POTENTIAL OF ENTOMOPATHOGENIC NEMATODES AS A BIOLOGICAL CONTROL AND MANAGEMENT TOOL FOR BANANA WEEVIL (*COSMOPOLITES SORDIDUS*) IN BANANA ORCHARDS

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A thesis submitted in partial fulfillment of the requirements for the award of a degree of Master of Science in Crop Protection in the Department of Plant Science and Crop Protection, Faculty of Agriculture of the University of Nairobi.

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Declaration

Student declaration

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

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Dedication

First of all, to God whose guidance surpassed many occasions. I wish to dedicate this work to my dear parents Mr. Gabriel Ndiritu and the late Mrs. Anne Ndiritu and my sisters, brother, friends and all my relatives for the encouragement and support during my studies and project work.

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Acronyms and abbreviations

AEZ	Agro Ecological Zone
ANOVA	Analysis of Variance
CABI	Centre for Agriculture and Biosciences International
DNA	Deoxyribonucleic Acid
EPN	Entomopathogenic Nematodes
FAO	Food and Agricultural Organization
GDP	Growth Domestic Product
HCDA	Horticultural Crops Development Authority
IITA	International Institute of Tropical Agriculture
IJs	Infective Juveniles
INIBAP	International Network for the Improvement of Banana and Plantain
IPM	Integrated Pest Management
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
LSD	Least Significance Difference
MoA	Ministry of Agriculture
NRCB	National Research Centre for Bananas
UK	United Kingdom
UM	Upper Midland
US	United States

Abstract

Banana weevil (*Cosmopolites sordidus*) as a pest has been identified as a major pest hindering sustainable banana production in Kenya and throughout the tropics in the world. Most damage is caused by the larvae that tunnel through the corm consequently interfering with nutrient, water intake and stability of the banana pseudostem and eventual reduction of yields. The study was carried out to determine the potential of local entomopathogenic nematodes as a sustainable biological management tool against the banana weevil.

Firstly, a survey was carried out where 90 farmers were interviewed to determine biotic constraints affecting small holder banana production. While administering the questionnaires the incidences of banana pests and diseases were determined on 30 farms. Secondly, a study on the prevalence of banana weevil in three identified agro-ecological zones, upper midlands 1, 2 and 3 (UM 1, UM 2 and UM 3, respectively), in two banana growing areas, Maragua in Central Kenya and Embu in Eastern Kenya was done. Banana weevils were trapped from 30 banana farms randomly spread in each zone (10 farms per zone) using pseudostem attractants, made of one foot length pseudostems split into two halves with the fresh side placed on the soil. Lastly, bioassays with adult weevils and larval stages were carried out in the laboratory to determine the pathogenicity and virulence of Kenyan Entomopathogenic nematode (EPN) species as a potential biological control and management tool for banana weevil.

Results showed that more than a third of the farmers interviewed grew banana as a major crop purposely for income generation. About half of the farmers were aware of banana pests and diseases by their ability to identify symptoms of damage for both pests and diseases known to them while the other half was not to aware. The farmers perceived that the banana weevil and yellow sigatoka disease at 51% and 43%, respectively were the biotic major constraining factors. Incidences of banana weevil and sigatoka disease were significantly

($P \leq 0.05$) affected by the environmental conditions experienced in the different agro-ecological zones. Other pests and diseases observed included thrips, nematodes, panama and cigar-end rot diseases. Agro ecological zone environmental conditions significantly ($P \leq 0.05$) affected the mean population of banana weevils with the lower altitude zone (UM 3) recording the highest number of banana weevils in Maragua region in both seasons. Embu region had the same trend but there were no significant difference between the mean populations of weevils recorded in the different agro ecological zones. Temperature has a role to play where lower areas with high temperatures recorded high occurrence of the weevil compared to the cooler areas.

Entomopathogenic nematodes did not parasitize the adult weevils hence no mortality was observed. The test EPNs significantly ($P \leq 0.05$) affected the mortality of banana weevil larvae. *Steinernema carpocapsae* was the most virulent while *Steinernema yirgalemense* was the least virulent. Nevertheless; all the test nematodes caused more than 90 % larval mortality.

This study has demonstrated that *C. Sordidus* a serious pest of bananas and that its incidence and occurrence is influenced by agro-ecological zone conditions. The control and management adopted by the farmers like, trapping, pruning, uprooting and the cutting down of banana crop are inadequate to deal with the banana weevil in the farms. This research has also demonstrated that the use of local EPNs can be utilized to control and manage banana weevil by targeting the larval stage described which is the most destructive stage to bananas.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Banana (Musa *spp*) is an important crop in the world trade. It is ranked fourth as the most important global food commodity after rice, wheat and maize (Bakry *et al.,* 2001). The total value of international banana trade ranges between US $ 4.5 and 5 billion per year (FAO, 2009). The world market has categorized banana into two, the cooking banana including plantains and dessert or sweet bananas, where the Cavendish sub-group is prominent with a 47% share of global banana production. In Kenya, banana is an important food and cash crop. The benefits include food security, nutrition and source of income for most smallholder farmers and urban households. Depending on the variety, banana can be eaten ripe or cooked. It is rated as the most important table fruit sold both at local and international markets (Karamura, 2004). In addition, banana is the most important starchy staple food after cassava and sweet potato (FAO, 2009). Other health benefits to humans include strengthening of bones, lowering of blood pressure and reducing the risks of colon, breast and kidney cancers (FAO, 2009). Ripe banana flour is mixed with wheat flour for making chapatis, pancakes, doughnuts, cookies, biscuits and cakes. Banana is a feed source for livestock where both banana leaves and fresh pseudostems are used especially during the dry seasons (FAO, 2009).

Despite the economic importance of banana, production in Kenya and other producer countries, banana is faced by various constraints ranging from biotic to abiotic factors (INIBAP, 2011). The most important constraints are biotic stresses such as pests and diseases (INIBAP, 2011). The main banana pests include the thrips (*Chaetanaphothrips signipensis* and *Hercinothrips bicintus*), nematodes (*Radopholus similis*) and banana weevils

(*Cosmopolites sordidus*) among others (INIBAP, 2011). Diseases limiting production include Sigatoka (both yellow and black sigatoka) caused by *Mycosphaerella musicola* and *Mycosphaerella fijiensis*, respectively, panama disease that is caused by *Fusarium oxysporum fsp cubense*, banana wilt (*Pseudomonas solanacearum*), cigar end rot (*Gloeosporium musanum*) among others. Abiotic problems affecting banana production includes declining soil fertility, poor crop management, lack of clean planting material, poor marketing infrastructure, postharvest losses, competition with other crops for land, labor and capital, genetic erosion and lack of inputs/credit facilities (NRCB, 2011).

Among the pests, banana weevil remains a major biotic constraint to sustainable banana production in Kenya and other parts of the world among the small-holder banana farmers (Treverrow, 2003). The pest causes yield losses ranging from 40% to 100% in severe infestations (Treverrow, 2003). The larvae tunnel the corm, pseudostem and true stem hence interfering with water and nutrient uptake and eventual weakening the stability of the crop (Rukazambuga *et al.*, 1998; Masanza *et al.*, 2005). Banana weevil damage also results in delayed maturity, snapping, toppling, reduced bunch weight, mat die-out and shortened plantation life (Gold *et al.*, 2004). Most farmers are unaware of the pest while the control strategies available are only partially effective. Entomopathogenic nematodes are potential biological control agents for banana weevil which have not been fully exploited in Sub Saharan Africa. They are environmentally friendly and the nematodes occur naturally in the soil (Mwaitulo *et al*., 2011). This study aimed at testing the effectiveness of Kenyan entomopathogenic nematodes against the banana weevil adult and larval stages, as a potential biological control tool.

1.2 Problem statement and justification

Sustainable banana production in Kenya is constrained by pests and diseases. As an important food and cash crop, there is need to protect the crop for increased yield, income generation to enhance food security. Infestation due to banana weevil hinders economic production and is reported to be one of the major constraints to banana production (KARI, 2002). The banana weevil is a main pest of banana rhizomes and it infests all *Musa* spp and cultivars (Treverrow, 2003). The ovipositing female do not discriminate any cultivars (Gertrude *et al.*, 2010). The injury caused on the rhizome interferes with root initiation and vascular transport in the plant thus the youngest leaves wilt and die prematurely and small bunches with undersized fruits are produced or eventual death of the plant occurs. Reduced bunch weight and number reduces the marketability of the crop. Toppling of banana stems also occurs due to weakened growth that results from poor uptake of both water and nutrients (KARI, 2002). There is need to determine the extent of the problem and test the effectiveness of entomopathogenic nematodes on the weevil as a potential biological management tool.

Banana weevils infest all cultivars of banana and plantains. Several methods are available for the management of the weevils but none is able to effectively manage the weevil. The use of entomopathogenic nematodes has not been fully exploited with most farmers remaining unaware of the pests and the management strategies. The use of biological control agents such as entomopathogenic nematodes is environmentally friendly since the nematodes occur naturally in soil and leave no residues as does with many pesticides. The pathogenicity of Kenyan entomopathogenic nematode isolates on weevils is not known. This study was carried out to establish the pathogenicity of EPNs and generate information that can be used to help the farmers in the management of the weevils. In addition, most entomopathogenic

nematodes can be produced in mass in the laboratory by rearing them in the last instar of *Galleria mellonella* (Griffin, 2012).

1.3 Significance of the study

This study will help both the researchers and the banana growers. Using EPNs, the pest can be managed below the economic threshold level with the aim of increasing yields and increased total incomes for the farmers. This can be reflected in the improved living standards not only in the area of study but also in the other potential banana growing regions. Contribution of agriculture to the country's' GDP will be increased in the long run through increased production and promotion of trade of the produce in the local, regional and international markets.

1.4 Objectives of the study

The broad objective of the study was to develop a sustainable strategy of managing the banana weevil in the small scale banana production systems.

The specific objectives of the study were:

i. To identify biotic constraints hindering banana production in Maragua sub-county.
ii. To determine the prevalence and incidence of banana weevils in Maragua and Runyenjes sub-counties.
iii. To determine the pathogenicity of selected entomopathogenic nematodes against banana weevil.

CHAPTER TWO

LITERATURE REVIEW

2.1 Economic importance of banana crop

Banana plays a dual role as a staple food in the tropical world and a table fruit sold both at local and international markets (Karamura, 2004). It is an important source of food and income to small-scale households all year round. It is a perennial crop that grows rapidly and can be harvested all year round (IITA, 2008). In sub Saharan Africa, banana provides more than 25 % of the carbohydrates and 10 % of the calorie intake for approximately 70 million people in the region (FAO, 2005).The absence of seasonality in production of bananas is an advantage because it provides continuity of carbohydrates in diet and represents a regular source of income (FAO, 2005). It also represents a disadvantage, because the plant is continually exposed to adverse environmental factors, pests and disease pathogens (Gowen, 1995). Banana is grown in more than 120 countries in five continents (Fon *et al.,* 2013) with an annual production estimated at 88 million metric tons (Sally, 2010).Banana farming is increasing worldwide with India being the largest producer of the crop (NRCB, 2011). India alone contributes 22.2% of the banana produced in the world. China, Philippines and Brazil are other large producers of banana in the world after India (NRCB, 2011). According to FAO STATS (2009), banana and plantain are critically important in East, Central and in West Africa as an important food commodity, source of income and nutrition. Eastern and central Africa region produces 63% while the western Africa contributes 37% of banana produced in Africa. Uganda is the major producer in the East African region with 45% of banana production (IITA, 2008). Kenya and Burundi follow with 16% and 17%, respectively. In west and central Africa, Cameroon leads with 37% while Democratic Republic of Congo is ranked second with 14% a level equivalent to that in Angola (IITA, 2008). Almost 85% of world banana production emanates from small plots, kitchen gardens or backyards although

statistics are lacking (IITA, 2008). About 90% of production comes from small scale farmers and is consumed locally (IITA, 2008). The average per capita consumption in Sub -Saharan Africa, Latin America and Caribbean is 150-300 g per day and provides 25% or more of daily calories.

In Kenya, banana is a major fruit crop for both subsistence and commercial use. In priority setting exercise for horticultural crops research undertaken in the year 2008, banana was ranked as the most important crop among the fruit crops (HCDA, 2008). It is estimated to cover 74,000 hectares (HCDA, 2008). In a report by HCDA, (2008), the crop is mainly grown in Central, Eastern, Western and Nyanza provinces in Kenya. It has emerged as a major food item and income earner in major parts of the country. Banana is used for cooking and dessert or for ripening. Banana is the most affordable fruit both in rural and urban households (HCDA, 2008). Banana production is practiced under irrigation in Mbooni (Makueni), Meru (Eastern) and Maragua (Central). Kenya is rated among the top fifty banana producing countries (FAO, 2009; INIBAP, 2011).

2.2 Banana weevil

Banana weevil (*Cosmopolites sordidus*) belongs to the Class Insecta and order Coleoptera. It has several synonyms which include Banana weevil borer, banana root weevil, banana root borer, banana rhizome weevil, banana borer, plantain weevil, corm weevil and banana beetle. It is an insect pest that attacks banana plantains as a host plant. The banana weevil *(C. sordidus)* is known in virtually all banana-growing countries of the world, including the New World, Afro tropics, and Oriental and Australasian regions (Treverrow, 2003).

It was introduced into the African continent from the South East Asia and it has moved to other banana production areas within the continent through infected planting material (Gold and Messiaen, 2000). It is a major pest in East Africa (Tinzaara *et al.*, 2008).

2.3 Biology and ecology of the banana weevil

All the four stages of development are associated with the banana plant throughout the year (Treverrow, 2003). The eggs are elongate-oval, about 2 to 3 mm long and white in colour which are laid singly in small cavities. The cavities are chewed out by the female in the base of the pseudostem just above ground level or in the upper part of the corm or in roots near the soil surface or at the end of cut stems (stumps). Since they are white in colour they are rarely seen in the corm tissue. The duration of the egg stage is very variable (4 to 36 days) depending on temperature. Hatching takes place after 6 to 8 days under tropical conditions (Treverrow, 2003).

The larvae (grubs) are creamy white legless grubs, stout and distinctly curved and swollen in the middle of the body. The head is reddish-brown with strong mouthparts. Fully-grown grubs are about 12 mm long. Under tropical conditions, the larvae complete their development and pupate in 20 to 25 days. This larval stage has been shown to be more responsive to entomopathogenic nematodes (Mwaitulo *et al.*, 2011). Pupae are white and about 12 mm long. Pupation takes place in holes bored by the grubs. As it develops, the shape of the adult becomes visible. Adults emerge from the pupae 5 to 7 days after pupation (Mwaitulo *et al.*, 2011). Adults are 10 to 16 mm long weevils (snout beetles), hard-shelled, with a rather long curved snout (Treverrow, 2003). Newly emerged weevils are red brown, turning almost black after a few days. They are free living. They are commonly found

between leaf sheaths, in the soil at the base of the mat or associated with crop residues. They often remain within the plant before biting the external sheath and leaving the banana plant. They feed on dead banana plants, newly cut stems and other decaying plant material near the base of banana plants (Ole *et al.*, 2011). Weevils may live for up to 4 years (Tinzaara *et al.*, 2008) and can live without food for 6 months. They are very sensitive to desiccation and will die within 48 hours if kept in a dry substrate. The weevils are active at night. The adults are sluggish and rarely fly, but commonly walk over the soil surface and vegetation and feign death when disturbed. Adults cover short distances and are attracted to the host plants by volatiles emanating from fresh and decomposing banana material (Treverrow, 2003). Studies have shown that adult weevils move either actively through crawling or passively in planting materials, the previous being slow (Gold *et al.*, 2001). Experiments on weevil behavior have been done in banana orchards (De Graf *et al.*, 2005 and Reddy *et al.*, 2009), and there is limited data on weevil behavior in banana-free areas and how they actively move before infesting new banana orchards. Widespread infestation is caused primarily by movement of planting materials containing the pest in its immature stage and, occasionally, adult stages. The weevils place their eggs in the rhizome or leaf sheaths at the base of the banana plant and the cycle repeats itself (De Graf *et al.*, 2005 and Reddy *et al.*, 2009).

2.4 Host range

Banana weevil infests banana and plantain (*Musa* spp.) and ensete (*Ensete* spp.). The highland cultivars are particularly susceptible to this pest (Kiggundu *et al.*, 2003).The weevil has contributed to the decline and disappearance of highland cooking banana in parts of East Africa. Heavy infestations have been recorded in Tanzania (Uronu and Mbwana, 2006). Ole (2011) indicated that the weevil is a major pest of all banana growing areas in the world. It has also been highlighted as a significant pest of bananas by the international network for

improvement of banana and plantain (INIBAP, 2011). The pest status in other groups of bananas is variable for example Cavendish variety (Gold and Messiaen, 2000).

2.5 Damage and symptoms

The larvae are the most destructive stage of the weevil (Kassim *et al.,* 2010). They feed by making irregular tunnels in the corm and rootstock. Tunnels are roughly circular and can reach up to about 8 mm in diameter (Kassim *et al.,* 2010). The corm can be riddled with tunnels, which promotes fungal infection and decay reducing the corm to a black mass of rotten tissue (Kassim *et al.,* 2010). Injury to the corm can interfere with root initiation and sap flow in the plant, as a result the leaves turn yellow, wither and die prematurely (Treverrow, 2003). In particular young suckers show symptoms of wilting and die, but older plants are retarded in their growth. Heavily infested plants produce small bunches, and are easily blown over by the wind. Damage is worst in neglected plants though it can attain pest status even in well managed orchards as well (Kassim *et al.,* 2010). The banana weevil damage is more serious in low altitude areas than in highland areas as a result of the influence of temperature. Weevils are usually not a problem beyond 1500 m above sea level (Gold and Messiaen, 2000).

Infestation by the banana weevil begins at the base of the outermost leaf-sheath and in injured tissues at the lower part of the pseudostem (Treverrow, 2003). Initially the young grubs make several longitudinal tunnels in the surface tissue until they are able to penetrate to adjacent inner leaf-sheaths; they then bore into the pseudostem base and rhizome/corm, but also into the base of suckers and into roots (Treverrow, 2003). Larval tunnels may run for the entire length of fallen pseudostem. Infested plants have dull yellow green and floppy foliage

(Masanza *et al.,* 2005).Young infested suckers often wither and fail to develop. Plants are easily blown down by mild to strong winds (Masanza *et al.,* 2005). The stages of banana development that are affected by weevil includes flowering stage, fruiting stage, seedling stage and vegetative growing stage and the parts affected are roots and stems (INIBAP, 2011).

2.6 Management of banana weevils

The management encompasses a range of methods which include cultural practices such as the use of clean planting material achieved through hot water treatment of peeled lesion free-rhizomes immersed in water at 54^0 C for ten minutes (Scot *et al.,* 2006). However, other sources indicate that hot baths are very effective in eliminating nematodes, but kill only a third of the weevil grubs. Thus, hot water treatment of planting material is likely to provide protection against weevil for several crop cycles only (Gold and Messiaen, 2000). Other cultural methods include selecting vigorous healthy planting material, paring or trimming and field sanitation (Gold *et al.,* 2002). Studies in Uganda showed a decline of weevil damage when the levels of sanitation changed from low to moderate and or high (Tinzaara *et al.,* 2003). Host plant resistance has proved to be effective as a management strategy through screening banana weevil for resistance using genotypes in Nigeria (Kassim *et al*., 2010).

Other methods include mass trapping using pheromone lures (Tinzaara *et al.,* 2005) or use of pseudostem traps (Gold *et al.,* 2002). Trapping has also been used to monitor weevil numbers. In China, farmers trap weevils and physically kill them but this method is laborious and time consuming (Tinzaara *et al.,* 2005). Biological control includes use of predatory enemies like ants. Predatory ants such as the big headed ant (*Pheidole megacephala*) and

Tetramorium spp. are important predators of the banana weevil. Studies in Tanzania and Uganda have shown that several species of ants are important natural enemies of the banana weevil in the region (Abera-Kalibata *et al.,* 2007). Some fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* have shown efficacy as control agents. *Beauveria bassiana* is reported to be effective against the banana weevil in combination with ants (CABI, 2000; NRCB, 2011). However, there is little information on the performance under field conditions. Some nematodes, *Steinerma* and *Heterorhabditis* spp attack both adults and grubs in the field, but the economic cost, their efficacy limit and their use on a large scale is not known (Gold and Messiaen, 2000). Entomopathogenic fungi and nematodes have shown potential against the adult weevils, causing mortality of greater than 90% under laboratory conditions (Waturu *et al,* 1997b). However, efficient and economically viable delivery systems still need to be developed. Existing methods of delivering biocontrol agents entails application at the base of every banana mat which is expensive. Strategies of aggregating the weevils are needed to reduce the cost of treatment.

Use of botanical extracts like neem powder has been tested in Kenya (Musabyimana *et al.,* 2001). In a study by Musabyimana *et* al (2001), neem applications were economical in fertile soils with moderate pest infestation. Neem applications to banana plants grown in poor soil and under very high pest attack were uneconomical. A combination of application of cow dung and neem treatments resulted in yield increases of 50 to 75% (Musabyimana and Saxena, 1999). Dipping suckers in a 20% neem seed solution at planting protects the young suckers from weevil attack by reducing egg laying through its repellent effect on adult weevils. Egg hatching rates were also lowered in neem-treated plants (Gold and Messiaen, 2000). Use of entomopathogenic nematodes has been demonstrated to be a potential

management strategy against the weevil (Mwaitulo *et al.,* 2011; Divya and Sankar, 2009; NRCB, 2011).

2.7 Use of entomopathogenic nematodes as biological control agents

Entomopathogenic nematode (EPNs) of the families Steinernematidae and Heterorhabditidae have been exploited for several decades as biological tools against many important insect pests in the world (Georgis *et al.,* 2006). This has been possible due to major advances in understanding the natural behavior of these nematodes (Divya and Sankar, 2009). They have also been studied intensively because of their ability to cause natural mortality of soil dwelling arthropods hence they have potential as biocontrol agents (Campos *et al.,* 2012). Use of EPN was part of integrated population suppression of pine weevil in the United Kingdom (Dillon and Griffin, 2008). They have been reported to control sweet potato weevils in India and Kenya (Rajasekhara *et al.,* 2010; Nderitu *et al,* 2009). In addition, use of *S.carpocapsae* as a biological control against flat-headed root dwelling weevils in roots of apricot trees showed 95% control (Martinez *et al*.., 2008).

There are many researchers in the world working on these important biological controls (Kaya *et al.,* 2006). Research on status of commercially available EPNs have been carried out intensively in North American countries and Europe while in Asian countries including China, Korea and India the much stressed research work is on the use of EPNs to control insect pests and plant pathogens and commercial products are available (Kaya *et al.,* 2006). The research in most African countries is still ongoing and in some countries non-existent .In developing countries more emphasis has been on mutualistic relationship between the EPNs

and bacteria hence use them as biological agents for soil pests (Kaya *et al.,* 2006). They are also commercially available in many parts of the world (Hazir *et al.,* 2004).

