]
AN in the funnel	20.14[a]	17.87[a]	20.14[a]
Significance of F	***	***	***
$L.s.d_{(0.05)}$	0.5435	0.5435	0.5435
CV%	1.3	1.5	1.3

Mean followed by the same letter in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (*** at P < 0.001).

4.11 Damage scores for SC 608, PHB 30B50 and SC 513 for the August and October plantings

In both the August and October plantings, Dipterex® 2.5 GR and Bulldock® 0.05 GR had less damage scores than that recorded in application of AN in whorl which did not differ from the control. In general the damage scores (Plates 4.5a and 4.5b) for October planting of

maize treated with AN in the funnel and the control were higher than the August planting (Tables 4.19 and 4.20).

Table 4.20 Damage scores for SC 608, PHB 30B50 and SC 513 for the August planting

Treatments	SC 608	PHB 30B50	SC 513
Control	2.03[a]	1.47[a]	2.00[a]
Dipterex® 2.5 GR	1.27[b]	1.00[b]	1.00[b]
Bulldock® 0.05 GR	1.00[b]	1.00[b]	1.00[b]
AN in the funnel	2.53[a]	1.87[a]	1.77[a]
Significance of F	***	***	***
$L.s.d_{(0.05)}$	0.3522	0.2431	0.3805
CV%	11.0	9.7	14.0

Mean followed by the same letter in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (*** at P < 0.001).

Table 4.21 Damage scores for SC 608, PHB 30B50 and SC 513 for the October planting

Treatments	SC 608	PHB 30B50	SC 513
Control	3.03[a]	2.33[a]	3.04[a]
Dipterex® 2.5 GR	1.90[b]	1.23[b]	1.40[b]
Bulldock® 0.05 GR	1.40[b]	1.00[b]	1.00[b]
AN the in funnel	3.07[a]	3.07[a]	2.87[a]
Significance of F	***	***	***
$L.s.d_{(0.05)}$	0.4943	0.672	0.2949
CV%	11.2	18.7	7.5

Means followed by the same letter in a column for each variety are not significantly different from each other at P = 0.05.

Key of significance (*** at P < 0.001).

Plate 4.5a Damage of stem borer on maize cob **Plate 4.5b** Damage of stem borer on maize cob

4.12 Stem borer natural enemies

4.12.1 Larval parasitoids

A tachinid parasitoid identified as *Schembria eldana* Barraclough (Plates 4.6-4.9) was recovered from the larvae of both *C. partellus* and *B. fusca.* Identification was made based on taxonomic keys outlined by Polaszek (1998). *Cotesia sesamiae* (Plate 4.10) was also recovered in both plantings from larvae of *B. fusca* and *C. partellus.*

Plate 4.6 *Schembria eldana* 1st part forewing veins close to the body (Image taken using a Moticam 1 SP eyepiece camera at × 3.2 magnification)

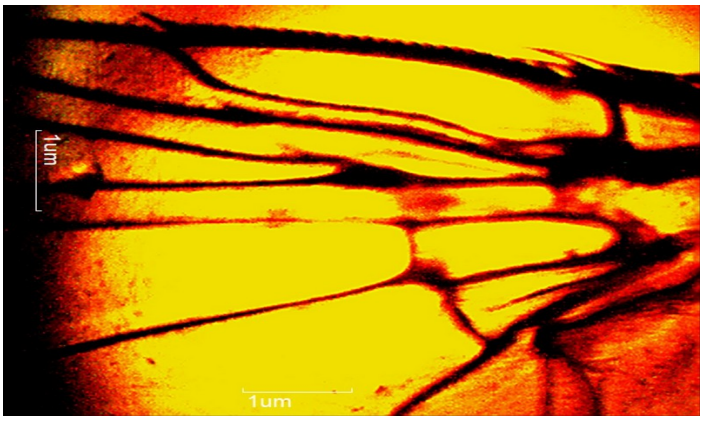

Plate 4.7 *Schembria eldana* 2nd part forewing veins close to the body (Image taken using a Moticam 1 SP eyepiece camera at × 3.2 magnification)

