Assessment of damage and yield losses on maize by the lepidopterans *Chilo partellus* (Crambidae), *Busseola fusca* (Noctuidae) and *Sesamia calamistis* (Noctuidae).

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DECLARATION

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DEDICATION

This thesis is dedicated to my parents, Mr. Jackson M.C. Akhusama and Mrs. Emmah Kisanda Akhusama and to my brothers and sisters for their support, encouragement and prayers throughout the study and research period.

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Abstract

Lepidopteran stemborers are among field insect pests responsible for the low maize production in sub-Saharan Africa. In Kenya, *Chilo partellus* Swinhoe (Pyralidae), *Busseola fusca* Fuller (Noctuidae) and *Sesamia calamistis* Hampson (Noctuidae) constitute the major proportion of stemborer community. Concerted efforts to reduce stemborer populations in maize fields have been emphasized without a good understanding of potential losses associated with damage by respective stemborer species. This study aimed at assessing larval effects of the three stemborers on maize growth and how these relate to yield losses. A field experiment was initiated with both stemborer species (*B. fusca, S. calamistis* and *C. partellus*) and densities (0, 10, 15 and 30) as the treatment factors. H513 maize variety was planted and artificially infested with the first instar larvae 21 days after emergence (DAE). Plants were caged immediately after infestation to restrict movement of the introduced larvae within the cage and eliminate external infestations. Effects of the treatment factors on the growth parameters were taken until the maize was harvested. Results indicated that larval survival for each stemborer species decreased with increasing larval infestations for all the stemborers regardless of the initial infestations. Not more than four larvae of each stemborer managed to survive in each stem of maize. It was observed that, *C. partellus* and *B. fusca* had comparatively higher percentage survival than *S. calamistis* larvae. There were no significant differences between the low infestation density of 10 larvae/plant and medium infestation density of 15 for all the stemborers ($p > 0.05$). However at higher infestation density of 30 larvae/plant, low survival of larvae was realized which was statistically lower as compared to the densities of 10 and 15 for all the stemborers. Proportionate larval effect of each species was observed and it was reported that, *C. partellus* and *B. fusca* larval reductions did not produce any difference on the plant height ($p > 0.05$). However, *S. calamistis* larva produced significantly lower effect on the height of maize ($p < 0.05$). There was evidence of variation in the lengths of stem tunnelling associated with the different stemborer species ($p < 0.05$). *Busseola fusca* larva caused the highest length of stem tunnelling, followed by *C. partellus* and *S. calamistis* larva produced the least. *Chilo partellus* and *B. fusca* larva produced significantly higher reductions in cob weights in comparison to *S. calamistis* ($p < 0.05$). *Busseola fusca* larva produced higher effect on grain weight reduction as compared to *C. partellus* and *S. calamistis.* Relationships between stemborer larva and their effect on maize growth showed a strong link between stem tunnelling and yield reduction. *C. partellus* and *B. fusca* were observed to be major stemborers of maize while *S. calamistis* was least important.

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CHAPTER ONE

1.0 GENERAL INTRODUCTION

Maize (*Zea mays*) is a major staple food crop in Africa as evidenced by the large land area under maize and high consumption of the crop. It is the most widely grown cereal in Africa and is increasing in both popularity and acreage (CIMMYT, 2002). In the developing world maize is produced on more than 80 million hectares of which 56 million is in the tropics and subtropics (CIMMYT, 2002). Majority of people in Kenya particularly the small-scale farmers grow maize for subsistence use (Songa *et al.* 2001). It is a member of the grass family Poaceae, to which all the cereals belong. Maize is consumed as green maize or milled into flour and used to make various foodstuffs. The remains of maize e.g. maize stalks and cobs are also used to feed cattle and other livestock.

The production of maize has not kept pace with the ever increasing human population and therefore this has put a high demand for the commodity (De Groote, 2002). Maize yields tend to be low and a host of biotic and abiotic factors are responsible, including drought, low soil fertility, pests and diseases. Yield losses due to agricultural pests are a major setback to maize production because a lot of potential harvest is lost when the crop is still in the field and also in storage. Pre-harvest damage and the consequential yield reduction by the major stemborers in Kenya have aggravated the situation and therefore there is need for concerted effort to bring the yield losses due to the stemborer complex to manageable levels. The families Pyralidae and Noctuidae are the most important lepidopteran pests of maize and other Poaceae in east and southern Africa (Polaszek, 1998).

These insects infest maize crop throughout its growth, from seedling stage to maturity. Yield losses of between 20-80% have been attributed to stemborers in Africa (Kfir *et al.*, 2002). The stemborers *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Sesamia calamistis* (Hampson) (Lepidoptera: Noctuidae) are the most important pests in Kenya and are often found together in the same maize plantations (Warui and Kuria, 1983). The pest status due to them varies in accordance with seasons and agro-climatic conditions where they are found (Schulthess *et al.*, 1997).

Yield loss assessment is an important tool in integrated pest management (IPM). However, reliable data on crop losses are inadequate, most of the data that is available, is subjective and difficult to relate to cultivars, growing conditions, climatic conditions and farming practices (Ajala and Saxena, 1994). Information on yield loss reduction by these stemborers would help in the determination of pest status of each borer. At present, we have insufficient information on the contributions of stemborer larva towards damage and grain yield losses.

Small-scale farmers working on small plots of land are often confronted with a myriad of biotic and abiotic constraints regarding maize production (CIMMYT, 2002). Compared with many traditional crops, maize is relatively susceptible to moisture and nutrient stress

(Edmeades *et al.,* 1989). Drought and low soil fertility are ubiquitous production constraints on small-scale farmers' fields in Africa. Outbreaks of important pests and diseases of maize are dependent upon difficult-to-predict global environmental factors (moisture and temperature regimes) and cultural activities (management of crop residues, crop rotations, intercropping etc) (Ndemah *et al.,* 2001).

Availability of sufficient rainfall and ambient temperatures throughout a cropping season ensures the planting of the crop throughout and the availability of nutrition and oviposition surfaces for the pests, hence their ability to multiply in numbers and infest more plants. At the same time crop remains that harbour diapausing larvae, if not well disposed, will carry the resting stages of the stemborers to the next cropping season. Likewise, crop rotations are effective means of transferring pests from field to field, if not properly managed, pests remain on farms and infest new crop in new planting seasons. Lack of farm inputs such as fertilizers, improved seed and labour have also led to low yield output. These farm inputs are expensive and cannot be afforded by the subsistence farmers. Increased population pressure has also forced many households to move to lands with lower yield potential where the soils are infertile (CIMMYT, 2002). The lands in the populated areas have been recultivated over time and the soil nutrients have been reduced. Priority biotic constraints of maize in Africa include insect pests (stem borers, grain borers and weevils), foliar diseases, ear rots and parasitic weed e.g. *Striga*. The ranking of these pests in terms of economic losses varies significantly across agro-ecosystems. Lepidopteran stem borers are the most geographically widespread, most frequently occurring and most damaging insect pests of maize.

Control of stem borers is difficult because the damage is inside stalks where they are protected from insecticides (Warui and Kuria, 1983). During the first three instars, stemborers cause damage by feeding initially on leaf tissues and later by tunneling within the stem where they feed on the stem tissue and the sap. During maturity, stem borers are occasionally found feeding in maize cobs as well (Songa *et al.,* 2001). The types of damage caused by these pests to field maize are variable and may lead to reduction in plant stand, reduction in the photosynthetic capacity of the plants, interference of water and nutrient uptake, tassel breakages, stem breakages, ear damages and the plant losses its aesthetic value as a result of damage to the ears (Kfir *et al.,* 2002).