Studies on the occurrence of EPNs in Africa have been reported. The first record of both families was evidenced in a survey done in Nigeria i.e. *H. bacteriophora* and *S. fertilae* (Akyazi *et al.,* 2012). A number of surveys have been documented showing new species and strains isolated from African countries. These are abundant and are associated with types of habitats in South Africa, Kenya, Ethiopia and Egypt (Shamseldean *et al.,* 1996; Burnell and Stock, 2000; Nguyen *et al.,* 2004; Mekete *et al.,* 2005; Mwaitulo *et al.,* 2011; Malan *et al.,* 2011; Kanga *et al.,* 2012). They were first reported in Kenya in a survey conducted in the central highlands and coastal areas of Kenya where a total of 154 nematode isolates among them the new species *Steinernema karii* were identified (Waturu *et al.,* 1997a; Waturu, 1998). Further surveys in the Rift valley yielded 12 more nematode isolates (Mwaniki, pers com.). Currently 33 nematode isolates are maintained in three laboratories at KARLO (Mwea, Thika and Kabete). The most studied genera are those that are useful in the control of insect pests, the Steirnematidae and Heterorhabitidae (Gaugler, 2002). Banana weevil has been listed as a susceptible important crop pest to EPNs (Divya and Sankar, 2009). Mortality of the weevils in the field within the set-up of banana traps has been reported in Kenya (Waturu, 2000).

2.8 Ecology and distribution of entomopathogenic nematodes

Entomopathogenic nematodes are naturally occurring organisms but they can be commercially produced (Divya and Sankar, 2009). They are soil dwellers and can be isolated from the soil (Mwaitulo *et al.,* 2011). A number of described EPNs have been isolated from the insects or soil worldwide i.e. 64 species of Steinernema, 8 species of Heterorhabditis and

one species of Neosteinenerma (Grewal *et al.*, 2001). Their global diversity and abundance is not well known as well as the host ranges (Adler, 2012). Effects of abiotic factors on EPNs have been widely studied in the laboratory using the soil and several artificial substrates (Glazer, 2002, as cited by Campos *et al*, 2012). In addition, several experiments in the laboratory, fields and greenhouses have been conducted to show effects of different abiotic factors(soil moisture, pH, temperatures, soil texture, bulk density and structure) on the occurrence, movement and persistence of EPNs species (Stuart *et al.,* 2006). Moreover, experiments on effects of human activities like fertilization and pesticide application on the EPNs have also been conducted. They can occur in both cultivated and uncultivated fields (Hominick, 2002).Soil moisture is considered to be a critical abiotic factor for the survival, behavior and efficacy of EPNs (Glazer, 2002; Shapiro–Ilan *et al.*, 2002 cited by Campos *et al.*, 2012).

It is generally accepted that natural habitats have the highest probability of the occurrence of native species suitable for mass release against local pests, because they are adapted to the climate and other population regulators (Carla *et al*., 2010). The genera Steinenerma and Heterorhabitidae are cosmopolitan being present in soils and sediments in several ecosystems, limited by water availability. They move through the pore and water films that cover soil particles travelling short distances, depending on the environmental conditions in their search for the host to feed on and reproduce (Treonia and Wall, 2005). These natural habitats present a higher probability of occurrence of native species, serving an important source in relation to biodiversity and use in bio-control (Stock and Gress, 2006).

Entomopathogenic nematodes are frequently detected in most terrestrial habitats either in natural, agricultural or other disturbed soils (Hominick, 2002). They have been considered important food web components in the natural habitat involved in two trophic and also in the higher trophic levels (Denno *et al.,* 2008; Ram *et al*., 2008; Stuart *et al.,* 2008). This demonstrates the importance of EPNs in the soil natural environment. Biotic factors are also essential in understanding the ecology and distribution of EPNs though this has received less attention compared to abiotic factors. Broad host range of non-host and host arthropods, competitors, predators, parasites and also pathogens can affect the reproduction and survival of EPNs (Stuart *et al.,* 2006). Infective juveniles may experience stressful conditions such as desiccation and high temperatures especially at the soil surface immediately after application (Gaugler, 2002). Waterlogged soils may develop anoxic conditions. They are also prone to a variety of diseases and predators ((Stuart *et al.,* 2006). They can survive in the soil for months if not affected. They have evolved a suite of adaptations such as high levels of energy reserves and a protective sheath that allow them to persist in this sometimes harsh environment. Lifespan of the Infective Juveniles (IJs) depends on the quantity and quality of food reserves that is built up during its prior feeding phase and by the rate at which the reserves are depleted (Qiu and Bedding, 2000). They survive longer at low temperatures, with optimal temperatures for survival of most species typically between 5^0C and 15^0 C though 20^0 C is optimal for storage of certain tropical strains (Georgis, 2006). The distribution on a global scale is strongly influenced by climate and chance dispersal events, including those associated with human activities (Hominick, 2002). Factors affecting local distribution patterns are soil texture, vegetation and availability of suitable hosts (Hominick, 2002). There is a growing evidence of preferences of nematodes species for certain habitats (Hominick, 2002).

2.9 Life cycle of entomopathogenic nematodes

Initially, eggs are laid into the host medium. Cycle begins with an infective juvenile, whose only function is to seek out and infect new hosts (Campos *et al.*, 2012). After infecting an insect, IJ release an associated mutualistic bacterium (Griffin, 2012). The nematodes provide shelter to the bacteria, which in turn kill the insect host and provide nutrients to the nematode. Together, the nematode and the bacteria feed on the liquefying host and reproduce for several generations inside the cadaver. When the food diminishes in the host, the adult produces new IJs adapted to withstand the outside environment. After about a week, hundreds of thousands of IJs emerge and leave the host in search of a new one, carrying with them an inoculation of mutualistic bacteria, received from the internal host environment (Boemare 2002; Gaugler, 2002).

2.10 Entomopathogenic nematodes' mode of action

The symbiotic relationship between EPNs and bacteria represents one of the best biological management strategies supporting insect control (Lang *et al.*, 2011). In the soil they actively seek the host and penetrate through the natural openings i.e. spiracles, mouth and anus or in some cases directly through the cuticle of certain insects, travel the haemocoel and release symbiotic bacteria cell. The latter multiply releasing a number of virulence factors. These are toxin complexes, hydrolytic enzymes, hemolysins and anti-microbial compounds that cause mortality of insects within 48 hours (French-constant-constant *et al.*, 2007; Eleftherianos *et al.*, 2010). This provides EPNs with nutrients needed for development and reproduction within insect cadaver. It has been demonstrated that the bacterial symbionts are the final causal agents of the insect mortality (Campos *et al.*, 2009). The bacterial symbionts play an important role in the death of the host which provides nutrients for EPNs involved (Ciche, *et*

al., 2006). During the growth phase of the bacteria, the effects on the nematodes are tremendous (Hirao and Ehlers, 2009). They also affect the behavior of would be scavengers of the insect cadaver (Zhou *et al.,* 2002). *H. bacteriophora* infected cadavers were protected from avian predator, the European robin due to red colour reinforced by unpalatable taste when cadavers were sampled (Fenton *et al.,* 2011). Characteristics of entomopathogenic nematodes that make them excellent biocontrol agents are broad-host range, ability to search actively for host and kill the host within 48 hours, can easily be mass produced and applied, long term efficacy and they are environmentally friendly (Abd El Rahman *et al.,* 2012).

2.11 Rearing and handling of entomopathogenic nematodes

Reproduction of EPNs is important to the practical use including mass production and population biology (Griffin, 2012). The rearing technique involves in vivo multiplication or mass production (Mwaniki *et al.,* 2010). Small quantities needed for laboratory work and greenhouse tests can be reared on the last instars of the greater wax moth which has and is conventionally used as a standard insect host (Campos *et al.,* 2012). The larvae is rich in nutrients source available in its body and is easy to multiply in economical semi-synthetic diet source containing wheat and corn flour based media (Divya and Sankar, 2009). The meal worm *Tenebrio molitor* has been used as an alternative model insect for determination of nematode virulence (Stepanka, 2010; Baliadi *et al.,* 2011). Development of standardized procedures to measure nematode virulence is a key factor in enhancing the effective utilization of EPN as a biological control. Nematode storage prior to assay involves keeping all nematode suspensions at 20-25^{0}C for 24 hours prior to testing.

2.12 Pathogenicity of entomopathogenic nematodes

Pathogenicity process depends on the characteristics of each of the partners of the interaction i.e. insect, nematodes and bacteria. It is influenced by insect resistance (humoral and cellular defenses) and by virulence factors of the bacteria and of nematode acting separately or together to overcome the defense system in which the insect do not get infected despite viability of the EPNs (Dowds and Peters, 2002). It is also influenced by the nematode doses which also affect the reproduction and development inside the cadaver (Baliadi *et al.,* 2011). Differences in pathogenicity among bacteria species have been recorded, principally in the larvae of the wax moth. Several other factors participate in the pathogenicity of nematodes including motility (Brillard *et al.,* 2001, 2002, 2003). The pathogenicity of different EPNs differs making them suitable to be adopted in biological programs (Abd El Rahman *et al.,* 2012).

2.13 Infective juvenile behavior

Nematode juveniles are small microscopic organisms 0.5 to 5 mm long depending on the species (Abd El Rahman *et al.,* 2012). They have a pair of sensory organs, the amphids, at the anterior end which is used in detecting cues potentially associated with the host and the behavioral repertoire for host finding. Behavior is divided into four .i.e. dispersal, foraging strategies, host discrimination and infection. Their social behavior is still not well known though indicators have shown that they can survive together outside the host irrespective of cooperation or competition (Griffin, 2012). Location of the Ijs within the soil profile is one of the most important behavioral characters that impair the biocontrol potential (Lewis, 2002). The parasite and the host must be in the same place at the same time to provide control. Dispersal behaviors and capabilities of EPNs vary among species, strains and even among

individuals emerging from the same (Campos *et al.,* 2012). Different species of EPN use different routes of entry into hosts either via natural openings (mouth, anus, spiracles) or penetration through the external cuticle (French-constant *et al.,* 2007 and Eleftherianos *et al.,* 2010). Most IJs also enter host that have been killed by other factors e.g. freezing. They can also reproduce in the same host (Puza and Mracek, 2010). They are adapted for host finding and for survival (Griffin, 2012).

2.14 Factors affecting entomopathogenic nematode behavior

Entomopathogenic nematodes' behavior is affected by several biotic and abiotic factors (Hannah *et al.,* 2013). It is affected by the status of the host, the sex and age of the infective juveniles (Lewis *et al.,* 2006). Several compounds affect the nematode. They include; cry proteins which affect nematodes by forming pores in their stomach wall. Cry proteins are activated by the enzymes in the gut which results in vacuole formation, degradation of the gut and death (Marroquin *et al.,* 2000). Differences in the infectivity of EPNs may also be due to the differences in biological characteristics of the nematodes and the bacteria they are associated with (Hannah *et al.,* 2013). The foraging behavior of different EPNs influences the infectivity (Hazir *et al.,* 2003). Temperature, soil physical and chemical properties, natural enemies and competition from other organisms are also important factors that influence the behavior of EPNs especially the infectivity. Reproduction and development of the EPNs is also affected by the temperature. (Stanislav *et al.,* 2005).

Genetic differences between the EPNs also affects their sensitivity to different temperature levels with each having an optimal temperature for infectivity and reproduction (Hannah *et al.,* 2013). Entomopathogenic nematodes associated with Xenorhabdus and Photorhabdus

bacteria have different optimal temperatures for infectivity (Rahoo *et al.*, 2011). Other factors in the field such as metal ions and fertilizers also affect EPNs infectivity (Brown *et al.*, 2006). Magnesium and manganese ion enhance EPN infectivity in different insects while fertilizers have a negative impact (Brown *et al.*, 2006).

CHAPTER THREE

FARMER PERCEPTIONS OF BIOTIC CONSTRAINTS AFFECTING BANANA PRODUCTION IN MARAGUA, CENTRAL KENYA

Abstract

Banana production is constrained by many biotic factors that include pests and diseases which contribute the decline in productivity. The aim of this study was to determine biotic factors influencing banana production in the farms which are located in Maragua, Central Kenya. A structured questionnaire was administered to 90 randomly selected banana farmers in three different AEZs and farm visits were made to assess the incidences of pests and diseases which occur in banana farms in the area. Banana weevil and yellow sigatoka were the most prevalent biotic constraints with 51% and 43% farmers, respectively being able to identify damage symptoms. Environmental conditions which were experienced within the AEZs significantly ($P \leq 0.05$) affected the incidences of banana weevil and sigatoka disease. Other pests and diseases included thrips, nematodes, panama disease and cigar-end rot. The control strategies applied by the farmers are not effective and are not sustainable in managing banana pests and diseases in the orchards especially the banana weevil. Consequently, efforts should be directed toward improving the current existing knowledge base of banana pests and diseases and management. Banana growing farmers require training on the identification of pests, diseases, symptoms of damage and their management in order to improve production.

3.1 Introduction

Banana (*Musa spp)* is an important food and cash crop in the world. It is the fourth most important global food commodity after rice, wheat and maize (Bakry *et al.,* 2001) and is rated as the most important table fruit sold at both local and international markets .It is grown in more than 120 countries of the world (Fon *et al.,* 2013) with an annual production estimated at 88 million metric tons (Sally, 2010). It is a perennial crop that grows rapidly and can be harvested all year round (IITA, 2008). Depending on the variety, banana can be eaten ripe or cooked. Green and ripe fruits as well as other value added products such as alcohol, canned banana slices, juice and jams are sold for income generation (INIBAP, 2011). In some communities leaves are used for thatching houses and as plates for serving food. The leaves can also be used to make mats, hats, baskets and ropes for sale especially in the urban markets. Fresh pseudostem can be fed to livestock during the dry seasons hence acting as a source of feed to livestock (INIBAP, 2011).

In Kenya, banana crop is grown in high rainfall areas and is grown for food and income generation in Western, Nyanza, Central and Eastern regions (Qaim, 1999). In recent years, banana has gained importance over traditional cash crops like coffee and various horticultural crops that are grown in short seasons mostly grown for export market (Maina and Mbaka, 2010). Bananas produced are consumed in major urban areas in the country. Kisii region is known to produce the cooking banana varieties while the Central and Eastern regions produce the desert type (Mbaka and Maina, 2008). Unlike other countries within East Africa where bananas are most preferred as cooked part of staple food, in Kenya the most preferred is the ripened variety (Biruma *et al.,* 2007). The crop is suitable for intercropping (growing more than one crop on a given piece of land), a practice which is common among small holder farmers who own small pieces of lands sizes averaging three acres (Qaim, 1999). This

practice gives additional yield per unit area than monocropping (Wambugu and Kiome, 2001).

Despite the increasing importance of bananas in Kenya, the production is limited by several constraints (Qaim, 1999, Okumu, 2007; Maina and Mbaka, 2010). Most of the challenges are associated with biotic constraints that include banana pests and diseases. Other constraint includes declining soil fertility, poor crop management, lack of clean planting material, poor marketing infrastructure, postharvest losses, competition with other crops for land, labour and capital, genetic erosion and lack of inputs/credit facilities (NRCB, 2011). These factors over time have lowered the annual production potential which in 2002 was 580,000 tons with yields of 4 tons per hectare which is far much below the potential yields of 30 tons per hectare reported in Kenya in the 1980s (Nguthi, 2007).

Inability of most resource poor small scale farmers to access clean planting materials has aggravated the problem of reduced production in the banana sector (Qaim, 1999). The use of untreated suckers leads to poor crop establishment due to pests and diseases hence leading to low yields (Qaim 1999). Most banana pests and diseases are transmitted through suckers from infected parent plant and exchange of planting material from one farm to another, a common practice among the small scale farmers (Kahangi *et al*., 2002). In response to the rapid decline of banana production in Kenya, the government through the Kenya Agricultural Research Institute introduced the tissue culture project (Raphael, 2013). The aim of the program was to disseminate clean planting materials to banana farmers. Its adoption among the small scale farmers promised to improve banana production thus reducing food insecurity and poverty in the main banana producing regions in the country. However, Mbaka and

Maina (2008) observed that the farmers were reverting to the old practice of using suckers from their own farms or neighbours since it was expensive for them to get the tissue culture banana seedlings. Maragua was one of the focal areas where the adoption of the technology was high and also an area where the tissue culture discontinuance has been observed Mbaka and Maina (2008).

3.2 Materials and methods

3.2.1 Study site selection

The area of study covered Maragua, one of the major banana production regions in central Kenya. The Sub County lies between altitudes 1100m and 2950m above sea level. The average minimum and maximum temperatures are 14^0 C and 27^0 C respectively. The rainfall received is between 1000-1100mm per annum. It lies in the main and marginal coffee zones where banana is the main source of livelihood for most small holder farmers (MoA, 2013).

3.2.2 Determination of farmer perceptions of constraints affecting banana production

3.2.2.1 Sampling

The survey was carried out by administering a structured questionnaire to 90 randomly selected banana farmers located within the three identified agro-ecological zones where experiments on banana weevil incidences was to be done. Thirty farmers (30) randomly selected were interviewed in each of the three identified agro-ecological zones within Maragua district. The identified zones were Upper midland UM 1 represented by Kaharo location); UM 2 represented by Gakoigo and Nginda location and UM 3 represented by Samar location).

The formula for sample size determination:

$$n = \frac{N}{1 + N(e^2)}$$

Where, **n** =sample size; **N**=population size and ***e***=level of precision. 95% confidence level is assumed for the equation (Israel, 2009).

3.2.2.2 Questionnaire administration and information collection within the field

The questionnaire was sub-divided into four sections that included household characteristics, land use practices, market and marketing information and finally production practices including identification and management of pests. The household information gathered included age, marital status, gender, level of education and sources of the household income. The general land use practices included size of the farm, ownership and utilization of the farm with regard to crop production. Agricultural information collected included crops grown, cropping system adopted, and type of soil fertility amendments applied in banana orchards. Information on the purpose and motivation behind growing banana as the major crop was also gathered. The questionnaire also sought to gather information on farmer awareness and knowledge about pests and diseases and management/ control measures and information on sources of banana planting materials used by the farmers. During the farm visits incidences of pests and diseases were assessed in the farms. Ten stools were randomly selected according to the size of the orchard within the farm. The known symptoms of disease and pest attack were used as a checklist to identify the target diseases or pests in the study (CABI, 2010). Field observations were carried out to assess the physical conditions of the banana orchards within the farm and verify the information provided. Banana weevil traps

were laid in ten identified farms in each of the three agro ecological zones. They comprised of five pseudostem attractants made of one foot length pseudo stems split into two halves with the fresh side placed on the soil within the orchard at a distance of six metres apart taking care of the farm boundary. This constituted a total of 150 traps, 50 from each zone. The traps were left for three days after which trap catches were enumerated.

3.2.2.3 Statistical analysis

The data collected was both quantitative and qualitative. The data collected through questionnaire was cleaned, coded and analysed using Statistical Package for Social Sciences (SPSS 19) and Genstat (14). The aim of the analysis was to assess farmers' perception and knowledge on the biotic factors affecting the banana production. The results are summarized and presented in descriptive statistics in tables and graphs.

3.3 Results

3.3.1 Characteristics of the banana farmers

In this study a high proportion of the respondent farmers were men (67%) and 33% were female. Most of the respondent farmers (88%) were married, 9% were widowers and widows while 3% were single. The assessment of farmer's age showed that 32 percent of the farmers were aged above sixty years (60) representing the highest proportion. The lowest proportion included farmers aged between 20-30 years which was 7 percent. The proportion of farmers aged between 31-40 years was 20 percent; 41-50 years was 24 percent while that of between 51-60 years was 17 percent (Table 3.1). This study showed that most farmers had attained basic education. Forty four percent (44) had attained secondary school level, 42 percent had attained primary school level and eleven percent (11%) had attended colleges or universities after secondary school level. Three percent (3%) had not attained any level of education (Table 3.1).

Table 3.1: Household characteristics of banana farmers in Maragua

Characteristic		Proportion in %
Gender	Males	67
	Females	33
Marital status	Single	3
	Married	88
	Widowed	9
Age in years	20- 30	7
	31-40	20
	41-50	24
	51-60	17
	>60	32
Level of education	None	3
	Primary	42
	Secondary	44
	Tertiary	11

3.3.2 Sources of the household income

About two thirds of the farmers earned income from the sale of farm produce (Figure 3.1) which included different crops, livestock and livestock products. However, bananas were the most grown and preferred among the grown crops, hence contributing a larger proportion of the total sales. The rest (formal employment, casual labour, small business, pension, house rentals) contributed an average of less than 10 percent proportion (Figure 3.1).

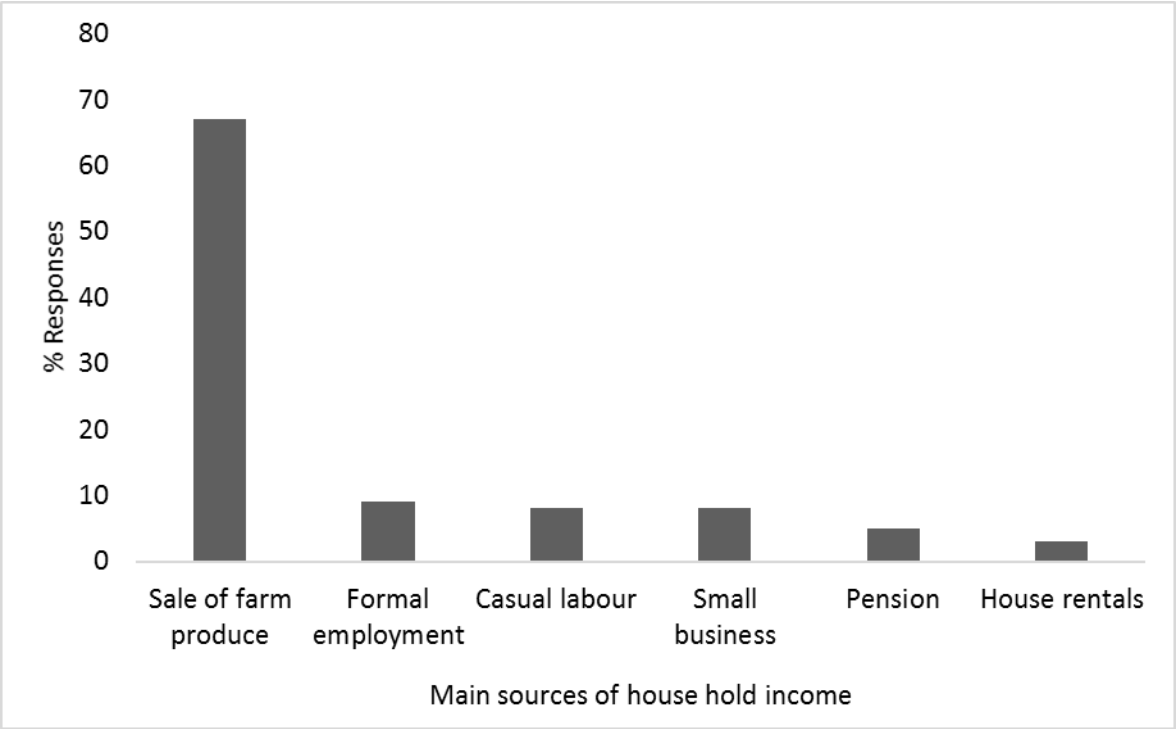


Figure 3.1: Main sources of household income for farmers in Maragua

3.3.3 Farm characteristics of the banana farmers in Maragua

More than three quarters of the respondents had their own land (Table 3.2). Only a small proportion of the farmers indicated that the land was family or communally owned at about 10% and 5%, respectively. About 11 percent did banana farming on hired farms. This study reinforces that majority of the small scale farmers own small plots of land. Forty eight percent of the farms ranged 1 - 2 acres in size. Farm sizes ranging between 7 to 8 acres were the least. Therefore most of the farmers are small scale farmers.

