

**EVALUATION OF CORM, PSEUDOSTEM AND PHEROMONE TRAPS
FOR THE MONITORING OF *COSMOPOLITES SORDIDUS*, GERMAR
(COLEOPTERA: CURCULIONIDAE) IN KADE, GHANA.**

BY

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DECLARATION

This is to certify that this thesis is the result of research undertaken by me, Mamudou Jallow, at the Forest and Horticultural Crops Research Center (FOHCREC) towards the award of Master of Philosophy in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS), University of Ghana, Legon. This thesis has not been submitted either in part or in whole for any other degree and all references to other peoples work has been duly acknowledged.



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ABSTRACT

Cosmopolites sordidus is a major pest of plantain in most plantain growing regions in the world and causing 34.8% yield loss in Ghana. Infochemicals (pheromones and kairomones) can be a potential monitoring tool for plantain weevil borer *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae). The adult weevil produces an aggregation pheromone which attracts both males and females and the attractive compound Sordidin has been identified and synthesised for commercial purpose. The objective of this research was to evaluate the effectiveness of the pheromone for monitoring the plantain weevil under Ghanaian conditions and to find suitable plantain cultivars that can serve as trap crops for the *C. sordidus*. Trap effectiveness was conducted in the field in three seasons (major rainy season, minor rainy season and dry season) from June 2012 to February 2013 and traps were examined twice a week and adults sexed into males and females. In all the seasons, pheromone traps attracted a total of 739 (68.36%) adults, corm traps attracted 196 (18.13%) adults, pseudostem traps attracted 146 (13.51%) adults and the pitfall (control) traps recorded no weevil (0%). More female than male *C. sordidus* were captured in all three trials in a ratio of 2:1. In this study pheromone traps attracted the highest number of females followed by corm traps and pseudostem traps and differences between them were statistically significant at $P=0.05$. *C. sordidus* abundance was negatively related to rainfall ($R^2= 0.69$) and temperature ($R^2= 0.58$), the number of *C. sordidus* trapped was highest during the driest months of the study (August, December and February). In the evaluation of trap sizes, the study showed that the 4L pitfall traps were the most effective trap sizes for pheromone trapping of the *C. sordidus*. The 4L pitfall traps significantly captured the highest percentage of weevils (50.3%), followed by the 8L pitfall traps (29.2%) and 12L pitfall traps (20.5%), indicating that trap performance can be maximized with the use of 4L pitfall traps. The varietal preference test

using *Brodewuio*, *Apantu pa* and *Apem* to *C. sordidus* in a choice assay showed that *Brodewuio* (37.2%) and *Apantu pa* (36.5%) attracted significantly more weevils compared with *Apem* which attracted (26.35%) weevils and Yam (control) attracted no weevils. Based on this result, *Brodewuio* was considered the most preferred cultivar than *Apantu pa* and *Apem*. Pheromone lures of the plantain weevil could offer an effective means of monitoring and managing the population of the plantain weevil in Ghana because it was 4 and 5 times more effective than corm and pseudostem traps respectively.



DEDICATION

This work is dedicated to Almighty Allah, my parents Alh. Yaya Jallow and Mariatou Jallow, my wife Jarra Manneh and children Alpha Amadou Jallow and Isatou Jallow, whose support have been instrumental during the course of this programme.



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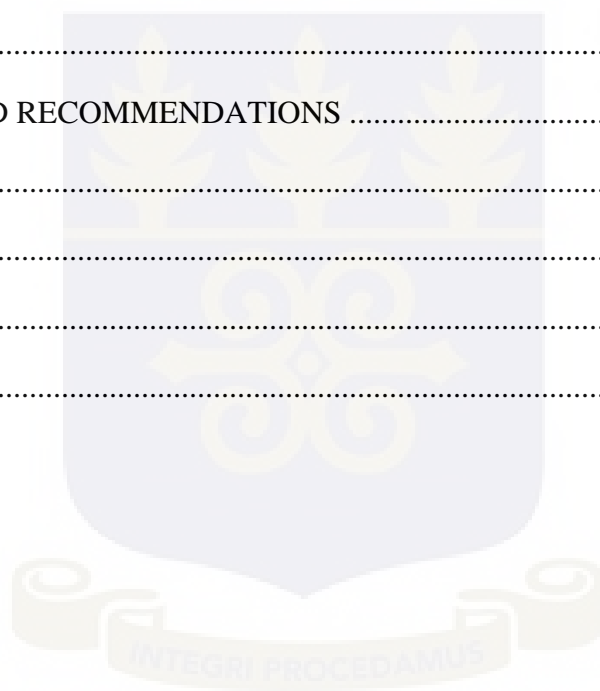
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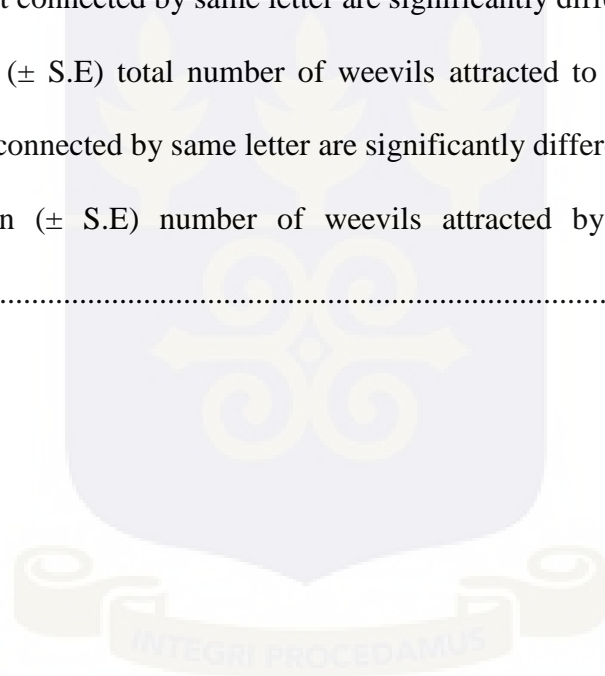
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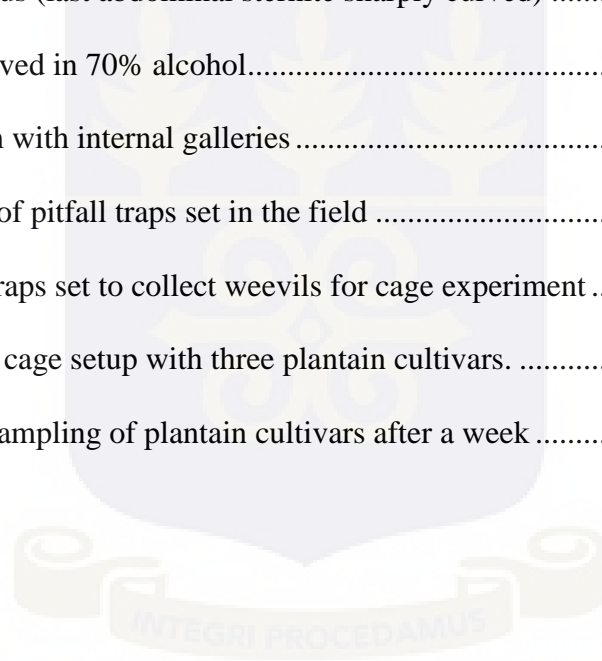


