# INFESTATION ASSESSMENT OF BANANA WEEVIL (*Cosmopolites sordidus* Germar) IN DIFFERENT BANANA-BASED FARMING SYSTEMS IN ARUSHA AND KILIMANJARO REGIONS, TANZANIA

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**A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Life Science of the Nelson Mandela African Institution of Science and Technology**

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# ABSTRACT

The present study was conducted to determine population size, infestation level and farmer's understanding of banana weevils in different banana-based farming systems (BFS) namely banana monoculture, banana-beans, banana-coffee and banana-maize. This was conducted by using banana pseudostem traps, coefficient of infestation method and standard interviewing. It was conducted from June to September 2017 in Nkoaranga, Mbuguni and Ngurdoto villages (Meru District) and Uduru, Uraa and Mbosho villages (Hai District) in Northern Tanzania. The physical and survey data collected were analyzed by using statistical packages of GENSTAT 11$^{th}$ edition and SPSS Version 21 respectively.

There were significant differences ($P<0.05$) in the number of banana weevils in different BFS. The highest banana weevil population (29.2 banana weevils/trap/farm over the period of three months) was recorded in banana-maize followed by banana-beans (8.2 banana weevils/trap/farm over the period of three months); however, this reading was not significantly different from the banana-monoculture and banana-coffee farming systems. Such results not only indicated that different BFS experience different banana weevil infestation levels but also that the banana-maize system attracted more banana weevils than any other BFS in this study. Of the banana cultivars, Kimalindi recorded the highest (153 weevils per farm) number compared to other banana cultivars indicating that different banana materials attract differently banana weevils. The results also showed that banana weevil was ranked to be the first insect pest of banana and a problem for about 68.8% of banana farmers. The present study calls for more studies on identifying factors responsible for the highest population in a banana-maize farming system unlike in other BFS and how banana weevils can be managed in Tanzania.

# DECLARATION

I, **Yusuph Mohamed** do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation titled '**Infestation assessment of banana weevil (*Cosmopolites sordidus* Germar) in different banana-based farming systems in Arusha and Kilimanjaro regions, Tanzania'** is my original work and has never been submitted for a degree in any other university.

YMHaL ..................................................... 18/12/2017 ..............................................

**Yusuph Mohamed** **Date**

## COPYRIGHT

# CERTIFICATION

This is to certify that this dissertation by **YUSUPH MOHAMED** has been accepted in partial fulfillment for requirements for the Degree of Master's in Life Science of Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania.

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## DEDICATION

I dedicate this piece of work to my lovely parents Mohamed Ng'imba and Tattu Ally who raised and nurtured me. I also dedicate this work to my Brother Haruna Seleman Kipika, Sister Amina Mohamed Ng'imba, my beloved Wife Kulthum Ally Marusu and her love and Our Sons Ayman and Numan for their encouragement and patience.

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## LIST OF ABBREVIATIONS AND SYMBOLS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| BFS | Banana-based farming system |
| COI | Coefficient of infestation |
| DMRT | Duncan Multiple Range Test |
| GENSTAT | General Statistics |
| $H_0$ | Null hypothesis |
| $H_1$ | Alternative hypothesis |
| IITA | International Institute of Tropical Agriculture |
| LSD | Least Significance Difference |
| μ | Population mean |
| m.a.s.l | Metre above sea level |
| SPSS | Statistical Package for Social Science |

# CHAPTER ONE

# INTRODUCTION

## 1.1 General background

Banana weevil (*Cosmopolites sordidus* Germar 1824) is an important insect pest (Coleoptera: Curculionidae) of banana (Musa spp.) in most banana growing regions worldwide (Gold *et al.*, 1998; Dahlquist, 2008; Wachira *et al.*, 2013). It is believed to have originated in the Indo-Malaysian region but its current geographical distribution is over Asia, Australia and the Pacific Islands, America and Africa (de Graaf, 2006; Cheraghian, 2015). In Africa, banana weevil is a serious pest in many countries including Benin, Burundi, Cameroon, Comoros, Democratic Republic of Congo, Gabon, Ghana, Guinea, Kenya, Madagascar, Malawi, Mali, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Tanzania and Uganda (Chernoh, 2014; Cheraghian, 2015).

The banana weevil has a complete life cycle that takes about 5-7 weeks under tropical conditions (Gold and Messiaen, 2000; Shukla, 2010; Njau *et al.*, 2011). The adult female lays superficially a few single eggs (1-4 weekly) at the banana plant base, corm and also in crop residues which hatch to form larvae (Gold *et al.*, 2006a; Shukla, 2010). The larvae is the most destructive stage through its feeding within banana corms causing numerous galleries forming oval chambers for pupation (Treverrow, 2003; Were *et al.*, 2015). They also attack the growing point of young suckers, true stem and rarely pseudostem (Shukla, 2010). The feeding results in non-recoverable secondary rots which facilitate the entry of other insects and plant pathogens such as the fungus *Fusarium oxysporum* f. sp. *cubense* (Omukoko *et al.*, 2014). Moreover, damage caused by banana weevil larvae can cause interference with root initiation and development, uptake of plant nutrients and water transport (Njeri *et al.*, 2011; Rannestad *et al.*, 2013). Symptoms of the banana weevils on plants include reduced plant vigour, leaf chlorosis, delayed flowering, chocking of the bunch in the pseudostem and small fruit bunches (Chernoh, 2014; Njeri *et al.*, 2011). It also reduces plant life and resistance to drought resulting into poor bunches and weak pseudostems which can break and fall as a result of high wind speed (Uzakah *et al.*, 2015). Banana weevil attacks all banana varieties in all phenological stages. Its infestation causes crop failure due to snapping and toppling at the base of the plant during windstorms under heavy infestations, severe yield loss and sometimes farm rejection (Mukasa *et al.,* 2008; Maldonado *et al.,* 2016). Young banana plants attacked by the weevil result into more damage and yield loss compared to old plants (Braimah and Van Emden, 2004). Adult weevils feed on banana debris, residues, rotting tissues and sometimes on young suckers but are less destructive and their yield loss are insignificant compared with their larvae (Mwaitulo *et al*., 2011; Rannestad *et al.,* 2011; Were *et al.,* 2015).

In East Africa, yield loss of about 14 metric tonnes per hectare per year and farm rejection rate of over 20% in warm temperature regions has been reported (Tinzaara *et al.,* 2008; Njau *et al.,* 2011). Yield losses of up to 100% has been reported in Uganda and Kenya followed by farm abandonment at Masaka and Rakai districts in Uganda due to high rate of banana weevil infestations (Rukazambuga *et al.,* 1998; Gold *et al.,* 2001; Gold *et al.,* 2002; Ocan *et al.,* 2008). In Tanzania, yield loss of about 30% and farm abandonment has been reported at Muleba district, Kagera region. Other regions reported to be infested by banana weevils include Arusha, Kilimanjaro, Mbeya and Morogoro (Gold *et al.*, 2001; Rannestad *et al.,* 2011).

The banana weevil occurrence has been reported to be responsible for diminishing and disappearance of the East African Highland Banana in the Kagera region of Tanzania (Gold *et al.,* 2001). Furthermore, high infestations by banana weevils result in the change of varieties by some banana farmers. For instance, the Nyakatoke village in the eastern Kagera has reported to have yields of about 3100 kilograms per hectare compared with the average yield of around 6800 to 7500 kilograms per hectare (den Broeck and Dercon, 2007). This yield loss was mainly attributed to an increasing banana weevil infestations and panama diseases (den Broeck and Dercon, 2007).

## 1.2 Problem Statement and Justification

Banana weevil (*Cosmopolites sordidus* Germar) is a major insect constraint to banana production in many parts of the world including Tanzania (Mwaitulo *et al*., 2011; Rannestad *et al.*, 2011; Cheraghian, 2015). A high rate of infestation by the banana weevil leads to significant banana yield losses, crop failure and sometimes farm rejection (Tinzaara *et al*., 2008; Njau *et al.,* 2011; Maldonado *et al.,* 2016). Banana weevil infestation has been reported to cause crop failure, banana farm abandonment and yield loss from 20% to 100% in different banana growing regions worldwide (Gold *et al*., 2002; Ocan *et al.*, 2008; Maldonado *et al.*, 2016). For instance, in Tanzania, yield loss of about 30% has been reported (Gold *et al*., 2001). Other countries where banana weevil has been reported to cause serious yield loss include Brazil (20-50%), Congo (up to 90%), Cameroon (20-90%) and Uganda and Kenya (up to 100%) (Rukazambuga *et al.*, 1998; Gold *et al.*, 2001; Gold *et al*., 2002; Ocan *et al.*, 2008).

Despite of its agricultural importance, banana weevils in the country, there was limited information regarding their population variations and damage levels in in different banana farming systems in Tanzania. Therefore it was an urgent need to assess the banana weevil population, infestation levels and farmers awareness in different banana farming systems so that the results may create awareness that will support need for appropriate approach for managing banana weevil in Tanzania.

## 1.3 Objectives

### 1.3.1 Main Objective

To assess the presence, damage level and farmer's understanding of the banana weevil infestation so that appropriate measures can be initiated for managing it in different banana-based farming systems in Kilimanjaro and Arusha regions of Tanzania.

### 1.3.2 Specific Objectives

i. To assess the presence of banana weevil in different banana-based farming systems
ii. To assess banana weevil damage levels in different banana-based farming systems
iii. To assess farmer's understanding of banana weevil in different banana-based farming systems

## 1.4 Research Questions

i. What is the population size of banana weevil in different banana-based farming systems?

ii. What is the damage level of banana weevil in different banana-based farming systems?

iii. What is the level of farmers understanding the banana weevil threat in different banana-based farming systems?

## 1.5 Hypothesis:

$H_o$: banana weevil infestations are the same across different banana-based farming systems

$H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4$

$H_1$: banana weevil infestations vary across different banana-based farming systems

$H_1: \mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4$

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Variation, biology and potential management strategies of banana weevil (*Cosmopolites sordidus* Germar) in Tanzania[1]

Banana weevil (*Cosmopolites sordidus* Germar: Coleoptera) is an important insect pest of the genus *Musa* (abaca, banana, plantain), *Ensette* and manila hemp (Kiggundu *et al*., 2007; Gokool *et al*., 2010; Dahlquist, 2008; Bortoluzzi *et al*., 2013; Dassou *et al*., 2015; Hölscher *et al*., 2016). It is found throughout the tropics, subtropics and almost all major banana producing regions around the world (de Graaf, 2006; Dahlquist, 2008). In West Africa, the banana weevil has been associated with the phenomenon termed **"**yield decline syndrome**"** (Valencia *et al*., 2016). This insect pest has been regarded as a major factor in diminishing and disappearance of East African Highland Bananas (EAHB) in Central Uganda and Western Tanzania (Gold *et al*., 2006; Kiggundu *et al*., 2007; Aby *et al*., 2015a). In East Africa, particularly in Uganda and Kenya, about 14 metric tons per hectare per year with yield losses of up to 100% has been noted due to the high rate of banana weevil infestation (Rukazambuga *et al*., 1998; Gold *et al.*, 2001; Gold *et al*., 2002a; Ocan *et al*., 2008; Njau *et al*., 2011). In Tanzania, 30% of yield loss and farm abandonment has been reported due to the same insect pest at Muleba district, Kagera region. Other regions in Tanzania reported to be highly infested by banana weevils include Arusha, Kilimanjaro, Mbeya and Morogoro (Bujulu *et al*., 1983; Gold *et al*., 2001; Rannestad *et al*., 2011).

Despite of the agricultural importance of banana weevils in the country, there is limited understanding of the biology and management strategies of the banana weevil which is mainly due to challenges related with its distribution and high expenses in the banana-based faming systems in Tanzania (Rannestad *et al*., 2013). Thus, this article describes the variation and causes, biology and potential management strategies so that banana growers can not only increase their understanding on the pest-plant relations but also have possible options for managing the banana weevil in Tanzania.

[1] Submitted to Journal of Biodiversity and Environmental Sciences and accepted for publication

### 2.1.1 Biology of banana weevil

The banana weevil is characterized by a K-selected life cycle, low fecundity and slow population growth (Night *et al*., 2010; Shukla, 2010; Rannestad *et al*., 2011; Rannestad *et al*., 2013). The adult female has a low oviposition rate of 1-4 eggs per week. It lays egg singly in the cavity mined on the base of the banana plant, corms, crop residues, interleaf sheaths and stems (Night *et al*., 2010; Dassou *et al*., 2015; Uzakah *et al*., 2015). Upon hatching, larvae penetrate into banana corms, pseudostems and true stems (de Graaf, 2006; Kiggundu *et al*., 200**7**; Rannestad *et al*., 2013). The larvae is the main destructive stage which results in multiple galleries within banana corms during feeding (Akello *et al*., 2008; Ocan *et al*., 2008; Dassou *et al*., 2015; Hölscher *et al*., 2016; Maldonado *et al*., 2016). The weevil adults are nocturnally active, sedentary, free living and measure 10-15 mm with fully second wings but rare or never observed to fly (Gold *et al*., 2006; Dahlquist, 2008; Shukla, 2010; Rannestad *et al*., 2011). Males secret six-specific detected compounds of aggregation pheromone, which is attractive to both sexes, with sordinin as a main component while female secret sex pheromones (Reddy *et al*., 2008; Reddy *et al*., 2009; Uzakah *et al*., 2015). The adult stage is the least destructive stage compared with the larval stage, having a long life span of up to one to four years and feeds on banana debris, rotting banana tissues and sometimes on young suckers (Night *et al*., 2010; Shukla, 2010; Mwaitulo *et al*., 2011; Rannestad *et al*., 2011; Were *et al*., 2015). Under dry substrates, weevils die within 3-10 days while under soil moisture conditions without food, their survival period is ambiguously reported to be 2-6 and 4-17 months (Gold *et al*., 2001; de Graaf, 2006). The restricted amount of host plant tissues trigger migration of most weevils possibly searching for oviposition sites and food sources (Umeh *et al*., 2010; Rannestad *et al*., 2011; Rannestad *et al*., 2013). The weevil growth stages such as eggs, larvae and pupae take place within banana plants and crop debris and usually complete their life cycle in a period of 5-7 weeks under tropical conditions (Gold *et al*., 2006; Kiggundu *et al*., 2007; Night *et al*., 2010; Shukla, 2010; Mwaitulo *et al*., 2011; Rannestad *et al*., 2013; Hasyim and Hilman, 2015; Uzakah *et al*., 2015). Banana farmers have limited knowledge on weevil biology with variations in their understanding. Some farmers don't recognize it, some fail to correlate weevil life cycle stages and other believe that larvae is more destructive than adult and others believe the opposite (Ssennyonga *et al*., 1998; Okech *et al*., 2006). This raises concerns in terms of their management banana-based farming systems. To fullfill this, Tanzania extension services are required to disseminate avalaible information to banana farmers to create awareness in terms of identification, population, action threshold (5 adult weevils/trap (de Oliveira *et al*., 2017), symptoms, damage and management startegies. This can be achieved through diffferent approaches like seminars and demostration studies to create awareness regarding to the pest.