Table 3.2: Farm characteristics of banana farmers in Maragua

Farm characteristic		Proportion in %
Ownership	Own	78
	Family	10
	Hired	11
	Communal	1
Size (acres)	< 1	11
	1-2	48
	3-4	22
	5-6	10
	7-8	1
	>9	8

3.3.4 Major farm activities

Mixed farming was the most practiced farm activity in the area by 55% of the farmers. Other respondents (27%) grew crops only. Woodlot/agro-forestry as a farming activity was evident in the area with about 18% of the respondents practicing it (Table 3.3).

Table 3.3: Major farm enterprises

Farm activity	Proportion (%)
Mixed farming	55
Crops only	27
Woodlot/ agro-forestry	18

3.3.5 Production practices in the sub-county

3.3.5.1 Diversity of the crops grown in Maragua

The major crop which was mentioned by the farmers was the banana crop grown by about a third of the respondents across the three zones. This shows that banana farming is the most important enterprise in the region for the farmer's livelihoods (Figure 3.2).Alongside the banana crop, maize and beans came second and third, respectively. Other crops grown included vegetables, irish- potatoes, cassava, yams and sweet potatoes.

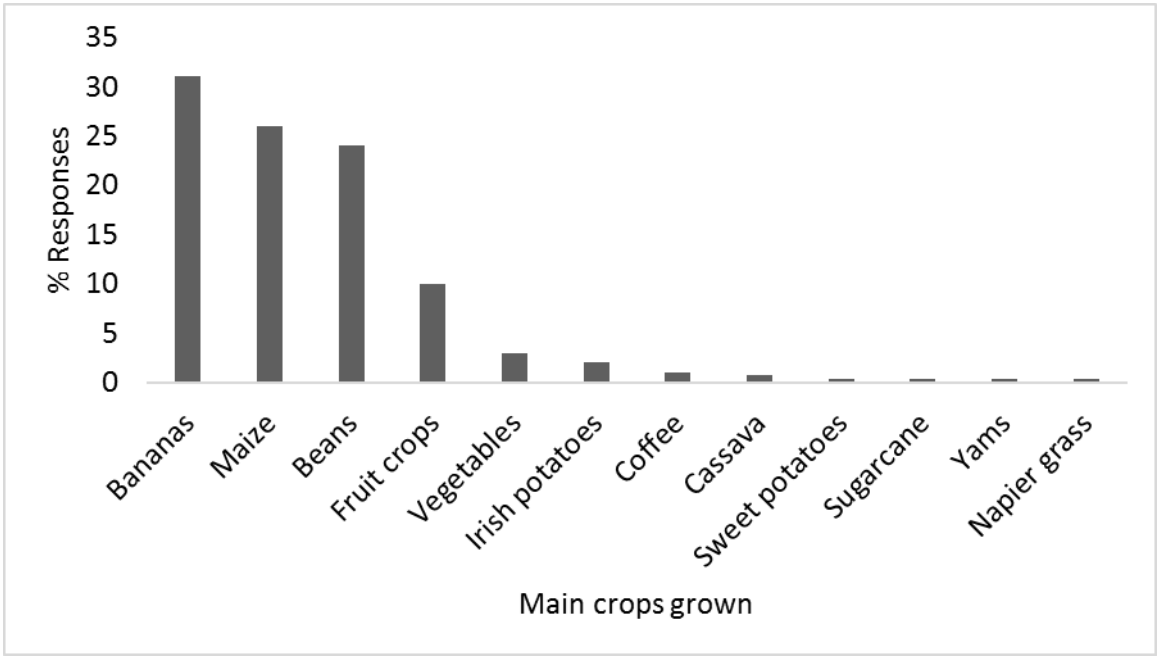


Figure 3.2: Diversity of crops grown by farmers in Maragua

3.3.5.2 Motivation for growing bananas

Banana is a major crop in the region as shown in the Figure 3.3. Seventy one (71%) of the respondents reported that they grow bananas for sale. However, it is also a food source for about 30% of the respondents. This indicates that the farmers grow bananas as a significant source of their income corroborating an earlier question of this study where 67% farmers

affirmed that their main source of income was from the sale of farm produce. Bananas are part of that farm produce.

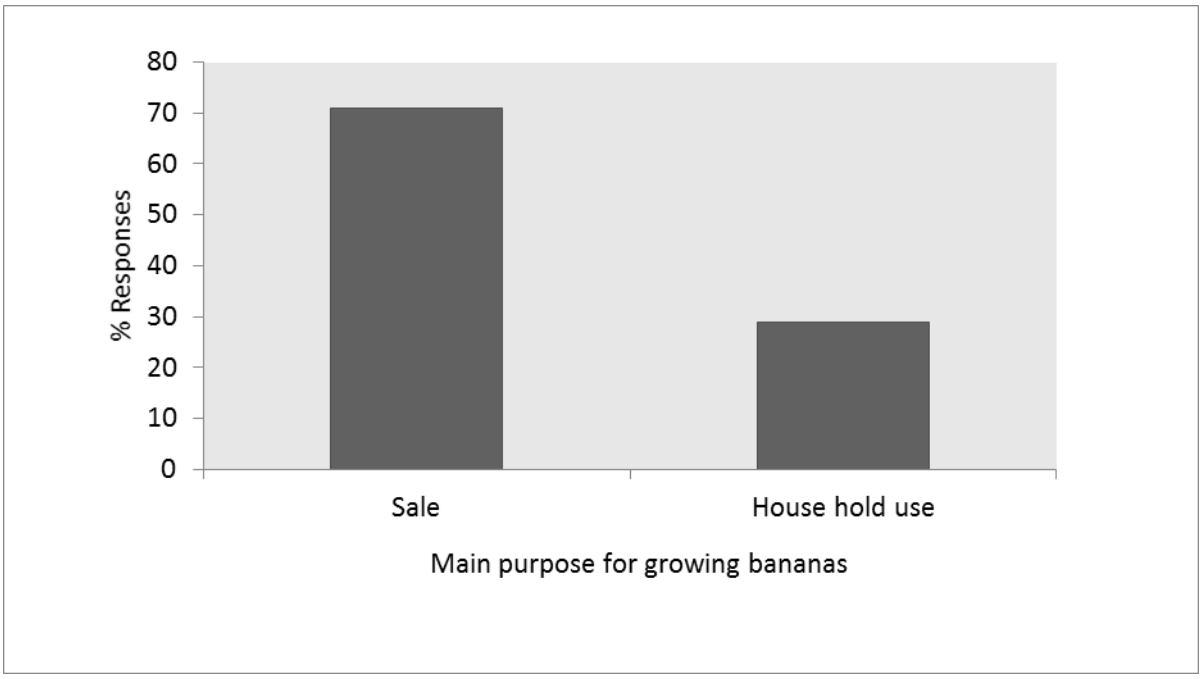


Figure 3.3: Reasons for growing bananas as a major crop in Maragua

3.3.5.3 Sources of banana planting materials for the farms

Most farmers (65%) sourced banana planting materials from their own banana orchards for transplanting. About 28% of the farmers got planting materials from their neighbors while the institutions (KARI and TC labs) and local markets occupied the rest of the proportion (7%) as shown in figure 3.4.

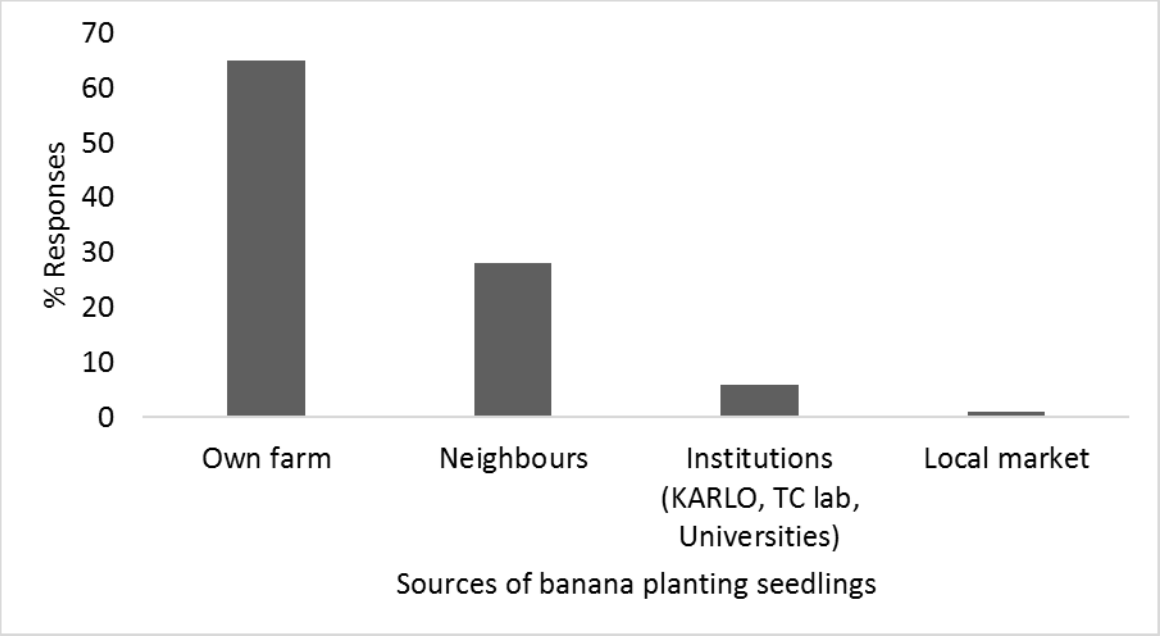


Figure 3.4: Sources of banana planting material by farmers in Maragua

3.3.5.4 Improving soil fertility within the banana orchards

The majority of farmers (97%) applied organic manure in their banana orchards and only 3% of the farmers applied inorganic fertilizer in the banana farms in addition to the organic manure as shown in Figure 3.5.

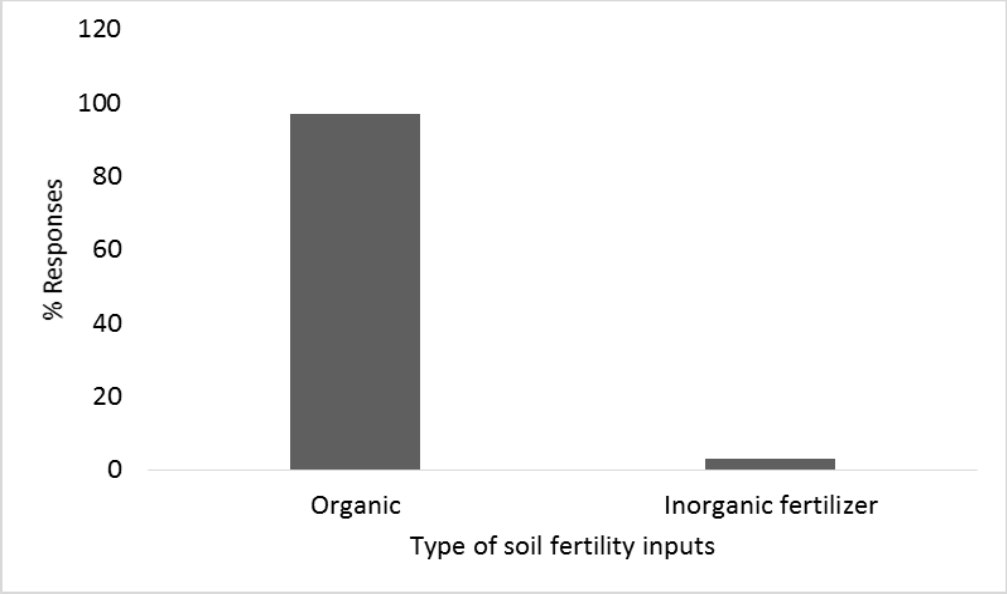


Figure 3.5: Type of soil amendments used by banana farmers in Maragua

3.3.5.5 Type of organic manure used by banana farmers

Cow manure was the most (91%) preferred and used by banana farmers in this region. The reason being that majority of farmers practiced mixed farming with cows as the most popular animals kept. Pig manure was used by a small proportion (6%) of farmers (Table 3.4). Compost manure was least used.

Table 3.4: Types of organic manure applied in banana orchards in Maragua

Type	Percentage
Cow manure	91
Pig manure	6
Compost	1
Chicken	2
Total	100

3.3.5.6 Organic manure application rates

The most used tool for measurement when applying rotten dry organic manure to banana in the study area was the wheelbarrow which is equivalent to 40 kg (Table 3.5). The number of fully loaded wheelbarrow varied according to the farmers and availability of the manure. Most farmers (71%) applied organic manure at a rate of 40-80 kg per stool. Eleven percent (11%) of the farmers had no specific measurement for organic manure application. These results show that most farmers have adopted the use of wheelbarrow probably because it is an essential farm tool among most of the farmers. The rates used by the farmers are slightly higher than the recommended 40kg of manure per stool.

Table 3.5: Organic manure application rates used by banana farmers in Maragua

Amount of dry rotten organic manure applied per stool	Proportion (%)
1-40 kg	8
40-80 kg	71
>80kg	10
No specific measurement	11

3.3.5.7 Recommended banana input application rates

The finding showed 30% of the farmers perceived that the application rates they used were correct and the recommended ones. However, 38% of the farmers were sure that the rates were not the recommended ones while 32% of them did not know (Table 3.6). The correct manure application rate per stool is 40kg each season. These results are an indication that the management of the banana orchards in terms of soil fertility inputs has not been properly communicated to most small scale farmers in the region. The response level was 30% implying that there exists no standard soil input application rates to banana orchards whether during orchard establishment or normal seasonal input additions. Another factor might be how much input the farmer can afford and the size of the banana orchard or the cost-benefit consideration.

Table 3.6: Banana farmers' response whether input application rates they used were the recommended practice

Farmer response	Proportion (%)
Yes	30
No	38
I don't know	32

3.3.5.8 Factors hindering the adoption of the recommended practices or application of inputs to bananas in Maragua

Most of the farmers who were interviewed lacked proper information about the adoption of better farming methods to improve their banana production. About 30% of the farmers regardless of their gender, age or marital status indicated that lack of information was a hindrance to the implementation of recommended practices and application of farm inputs (Figure 3.6). About a quarter of farmers responded that it was expensive to carry out the proper recommended rates. Close to 15% of the farmers responded that they experienced inadequacy of inputs while similar proportion felt that the decision to use proper application rates depended on the availability of the manure. A small proportion of the farmers responded that it was a high labor demanding practice probably due to transport and manual application of manure into the stools. In addition, a small proportion of the farmers responded that the application rates depended on the growth condition of the banana crop. About 1% of the farmers attributed not applying recommended rate to hiring an uneducated farm laborers and own choice.

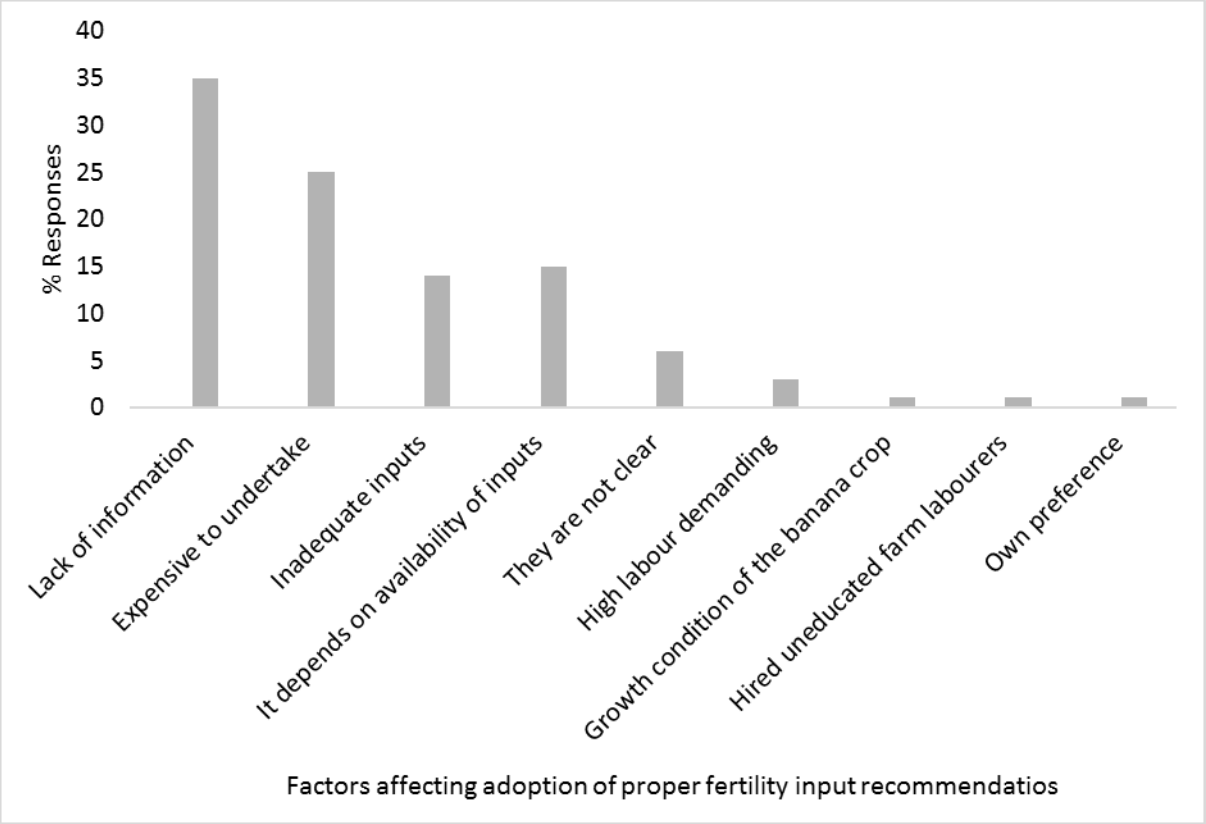


Figure 3.6: Factors hindering adoption of recommended input application rates to banana orchards in Maragua.

3.3.1 Challenges to banana production in Maragua

3.3.1.1 Farmer knowledge of pests and the management practices

The farmers in the area admitted that there were pests and diseases in their banana orchards but this was guided by the level of awareness for instance, the farmers were split into two almost equal groups with regard to the presence of pests in their orchards. Almost half of respondents (49%) were aware and admitted to observing pests in the farms while the rest 51% did not think so. Similarly, 52% of the farmers admitted that there were diseases which attacked the banana orchards whereas 48% perceived that there were no diseases evident in their banana farms (Table 3.7).

Table 3.7: Banana farmers' awareness about banana pest and diseases in the orchards

Biotic constraint	Response whether pests and diseases exist	Proportion (%)
Pests	Yes	49
	No	51
Diseases	Yes	52
	No	48

3.3.1.2 Perceived important pests and diseases attacking bananas in the field in Maragua

The common diseases that attacked bananas in the region were Sigatoka, Panama and Cigar end rot (Figure 3.7). Farmers associated these diseases with different symptoms which included yellowing of banana leaves, drying up of banana leaves from end when the crop is approaching maturity, banana fruits having ash-like coatings at the tips and the banana stems produce unpleasant smell when cut. The common arthropods pests that attacked bananas in this region were the thrips, banana weevil, ants and nematodes, while the vertebrate pests were moles and rats associated with damage on leaves, pseudostem, root, fruit and corm damage. Sigatoka and panama diseases were the most common biotic constraints among the banana farmers in this region (Figure 3.7) with 50% and 37% of the farmers, respectively responding positively that these diseases were present in their banana orchards. Cigar-end rot disease was another disease name by 13% or the farmers.

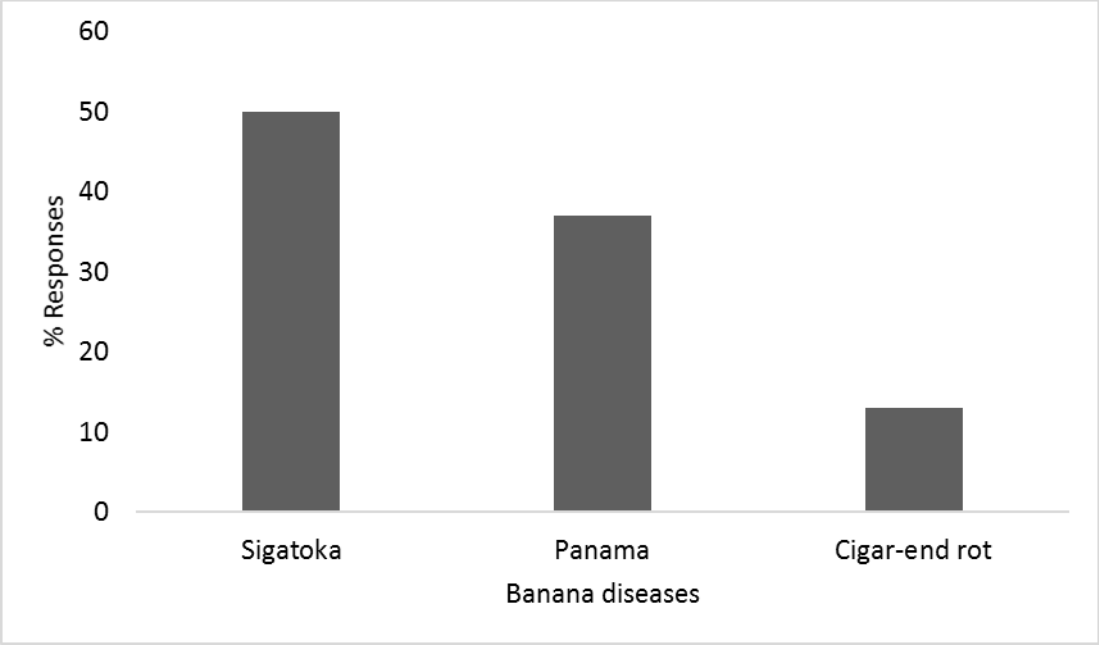


Figure 3.7: Diseases that attack banana orchards in Maragua

Fifty two (52%) of the farmers termed banana weevils as the major pest influencing sustainable banana production. Vertebrate pests that included moles and rats were also named, with moles being the most destructive. Nematodes, thrips, whiteflies, rats and ants were less known with an average proportion of less than five percent (5%) respondents naming them (Figure 3.8).