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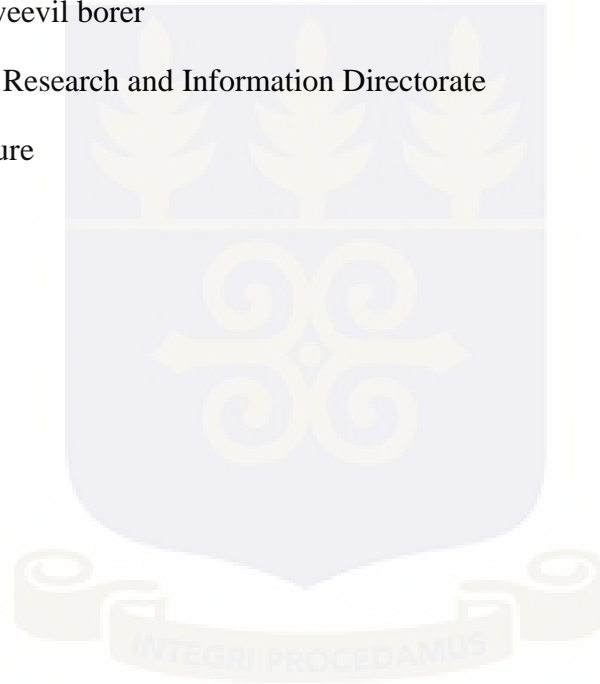
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LIST OF ABBREVIATIONS

CGIAR-	Consultative Group for International Agricultural Research
GMA-	Ghana Meteorological Agency
IITA-	International Institute of Tropical Agriculture
INIBAP-	International Network for the Improvement of Banana and Plantain
ISSER-	Institute of Statistical, Social and Economic Research
MoFA-	Ministry of Food and Agriculture
PWB-	Plantain weevil borer
SRID-	Statistics, Research and Information Directorate
Temp. -	Temperature



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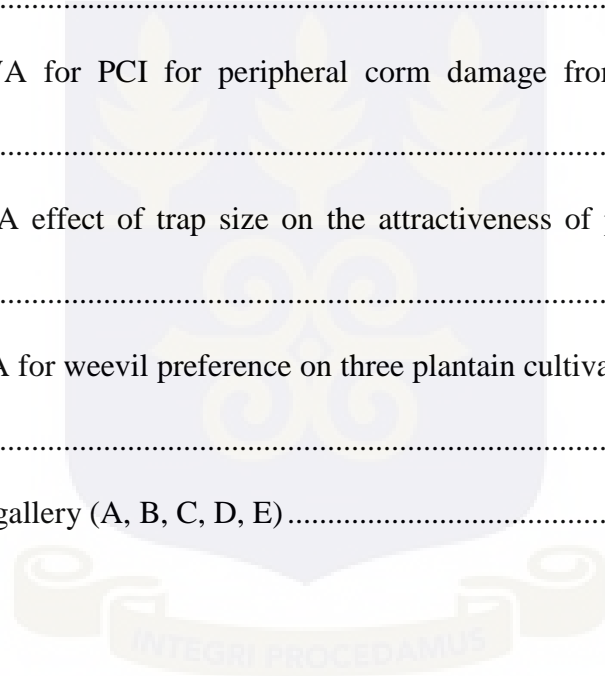
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CHAPTER ONE

1.0 INTRODUCTION

Plantains are cultivated in over 52 countries throughout the tropical and sub-tropical regions of the world (FAO, 2006). They are grown over an area of approximately 10 million hectares, with an annual production of around 37 million metric tonnes (CGIAR, 2010), of which approximately one third is produced in each of the African, Asian-Pacific and Latin American and Caribbean regions. The vast majority of producers are small-scale farmers (Dzomeku *et al.*, 2011) growing the crop either for home consumption or local markets (Ortiz and Vuylsteke, 1996).

Plantain production in Africa is estimated at more than 50% of worldwide production (FAO, 1990). The majority (82%) of plantains in Africa are produced in the area stretching from the lowlands of Guinea and Liberia to the central basin of the Democratic Republic of Congo. West and Central Africa contribute 61 and 21% respectively (FAO, 1986). It is estimated that about 70 million people in West and Central Africa derive more than 25% of their carbohydrates from plantains, making them one of the most important sources of food energy throughout the African lowland humid zones (Swennen, 1990).

Ghana is the largest producer of plantain in Western and Central Africa (FAO, 2010). Plantain intercropped with cocoa, provides shades to the tender cocoa seedlings during the first 3 to 4 year period of the establishment of cocoa and this system has being a common practice within cocoa growing regions of Ghana (Afreh-Nuamah and Hemeng, 1991). In the Ghanaian agricultural sector, plantain is ranked third after yam and cassava in terms of yield and cultivated area (FAO, 2010) and contributes about 13.1% to the agricultural gross domestic product

(AGDP). Plantain cultivation is of great socio-economic importance in Ghana in terms of food security and job creation. Plantain and banana are also very important sources of rural income (Ortiz and Vuylsteke, 1996).

Although plantain is a crop with permanent production, harvesting periods are influenced by external factors such as strong winds and rainfall. These harvesting periods in turn cause fluctuation in price trends according to supply and demand volumes. Plantains are scarce on the Ghanaian market from May to August every year. The scarcity is due to the strong winds experienced at the beginning of the rainy season and the two months dry period experienced from December to February that dehydrate the plants (Dzomeku *et al.*, 2011)

Despite the benefits, the effect of key biotic constrains have contributed to reduction in production yields and also reduction in plantation longevity. These include a complex of root nematodes (*Pratylenchus speijeri* n. sp., *Meloidogyne spp.*, *Helicotylenchus multicinctus* Cobb and *Radopholus similis* Cobb (Thorne)); the foliar disease (black sigatoka) and plantain weevil borer (*Cosmopolites sordidus* Germar). An estimated yield loss of 34.8% due to banana weevils alone during the first year of cropping has been reported in Ghana (Udzu, 1998). The larvae of *C. sordidus* feed by tunneling in the corm, eventually causing corm decay which exposes the plant to secondary infection leaving a mass of rotten tissue (Franzmann, 1972; Gold *et al.*, 2001). The weakening of the corm prevents nutrient uptake by the plant, leads to poor crop establishment, cause plant loss due to snapping and toppling, lower bunch weights, mat disappearance (failure to produce suckers), and shortened plantation life (Rukazambuga *et al.*, 1998; McIntyre *et al.*, 2001). Measures to prevent plantain weevil borer damage vary widely depending upon the type of plantain production systems practiced. Large-scale plantations resort to regular application of chemical insecticides to control the weevil. Resource-limited marginal farmers cultivating

plantain as a subsistence crop are unable to undertake chemical pesticide interventions on a regular basis. In this situation, cultural control strategies assume greater significance due to their ease of application and their compatibility with other methods of control.

The use of semiochemicals to trap the plantain weevil borer, *Cosmopolites sordidus* (Germar) (Coleoptera: Curculionidae), has been employed since the early twentieth century and still used as a monitoring and control tool (Gold *et al.*, 2002). In the past, semiochemical trapping of the plantain weevil borer was mainly based on chemicals emitted by the host plant (serving as kairomones) (Cuille, 1950; Budenberg *et al.*, 1993a). These traps are still used today and are made from residual pseudostems and corms of the plantain plant (Gold *et al.*, 2003). Successful chemical identification of insect pheromones (Butenandt *et al.*, 1959) led to an interest in pheromone research. Pheromones are considered a new generation of pest control agents and a rapid progress was made in the identification and isolation of pheromones from a wide range of insects. The concept of semiochemical-based trapping has been given prominence in plantain weevil borer management and pheromones have been used for monitoring population of crop pests and orchard pests (Wall, 1989; Suckling, 2000). Monitoring can assist in detecting the arrival and migrating insect pests, timing of control measures, risk assessment and population density estimates (McVeigh *et al.*, 1990; Howse *et al.*, 1998). Infochemical, particularly pheromones, have been widely used in pest management and is reported to have the advantage of being non-toxic to humans and arthropods (Ridgway *et al.*, 1990; Agelopoulos *et al.*, 1999) and could be an alternative to insecticides currently in use.