### 2.1.2 Species of banana weevils

There exist two known species of banana weevils namely; *Cosmopolites sordidus* Germar 1824 and *Cosmopolites pruinosus* Heller (Zimmerman, 1968a; de Graaf, 2006). *C. sordidus* Germar 1824 has numerous synonyms such as banana beetle, banana corm borer, banana root borer, banana weevil, black banana borer, corm weevil, plantain black weevil and many common names. The name **“**banana root borer**”** raises confusion due to neither the larvae nor the adults attacks banana roots (de Graaf, 2006). *C. pruinosus* Heller is an important pest and has been considered to be a banana secondary pest in some countries such as in Borneo, the Caroline Islands, Micronesia and Philippines (Zimmerman, 1968a; Zimmerman, 1968b). These two banana weevils have a very similar morphology with their distinctive features founded in the nature of pruinosity on the dorsum and the elytral striae (Zimmerman, 1968; de Graaf, 2006). Although the banana weevil *C. sordidus* is reported to be an insect pest attacking banana in some regions of Tanzania, there is limited information on its prevalence and distribution across different banana-based farming systems in Tanzania. More studies are recommended to gain knowledge on the status of this destructive insect pest in different banana-based farming systems of Tanzania.

### 2.1.3 Symptoms and their effects on banana plants

The banana weevil is monophagous with its host range restricted to the genera *Musa* and *Ensete* (Gold *et al.*, 2006; Mwaitulo *et al*., 2011). It attacks all banana plant varieties at all growth stages (Gold *et al*., 2006; Reddy *et al*., 2008; Reddy *et al*., 2009). Its corm damage interferes with root initiation and development, water and nutrient uptake (Akello *et al*., 2008; Night *et al*., 2010; Maldonado *et al*., 2016). The infested plants exhibit symptoms of leaf chlorosis, reduced sucker vigour and number, weak plants, low fruit bunch weight, premature plant death, stunted growth and delayed flowering and fruit maturation (Hasyim *et al*., 2009; Njau *et al*., 2011; Rannestad *et* *al*., 2013). Serious weevil damage causes toppling and snapping of the pseudostems at the base, particularly during windstorms and plant death (Night *et al*., 2010; Sadik *et al*., 2010; Rannestad *et al*., 2013). The banana weevil is associated with yield losses of up to 100% in severely infested fields and can cause total crop failure (Reddy *et al*., 2009; Sahayaraj and Kombiah, 2010; Omukoko *et al*., 2014; Aby *et al.*, 2015a; Tinzaara *et al*., 2015; Carval *et al*., 2016; Maldonado *et al*., 2016). de Graaf (2006) reviewed that the symptoms are similar to banana root nematodes symptoms**.** Hence, research efforts aiming at distinguish weevil symptoms from nematodes symptoms should be undertaken.

### 2.1.4 Current management strategies

Banana weevils can be managed through different strategies such as biological, chemical, cultural, botanical and host resistance (Sahayaraj and Kombiah, 2010; Nwosu, 2011; Tinzaara *et al*., 2015; Maldonado *et al*., 2016).

#### i. Biological control

Biological techniques include classical biological control, endemic natural enemies, secondary host association and microbes (Shukla, 2010; Mwaitulo *et al.*, 2011; Fancelli *et al.*, 2013; Hasyim and Hilman, 2015). Beneficial insects of myrmicine ants *Tetramorium guineense* Nylander and *Pheidole megacephala* Fabricius have been reported to be effective against banana weevils in some countries such as Cuba (Hasyim and Hilman, 2015). Laboratory evaluation carried out by Hasyim and Hilman (2015) showed promising control potential of two predators staphylinid *Belonochus ferrugatus* (Erichson) and histerid *Plaesius javanus*. The Jepson's beetle, *P. javanus* larvae and adults seemed to cause high mortality rates to weevil eggs and pupae (Hasyim, 2009; Hasyim and Hilman, 2015). Other successful control strategies have been achieved by using entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* and entomopathogenic nematodes (Shukla, 2010; Fancelli *et al.*, 2013; Omukoko *et al*., 2014; Hasyim and Hilman, 2015). In Tanzania, a study by Mwaitulo *et al*. (2011) showed that weevil control by entomopathogenic nematodes (EPNs) in the genera *Heterorhabditis* and *Steinernema* (Rhabditida) provided promising banana weevil control measures. The approach seemed to contribute to agricultural sustainability compared with the chemical control. This approach is believed to be cost-effective to small-scale farmers (Fancelli *et al.*, 2013; Tinzaara *et* *al*., 2015). However, limited reports are available on the wide application under field conditions and evaluation of entomopathogens (biological agent) in the tropical farming system (Sadik *et al*., 2010; Omukoko *et al*., 2014). Research studies need to be conducted on myrmicine ants especially *Pheidole megacephala* Fabricius and entomopathogenic nematodes of the genera *Heterorhabditis* and *Steinernema* reported to be available in East Africa (Rhabditida) in banana-based farming systems (Bonhof *et al*., 1997; Mwaitulo *et al*., 2011). These should center on their field performance and distribution systems to the small scale banana farmers forming a large proportion of the banana industry in East Africa.

### ii. Chemical control

Chemical control includes the application of insecticides such as aldicarb, carbofuran, chlorpyrifos, cyclodiene, dusband, organophosphates and pirimiphos-ethyl (Aba *et al*., 2011; Marilene *et al*., 2013; Bwogi *et al*., 2014; Carval *et al*., 2016). Use of these chemicals can result in high mortality of the weevil population and perceived by banana farmers as fast acting, manageable and effective (Aby, 2015; Tinzaara *et al*., 2015). However in Tanzania, chemical application in weevil control is challenged by complex undescribed banana distribution patterns in different farming systems and high cost (Bujulu *et al*., 1983; Rannestad *et al*., 2013). Use of chemicals such as dieldrin, endosulphan and fenitrothion against banana weevil infestation in Tanzania has met little success (Bujulu *et al*., 1983). However, chemical control is reported to provide a short-time solution to the banana weevil problems while its long-time application resulted in weevil resistance (Gokool *et al*., 2010; Bortoluzzi *et al*., 2013; Bwogi *et al*., 2014; Aby *et al*., 2015a). Moreover, chemicals are less available, more toxic to human health and environment unfriendly due to destroying non-targeted beneficial natural insects (Sadik *et al*., 2010; Bwogi *et al*., 2014; Aby, 2015b; Tinzaara *et al*., 2015). The sole chemical approach is basically effective due to high death rate but there is limited information on application combination with other strategies. To reduce chemical applications but maintain their effectiveness, research studies should focus on the integration of chemicals and non-chemical strategies to control banana weevils.

### iii. Cultural control

Cultural controls involves cleaning planting material, practicing crop sanitation, corm paring, intercropping, mulching and pseudostem trapping (Okech *et al*., 2006; Akello *et al*., 2008; Dahlquist, 2008; Sahayaraj and Kombiah, 2010; Mwaitulo *et al*., 2011; Aby *et al*., 2015a; Carval *et al*., 2016). Some banana farmers in Tanzania have been reported to apply these cultural control strategies (Mgenzi *et al*., 2006). Commonly practiced cultural methods include the cleaning of planting materials by corm paring and dipping in hot water of 52-55°C for 15-27 minutes to kill the present eggs and larvae (Gold and Messiaen, 2000; Shukla, 2010). Tenkouano *et al.* (2006) pointed that sucker sanitation can be achieved through treatment with either hot water at 52°C in 20 minutes or boiling water of 100°C in short time of 30 seconds.

Cultural technique also involves use of good non-infested banana planting materials (tissue culture) in cleaned farms. Replanting in previously infested fields with old corms is not recommended. Rather than using weevil-free planting materials, Tanzanian small-scale farmers are often reported to use the suckers from their neighboring fields which in turn seemed to increase weevil problem (Mwaitulo *et al*., 2011). Practicing crop sanitation measures involving destroying of infested old corms, pseudostems and crop residue materials after harvesting aiming to remove oviposition sites have also been used (Shukla, 2010; Jallow *et al*., 2016). This is accompanied by three months of weevil population die out. For instance, the study by Okech *et al*. (2006) reported that high crop sanitation reduced weevil numbers and their damage compared with banana farms of low to moderate crop sanitation. It also contributed to the production of larger bunchs with >20 kg compared to about 12 kg. Although crop sanitation has been reported to be beneficial in different regions, banana farmers in Tanzania do not practice it (Mgenzi *et al*., 2006).

Another important technique proven to be effective includes trapping of adults using traps of pseudostem, corm disc (disc on stump/Columbian trap), pheromone (sordinin or cosmolure), cheese, modified roof tile, wedge and inoculated trap (Rannestad *et al*., 2013; Aby *et al*., 2015a; Jallow *et al*., 2016; Queiroz *et al*., 2017). The pseudostem traps can be treated with chemicals like Confidor (imidachloprid), Baythroid (cyfluthrin) and Karate (lambda-cyhalothrin) (Gokool *et al*., 2010). They are good for monitoring the weevil population and can be used for two weeks

(Jallow *et al*., 2016). Pheromone traps have been reported to be 5-10 times and up to 18 times better compared with pseudostem traps in Costa Rica and Uganda respectively (Gokool *et al*., 2010). Its trapping performance has been reported to be higher during dry seasons than in the rainy seasons (Jallow *et al*., 2016).

A study by Gold *et al*. (2006b) reported that the application of banana mulches favors weevil population build-up as they provide organic matter and preserve soil moisture. However, this approach is unable to manage banana weevils (Mgenzi *et al*., 2006; Akello *et al*., 2008; Sadik *et al*., 2010; Tinzaara *et al*., 2015). Cultural control strategies seems to be environmental and human health friendly, but there is limited information especially on modified cultural strategies such as inoculated and pheromone (sordinin or cosmolure) traps. Therefore, intensive application of these strategies need to be exploited by farmers and hence extension service agents required to extend outreach programs.

**iv. Botanical control techniques**

Several plants such as *Azadrachta indica*, *Tephrosia vogelii*, *Tagetes erecta*, *Phyotolaca dodecandra*, *Ricinus communis* and *Nicotiana tabacum* have been tested for controlling banana weevil (Sahayaraj and Kombiah, 2010; Shukla, 2010; Bwogi *et al*., 2014). Neem seed powder (rich in azadrachtin) has been reported to have insecticidal effects and thus to have ability to decrease weevil infestation (Sahayaraj and Kombiah, 2010). A study in Tanzania by Mgenzi *et al*. (2006) pointed out that neem seed powder produced promising results on weevil control. Dipping of young suckers in 20% neem seed solution during planting helped to repel weevil adults and thus reduced oviposition and their attacks (Shukla, 2010). Umeh *et al*. (2010) pointed that neem mulch leaf have insecticidal effects which managed to suppress banana weevil population in plantain and banana in Nigeria. Similarly a study by Bwogi *et al*. (2014) in Masaka and Mpigi districts of Uganda pointed that mixture of extracts from *Tephrosia*, tobacco and *Phytolaca* together with animal urine and ash produced similar positive management effects on banana weevil population in levels similar with synthetic chemicals of Carbofuran and Dusband. Botanical pesticidal plants may provide instant accessible pesticides to the farmer's and hence their promotion should be encouraged.

### v. Host plant resistance

This technique involves using resistant cultivars with detrimental effects on weevil physiology. Its mechanisms include antibiosis, antixenosis (non-preference), corm hardness, host plant tolerance, plant antifeeds, extending larval mortality as well as extending larval development and growth (Kiggundu *et al*., 2007; Night *et al*., 2010; Arinaitwe *et al*., 2015; Valencia *et al*., 2016). Antibiosis is concerned with plant defense by affecting larval performance negatively by secreting sap and latex, corm hardness, antifeedants, toxic secondary plant substances and nutritional deficiencies and hence result weevil death (Kiggundu *et al*., 2007). Antixenosis contributes resistant cultivars to deter weevil attacks through non-preference of larval and adult feeding as well as female oviposition. However, antibiosis has been reported to be important to weevil resistance mechanism rather than antixenosis due to cultivar non-discrimination behavior of the female oviposition (Sadik *et al*., 2010; Night *et al*., 2010)**.** Nevertheless in Tanzania, the East African Highland banana (the commonest cultivars) have been reported to be highly susceptible to weevil attacks (Night *et al*., 2010; Sadik *et al*., 2010; Shukla, 2010). Antibiosis seemed to provide plant self-protection against banana weevil but has less information. More research studies required to be conducted on banana plant secretions mainly toxic secondary plant substances.

In conclusion, this review section has highlighted the biology of weevils, causes of weevil variation in the banana farming systems and a number of banana weevil management strategies such as biological, chemical, cultural, botanical and host resistance. Of the methods, this review article recommends a combination of all except synthetic chemicals. More sustainably biological and host plant resistance can be the best options, however studies are needed to explore how these options can be developed.