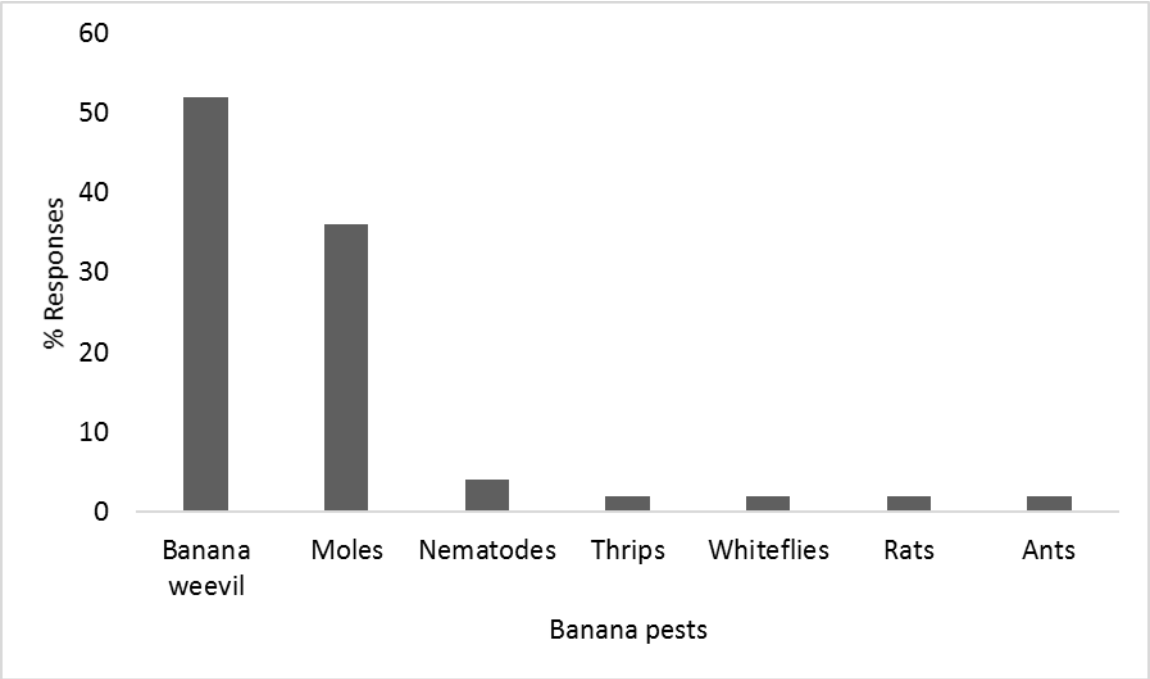


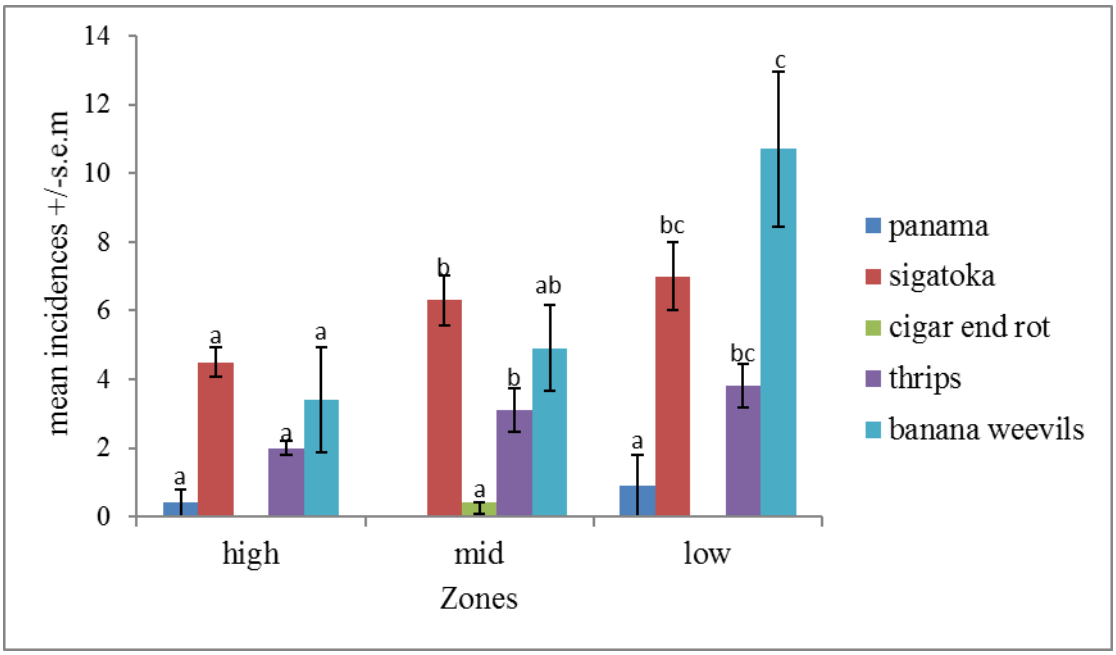
Figure 3.8: Pests that attack banana orchards in Maragua

3.3.1.3 Incidences of banana pests and diseases

Pest incidence was evident in the three banana production zones with the lower zone (UM 3) recording the highest incidence of the target pests. Banana weevil mean incidence and occurrence was significantly ($P \leq 0.05$) different and was highest in the lower zone (UM 3) with a mean of 10.7 while the least was in the high altitude zone (UM 1) with a mean of 3.4. The transitional zone (UM 2) had a mean of 4.9. Thrips also occurred across all the agro ecological zones. Thrips mean incidence and occurrence was significantly ($P<0.05$) different and was highest in UM 3 zone with a mean of 3.8 and least in UM 1 with a mean of 2.0. the upper midland zone 3 (UM3) had the highest mean incidence of thrips and the banana weevils with 53.3% and 56.3% of the fields, respectively recorded as having the pests (Figure 3.9).

Sigatoka disease was observed across the three banana growing zones with lower zone (UM 3) recording the highest mean incidence of 7.0, while UM 2 and UM 1 had a mean of 6.3 and 4.5, respectively. Panama disease was observed in two zones i.e. UM 1 and UM 3 while it was absent in UM 2. Upper Midland zone had a mean incidence of 0.4 while UM 3 had 0.9. In addition, cigar end-rot was observed in one zone only i.e. UM 2 with a mean incidence of 0.4 as shown in Figure 3.9 below.

The incidences and occurrences of banana weevil, thrips and sigatoka disease were found to be significantly ($P \leq 0.05$) influenced by the agro-ecological zone conditions. Panama disease was found not to be affected by the banana production zones. There was no difference ($P \geq 0.05$) in the means incidences recorded in the two zones i.e. UM 1 and UM 3 in which the disease was observed. Cigar-end rot could not be compared since it was only observed in one zone i.e. UM 2 (Figure 3.9).



(Means with the same letter are not significantly different ($P \leq 0.05$) Turkey's multiple range test). S.E.M - standard error of mean)

Figure 3.9: Incidence and occurrence of pests and diseases that attack banana orchards in Maragua.

3.3.1.4 Control measures used by the farmers to manage pests and diseases

Farmers applied different control measures for both pests and diseases. Seven percent preferred cutting down the affected banana pseudostems and uprooting the whole stool as a key control strategy for both pests and diseases (Figure 3.10). Measures such as pruning were considered as an important practice. Three percent of the farmers practiced field sanitation as one of the control methods (Figure 3.10). Use of traps and chemicals such as fuko-kill was reported as a strategy of controlling and eliminating vertebrate pests such as rats and moles. The traditional method of pests and disease control practiced by farmers was ash applied to the affected stools or stems to control pests and disease pathogens. About a fifth of the farmers did not apply any control measures in their farms. A number of farmers (7%) had already started planting resistant banana varieties like Israel (short and long), grand-nine and grossmichel among others to replace the Kampala variety that they mentioned was very susceptible to panama disease.

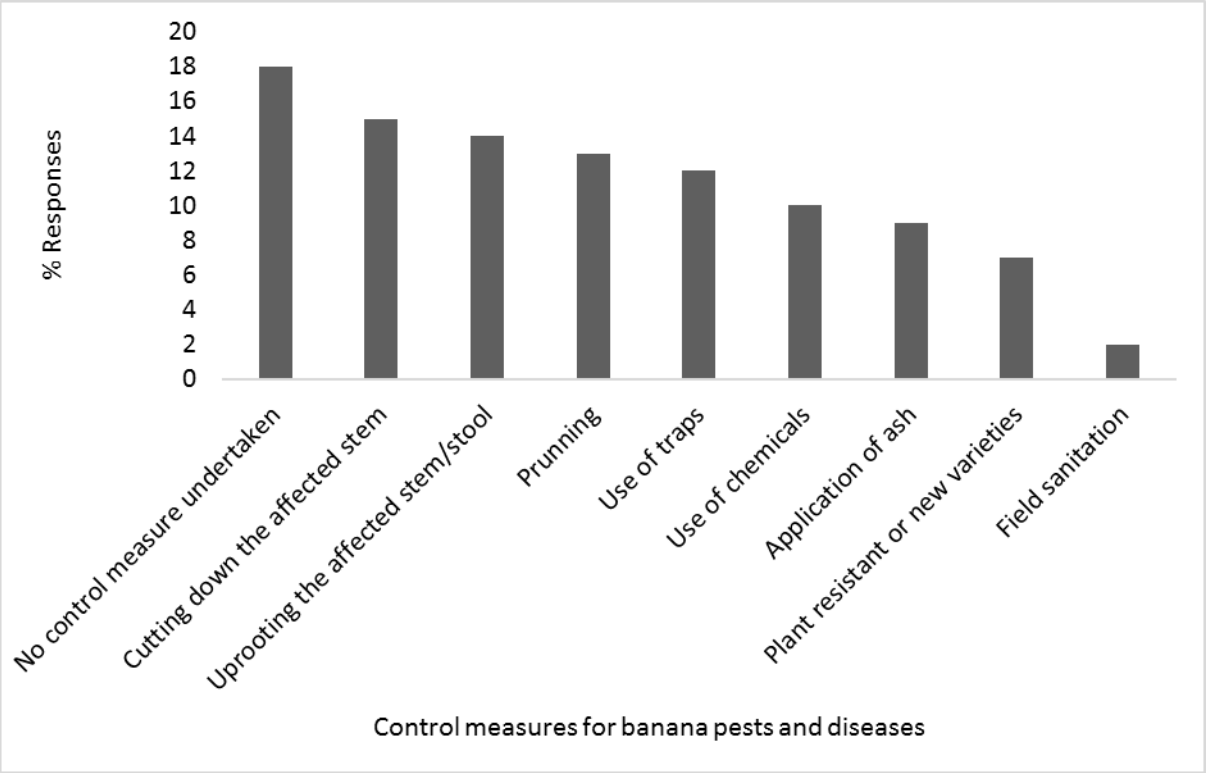


Figure 3.10: Range of control measures practiced by farmers in Maragua

Proportion of the farmers who sourced planting materials from their own farm reported more incidences and occurrences of both pests and diseases (Figure 3.11). The incidences and occurrences of almost all diseases were higher in farms that used planting materials from the same farm. In addition, sourcing from neighbors had a similar influence on almost all diseases (Figure 3.11).

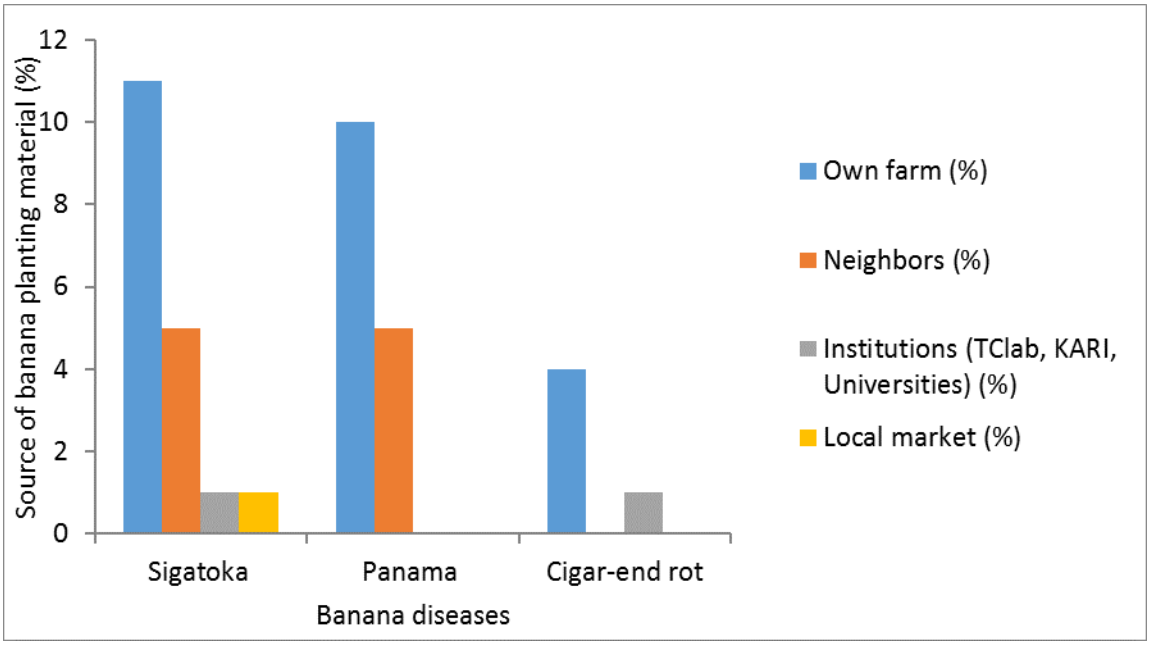


Figure 3.11: Incidences of diseases in relation to sources of banana planting materials farmers used in Maragua (% and totals based on respondents**).**

Similarly, sources of planting materials had an influence on the occurrence and incidence of insect pests but lower when compared with diseases. Banana weevil incidence was highest (24%) in farms that sourced planting materials from the same farm compared to neighbors (9%), institutions (4%) and the local market (1%) as shown in Figure 3.12.

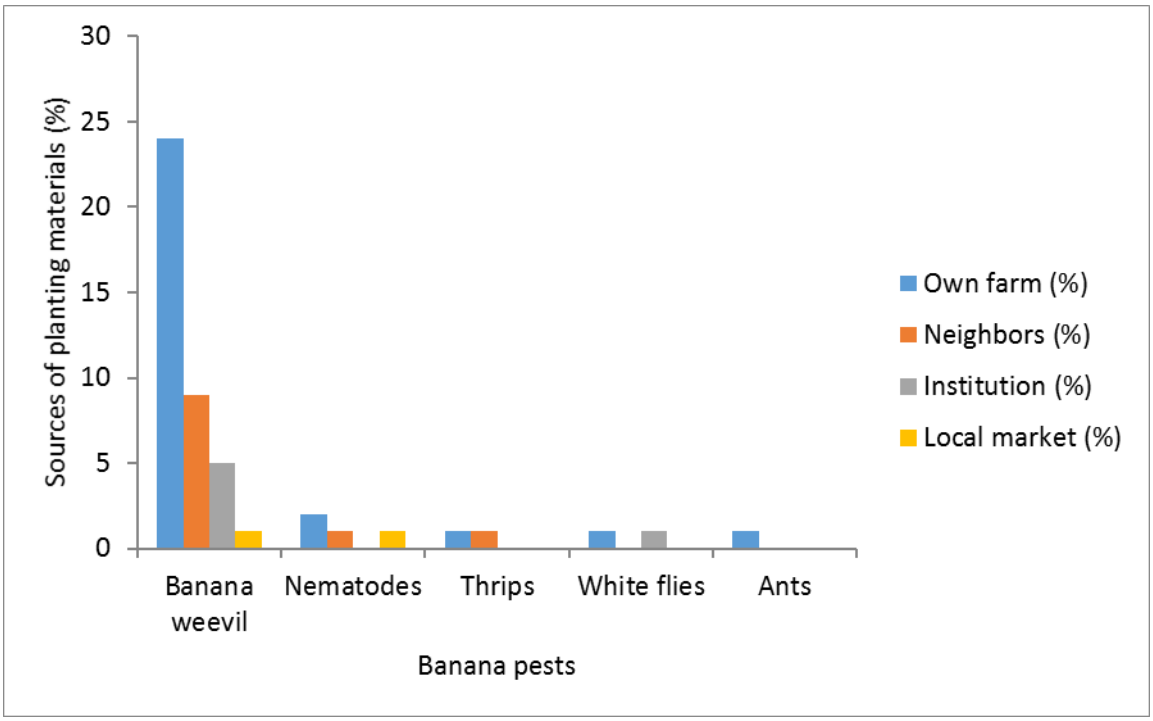


Figure 3.12: Incidences of pests in relation to sources of banana planting materials farmers used in Maragua (% and totals based on respondents).

Farmers used similar control methods for both pests and diseases. It was distinctive that for the banana weevils sixteen percent (16%) of the farmers did not apply control measure (Figure 3.13). The pest is known to infest banana corms and pseudostems hence affecting both water and nutrient uptake. Farmers practiced different types of control measures against the banana weevil as shown in Figure 3.13.

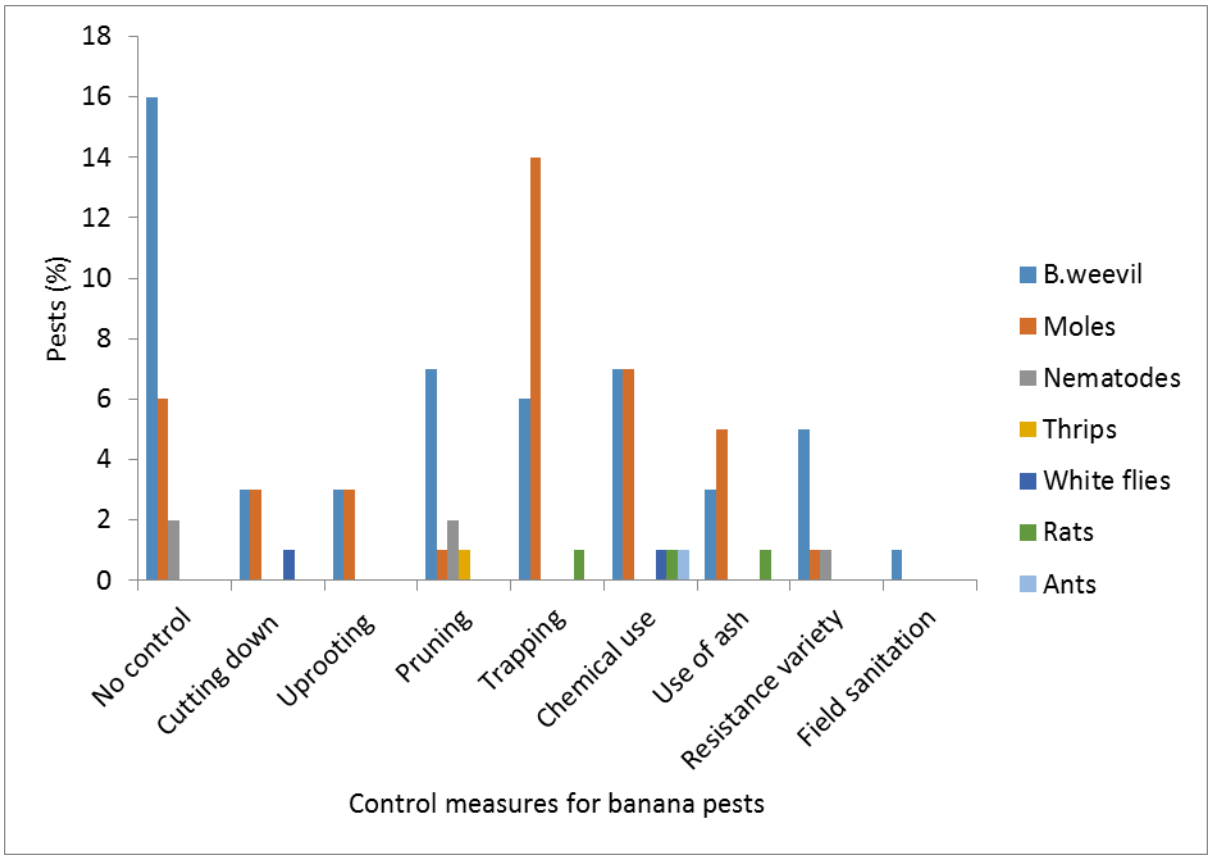


Figure 3.13: Control measures used by farmers against the reported pests that attacked bananas in the orchards in Maragua ((% and totals based on respondents).

Pruning as a control method was used for almost all the diseases and was most used for sigatoka (11%) and panama (4%) diseases. All the other control measures were only applied against panama diseases. About 15% of the farmers reported they did not apply any control measures. Use of chemicals and ash application were the least used control measures (Figure 3.14).

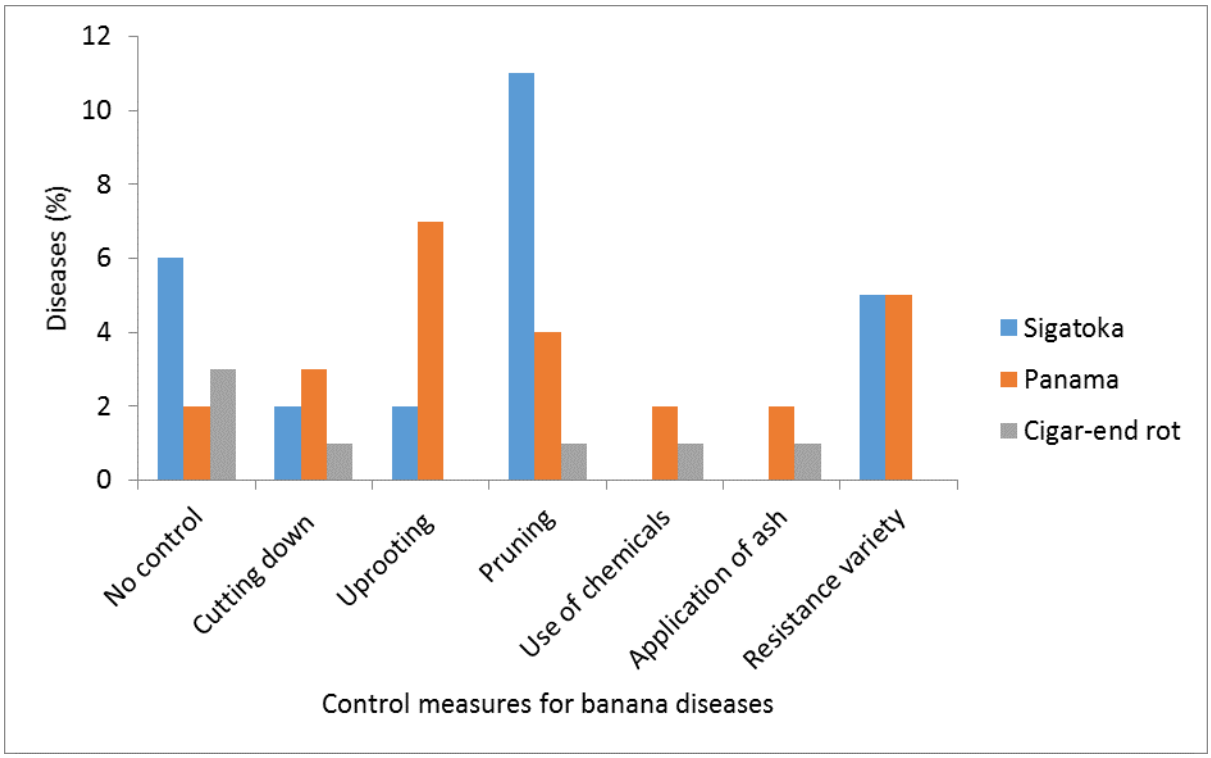


Figure 3.14: Control measure used by farmers against the reported diseases that attacked bananas in the orchards in Maragua (% and totals based on respondents).