1.1: Justification

Global plantain production has increased by nearly 60% over the last 30 years to 37 million metric tonnes and Ghana is the largest producer in West and Central Africa. Other important producers are Rwanda, Nigeria, Cameroon, and Colombia (CGIAR, 2010). Plantain is the third most important food crop after yam and cassava in terms of volume of production and contributes 13.1% to the Agricultural Gross Domestic Product in Ghana (FAO, 2006). About 328,000 ha of land area is under plantain production in Ghana, producing 3,538,000 MT of fruits, of which more than 95% is sold on the local market and the rest exported (SRID-MoFA, 2010). In 2010 and 2011 the value of plantain export was \$ 141,000.76 and 182,000.35 respectively, recording a 28% increase from 2010 (ISSER, 2012). The agro-based industry development of plantain processing is new and recently five industries are recognized to be involved in processing plantain into fufu flour and chips e.g. Juaboso agro processing industries. The chips are mainly for local consumption with minimal export while the fufu flour is targeted for the Africans in the Diaspora (Dzomeku *et al.*, 2011). According to FAO statistic, Ghanaian *Musa* production in 2005 was valued at \$710 million of which plantain forms the largest share (I.I.TA, 2009).

The plantain weevil borer (PWB) (*C. sordidus*) is an important pest of plantains (*Musa spp.*) in Ghana (Gorenz, 1963; Udzu, 1998) and throughout the tropics (Gold *et al.*, 2001). The PWB has eluded control in small-holder production systems which constitute about 90% of the cultivated area in Ghana. Management of this pest has depended on the use of synthetic insecticides, which though feasible for larger commercial growers, is beyond the economic capacity of most plantain producers in developing countries such as Ghana and Uganda, and the plantain weevil borer is

resistant to a wide range of chemicals (Gold *et al.*, 1999a). There are hardly any banana and plantain varieties identified with useful tolerance or resistance to *C. sordidus* (Ortiz *et al.*, 1995). The management of the weevil by cultural methods such as mulching or the use of split pseudostem traps to detect, catch and kill resident and invading weevil populations has been only partially successful (Okech *et al.*, 1999; Gold *et al.*, 2002).

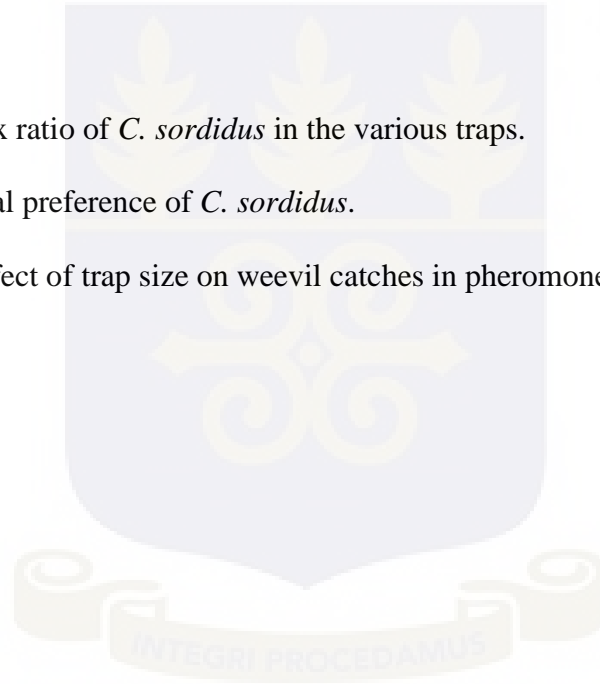
Farmers use various management measures, but not all have been evaluated widely for their efficacy or potential integration with other practices (Karamura and Gold, 2000). These measures include cultural control such as clean planting material, intercropping, destruction of residues after harvest, pseudostem and rhizome traps. Other possibilities for control include biological control with myrmicine ants (Castineiras and Ponce, 1991) or entomopathogens (Pena *et al.*, 1995, Godonou *et al.*, 2000), botanical or synthetic pesticides (Gold *et al.*, 2001) and mass trapping with pheromone lures (Tinzaara *et al.*, 2002). The main method of monitoring or estimating the population of *C. sordidus* is trapping and the most commonly used traps in Ghana are the pseudostem and corm traps. One possibility for improved plantain weevil borer monitoring is the use of pheromone lures (an aggregation pheromone of the plantain weevil) for monitoring and mass trapping. Use of this pheromone has been shown to increase the efficiency of trapping adult weevils in banana plantations (Jayarama *et al.*, 1997). Several factors such as the pest biology, pheromone efficacy, trap parameters, cropping system and environmental factors were found to variously influence the effectiveness of the pheromone-baited traps. However, further evaluation of pheromone lures in small-holder production systems and under different ecological conditions is needed (Tinzaara *et al.*, 2002). In Ghana, split pseudostem traps are used exclusively and the effectiveness of pheromone traps is unknown.

1.2: General objectives

To investigate whether pheromone-based trapping system can be used for the monitoring of *C. sordidus* under the semi-deciduous rain forest condition of Ghana.

Specific objectives

1. To evaluate the attractiveness of host plant volatiles (corm and pseudostem) and the aggregation pheromone to the PWB, *C. sordidus* for monitoring.
2. To determine seasonal population abundance of the plantain weevil borer (*C. sordidus*) at kade.
3. To determine the sex ratio of *C. sordidus* in the various traps.
4. To determine varietal preference of *C. sordidus*.
5. To determine the effect of trap size on weevil catches in pheromone-baited traps.



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1: Origin and description of plantain

Plantains (*Musa spp.* AAB group) were originally introduced from Southeast Asia and are currently grown in all tropical (North and South of 20° latitude) and subtropical regions (between 20 and 30° N and S latitude) of the world (Simmonds, 1959; Wardlaw, 1961; Stover and Simmonds, 1987; Valmayor *et al.*, 1991), including Asia, South and Central America, Oceania, Africa, Europe and Australia (Robinson, 1996). In the tropics some clones are grown up to 2000m above sea level (Central and East Africa), but mostly below 1500m altitude (Stover and Simmonds, 1987). Plantains belong to the order *Scitamineae*, family *Musaceae* and genus *Musa* (Simmonds, 1976). Most cultivated *Musa* are triploid ($2n=33$) (Purseglove, 1972). Almost completely sterile, they develop fruits by parthenocarpy (Swennen, 1990). The genome of this plantain cultivar (AAB) is derived from a diploid species, *Musa acuminata* and *Musa balbisiana*, which contributed the A and B genomes, respectively (IITA, 1993).

There is some evidence suggesting that the East African Highland banana (EAHB) and the tropical lowland plantain were cultivated on the African continent before AD 0. It is likely that Arabian traders (from 600 AD) brought AAB, AB and dessert AAA bananas from India to the continent and that these were slowly spread in East Africa. Bananas spread throughout the continent during colonial times from botanical gardens (e.g. Zanzibar, Zomba in Malawi, Entebbe in Uganda and Amani in Tanzania) (Blomme *et al.*, 2011).