## 2.2 Banana weevil population in different farming systems

### 2.2.1 Factors affecting banana weevil distribution

There are different factors that influence prevalence of banana weevil (Fig. 1a and b) in different agroecological zones (Gold, 2000; Treverrow, 2003; de Graaf, 2006; Dahlquist, 2008). Important cited factors are presence of feeding materials, altitude, rainfall patterns, temperature, banana genotypes and banana management practices (Bujulu *et al.*, 1983; Njau *et al.*, 2011; Rannestad *et al.*, 2011; Mwaitulo *et al.*, 2011; Were *et al.*, 2015).

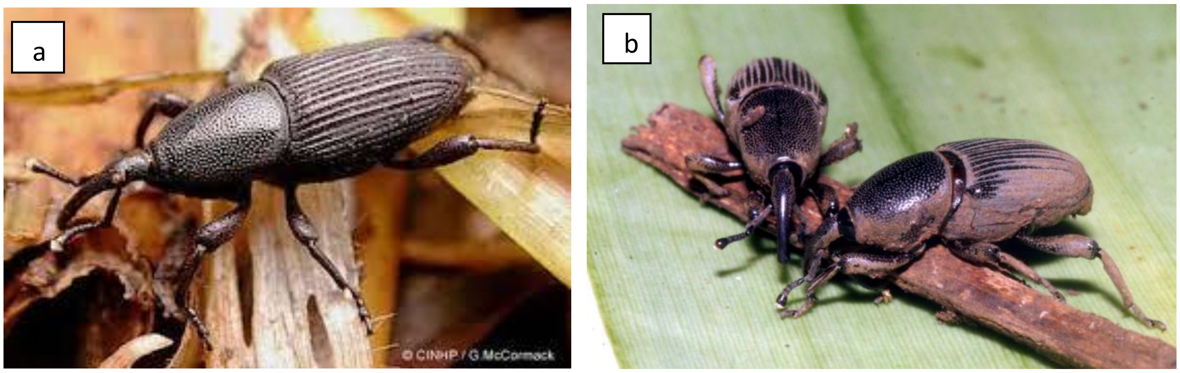


Figure 1a and 1b: Adult banana weevils. Photos by G. McCormack, Cook Islands Biodiversity Database and Scot Nelson, Flickr, CC BY-SA 2.0.

### i. Feeding materials

Adult weevils feed on banana residues or debris, tissues and sometimes on young suckers but their resultant damage is negligible (de Graaf *et al.*, 2008; Mwaitulo *et al.*, 2011; Were *et al.*, 2015). Apart from nutrients, the decomposing banana materials provide shelter and oviposition sites for banana weevils (Nwosu, 2011). When fresh and dried banana residues decompose, they produce kairomones which attract adult weevils and aggregates (Mwaitulo *et al.*, 2011; Tinzaara *et al.*, 2015). These kairomones are mainly composed of iso-butyl-aldehyde and limonene which is present in the banana corms (Tinzaara *et al.*, 2015). Under limited amount of host plant tissues, most weevils will move away possibly searching for oviposition and feeding sites (Rannestad *et al.*, 2011).

### ii. Altitudes

Banana weevil prevalence is reported to be with inverse relationship with altitude (Njau *et al.*, 2011; Wachira *et al.*, 2013). In East and West Africa, banana weevils are not in high numbers at an attitude beyond 1500 meter above sea level and temperature range of 25°C - 30°C (Njau *et al.*, 2011; Wachira *et al.*, 2013).

### iii. Rainfall

Banana weevils are strictly hydrotrophic and are prone to dry environments (Gold *et al.*, 2006). The presence of adequate moisture conditions encourage their activity (Gokool *et al.*, 2010). Their populations stay all-round the year but increase during rainy seasons (Njau *et al.*, 2011). A survey study in Bukoba district of Tanzania showed that there were high occurrence of banana weevil populations during rainy season in lake littoral zone than to drier upland (Bujulu *et al.*, 1983). In other parts of the world such as in the Nouvelle France region located at altitude of 400-600 m.a.s.l with high rainfall and humidity, weevil population was high while in the Clemencia rsegion with low rainfall and humidity climatic conditions the weevil population was reported to be low (Gokool *et al.*, 2010).

### iv. Temperature

According to Gold and Messiaen (2000) and Gokool *et al.* (2010), banana weevil life cycle development rates and activities are influenced by temperature changes. At a temperatures below 12°C, weevil eggs fail to develop, and in combination with altitudes of above 1600 m.a.s.l, their prevalence becomes insignificant. For instance, a study by Traore *et al.* (1993) pointed out that both weevil eggs developed and adult emerged within optimal temperature range of between 25-32°C. However, egg development delayed at temperature range of 15 and 18°C while adult weevil emergence rate delayed and stopped at temperature of 15°C and 34°C respectively.

### v. Banana genotypes

There exist some banana genotypes that are resistant to banana weevil infestation in some countries, for instance, a study by de Oliveira *et al.* (2017) in Brazil showed that banana cultivars Prata Anã (Genotypes AAB) and Pacovan (Genotypes AAB) managed to resist banana weevil attacks and did not experience weevil infestation. However, it was also pointed out that banana hybrids with genotypes AAAB and AAAA such as BRS Victoria (AAAB) and Bucaneiro (AAAA) showed intermediate resistance to weevil damage respectively. In East Africa, Desert banana cultivars of Sukali Ndiizi genotypes AAB and Kayinja genotypes ABB, Plantain variety of Gonja genotypes AAB experienced lowest and moderate weevil damage levels respectively

(Ocan *et al.,* 2008). Moreover, East African highland Bananas (EAHB) variety Lwadungu genotypes AAA-EAHB has been reported to have the highest weevil damage (Ocan *et al.*, 2008).

### 2.2.2 Banana weevil damage in different banana-based farming systems

Banana weevils are known to attack the plant regardless of its development stage through destructive larval feeding which creates numerous galleries in corms which may result into toppling of plants (Fig. 2 and Fig. 3) (Sadik *et al.,* 2010; Fancelli *et al.*, 2013). Its damage can be assessed by using the coefficient of infestation or percentage coefficient of infestation (Gold *et al.*, 1994; de Oliveira *et al.*, 2017). It involves a banana corm cross-sectional dissection followed by scoring of weevil galleries present in its inner regions (central cylinder) and cortex (outer region). The damage scores used to establish coefficient of infestation or percentage coefficient of infestation implies susceptibility/resistance levels of banana genotypes towards banana weevils (Ortiz *et al.*, 1995; Gold *et al.,* 1998).

The coefficient of infestation can be established according to Vilardebo (1973) damage index as 0 galleries= 0%, 1 or 2 galleries=5%, 10 galleries=10%, 30 galleries= 25%, 40 galleries= 50%, 60 galleries= 75%, and 100 galleries= 100% of corm circumference damage (Dassou *et al.*, 2015). de Oliveira *et al.* (2017) modified the damage score as 0 galleries =0%, traces of galleries=5%, 5-20 galleries=10%, 20 galleries= 25%, 30 galleries= 20-40%, 40 galleries =50%, 50 galleries =75% and 100 galleries=100% over the entire corm.

Weevil damage due to its larval feeding occurs underneath the soil surface mainly on the banana corm cortex and central cylinder (Gold *et al*., 2001; Njau *et al.,* 2011). The study by de Oliveira *et al.* (2017) showed that 94.2 % of weevil infestation occurred on the banana corm cortex followed by central cylinder (5.8%).

Figure 2: Corm damage by banana weevil Photo by Swennen Rony, IITA.

Figure 3: Plant toppling due to banana weevil infestation. Photo by David Astridge, Agri- Science Queensland.

Research studies by a number of authors revealed that weevil damage can be influenced by different factors such as banana cultivars, altitudes, temperature and farming systems (Wortmann and Sengooba, 1993; Gold *et al.,* 1994; Gold *et al.,* 1998; McIntyre *et al.,* 2001; Tushemereirwe *et al.,* 2001; Rukazambuga *et al.,* 2002; Zake, 2015; de Oliveira *et al.,* 2017).

### 2.2.3 Farmer's understanding on banana weevils in different banana-based farming systems

Some studies have shown that banana farmers have ambiguous understanding of banana weevil biology, population density and damage in relation to different banana-based farming systems (Gold *et al.,* 1994; Okech *et al.,* 2004; Okech *et al.,* 2006; Lwandasa *et al.,* 2014). Based on their studies, the majority of banana farmers have limited or low understanding of banana weevil and its damage mechanism (Ssennyonga *et al.,* 1998; Okech *et al.,* 2006). For instance 58.2% of 65 banana farmers from Masaka district of Uganda have reported that the banana weevil larva and its adult stage are two different insects (Ssennyonga *et al.,* 1998). A similar understanding exists among the majority of banana farmers in the whole Eastern African region including Tanzania.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Study location and materials

This study was conducted in the villages of Nkoaranga, Mbuguni and Ngurdoto with altitude of 1343, 941 and 1304 m.a.s.l respectively (Meru District, Arusha region) and Uduru, Uraa and Mbosho with altitude of 1277, 1384 and 1287 m.a.s.l respectively (Hai District, Kilimanjaro region) from June to September, 2017. During the study, Mbuguni village was only experiencing rainy season while the rest villages experienced dry seasons. Materials used were GPS, camera, desuckering tool, machete, square grid, thermometer, questionnaire sheets and colour banana weevil image plate.

### 3.2.1 Assessing the presence of banana weevils in different banana-based farming systems

To assess the banana weevil presence, three banana pseudostems were cut in small pieces of about 25-30 cm and halved to make the traps as described by Swennen (1990). Then three traps (representing three replications) set [based on the procedures described by the same author (Swennen, 1990)] were placed per farm in four farms randomly selected in banana-based farming systems per village and maintained over the period of five days. With cut surfaces facing the soil, the pseudostem pieces were placed 50 cm radius around the bases of three randomly selected mats consisting of three to four banana plants in each banana farms. Weevil adults were counted daily over period of three months weeks. The banana varieties, GPS coordinates and temperature of the environment during the early morning hours were recorded.

### 3.2.2 Weevil damage levels in different banana-based farming systems

The damage was assessed by using coefficient of infestation method according to de Oliveira *et al.* (2017) involving destructive random sampling. Three randomly selected banana plants per banana-based farming system were uprooted. The soil debris around banana corms were removed followed by paring to remove banana roots. The corms were then cut cross-sectionally at their maximum diameter to expose weevil galleries. Finally, square grid of 2025 $cm^2$, with cells of 2.25 $cm^2$ was placed over their cut surfaces followed by counting cells (symptoms of necrotic or dark tissue). Total number of cells affected and its respective banana cultivar from each banana-based farming system were recorded.

Coefficient of infestation were established according to damage scale of 0 (no galleries), 5 (traces of galleries), 10 (between 5 and 20 galleries), 20 (galleries in approximately 25% of the corm), 30 (galleries in approximately 20%-40% of the corm), 40 (galleries in approximately 50% of the corm), 50 (galleries in approximately 75% of the corm) and 100 (galleries in the entire corm).

### 3.2.3 Farmers understanding on banana weevil in different banana-based farming systems

This was done according to Wachira *et al.* (2013) with modifications. The procedure involved a semi structured questionnaire and standard interview. A total of 24 males and 24 female randomly selected respondents were interviewed in the study area. Coloured plate with images of adult banana weevils, infested banana corm and pseudostem traps with trapped-adult weevils was used during interview to facilitate the farmer's recognition of the banana weevils.

## 3.3 Data Collection and Analysis

The main parameters collected were number of adult weevils per banana-based farming system, type of banana-based farming system, number of weevil galleries per banana corm, season (dry or rainy), banana cultivars, temperature and GPS coordinates. Physical data were analyzed by using GENSTAT 11$^{th}$ Edition subjected to one-way ANOVA under F-test with significance level of 5% based on the DMRT, while survey data were analyzed by using SPSS Version 21**.**

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Results

Results showed that there was significant difference (p<0.05) between the number of banana weevils recorded in different banana-based farming systems (Table 1). Of the four commonly practiced banana-based farming systems, banana-maize system seemed to attract the highest average value (29.17) followed banana-beans (8.17), the latter not being significantly different from banana-coffee and banana monoculture (Table 1). The results also showed that the coefficient of infestation was not significantly different (P<0.05) between the banana-based farming systems (Table 1). The results also showed that Mbuguni in Meru had the highest population (124 banana weevils) per farm compared to other locations where the second highest (24 banana weevils per farm) was at Nkoaranga in Meru District and other locations seemed to have a small range (Fig. 3). The results also showed that banana weevil number was the highest (153 weevils per farm) in the banana cultivar Kimalindi compared to other cultivars which seemed to have small numbers ranging from 1 in cultivar Ng'ombe to 22 in cultivar Cavendish subspecies (Fig. 4).

**Table 1: Number of weevils per trap and coefficient of infestation per corm in different banana-based farming systems in this study over period of three months.**

| Item | Farming system | Average number of weevils per trap | Coefficient of infestation per banana corm (%) |
|---|---|---|---|
| 1 | Banana monoculture | 5.50b | 18.75a |
| 2 | Banana-beans | 8.17b | 31.25a |
| 3 | Banana-coffee | 5.08b | 24.58a |
| 4 | Banana-maize | 29.17a | 15.00a |
| | Mean | 12.00 | 22.4 |
| | LSD (0.05) | 17.93 | 20.65 |
| | F-Statistics | * | ns |
| | p-value | 0.027 | 0.420 |

Mean followed by the same letter within a column are not significant different based on Duncan Multiple's Range Test at p=0.05., ns=non-significant. *=significant at P≤0.05.