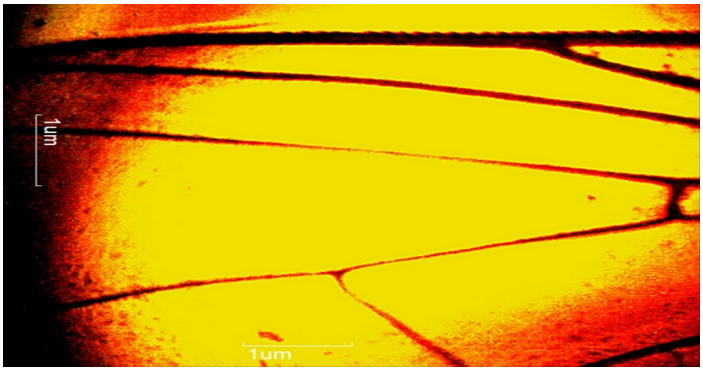

Plate 4.8 *Schembria eldana* 3rd part forewing veins close to the body (Image taken using a Moticam 1 SP eyepiece camera at × 3.2 magnification)

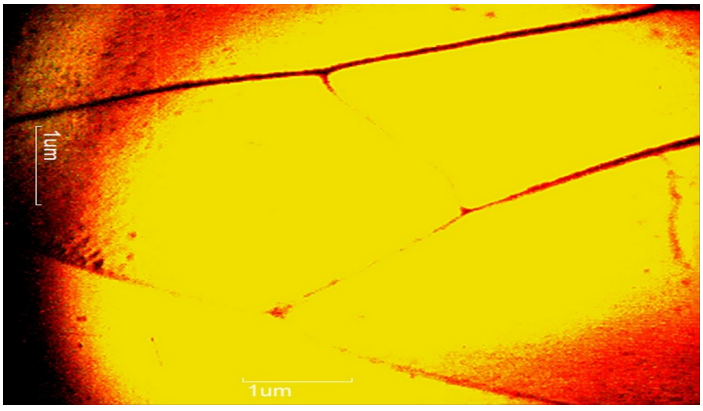

Plate 4.9 *Schembria eldana* 4th part forewing veins close to the body (Image taken using a Moticam 1 SP eyepiece camera at × 3.2 magnification)

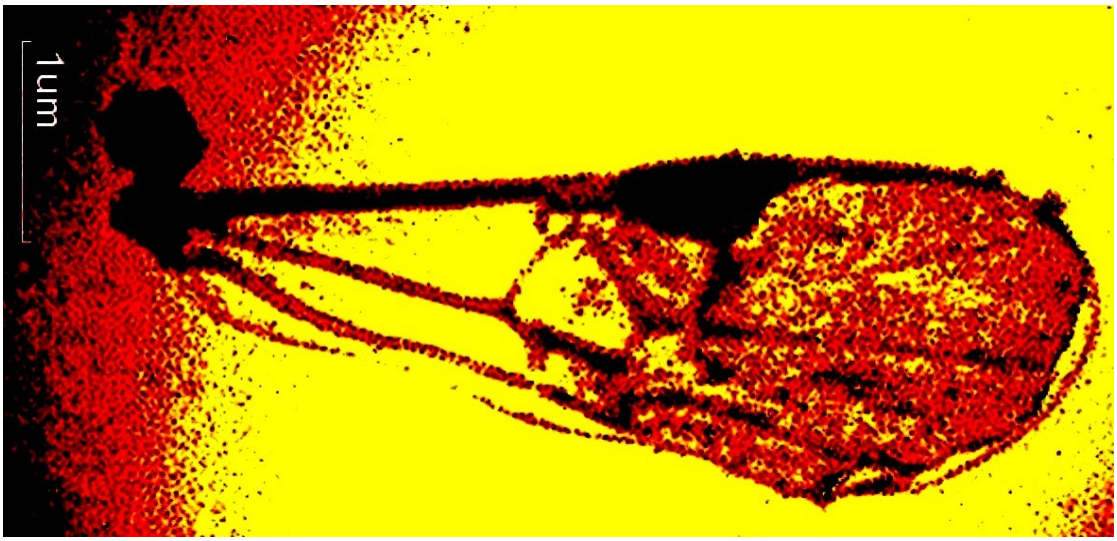

Plate 4.10 *Cotesia sesamiae* parasitoid forewing veins (Image taken using a Moticam 1SP 1.3 eyepiece camera at × 3.2 magnification).