Basically, plantain is a large perennial herbaceous plant comprising of an underground stem known as the corm. This corm bears buds on its middle and upper parts which develop into suckers. Numerous roots emerge from the corm, most of which grow horizontally at a depth of 15 cm (Simmonds, 1966; Swennen, 1990). The corm is internally divided into two main regions, the central cylinder consisting of a starchy parenchyma and a whitish cortex (Simmonds, 1966; Stover and Simmonds, 1987; Price, 1995a). Adventitious roots arise from cambium-like meristematic tissue on the periphery of the central cylinder (Skutch, 1932) and produce various laterals that produce root hairs (Simmonds, 1959). Roots generally extend laterally up to 5m from the plant, but are concentrated in a 60cm radius of the pseudostem in the top 40cm of the soil (Gousseland, 1983; Price, 1995a; Robinson, 1996). The apical portion of the corm contains the meristematic tissues from which the vascular system, aerial parts, corm proper and central cylinder develops (Skutch, 1932).

Floral initiation is characterized by the apical meristem at the base of the pseudostem ceasing to produce leaves and starting to develop a terminal inflorescence (Simmonds, 1976; Robinson, 1996). The internodes at the apex of the corm lengthen and change from a subterranean to an aerial true stem (Simmonds, 1966). The aerial true stem (supported by the pseudostem) carries the inflorescence and bears the last leaves, important for bunch filling (Stover and Simmonds, 1987). Elongation of the aerial stem forces the inflorescence through the center of the pseudostem, until it is 'shot' (Karamura and Karamura, 1995). At emergence the inflorescence is initially erect but quickly points downward due to its weight, the continued growth of the aerial stem and geotropic effects (Robinson, 1996).

2.2: Uses of plantain

Almost every part of plantain plants has some economic or medicinal use. Besides use as a dessert or cooking fruit, the plantain plant can be used for many other purposes. The fibers obtained from the pseudostem can be utilized in the paper and pulp industry as biodegradable binding ropes and in the textile industry. The fruit peel is used in dyeing, and as a base material for alcohol production, biogas production and pectin extraction. Medically, plantain can be used to cure a lot of ailments including sore throat, tonsillitis, diarrhea, vomiting and it is said to be used in the treatment of kwashiorkor (Idachaba, 1995).

Plantains form an important part of the daily diet of Ghanaians. In many areas the boiled matured fruits “ampesi” are eaten with stew (preferably, boiled cocoyam leaves “nkontomire” plus palm oil) or pounded (with or without cassava) into a thick paste as “fufu” and eaten with soup. When the fruits are allowed to ripen, it may be fried and eaten with beans stew, a great favourite among Ghanaian students, who nicknamed it as ‘Red-Red’, roasted and eaten with roasted groundnuts, or mashed and fried and eaten with boiled beans stew. In addition, the unripe fruits could be roasted or sliced and fried (chips) and eaten with roasted groundnuts as snacks. While bananas are often eaten as snacks, and or as dessert in some parts of the country (Akans), it is generally believed that a meal without plantain is not a complete meal (Karikari, 1971; Afreh-Nuamah and Hemeng, 1991). Compared to the major plantain producing countries in West and Central Africa, Ghana has the highest per capita consumption of 92kg/head/year (Table 2.1), highlighting the domestic importance of plantain in Ghana (FAO, 1997).

Plantain serves as a source of vitamin A as well as animal feed for livestock; both the leaves and peels serve this purpose (INIBAP, 1992). In certain parts of the Volta region of Ghana, animals are fed with rejected immature and over-ripened fruits, whilst fibers obtained from the

pseudostem are used as ropes and doormats (Akomeah *et al.*, 1995). The leaves are used as roofing material as well as wrappings for certain local foods such as kenkey (*Fante dorkono*).

Plantains and bananas are major components of sustainable agricultural systems in densely populated and high rainfall areas. Plantains are grown by cocoa farmers mainly as a shade crop for young cocoa plants and the plantain disappears in 3-4 years after the cocoa has established (Afreh-Nuamah and Hemeng, 1991). As a subsistence crop, plantain is very important in minimizing soil erosion on steep slopes by minimizing run-off and acting as wind barrier and also providing mulch for maintaining and improving soil fertility through the dropped leaves (INIBAP, 1986).

Table 2.1: Production of some staple food crops in West and Central Africa and per capita consumption of plantain production (000's MT).

Country	Plantain	Cassava	Yam	Rice	Maize	Consumption of plantain (kg)
DR Congo	2,400	16,800	300	400	1,100	40
Ghana	1,800	7,100	2,200	200	1,000	92
Nigeria	1,700	31,400	23,200	3,100	5,700	15
Cote d'ivoire	1,400	1,600	2,900	800	600	83
Cameroon	1,000	1,700	100	50	750	72
Guinea	400	600	90	700	80	49
Gabon	300	200	140	01	30	153

FAO Production Statistics (1997)

2.3: Local plantain cultivars and production systems in Ghana

Plantain may be classified into three major types according to their degree of inflorescence degeneration; French, False-horn, and True-horn (INIBAP, 1990). French plantain cluster possesses a persistent male axis, whereas that of ‘Horn’ type is absent or degenerates quickly after flowering. Plantain was introduced from Southeast Asia in tropical Africa, but it is neither unknown how many varieties reached West Africa, and Ghana in particular, nor is it known who introduced them (Karikari, 1971). According to Karikari (1971) and Hemeng *et al.*, (1996) several intermediaries are found within each group. Fourteen *Apem* and *Apantu* cultivars were reported by Karikari (1971). Table 2.2 below shows the names of cultivars in ‘Akan’ language and their literal meanings.

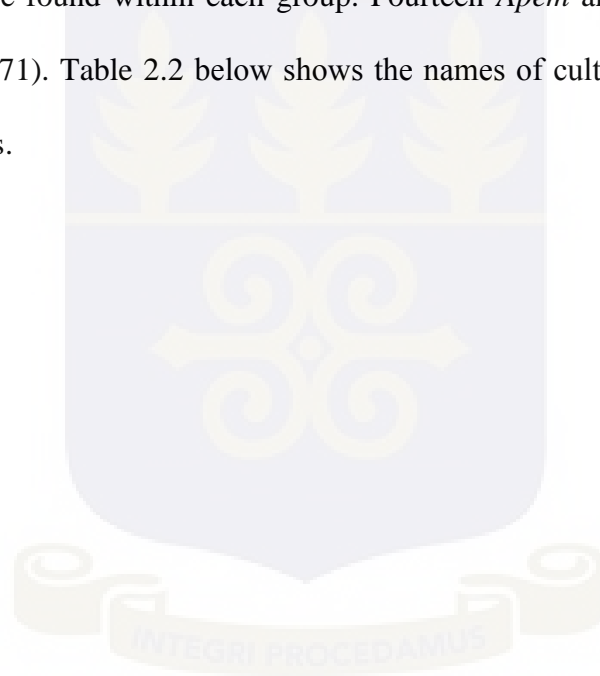


Table 2.2: Plantain cultivars in Ghana.

Local cultivars (Akan)	Literal translation (English)
Apantu	Horn plantain
	False Horn
Brode pa/Apantu pa	True Apantu
Brode Sebo	Plantain fruit with spotted skin
Brodewuio	Pink pseudostem
Abomienu/Aduromienu	Bears two bunches
Abomiensa/Aduromiensa	Bears three bunches
	True Horn
Sakoro	One hand
Asamienu	Two hands
Asamiensa	Three hands
Apem	French Plantain
Oniaba	Without seed
Apem pa/Apem Ankasa	True French plantain
Nyiretia apem	Short finger
Osabum/Ogyebim	Big hand

Source: Ahiekpor, 1996.