Yield is influenced by the combination of the numbers of the pest present, their development stages, genetic constitution of the plant and physiology and the duration of the pest attack (Dent, 2000). Often the variation in the levels of the pest incidence from field to field and season to season makes it impossible or extremely difficult to plan and carry out meaningful yield loss studies. Understanding the relationship between stemborer species, infestation, damage and yield losses in maize is important in determining economic threshold levels which are essential for developing efficient management strategies.

1.1 Justification

The importance of reducing food losses due to insect pests has been a matter of priority by many countries (Seshu Reddy and Walker, 1990). Many control efforts to combat these pests have been put in place with less success. Crop losses are still unacceptably high particularly in sub-Saharan Africa. Attacks by the stem borers *B.fusca, C.partellus* and *S.calamistis* are considered to be the most important biotic constraints limiting potentially harvestable yields of maize on small-scale farmers fields in Kenya (Seshu Reddy, 1998).

Several studies that were mainly subjective and on farmers' fields, did not give real estimates of stem borer yield losses (Seshu Reddy and Walker, 1990, De Groote, 2002). Practical methodologies for collection of statistically reliable data to determine the magnitude of the losses have not been sufficiently tested. In this regard, there is need to carry out experiments to generate objective data that can be analysed to ascertain yield losses on farming systems.

The information will provide essential data for the development of pest control strategies and for the assessment of their effectiveness. As a result of the above shortcomings in yield assessment, efforts to reduce ravages by these insect pests have not been very successful. The magnitude of yield losses caused by these insects is still high. Control measures can only work effectively once the levels of attack are assessed and the pest status of each stem borer established.

Knowledge of the often-complex relationship between insect populations and their effects on the yield forming processes of crops is useful for assessing pest status and for devising methods of minimizing the effects of infestation on yield. Ravages by stemborers are a menace and usually the control measures taken are not enough to destroy the pest. A lot more needs to be done apart from studying the biology and ecology of these pests. The interaction between yield and pest abundance and the losses attributed to pest damage need to be quantified. Such relationships are essential in determination of economical injury levels and threshold levels. These are important in decision making in pest control.

The Kenyan highlands are best known for high production and harvest of maize yet the voracious noctuids (*B. fusca* and *S. calamistis*) are wrecking damage unnoticed. Because of the high harvests, plenty of the harvest is lost in the field by larval feeding. *Chilo partellus* is important in the lowland areas of Kenya and causes high damage to maize. It has been reported to causing varying degrees of damage to maize in the country (Songa *et al.,* 2001). However in nature, these stem borers occur as a complex and their abundance depends on the agroecological conditions and other variations of seasons.

Previous studies have given general percentage damage due to this complex yet each borer in itself has its own damage effect on the crop. It is therefore important to establish how much voracity in crop damage each stem borer has. Although information on the nature of insect pests is available (i.e. on the biology and control of these pests), objective and reliable assessment of losses in maize production due to these pests are not sufficient (Bonhof, 2000).

1.2 Research questions

(a) What is the relationship between initial larval infestations and the final percentage larval survival for each stem borer species?

(b) What is the contribution of stem borer larvae of each species on maize growth towards damage and yield reduction?

1.3 Hypotheses

(a) Stem borer larval survival among the species is not affected by the initially Introduced first instar larval densities.

(b) Damage and yield losses caused by larvae of the different stem borer species on maize are uniform.

(c) Damaged maize growth parameters have equal effect on yield reduction.

1.4 General objective

Assess the damage and yield losses caused by artificial infestations of individual stem borer larvae of *Chilo partellus*, *Busseola fusca* and *Sesamia calamistis* on maize.

1.5 Specific objectives

(a) To estimate the percentage stem borer larval survival at each introduced larval infestation density.

(b) To estimate the damage of individual stem borer larvae on growth and yield of the maize plants.

(c) To determine the relationship between the different maize growth parameters.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Biology and distribution of stem borers

In Africa, several species of stemborers attack maize and other cereals within the family Poaceae. Most important stem borers of maize belong to the families Pyralidae and Noctuidae and across Africa, there are marked differences in the distribution of these lepidopteran pests of maize. Their pest status varies with regions and often between countries (Schulthess *et al.*, 1997). Twenty-one stem borer species have been recorded as being detrimental to cultivated grasses which include maize, sorghum, millet, sugarcane and rice. However, the most important lepidopteran stem borers in East Africa are *Chilo partellus* Swinhoe (Crambidae), *C. orichalcociliellus* Strand, *Busseola fusca* Fuller (Noctuidae) and *Sesamia calamistis* Hampson (Polaszek, 1998).

2.1.1 Biology and distribution of *Chilo partellus*

Chilo partellus is a major stemborer of maize and sorghum in East and southern Africa (Kfir, 1998). It originated from Asia and currently it is well distributed and in some areas it is displacing the indigenous stem borers (Kfir *et al.,* 2002). Its distribution has spread and now includes countries like Ethiopia, Sudan, Somalia, Kenya, Tanzania, Uganda, Mozambique, South Africa, Swaziland, Lesotho, Zimbabwe, Zambia, Malawi and Botswana (Overholt *et al.,* 2001). It covers the lowland tropics and is well distributed at altitudes below 1500m, but also covers some highland areas of upto 2300m (Zhou *et al.,* 2001). It attacks maize, sorghum, rice, sugarcane and several wild grasses (Kfir *et al.*, 2002).

Chilo partellus moths emerge in the late afternoon and early evening. Mating occurs soon after emergence, egg batches of 10-80 are laid on the undersides or upper sides of maize leaves, often near midribs (Bonhof, 2000). Adults may live for 2-5 days and its thought that they do not disperse far from their emergence sites (Overholt *et al.*, 2001). Eggs hatch out and young larvae ascend plants to enter leaf whorls, where they start to feed. Larvae develop to the late third or fourth instar then they bore into the stem, feeding on tissues and making tunnels (Ajala and Saxena, 1994). After feeding for 2-3 weeks, they pupate in the stems for 5-12 days. Under favourable conditions of moisture and temperature, the life cycle is completed in 25-50 days, and five or more generations may develop during a single maize growing season, depending on environmental conditions and the number of times the maize is grown that year. Larvae may also enter diapause in crop residues during unfavourable climatic conditions and pupate in the next growing season (Harris, 1990).

2.1.2 Biology and distribution of *Chilo orichalcociliellus*

This is a pest of maize and sorghum and usually occurs along the coast of East Africa. The stemborer has been recovered at elevations below 600m in the lowland coastal area of Kenya (Zhou *et al.*, 2001). The life cycle of *C. orichalcociliellus* is largely similar to that of *C. partellus* and the only differences that arises is the competitiveness of *C. partellus* i.e. ability to complete a generation in less time than *C. orichalcociliellus*, this results in higher populations of *C. partellus.* Kfir *et al.* (2002) reported that *C. partellus* had the ability to terminate diapause more rapidly as compared to *C. orichalcociliellus* hence its ability to displace the native stem borer species. It is therefore expected that *C. partellus* will cause higher damage to maize compared to *C. orichalcociliellus.*

2.1.3 Biology and distribution of *Busseola fusca*

This is an indigenous stemborer in Africa and it is predominant in the cooler regions (high altitude areas) of East and southern Africa where the larvae of the stem borer are found feeding on growing maize (Wale, 1998; Zhou *et al*, 2001; Kfir *et al.*, 2002). The stem borer also attacks sorghum, pearl millet and other wild hosts of the Poaceae family (van den Berg *et al.*, 1991). Overholt *et al.* (2001) reported that *B. fusca* is widely distributed in sub-Saharan Africa but the populations in eastern and southern Africa are reported to be adapted to different environments from those in West Africa. Due to the ecological differences between regions, these stemborers have varied pest status.