The total number of stem borer larvae that infested the green mealies trials was not counted during the study. The numbers of larvae mentioned in table 4.21 are those that were collected during field inspections. Parasitoids emerged from the reared stem borer larvae.

Table 4.22 Relative percentage parasitism of *C. partellus* and *B. fusca* larvae by *S. eldana* and *C. sesamiae* on August and October Maize plantings at Africa University farm

	August planting					**October planting**				
Variety	Larvae found		Parasitoids found			Larvae found		Parasitoids found		
	Species	No	Species	No	%paras	Species	No	Species	No	%paras
SC 608	*B.fusca*	6	*S.eldana*	2	33.3	*C.partellus*	4	*S.eldana*	1	25
	C.partellus	2	-	-	-	*B. fusca*	7	*S.eldana*	4	57
SC 513	*C.partellus*	2	-	-	-	*B. fusca*	9	*C.sesamiae*	4	44.4
PHB 30B50	*B.fusca*	4	*S.eldana*	2	50	*B.fusca*	5	*C.sesamiae*	3	60
	C.partellus	2	-	-	-	*C.partellus*	2	*C.sesamiae*	1	50

-= Nothing

%paras = Percentage parasitism
No = Number

4.12.2 Predators

Earwigs (Dermaptera: Forficulidae), wasps (Hymenoptera: Vespidae) and ants (Hymenoptera: Formicidae) were observed preying on *B. fusca* and *C. partellus* larvae.

CHAPTER 5

DISCUSSION

5.1 Stem borer species identified at Africa University farm

The two stem borer species identified at AU farm were *B. fusca* and *C. partellus.* This concurs with Chinwada and Overholt (2001) who suggested that the lepidopterous stem borer *B. fusca* and *C. partellus* are by far the most important insect pests that attack maize and sorghum in Zimbabwe. No *S. calamistis* was found in the study area. Chinwada *et al.* (2001) also suggested that *S. calamistis* does attack Gramineous crops in Zimbabwe, but in very low proportions.

5.2 Effectiveness of granular insecticides and the use of ammonium nitrate in the funnel to manage stem borers in green mealies

The granular insecticides used in the August and October trials are all registered for stem borer control and are used by farmers to control stem borers in Zimbabwe. Dipterex® 2.5 GR and Bulldock® 0.05 GR granular insecticides were effective against *B. fusca* and *C .partellus* infestation in green mealies. The granular insecticides used in the experiment had active ingredients that act on different components of the nervous system with different modes of action. Beta-cyfluthrin, the active ingredient in Bulldock® 0.05 GR, acts on the axonal membrane by causing its permanent

depolarization (Thatheyus and Selvam, 2013; Brown, 2013), and affects both the peripheral and central nervous system of the insect (Hetrick *et al.,* 2013). Trichlorfon, the active ingredient in Dipterex® 2.5 GR, acts as inhibitor of acetylcholinesterase enzyme (Čolović *et al.,* 2013).

Both insecticides have contact and stomach action on the targeted insect pests (Brown, 2013) with no penetrating effects within the plants. The degree of survival of a pest depends upon the residual characteristics of an insecticide (Brown, 2013). Pyrethroids (such as Bulldock® 0.05 GR) have long (14 days in plants) residual activity and are applied at low rates, but they are not photo-stable as they degrade in sunlight while organophosphates (such as Dipterex ® 2.5 GR) have short (7-10 days in plants) residual activity (Thatheyus and Selvam, 2013).

However, the protective effects of Bulldock® 0.05 GR and Dipterex® 2.5 GR were the same. Plants treated with both chemicals had significantly more biomass, more cob weights and less damage scores compared to AN- treated maize and the control.