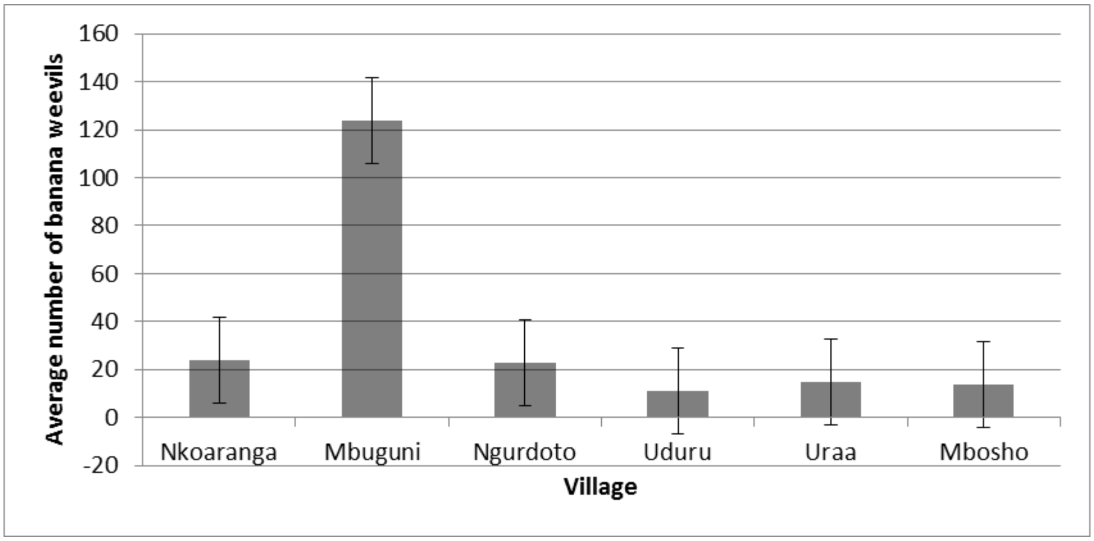


**Figure 4: Average number of banana weevils in different locations**

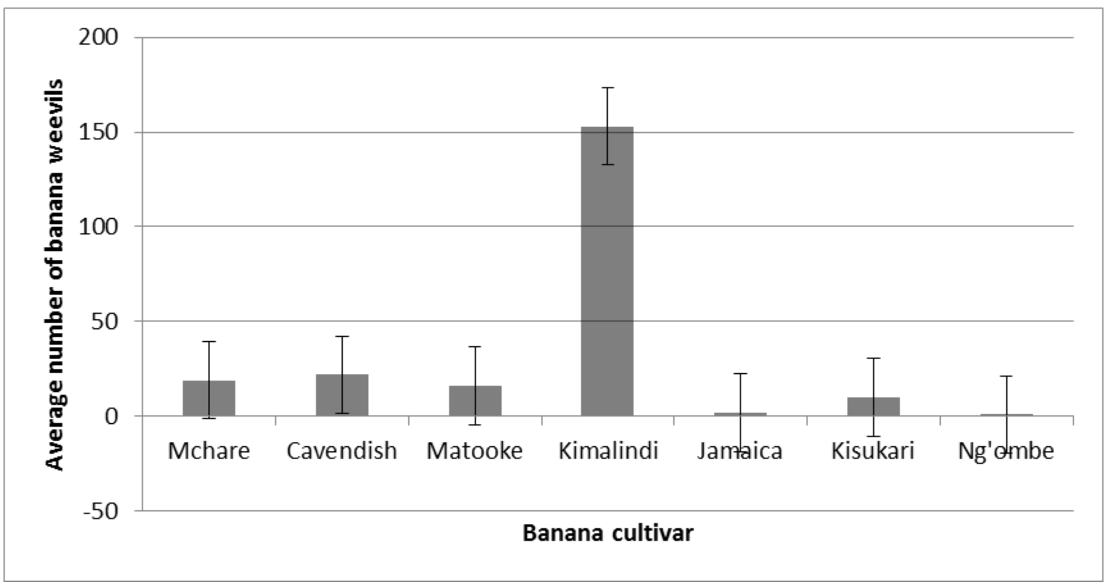


**Figure 5: Average number of banana weevils in different cultivars in the study area**

Results on farmer's understanding of weevils indicated that 68.8% of banana farmers ranked banana weevil the major banana insect pest and a problem that causes high damage and yield loss (Table 2). The results also showed that there was limited understanding of weevil biology. About 39.6 % of banana farmers know the weevil adult stage but not the larval stage while about 60.4% of them did not associate the symptoms of banana weevil infestation with the weevil itself, but rather they generally called them diseases. To manage banana weevil, 64.4% of farmers, even though they have no knowledge of the insect itself, use ash or lime or a combination of ash, lime and manure. The results also showed about 75% of farmers said the type of banana-based farming system does not affect the population of weevils (Table 2).

**Table 2: Farmers' understanding on banana weevil**

| SN | Variable | Response | Number | Percentage (%) |
|---|---|---|---|---|
| 1 | What is the major insect pest to your banana production? | Banana weevils | 33 | 68.8 |
| | | Others | 5 | 10.4 |
| | | Don't know | 4 | 8.2 |
| | | Banana spider mites | 3 | 6.3 |
| | | Banana aphids | 3 | 6.3 |
| 2 | Do you know stages of weevil development? | No | 29 | 60.4 |
| | | Yes | 19 | 39.6 |
| 3 | How do you know banana weevil? | Observation | 24 | 50 |
| | | Fellow farmers | 1 | 2.0 |
| | | Extension service | 2 | 4.2 |
| | | TV | 1 | 2.1 |
| | | Training | 4 | 8.4 |
| | | Other | 16 | 33.3 |
| 4 | Is banana weevil presence throughout the year? | Yes | 21 | 43.8 |
| | | Don't know | 15 | 31.8 |
| | | No | 11 | 22.3 |
| | | All the season | 1 | 2.1 |

| | | | | |
|---|---|---|---|---|
| 5 | Season of high presence of banana weevil in different farming systems | Dry season<br>Rainy season<br>Others<br>Don't know<br>All the season | 19<br>13<br>3<br>12<br>1 | 39.6<br>27.1<br>25.0<br>6.2<br>2.1 |
| 6 | Is banana weevil infestation a problem? | Yes<br>No | 33<br>15 | 68.8<br>31.2 |
| 7 | Control application | Ash, lime, manure<br>Nil | 31<br>17 | 64.4<br>35.6 |
| 8 | Do different banana-based farming system reduce weevil infestation? | Yes<br>No | 12<br>36 | 25<br>75 |

## 4.2 Discussion

The banana weevil was found in all villages investigated and attacking different banana cultivars. This was not surprising since the banana weevil, *Cosmopolites sordidus* Germar has been reported to be present globally in banana growing regions (Gold *et al*., 1998; Dahlquist, 2008).

In this study, the banana weevil population was observed to be high in Mbuguni village compared to other villages, and of all cultivars, the cultivar Kimalindi was found to be highly attacked by this pest. Such high numbers of banana weevil could be related to a favorable temperature for the weevil of more than 20°C in Mbuguni village (941 m.a.s.l), a factor that favour banana weevil growth as per Traore *et al*. (1993), Gold and Messiaen (2000) and Gokool *et al*. (2010). In areas such as Nkoaranga, Ngurdoto, Uduru, Uraa and Mbosho villages (covered in this study) with a temperature range between 13-15°C, the weevil infestation was also low. This finding is supported by Traore *et al*. (1993) who reported temperature range of 15-18° C to be responsible for delayed egg development.

Also, significant difference across sites with respect to weevil population could be related to altitude, crop sanitation and banana mulches. Mbuguni village is an area with low 941 m.a.s.l. According to Wachira *et al*. (2013), areas with low altitude experience higher number of weevil population. Njau *et al*. (2011) reported that weevil population weren't observed in high altitudes of Mathioniya (1915 m.a.s.l) as well as in Kiharu and Muranga regions (1680 m.a.s.l). The same trend was observed in Maragua region of Kenya by Wachira *et al*. (2013). The present study recorded the same behaviour in Nkoaranga, Ngurdoto, Uduru, Uraa and Mbosho villages with altitudes of 1343, 1304, 1277, 1384 and 1287 m.a.s.l respectively.

In terms of crop sanitation, it was apparently observed that in banana-maize farms, at Mbuguni, new banana planted fields were bordered by old infested banana corms and weeds all of which could be responsible for high banana weevil population (results not presented). A study by Masanza *et al*. (2006) in Uganda reported that a low level of sanitation encourages weevil population growth compared to moderate and high level. Conversely, these corms and other crop residues were acting as a source of food and breeding ground for weevils and oviposition (Kiggundu and Muchwezi, 2009). Another banana weevil encouraging practice at Mbuguni was mulching with banana leaves. This practice preserves soil moisture and discourages weeds and hence is good for banana production (Gold *et al*., 2006; Okech *et al*., 2006). However, since it conserves moisture, it encourages weevil population growth through creating a good environment for them to thrive and survive (Gold *et al*., 2006; Rukazambuga *et al*., 2002; Shukla, 2010; Mgenzi *et al*., 2006).

This study has also shown that a majority of farmers in the study area lack the understanding of the banana weevil infestation and biology. This is supported by a number of different studies in other parts of the world which also showed that banana farmers have a limited understanding of weevil and its related infestation (Gold *et al.*, 1994; Ssennyonga *et al.*, 1998; Okech *et al.*, 2004; Okech *et al.*, 2006; Lwandasa *et al*., 2014). The current study has indicated that a majority of farmers have not noticed differences in infestation levels in different banana-based farming systems in the study area. This could be attributed by a low understanding of the farmers on the banana weevil problem as found in this study. The low understanding of banana farmers on banana weevil could be attributed to the cryptic nature of the insect (de Graaf, 2006; Shukla, 2010). Banana weevil is a free and soil-dwelling insect which can be found between leaf sheaths, within banana corms and crop residues and is more active during the night (Gold *et al.*, 2004; Shukla, 2010). All immature stages grow within banana plants (Mwaitulo *et al.*, 2011; Rannestad *et al.,* 2013; Uzakah *et al.,* 2015). This behaviour prevent visual observation by banana farmers and hence their low understanding unless otherwise the infested banana corms are opened up.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

This study concludes that banana weevil is in fact a problem in the study area. Its infestation levels differ between different banana-based farming systems. In the current study, the banana-maize system attracted a higher average number of banana weevils per farm at Mbuguni; a village at a low altitude and higher temperature compared to other villages covered in this study. The fact that farmers did perceive banana weevils variation in different studied banana-based farming systems contrary to the current results where there was significant difference between the number of banana weevils and infestation levels in different banana cultivars and locations. This has been explained in this study as due to the lack of understanding of insect biology and their movement which is more active at night compared to the day as thus too difficult to be observed by farmers. Nevertheless, since the same farmers perceived the insect to be the main insect problem, this study concludes that banana weevil is indeed a problem in the study area.

## 5.2 Recommendations

The present study recommend further studies on finding out factors for highest population in a banana-maize farming system compared to other systems and how the banana weevil problem can be managed in the study area and other locations in Tanzania.

## REFERENCES


Aba, S. C., Baiyeri, P. K. and Tenkouano, A. (2011). Impact of poultry manure on growth behaviour, black Sigatoka disease response and yield attributes of two plantains (*Musa* spp. AAB) genotypes. *Tropicultura*. **29**(1): 20-27.

Aby, N., Badou, J., Traoré, S., Kobénan, K., Kéhé, M., Thiémélé, D. E. F., Gnonhouri, G. and Koné, D. (2015a). Inoculated traps an innovative and sustainable method to control banana weevil, *Cosmopolites sordidus* in banana and plantain fields. *Advances in Crop Science and Technology*. **3**: 1-5.

Aby, N., Séka, C. L., Traoré, S., Kobénan, K. and Kouakou, T. H. (2015b). Effects of some fungicides and nematicides used in banana plantation on pathological characteristics of *Metarhizium* sp., biological agent control of banana weevil, *Cosmopolites sordidus* Gemar (Coleoptera: Curculionidae). *International Journal of Current Microbiology Application Science*. **4**: 1050-1065.

Akello, J., Dubois, T., Coyne, D. and Kyamanywa, S. (2008). Effect of endophytic *Beauveria bassiana* on populations of the banana weevil, *Cosmopolites sordidus,* and their damage in tissue-cultured banana plants. *Entomologia Experimentalis et Applicata*. **129**: 157–165.

Blomme, G., Ploetz, R., Jones, D., De Langhe, E., Price, N., Gold, C. S. and Geering, A. (2013). A historical overview of the appearance and spread of Musa pests and pathogens on the African continent: Highlighting the importance of clean Musa planting materials and quarantine measures. *Annals of Applied Biology*. **162**(1): 4–26.

Bwogi, G., Mwine, J., Jumba, F., Murongo, M., Grace, N. N., Kabango, F. and Mutumba, N. K. P. (2014). Assessing the effectiveness of ethnomedicinal products on banana weevils using REML. *Agriculture, Forestry and Fisheries*. **3**(5): 420-426.

Bonhof, M. J., Overholt, W. A., Van Huis, A. and Polaszek, A. (1997). Natural enemies of cereal stem borers in East Africa: A Review. *Insect Science Application Journal*. **17**(1): 19-35.

Bortoluzzi, L., Alves, L. F. A., Alves, V. S. and Holz, N. (2013). Entomopathogenic nematodes and their interaction with chemical insecticide aiming at the control of banana weevil borer, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae). *Arquivos do Instituto Biológico.* **80**(2): 183-192.

Braimah, H. and Van Emden, H. F. (2004). Attractiveness of some host plant and conspecific male semiochemicals to the banana weevil, *Cosmopolites sordidus* (Germar, 1824). Accra, National Science and Technology Press. *Ghana Journal of Agricultural Science.* **37**: 75-84.

Bujulu, J., Uronu, B. and Cumming, C. N. C. (1983). The control of banana weevils and parasitic nematodes in Tanzania. *East African Agricultural and Forestry Journal.* **49**(1): 1-13.

Carval, D., Resmond, R., Achard, R. and Tixier, P. (2016). Cover cropping reduces the abundance of the banana weevil, *Cosmopolites sordidus* but does not reduce its damage to the banana plants. *Biological Control.* **99**: 14–18.

Chernoh, E. (2014). Banana weevil, *Cosmopolites sordidus*. Plantwise Knowledge Bank. Africa Soil Health Consortium. 133-134.