The life cycle of *B. fusca* takes about 30-45 days under favourable temperature and moisture conditions. After mating, the adult female moths deposit about 200 eggs in batches of 30-100 between the leaf sheaths and the stem of the maize plant and close to 1000 eggs could be laid. Eggs hatch after one week and young larvae congregate and start feeding on the leaf whorls, they then penetrate into the stems where they feed for 3-5 weeks producing extensive tunnels (Overholt *et al.,* 2001). Sometimes the growing point is destroyed as they tunnel downward in the stem. They later pupate in the tunnel and after 10-20 days, adults emerge. The cycle is repeated again under favourable temperature and moisture conditions. Under unfavourable climatic conditions, larvae of the last generation enter diapause in maize and sorghum stubble. They pupate a few months later at the start of the following rainy season.

2.1.4 Biology and distribution of *Sesamia calamistis*

This is an indigenous stem borer in Africa and is well distributed in all the agroecological zones. It attacks a variety of cereal plants which includes a variety of native grass species and also cultivated cereals like maize, sorghum, sugarcane, rice and wheat (Wale, 1998; Kfir *et al.,* 2002). Its distribution ranges from east and southern Africa to West Africa and its importance varies within the agroecological zones where the borer is found. It is a serious pest of cultivated cereals in West Africa (Bosque-Perez and Mareck, 1990). In Benin, *S. calamistis* is the predominant stemborer found attacking maize alongside the Pyralids *Eldana saccharina* Walker and *Mussidia nigrivenella* (Setamou *et al.,* 2000). In East Africa, *S. calamistis* is widely distributed in all ecological zones (Zhou *et al.,* 2001).

The biology of *S. calamistis* involves a life cycle that is completed in about 6-8 weeks on maize. Eggs, larvae, pupae and adults can be present in a population at any one time with no distinct generations (Overholt *et al.,* 2001). After pupation, adults emerge and start mating immediately. The eggs are spherical and flattened at the poles and hatch out to yellowish pink larvae on the undersides of leaves. Eggs hatch about a week after being laid. Soon after emergence, the larvae start feeding on the leaf sheaths and then enter the stems. Infestations can lead to entire crop destructions due to deadhearts. Songa *et al* (2001) also reported larval feeding by *S.calamistis* in the cobs. Larval development takes 3-6 weeks depending on the climatic conditions (Overholt *et al.,* 2001). The pupal period takes about 10-12 days. It is reported to occur at all elevations from sea level to 2400m (Zhou *et al.,* 2001).

2.2 Stem borer damage, larval behaviour and yield losses

Damage to cereal crops by stem borers and larval behaviour has been studied and reviewed by various authors (Polaszek, 1998; Kfir *et al.,* 2002). The most conspicuous injuries caused by insect pests include feeding on plant tissue or sucking on sap and sometimes these feeding leads to death of the entire plant. In some occasions, the tassels dry and break as a result of severe tunnelling in the peduncle. All Stem borer species produce similar injury symptoms on attacked grass plants.

Newly hatched larvae feed by initially scrapping the leaf whorls of young plants producing characteristic 'window paning' and pinholes (Bonhof, 2001). However, *S. calamistis* is mostly found feeding directly on the stems after the larvae hatch from eggs (Overholt *et al*., 2001). Tunnelling by larvae in maize stems restricts translocation of water and nutrient uptake and therefore weakens the stem leading to lodging. Grain damage by lepidopteran stem borers also predisposes maize to pre- and post-harvest infestations by storage beetles, infections by *Aspergillus flavus* and *Fusarium verticillioides* and subsequent contamination by mycotoxins such as aflatoxin and fumonisin (Ndemah and Schulthess, 2002).

Reported crop yield losses due to stem borers in Africa vary widely among ecological zones, regions and seasons and depend on crop, cultivar, crop age at the time of infestation, stem borer density and species (Kumar, 1988). Most of these data are unreliable owing to the multiplicity and non-uniformity of the methodologies used. Yield loss reviews from West, central, East and southern Africa due to *B.fusca*, *C. partellus* and *S.calamistis* are available. In East Africa, data on yield losses attributed to stemborers are few (De Groote, 2002; Bonhof, 2001). Comparative damage and yield loss assessments caused by *C. partellus, B. fusca* and *S. calamistis* occurring concurrently on maize in the fields is lacking.

In Kenya stemborers cause between 15 and 45% damage on maize grain yields (Ajala and Saxena, 1994; De Groote, 2002). None of these estimates included actual crop loss measurements. Estimates were based on visual and verbal examinations, where farmers were just asked to give estimates of the extent of damage caused by the stem borers on their fields. The data acquired from such examinations are very subjective and do not really give accurate measures on yield loss. Such data cannot be relied upon as true yield loss damage from stem borers.

Crop loss estimates of 13.5% of potential harvest have been recorded due to stemborers, with 11% loss in the highlands and 21% in the dry areas (De Groote *et al.,* 2002). These results were combined with data on stem borer species prevalence in a GIS based model and the results showed that high losses occurred in high potential zones. The three stemborer species caused 98.9% loss: *B. fusca* caused 63% loss in the highlands, *C. partellus* caused 29% in the lowlands and *S. calamistis* caused 7% loss.

Ajala and Saxena (1994) investigated the damage and yield losses caused by *C. partellus* on maize of varying resistance at ICIPE-Mbita and used 30 first instar larvae. They looked at parameters of growth and how the borer infestation damaged the crop. Some of the parameters they looked at included foliar damage, dead hearts and stem tunneling. Stem tunneling was positively and significantly correlated with yield reduction in all the groups of genotypes they tested. Yield losses from the artificial infestation ranged between 34% and 43%.

Usua (1968) in Nigeria worked on *B. fusca* separately with varying densities of the stem borer on maize and found out that increased densities of *B. fusca* larvae decreased growth and yield of maize. Plant height was greatly affected by increasing infestations of *B. fusca.* The number of dead hearts also increased as the number of borers per plant increased. The effect of single and mixed populations of *B. fusca* and *C. partellus* on damage to sorghum has been studied in Potchefstroom, South Africa using artificial infestation on caged plants by van den Berg and Rensberg, (1991). At high infestation levels, plant damage and yield loss caused by the two borer species was very similar. However, yield loss increased when *B. fusca* and *C. partellus* formed mixed populations. Under mixed populations, the two borers fed more and damaged the maize more than single populations probably due to competition. In these experiment, only high densities of larvae were used and could not give proper variation on how yield is influenced by varying infestation levels.