3.4 Discussion

The findings in this study showed that two thirds of the respondent farmers were males while only a third were females. Although literature has over time indicated that women dominate small holder banana farming (Qaim, 1999), these results show that more men are getting involved in banana farming. This could be because men farmers prefer dealing with the enterprise that brings cash in the farm. According to FAO (2011) women contribute over 50% of the labour force in agriculture in East and Eastern Africa. A study conducted by Raphael (2013) in Maragua showed that majority of the respondents who were banana growers were males representing 56% while females were 44% of the sampled population. In Kenya, Shellminth (2013) found that gender of the household head was not statistically significant in the production of bananas. In a similar study, in Oriental Philippines, Bates and Flordeliza (2010), reported that majority of the banana growers were males accounting for 83% of the banana farmers. This study is a contrast to a study in Rwanda that showed that a large number of the interviewed banana farmers were females compared to males since most women attended farmers' field schools more than their counterpart males (Mubashankwaya *et al.,* 2013).

It is clear from the study that majority of the banana farmers were aged above 51 years (47%) showing that fewer youths are involved in agricultural activities. This concurs with a study in Rwanda and other sub-Saharan countries that agriculture is practiced more by the adult than the young people. The adults adopted agricultural technology more easily than the young people ((Mubashankwaya *et al.,* 2013). A study by Henry (2008), reported that there was need to attract more youths in farming meaning that young people were not engaged in agriculture in Kenya.

Education is a variable which is usually associated with many factors for instance technology adoption and use especially among the small scale farmers. According to Muyanga (2009), educated farmers are considered to be better in processing information and search for right information to alleviate and manage any production constraints. In this study, a high proportion of the banana farmers had attained secondary school education. Only a small proportion had not gained any education level. A high number had attained tertiary education i.e. universities, colleges and technical institutions. This is in contrast with a study by Mubashankwaya *et al.,* (2013) in Rwanda who reported that majority of the interviewed banana farmers had attained primary education while the lowest percentage had secondary education.

Land is an important factor for agricultural production. The tenurial status in this study showed that over eighty percent of farmers owned the pieces of land. Hired farms were also common together with family owned farms. The least proportion was the communally owned lands that belonged to the community at large. This study is different from that of Bates and Flordeliza (2010) who reported in a study that only nineteen percent of the farmers had own-operated farms while the rest were on leasehold. Land ownership rights and land tenure security are known to be the major factor influencing land use, long-term investment of land and intensification of farming activities (Keijiro and Frank, 2014).

Most farmers in the developing world do small scale farming. This is dictated by the small sizes of the land owned by the majority of the farmers. In this study it is clear from the findings that most of the farmers in this region owned a land size of below five acres but the majority were concentrated in the range of one to two acres. In a survey conducted to analyze

the socio-economic conditions and innovations in Kenyan banana sector in major banana growing areas such as Meru, Murang'a, Embu, Kiambu, Kirinyaga and Thika, it was found that most of the farmers were small-scale and most of them owned pieces of land of less than five acres (Enoch *et al.*, 2013). The findings in this study disagree with those of Qaim, (1999) and Henry (2008), who showed that the small-scale farmers had less than 1.2 and 0.3 acres, respectively.

It is expected that most small-scale farmers diversify their farming activities. Most studies have shown that this is because of the small farm sizes they own. In this study, majority of the farmers practiced mixed farming. This is similar to a recent study conducted in the major banana growing areas in Central and Eastern parts of Kenya that showed apart from bananas, farmers also grow other crops and practice livestock farming (Enoch *et al.*, 2013). Intercropping was a major pattern used to grow crops in this region probably to efficiently utilize the available land and increase food security and source of family income. These findings agrees with those of (Raphael, 2013) who reported that, apart from bananas, farmers in Maragua grow other crops such as maize, beans, sweet-potatoes, irish-potatoes, mangoes and paw paws.

A high proportion of famers practice mixed farming to diversify the enterprises and enhance food security and income generation. In Uganda, there were similar findings by the government in the national development plan (2010-2013), which recorded that the main reasons of the key agricultural activities were to alleviate poverty and ensure national food security. Food security and poverty reduction has been a major campaign in most of the developing world. Banana farming is a major source of income for most small scale farmers

(INIBAP, 2011). Majority of the farmers grow the crop for sale and a small proportion for household use. Banana is rated as an important cash crop and a food crop (INIBAP, 2011).

Since banana crop was a major crop in the region, it was also important to consider the sources of banana plantlets that farmers relied on. Majority of the farmers' sourced them from their own orchards or from neighbors. This can be explained by the distance from their farms and the labor force, time factor and inadequacy of systems for availing these planting materials.

Own farm representing the greatest share is suggestive that both pests and diseases present in the orchard are passively spread during the transplanting of the suckers. This could be the reason why the results indicate that more diseases and pests were observed in the orchards established from planting material sourced within farmers' field or from the neighbors. Most pests and disease pathogens are carried in vegetatively propagated planting materials. This makes the control and management strategies in place difficult to implement. According to Qaim (1999), the practice of using suckers from own farm is more common among the small holder banana farmers than large scale farmers who get them from research institutions like tissue culture laboratories.

Banana production in smallholder farmer systems in East Africa is traditionally propagated by means of suckers, which may harbor pests and diseases pathogens. In a study conducted by Mbaka and Mwangi (2008), revealed that banana farmers were discontinuing the use of tissue culture plantlets for transplanting due to improper procurement procedures and costs, instead they were reverting to the old practice of using suckers from their own farms and

neighbors. This has aggravated the problems of pest and disease attack in the orchards (Qaim, 1999). Wambugu *et al.,* (2000), observed that the use of infected suckers reduces the banana yield by up to 90% among the small holder farmers. The resulting yield loss reduced the potential of the crop to contribute to food security and income generation among the rural people (Wambugu *et al.*, 2000).

Banana production has continued to decline in the country and it could be because of the continued increase of pest and diseases with little practices to control and manage them (Mbaka and Mwangi, 2008). The pests of great concern in Kenya are banana weevil and nematodes supposed to cause the decline being reported (Macharia *et al.,* 2010). Banana diseases of concern causing productivity losses are sigatoka (black and yellow) and panama.

In this study, weevils were found to be the most prevalent pest attacking the bananas in all the agro-ecological zones (UM 1, UM 2 and UM 3) surveyed. The mean population of banana weevils varied with AEZ which could be the result of temperature changes and other environmental conditions. This implies that the pest can be a nuisance in areas with high temperatures. About half of the respondent described banana weevil as the main biotic constraint in the region. In Kenya, Macharia *et al* (2010) attributed banana weevil to be a major hindrance to banana production. A study conducted in Rwanda showed that population density of banana weevils was highest in low altitude zones that included Imbo zone compared with the highland zones of the Cyangugu province (Gatarayiham *et al.,* 2003). Among the diseases mentioned, Sigatoka disease, a fungal disease caused by a pathogen *Mycosphaerella musicola* (Juliane *et al.,* 2006), was the most prevalent and highly mentioned by close to half of respondent farmers. Another important disease was panama, caused by a

fungal pathogen *Fusarium oxysporium f sp cubense* (Margaret, 2012). Cigar end-rot is the most important banana fruit disease in Eastern and Central Africa and it is caused by a fungal pathogen *Verticillium theobromae* (Alassa *et al.,* 2007). In this particular study, cigar end-rot was easily recognized by the farmers probably due to its unique characteristic of ash-like moulds on the finger tips of banana fruit or the cigar end-rot characteristic.

The history of banana industry has been closely linked to the pests and diseases of the crop. The major biotic constraints to banana production are diseases such as black sigatoka (*Mycosphaerella fijiensis*), yellow sigatoka (*Mycosphaerella musicola*), panama (*Fusarium oxysporium* .f .sp *cubense*) and invertebrate pests; burrowing nematodes (*Radopholus similis*) and weevil borer (*Cosmopolites sordidus*) (Jegger *et al.,* 1996).

Yellow sigatoka is now found in most banana growing countries (Jegger *et al.,* 1996). Yellow sigatoka is more dominant at higher altitudes (>1200m) although studies have reported that black sigatoka is becoming adapted to higher altitudes and gardually replacing yellow sigatoka in these agro-ecological zones (Carlier *et al.,* 2000). The results in the study have indicated the incidence of yellow sigatoka was significantly higher in lower altitude zones compared to high altitude zone. Yellow sigatoka had the highest proportion among the disease reported by the respondents. This can be attributed to the rapid spread of the pathogen via wind, rain splash and also farm tools used in the banana orchards. Yellow sigatoka is more widespread than black sigatoka (Carlier *et al.,* 2000). Ploetz (2005), reported that panama disease was the most devastating biotic constraints affecting commercial and subsistence banana production throughout the banana producing areas in the world. Panama has been ranked as the top of the six most important plant disease in the world (Ploetz and

Pegg, 1997). Notably,panama had occurred in two agro-ecological zones but significantly higher in lower altitude zone (UM 3). Slightly above a third of the respondents had noted presence of panama disease in their banana orchards. Panama has been reported in all banana growing regions in the world (Africa,Asia, Australia and the tropical Americas) (Ploetz and Pegg, 2000).

A complex of nematodes and thrips have been reported to be among the most important pests of bananas in major banana growing regions in Kenya (Kung'u *et al*., 1996). Banana weevil are mainly managed by trapping , use of chemical control and biological control (Gold and Messiaen, 2000). About a quarter of respondent farmers used no control or management measures against the identified banana pests. Banana weevil topped the list of banana pests with a sixth of respondents who had identified banana weevil as a pest applying no control measure. Other control measures used against identified banana pests included uprooting affected banana stools and cutting down affected pseudostems. Trapping (for banana weevil, moles and rats), pruning to open up banana canopies, planting new banana varieties, use of chemicals, application of ash and finally field sanitation to make environment for banana pests unfavourable for survival were other measures used by farmers. This implies that banana farmers in this region use different control measures to manage banana pests in the banana orchard and in addition, they do not have specific control measures for specific banana pests except for invertebrate pests like rats and moles.

On the other hand,the identified banana diseases had a spectrum of control measures that farmers reported to use. Pruning was the most practised control measure for almost all the diseases. This probably could be to remove the infected leaves to reduce disease pathogen

and protect other healthy banana crops. This implies that prunning is the most affordable and requires less labour hence it has been adopted by many small scale farmers. Panama and sigatoka greatly affect the leaves and petiole and their symptoms are easily noted. Control of sigatoka can be carried out in a number of ways incuding removal of infected leaf area, chemical control or use of more resistant varieties (Juliane *et al.,* 2006). Panama disease can be managed via removal of infected banana crop, use of resistant varieties like Cavendish, crop rotation and use of clean farm tools (Rob *et al.,* 2014). Various methods have been developed to control the cigar end-rot disease such as removal of pistils, inflorescences sheathing or ligature before the opening of the bracts, use of chemicals such as (fungicide ridomil) (Mouloin *et al.,* 2004 as quoted by Alassa *et al.,*2007). Other control measures for banana diseases included use of ash, cutting down infected pseudostems and uprooting infected stools.

In terms of management of banana orchards farmers applied manure to improve soil fertility whereby the highest proportion of banana farmers used organic manure as opposed to inorganic fertilizer. Banana farmers add nutrients according to the type of banana crop under production. According to Kabunga *et al.,*(2011), adopters of tissue culture banana used more manure and fertilizer than non-adopters (those who grew local varieties).

The type of organic manure applied cut across cow manure, chicken manure, pig manure and compost. In deed, high proportion of farmers used cow manure compared to those farmers who used chicken manure, pig manure or compost. The rates and measurement tools used to apply organic manure differed with the respondent farmers. Most farmers applied organic manure at a rate of 40-80kg per stool while the least applied at a rate of 1-40kg per stool. the

recommended application per stool is 40 kilograms per stool at planting or seasonally (Nguthi, 1996). Slighly above a tenth of farmers followed no specific measurements. This implies lack of proper information on agronomic practices of banana production. Almost a similar response was noted regarding whether the measurement respondents used were correct, incorrect or did not know. It is noted that declining soil fertility is among the factors contributing to the continued decline in banana production potential in many African countries (Fen and Richard, 2008). It is supposed that the major challenge to proper adoption of the recommended manure application per stool is because of lack of information among most of the respondent farmers. Fen and Richard (2008) have reported that majority of the small scale farmers lack adequate information of the required production chain of bananas from production to marketing. Other reasons could include ambiguity of measurements recommended, high labor demand and costs involved, probably hired farm labor costs and physical energy (transport and application), unvailability of inputs and stage of banana development or growth.

3.5 Conclusions and recommendations

The area under banana and plantain cultivation in Kenya has continued to increase over the years. However, banana production has been on the decline due to biotic and abiotic constraints some of which are addressed in this study. From this study, it is clear that biotic factors hindering sustainable production of bananas are pests and diseases. Banana weevil is the most reported insect pests and sigatoka in the category of diseases. Banana weevil was the only pest with least control measures. Therefore, this study confirmed banana weevil to be a threat to banana production. Other pests and diseases included thrips, nematodes, panama and cigar-end rot. Few sustainable control measures of banana pests and diseases are available for farmers. Abiotic factors that synergize this problem and some of which have been addressed

in this study include environmental conditions, declining soil fertility, poor crop management, lack of clean planting materials, poor marketing infrastructure, post-harvest losses and lack of proper information about farming among others need to be addressed.

In order to increase banana production in Maragua and other potential production areas in Kenya, there is need to address the problem of biotic factors, improve the current knowledge base on banana pests and diseases, identification, control and management strategies by plant pathologists and entomologists. Other research especially on soil fertility, information and communication technologies, and marketing should be carried out for sustainable banana production. There is need for a long term strategic plan to promote and to protect banana value chain especially the issues to do with pests and disease management, marketing and pricing of banana produce in the country.

CHAPTER FOUR

EFFECT OF AGRO-ECOLOGICAL CONDITIONS AND BANANA FARMING PRACTICE ON BANANA WEEVIL PREVALENCE IN THE MAJOR BANANA PRODUCTION AREAS IN KENYA

Abstract

Banana weevil has been identified as a major pest hindering sustainable banana production in Kenya and throughout the tropics in the world. The damage is caused by larvae that tunnel through the corm hence interfering with nutrient and water intake. This study aimed at determining the prevalence of banana weevil in two major banana growing areas in Kenya i.e. Maragua in Central Kenya and Runyenjes in Eastern Kenya. In each area, three agro ecological zones (AEZ) i.e. high (UM1), medium (UM2) and low (UM3) altitudes were identified. Banana weevils were trapped using pseudo stem attractants. Trapping was also done in randomly selected banana farms categorized as mulched /with no mulch and monocropped/ intercropped. There was a significant difference in the prevalence of the banana weevils ($P \leq 0.05$) which were affected by the AEZs in Maragua while no significant differences was observed across the three AEZs in Runyenjes. In both regions, the findings were that there was an increase in weevil abundance with decrease in altitude since the UM3 recorded the highest number of banana weevils while UM1 recorded the least mean number. Mulching within the orchards significantly ($P \leq 0.05$) increased the population of weevils in the orchards.

In order to improve banana production, there is need to sensitize farmers about the banana weevil by entomologists and find ways of controlling and managing this pest in the area.

4.1 Introduction

Banana weevil is the most important banana pest in the whole world. It evolved from South East Asia (Gold and Messiaen, 2000) and it is now found in all the banana growing regions including the New World, Afro tropics, and Oriental and Australasian regions (Treverrow, 2003). It came into the African continent from the South East Asia through infested planting material and has since established in banana production areas within the continent such as Nigeria, Rwanda, Democratic Republic of Congo, Uganda, Tanzania and Kenya (Gold and Messiaen, 2000). It is a major pest in East Africa (Tinzaara *et al.,* 2008). The banana weevil (*Cosmopolites sordidus*) is also known as banana weevil borer, banana root weevil, banana root borer, banana rhizome weevil, banana borer, plantain weevil, and corm weevil and banana beetle. It is a coleopteran order insect and it belongs to class insecta (Treverrow, 2003).The adult weevil nocturnally active, very susceptible to desiccation and it rarely flies (Gold and Messiaen, 2000). It is black in colour and measures about 12mm, hard shelled and it has a pronounced snout. The newly emerged adult is red brown but turns black two to three days later (Treverrow, 2003). The four life stages of the weevil are associated with the banana plant throughout the season (Treverrow, 2003, Gold and Messiaen, 2000). Weevils may live for up to 4 years (Tinzaara *et al.,* 2008) and can live without food for 6 months.

Banana weevil infests banana and plantain (*Musa* spp.) and ensete (*Ensete* spp) (Tinzaara *et al.,* 2008). The highland cultivars are particularly susceptible to this pest (Kiggundu *et al.,* 2003). It has led to the decline of highland cooking banana in parts of East Africa. Heavy infestations have been recorded in the Democratic Republic of Tanzania (Uronu and Mbwana, 2006). According to Ole (2011) the weevil is a major pest of all banana growing areas in the world. It has also been highlighted as a significant pest of bananas by the international network for improvement of banana and plantain (INIBAP, 2011). The main

pests interfering with development of the corm and root initiation of banana are banana weevils and nematodes (Gold *et al.,* 2001 as quoted by (Ocan et *al.,* 2008).The larvae are the most destructive stage of the weevil (Kassim *et al.,* 2010).

4.2 Materials and methods

4.2.1 Site description

The sites of the study were Maragua and Runyenjes. Maragua is located at an altitude of 1331 m (4366 feet) above sea level in the Central part of Kenya about 64 kilometers East of Nairobi, the capital city of Kenya. It lies between latitude 0°46′59″ S and longitude 37°07′59″ E. The average minimum and maximum temperatures are 14^0 C and 27^0 C respectively. The rainfall received is between 1000-1100mm per annum (MoA, 2013).

Runyenjes is located at an altitude of 1324 meters above sea level. It is within the Eastern region of Kenya, Nairobi. It is situated between latitudes 0° 08' and 0° 35' South and Longitudes 37 ° 19' and 37° 40' East and is about 130 kilometers east of the capital city of Kenya. The average minimum and maximum temperatures experienced are 12^0 C and 26^0 C, respectively. The rainfall received ranges from 1200mm to 1700mm per annum (MoA, 2013).

4.2.2 Experimental design

This study was conducted as a form of survey, since no treatments were applied. The areas involved were stratified according to the agro-ecological zones (AEZ). The zones were differentiated from each other by the elevation above sea level which was classified as high, mid and low altitude areas (MoA, 2006). A preliminary study was carried out in Runyenjes covering Kyeni North West location (Upper Midland- a tea and coffee zone), Kyeni Central

(Upper Midland 2- a mainly Coffee zone) and Kyeni South (Upper Midland 3) a marginal coffee zone (MoA, 2013) for one season only. A similar study was conducted in Maragua for two seasons. The zones covered Kaharo location (Upper Midland 1- a tea and coffee zone), Nginda and Gakoigo location (Upper Midland 2- mainly coffee zone) and thirdly Samar location (Upper Midland 3-a marginal coffee zone).

Simple random and purposive sampling was used to select banana farms in the two sites of study. Ten farms were selected from each zone making 30 farms in Maragua and 30 in Runyenjes. Personal observations were used to randomly identify banana farms that had mulches around the banana stools and within the inter-rows and those that had no mulches. Simultaneously, banana farms with intercrops and those planted with bananas only (monocultures) were also identified. In the two categories 15 farms were randomly selected. Five (5 mulched and 5 unmulched; 5-monocultures and 5 with bananas intercropped with crops such as maize, beans, sweet potatoes, cassava, yams, coffee and fruit crops. Farms were selected from each zone making 30 farms per study site. Pseudostem traps were laid as described above and weevil catches were recorded after three days.

4.2.3 Source of traps and placement in the orchards

The pseudostem traps were prepared using freshly cut banana stems from each farm per zone. The traps used were sourced from the same farm. In each farm, five pseudostem attractants made of one foot length pseudo stems split into 2 halves with the fresh side placed on the soil within the orchard at a distance of six metres apart taking care of the farm boundary. This constituted a total of 150 traps, 50 from each zone. The traps were left for three days after which trap catches/counts were recorded. Trapped weevils were counted and recorded per

farm and computed as totals for each zone. Trapping of weevils was extended for a period of one month to elucidate the effects of pseudostem traps on weevil population.

4.2.4 Statistical analysis

The data collected was subjected to one-way analysis of variance (ANOVA) using Genstat statistical package version 14 to compare the mean population and prevalence of the adult weevils in the three agro ecological zones and between cultural practices applied on the farm. Mean comparison was done using the least significance difference.

4.3 Results

4.3.1 Population density of banana weevils in Runyenjes

In Embu the findings were that lower altitude zone (UM 3) had the highest mean number of banana weevil population of 2.3 while the least population was observed in the high altitude zone (UM 1) with only 6 weevils from the ten selected banana farms with a mean of 0.6. The transitional middle zone (UM 2) had a mean population of 1.7. The trend was such that the low altitude zone had higher populations although not significantly different from those of the other zones (UM1 and 2) (Table 4.1).

Table 4.1: Prevalence of banana weevils' population in the three banana production Agro-Ecological zones in Runyenjes

AEZ	Mean population
Lower (UM3)	2.3[a]
Middle (UM2)	1.7[a]
High (UM1)	0.6[a]
P. value	0.198
l.s.d	1.9

(Means with the same letter are not significantly different ($P \leq 0.05$, L.S.D: least significant difference)

4.3.2 Population density of banana weevils in Maragua

During the first season of the study (June to July) the high altitude zone (UM 1) recorded the lowest number of weevils from the 10 selected farms with a mean population of 2.3. In addition, the transitional zone i.e. middle zone or UM 2 had a mean population of 8.2. The zone with the highest number of weevils was the lower altitude zone or UM 3 with a mean population of 10.3. The mean populations of weevils from the different zones significantly ($P < 0.05$) differed.

In the second season of the study (February to March), the lower altitude zone (UM 3) had a mean weevil population of 10.7 which was the highest population among the three zones and significantly differed ($P< 0.05$) from the rest. Middle altitude zone (UM 2) followed with a mean population of 4.9 weevils while the high altitude zone (UM 1) had the least mean population of 3.4.In both seasons, the low altitude zones significantly ($P< 0.05$) had higher populations than the middle and high altitude zones (Table 4.2 and plates 4.1 & 4.2).

Table 4.2: Prevalence of banana weevil's population in the three banana production zones in Maragua

	Mean population	
Zones	Season 1	Season 2
Lower (UM3)	10.3^{a}	10.7^{a}
Middle (UM2)	8.2^{a}	4.9^{b}
High (UM1)	2.3^{b}	3.4^{b}
P. value	0.018	0.015
l.s.d	5.58	5.06

(Means with the same letter are not significantly different ($P\leq0.05$, l.s.d: least significant difference).