Dahlquist, R. (2008). Biology and management of the banana weevil (*Cosmopolites sordidus* Germar) in the socioeconomic and agroecological context of the indigenous territories of Talamanca, Costa Rica. Unpublished PhD Thesis, University of Idaho, United State, 1-7.

Dassou, A. B., Carval, D., Dépigny, S., Fansi, G. and Tixier, P. (2015). Ant abundance and *Cosmopolites sordidus* damage in plantain fields as affected by intercropping. *Biological Control.* **81**: 51–57.

de Graaf, J. (2006). Integrated pest management of the banana weevil, *Cosmopolites sordidus* (Germar) in South Africa. Unpublished PhD Thesis. University of Pretoria, University of South Africa, 1-37.

de Oliveira, F. T., Neves, P. M. O. J. and Bortolotto, O. C. (2017). Infestation of the banana root borer among different banana plant genotypes. *Ciência Rural*. **47**(1): 1-5.

den Broeck, K. V. and Dercon, S. (2007). Social interactions in growing bananas: Evidence from a Tanzanian Village. University of Copenhagen and University of Oxford, CSAE WPS/2007-05. 1-33.

Gokool, A., Abeeluck, D., Dooblad, V. and Facknath, S. (2010). Investigation on the use of trapping in the management of the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) in Mauritius. *University of Mauritius Research Journal*. **16**: 332-344.

Gold, C. S., Rukazambuga, N., Karamura, E. B., Nemeye, P. and Night, G. (1998). Recent advances in banana weevil biology, population dynamics and pest status with emphasis on East Africa. *In:* Mobilizing IPM for sustainable banana production in Africa. Proceedings of a workshop on banana IPM, Nelspruit, South Africa, 35-50.

Gold, C. S. and Messiaen, S. (2000). The banana weevil, *Cosmopolites sordidus*. Musa Pest Fact Sheet No. 4, INIBAP, 1-3.

Gold, C. S., Pena, J. E. and Karamura, E. B. (2001). Biology and integrated pest management for the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Integrated Pest Management Reviews*. **6**: 79–155.

Gold, C. S., Okech, S. H. and Nokoe, S. (2002a). Evaluation of pseudostem trapping as a control measure against banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) in Uganda. *Bulletin of Entomological Research*. **92**: 35-44.

Gold, C. S., Rukazambuga, N. D. T. M., Gowen, S. R. and Ragama, P. (2002b). The influence of crop management on banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) populations and yield of highland cooking banana (cv. Atwalira) in Uganda. *Bulletin of Entomological Research.* **92**: 413–421.

Gold, C. S., Night, G., Ragama, P. E., Kagezi, G. H., Tinzaara, W. and Abera, A. M. K. (2004). Field distribution of banana weevil, *Cosmopolites sordidus* (Germar) adults in cooking banana stands in Uganda. *International Journal of Tropical Insect Science.* **24**(3): 242–248.

Gold, C. S., Okech, S. H., McIntyre, B. D., Kagezi, G., Ragama, P. E. and Night, G. (2006). Effects of mulch on banana weevil, *Cosmopolites sordidus* (Germar) populations and damage in Uganda. *Crop Protection.* **25**(11): 1153–1160.

Hasyim, A., Azwana, A. and Syafril, S. (2009). Evaluation of natural enemies in controlling of the banana weevil borer, *Cosmopolites sordidus* Germar in West Sumatra. *Indonesia Journal of Agricultural Science.* **10**: 43-53.

Hasyim, A., Hilman, Y. and Eri, S. (2015). Classical biological control of banana weevil borer, *Cosmopolites sordidus* (Coleoptera; Curculionidae) with natural enemies from Indonesia (With emphasis on west Sumatera). 1-16.

Hölscher, D., Buerkert, A. and Schneider, B. (2016). Phenylphenalenones accumulate in plant tissues of two banana cultivars in response to herbivory by the banana weevil and banana stem weevil. *Journal of Plants.* **5**: 1-6.

Kiggundu, A., Gold, C. S., Labuschagne, M. T., Vuylsteke, D. and Louw, S. (2007). Components of resistance to banana weevil (*Cosmopolites sordidus*) in *Musa* germplasm in Uganda. *Entomologia Experimentalis et Applicata.* **122**: 27–35.

Maldonado, W. J., Barbosa, C. J., Pavarini, R., Maruyama, W. I. and Oliveira, R. A. (2016). Spatial distribution and sequential sampling of the banana root borer. *Agronomy Journal*. **108**: 1030-1040.

Masanza, M., Gold, C. S., van Huis, A. and Ragama, P. E. (2006). Effects of crop sanitation on banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), populations and crop damage in Uganda. *African Entomology*. **14**(2): 267–275.

Mgenzi, S. R. B., Mkulila, S. I., Blomme, G., Gold, C. S., Ragama, P., Karamura, E. B., Nkuba, J. M. (2006). The effect of pest management practices on banana pests in the Kagera region of Tanzania. Blomme, G., Gold, C. S. and Karamura, E. (Eds). *In*: Proceedings of the workshop on Farmer-participatory testing of IPM options for sustainable banana production in Eastern Africa, held in Seeta, Uganda, 8-9 December 2003. INIBAP: Kampala (UGA), 2006, 43-52.

McIntyre, B. D., Gold, C. S., Kashaija, I. N., Ssali, H., Night, G. and Bwamiki, D. P. (2001). Effects of legume intercrops on soil-borne pests, biomass, nutrients and soil water in banana. *Biology and Fertility of Soils*. **34**: 342–348.

Mukasa, D., Olila, D., Tinzaara, W. and Kagezi, G. H. (2008). Effects of Tithonia and Phytolacca extracts against the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *African Journal of Animal and Biomedical Sciences*. **3**(1): 24-29.

Mwaitulo, S., Haukeland, S., Sæthre, M. G., Laudisoit, A. and Maerere, A. P. (2011). First report of entomopathogenic nematodes from Tanzania and their virulence against larvae and adults of the banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae). *International Journal of Tropical Insect Science*. **31** (03): 154-161.

Njau, N., Mwangi, M., Gathu, R., Mbaka, J. and Muasya, R. (2011). Banana weevil (*Cosmopolites sordidus*) reduces availability of corms for seedling production through macropropagation technology. *Journal of Animal and Plant Sciences.* **12**(1): 1537-1542.

Ocan, D., Mukasa, H., Rubaihayo, P. R., Tinzaara, W. and Blomme, G. (2008). Effects of banana weevil damage on plant growth and yield of East African Musa genotypes. *Journal of Applied Biosciences.* **9**(2): 407- 415.

Night, G., Gold, C. S. and Power, A. G. (2010). Survivorship and development rates of banana weevils reared on excised plant material of different banana cultivars. *International Journal of Tropical Insect Science.* **30**: 77–83.

Nwosu, L. C. (2011). Impact of cultural practice on the control of Cosmopolites sordidus in banana and plantain communities in Ore, Odigbo, Local Government area, Ondo, State, Nigeria. *Ethiopian Journal of Environmental Studies and Management.* **4**: 33-37.

Okech, S. H., Gold, C. S., Bagamba, F., Masanza, M., Tushemereirwe, W. K. and Ssennyonga, J. (2006). Cultural control of banana weevils in Ntungamo, southwestern Uganda. Blomme, G., Gold, C. S., Karamura, E. (Eds). *In*: Proceedings of the workshop on Farmer-participatory testing of IPM options for sustainable banana production in Eastern Africa, held in Seeta, Uganda, 8-9 December 2003. INIBAP: Kampala (UGA), 2006, 116-128.

Omukoko, C. A., Wesonga, J. M., Kahangi, E. M. and Wamocho, L. S. (2014). Virulence of three strains of *Beauveria bassiana* against the banana weevil. *Journal of Agricultural and Biological Science.* **9**(10): 333–336.

Rannestad, O. T., Sæthre, M. G. and Maerere, A. P. (2011). Migration potential of the banana weevil, *Cosmopolites sordidus*. *Agricultural and Forest Entomology.* **13**(4): 405–412.

Rannestad, O. T., Maerere, A. P., Torp, T. and Sæthre, M. (2013). A farmer participatory research approach to assess the effectiveness of field sanitation and regular trapping on banana weevil populations. *Fruits*. **68**: 83–93.

Reddy, G. V. P., Cruz, T. Z., Naz, F. and Muniappan, R. (2008). A pheromone-based trapping system for monitoring the population of *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). *Journal of Plant Protection Research.* **48**: 515-527.

Reddy, G. V. P., Cruz, Z. T. and Guerrero, A. (2009). Development of an efficient pheromone-based trapping method for the banana root borer, *Cosmopolites sordidus*. *Journal of Chemical Ecology*. **35**: 111–117.

Rony, S. (1990). Plantain cultivation under West African conditions. A Reference Manual. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 1-29.

Rukazambuga, N. D. T. M., Gold, C. S. and Gowen, S. R. (1998). Yield loss in East African highland banana (Muss spp., AAA-EA group) caused by the banana weevil, *Cosmopolites sordidus* Germar. *Crop Protection.* **17** (7): 581-589.

Sadik, K., Nyine, M. and Pillay, M. (2010). A Screening method for banana weevil (*Cosmopolites sordidus* Germar) resistance using reference genotypes. *African Journal of Biotechnology*. **9**: 4725-4730.

Sahayaraj, K. and Kombiah, P. (2010). Insecticidal activities of neem gold on banana corm weevil (BRW), *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae*). Journal of Biopesticides.* **3**: 304 – 308.

Shukla, A. (2010). Insect pests of banana with special reference to weevil borers. *International Journal of Plant Protection.* **3** (2): 387–393.

Ssennyonga, J. W., Bagamba, F., Gold, C. S., Tushemereirwe, W. K., Karamura, E. B. and Katungi. (1998). Understanding current banana production with special reference to integrated pest management in southwestern Uganda. Frison, E. A., Gold, C. S., Karamura, E. B. and Sikora, R. A. (Eds). *In*: Proceedings of a workshop on Mobilizing IPM for sustainable banana production in Africa, held in Nelspruit, South Africa, 23-28 November 1998, 291-310.

Tinzaara, W., Gold, C. S., Dicke, M., Van Huis, A. and Ragama, P. E. (2008). Effect of mulching on banana weevil movement relative to pheromone traps. *African Crop Science Journal*. **16** (1): 59–66.

Treverrow, N. (2003). Banana weevil borer. Agfact H6. AE.1, Centre for Tropical Horticulture Alstonville. Third edition, 1–3.

Tushemereirwe, W. K., Kashaija, I. N., Tinzaara, W., Nankinga, C. and New, S. (2001). Banana Production Manual: A guide to successful banana production in Uganda. First Edition, 27-36.

Uzakah, R. P., Odebiyi, J. A., Chaudhury, M. F. B. and Hassanali, A. (2015). Evidence for the presence of a female produced sex pheromone in the banana weevil, *Cosmopolites sordidus* Germar (Coleoptera : Curculionidae). *Scientific Research and Essays*. **10**(15): 471–481.

Valencia, A., Wang, H., Soto, A., Aristizabal, M., Arboleda, J. W., Eyun, S., Noriega, D. D. and Siegfried, B. (2016). Pyrosequencing the Midgut Transcriptome of the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) reveals multiple protease-like transcripts. *PLoS ONE*. **11**: 1-16.

Wachira, P. M., Kimenju, J. W., Kiarie, J. W., Mwaniki, S. W. and Gathaara, V. N. (2013). Incidence of pests and diseases affecting banana in a commercial banana production setting in Kenya. *International Journal of Research in Agriculture and Food Sciences*. **1** (1): 23–29.

Were, E., Nakato, G. V., Ocimati, W., Ramathani, I., Olal, S. and Beed, F. (2015). The banana weevil, *Cosmopolites sordidus* (Germar), is a potential vector of *Xanthomonas campestris pv*. *musacearum* in bananas. *Canadian Journal of Plant Pathology*, **37**(4): 427–434.

Zake, J. (2015). Climate variability triggers innovations for adaptation and mitigation: A case for smallholder banana farmers in Central Uganda. *In:* Smallholder banana farming systems and climate variability: Understanding the impacts, adaptation and mitigation in Mpigi District, Uganda. Unpublished Doctoral Thesis. University of Natural Resources and Life Sciences, Institute of Soil Research and Centre for Development Research, Vienna, Austria, 1-74.

Zimmerman, E. C. (1968a). *Cosmopolites pruinosus*, a New Pest of Banana. *Journal of Economic Entomology*. **61**(3): 870-871.

Zimmerman, E. C. (1968b). The Cosmopolites banana weevils (Coleoptera: Curculionidae). *Pacific Insects.* **10**(2): 295-299.