2.2.1 Damage and yield losses associated with *Busseola fusca*

Busseola fusca is a highland stem borer and is responsible in causing low yields in maize in this region. A natural assessment of stem borers in maize and sorghum based on damage on individual plants done by Ogwaro (1983) in ICIPE-Mbita, showed that the development of single larvae of *B. fusca* reduced the yielding capacity of stems by 28% of mean dry cob weight. Grain yield loss estimates of 18-37% in maize and 50% in sorghum have been recorded in Uganda (Kalule, *et al.,* 1997). In South Africa, *B. fusca* damage, ranges from 10% to total loss in maize (Kfir *et al.*, 2002). Yield losses on maize attacked by *B. fusca* varied between 10% and 39% in Lesotho (van den Berg *et al.,* 2001). Information on yield loss assessments due to *B. fusca* and other lepidopteran stem borers of cereals is still not available in some parts of Africa e.g. Central Africa (Ndemah *et al.*, 2001).

2.2.2 Damage and yield losses associated with *Sesamia calamistis*

Yield losses attributed to this borer in Kenya was about 7% in a survey where farmers gave estimates due to stemborers (De Groote, 2002). It is reported not to be a major pest of maize in Kenya in comparison to *C. partellus* and *B. fusca.* Even though, it causes low yield losses, it plays part in the overall yield loss reduction by the stem borer community. In West Africa, *S. calamistis* is a major stem borer of maize and sorghum alongside *B. fusca* and *E. saccharina* (Ndemah *et al.* (2001). In east and southern Africa, *S. calamistis* is a less important stem borer found across all agro climatic zones in Kenya. *S. calamistis* is characteristically associated with lodging of stems and causing dead hearts (Usua, 1968). However, the quantification of the contribution of this borer in the stemborer community is still not sufficient.

2.2.3 Damage and yield losses associated with *Chilo partellus*

This stem borer is important in the sub-Saharan Africa where it is responsible for massive damage on maize and other cereal crops like sorghum in the lowlands. It attacks maize at early developmental stages and at anthesis and causes serious crop losses (Seshu Reddy and Sum, 1991). However, damage caused at the young age of development of maize is usually higher and sometimes leads to stunted growth or even death of the plant. The survival of *C. partellus* in the dry season depends upon alternate hosts and wild grasses, although the greatest carryover is in maize/sorghum residues left in the field (Warui and Kuria, 1983). This residual infestation makes the borer population sufficiently large to ensure infestation of the succeeding crop. In eastern and southern Africa, the yield losses ascribed to *C. partellus* have been mostly based on visual scores of the borer on the nature of damage it causes on maize and sorghum (Sithole, 1990).

The loss caused by *C. partellus* varies depending on the crop, methodology adopted in assessing the losses, seasons and the country where the assessment was carried out. On maize, *C. partellus* caused between 23-53% yield losses in Kenya when pesticide trials for comparisons of treated and untreated plots were used (Seshu Reddy and Walker, 1990). Ampofo (1986) working on some cultivars of maize using pesticide trials and assessment of yield in artificially infested caged plants recorded yield losses ranging from 4-73% in Kenya. Warui and Kuria (1983) recorded a 20% yield reduction in maize in the coast of Kenya due to *C. partellus* and *C. orichalcociliellus.* They artificially infested maize plants and caged them to prevent external infestations.

A reduction of yield by 74.4% in sorghum was due to *C. partellus* when five larvae were introduced to sorghum at 10 days after emergence; 87.8% when plants were infested with 10 larvae and 2-13% at 60 DAE (Seshu Reddy, 1988). It was also reported in an artificially infested experiment by Minja (1990), that 56% grain loss was attributed to *C.*

partellus on 20 day old sorghum in Uganda. In Lesotho 8-35% loss of sorghum in the field was reported to be due to *C. partellus*. (van den Berg *et al.*, 2001).

2.2.4 Damage and yield losses associated with *Chilo orichalcociliellus*

Warui and Kuria (1983) reported 18% yield losses due to *C. orichalcociliellus and C. partellus* in maize at the Kenyan coast. It has been reported that *C. partellus* has displaced *C. orichalcociliellus* and currently not much has been done to establish the yield reduction effects of this borer on maize. The damage and yield losses caused by this borer on maize is minimal and is therefore not a threat to maize production.

2.3 Control strategies for stemborers

Several methods are being used in many parts of Africa to combat the stem borers. The choice of control is governed by the size of the farms, age of the crop and the availability of adequate resources that can enable a farmer acquire the desired method. In Kenya, chemical, biological, cultural as well as planting of resistant maize varieties have been used. All these strategies can also be used in the formulation of an Integrated Pest Management (IPM) strategy that can be used to control the maize stem borers. The primary objective of IPM strategies is to develop ecologically acceptable management strategies to control pests. These methods should be economically feasible for small scale farmers (Seshu Reddy, 1989).

2.3.1 Chemical control

This is the most commonly recommended method for stem borer control even though continuous applications have to be made to achieve effectiveness. This is due to the short period that the larvae are exposed and therefore prompt and frequent applications have to be made. This can be very uneconomical to the small scale farmer (Bonhof, 2000). For effective chemical control, a good understanding of the biology, ecology and population dynamics of the pest are important. Therefore it is important to also define economic threshold levels clearly. Some of the pesticides used include carbaryl, endosulfan, trichlorfon and synthetic pyrethroids. These formulations come as granules, foliar sprays and soil applied systemics. The smallholder farmer has adopted granular leaf applications because it does not require special application equipment (Chinwada, 2002). However, chemical applications have been a preserve of large-scale farmers who produce large quantities of maize and can also afford the chemicals.

2.3.2 Cultural control

This method of control is concerned with the manipulation of the environment to make it unfavourable for the pest. Some of the methods involved in cultural control include adjustment of planting dates when the pest is not present, crop rotation and management of crop residues e.g. burning or removing stems and stubble. Early planted maize had a lower incidence of *C. partellus* and *C orichalcocillielus* than late planted (Warui and Kuria, 1983). Manipulation of sowing dates indicated that early planted maize suffered less attack of *B. fusca* in Ethiopia (Azerefegne *et al.*,2001). Uprooting, burning and deep ploughing too have been adopted in cultural control to reduce the stem borer infestations.

Soil tillage helps in the destruction of diapausing larvae, burying the crop residues so that the moths do not emerge (van den Berg *et al.,* 1998). Tillage also destroys volunteer plants and weeds that may serve as breeding sites for pests. The choice of these control measures depends on the weather conditions and how best they suit a farmers' cropping systems and also his financial resources.

2.3.3 Biological control

Biological control is the suppression of pest populations using predators, parasitoids and pathogens. Biological control agents have been used in the manipulation of parasitoids, predators and pathogens of pests to reduce pest populations to a level where economic damages due to these pests are brought to tolerable levels (Kumar, 1984). Naturally occurrying biocontrol agents have been reported for the different growth stages of stemborers in different parts of Eastern Africa. Examples of parasitoids include the egg parasitoids *Trichogramma* sp that attack *C. partellus* eggs. Pupal parasites that have been found attacking maize stemborers include *Dentichasmias busseolae* and *Pediobus furvus* (Sithole, 1990). Larval parasitoids of stemborers are mainly Hymenoptera and majority belong to the Braconidae family e.g. *Cotesia sesamiae* has been recovered attacking the stemborers *B. fusca, C. partellus, C. orichalcociliellus* and *S. calamistis* (Polaszek, 1998). Predators of stemborers include ants, spiders, earwigs and ladybirds. These prey on eggs and first instar larvae.