(Source: author Moses Ndiritu)

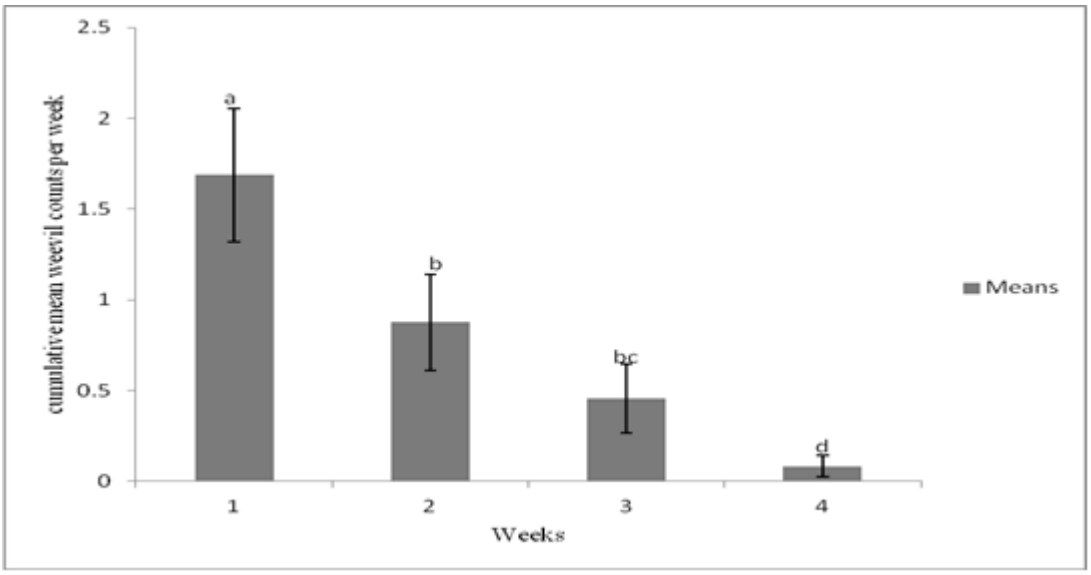
Plate 4.1: Banana pseudostem trap in the field

(Source: author Moses Ndiritu)

Plate 4.2: Trapped banana weevil in the field

4.3.3 Effect of continuous pseudostem trapping on banana weevils population in banana orchards in Maragua

The data obtained from cumulative recording of weevil population for four weeks from the pseudostem traps in Maragua indicated a highly significant ($P \leq 0.05$) reduction of population between week one and week four (Figure 4.1). Although there was no significant reduction in the weevil population trapped between weeks 2 and 3 the reduction trend was evident which continued to week 4 (Fig 4.1).



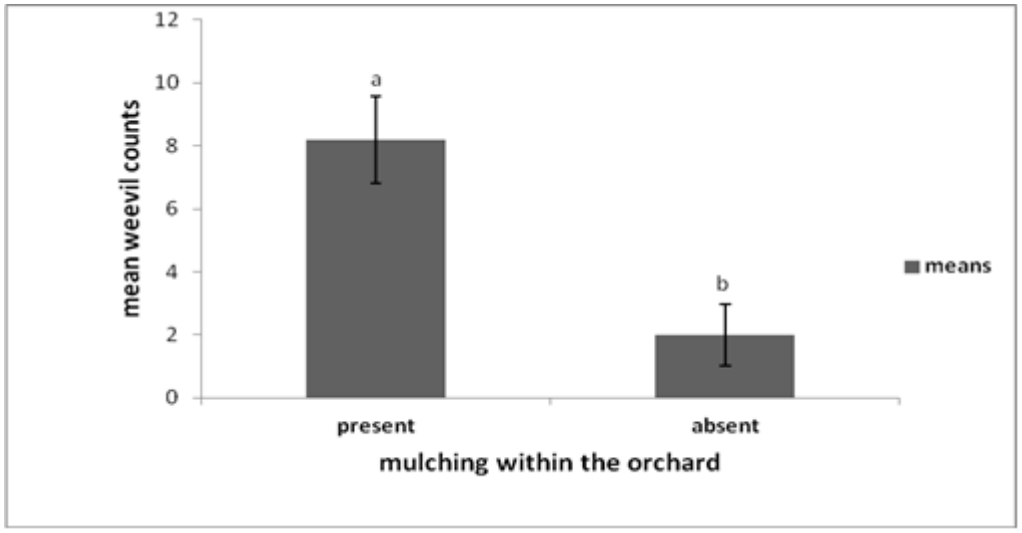
(Means with the same letter are not significantly different ($P \leq 0.05$, Turkey's multiple range test)

Figure 4.1: Cumulative reduction of banana weevil population as a result of pseudostems trapping in Maragua.

4.3.4 Effect of banana farming practices on adult weevil population within the banana orchards in Maragua

The results from this study established that the presence or absence of mulch within the banana plots had an effect on the population density of banana weevils. With respect to

mulches, the banana farms that had mulches had significantly ($P \leq 0.05$) higher weevil population than the banana farms without mulches (Figure 4.2). The kind of mulches present included old banana leaves, corms, mats and pseudostems (plates 4.3 and 4.4).

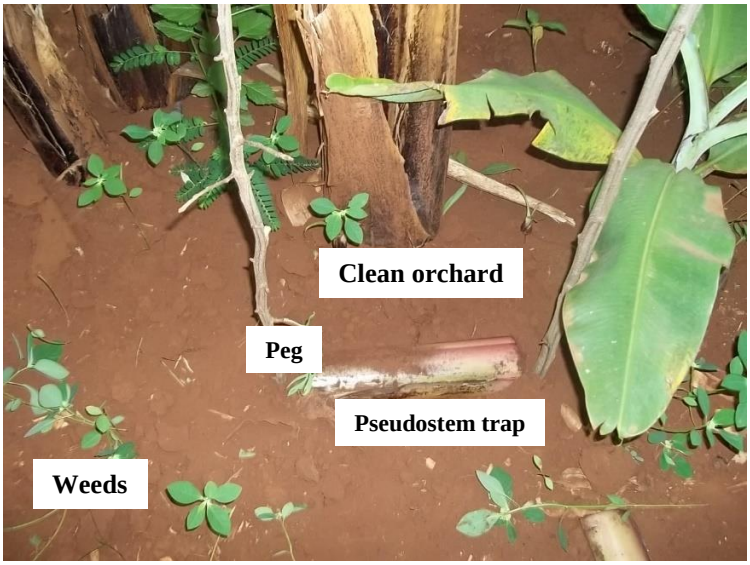


(Means with the same letter are not significantly different (P<0.05, Turkey's multiple range tests)

Figure 4.2: Effects of mulching on the population density banana weevils in Maragua.

(Source: author Moses Ndiritu)

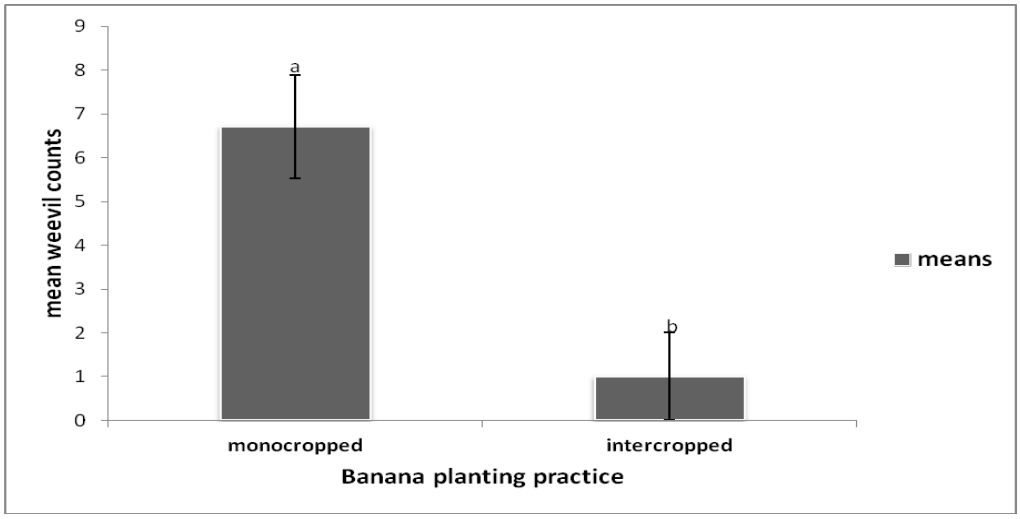
Plate 4.3: A banana orchard with mulch



(Source: author Moses Ndiritu)

Plate 4.4: A banana orchard with no mulch

Banana farms with banana only had significantly ($P \leq 0.05$) higher number of weevil population than banana farms with intercrops (Figure 4.3). The intercrops included maize, beans, sweet potatoes, yams, coffee, fruit crops and cassava (plate 4.5).



(Means with the same letter are not significantly different (P<0.05, Turkey's multiple range tests)

Figure 4.3: Effect of banana farming practice on the population density of banana weevils in Maragua.

(Source: author Moses Ndiritu)

Plate 4.5: A banana orchard intercropped with beans

4.4 Discussion

In this study, banana weevils were found in different agro-ecological zones associated with the banana crop in the two areas in Central and Eastern parts of Kenya. From the results it is evident that banana weevil population density was affected by the environmental conditions probably temperatures in this case. This is because the weevil population increased with the highest population recorded in upper midland zones 3 in both sites. Normally, temperatures decrease with increasing altitude. These results are similar to the study conducted in Rwanda that showed population density was highest in low altitude zone that included Imbo zone compared to other highland zones of the Cyangugu province (Gatarayiham *et al.,* 2003). In yet another study, Gold *et al* (2001) showed that the effect of temperature on banana weevil population was positively related to the differences in altitude in that high altitude areas with lower temperatures favored lower population of weevils than low altitude areas with higher temperatures. A study in French-constant West Indies by Duyck *et al* (2012), showed that the population of banana weevil was positively related to the temperature.

In Kenya, Njeri *et al.,* (2011) while sourcing for healthy banana corms for macropropagation and certification assessment, reported that some plantations in Eastern region were heavily infested with weevils leading to the rejection of over 20% macropropagation corms from where the temperatures were warm and had favoured weevil multiplication compared to other sources where the temperatures were lower. The high infestation of banana with weevils due to warm temperatures concurs with this study that cooler temperatures found at higher altitude zones (UM 1) did not favour fast multiplication of the weevil hence the lower population density of banana weevils observed compared to areas with high temperatures such as the low altitude zones (UM 3).

The results of this study have demonstrated that use of pseudodtem traps have a potential in reducing banana weevil population in the orchards. There was a reduction of weevils trapped weekly. This study findings agrees with those of De Graaf *et al*. (2005) who reported that use of pseudostem traps is effective in trapping weevils and it is the most common and most preffered method by most banana growers. In Cameroon, Justin *et al.,* (2009) observed that the number of adult banana weevils captured per trap varied with agro-ecological zone.

Mulching has a range of benefits to any cropping systems. It adds nutrients, contributes to conservation of moisture and suppresses weeds among other benefits such as soil conservation. Therefore, it is an important component in improving the yields of highland bananas. However from this study, the presence of mulches which mostly included the old banana leaves mats and even old pseudostem trunks seemed to play a role in promoting the survival of banana weevil which is a major pest of bananas. Mulched banana plots had higher weevil population than unmulched banana plots. The lower number of adult weevil population in unmulched banana plots can be explained by the fact that field sanitation is one of the control measures for banana weevils. In addition, banana weevil prefers moist conditions which can be created and enhanced by the mulches within the orchard plus the effect of the banana canopy. In a study carried out by Masanza *et al.* (2005) it was reported that increasing crop sanitation significantly reduced the number of adult weevils' population. The results in this study are similar to those of Gold *et al*. (2006) who confirmed that mulch presence did favor banana weevils. Banana weevil adult populations in unmulched orchards at Ntungano were 32% lower compared to mulched systems of Kawanda which recorded 44%. The damage assessed was higher in mulched than in unmulched systems (Gold *et al.,* 2006). Therefore, absence of mulches within and around the banana stools in an orchard increases sanitation levels hence reducing the population density of banana weevils.

On the other hand, this study established that banana weevil population was high in banana monocultures compared to farms that were intercropped. This can be explained probably by the fact that regular ploughing within the orchard in preparation for seasonal or annual planting of preferred intercrops was interfering with weevil movement from one mat to another or exposing the eggs, larva, pupae or adults to harsh conditions making it difficult to complete the life cycle. It's been shown that ploughing the soil covers the banana corm making it inaccessible for female banana weevils to oviposit (Seshu *et al*., 1999). A similar study in Rwanda demonstrated that the adult weevil population reduced in intercropped areas compared to banana monoculture plots (Gatarayiham *et al.,* 2003). The high number of weevils in monocropped plots may have been encouraged by plenty of host plants or because of minimal disturbance of orchard ground.

4.5 Conclusion and recommendations

Weevils are associated with the banana crop in Runyenjes and Maragua. Agro-ecological zones affect the prevalence and incidence of weevils as evidenced by the high population observed in the warmer lower altitude areas (UM 3) compared to the rest of the zones with a possibility that temperatures had an influence on the prevalence of banana weevil populations. It is important to understand how the population dynamics of insect pest are affected by environmental factors is important for pest management strategies.

Using pseudostem traps is a simple and easily adaptable monitoring tool by farmers to help detect the weevil presence by sacrificing a few pseudostems. Its effectiveness in establishing the prevalence of banana weevils in banana growing regions has been confirmed in this study. The method is labor intensive but it provides an insight of population dynamics of the

weevils in addition to reducing the populations if the farmers consistently use them for not only monitoring but to attract and kill.

Sanitation of banana fields is also effective in controlling and managing banana weevil damage. This can be achieved through removal of mulches within the orchard particularly the old pseudostems and leaves from which banana bunches have been harvested. Mulching can be used in an integrated pest management programme for banana weevils. Furthermore, intercropping banana orchards reduces the populations and hence the damage levels that may be caused by the banana weevils.

Banana farmers need to be enlightened more about the occurrence and incidence of the banana weevil, symptoms of damage, control measures and economic losses associated with it. Knowing the environment in which the banana orchards are established; utilization of pseudostem traps, practicing good sanitation and intercropping are viable options that can be incorporated in an integrated pest management programme for use by small scale farmers. The methods are cheap and available within the farm and the farmers need not rely on any external inputs to reduce damage in the farm.

CHAPTER FIVE

PATHOGENICITY OF THE SELECTED LOCAL ENTOMOPATHOGENIC NEMATODES (EPNS) AGAINST BANANA WEEVIL (*COSMOPOLITES SORDIDUS*)

Abstract

Banana weevil is a pest with a great impact on banana production in the world. The objective of this study was to evaluate the pathogenicity of the Kenyan entomopathogenic nematodes (EPNS) of genus *Steinernema* against the weevil (*Cosmopolites sordidus*) (Germar) under laboratory conditions. Adult weevils were trapped from banana fields in Maragua, Central Kenya and larvae extracted from infested banana rhizomes. The adults were treated with three Kenyan EPNs *Steinernema weiseri, Steinernema yirgalemense* and a new *Steinernema spp* and with *Steinernema carpocapsae* strain as a standard and distilled water as a control in five replicates. The treatments were 500ijs, 750ijs and 1000ijs per adult on petri dishes and 1000ijs, 3000ijs and 5000ijs per adult on pseudostems. The treatments for larvae in petri dishes were 300ijs, 400ijs and 500ijs. The adults were not susceptible to all the nematodes at all doses and preparations while larvae were highly susceptible to the four test EPNs at all concentrations. There was a significant difference at $P<0.05$ in the mortality of larvae between test nematodes . Nevertheless, all the test nematodes caused more than 90 % of the larval mortality the test nematodes caused over 90 % larval mortality within 48 hours. The mean percent mortality of larva increased with nematode concentration for all the test nematodes. The four test EPNs significantly ($P<0.05$) caused high mortality within 24-48 hrs.

Therefore, the banana weevil larvae are susceptible to the local entomopathogenic nematodes and potentially useful in the management of the banana weevil. It is however recommended that more research be made on formulation and application technology to enhance their effectiveness in the field.

5.1 Introduction

Entomopathogenic nematodes (EPNs) of the families Steinernematidae and Heterorhabditidae have been exploited for several decades as biological tools against many important insect pests in the world (Georgis *et al.,* 2006; Hannah *et al.,* 2013). This has been made possible due to major advances in understanding the natural behavior of these nematodes (Divya and Sankar, 2009). They have also been studied intensively because of their ability to cause natural mortality of soil dwelling arthropods hence the potential as biocontrol agents (Campos *et al.,* 2012). Use of EPNs was part of integrated population suppression of pine weevil in the United Kingdom (Griffin, 2008). They have been reported to control sweet potato weevils in India and Kenya (Rajasekhara *et al.,* 2010; Nderitu *et al*., 2008) and according to Martinez de Altube *et al*. (2008) use of *S.carpocapsae* as a biological control against flat-headed root dwelling weevils in roots of apricot trees achieved 95% control of the weevils.

Many researchers in the world are working on these important biological controls (Kaya *et al.,* 2006). Of these, research on status of commercially available EPNs have been carried out intensively in North American countries and Europe while in Asian countries including China, Korea and India the much stressed research work is on the use of EPNs to control insect pests and plant pathogens (Kaya et al., 2006). For most African countries EPN research is still taking place and in some countries non-existent. In developing countries more emphasis and interest is in the mutualistic relationship between the EPNs and bacteria hence the need to use them as biological agents for soil pests (Kaya *et al.,* 2006). The EPNs are also commercially available in many parts of the world (Hazir *et al.,* 2004). Studies on the occurrence of EPNs in Africa have been reported. The first record of both families was in a survey done in Nigeria where *H. bacteriophora* and *S. fertilae* were reported (Akyazi *et al.,*

2012). A number of surveys have been documented showing new species and strains isolated from African countries. These have been found to have widespread abundance and are associated with types of habitats in South Africa, Kenya, Ethiopia and Egypt (Shamseldean *et al.,* 1996; Burnell and Stock, 2000; Nguyen *et al.,* 2004; Mekete *et al.,* 2005; Mwaitulo *et al.,* 2011; Malan *et al.,* 2011; Kanga *et al.,* 2012).

The EPNs were first reported in Kenya in a survey conducted in the central highlands and coastal areas of Kenya where a total of 154 nematode isolates among them the new species *Steinernema karii* were identified (Waturu *et al.,* 1997a; Waturu, 1998). Further surveys in the Rift valley yielded 12 nematode isolates (Mwaniki, pers com.). Currently 33 nematode isolates are maintained in three laboratories at KARLO (Mwea, Thika and Kabete). The most studied genera are those that are useful in the control of insect pests, the Steirnematidae and Heterorhabitidae (Gaugler, 2002). They have been identified in Kenya with different species described in Central Highlands, Rift Valley and Coastal areas (Mwaniki *et al*., 2008). The banana weevil is the most important banana pest in the whole world. It evolved from South East Asia (Gold and Messiaen, 2000) and it is now found in all banana growing regions including the New World, Afro tropics, and Oriental and Australasian regions (Treverrow, 2003). It came into the African continent from the South East Asia through infested planting material and has since established in banana production areas within the continent such as Nigeria, Rwanda, Democratic Republic of Congo, Uganda, Tanzania and Kenya (Gold and Messiaen, 2000). It is a major pest in East Africa (Tinzaara *et al.,* 2008). The adult weevil rarely flies but is active in the night and very susceptible to desiccation and it rarely flies (Gold and Messiaen, 2000). It is black in colour measuring about 12mm has a hard shell and a pronounced snout. The newly emerged adult is red brown but turns black two to three days later (Treverrow, 2003). The larval stage is the most destructive stage (Gold and Messiaen,

2000). The weevil develops from the egg and gets into the corm and sometimes in the pseudostems making numerous tunnels. The tunneling interferes with root initiation and development, nutrient and water uptake thereby weakening the plant leading to production of a bunch with less weight or eventual death (Tinzaara *et al.,* 2008). This study was undertaken to evaluate the pathogenicity potential of the Kenyan entomopathogenic nematodes (EPNs) of genus *Steinernema* against the weevil (*Cosmopolites sordidus*) (Germar) under laboratory conditions.

5.2 Materials and methods

5.2.1 Entomopathogenic nematodes

Laboratory investigations were carried out in the entomological laboratory of the National Agricultural Research Laboratory at Kenya Agricultural and Livestock Research Organization (KALRO) in Nairobi. Entomopathogenic nematodes were obtained from the same entomological laboratory. Multiplication of the nematodes was done by in-vivo method or the insect-bait technique with *Galleria mellonella* larvae described by Poinar (1979) and modified by Woodring and Kaya (1988) and Parra (1998). Four nematode species were tested against the adult weevil and the larval stage. These were the new *Steinernema sub spp, Steinernema. Carpocapsae, Steinernema weiseri* and *Steinernema yirgalemense*. Three selected EPNs were Kenyan nematode species. These were new *Steinernema sub spp, Steinernema weiseri* and *Steinernema yirgalemense*. The nematode *Steinernema carpocapsae* which is a United Kingdom strain was used as a standard. Infective juveniles were kept in aqueous suspension in plastic containers with perforated lids at room temperatures and used in the experiment seven days after.

Entomopathogenic nematodes are soft bodied, non-segmented roundworms that are obligate or sometimes facultative parasites of insects (Tofangsazi *et al.,* 2012). The insect cadaver becomes red if the insects are killed by Heterorhabditids and brown or tan if killed by Steinernematids (Kaya and Gaugler 1993). The color of the host body is indicative of the pigments produced by the monoculture of mutualistic bacteria growing in the hosts (Tofangsazi *et al.,* 2012).

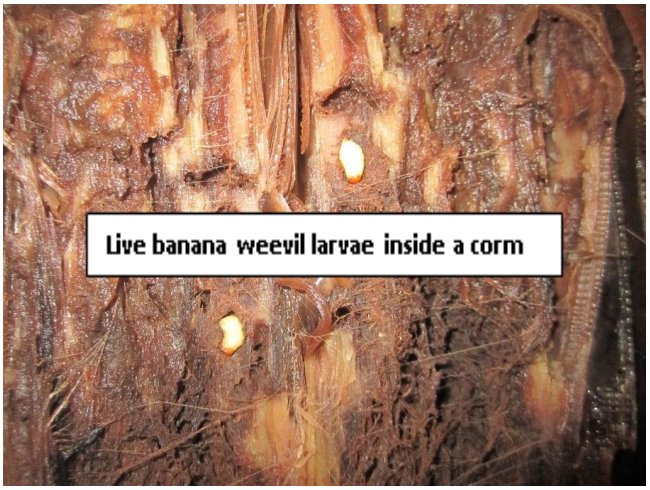
Morphologically, entomopathogenic nematodes for identification are heat-killed in 60°C Ringer's solution. The heat-killed nematodes are then placed in triethanolamine formalin (TAF) fixative and processed to anhydrous glycerine for mounting (Razia and Sivaramakrishnan, 2014). The morphological features of males and IJs and hermaphroditic female are examined under light microscopy according to procedures described by Seinhorst method (1959). The identity is verified by comparing its morphometries with the data from original descriptions as described by Nguyen and Smart Jr (1996).

Molecular identification is done by analysis of large-subunit of ribosomal deoxyribonucleic acid (DNA) sequences. An existing library of EPNs is used for sequence comparisons and phylogenetic interpretation (Stock *et al*., 2004). Total genomic DNA isolation, Polymerase Chain Reaction (PCR) amplification (reaction, cycling conditions and primers) and sequence analysis is followed by protocols described by Stock *et al.* (2001).

5.2.2 Source and extraction of adult banana weevil and larval stage

Adult of *C. sordidus* were collected with the use of pseudostem traps placed in banana plots in Maragua (0°46′59″ S and 37°07′59″ E) in Central Kenya. They were transferred to the

laboratory, and maintained in plastic buckets with moistened soil and pieces of banana pseudostems and corms. They were covered with opaque clothing and kept at room temperature. They remained until their use in experiment. Every week, there was exchange of soil and both pseudostem pieces and corms. In addition, banana corms heavily infested with weevil larvae were obtained from banana plots from Maragua and transferred in sacks bags to the laboratory. Extraction of the larvae was done the following day by opening up the corms that were characterized by holes due to infestation. They were carefully handled to avoid any injury or mortality before the assay was carried out. The extracted larvae were removed and immediately inoculated with nematode treatments (Plate 5.1).