## LIST OF APPENDICES

**Appendix 1: Presence of banana weevil in different banana-based farming systems**

Region District ________________ Ward/village ________________

**GPS coordinates:** Date:

**Season:** rain ( ) dry ( )

**Farming type**: banana monocrop ( ) banana-beans ( ) banana-coffee ( ) banana-maize ( )

| **Date Series** | **Trap per weevil adult number** | | | **Total weevil per date** | **Remarks** |
|---|---|---|---|---|---|
| | **1st trap** | **2nd trap** | **3rd trap** | | |
| | | | | | |
| | | | | | |
| **Grand total ( Σ )** | | | | | |
| **Sample mean ($\bar{X}$)** | | | | | |
| **Standard deviation (SD)** | | | | | |

**Remarks:……………………………………………………………………………...……………**
**……………………………………………………………………………………………………**

**Appendix 2: Damage levels of banana weevil in different banana-based farming systems**

Region District Ward/village

GPS coordinates: Date:

**SECTION I: Banana farming system *(tick relevant)***

Banana monocrop ( ) banana-beans ( ) banana-coffee ( ) banana-maize ( )

Age of banana crops: ( ) Farming area ( ) Sample area: ( )

Banana variety

**SECTION II: Weevil damage to banana corm per banana farming system**

**REFERENCE:** Damage scale according to de Oliveira *et al.*, (2017).

0 (no galleries present)

5 (traces of galleries observed)

10 (between 5 and 20 galleries present)

20 (galleries in approximately 25% of the corm)

30 (galleries in approximately 20%-40% of the corm)

40 (galleries in approximately 50% of the corm)

50 (galleries in approximately 75% of the corm)

100 (galleries in the entire corm).

| **Plant number** | **Number of corm infested cells** | **Coefficient of infestation (%)** |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| | | |

**Remarks………………………………………………………………………………………**

**…………………………………………………………………………………………………**

**…………………………………………………………………………………………………**

**Appendix 3: Farmers understanding of banana weevil in different banana-based farming systems**

Region: District: Ward/village:

Questionnaire number: Date:

GPS coordinates:

**SECTION I: Banana farmer personal information**

Name: Gender: ( ) Phone number:

Age in years: ( )

Marital Status: Single ( ) Married ( ) Divorced ( ) Widowed ( )

Educational level: Adult education ( ) Primary ( ) Secondary ( ) College ( ) others ( )

Family head: Male ( ) Female ( )

Occupation: Housewife ( ) Peasant ( ) Government ( ) Private company ( ) others ( )

**SECTION II: Banana production and banana weevil**

1. How many years have you been in banana production activities? ( )
2. What are your banana yield in past three years ago in terms of bunches?
   First year ( ) Second year ( ) Third year ( )
3. What affects your banana yield?
   Diseases ( ) Insects ( ) Nematodes ( ) Climate change ( ) Fusarium ( ) Sigatoka ( ) Others ( )
4. What are the major insect pests that cause great damage to the banana *(Rank in 1, 2, 3...)*
   Banana aphids ( ) Banana white flies ( ) Banana weevils ( ) Banana thrips ( ) Banana spider mites ( ) others ( )
5. Do you know banana weevil? Yes ( ) No ( ) Uncertain ( )
6. **If answer 5 is** yes, how did you know banana weevil?
   Fellow farmers ( ) observation ( ) extension service ( ) Agricultural exhibitions ( ) TV ( ) Radio ( ) Training ( ) others ( )
7. Are weevil populations present throughout the year? Yes ( ) No ( )
8. Which season of the year weevil populations are said to be higher?
   Rainy seasons ( ) dry seasons ( ) others ( )

**SECTION III: Banana weevil infestation**

9. Do scout for insect pests in your banana farms? Yes ( ) No ( )

10. **If Question 9 answer is yes**, how frequently in a week? Once ( ) twice ( ) thrice ( ) all the week ( )

11. How many times you observe weevil infestation in your banana farms during scouting? Occasionally ( ) often ( ) always ( ) all the time ( )

12. At which banana plant stage, weevil damage is frequently observed during scouting? Young ( ) flowering ( ) matured ( ) old ( )

13. Is the weevil infestation a problem to your banana production? Yes ( ) No ( )

14. If **Question 13 answer is yes,** what method(s) do you apply to control weevil infestations? Chemical ( ) Biological ( ) Host plant resistance ( ) Cultural ( )
    Specify:
    ……………………………………………………………………………………………………

15. What are the symptoms of weevil infestation do you know? *(tick appropriate)*
    1. Leaf chlorosis ( ) 2. Snatching ( ) 3. Toppling ( ) 4. Flowering delaying ( )
    5. Weak plants (less vigour) ( ) 6. Others ( )

16. What are the results caused by high weevil infestations to your banana farm? (*Rank 1, 2).* Yield loss ( ) farm rejection ( ) crop failure ( ) NIL ( ) others ( )

**Section IV: Banana farming systems**

17. Which of the banana-based farming systems are you practiced?
    Monocropping ( ) Intercropping ( ) Mixed cropping ( )
    Specify farming activity (ies): …… …………………………………………

18. Does different banana farming systems affects weevil infestation? Yes ( ) No ( )

19. **If Question 18 answer is yes**, then which of the following banana-based farming system reduce weevil infestations to banana crops?
    Banana monocrop ( ) banana-beans ( ) banana-coffee ( ) banana-maize ( )

20. **If Question 18 answer is no**, then which of the following banana-based farming system favor weevil infestations to banana crops?
    Banana monocrop ( ) banana-beans ( ) banana-coffee ( ) banana-maize ( )

## RESEARCH OUTPUTS

# Variation, biology and potential management strategies of banana weevil (*Cosmopolite sordidus* Germar) in Tanzania

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**Key words:** Banana, *Cosmopolites sordidus*, control strategies, entemopathogenic and pheromones.

**ABSTRACT**

Banana weevil (*Cosmopolite sordidus* Germar: Coleoptera) is an important insect pest of the genus *Musa* and has been regarded as a major factor causing about 30% of yield loss and farm abandonment in Tanzania. Despite of the agricultural importance, there is limited understanding of the variation and their causes, biology and management strategies of the banana weevil in the country. Thus, this review describes the causes, biology and identifies potential management strategies so that banana growers can not only increase their understanding on the pest-plant relations but also on possible options for managing banana weevil in Tanzania.

**INTRODUCTION**

Banana weevil (*Cosmopolite sordidus* Germar: Coleoptera) is an important insect pest of the genus *Musa* (abaca, banana, plantain), *Ensette* and manilla hemp ( Kiggundu *et al.,* 2007; Gokool *et al.,* 2010; Dahlquist, 2008; Bortoluzzi *et al.,* 2013; Dassou *et al.,* 2015; Hölscher *et al.,* 2016). It is found throughout tropics, subtropics and almost major banana producing regions around the world (de Graaf, 2006; Dahlquist, 2008). This insect pest has been regarded as a major factor in decline and disappearance of East African Highland Banana (EAHB) in Western Tanzania resulted to replacement of annual crops, brewing or dessert bananas (Rukazambuga *et al.,* 1998; Gold *et al.,* 2006; Mgenzi *et al.,* 2006; Kiggundu *et al.,* 2007; Aby *et al.,* 2015a). Banana farmers in Tanzania have been reported to rank it as first key banana insect pest **(**Nkuba *et al.,* 2015). Also, banana weevil has been attributed to banana yield loss of 30% and farm abandonment at Muleba district, Kagera region of Tanzania (Gold *et al.,* 2002). Other regions in Tanzania reported to be highly infested by banana weevils include Arusha, Kilimanjaro, Mbeya and Morogoro (Bujulu *et al.,* 1983; Gold *et al.,* 2001; Rannestad *et al.,* 2011). Despite of the agricultural importance of banana weevils in the country, there is limited understanding of the biology and management strategies of the banana weevil which is mainly due to challenges related with its distribution systems and high expenses in the banana faming systems in Tanzania (Rannestad *et al.,* 2013). Thus, this review describes the variation and causes, biology and potential management strategies so that banana growers can not only increase their understanding on the pest-plant relations but also on possible options for managing banana weevil in Tanzania.

**CAUSES OF WEEVIL VARIATION IN THE BANANA FARMING SYSTEMS**

There are different factors that influence weevil prevalence such as feeding materials, altitude, rainfall distribution, temperature, banana cultivars and volatiles, soil status and types, banana management practices and farming systems (Uronu and Cumming, 1983; Njau *et al.,* 2011; Rannestad *et al.,* 2011; Mwaitulo *et al.,* 2011; Were *et al.,* 2015).

Presence of banana residues or debris, tissues, fresh and decomposing materials normally serve as food sources and oviposition sites for banana weevils (de Graaf *et al.,* 2008; Mwaitulo *et al.,* 2011; Were *et al.,* 2015). They also provide shelters which harbor them (Nwosu, 2011). Mwaitulo *et al*. (2011) and Tinzaara *et al*. (2015) reported that fresh and decomposing banana residues produce kairomones which attracts weevil adults and aggregates them.

Banana weevils are very sensitive to dry environments while adequate moisture conditions encourages their activity and population growth (Gold *et al.,* 2006; Gokool *et al.,* 2010). Although their population present throughout the year but they prevail much during rainy seasons (Njau *et al.,* 2011). In Tanzania, high banana weevil population reported to be observed during rainy season in Kagera region (Uronu and Cumming, 1983).

Development and growth of weevil life cycle of banana weevil is related to temperature (Gold and Messiaen, 2000). Temperature reported to influence weevil activity (Gokool *et al.,* 2010). At a temperature below 12°C, weevil eggs fail to develop, and in combination with altitudes of above 1600 m.a.s.l, their prevalence is insignificant. Njau *et al*. (2011) explained that a high temperature range of 25-30°C favour growth of the weevil population.

Research studies showed that prevalence of banana weevils has inverse relationship with altitude. At high altitude, their population is unimportant and vice versa (Njau *et al.,* 2011; Wachira *et al.,* 2013). In East Africa, banana weevils are not in high numbers at an attitude beyond 1500 meter above sea level (Njau *et al.,* 2011). Higher weevil damage were observed on local matooke banana types produced in regions with altitudes range of 1000-1200 m.a.s.l than to exotic cultivars produced in regions with altitudes beyond 1500 m.a.s.l damage (Tushemereirwe *et al.,* 2001).

Some banana systems reported to influence weevil population while others not (Wortmann and Sengooba, 1993; McIntyre *et al.,* 2001; Zake, 2015; Rukazambuga *et al.,* 2002; de Oliveira *et al.,* 2017).

McIntyre *et al*. (2001) reported that weevil population to banana plants were not affected by the three leguminous crops *Canavalia ensiformis, Mucuna pruriens and Tephrosia vogelii* when intercropped with banana in Uganda. In Tanzania, the banana-bean farming system did not reduce the weevil population in banana (Gold *et al*., 1998). Ouma (2009) reviewed that weevil damage and infestations in banana plantation monocultures is more or less similar as in the banana-beans system.

Banana, coffee and hot pepper (*Capsicum sp.)* farming systems reported to have suppress weevil population in Mpigi district of central Uganda (Zake, 2015). Also, Ouma (2009) reviewed that banana-millet farming suppressed the weevil population. A study by Rukazambuga *et al*. (2002)

in Uganda reported that banana-finger millet (*Eleusine corocana*) system diminished the weevil population but contributed to banana stress and stunting due to water and nutrient competition.

In Tanzania, trials on effects of banana-sweet potatoes on banana weevil population produced mixed results. In these studies, weevil population was reduced but caused banana stunting due to intercropping competition (Gold *et al.,* 2001). Generally, some banana farming systems were reported to produce mixed effects on both weevil population and banana plants, but there is lack of information which counteract these negative effects. Hence, more studies are needed to establish on how to eliminate the negative effects which affects banana plant physiology.

**BIOLOGY OF BANANA WEEVIL**

Banana weevil is characterized by a K-selected life cycle, low fecundity and slow population growth (Night *et al.,* 2010; Shukla, 2010; Rannestad *et al.,* 2011; Rannestad *et al.,* 2013). Adult female has low oviposition rate of 1-4 eggs per week. It lays egg singly in the cavity mined on the base of the banana plant, corms, crop residues, interleaf sheaths and stems ( Night *et al.,* 2010; Dassou *et al.,* 2015; Uzakah *et al.,* 2015). Upon hatching, larvae penetrate into banana corms, pseudostems and true stems (de Graaf, 2006; Kiggundu *et al.,* 200**7**; Rannestad *et al.,* 2013). The larvae is the main destructive stage which results multiple galleries within banana corms during feeding (Akello *et al.,* 2008; Ocan *et al.,* 2008; Dassou *et al.,* 2015; Hölscher *et al.,* 2016; Maldonado *et al.,* 2016). The banana weevil adults are nocturnally active, sedentary, free living and measure 10-15 mm with fully second wings but rare or never observed to fly (Gold *et al.,* 2006; Dahlquist, 2008; Shukla, 2010; Rannestad *et al.,* 2011). Male secret six-specific detected compounds of aggregation pheromone, which is attractive to both sexes, with sordinin as a main component while female secret sex pheromone (Reddy *et al.,* 2008; Reddy *et al.,* 2009; Uzakah *et al.,* 2015). They are closely related and attracted to the host plants by volatiles, kairomones produced from fresh and decomposing banana materials (Rannestad *et al.,* 2011; Tinzaara *et al.,* 2015). The adult stage is the least destructive stage compared with larval stage, having long life span of up to 6 months, two to four years and feeds on banana debris, rotting banana tissues and sometimes on young suckers (Night *et al.,* 2010; Shukla, 2010; Mwaitulo *et al.,* 2011;Rannestad *et al.,* 2011; Were *et al.,* 2015). Under dry substrates, weevils die within 3-10 days while under soil moisture conditions without food, their survival period is ambiguously reported to be 2-6 and 4-17 months (Gold *et al.,* 2001; de Graaf, 2006). The restricted amount of host plant tissues trigger migration of the most weevils possibly searching for oviposition sites and food sources (Umeh *et al.,* 2010; Rannestad *et al.,* 2011; Rannestad *et al.,* 2013). The weevil growth stages such as eggs, larvae and pupae take place within banana plants and crop debris and usually complete its life cycle in a period of 5-7 weeks under tropical conditions (Gold *et al.,* 2006; Kiggundu *et al.,* 2007; Night *et al.,* 2010; Shukla, 2010; Mwaitulo *et al.,* 2011; Rannestad *et al.,* 2013; Hasyim and Hilman, 2015; Uzakah *et al.,* 2015). Banana farmers reported to have limited knowledge on weevil biology with variations in their understanding. Some farmers don't recognize it, some fail to correlate weevil life cycle stages and other believe that larvae is destructive than adult and other belive vice versa (Ssennyonga *et al.,* 1998; Okech *et al.,* 2006). This raise concerns in terms of their management to banana farming systems. To fullfill this, Tanzania extension services required to disseminate avalaible information to banana farmers to creates awareness in terms of its identification, population action threshold (5 adult weevils/trap, de Oliveira *et al.,* (2017), symptoms, damage and management startegies. This can be achieved through diffferent approaches like seminar and demostration studies to creates awareness regarding to the pest.