One of the major contribution by ICIPE has been the introduction of the parasitoid, *Cotesia flavipes* in parts of Eastern and Southern Africa. The larval parasitoid has achieved varying success against *C. partellus* control since its introduction in 1991. *C. flavipes* is native to the Indo-Australian region, and has been widely introduced against various stemborers in the neotropics, several Indian Ocean Islands, and also been redistributed within Asia (Overholt *et al*., 1994). Releases and recoveries of the parasitoid have been achieved in Kenya, Uganda, Zimbabwe, Mozambique, South Africa, Tanzania and Zanzibar (Omwega *et al*.,v 1995). In general, the success of these biological control agents largely depends on the well establishment of the agent and its ability to multiply and expand to other areas. Host specificity of these control agents is important to ensure that the pest is targeted without undue interference with other non target hosts.

2.3.4 Host plant resistance

The incorporation of resistant and tolerant factors into maize cultivars has been used to control stemborers attacking the crop and a lot more studies and experiments are underway to develop cultivars of maize that will be used to improve yield. Various maize varieties have been evaluated for resistance against stemborers and several lines have provided a wide scope in multiple resistance against oviposition and larval establishment on maize (Omolo, 1983, Minja, 1990). Aspects of injuriousness of the maize stemborers have been tested on various maize cultivars to show how maize growth parameters are affected on maize of varying resistance (Kumar, 1994). A subsequent rise in maize yields is bound to be realized with increasing levels of resistance. However it is only by doing more yield assessment studies that this can be ascertained.

The manipulation and the incorporation of all or some of the above pest management strategies have an eventual effect of reducing levels of the pest attacking the crop (Kumar, 1984). Integrated pest management options contribute a great deal in reducing pests not to reach economic injury levels and hence high yields can be achieved with minimal costs of production. However, an efficient pest management system will only become reality if proper data on yield loss is incorporated into control decision making.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental design

The study was conducted at the ICIPE- Kasarani on a plot measuring 21x21m. Maize H513 that matures after three months was planted at a spacing of 70x70cm. DAP fertilizer was applied at planting. The field was weeded twice and sprinkle irrigated when rain was scarce. The maize was infested with varying numbers of stem borer larvae at 21 days after emergence. Each infestation level was replicated 9 times except the controls (0 density) (Table 1). The experiment was repeated twice in a completely randomized plot design.

Table 1: Infestation of stem borer larvae on maize plants at various densities.

	Densities			
stemborer	0	10 larvae	15 larvae	30 larvae
C .partellus		9 plants	9 plants	9 plants
B .fusca		9 plants	9 plants	9 plants
S. calamistis		9 plants	9 plants	9 plants
control	9 plants			

Plants infested with different stem borer larvae were separately caged using netted cages. Each cage was 3 metres high and 70cm in circumference. The cages excluded external insect infestations and restricted larval movements from plant to plant. Each cage housed one plant only. The larvae of the stem borers used for treatments were artificially reared at the ICIPE's insect rearing unit.

A similar experiment was done under screen house conditions to find out whether survival of larvae in the screenhouse was similar to survival of larvae in the field. Maize plants were grown in pots and infested with larvae of the three stem borer species at the same densities as the field experiment. After 40 days the maize stems were harvested and dissected to retrieve any larvae.

3.2 Damage assessment

Data was collected on both infested and control plants for the following parameters measured at harvest of the maize; number of dead and surviving larvae per plant, plant height, stem diameters, length of larval tunnelling within the stems, cob weights and the grain weights. The number of larvae that survived within the stalks to cause the damage was determined by counting the number of exit holes, pupae, pupal cases and dead larvae in the maize stems at harvest. The percentage survival at each density and stemborer species was determined by getting the proportion of surviving larvae out of the total number of larvae that were initially infested on the maize.

The average height of the uninfested maize (control) was used to compute the height difference attributed to larval damage. Proportionate larval reduction of height was achieved by getting the difference in the height, then dividing it by the number of larvae that were responsible for causing that change in height. Similar measurements were collected for the stem diameter, where proportionate larval reductions were calculated from the controls.

The number of tunnels made by the different stem borer species was counted after the stems were split longitudinally. The length for each tunnel was measured and the average proportionate stem tunnelling for each larva was recorded. Each maize cob was dried at 40°C and the weights were recorded to obtain the cob weights. The difference between the cob weights of infested maize and the uninfested maize constituted the reduction due to stemborer effect. The difference in cob weight was divided by the number of larvae found in each stem responsible for causing the weight loss and thus attributing the damage to each larva of each stem borer species.

3.3 Data Analysis

Larval effects on maize growth parameters for each stem borer species were done using Analysis of Variance (ANOVA). Statistically different means were separated using Student-Newman-Keuls (SNK) ($p< 0.05$). Student's t-test was used to compare between means of larval survival in the field and screen house experiments. A correlation between stem borer larva and damage parameters was done to show relationships between larva and the damage parameters.

CHAPTER FOUR

4.0 RESULTS

4.1: Survival of the introduced stem borer larvae

There were no significant differences in larval survival under screen house conditions between the densities of 10 and 15 for all the stem borer species ($p > 0.05$). At the infestation density of 30 larvae/plant, the proportion of larval survival for all the three stemborers was significantly lower as compared to the infestation densities of 10 and 15 larvae/plant ($p < 0.05$) (Table 2).

Table 2: Stem borer species survival (Mean ± SE (%)) against the number of larvae introduced under screen house condition

Densities	Stemborer species		
	C. partellus	*B. fusca*	*S. calamistis*
10	22.73 ± 1.95^{a}	19.17 ± 2.29^{a}	20.00 ± 2.89^{a}
15	20.56 ± 1.73^{a}	20.00 ± 1.99^{a}	15.33 ± 1.42^{a}
30	10.28 ± 0.87^{b}	12.00 ± 1.51^{b}	8.61 ± 0.76^{b}

Means followed by the same letter in the same column are not significantly different. SNK ($p < 0.05$)

In the field experiment, the proportions of larval survival between *C. partellus* and *B. fusca* at the infestation density of 15 were not significantly different from the 10 and 30 larvae/plant densities. However, larval survival at 30 larvae/plant was significantly lower than survival at 10 larvae/plant ($p < 0.05$) (Table 3). *Sesamia calamistis* larval survival did not show any significant differences regardless of the infestation levels.

Table 3: Stem borer species survival [(Mean ± SE (%)] against the number of larvae introduced under field condition.

Densities	Stemborer species		
	C. partellus	*B. fusca*	*S. calamistis*
10	26.67 ± 1.87^{a}	23.57 ± 3.08^{a}	16.43 ± 2.25^{a}
15	22.05 ± 2.43^{ab}	17.33 ± 2.04^{ab}	14.07 ± 2.34^{a}
30	16.67 ± 0.96^{b}	13.03 ± 1.14^{b}	9.69 ± 1.71^{a}

Means followed by the same letter in the same column are not significantly different. SNK ($p< 0.05$)

The proportion of *C. partellus* larval survival between the field and screen house experiments did not vary at 10 and 15larvae/plant ($p= 0.16$ and 0.63 respectively) (Table 4). However, significant differences were observed at 30 larvae/plant, where the survival was higher in the field than in the screen house. The proportions of larval survival for *B. fusca* and *S. calamistis,* were not different from each other at all the infestation levels for the two experiments.