There is limited cultivar diversity in the Southern belt of Ghana (Schill *et al.*, 1996) as compared to reports from Cameroon (Forgain and Price, 1994). In a study to determine cultivar diversity in Ghana, Schill *et al.*, (1996) reported five French plantains, 10 False Horn and one True Horn with the apem, Oniaba, Apantu, and Asamienu occurring in all the villages studied. When the farmers quantified the importance of the cultivars, Apantu the ‘False horn’ plantains were rated as the principal cultivar followed by Apem, the ‘French plantain’. The other cultivars are grown but they are of little importance (Schill *et al.*, 1996) and preference of ‘False Horn’ was because it lives longer, produces superior suckers and suitable for production of ‘fufu’.

In Ghana, plantain is grown in mixed cropping systems with root crops, cereals and vegetables (Afreh-Nuamah and Hemeng, 1991) as a dominant crop in most cases (Ahiokpor, 1996). In the majority of food production systems, however, maize and the various vegetables are often planted first after the land is cleared, followed by plantain and cocoyam (Afreh-Nuamah and Hemeng, 1991). Plantains are also cultivated intensively in households backyards with effective management practices such as weed control, application of household refuse and animal waste which result in good crop production for many years (INIBAP, 1992). Plantain is extensively produced throughout the forest zone of the country and also grown in backyard gardens in almost every village, town and city. In 2004 more than two million *Musa* seedlings, covering 1300 hectares and worth \$2.5m annually to the farming economy of Ghana, were propagated and distributed to about 4000 banana and plantain farmers in a rapid two year time frame (IITA, 2009). Major production of the crop takes place in the Southern parts of the country with an annual rainfall of 1500mm and annual deficit of 400mm (Ahiokpor, 1996).

2.4: Economic importance of plantain

According to FAO (1999, 2007), bananas and plantains together serve as staple food for at least 400 million people in the world. Plantains form one-quarter of the total world production of *Musa spp.* (Swennen, 1990). Africa produces almost 50% of the total world output of plantain of which only 2% is exported. This demonstrates that plantain is more important as a food crop and for generation of household income than being an export commodity (Swennen and Vuylsteke, 1991). In Central and West Africa, plantains play an important role in food security (consumed as an energy-yielding food), provide employment for majority of rural farmers, revenue diversification in rural/urban zones, and poverty reduction (Nkendah and Akyeampong 2003; Nghoh Newilar *et al.*, 2005). When compared to other staples such as cassava, rice and yam, plantains and bananas are the most economical source of carbohydrates in terms of production costs per hectare, per tonne, and per calorie (Swennen, 1990).

Plantain contributes about 770 Kcal/Kg and it serves as a source of iron and zinc (Babatunde *et al.*, 2007). It is the third most important food crop after yam and cassava in terms of volume of production (Table 2.4) and contributes 13.1% to the Agricultural Gross Domestic Product in Ghana (FAO, 2006). About 328,000 ha of land area has been cultivated to plantain in Ghana with an annual growth rate of 2.5% of area planted, and this produces an annual average of 2.0 million tonnes of fruits with a mean annual production growth rate of 5.22% (SRID-MoFA, 2010). Six of the ten administrative regions of Ghana, namely Ashanti, Eastern, Brong-Ahafo, Western, Central and Volta regions, are designated as plantain producing regions (Banful, 1998). Plantain has become an important export commodity in the international market (ISSER, 2012) with an average price of US\$ 1.53 per kg for the period 1995 to 1998 (Martinez and Saavedra,

2001) and there has also been a steady increase in the rural wholesale price between 2004-2010 (Figure 2.1) which is an encouragement for more involvement in plantain production.

Plantain cultivation is of great socio-economic importance in Ghana from the view point of food security and job creation. Apart from 2000 and 2005, Eastern Region has had the largest area under plantain production in Ghana since 1996. Below is a table showing the annual plantain production of the major growing regions.

Table 2.3: Annual plantain productions by region in Ghana (000's MT)

Region	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Ashanti	435.0	435.0	476.3	531.3	584.4	568.7	606.0	607.9	600.6	1063.2
Eastern	855.0	818.1	817.0	758.9	556.8	672.0	705.6	700.2	757.5	788.9
Brong- Ahafo	173.9	189.4	218.5	278.7	295.4	310.2	387.8	432.3	458.1	630.0
Western	279.8	305.7	325.4	392.9	404.6	428.8	470.3	473.3	521.2	573.3
Central	49.9	41.9	47.7	52.9	58.5	60.3	66.9	70.4	-	468.5
Volta	29.8	28.2	27.8	31.4	32.7	33.8	42.1	44.4	43.5	48.0

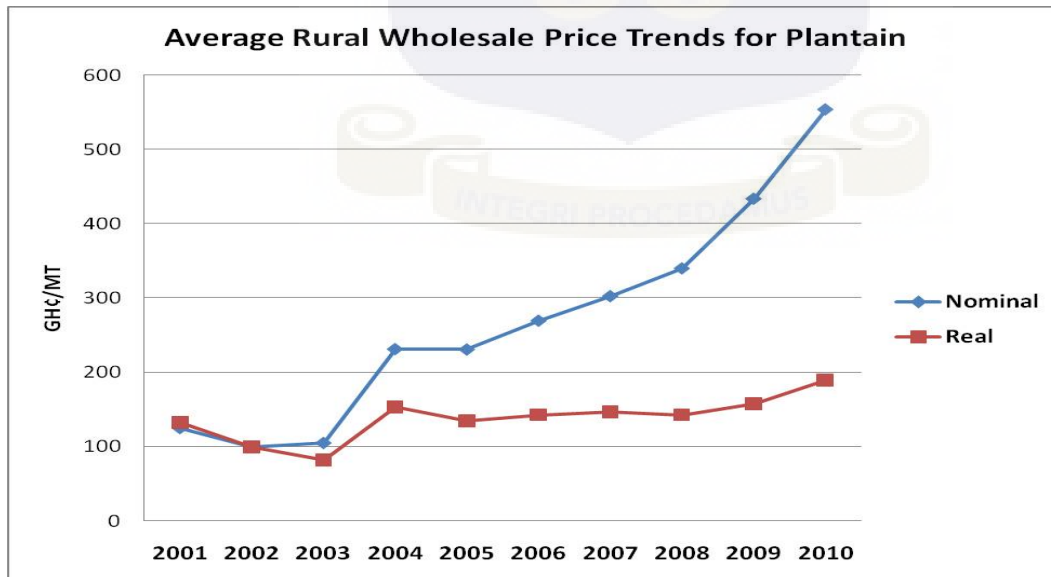
Source: SRID, MOFA 2006

Table 2.4: Production of selected food crops ('000 Mt)

Crop	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Maize	1,013	938	1,400	1289	1158	1171	1189	1220	1470	1620	1872
Millet	169	134	159	176	144	185	165	113	194	246	219
Rice (paddy)	215	253	280	239	242	237	250	185	302	391	492
Rice (milled)	129	152	168	143	145	142	150	111	181	235	295
Sorghum	280	280	316	338	287	305	315	155	331	351	324
Plantain	1932	2074	2279	2329	2381	2792	2900	3234	3338	3563	3538
Cassava	8107	8966	9731	10239	9739	9567	9638	10218	11351	12231	13504
Yam	3363	3547	3900	3813	3892	3923	4288	4376	4895	5778	5960
Cocoyam	1625	1688	1860	1805	1716	1686	1660	1690	1688	1504	1355

Source: SRID, MOFA 2010

Figure 2.1: Average Rural Wholesale Price Trends for Plantain



Source: SRID, MOFA 2010

2.5: Production constraints

As a tropical crop, plantain is faced with lots of challenges ranging from abiotic factors such as poor soil, lodging due to wind and drought stress (Akomeah *et al.*, 1995) to biotic factors such as weeds, diseases and pests. All of these factors contribute to reduction in production yields and also decrease the crop cycles. Although plantain is perennial, harvesting periods are influenced by external factors such as strong winds and rainfall. These production movements or periods in turn cause upward and downward price trends according to volume supply and demand. Plantains are scarce on the market from May to August. The scarcity is due to the strong winds experienced at the beginning of the rainy season. During Dec/Feb the plants become dehydrated as a result of the two months dry season and this lowers production output. Plantains become abundant on the market from September to March with the peak in December-January.