**SPECIES OF BANANA WEEVIL**

There exist two known species of banana weevils namely; *Cosmopolites sordidus* Germar 1824 and *Cosmopolites pruinosus* Heller (Zimmerman, 1968a; de Graaf, 2006). *C. sordidus* Germar 1824 has numerous synonyms such as banana beetle, banana corm borer, banana root borer, banana weevil, black banana borer, corm weevil, plantain black weevil and many common names. The name **"**banana root borer**"** raise confusion due to neither the larvae nor the adults attacks banana roots (de Graaf, 2006). *C. pruinosus* Heller is an important pest and has been considered to be a banana secondary pest in some countries such in Borneo, the Caroline Islands, Micronesia and Philippines (Zimmerman, 1968a; Zimmerman, 1968b). These two banana weevils have a very similar morphology with their distinctive features founded in the nature of pruinosity on the dorsum and the elytral striae (Zimmerman 1968; de Graaf, 2006). Although banana weevil *C. sordidus* reported to be an insect pest attacking banana in some regions of Tanzania, but still there is limited information on its prevalence and distribution across different banana farming systems in Tanzania. More studies are recommended to gain knowledge on the status of this destructive insect pest in different banana farming systems of Tanzania.

## SYMPTOMS AND THEIR EFFECTS ON BANANA PLANTS

The banana weevil is monophagous with its host range restricted to genera *Musa* and *Ensette* (Gold *et al.,* 2006; Mwaitulo *et al.,* 2011). It attacks all banana plant varieties and at all growth stages (Gold *et al.,* 2006; Reddy *et al.,* 2008; Reddy *et al.*, 2009**).** Its corm damage interferes with root initiation and development, water and nutrient uptake (Akello *et al.*, 2008; Night *et al.*, 2010; Maldonado *et al.,* 2016). The infested plants exhibit symptoms of leaf chlorosis, reduced sucker vigour and number, weak plants, low fruit bunch weight, premature plant death, stunted growth and delayed flowering and fruit maturation (Hasyim *et al.,* 2009; Njau *et al.,* 2011; Rannestad *et al.,* 2013). Serious weevil damage causes toppling and snapping of the pseudostems at the base, particularly during windstorms and plant death (Night *et al.,* 2010; Sadik *et al.,* 2010; Rannestad *et al.,* 2013). Banana weevil is associated with yield losses of up to 100% in severely infested fields and can cause total crop failure (Reddy *et al.,* 2009; Sahayaraj and Kombiah, 2010; Omukoko *et al.,* 2014; Aby *et al.,* 2015a; Tinzaara *et al.,* 2015; Carval *et al.,* 2016; Maldonado *et al.,* 2016). Regarding to the weevil symptoms to be familiar, de Graaf (2006) reviewed that these symptoms are said to be similar with banana root nematodes symptoms**.** In view of the above, research efforts aiming at distinguish weevil symptoms from nematodes symptoms should be undertaken.

## CURRENT MANAGEMENT STRATEGIES.

Banana weevils can be managed through different strategies such as biological, chemical, cultural, botanical and host resistance (Sahayaraj and Kombiah, 2010; Nwosu, 2011; Tinzaara *et al.*, 2015; Maldonado *et al.*, 2016).

## BIOLOGICAL CONTROL

Biological techniques include classical biological control, endemic natural enemies, secondary host association and microbes (Shukla, 2010; Mwaitulo *et al.*, 2011; Fancelli *et al*, 2013; Hasyim and Hilman, 2015). Beneficial insects of myrmicine ants *Tetramorium guineense* Nylander and *Pheidole megacephala* Fabricius have been reported to be effective in banana weevil in in some countries such as Cuba (Hasyim and Hilman, 2015). Laboratory evaluation carried out by Hasyim and Hilman, (2015) showed promising control potential of two predators staphylinid *Belonochus ferrugatus* (Erichson) and histerid *Plaesius javanus*. The Jepson's beetle, *P. javanus* larvae and adults seemed to cause high mortality rate to weevil eggs and pupae (Hasyim, 2009; Hasyim and Hilman, 2015). Other succesiful control strategies has been achieved by using entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* and Entomopathogenic nematodes (Shukla, 2010; Fancelli *et al*, 2013; Omukoko *et al.*, 2014; Hasyim and Hilman, 2015). In Tanzania, study by Mwaitulo *et al*. (2011) showed that weevil control by using Entomopathogenic nematodes (EPNs) in the genera *Heterorhabditis* and *Steinernema* (Rhabditida) provided promising banana weevil control measure. The approach seemed to be good for sustainable production system and can contribute for agricultural sustainability compared with the chemical control. This approach is believed to be cost-effective to small-scale farmers in terms of purchasing and maintaining them in the field (Fancelli *et al*, 2013; Tinzaara *et al.*, 2015). However, limited reports are available on wide application under field conditions and evaluation of entomopathogens (biological agent) in the tropical farming system (Sadik *et al.*, 2010; Omukoko *et al.*, 2014). Research studies need to be conducted on myrmicine ants especially *Pheidole megacephala* Fabricius and Entomopathogenic nematodes of genera *Heterorhabditis* and *Steinernema* reported to be available in East Africa (Rhabditida) in banana farming systems (Bonhof *et al.*, 1997; Mwaitulo *et al.*, 2011). These should center on their field performance and distribution systems to the small scale banana farmers forming large proportion of banana industry in East Africa.

## CHEMICAL CONTROL

Chemical controls include application of insect pesticides such as aldicarb, carbofuran, chlorpyrifos, cyclodiene, dusband, furadan, organophosphates and pirimiphos-ethyl (Aba *et al.*, 2011; Marilene *et al.*, 2013; Bwogi *et al.*, 2014; Carval *et al.*, 2016). Use of these chemicals can results in high mortality of the banana weevil population and perceived by banana farmers as fast acting, manageable and effective (Aby, 2015; Tinzaara *et al.*, 2015). However in Tanzania, chemical application in banana weevil control is challenged by complex un-described banana distribution patterns in different farming systems and high cost (Bujulu *et al.*, 1983; Rannestad *et al.*, 2013). Use of chemicals such as dieldrin, endosulphan and fenitrothion against banana weevil infestation in Tanzania has been reported with little success (Bujulu *et al.*, 1983). However, Chemical control is reported to provide short-time solution to the banana weevil problems while its long-time application resulted to development of banana weevil resistance (Gokool *et al.*, 2010; Bortoluzzi *et al.*, 2013; Bwogi *et al.*, 2014; Aby *et al.*, 2015a). Moreover, chemicals are less available, more toxic in terms of human health hazards and environments unfriendly due to destroying non-targeted beneficial natural insects (Sadik *et al.*, 2010; Bwogi *et al.*, 2014; Aby, 2015b; Tinzaara *et al.*, 2015). Sole chemical approach is basically effective due to result high death rate but it has limited information on application combination with other strategies. To reduce chemical applications but maintain their effectiveness, research studies should focus on integration of chemicals and non-chemical strategies to control banana weevils in the country.

## CULTURAL CONTROL

Cultural controls involves cleaning planting material, practicing crop sanitation, corm paring, intercropping systems, mulching and pseudostem trapping (Okech *et al.*, 2006; Akello *et al.*, 2008; Dahlquist, 2008; Sahayaraj and Kombiah, 2010; Mwaitulo *et al.*, 2011; Aby *et al.*, 2015a ; Carval *et al*,. 2016). Some banana farmers in Tanzania have been reported to apply these cultural control strategies (Mgenzi *et al.*, 2006). Commonly practiced cultural method include cleaning planting materials involves corm paring and dipping it in hot water of 52-55°C for 15-27 minutes to kill the present eggs and larvae (Gold and Messiaen, 2000; Shukla, 2010). Tenkouano *et al*,

(2006) pointed that sucker sanitation can be achieved through treatment with either hot water at 52°C in 20 minutes or boiling water of 100°C in short time of 30 seconds.

Cultural technique also involves use of good non-infested banana planting materials (tissue culture) in cleaned farms. Materials replanting in the previously infested fields with old corms is strictly not recommended unless destroyed. Rather than using weevil-free planting materials, Tanzanian small-scale farmers are often reported to use the suckers from their neighbor fields which in turn seemed to increase weevil problem (Mwaitulo *et al.,* 2011). Practicing crop sanitation measures involving destroying of infested old corms, pseudostems and crop residues materials after harvesting aiming to remove oviposition sites have also been used (Shukla, 2010; Jallow *et al.,* 2016). It has been accompanied with allowing three months for the weevil population to die out. For instance, the study by Okech *et al*. (2006) reported that high crop sanitation reduced weevil and their damage compared with banana farms of low to moderate crop sanitation. It also contributed to production of larger bunch weights with >20 kg compared to about 12 kg. Although crop sanitation has been reported to be beneficial in different regions, banana farmers in Tanzania reported to practice it less (Mgenzi *et al.,* 2006).

Another important technique that has proved to be effective includes trapping of adults using systematic traps of pseudostem, corm disc (disc on stump/Columbian trap), pheromone (sordinin or cosmolure), cheese, modified roof tile, wedge and inoculated trap (Rannestad *et al.,* 2013; Aby *et al.,* 2015a; Jallow *et al.,* 2016; Queiroz *et al.,* 2017). Pseudostem traps can be treated with chemical like Confidor (imidachloprid), Baythroid (cyfluthrin) and Karate (lambda-cyhalothrin) (Gokool *et al.,* 2010). They are good for monitoring weevil population and can be applied to two weeks before replacing with new ones (Jallow *et al.,* 2016). Pheromone traps have been reported to be far better 5-10 and up to 18 times compared with pseudostem traps in Costa Rica and Uganda respectively (Gokool *et al.,* 2010). Its trapping performance has been reported to be higher during dry reasons than in rain seasons (Jallow *et al.,* 2016).

One other important cultural practice involves the use of mulching techniques. A study by Gold *et al*. (2006b) reported that application of banana mulches as one of crop management practice favor weevil population build-up as they provide organic matters and preserving soil moisture.

However, this approach has been reported to be unable to manage banana weevil (Mgenzi *et al.,* 2006; Akello *et al.,* 2008; Sadik *et al.,* 2010; Tinzaara *et al.,* 2015). Cultural control strategies seems to correspond friendly with environmental and human health, but in country, there is limited information especially modified cultural strategies such as inoculated and pheromone (sordinin or cosmolure) traps. Therefore, intensive application of these strategies need to be exploited by farmers and hence extension service agents required to extend outreach programs to them to address the problem.

## BOTANICAL CONTROL TECHNIQUES

Several plants such as *Azadrachta indica, Tephrosia vogelii*, *Tagetes erecta*, *Phyotolaca dodecandra, Ricinus communis* and *Nicotiana tabacum* have been tested for controlling banan weevil (Sahayaraj and Kombiah, 2010; Shukla, 2010; Bwogi *et al.,* 2014). Neem seed powder (rich in azadrachtin) has been reported to have insecticidal effects and thus to have ability to decrease weevil infestation (Sahayaraj and Kombiah, 2010). A study in Tanzania by Mgenzi *et al*. (2006) pointed out that neem seed powder produced promising results on weevil control. Dipping of young suckers in 20% neem seed solution during planting helped to repel weevil adults and thus reduced oviposition and their attacks (Shukla, 2010). Umeh *et al*. (2010) pointed that neem mulch leaf have insecticidal effects which managed to suppress banana weevil population in plantain and banana in Nigeria. Similarly a study by Bwogi *et al*. (2014) in Masaka and Mpigi districts of Uganda pointed that mixture of extracts from *Tephrosia*, tobacco and *Phytolaca* together with animal urine and ash produced similar positive management effects on banana weevil population in levels similar with synthetic chemicals of Carbofuran and Dusband. Botanical pesticidal plants may provide instant accessible pesticides to the farmer's and hence their promotion should be encouraged.

## HOST PLANT RESISTANCE

This technique involves using resistant cultivars with detrimental effects on weevil physiology. Its mechanisms include antibiosis, antixenosis (non-preference), corm hardness, host plant tolerance, plant antifeeds, extending larval mortality as well as extending larval development and growth (Kiggundu *et al.,* 2007; Night *et al.,* 2010; Arinaitwe *et al.,* 2015; Valencia *et al.,* 2016).

Antibiosis is concerned with plant defense by affecting larval performance negatively by secreting sap and latex, corm hardness, antifeedants, toxic secondary plant substances and nutritional deficiencies and hence result weevil death (Kiggundu *et al.,* 2007). Antixenosis contributes resistant cultivars to deter weevil attacks through non-preference of larval and adult feeding as well as female oviposition. However, antibiosis has been reported to be important to weevil resistance mechanism rather than antixenosis due to cultivar non-discrimination behavior of the female oviposition (Sadik *et al.,* 2010; Night *et al.,* 2010)**.** Nevertheless in Tanzania, the East African Highland banana (the commonest cultivars) have been reported to be highly susceptible to weevil attacks (Night *et al.,* 2010; Sadik *et al.,* 2010; Shukla, 2010). Antibiosis seemed to provide plant self-protection against banana weevil but has less information. More research studies required to be conducted on banana plant secretions mainly toxic secondary plant substances.

## CONCLUSIONS AND RESEARCH GAPS

This review has highlighted the biology of weevils, causes of weevil variation in the banana farming systems and a number of banana weevil management strategies such as biological, chemical, cultural, botanical and host resistance. Of the methods, this review article recommends a combination of all except synthetic chemicals. More sustainably biological and host plant resistance can be the best options, however studies are needed to explore how these options can be developed.

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## REFERENCES

**Aba SC, Baiyeri PK, Tenkouano A.** (2011). Impact of poultry manure on growth behaviour, black Sigatoka disease response and yield attributes of two plantains (Musa spp. AAB) genotypes. Tropicultura **29**, 20-27.

**Aby N, Badou J, Traoré S, Kobénan K, Kéhé M, Thiémélé DEF, Gnonhouri G, Koné D.** 2015a. Inoculated Traps an Innovative and Sustainable Method to Control Banana Weevil *Cosmopolites sordidus* in Banana and Plantain Fields. Advances in Crop Science and Technology **3,** 1-5.

**Aby N, Séka CL, Traoré S, Kobénan K, Kouakou TH.** 2015b. Effects of some fungicides and nematicides used in banana plantation on pathological characteristics of *Metarhizium* sp., biological agent control of banana weevil *Cosmopolites sordidus* Gemar (Coleoptera: Curculionidae). International Journal of Current Microbiology Application Science **4**, 1050-1065.