Table 4: Comparison of larval survival (Mean ± SE (%)) among different densities between field and screen house experiments

Species	Larval density	Experimental condition		*t* value	*df*	*p* value
		Field	Screen house			
C. partellus	10	26.67± 1.87	22.73± 1.95	1.43	24	0.16^{ns}
	15	22.05 ± 2.43	20.56 ± 1.73	0.49	23	0.63^{ns}
	30	16.67 ± 0.96	10.28 ± 0.87	4.90	19	0.0001*
B. fusca	10	23.57 ± 3.08	19.17 ± 2.29	1.12	24	0.28^{ns}
	15	17.33 ± 2.04	20.00 ± 1.99	0.89	23	0.38^{ns}
	30	13.03 ± 1.14	12.00 ± 1.51	0.55	19	0.59^{ns}
S. calamistis	10	16.43 ± 2.25	20.00 ± 2.89	0.98	21	0.34^{ns}
	15	14.07 ± 2.34	15.33 ± 1.42	0.47	17	0.64^{ns}
	30	9.69 ± 1.71	8.61 ± 0.76	0.59	21	0.56^{ns}

4.2: Effect of stem borer species on the height and diameter of maize plants

Proportionate plant height reduction was not significantly different between *C. partellus* and *B. fusca* larva ($p > 0.05$) (Fig 1). However, the reduction in height attributed to *S. calamistis* height reduction was significantly lower compared to the two other stem borers ($p < 0.05$). There was no evidence of significant differences in the stem diameter reduction associated with the three stemborers ($p > 0.05$) (Fig. 2).

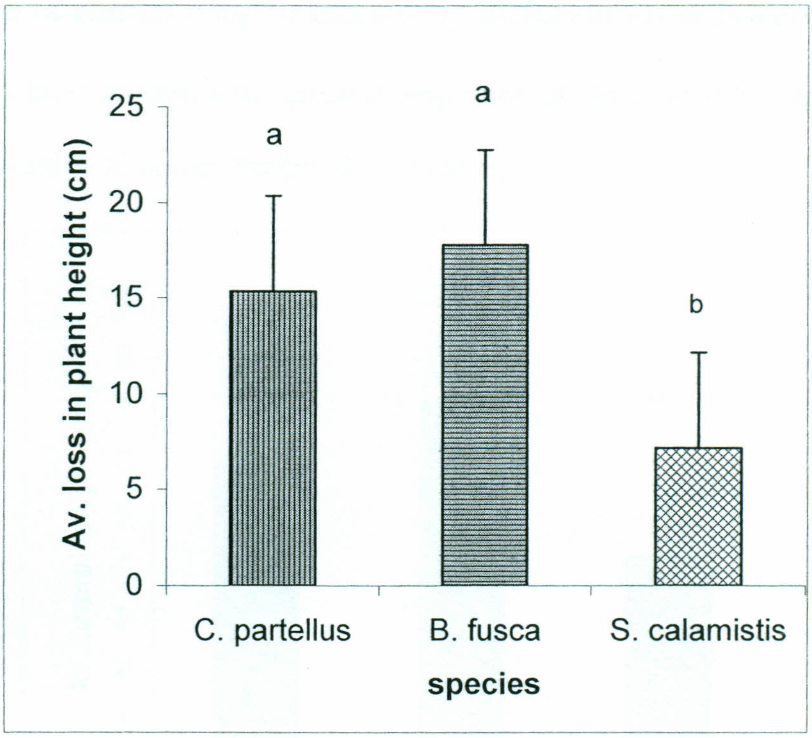

Figure 1: Average plant height reduction (cm) associated with different stem borer species

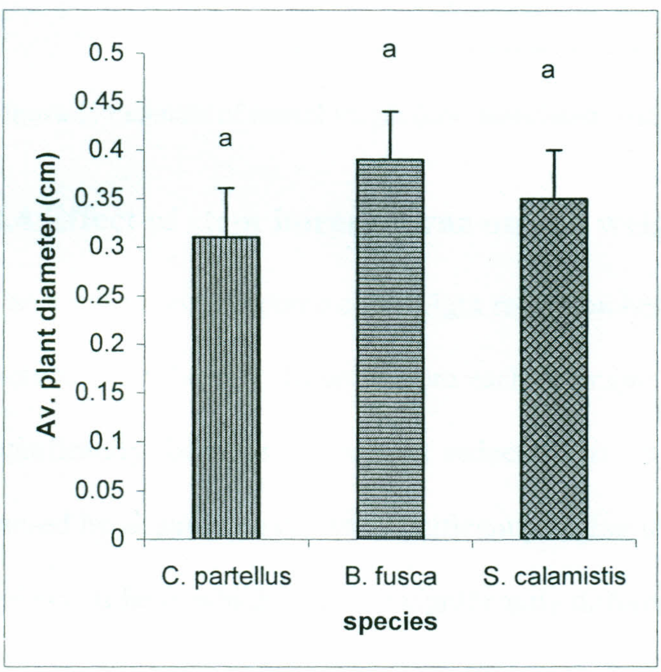

Figure 2: Average maize stem diameter (cm) associated with the stemborer species

4.3 Estimate of tunnel lengths caused by different stem borer species

Busseola fusca larva produced the greatest proportion of stem tunnelling followed by *C. partellus* and least by *S. calamistis* ($p < 0.05$) (Fig. 3).

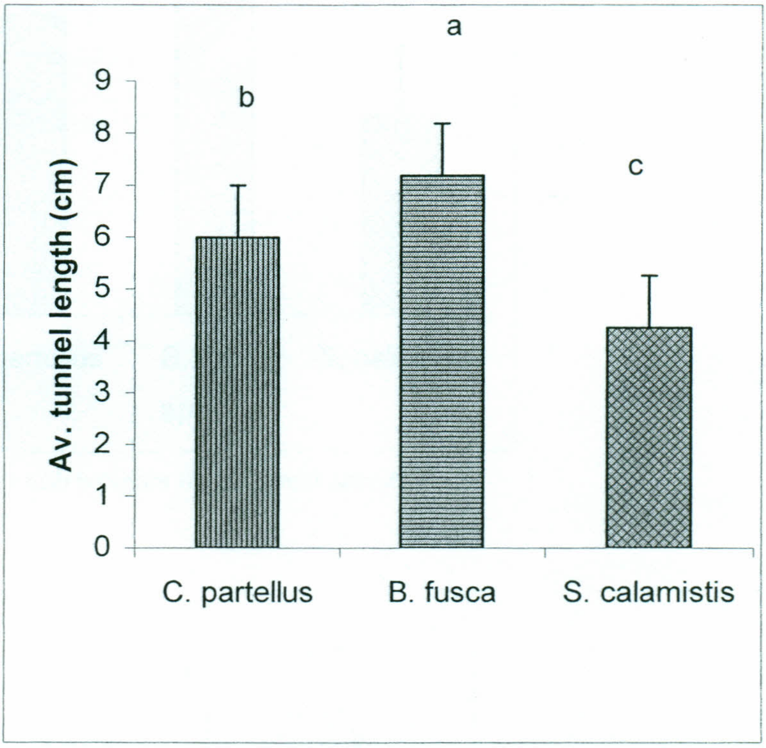

Figure 3: Estimate of tunnel length (cm) associated with different stem borer species

4.4 Effect of stem borer larvae on cob weight and grain weight

The average proportionate cob weight reduction between *C. partellus* and *B. fusca* larva, were not significantly different from each other ($p > 0.05$). However, *S. calamistis* caused significantly the least cob weight reduction ($p < 0.05$) (Fig 4). Grain weight reduction caused by *B. fusca* larva, was significantly higher than that caused by *C. partellus* and *S. calamistis* larva which were not significantly different ($p > 0.05$) (Fig 5).