The chemical concentration of an insecticide can also determine the level of survival of a pest (Brown, 2013). For example, granular formulations of beta-cyfluthrin were found to be highly effective against *C. partellus* in South Africa at a very low concentration of 0.5 active ingredients per hectare (Van den Berg and Rensburg, 1993). Granular formulations of trichlorfon were also found to be the most economic insecticides against *C. partellus* control in maize in Kenya (Polaszek, 1998). The effectiveness of the granular insecticides used in the experiment concurs with Polaszek (1998) who

suggested that granular application of insecticides in whorls of maize plants is the most effective and economic method for control of stem borer species which feed in whorls.

These insecticide formulations have several advantages for borer control in maize as they are easy and safe to handle, can be applied by hand and can be applied accurately in a controlled manner. Once applied, the granules disintegrate in water that is often found in maize funnels and are retained there under conditions of wind and water. The recommended rates of application on the labels of the insecticides used in the trials contributed to the efficacy of the insecticides against *B. fusca* and *C. partellus* infestation in green mealies.

Although insecticide use can be of benefit to farmers in the short term, their use thereof has not been without problems. For example, foliar applications of pyrethroids were found affecting epiphytic predators than epigeal predators on maize and sorghum under commercial farming systems in South Africa (Van den Berg and Rensburg, 1993).

On the other hand, granular formulations of insecticides applied in plant whorls were found to have no deleterious effects on natural enemies of stem borers (Du Toit, 1995). Therefore, for a successful reduction in insect populations, timing of control measures is crucial as the larval stages feed deep within plant tissues. Granular application must be applied when larvae are still feeding outside on maize leaves.

The use of AN in the funnel as a control method against stem borer larvae was ineffective as it had no effect on the infestations of *B. fusca* and *C. partellus* in the trials. The maize varieties used in the trials were not resistant to *B. fusca* and *C. partellus*

attack as observed from the untreated plots. Silicon in plant epidermal cells was found to provide a physical barrier by increasing leaf abrasion, which subsequently increases wearing off of the mandibles of *B. fusca* larvae, which physically deter larval feeding (Juma *et al.,* 2015).

The assessment of windowed leaves showed that maize plots treated with AN in the funnel as well as the controls had high infestation percentages than those treated with insecticides especially in the August trial. It was also observed that plants treated with AN in the funnel and the control were shorter than those treated with insecticides. These results concur with Songa *et al.* (2001) who also observed a decrease in plant height from 154 to 140cm due to high borer density in maize.

During the reproductive growth stage, *B. fusca* and *C. partellus* larvae were occasionally found feeding on maize cobs of plots treated with AN in the funnel as well as the control with higher damage scores in the October planting than the August planting. The tunnels of stem borers significantly affected yield as was the case on fresh cob weights of maize treated with AN in the funnel and the control. These results concur with Songa *et al.* (2001) who also observed that one cm of stem borer tunnel reduces maize yield by 3g/plant.

There are risks that arise from using AN in the funnel by smallholder farmers. Over application of AN in the funnel burns terminal bud of maize and the plant may die completely. In addition, application to a water stressed plant causes more damage that may leads to plants death.

5.3 Planting period in relation to planting season of green mealies

The August planting had high infestation percentages than the October planting. The rainfall season started when the October planting was not yet ready for harvesting resulting in low stem borer infestation on maize plants. Probable explanations for the deleterious effect of rainfall on stem borers include hindrance of adults from flying for mating, stopping or depressing egg laying, and causing high mortality in whorl-feeding early instars and moths (Chinwada *et al.,* 2001; Niyibigira *et al.,* 2001). Washed away larvae are unlikely to survive on the ground due to starvation, desiccation and predation (Bonhof and Overholt, 2001).

A drought spell which occurred from December to January when the October planting was still immature resulted in high damage scores on the October planting than the August one. The higher damage could have been influenced by high temperature and low rainfall which are favourable conditions for stem borer multiplication. These results are in agreement with Kisimoto and Dyck (1976) who suggested that high temperature and low rainfall can cause a severe stem borer infestation.