**Akello J, Dubois T, Coyne D, Kyamanywa S.** 2008. Effect of endophytic *Beauveria bassiana* on populations of the banana weevil, *Cosmopolites sordidus*, and their damage in tissue-cultured banana plants. Entomologia Experimentalis et Applicata **129**, 157–165.

**Arinaitwe IK, Barekye Al, Kubiriba J, Sadik K, Karamura E, Edema R.** 2015. Genetic analysis of weevil (*Cosmopolites sordidus*) resistance in an F2 Diploid banana population. Journal of Plant Breeding and Genetics **3**, 77-91.

**Bonhof MJ, Overholt WA, Van Huis A, Polaszek A.** 1997. Natural enemies of cereal stem borers in East Africa: A Review. Insect Science Application Journal **17,** 19-35.

**Bortoluzzi L, Alves LFA, Alves VS, Holz N.** 2013. Entomopathogenic nematodes and their interaction with chemical insecticide aiming at the control of banana weevil borer, *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae). **Arquivos do Instituto Biológico, 80**, 183-192.

**Bujulu J, Uronu B, Cumming CNC, 1983.** The control of banana weevils and parasitic nematodes in Tanzania. East African Agricultural and Forestry Journal **49,** 1-13.

**Carval D, Resmond R, Achard R, Tixier P.** 2016. Cover cropping reduces the abundance of the banana weevil *Cosmopolites sordidus* but does not reduce its damage to the banana plants. Biological Control **99,** 14–18.

**Dahlquist, Ruth** 2008. Biology and management of the banana Weevil (*Cosmopolites sordidus* Germar) in the socioeconomic and agroecological context of the indigenous territories of Talamanca, Costa Rica. PhD Dissertation, University of Idaho, United State, 1-7.

**Dassou AB, Carval D, Dépigny S, Fansi G, Tixier P.** 2015. Ant abundance and Cosmopolites sordidus damage in plantain fields as affected by intercropping. Biological Control **81,** 51–57.

**de Graaf, Johan. 2006.** Integrated pest management of the banana weevil, *Cosmopolites sordidus* (Germar), in South Africa. PhD Thesis, University of Van Pretoria, South Africa, 1-37.

**de Graaf J, Govender P, Schoeman AS, Viljoen A.** 2008**.** Efficacy of cultural control measures against the banana weevil, *Cosmopolites sordidus* (Germar), in South Africa. Journal of Applied Entomology **132,** 36–44.

**de Oliveira FT, Neves PMOJ, Bortolotto OC.** 2017. Infestation of the banana root borer among different banana plant genotypes. Crop Protection **47,** 1-5.

**Gold CS, Messiaen S.** 2000. The banana weevil *Cosmopolites sordidus*. *Musa* Pest INIBAP, Montpellier. Fact Sheet No. **4,** 1-4.

**Gold, C.S., S.H. Okech, S. Nokoe. 2002**. Evaluation of pseudostem trapping as a control measure against banana weevil, Cosmopolites sordidus (Coleoptera: Curculionidae) in Uganda. Bulletin of Entomological Research **92,** 35-44.

**Gold CS, Pena JE, Karamura EB.** 2001. Biology and integrated pest management for the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). Integrated Pest Management Reviews **6,** 79–155.

**Gold CS, Okech SH, Nankinga CM, Tushemereirwe WK, Ragama PE.** 2006a. The biology and pest status of the banana weevil in the East Africa Great Lakes Region: A review of research at IITA and NARO. In: Blomme, G, Gold C, Karamura, E, Eds. Proceedings of the workshop on Farmer-participatory testing of IPM options for sustainable banana production in East Africa, held in Seeta, Uganda, 8-9 December 2003. INIBAP: Kampala (UGA), 129-140.

**Gold CS, Okech H, McIntyre BD, Kagezi G, Ragama PE, Night G. 2006b.** Effects of mulch on banana weevil *Cosmopolites sordidus* (Germar) population and damage in Uganda. Crop Protection **25,** 1153–1160.

**Gokool A, Abeeluck D, Dooblad V, Facknath S. 2010**. Investigation on the use of trapping in the management of the banana weevil, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) in Mauritius. University of Mauritius Research Journal **16,** 332-344.

**Hasyim, Ahsol Yusdar Hilman, Sofiari Eri. 2015.** Classical biological control of banana weevil borer, *Cosmopolites sordidus* (Coleoptera; Curculionidae) with natural enemies from Indonesia (With emphasis on west Sumatera), 1-16.

**Hasyim Ahsol, Azwana, Syafril.** 2009. Evaluation of natural enemies in controlling of the banana weevil borer Cosmopolites sordidus Germar in West Sumatra. Indonesia Journal of Agricultural Science **10**, 43-53.

**Hölscher D, Buerkert A, Schneider B.** 2016. Phenylphenalenones accumulate in plant tissues of two banana cultivars in response to herbivory by the banana weevil and banana stem weevil. Journal of Plants **5,** 1-6.

**Jallow M, Akotsen-Mensah C, Achiri D. T, Afreh-Nuamah K.** 2016. Performance of three trap types for monitoring plantain weevil (*Cosmopolites sordidus*, Germar) in plantain cropping systems in Ghana. Journal of Agriculture and Veterinary Science **9,** 17-23.

**Kiggundu A, Gold CS, Labuschagne MT, Vuylsteke D, Louw S. 2007.** Components of resistance to banana weevil (*Cosmopolites sordidus*) in *Musa* germplasm in Uganda. Entomologia Experimentalis et Applicata **122,** 27–35.

**Maldonado WJ, Barbosa CJ, Pavarini R, Maruyama WI, Oliveira RA. 2016.** Spatial Distribution and Sequential Sampling of the Banana Root Borer. Agronomy Journal **108,** 1030-1040.

**McIntyre BD, Gold CS, Kashaija IN, Ssali H, Night G, Bwamiki DP.** 2001. Effects of legume intercrops on soil-borne pests, biomass, nutrients and soil water in banana. Biology and Fertility of Soils **34**, 342–348.

**Mgenzi SRB, Mkulila SI, Blomme G, Gold CS, Ragama P, Karamura EB, Nkuba , JM.** 2006. The effect of pest management practices on banana pests in the Kagera region of Tanzania. In: Blomme G, Gold CS, Karamura E, Eds - Proceedings of the workshop on Farmer-participatory testing of IPM options for sustainable banana production in Eastern Africa, held in Seeta, Uganda, 8-9 December 2003. INIBAP: Kampala (UGA), 2006, 43-52.

**Mwaitulo S, Haukeland S, Sæthre MG, Laudisoit A, Maerere AP.** 2011. First report of entomopathogenic nematodes from Tanzania and their virulence against larvae and adults of the banana weevil *Cosmopolites sordidus* (Coleoptera: Curculionidae). International Journal of Tropical Insect Science **31,** 154–161.

**Njau N, Mwangi M, Gathu R, Mbaka J, Muasya R.** 2011. Banana weevil *(Cosmopolites sordidus*) reduces availability of corms for seedling production through macropropagation technology. Journal of Animal and Plant Science **12,** 1537- 1542.

**Night G, Gold CS, Power AG. 2010.** Survivorship and development rates of banana weevils reared on excised plant material of different banana cultivars. International Journal of Tropical Insect Science **30,** 77–83.

**Nkuba J, Tinzaara W, Night G, Niko N, Jogo W, Ndyetabula I, Mukandala L, Privat N, Niyongere C, Gaidashova S, Ivan R, Opio F, Karamura E. 2015.** Adverse impact of Banana Xanthomonas Wilt on farmers' livelihoods in Eastern and Central Africa. African Journal of Plant Science **9**, 279-286.

**Nwosu LC,** 2011. Impact of cultural practice on the control of Cosmopolites sordidus in banana and plantain communities in Ore, Odigbo, Local Government area, Ondo, State, Nigeria. Ethiopian Journal of Environmental Studies and Management **4,** 33-37.

**Okech SH, Gold CS, Bagamba F, Masanza M, Tushemereirwe WK, Ssennyonga J.** 2006. Cultural control of banana weevils in Ntungamo, southwestern Uganda. In: Blomme, G, Gold C, Karamura, E, Eds. Proceedings of the workshop on Farmer-participatory testing of IPM options for sustainable banana production in Eastern Africa, held in Seeta, Uganda, 8-9 December 2003. INIBAP: Kampala (UGA), 2006.

**Ocan D, Mukasa HH, Rubaihayo PR, Tinzaara W, Blomme G.** 2008. Effects of banana weevil damage on plant growth and yield of East African *Musa* genotypes. Journal of Applied Biosciences **9,** 407 - 415.

**Omukoko CA, Wesonga JM, Maniania KN, Kahangi EM, Wamocho LS**. 2014. Screening of *Beauveria bassiana* isolates to the banana weevil and horizontal transmission under laboratory conditions. Jomo Kenyatta University of Agriculture and Technology **16,** 1-12.

**Queiroz JS, Fancelli M, Filho MAC, da Silva Ledo CA, Sánches CG.** 2017. New type of trap for monitoring banana weevil Population. African Journal of Agricultural Research **12,** 764-770.

**Rannestad, Ole Tobias, Sæthre M, Maerere, AP.** 2011. Migration potential of the banana weevil *Cosmopolites sordidus.* Agricultural and Forest Entomology **13,** 405–412.

**Rannestad OT, Maerere AP, Torp T, Sæthre M.** 2013. A farmer participatory research approach to assess the effectiveness of field sanitation and regular trapping on banana weevil populations. Fruits **68,** 83–93.

**Reddy GVP, Cruz TZ, Naz F, Muniappan R.** 2008. A pheromone-based trapping system for monitoring the population of *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). Journal of Plant Protection Research **48,** 515-527.

**Reddy GVP, Cruz ZT, Guerrero A.** 2009. Development of an efficient pheromone-based trapping method for the banana root borer *Cosmopolites sordidus*. Journal of Chemical Ecology **35,** 111–117.

**Rukazambuga NDTM, Gold CS, Gowen SR.** 1998. Yield loss in East African highland banana *(Muss* spp., AAA-EA group) caused by the banana weevil, *Cosmopolites sordidus* Germar. Crop Protection **17,** 581-589

**Rukazambuga NDTM, Gold CS, Gowen SR, Ragama P.** 2002. The influence of crop management on banana weevil, *Cosmopolites sordidus* (Coleoptera: Curculionidae) populations and yield of highland cooking banana (cv. Atwalira) in Uganda. Bulletin of Entomological Research **92,** 413–421

**Sadik K, Nyine M, Pillay M.** 2010. A Screening method for banana weevil (*Cosmopolite sordidus* Germar) resistance using reference genotypes. African Journal of Biotechnology **9,** 4725-4730.

**Sahayaraj K, Kombiah P.** 2010. Insecticidal activities of neem gold on banana corm weevil (BRW), *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae). Journal of Biopesticides **3,** 304 – 308.

**Shukla A.** 2010. Insect pests of banana with special reference to weevil borers. International Journal of Plant Protection **3**, 387-393.

**Tenkouano A, Hauser S, Coyne D, Coulibaly O. 2006.** Clean planting materials and management practices for sustained production of banana and plantain in Africa. International Society for Horticultural Science. Chronica Horticulturae **43,** 14-18.

**Tinzaara W, Emudong P, Nankinga C, Tushemereirwe WKG, Gold CS, Dicke M, Van Huis A, Karamura E.** 2015. Enhancing dissemination of *Beauveria bassiana* with host plant base incision trap for the management of the banana weevil *Cosmopolites sordidus*. African Journal of Agricultural Research **10,** 3878-3884.

**Tushemereirwe WK, Kashaija IN, Tinzaara W, Nankinga C, New S**. 2001. Banana Production Manual: A guide to successful banana production in Uganda. First Edition, 27-36.

**Umeh VC, Onukwu D, Adebowale EM, Thomas J. 2010.** Control options for banana weevil (*Cosmopolites sordidus*) and termites (*Microtermes* spp.) on banana and plantain (*Musa* spp.) in Nigeria. In: Proceedings on International Conference on Banana and Plantain in Africa. Eds.: T. Dubois *et al*. International Society for Horticultural Science, Acta HortIculturae 879, 361-366.

**Uzakah RP, Odebiyi JA, Chaudhury MFB, Hassanali A.** 2015. Evidence for the presence of a female produced sex pheromone in the banana weevil *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae). Scientific Research and Essays **10,** 471-481.

**Valencia A, Wang H, Soto A, Aristizabal M, Arboleda JW, Eyun Seong-li, Noriega DD, Siegfried B.** 2016. Pyrosequencing the Midgut Transcriptome of the banana weevil *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae) reveals multiple protease-like transcripts. PLoS ONE **11,** 1-16.

**Were E, Nakato GV, Ocimati W, Ramathani I, Olal S, Beed F.** 2015. The banana weevil, *Cosmopolites sordidus* (Germar) is a potential vector of *Xanthomonas campestris pv. musacearum* in bananas. Canadian Journal of Plant Pathology **37**, 1-8

**Wortmann, C.S, Sengooba T,** 1993. The banana-bean intercropping system - bean genotype × cropping system interactions. Field Crops Research **31,** 19-25.

**Zake, Joshua**. 2015. Climate Variability triggers Innovations for Adaptation and Mitigation: A case for Smallholder Banana Farmers in Central Uganda. *In:* Smallholder Banana Farming Systems and Climate Variability: Understanding the Impacts, Adaptation and Mitigation in Mpigi District, Uganda. PhD Thesis. University of Natural Resources and Life Sciences, Institute of Soil Research and Centre for Development Research, Vienna, Austria, 1-74.

**Zimmerman, EC. 1968a.** *Cosmopolites pruinosus*, a New Pest of Banana. Journal of Economic Entomology **6,** 870-871.

**Zimmerman, EC. 1968b.** The Cosmopolites banana weevils (Coleoptera: Curculionidae). Pacific Insects **10,** 295-299.