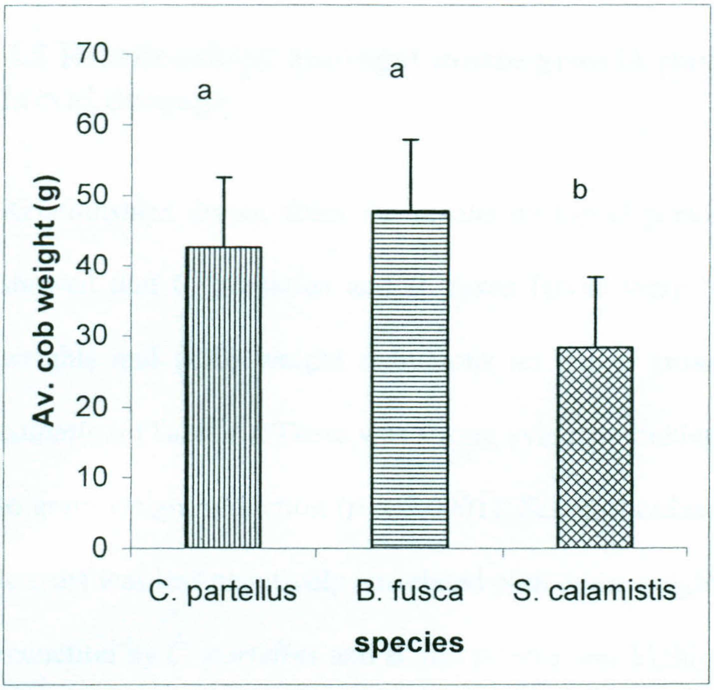

Figure 4: Average cob weights for different species

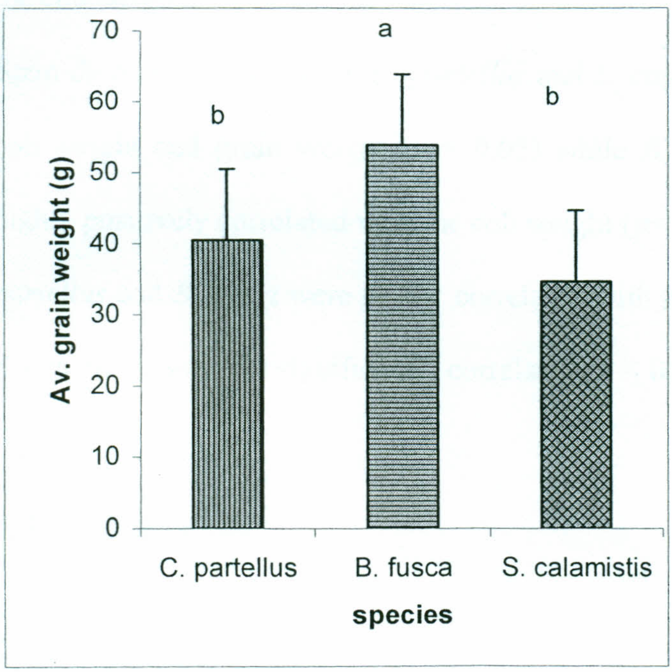

Figure 5: Average grain weights for each species

4.5 Relationships amongst maize growth parameters and stem borer larval damage

Relationships drawn from the results on larval perfomance of the various stemborers, showed that *C. partellus* and *B. fusca* larvae were highly correlated with height, cob weights and grain weight reductions on maize growth parameters as compared to *S. calamistis* (Table 5). There was strong evidence linking stem tunnelling by *B. fusca* larva to grain weight reduction ($p < 0.0001$). *Sesamia calamistis* larval reduction of the tunnel lengths was less negatively correlated with grain weight reduction ($p < 0.05$). Stem height reduction by *C. partellus* and *B. fusca* larva was highly positively correlated with the cob weights and grain weights of maize ($p < 0.0001$). *Sesamia calamistis* height reduction was correlated with the grain weights ($p < 0.05$) but was not significantly correlated with the cob weights.

Stem diameter reduction by *C. partellus* and *S. calamistis* larva was correlated with the cob weight and grain weight ($p < 0.05$) while *B. fusca* stem diameter reduction was highly positively correlated with the cob weight ($p < 0.0001$). Cob weight reduction by *C. partellus* and *B. fusca* were highly correlated with the grain weights ($p < 0.0001$) while *S. calamistis* was less significantly correlated ($p < 0.05$).

Table 5: Correlations between maize growth parameters and stemborer damage

	Tunnel length	Plant height	Stem diameter	Cob weight	Grain weight
C. partellus					
length	1.000				
height	-0.147	1.000			
stemdiam	-0.209	0.137	1.000		
cobwgt	-0.698**	0.705**	0.439*	1.000	
Grainwgt	-0.629**	0.872**	0.376*	0.895**	1.000
B. fusca					
length	1.000				
height	-0.376*	1.000			
stemdiam	-0.588	0.497*	1.000		
cobwgt	-0.686**	0.726**	0.736**	1.000	
Grainwgt	-0.660**	0.627**	0.487*	0.859**	1.000
S. calamistis					
length	1.000				
height	-0.239	1.000			
stemdiam	-0.688*	0.511	1.000		
cobwgt	-0.721*	0.645	0.795*	1.000	
Grainwgt	-0.754*	0.669*	0.927*	0.849*	1.000

** and * significant at $p < 0.0001$ and 0.05 respectively.

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Stem borers are among the major insect pests of maize and other cereals reducing maize yields in Africa. The three major lepidopteran species attacking maize in Kenya that were studied in this work, showed that damage to the growing maize was responsible in causing low yields on maize. As earlier reported in biological studies of these stem borers, they lay different number of eggs that considerably vary among species. *Chilo Partellus,* which occurs in abundance in the lower altitude areas, lays between 200 to 600 eggs in batches of 10 – 80 eggs on the undersides of leaves (Harris, 1990). *Busseola fusca* female moth lays her eggs in batches that contain from 30 to 100 eggs and on average, a female lays about 400 eggs (Polaszek, 1998). Under natural conditions, *S. calamistis* female lays upto 350 eggs, deposited in batches of 10 – 40 eggs.

Once the eggs hatch out into larvae they immediately start feeding on the young leaves of maize and the mortality of the first instars has been reported to be very high under natural conditions and close to 90% that hatch out do not usually complete their development (Bonhof, 2000). This study showed in both the screen house and field experiments, that a great majority of the infested larvae suffered high mortalities regardless of the species. The larval survival for all the three species between the densities of 10 and 15 did not vary significantly but were however higher compared to the 30 larvae/plant. The lower survival of the first instar larvae was probably due to competition for feeding that led to lower survival rates. However at the lower infestation densities of 10 and 15, the percentage survival was higher and this was probably due to less competition for feeding space for the larvae. These findings have also been reported by Bonhof and Overholt (2001), who showed more *C. partellus* larvae had a higher percentage of survival at lower initial infestation densities compared to higher densities. Though they did not work on the indigenous stem borers, the current results on *B. fusca* and *S. calamistis* larval survivals do not show any significant differences with *C. partellus* larval survival. Sufficient data is not available on the survival of *B. fusca* and *S. calamistis* larvae on maize that would form basis of comparison for this study. However, the number of *C. partellus* larvae recovered per plant in this study was more or less the same as in initial field results.

Generally, many of the small larvae could have failed to establish on the maize leaves due to other environmental factors like desiccation resulting from the intense sunshine at that time and also as a result of predation by ground dwelling arthropods that fed on the larvae. At the same time, many larvae could have fallen to the ground from the leaves due to their failure to establish properly on the leaves.