According to Udzu (1998) yield reduction in plantain due to plantain weevil borer and nematode pests, are estimated at 85% in the first year of cropping. In much of West Africa for instance, plantain is now treated as an annual crop whereas in the past it was ratooned for 25 years or more (Gold *et al.*, 1993).

Black sigatoka disease, *Mycosphaerella fijiensis*, is the most important disease affecting plantain in Ghana (Ahiokpor, 1996; Hemeng *et al.*, 1996; Schill *et al.*, 1996). The disease was first identified in Fiji, and accidentally introduced into Southern Africa in the 1970's (Raemakers, 1975), and first spread to Central and West Africa (Wilson and Budenhagen, 1990), and later to East Africa (I.I.T.A, 1996). Once established the pathogen causes severe leaf necrosis reducing yield of plantain between 20-50% (Pasberg-Gauhl, 1993). According to Hemeng *et al.*, (1996) all known local plantain and banana cultivars are susceptible to the disease. Symptoms of black sigatoka disease include the appearance of yellow spots on leaves, which turn brown and later

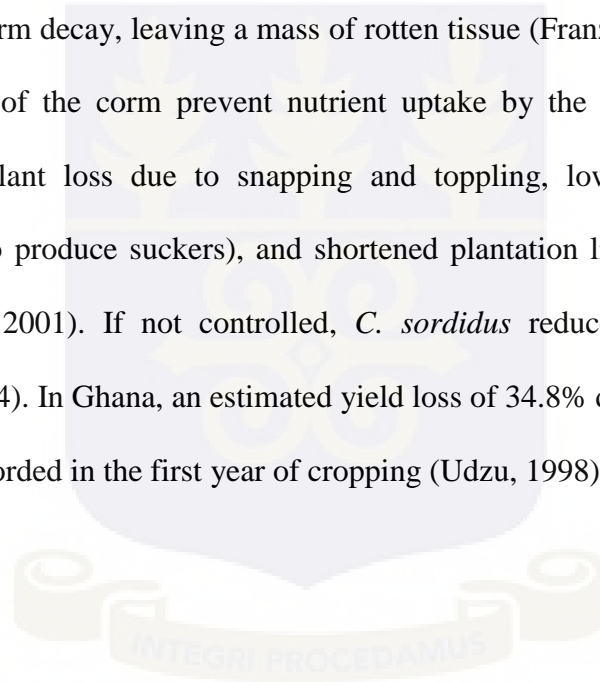
black. In severe cases, all the leaves may die before harvesting, leading to at least 50% yield losses (Hemeng *et al.*, 1996).

A number of the most important plant parasitic nematodes of *Musa* have a widespread distribution; others have a more restricted spread in the main banana and plantain growing areas of the world. The nematode species known to cause the most serious damage to *Musa sp.* are *Radopholus similis* (Cobb) Thorne, *Pratylenchus coffeae* (Zimmerman) Filipjev, Schuurmans and Stekhoven, *Pratylenchus goodeyi* Sher and Allen and *Helicotylenchus multicinctus* (Cobb) Golden (Bridge, 1991). The pre-adult and adult females of these nematodes puncture the epidermal cells along the entire length of the roots by repeated stylet thrusts. They then enter through the wounds and occupy an intracellular position within the cortex where they feed on the cytoplasm of adjacent cells causing their cell walls to rupture, and the nucleus is either ingested or degenerates. Such cell destruction according to Blake (1972) and Stover (1972), leads to the formation of extensive cavities in the cortex. Folkertsma (1987) reported that severe infestation by *R. similis* could lead to toppling or uprooting of the plant. This is when remnants of the root system attached to the corm are pulled out of the ground when the plant falls.

Helicotylenchus dihystra and *Meloidogyne sp.* are among the pests that attacked plantains in Ghana (Lamprey and Karikari, 1975). Afreh-Nuamah and Hemeng (1995) also identified *Meloidogyne spp.*, *Pratylenchus spp.* and *Helicotylenchus spp.* In a survey to assess and characterize plantain production constraints in Ghana, Schill *et al.*, (1996) reported that majority of the nematode species encountered were lesion forming nematodes. The report revealed that *Pratylenchus coffeae* and *Helicotylenchus multicinctus* were the most widespread nematode species, while *R. similis* even though present had a localized occurrence.

Chemical control has been one of the most effective methods of managing nematode populations. Nematicides such as carbofuran (Furadan 5 G^R), Vydate^R (oxamyl), and Nematicur^R (phenamiphos) have been successfully used on large scale banana and plantain fields in Ivory Coast and Cameroon (INIBAP, 1994) as well as Indonesia and Philippines (Davide, 1994).

The plantain weevil borer is one of the most serious insect pests of plantains in most plantain growing regions (Stover and Simmonds, 1987). The larvae of *C. sordidus* feed by tunneling in the corm, eventually causing corm decay which exposes the plant to secondary infection by other pathogens that causes corm decay, leaving a mass of rotten tissue (Franzmann, 1972; Gold *et al.*, 2001). This weakening of the corm prevent nutrient uptake by the plant, lead to poor crop establishment, causes plant loss due to snapping and toppling, lower bunch weights, mat disappearance (failure to produce suckers), and shortened plantation life (Rukazambuga *et al.*, 1998, McIntyre *et al.*, 2001). If not controlled, *C. sordidus* reduce yield by up to 100% (Koppenhofer *et al.*, 1994). In Ghana, an estimated yield loss of 34.8% due to the plantain weevil borer alone has been recorded in the first year of cropping (Udzu, 1998).



2.6: The plantain weevil borer, *Cosmopolites sordidus* Germar:

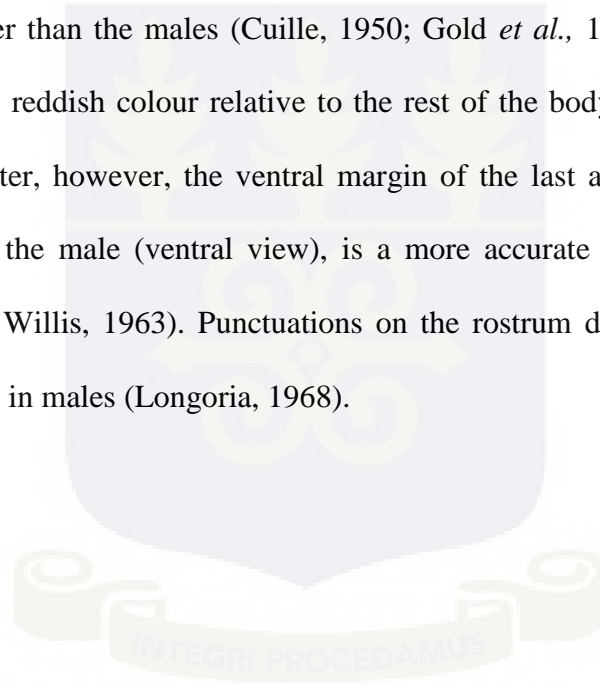
2.6.1: Origin and classification

The plantain weevil borer (*Cosmopolites sordidus* Germar) is believed to be a native of the Indo-Malaysian region (Zimmerman 1968c, Clausen 1978). However, banana and plantain (and the weevil) have long been disseminated throughout the world; therefore, the centre of origin of the weevil remains obscure. The banana weevil was most likely introduced in Uganda around 1908 with imported banana plants, which had been established in the Botanic Gardens at Entebbe (Blomme *et al.*, 2011).