(Source: Author Moses Ndiritu)

Plate 5.1: Banana weevil larvae inside the corm during extraction in the laboratory

5.2.3 Laboratory pathogenicity assay

Procedures of inoculation and incubation were the same as those used for entomopathogenic nematode multiplication with *Galleria mellonella* larvae (Poinar, 1979; Kaya, 1988; Parra, 1998). The only difference was that this time adult banana weevil and larval stages were used instead of the normal last instar stage of the wax moth (*Galleria mellonella).*

The only difference was that this time adult banana weevil and larval stages were used instead of the normal last instar stage of wax moth.

In the first bio-assay experiment adult weevils were used as the target insect pests to test the laboratory pathogenicity of the selected entomopathogenic nematodes. Four entomopathogenic nematodes were used as described above. Five adult weevils were introduced in well cleaned, sterilized and disinfected petri dishes per nematode species. Filter papers were lined on the surface of petri dish to absorb the excess water that carried the nematode suspension. Inoculation was done by introducing aqueous suspension containing nematodes through sterilized pipette that was specific for each nematode treatment. Each nematode treatment was replicated five times. Three different nematode concentrations were used and they included: 500 Ijs, 750 Ijs and 1000 Ijs per adult weevil in the petri dish and a control that contained distilled water only. This first experiment was repeated using the same procedure. After the inoculation, each petri dish was sealed well with a parafilm to prevent the weevils from escaping. They were then transferred to a chamber in total darkness and at room temperatures. The experiment was checked after 24 hours, 48 hours, 72 hours and 96 hours. Mortality of weevils was recorded and checked for entomopathogenic infection by dissecting the cadaver under light microscope (×100) to confirm if that mortality was a result of nematode infection.

A second bio-assay with adult weevils was conducted using the same procedure but this time with a much higher dose of entomopathogenic nematodes. The dosage levels were 1000 Ijs, 3000 Ijs and 5000 Ijs per adult weevil and control where plain distilled water was used. The

data on mortality was checked in the same way as the first experimental bioassay. This bioassay was also done twice.

A third bioassay with the adult weevil was conducted by using pseudostems which were laced with EPNs. Small blocks of pseudostem were cut from a fresh banana pseudostem. Each nematode treatment was applied to the small blocks using a hand pump. This was done all around to maximize the introduction of nematodes. Sterilized plastic containers were used in place of petri-dishes. They were lined up with filter papers at the bottom to remove excess water containing nematode suspension. The same nematode concentration was applied as in the second weevil bioassay. Only one weevil was introduced per treatment with five replications. Distilled water was used as the control per concentration level.

The last laboratory experiment involved the use of banana weevil larval stage. The procedure was similar to the first bioassay that was conducted using the adult weevil. However, the number of larvae introduced per petri dishes was three and the concentrations were 300, 400 and 500ijs per larval stage. Nematode suspensions were introduced into the petri dishes through a sterilized pipette. Plain distilled water was used as a control. Each concentration level was replicated five times. The petri dishes were then closed and sealed with parafilm to prevent the larvae from escaping. They were then incubated at room temperatures and in chambers with total darkness. The experiment was done twice. Mortality was assessed every 24 hours up to 96hours. The criterion was to consider a dead cadaver that did not move or response after brushing. Infection of EPN was confirmed by dissecting the cadaver under the light microscope (×100) to check the presence of nematodes. The number of the dead larvae was recorded.

5.2.4 Experimental design

Experimental design was completely randomized with five treatments, each treatment had five replicates and the experimental unit consisted of six petri –dishes 9cm in diameter with 3 banana weevil adults or larvae.

5.2.5 Statistical analysis

The mortality data was subjected to one and two way analysis of variance (ANOVA). Mean separation of the treatments that were significantly different at $p \leq 0.05$ was done using the Turkey-cramers comparison test. The analysis was done to compare the pathogenicity of the selected local entomopathogenic nematodes and test their effectiveness against banana weevil adult and larval stage.

5.3 Results

5.3.1 Pathogenicity of different entomopathogenic nematodes on the adult stage of the banana weevil under laboratory conditions

All the four entomopathogenic nematodes did not cause mortality of the adult weevils under room temperatures that ranged between 20^0 and 21^0 C during the period of the experiment.

In the first experiment that involved entomopathogenic nematode concentrations at 500 Ijs, 750 Ijs and 1000 Ijs, there was no mortality for the adult weevils. Similarly in an experiment where the concentrations were increased to 1000 Ijs, 3000 Ijs and 5000 Ijs per adult weevil and control, there was zero mortality caused by entomopathogenic nematode infection regardless of the concentration levels for all the nematode isolates.

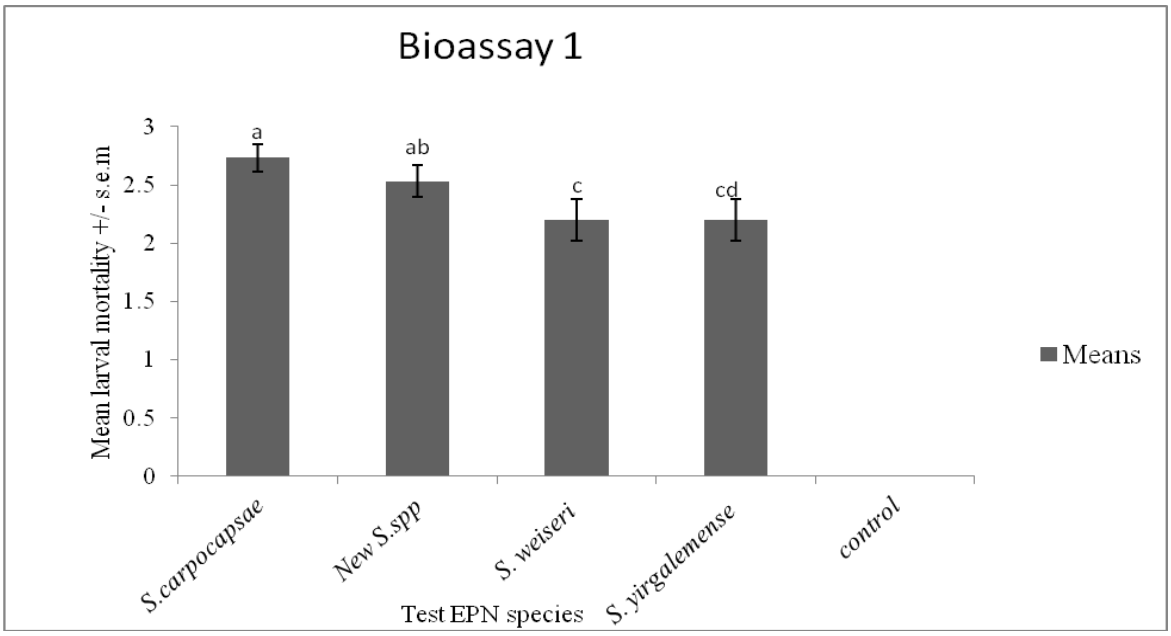
For the pseudostem EPN-treated experiment, there was no dead adult weevil caused by the nematode species treatment in all the concentration levels. The concentrations which were used were 1000 Ijs, 3000 Ijs and 5000 Ijs per adult weevil and control. Even after extending the cumulative exposure time to ten days for each bioassay conducted, no mortality of the adult weevils due to entomopathogenic nematodes treatment was recorded.

5.3.2 Comparison of pathogenicity and virulence of selected entomopathogenic nematodes against the larvae of banana weevil under laboratory conditions

In both experiments which were carried out in this study, results showed that all the test EPNs were pathogenic to the larvae of *Cosmopolites sordidus* (Figures 5.1 and 5.2). The dead larvae got a soft consistency and a yellow-brown to black colour (Plate 5.2) a characteristic of

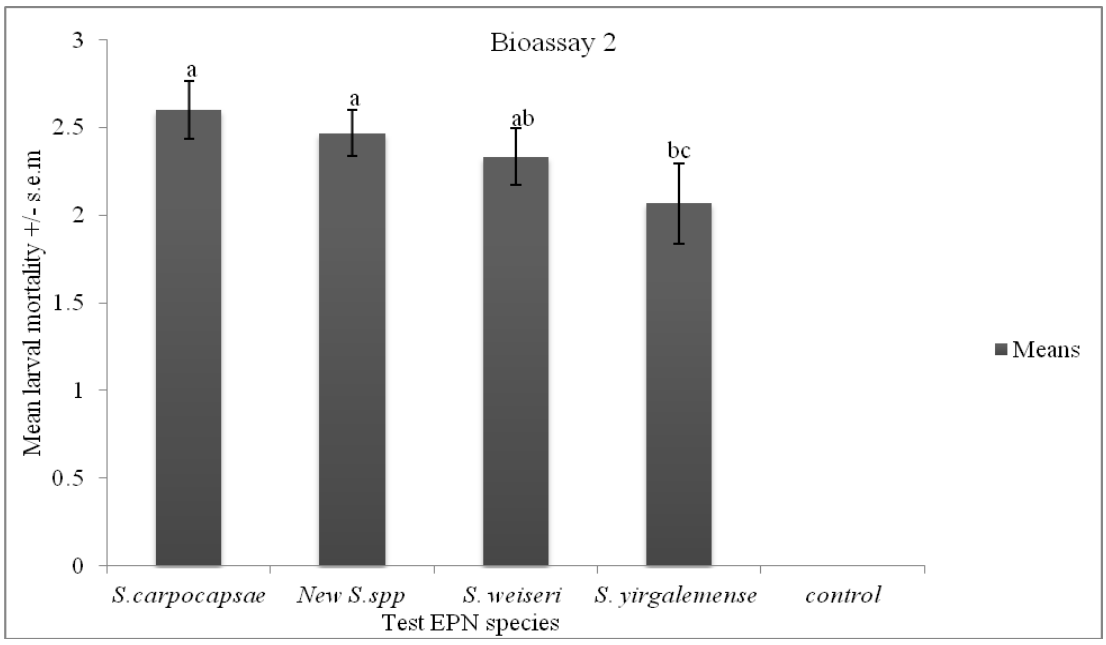
larvae killed by the bacteria of the genus Xenorhabdus associated with *Steinernema* species (Koppernhoofer, 2007). The mean mortality for *Steinernema yirgalemense spp* ranged from (2.00 -2.20), new *Steinernema spp* (2.40-2.55), *Steinernema weiseri* spp (2.20-2.33) and *Steinernema carpocapsae* (2.60-2.73). There was no mortality recorded in the control treatment in both experiments. No significant difference ($P \geq 0.05$) was observed for the two larval assays in all the treatments. However, *Steinernema carpocapsae spp* was found to be the most pathogenic among the tested EPNs in both larval assays in all concentration levels (300ijs, 400ijs and 500ijs) compared to other test nematodes.

There was a significant difference ($P \leq 0.05$) in mortality of banana weevil larvae attributed to the four nematode species. The mean mortality of banana weevil larvae caused by *Steinernema carpocapsae* was significantly higher ($P \leq 0.05$) compared to *Steinernema weiseri* and *Steinernema yirgalemense* (Figure 5.1). The new *Steinernema spp* did not differ in pathogenicity to the weevil larvae with *Steinernema carpocapsae* but differed significantly with *Steinernema weiseri* and *Steinernema yirgalemense. Steinernema weiseri* and *Steinernema yirgalemense* did not differ in pathogenicity to the weevil larvae but were significantly different from *Steinernema carpocapsae* and the *new Steinernema spp* (Figure 5.1). In bioassay 2, *Steinernema carpocapsae* and the new *Steinernema spp* did not differ in pathogenicity to the weevil larvae but differed significantly with *Steinernema yirgalemense. Steinernema weseri* did not differ in pathogenicity with *S. yirgalemense* which had the lowest mean larval mortality nor did *Steinernema carpocapsae* and the new *Steinernema spp* which had higher mean larval mortalities (Fig 5.2).



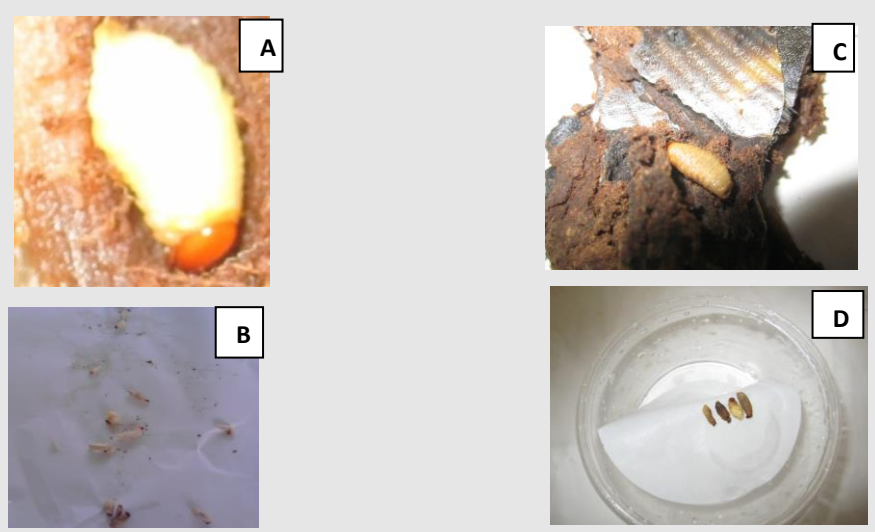
(Means with the same letter are not significantly different (P≤0.05, Turkey's multiple range test). S.E.M - standard error of mean)

Figure 5.1**:** Mean mortality of banana weevil larvae following 96hr of exposure to infective juveniles of selected EPNs in the one-on-one assay



(Means with the same letter are not significantly different (P≤0.05, Turkey's multiple range test). S.E.M - standard error of mean)

Figure 5.2: Mean mortality of banana weevil larvae following 96hr of exposure to infective juveniles of selected EPNs the one-on-one assay.



(Source: Author Moses Ndiritu)

Plate 5.2: Live banana weevil larvae and dead banana weevil larvae.

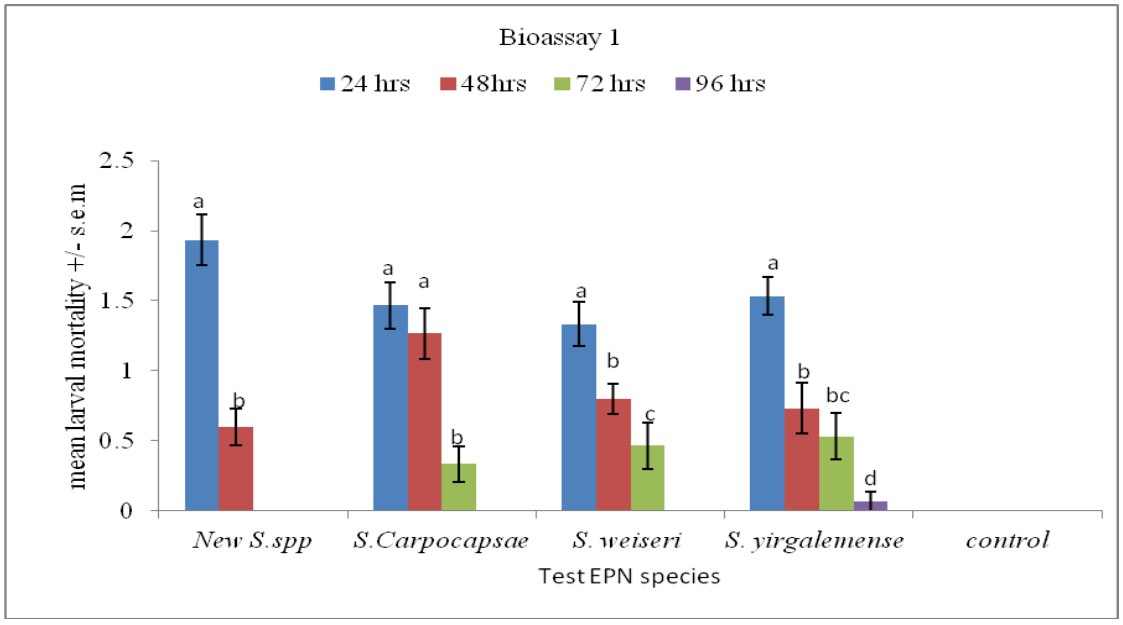
A and B: Live banana weevil larvae at extraction (creamy white and legless).

C and D: EPN infected banana weevil larvae (brown to black in colour).

5.1.1 Comparison of banana weevil larvae mortality recorded at different time periods in an assay under laboratory conditions

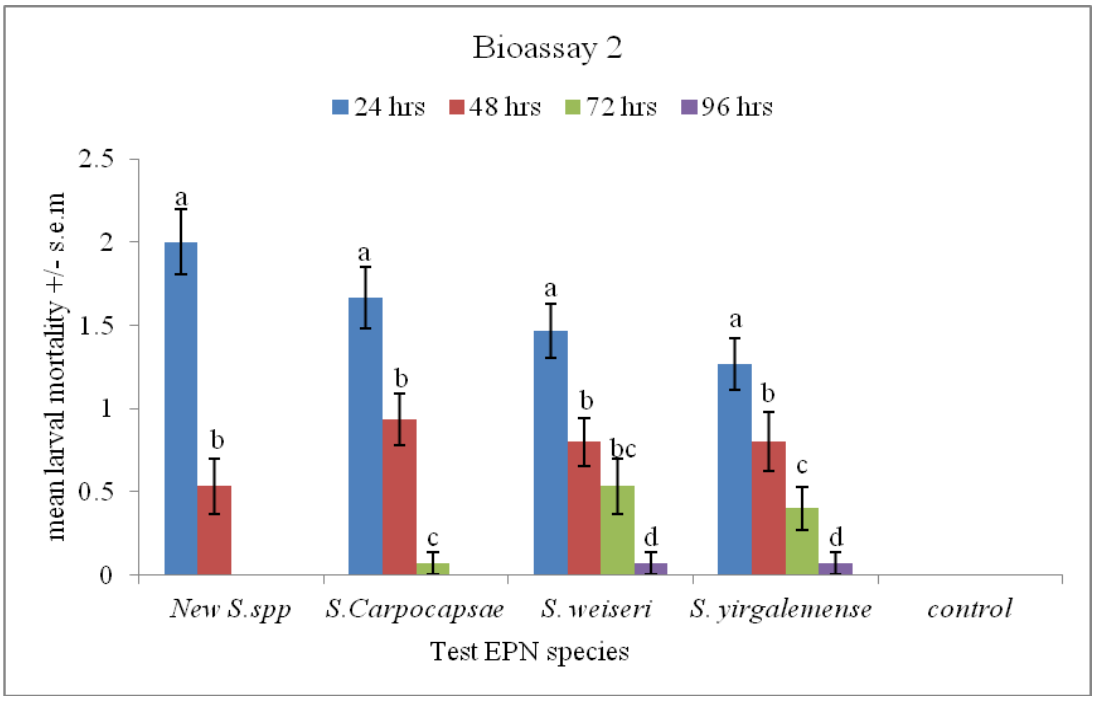
There were significant differences ($P \leq 0.05$) between the exposure times of larvae to the test entomopathogenic nematodes. All the nematodes tested caused a high mortality of banana weevil larvae within the first 24 hrs of exposure as shown in Figures 5.3 and 5.4 below except for *Steinernema carpocapsae* (Figure 5.3). The new *Steinernema spp* caused the highest percent larval mortality within 24hrs compared to the rest of the test nematodes. It took only 48 hrs for the new *Steinernema spp* to cause more than 90% larval mortality. *Steinernema weiseri* and *Steinernema* yirgalemense took the longest time period to cause more than 90% larval mortality (Figures 5.3 and 5.4). At 48 hrs exposure time, *Steinernema carpocapsae* achieved a significantly ($P \leq 0.05$) higher mean mortality compared to other test nematodes (Figures 5.3 & 5.4). At 72 hrs, *Steinernema carpocapsae* differed with

Steinernema weseri but not *Steinernema yirgalemense* while within the same exposure time, *Steinernema weseri* did not differ with *Steinernema yirgalemense* (Fig 5.3). Similar results were observed in bioassay 2 (Fig 5.4).



(Means with the same letter are not significantly different (P≤0.05, Turkey's multiple range test). S.E.M - standard error of mean)

Figure 5.3: Mean mortality of banana weevil larvae recorded after exposure to infective juveniles of selected EPNs for a variable time periods



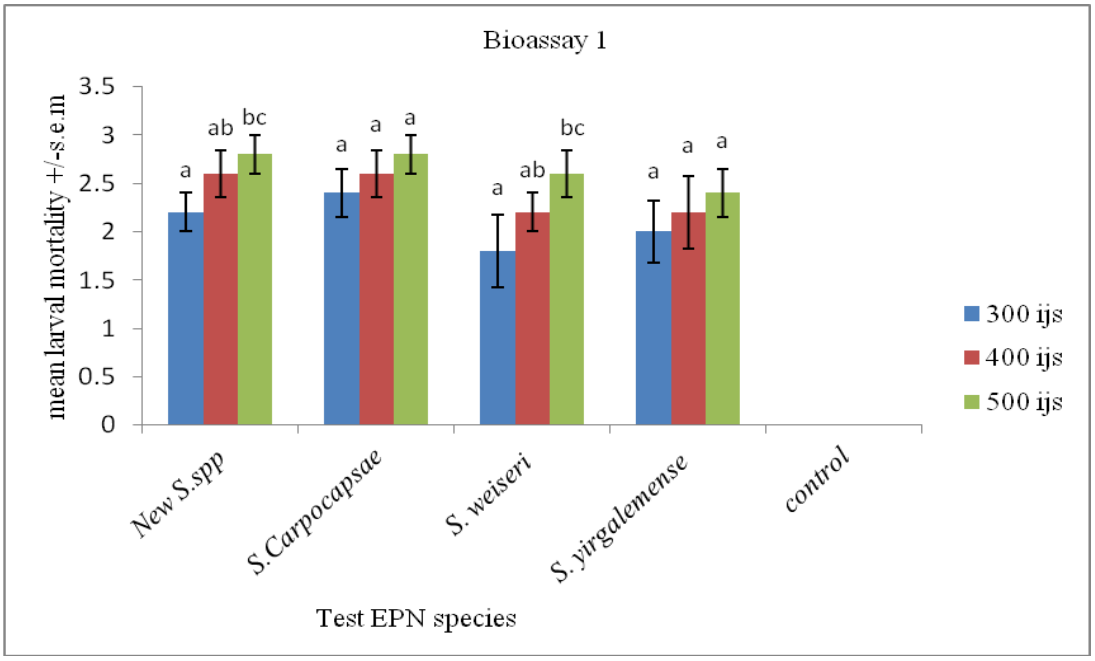
(Means with the same letter are not significantly different (P≤0.05, Turkey's multiple range test). S.E.M - standard error of mean)

Figure 5.4: Mean mortality of banana weevil larvae recorded after exposure to infective juveniles of selected EPNs for a variable time periods.