Sithole (1989) also suggested that in Zimbabwe, two distinct generations emerge in November and January-February and a third generation occurs only when conditions are favourable. Manipulation of planting date is commonly recommended for *B. fusca* control in South Africa and Zimbabwe, since this borer has a distinct moth flight with

months being virtually absent for a period of 2-4 weeks between the first and second generation moth flight (Van den Berg and Rensburg, 1993; Sithole, 1995).

In order to efficiently utilize planting date as a means of escaping borer damage, it is crucial to define what should be regarded as early or late planting within an agro ecological region and to know the local seasonal patterns of stem borer life cycles. Planting dates can then be planned to ensure that the most susceptible stage of crop growth does not coincide with periods of peak moth activity (Polaszek, 1998).

According to the local farmers, stem bores do not infest the late sown crop (October) much as they are affected by rainfall during plant growth as compared to those planted early under irrigation in August. Later sowing of maize is less affected by stem borer larvae than earlier sowings (ISU, 2012). Therefore, the findings of the present study are also in agreement with the local farmers cultivating maize in the study area.

5.4 Diversity of stem borer natural enemies

The larval parasitoid which bore resemblance to *S. parasitica* was identified to be *Schembria eldana* Barraclough. In the trials, parasitism due to *S. eldana* was 25 and 18.5% in the August and October planting respectively. *S. eldana* was first collected in the Tongaat area of the South African sugarcane belt attacking E. *saccharina* in *Cyperus papyrus* umbels*,* also in Kenya and Ethiopia (Barraclough, 1991; Assefa *et al.,* 2006). In South Africa, it was recorded with 5.26% at the time of surveys (Assefa *et al.,* 2006). Apart from *E. saccharina,* the species has never been reported attacking other species of stem borers. This is the first time that *S. eldana* is recorded in Zimbabwe and found

parasitizing *B. fusca* and *C. partellus* larvae. In the trials, more of it recovery was observed on *B. fusca* than *C. partellus* larvae.

The biology of this parasitoid and the suitability of cereal stem borers in Zimbabwe for its development need to be investigated to prove this finding. The recovery of *S. eldana* on *B. fusca* and *C. partellus* contradicted the studies by Barraclough (1991) who recovered it on *E. saccharina* only.

Though the species resembles *S. parasitica,* the latter is found in abundance in the Harare area and it would seem more likely that there are unknown abiotic or biotic factors that favour this particular parasitoid in the area (Chinwada *et al.,* 2004). In addition, in Zimbabwe, *S. parasitica* is carried over from one cropping season to the next by synchronizing its larval development with that of diapausing *B. fusca* larvae (Chinwada and Overholt, 2001). This carryover mechanism has never been reported with *S. eldana.* Therefore, careful identification with a specialist tachinidae is needed when a larval dipteran tachinidae is recovered on stem borer larvae.

Cotesia sesamiae was another parasitoid identified in the trial with relative percent parasitism of 29.6% in October planting only. In the August planting no *C. sesamiae* was recovered from sampled larvae. It is a gregarious endoparasitoid of medium and large-instar larvae of lepidopterous stem borers in the families Noctuidae and Pyralidae including *B. fusca, C. partellus, C.orichalcociliellus, E. saccharina* and *S. calamistis* that feed on maize and sorghum in sub-Saharan Africa (Mochiah *et al.,* 2001; Ngi-Song *et al.,* 2001; Mochiah *et al.,* 2002).

Cotesia sesamiae is indigenous to Africa and it is found in Benin, Burkina Faso, Cameroon, Central Republic, Ethiopia, Ghana, Ivory Coast, Kenya, Madagascar, Mauritius, Mozambique, Nigeria, Senegal, South Africa, Soudan, Tanzania, Zanzibar, Uganda, DR Congo and Zimbabwe (Polaszek, 1998). In order to ensure synchrony between their life cycles and host stem borers, the indigenous parasitoids must have mechanisms of synchronizing themselves in diapausing larvae to survive through to the next cropping season. For example, in Zimbabwe, *S. parasitica* overwinters by going into a synchronous diapause inside diapausing larvae of *B. fusca* (Chinwada and Overholt, 2001).