The plantain weevil borer is a Coleopteran, the largest order of living organisms with an estimated 350,000 described species in approximately 23,000 genera (Zimmerman, 1968b, 1968c; Endrody-Younga, 1985); the super family Curculionoidea, regarded to represent the most highly evolved of all beetles and within the diverse Curculionidae (Zimmerman, 1968b, 1968c), the largest family of animals in the world with more than 45,000 described species (Oberprieler and Louw, 1985; Picker *et al.*, 2002). Members of this family have a cosmopolitan distribution and are characterized by a globular head produced into a rostrum (Oberprieler and Louw, 1985). Based on the ventral visibility of the rostrum curculionids are classified into the “short-nosed” Adelognatha and “long-nosed” Phanerognatha (Oberprieler and Louw, 1985). The plantain weevil borer belongs to the tribe Phanerognatha whose larvae mainly develop in plant tissues and to the subfamily *Rynchophorinae* and genus *Cosmopolites*. The genus comprises of two species namely *C. sordidus* and *C. pruinus*. *Cosmopolites pruinus* was first described in 1934 and is morphologically very similar to *C. sordidus*, but differs externally in the nature of pruinosity on the dorsum and the character of the elytral striae (Zimmerman, 1968a, 1968c).

The plantain weevil borer was first described in 1824 as *Calandra sordid* Germar (Zimmerman, 1968c). The name was changed to *Cosmopolites sordidus* by Chevrolat in 1885 and is still recognized today (Zimmerman, 1968c). *Sphenophorus striatus* Fahreus and *S. cribricollis* Walker are synonyms (Zimmerman, 1968b, 1968c). Several common names including banana weevil, banana corm borer, banana beetle, corm weevil, black banana borer (Zimmerman, 1968b, 1968c; Masanza, 2003), migratory borer (Smith, 1995), plantain black weevil and many vernacular names have been assigned to *C. sordidus*.

Females tend to be larger than the males (Cuille, 1950; Gold *et al.*, 1999c) and have rostrums with a more accentuated reddish colour relative to the rest of the body (Longoria, 1968). As a secondary sexual character, however, the ventral margin of the last abdominal segment being more sharply curved in the male (ventral view), is a more accurate feature in distinguishing weevil sexes (Roth and Willis, 1963). Punctuations on the rostrum do not extend beyond the antennae as can be found in males (Longoria, 1968).



2.6.2: Biology and life history

Mating usually occurs at night (Delattre, 1980) and only mated females produce chorionated eggs (Treverrow and Bedding, 1993). Females oviposit single white, elongate, oval eggs (Froggatt, 1925; Simmonds, 1966; Franzmann, 1972) in small crevices chewed in the plant tissue, sealed by latex-containing plant sap and necrotic tissue (Beccari, 1967). Eggs are usually laid at above ground level (Franzmann, 1972) in the crown of the corm and pseudostem base (Abera *et al.* 1999). However, eggs can also be found in harvested stumps, larval tunnels, and on the surface of root bases (Koppenhofer, 1993b). Oviposition occurs at night (Cuille, 1950) and the total number of eggs laid varies in a lifetime. A single female can lay up to 100 eggs but usually does not exceed 50 (Cuille, 1950; Simmonds, 1966), with an average of 4.8 eggs per female per month (Cuille, 1950). Due to temperature, relative humidity, feeding and aggregation the total number of eggs laid may vary considerably during the year (Cuille, 1950; Beccari, 1967). The incubation period of the eggs ranges from 4-36 days. Most investigators suggest a period of one week or less under optimum conditions of temperature, humidity and food (Abera *et al.*, 1996). Afreh-Nuamah (1999) sets the duration at 5-8 days under laboratory conditions. The egg, measures between 1-2 mm in length and 0.5 mm in breadth.

Upon emergence, the legless, crescent-shaped larvae immediately tunnel downwards towards the corm (Cuille, 1950; Beccari, 1967) or occasionally the pseudostem, producing distinctive circular, debris filled-tunnels (Franzmann, 1972) up to 8 mm in diameter. Larvae pass through five to eight instars (Traore *et al.*, 1996; Gold *et al.*, 1999b) reaching approximately 10-20 mm in length (Treverrow *et al.*, 1992; De Jager, 1993). In the laboratory, larval period lasted between 21-28 days (Afreh-Nuamah, 1999).

The pupa measures 12 mm long and 6 mm wide and it develops in a chamber at the corm periphery (Franzmann, 1972). Body structures such as snout, antennae, wing pads and legs of the adult are clearly visible through the pupal skin (Abera *et al.*, 1996). Eclosion produces a reddish, brown adult (teneral stage), which becomes uniformly dull black (Pinese and Elder, 2004) after about 14 days (Frogatt, 1925). The teneral stage is passed within the corm or pseudostem (Gold *et al.*, 1999c).

2.6.3: Distribution and host range

The plantain weevil borer is reported to have originated in the Indo-Malayian region (Zimmerman, 1968c; Stover and Simmonds, 1987), but Hasyim and Gold (1999) suggested this to be uncertain. The plantain weevil borer is mostly disseminated by infested plant materials to new areas (Swennen, 1990; Simmonds, 1966; Afreh-Nuamah, 1994) but crawling adults also colonize nearby plantations (Franzmann, 1972; Seshu Reddy *et al.*, 1999). Currently, the weevil is found in Southeast Asia, East and West Australia, the Pacific, Indian Ocean Islands, tropical and South Africa and tropical America (Southern U.S.A to Southern Brazil, including the Caribbean (Robinson, 1996; Bellis *et al.*, 2004). The weevil has not been identified in banana growing regions of North Africa (Cardenosa, 1953; Cuille and Vilardebo, 1963) and Israel (Cardenosa, 1953). The weevil is found in all banana and plantain growing areas in the tropics and subtropics (Gold and Messiaen, 2000). In Ghana, *C. sordidus* occurs in almost all the plantain and banana growing regions (Ahiokpor, 1996; Hemeng *et al.*, 1996) and is considered a major pest (Afreh-Nuamah and Hemeng, 1991; Hemeng *et al.*, 1996; Schill *et al.*, 1996).

C. sordidus is a pest specific to *Musa* (bananas and plantains) and *Ensete* (Stover and Simmonds, 1987; Gold *et al.*, 2003), but has been reported as a monophagous pest of *Musa* (Zimmerman, 1968b, Pavis and Lemaire, 1996). The adult weevil will feed on yam (*Dioscorea rotundata* Poir)

and cocoyam (*Xanthosoma sagittifolium* Poir) if severely starved (Schmitt, 1993, cited in Traore *et al.*, 1993) and has been found on sweet potato tubers (*Ipomoea batatas* (L.) Lam.) and canna corms (*Canna edulis* Kerr) (Froggatt, 1925). Reports of hosts other than *Musa* and *Ensete* are possibly in error (Gold *et al.*, 2003). Studies on host preference among *Musa* cultivars have shown that plantains (AAB) are the most preferred and damaged cultivar whilst bananas (AAA) are the least with the ABB bluggoes as intermediate (Fogain and Price, 1994).