Chilo partellus and *B. fusca* larvae were however capable of higher larval survival than *S. calamistis* larvae as shown from the percentage larval survivals. The larval survivals of these stem borers could have been favoured by plant factors that probably made the plant tissues more palatable for them. This could have ensured greater feeding and survival of the borers. In comparison, *S. calamistis* larvae failed to successfully develop on the maize plants. The failure could have been attributed to the physiology of the plant tissues that probably made them less palatable. This feeding deterrence could have led to the low survival of *S. calamistis* larvae on the maize.

Environmental factors also play crucial roles in determining the larval survival patterns of stemborers, Ofomata *et al.,* (2000) attributed higher larval survival of *C. partellus* to greater larval tolerance at higher temperatures, short developmental time and greater food consumption in comparison to *C. orichalcociliellus.* However, research on the comparative effect of abiotic and biotic factors on the survival of stemborers is presently scanty and there is need for further studies to evaluate how these factors influence larval survival.

In the current experiment, grain reduction by *C. partellus* and *B. fusca* larvae were highly influenced by stem tunnelling. Stem tunnelling has been reported initially to be responsible in reducing the yield of maize (Ajala and Saxena, 1994). Correlations done to establish the relationship between the growth parameters indicated that stem tunnelling was a determining factor in yield loss of maize and increased larval feeding within the stems could have led the decrease in grain weights. *S. calamistis* larvae have not been reported to cause high yield losses to maize in the field (Kfir *et al.,* 2001). This study showed that *S. calamistis* larvae was not responsible in causing high yield loss of maize and this could also be attributed to the low larval survival and feeding deterrence.

Chilo partellus larval activities have been reported to cause lower yields and reduced growth potential of maize and sorghum plants in the Eastern and Southern parts of Africa (Ampofo, 1988, Polaszek, 1998, Kfir *et al.,* 2001). Similar damage activities have also been reported for *B. fusca* in the highland areas where the borer is abundant (Kfir *et al.*, 2002). Ndemah *et al.*, (2002) attributed high damage by *B. fusca* to excessive feeding as a result of its big larval size. The borer made comparatively longer stem tunnels in maize compared to *C. partellus* and *S. calamistis.*

Chilo partellus and *B. fusca* larvae are usually characterised by leaf and stem feeding. Once inside the plant, the borers make extensive tunnels that interfere with the physiological activities of the plants. Feeding similarities between these two borers have been reported by Van den Berg *et al.* (1991) on sorghum in South Africa. Grain weight reduction was highly influenced by stem tunnelling. Increased stem tunnelling was responsible in reducing the vitality of growth of the maize plants. As a result of stem tunnelling, other maize parameters like height and stem diameter were reduced. *Chilo partellus* and *B. fusca* larva demonstrated a higher degree of feeding aggressiveness and were capable of causing higher damage as compared to *S. calamistis* larva.

Previous studies conducted under field conditions, have characterised damage due to *S. calamistis* larvae to stem breakages and lodging of stems (Usua 1968, Ajala and Saxena, 1994). Attack of *S. calamistis* larvae frequently resulted in dead heart effects and therefore the extent of damage to other parameters was shadowed. In the current study, *S. calamistis* larva was not characterised by extensive stem tunnelling or height reduction as compared to the two other borers. Some of the plants infested with the borer were either dead or the larva did not complete their larval stages within the stems. Some of the recovered *S. calamistis* larvae only tunnelled short distances and died within the stems.

The disruption of plant physiological activities through insect damage has been reported to cause low yields to crops (Bardner and Fletcher, 1974). Stem borer damage on the growing maize plants have usually led to low grain yields. Low quantities and poor quality maize have been harvested in small-scale farmers fields as a result of stem borer damage (Songa *et al.,* 2001). In this study, the stem borer species had varying damaging effects on the maize. *Chilo partellus* and *B. fusca* larvae probably had longer feeding durations in the maize than *S. calamistis.* This caused them to cause more damage on the maize. *B. fusca* takes a longer time to finish its life cycle and therefore the larval period is longer, this in turn could have resulted to extended feeding within the stems. Longer periods of larval feeding by these insect pests have been reported to contribute to low yields (Seshu Reddy, 1992).

Grain yield of maize is highly dependent on plant growth characters and how these characters interact with each other and with environmental factors. The quality and quantity of the maize yield are reduced through damage to the growing parts of the maize plant. Stem borer damage highly contributes to the reduction of the maize yield in small scale farmers fields (Songa *et al.,* 2001, De groote *et al.,* 2002). The correlation analysis showed that stem tunnelling caused by *C. partellus* and *B. fusca* larva had a negative effect on the grain weights of maize as compared to *S. calamistis* larva. Previous studies on stem borer damage that mainly focused on *C. partellus* larvae, attributed stem tunnelling as the major factor causing low grain yields. Ajala and Saxena, (1994) attributed grain yield reduction to stem tunnelling by *C. partellus* larva. Similarly Kumar

(1988) reported a reduction in plant performance as a result of the effect of stem tunnelling by *C. partellus* larvae. Grain weight reduction was less affected by *S. calamistis* stem tunnelling. Plant height reduction by *C. partellus* and *B. fusca* was a consequence of the stem tunnelling. The larval activities of these borers highly influenced the grain weights of maize. However, it has also been reported previously that, apart from stem borer damage on maize, yield of maize was also affected by the interactions between the growth parameters, physiologic processes and the pests (Ngoko *et al.*, 2002). This study showed the differential larval effect on the maize yield and it was observed that stem borers in general reduce the quality and quantity of maize and therefore potentially harvestable maize is lost. *C. partellus* and *B. fusca* larva were capable of causing higher damage to maize compared to *S. calamistis* larva.

5.2 Conclusions

This study shows that yield of maize is greatly reduced by the stem borer larvae that survive within the plant tissues. The larval survival among the species was shown to be very low regardless of the initial larval infestations. Very high mortality of the stem borer larvae was observed irrespective of the species. An average of not more than four larvae was recorded. However, *C. partellus* and *B. fusca* showed comparatively higher survival compared to *S. calamistis.* Survival of larvae decreased with increasing infestation levels.

The studies indicated that *C. partellus* and *B. fusca* larvae had the most effect on damage and yield of maize and this was probably due to the increased stem tunnelling that reduced the uptake of nutrients and transportation of food to other parts of the plant. Stem tunnelling was a significant parameter in the reduction of grain weights. The incidence of stem borer larvae on maize in this study, closely relates to conditions in the natural environment and therefore findings of this work can be used to predict yield losses over wider areas where maize is grown.

Information about the relative importance of each species is the prerequisite for priority setting in biological control programs. Knowledge on larval damage can be used to estimate the amount of yield reductions that each stem borer species can cause in their respective ecological zones. Farmers will be able to know how much of their produce they are losing due to stemborers and how much input they need to put in place in terms of control.

5.3 Recommendations

Yield loss assessment is important in the management of stem borers and it can be incorporated in integrated pest management programmes. The efficiency of control strategies can be tested by such yield loss studies. This can enable for better and effective decision making before initiating control strategies. I therefore recommend:

1. More studies need to be carried out to establish the larval mortality factors that immensely contribute to low larval survivals.
2. Yield loss assessment by stem borers need also to be tested on various maize varieties in order to advice farmers accordingly on stem borer resistant varieties which they can plant to obtain higher yields.

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