The current study, however, did not elucidate seasonal carryover mechanisms of *S. eldana* and *C. sesamiae.* In the study, *C. sesamiae* parasitized more from *B. fusca* than *C. partellus.* Chinwada *et al.* (2003) also found that *C. sesamiae* prefers *B. fusca* and *S. calamistis* to *C. partellus* for oviposition, possibly reflecting its long coevolutionary history with the noctuids in Zimbabwe.

However, the findings of the present study contradicts the results obtained by Machiah *et al.* (2001), who suggested that *C. sesamiae* did not successfully develop in *C. partellus.* Probably, the population origin of *C. sesamiae* used in that particular study was different from the one detected in the trials at Africa University farm in Zimbabwe. It was observed that stem borers were pupating close to the tunnel exit or even partly outside the stem. This pupation behaviour increases their accessibility to parasitoid attacks (Zhou *et al.,* 2003).

Predators are valuable components of Integrated Pest Management. Ants (Hymenoptera: Formicidae), wasps (Hymenoptera: Vespidae) and Earwigs (Dermaptera: Forficulidae) were found preying on the larvae and pupae of *B. fusca* and *C. partellus* in the current study.

The observation was that bored maize stems had no stem borer larvae in them when the ants or earwigs were present on the maize plants. These findings are in agreement with Bonhof (2000) in Kenya, Ebenebe *et al.* (2001) in Lesotho and Wale *et al.* (2006) in Kenya, who also observed ants (Hymenoptera: Formicidae) and earwigs (Dermaptera: Forficulidae) preying on larvae and pupae of stem borers in maize fields. *Componotus* spp. and *Pheidole* spp. appear to be the most important and common species that prey on stem borer larvae and pupae. Ants of the genus *Lepisiota* can prey on stem borer eggs and pupae (Bonhof, 2000).

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The lepidopterous stem borers, *B. fusca* and *C. partellus* caused yield losses and cob quality reduction of green mealies as they attacked maize plants from the seedling stage up to the harvesting stage. When insecticides were not applied, there were qualitative and quantitative losses of green mealies than when an insecticide like Bulldock® 0.05 GR and Dipterex® 2.5 GR was applied. The use of AN in the funnel as a cultural control method should be discouraged as its application did not have any effect in terms of controlling infestations by *B. fusca* and *C. partellus.* Breeding maize varieties that are tolerant to stem borers is crucial as the present study did not reveal any tolerant variety. This will help smallholder farmers who generally cannot afford to buy insecticides. Renewed research efforts on chemical control, with smallholder farmers as the targeted group, are clearly necessary. There is a need to adopt reliable stem borer management methods through the use of registered granular insecticides such as Bulldock® 0.05 GR and Dipterex 2.5® GR in combination with cultural control. Combining whorl-applied granular insecticides with cultural practices such as planting date manipulation, crop rotation, tillage practices, intercropping and crop residue management practices will help to reduce the damage caused by *B. fusca* and *C. partellus* in green mealies production. The current study established that *B. fusca* and *C. partellus* are the predominant stem

borer species at Africa University farm and possibly the Old Mutare valley. The study also established the presence of some parasitoids of stem borers namely a *S. eldana* Barraclough (Diptera: Tachinidae) and *C. sesamiae* in the Old Mutare valley.

6.2 Recommendations

1) **Smallholder and commercial farmers**

Commercial and smallholder farmers are recommended to use registered insecticides such as Bulldock® 0.05 GR, Dipterex® 2.5 GR and apply granules in the whorls of infested plants as well as the whorls of one or two adjacent plants on either side as soon as whorls damage symptoms are observed in the field. These applications must be made using the manufacturers' recommended rates on the labels. The rationale of this method is that the insecticide will also control larvae that migrate from the primary infested plants to adjacent plants.

2) **Plant breeders**

Plant breeders are recommended to breed maize varieties that are tolerant to stem borer attacks hence reduce the use of chemical insecticides.

3) **Africa University –Faculty of Agriculture and Natural Resources**

Further studies must be conducted to determine the impact of stem borers in sorghum and maize production.

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