5.1.2 Effect of ijs concentrations on the mortality of banana weevil larvae in a dose-response study under laboratory conditions

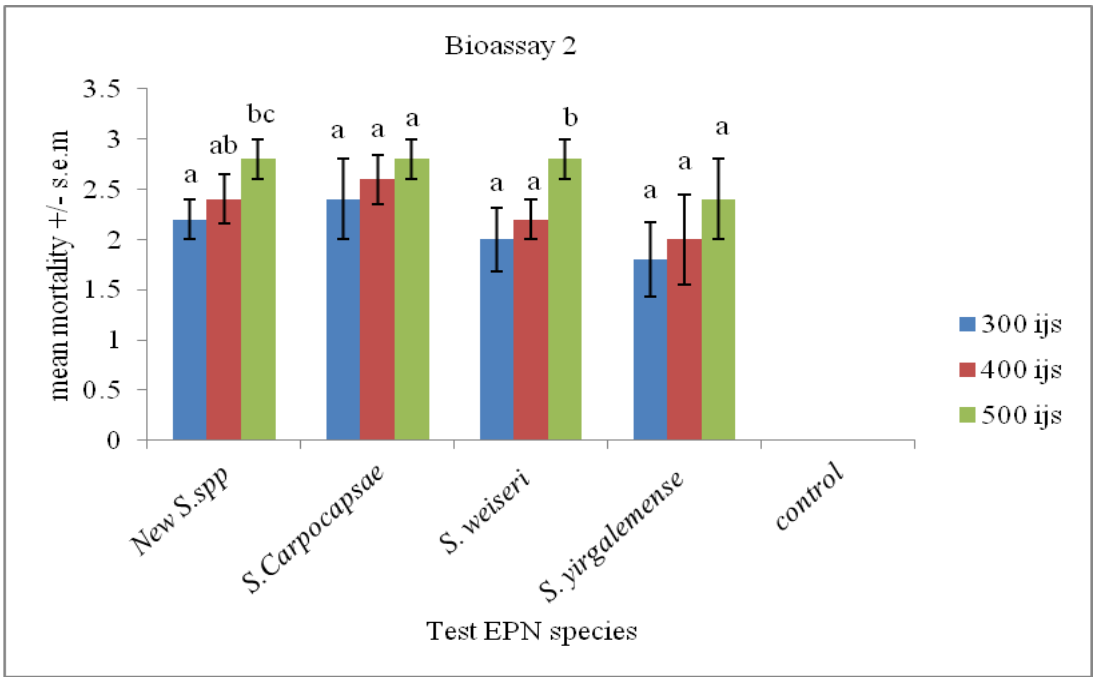
In this study, the results indicate that the mean mortality of banana weevil larvae increased with increasing nematode concentration (300ijs, 400ijs and 500ijs) as shown in Figure 5.5 and Figure 5.6. There was a significant difference (P≤0.05) in larvae mortality between nematode concentrations 300ijs and 500ijs for the two nematodes new *Steinernema spp* and *Steinernema weiseri* (Figures 5.5 and 5.6). However, no significant (P≥0.05) differences were observed between nematode concentrations 300 ijs and 400 ijs in all the test nematodes. No mortality was observed in control treatment. Test nematodes *Steinernema yirgalemense spp* and new *Steinernema spp* did not show significant difference in all the three nematode

concentrations in both bioassays. However, the trend in all the test nematodes was evident that after 96 hr of exposure the 500 ijs concentration caused the highest larval mortality (Figures 5.5 & 5.6).



(Means with the same letter are not significantly different (P≤0.05, Turkey's multiple range test). S.E.M - standard error of mean)

Figure 5.5: Mean mortality of banana weevil larvae following inoculation with different concentrations of infective juveniles of the selected EPNs in a dose-response assay.



(Means with the same letter are not significantly different (P≤0.05, Turkey's multiple range test). S.E.M - standard error of mean)

Figure 5.6: Mean mortality of banana weevil larvae following inoculation with different concentrations of infective juveniles of the selected EPNs in a dose-response assay.

5.4 Discussion

In this study it was evident that all EPNs tested were pathogenic to *Cosmopolites sordidus* larvae and they caused different mortality rates under laboratory conditions. However, none of the test nematodes affected the adult stage of the banana weevil. Although high concentrations of the test EPNs were used, the adult stage was not susceptible. This can probably be attributed to the heavily sclerotized body and pronounced long snout of the adult weevil (Treverrow, 2003) making it difficult for the Ijs to penetrate inside the weevil. Infective juveniles penetrate the host through the natural openings i.e. spiracles, mouth and anus or in some cases directly through the cuticle of certain insects (French-constant *et al.,* 2007; Eleftherianos *et al.,* 2010). Treverrow and Bedding (1993) reported that the resistance is almost certainly due to difficulty of nematode entering the adult weevil than from establishment once infection is successful. Once inside the insect host, they work symbiotically with bacteria carried in their guts. The latter multiply releasing a number of virulence factors. These are toxin complexes, hydrolytic enzymes, hemolysins and anti-microbial compounds that cause mortality of insects within 24- 48 hours (French-constant *et al.,* 2007; Eleftherianos *et al.,* 2010). A study done by Sirjusignh *et al.* (1991) demonstrated similar results that local Caribbean EPNs were not effective on the adult weevil under laboratory conditions.

Furthermore, the introduction of fresh pseudostem laced with nematode at different dose rates was to maximize the contact between the adult weevil and the nematodes in the process of feeding. Adults are attracted to the volatiles emanating from the flesh or decomposing pseudostems (Masanza *et al.,* 2005). However, no mortality was recorded. In Tanzania, a study carried out by Mwaitulo *et al.,* (2011) reported similar results of resistance of the adult

weevil to locally isolated EPNs from banana fields in three regions of Morogoro, Mbeya and Pwani.

All test EPNs caused larval mortality. These results are consistent with a study conducted in Tanzania by Mwaitulo *et al* (2011) that showed all local isolates were pathogenic to banana weevil larvae hence causing mortality. The test nematodes caused different mortality rates of the weevil larvae. The dead larvae got a soft consistency and a yellow to brown to black colour, characteristic of larvae killed by bacteria of the genus *Xenorhabdus* (Koppernhoofer, 2007). *Steinernema carpocapsae* caused higher mean mortality compared to the rest of the test nematodes. This can be attributed to the specificity in pathogenicity and virulence of individual EPN isolate. Koppernhoofer and Fuzy (2003) noted that differences in the pathogenicity of infective juveniles can be attributed to their foraging strategy, the responsiveness of the host immune system, the pathogenicity of the symbiotic bacteria and the number of bacterial cells transported by dauers. This explains why in this particular study, the test nematodes caused different mortality rates. A report by Koppernhoofer and Kaya (1999) indicated that *Steinernema* dauers can carry different amounts of bacterial cells in their intestines. For instance, the species *S. scapterisci* contains a small amount of bacterial cells compared to *S.carpocapsae* that has a large number of bacterial cells, causing higher pathogenicity but at the expense of lower survival in the environment (Emelianoff *et al.,* 2007).

All tested nematodes caused more than 90% mortality of the larvae. In a study conducted in Canary Island, a 100% mortality banana weevil larva was reported using indigenous EPN (*Heterorhabditis* and *Steinernema* species) (Padilla-cubas *et al* 2010). Literature have

reported susceptibility to EPNs among larvae of other beetles such as *Diaprepes abbreviatus* (Coleoptera: curculionidae) (Jenkins *et al.*, 2008); *Capnodis tenebrionis* (Garcia and Morton, 2005) and *Premnotrypes sutulicallus* (Parsa *et al.,* 2006). The mortality of banana weevil larvae in this study could be attributed to the physical appearance (soft and fleshy cuticle, abdominal segments) that enabled EPNs to penetrate easily alongside the mouth and anus. Previous histopathological studies have shown that Ijs enters the larvae through the cuticle and less often through the anus and mouth (Dolinski *et al*., 2006).

From the results in this study all the test nematodes caused a significant high mean mortality rate of larvae within the first 24-48 hours of exposure. This demonstrates the high virulence and infectivity potential of the local EPNs tested against the banana weevil larval stage. The mortality was confirmed to be due to EPN infection through dissection of the cadavers to check for the presence of Ijs in the haemocoel. Entomopathogenic nematodes kill the host by inducing septicaemia within 24-48 hours of infection (Griffin *et al.*, 2005).

A dose-response assay showed no significant difference in larval mortality between 300ijs and 400ijs concentrations for all the test nematodes. 500 ijs concentration caused the highest mean percent mortality of larva. This can probably be attributed to the numbers. It is said there is strength in numbers and hence the higher concentration of ijs showed high virulence and pathogenicity differences in the EPN species, humoral and immune response of the host (Griffin *et al.,* 2005). Although there was no consistency across all the three Ijs concentrations, there was a positive relationship that weevil larval mortality increased with increasing concentrations. Larval mortality observed for *Steinernema carpocapsae* and *Steinernema yirgalemense* did not differ in the mortality rates caused to the larvae based on

concentration. *Steinernema weiseri* and the new *Steinernema spp* in caused significant difference ($P<0.05$) larval mortality at the two concentration levels of 300ijs and 500ijs. This indicates the importance of dosage rates. The results partially concur with a study conducted by Mwaitulo *et al* (2011) who reported that the banana weevil mortality increased significantly with increasing native nematode dosage. However, these same results differ with a study conducted by Padilla-cubas *et al* (2010) that showed an increase in Ijs dosage does not necessarily cause an increase of banana larvae mortality. A dose- mortality response was observed by Schmitt (1993). Previous studies have reported significant differences based on EPN concentration and larvae stage mortality in other insect pest orders. A study conducted in Turkey showed that native EPN Ijs concentration (0,100, 500 and 1000ijs) had differences in causing mortality of *P. operculella* larvae (Kepenecki *et al.,* 2013).

5.5 Conclusions and recommendations

The native EPNs in Kenya have the ability to parasitize *Cosmopolites sordidus* larvae but not the adult under laboratory conditions. The EPNs which were tested namely *Steinernema carpocapsae, Steinernema weiseri, Steinernema yirgalemense* and new *Steinernema spp* caused above 90% of banana weevil larval mortality. Nematode species and the nematode concentration levels showed differences in causing mortality of the weevil larvae. In addition all tested nematodes caused high mortality within 24-48 hrs of exposure indicating a high virulence on banana weevil larvae. These tested nematodes have potential for field management of the banana weevil since EPNs are known to search and locate susceptible hosts in cryptic habitats like within the banana pseudostem and corms. Larvae are found within the small holes on the surface of the rhizome, which are in contact with exterior. They are also found living in long galleries inside the rhizomes which are ideal conditions for EPNs survival and infection of hosts. The effect of EPNs on the adult weevil was negligible

.The larval stage is the most destructive stage of the banana weevil. Therefore, if controlled and managed through EPN application, reduction of pest attack can be minimized translating to higher banana yields. The most effective EPN was *S.carpocapsae* and can be used at 500 ijs concentration level in the laboratory to kill the weevil larvae

Future work is necessary to determine the efficacy, feasibility and optimum concentration levels to enable the use of native EPNs against the banana weevil larvae in the field. In addition, further research in EPN formulation is needed to maintain the life span of the EPN and deliver the same in the field to manage weevils since they are very delicate. Better storage and application technology of EPNs is needed to enhance the effectiveness of field control of banana weevil larvae. Entomopathogenic nematodes can be included in integrated pest management programs targeting the banana weevil specifically the larval stage.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 General discussion

This study established that banana is the major crop grown in Maragua, Central Kenya. This coincides with the report by (HCDA, 2005-2007) that listed Maragua as one of the major banana growing regions in Kenya. The motivation for growing banana as a major food crop was mostly for income generation and also for household food security. The results are similar to a study conducted by Karamura (*et al* 2012) who reported that banana plays a dual role as a staple food in the tropical world and a table fruit sold both at local and international markets. Therefore, there is a need to protect the crop from both biotic and abiotic factors affecting banana production. This study has documented various biotic factors hindering sustainable banana production in Maragua and other banana production areas within the country. The insect pests which were identified included banana weevil (*Cosmopolites sordidus*), thrips, nematodes and other invertebrate pests. Crop diseases associated with banana were panama (*Fusarium oxysporum fsp cubense*), sigatoka (*Mycosphaerella musicola* and *Mycosphaerella fijiensis*) and cigar-end rot (*Gloeosporium musanum*). Among the pests, banana weevil was the most important banana pest while sigatoka was the most prevalent disease. Other constraints included declining soil fertility, poor crop management, lack of clean planting material, poor marketing infrastructure, postharvest losses, competition with other crops for land, labour and capital, erosion and lack of inputs/credit facilities (NRCB, 2011).

This study on banana weevil and its prevalence showed that the weevil incidence was influenced by agro-ecological zones and temperature is a factor that is contributing to banana

weevil abundance. Banana weevil was the most problematic pest probably because a significantly high number of banana farmers applied no measure to control and manage the pest. The fact that majority of the farmers used own farm and neighbors as a source of banana planting materials could be another factor promoting the spread and establishment of banana weevil in the existing and new banana fields. A report by Macharia *et al.* (2010) describes banana weevil as a major banana pest contributing to decline in banana production in Kenya. Weevils are mainly managed by trapping , use of chemical control and biological control (Gold and Messiaen, 2000).

This study has demontrated that use of pseudostem traps can monitor abundance and significantly reduce the population over time in banana field. This practice is cheap to small scale banana farmers though laborious. Use of pseudostem traps has been successful and most preffered by most growers in trapping of banana weevils (De Graaf *et al*., 2005). Population of weevils can be associated with level of sanitation as it has been shown in this study. Orchards with mulch recorded high number of weevils as compared to clean or orchards with thin mulch. In a study carried out by (Masanza *et al.,* 2005), it was reported that increasing the level of crop sanitation significantly reduced the number of adult weevil population. The higher number of weevils in the banana monoculture orchards compared to the orchards with intercrops can be explained by the fact that regular ploughing within the orchard in preparation for seasonal or annual planting of the preferred intercrops could be interfering with weevil movement from one mat to another or completion of development cycle by exposing the eggs, larvae, pupae or adults to harsh conditions thereby reducing numbers present. A similar study in Rwanda found that adult weevil population reduced in the intercropped banana plots compared to the banana monoculture plots (Gatarayiham *et al.,*

2003). During ploughing it was shown that the soil covered the banana corm hence making it inaccessible to the female banana weevils to oviposit (Seshu *et al*., 1999).

Entomopathogenic nematodes have been exploited for several decades as biological tools against many important insect pests in the world (Georgis *et al.,* 2006 and Hannah *et al.,* 2013). In this study, EPNs of the genus *Steinernema* were tested for pathogenicity and virulence against banana weevil adults and larval stages. It was evident from the results that the tested EPNs were pathogenic to *Cosmopolites sordidus* larvae causing different mortality rates under laboratory conditions. However, none of the tested EPNs were effective to the adult banana weevil stage though a considerable higher concentration of Ijs were used when compared to larval stage. This might be due to the hard-shelled body and pronounced long snout of the adult weevil (Treverrow, 2003) making it difficult for the Ijs to penetrate inside the weevil. Treverrow and Bedding (1993) reported that the resistance is certainly due to the difficulty of nematode entering the adult weevil than the establishment once infection is successful.

The larval stage was more susceptible due to the physical appearance (soft and fleshy cuticle, abdominal segments) that enabled test EPNs to penetrate easily through the mouth, spiracles and anus. Previous histopathological studies have shown that Ijs enter the larvae through the cuticle and less often through the anus and mouth (Dolinski *et al*., 2006). Infective juveniles of EPNs penetrate the host insect pest through the natural openings i.e. spiracles, mouth and anus or in some cases directly through the cuticle of certain insects (French *et al.,* 2007; Eleftherianos *et al.,* 2010). The tested EPNs caused larval mortality and the results agrees with those of Mwaitulo *et al.* (2011) who showed that all local Tanzanian nematode tested

were pathogenic to banana weevil. *Steinernema carpocapsae* caused a higher mean mortality compared to the other EPNs tested. Koppernhoofer and Fuzy (2003) noted that differences in the pathogenicity of dauers can be attributed to their foraging strategy, the responsiveness of the host immune system, the pathogenicity of the symbiotic bacteria and the number of bacterial cells transported by dauers. This explains why in this particular study, the test EPNs caused different mortality rates. In addition, all the test nematodes caused a high mean mortality of larvae within 24-48 hours of exposure. However, no data was evident from the control treatment and indication that the mortality was due to EPN infection was subsequently confirmed through dissection of the cadaver to check for the presence of Ijs in the haemocoel. Entomopathogenic nematodes kill the host by inducing septicaemia within 24-48 hours of infection (Griffin *et al.*, 2005). A dose-response assay showed no difference in larval mortality between 300 and 400 ijs concentrations but there was a difference in larval mortality between 300ijs and 500 ijs concentration for all the test nematodes. This can probably be attributed to the virulence and pathogenicity differences in the EPN species, humoral and immune response of the host and the population attacking the larvae. The results partially agree with those of Mwaitulo *et al.* (2011) who reported that the banana weevil mortality increased with increasing native nematode dosage. This differs with a study conducted by Padilla-cubas *et al.* (2010) that showed an increase in Ijs dosage does not necessarily cause an increase in rate of banana larvae mortality.

6.2 Conclusions

Pests and diseases hinder sustainable production of bananas and these included banana weevil, thrips, nematodes, cigar end-rot, panama and sigatoka. The banana weevil is the most serious insect pest while sigatoka is the major disease. Banana weevil was the only pest with the least control measures. This pest is therefore, a threat to banana production and there are

no effective control measures which have been practiced. Other pests and diseases included thrips, nematodes, panama and cigar-end rot. Abiotic factors that compound this problem and some of which have been addressed in this study include high temperatures that favor weevil population increase, declining soil fertility, poor crop management, lack of clean planting materials, poor marketing infrastructures, post-harvest losses and lack of proper information about banana farming. Use of pseudostem traps can help reduce population density of the banana weevils.

Use of pseudostem traps can help reduce population density of the banana weevils. There are native EPNs in Kenya with the ability to parasitize *Cosmopolites sordidus* larvae under laboratory conditions. The *Steinernema* species which was tested caused above 90% of the banana weevil larval mortality rate. However, the effect of EPNs on the adult weevil was negligible. In addition the tested nematode species caused high mortality within 24-48 hrs of exposure. The dose response assay showed that mortality of the banana weevil larvae can be increased when the concentration of infective juveniles is increased. The most virulent/pathogenic test nematode was *S.carpocapsae* used at a concentration of 500 ijs caused larval mortality in the laboratory. Using EPNs for the management offers a sustainable strategy that is self-perpetuating. This is likely to disrupt the breeding of banana weevil and lead to reduced infestation of the banana crop.

6.3 Recommendations

- Further research should be conducted to improve the current knowledge base of banana pests and diseases, identification, control and management strategies by plant

pathologists and entomologists to address the pest and disease constraints affecting the banana farmers.

- Develop an IPM programme considering environmental conditions where the orchards are located, good sanitation, intercropping, pseudostem trapping methods and/ or the inclusion of EPNs which are easily available to the small scale farmer without involving a lot of external inputs to reduce banana weevil damage in their farms
- Other research especially on soil fertility, information and communication technologies, and marketing should be undertaken to help provide information for proper sustainable banana production.
- Future research is necessary to determine the efficacy and feasibility of these native EPNs in aqueous suspension against the banana weevil larvae in the field and the best method of delivery.
- Further research in EPN formulation is needed to maintain the life span of the EPN. Better storage and application technology of EPNs is needed to enhance the effectiveness of field control of banana weevil larvae
- There is need to find a sustainable way of including entomopathogenic nematodes in the integrated pest management programs for banana weevil.

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APPENDIX 1: BASELINE SURVEY QUESTIONNAIRE

Biotic and other abiotic factors affecting small holder banana farmers in Maragua, Murang'a County

HOUSEHOLD CHARACTERISTICS

1.1 Name of the farmer ……Location/Zone…… GIS……

1.2 Gender of the head of household 1= Male……2=.Female

1.3 Marital Status 1= Married 2= Singe 3= Widowed

1.4 Age of farmer in years: 1= 20-30 2= 31-40 3= 41-50

4= 51- 60 5=>60

1.5 Highest level of education for the head of the household

1 = None, 2 = Primary, 3 = Secondary,

4 = Tertiary

1.6 What are the three (3) main sources of the household income?

1= Sale farm produce 2= Formal employment 3= Sale of livestock

4= Small Business 5= Casual labour 6= Pensions 8 = Dividends 9 = House rentals 10 = Interest savings 11 = others Specify……

2.0 Land use Practices

2.1 What is the size of your farm……Acres

2.2 What is the type of land ownership?

1= Own 2= Family owned 3= Communal

4= Rented/Hired 5= others specify……

2.3 What are the major farm enterprises?

1= mixed farming 2= crops only 3= Livestock only (cattle, poultry etc.)

3= Woodlot//agro-forestry 4= other (specify)……..

2.4 What factors influence the size of land allocated to the different enterprises?

1=Food security 2= Income generation 3= Size of family 4= Social status 5= others (specify)……

2.5 If growing crops, what cropping patterns do you practice?

1= Crop rotation 2= Inter-cropping 3= Relay cropping

4= others (specify)…….

2.6 What are the major crops grown on your farm?

Crop	Usage : 1= HH use 2=Sale(specifically for bananas only)
1	
2	
3	
4	
5	

2.7 Are there any diseases that attack banana in the field? 1= Yes

2= No

2.8 If yes, name the diseases and control measures you

Disease/symptoms	Control measures

	1. 2. 3
	1. 2. 3
	1. 2. 3
	1. 2. 3

2.9 Are there any pests that attack your bananas? 1=Yes

2=No

2.10 If yes, name the pest and state the methods applied to control them

Type of pest/ description	Control measures
	1. 2. 3

	1. 2. 3
	1. 2. 3
	1. 2. 3.

2.11. What are the main sources of banana planting materials (based on your demand?)

Source	Tick appropriately	Remarks
Own Farm		
Neighbors		
Local market (Specify)		
Institution/organizations (KARI, TC lab, University- specify		
Other sources(e.g. shows		

3. 0 |Farmers Perception of their soil quality

3.1 Do you apply any soil fertility inputs to your banana crop?

Input	Type of the input	Amount applied per stool	Is that the recommended amounts
Manure	1. Compost 2. Farm yard 3. Chicken Manure 4. Pig manure	1. 2. 3 4	1= Yes 2= No 3= I don't know
Fertilizer	1. 2. 3.	1. 2. 3.	1= Yes 2= No 3= I don' know

3.2 What hinders you from adopting recommended practices or inputs?

1. They are expensive to undertake
2. Lack of information
3. High labour demanding
4. They are not clear
5. Other specify ……

4.0 Market and marketing Information

4.1 How do you market your banana produce?

1= Farm gate 2= Brokerage

3= Contract 4= Group marketing

4= others (specify)……

6.0 Agricultural information

6.1 In the past one year has the household had access to agricultural information in the

Last one year?

1 = Yes, 2 = No

6.2 What are main sources of agricultural information in order of preference?

Source of Information	Tick appropriately
Government extension staff	
Shows	
Field days	
Radio e.g. Shamba Shape-up	
TV	
Newspaper	
Family and friends	
Private extension staff	
NGOs	
Agro vet shops	
Neighbors	
Internet	
Cell phones	
Other farmers	

THANK YOU FOR YOUR PARTICIPATION