2.6.4: Factors affecting plantain weevil borer abundance and activity

Environmental conditions, such as temperature and rainfall, are known to have a huge influence on pest distribution and population dynamics (Huffaker and Gutierrez, 1999).

The plantain weevil borer has a relatively low reproductive activity (Cuille, 1950), with high egg and larval mortality in the field (Abera *et al.*, 1997, cited in Gold *et al.*, 1999c). Field oviposition rates are a negative function of weevil density (Abera *et al.*, 1999; Gold *et al.*, 1999c, 2002a), but Koppenhofer (1993b) reported that it only occurs at very high densities, which are unlikely to be attained under field conditions. Environmental conditions such as temperature negatively influence egg laying activity (Franzman, 1972; Gold *et al.*, 2002a) and generally ceases during the Australian winter (Treverrow and Bedding, 1993). Under tropical conditions, females usually lay one egg per week (Abera *et al.*, 1999). In the sub-tropics, two eggs are laid per week and 50-100 eggs per annum.

The emergence and activity of adults peak shortly after rains in the tropics (Gold *et al.*, 1999c) and sub-tropics (Treverrow *et al.*, 1992; Smith, 1995; Govender and Viljoen, 2002; Pinese and Elder, 2004). A study in Brazil showed no correlation between adult weevils and rainfall, relative humidity and temperature (Batista Filho *et al.*, 1990). In South Africa (Kiepersol area), catches

in corm traps peak in October (spring) and showed a weak correlation with temperature (Schoeman, 1996). Reports of seasonal fluctuations in weevil populations depend on crop management, predators, weevil density, sampling method, weevil development rate, and or weevil biotype. Differences in crop management (e.g. mulching material or mulching location) influence weevil distribution (Gold *et al.*, 2004b), and can also change the microclimate of a field, thereby altering temperatures and relative humidity (Seshu Reddy *et al.*, 1999). Weevil numbers are also influenced and can be negatively related to predator densities (Hasyim and Harlion, 1998). Development rate of *C. sordidus* depends on cultivar, plant stage, diet, relative humidity and population density (Gold *et al.*, 1999b; Kiggundu, 2000)

2.6.5: Behaviour

Adult plantain weevil borers are found in moist environments, leaf bases and decayed corms and pseudostems (Treverrow *et al.*, 1992), feeding on plant tissues or crop debris (Franzmann, 1972). Plantain weevil borer has well developed wings, but flight is considered limited and it is negatively phototropic. The main form of mobility is walking at night (Ostmark, 1974; Uzakah, 1995, cited in Gold *et al.*, 1999c). Adults are gregarious and usually distributed in patches in the field (Treverrow *et al.*, 1992). Migration is slow and weevils normally move less than 10 m per month (Gold *et al.*, 1999c), while small proportion will move more than 25 m in 6 months (Gold and Messiaen, 2000). During low humidities weevils show aberrant behaviour and difficulty in walking (Roth and Willis, 1963). The weevil is highly susceptible to desiccation and usually dies within 3-10 days on a dry substrate (Gold *et al.*, 1999c) and survives approximately between 4-17 months in moist soil without food (Franzmann, 1972; Treverrow *et al.*, 1992). Adults are thigmotactic (Delattre, 1980) and exhibit hydrotropism; *C. sordidus* uses hydrotropism for the search of higher humidity and liquid water (Cuille, 1950). Orientation in humidity gradients is by

means of orthokineses, klinokineses, klinotaxis and titubant reactions (Roth and Willis, 1963). Disturbed adults display thanatosis (feigning death) (Feakin, 1971). Residual corm, pieces of freshly cut pseudostem and stressed or damaged plants attracts both males and females of the weevil (Froggatt, 1925; Treverrow *et al.*, 1992; Gold *et al.*, 1994b). Males aggregate at lower humidities than females (Roth and Willis, 1963), but males and females have a similar distribution pattern in the field (Gold *et al.*, 1999c). An aggregation pheromone is produced by the males and it attracts both sexes (Budenberg *et al.*, 1993a).

2.7: Integrated management of plantain weevil borer

Several studies have been conducted to find out different techniques that can be used to manage the plantain weevil borer. These techniques include the use of chemicals, biocontrol agents, cultural and genetic control (Walangululu *et al.*, 1993; Speijer *et al.*, 1999). The most vulnerable stage of a pest is usually targeted in pest management. Literally, *C. sordidus* adults have been considered a more important target than larvae; because the rate of oviposition is relatively limited and population build-up is slow (Treverrow *et al.*, 1992).

2.7.1: Use of semiochemicals for monitoring (sampling)

Semiochemical are chemicals emitted by plants and animals which modify the behaviour of receptor organisms of like or different kind (pheromones, allomones and kairomones). All organisms utilize information they perceive from their environment to maximize fitness, e.g. by improving food location, mate finding and predator avoidance. Information on environmental conditions is often available through chemical cues (Bell and Carde, 1984; Carde and Bell, 1995; Dicke, 1999a). Chemicals involved in conveying information in intra- and inter-specific interactions between organisms are termed infochemicals and constitute a subcategory of

semiochemicals (Dicke and Sabelis, 1988). Infochemicals play an important role in the biology of many insect species. An understanding of their role in plant-herbivore-carnivore interactions can be used in the development of tools for the enhancement of environmentally benign alternatives to synthetic pesticides. Infochemicals can be used in pest monitoring and as a control measure through mating disruption, mass trapping and as a means of aggregating herbivores at delivery sites for biological control agents.

Semiochemicals have been used since the twentieth century for the trapping of the plantain weevil borer, and has been retained in modern recommendation for the monitoring and control of the plantain weevil borer (Cuille, 1950; Mestre and Rhino, 1997). The traditional method of trapping the plantain weevil borer relies exclusively on the use of semiochemicals emitted by the host plant (serving as kairomones) (Cuille, 1950; Budenberg *et al.*, 1993a). These plants are still in use today and are developed from residual pseudostems and corms (Gold *et al.*, 2003) and the tissues are attractive only over a period of 7-14 days, depending on environmental conditions (Schmitt *et al.*, 1992). There are different types of trap designs (Batista Filho *et al.*, 1990; Treverrow *et al.*, 1992; Price, 1993; Raga and De Oliveira, 1996), but the most common traps are disk-on-stump traps, pseudostem-disk traps and split pseudostem (Mitchell, 1978; Treverrow *et al.*, 1992; Gold *et al.*, 1999a). Traps obtained from different plant clones show great variation in weevil capture, although reports are inconsistent (Gold *et al.*, 2003). The efficiency of the kairomones in attracting insects depends on the odour quality and/or the amount released. Fermented plant tissues produce a spectrum of odorants that are significantly different from those released by healthy plants (Metcalf and Metcalf, 1992; Braimah and van Emden, 1999; Rochat *et al.*, 2000). Pseudostems (Cuille, 1950; Sumani, 1997) and corms (Cerdeira *et al.*, 1995) are considered the most effective trapping material. Fresh (Delattre, 1980; Koppenhofer *et al.*,

1994) or decayed (Budenberg *et al.*, 1993b) material may attract the most weevils. Pseudostem traps are most common and preferred by farmers because corm trap preparations are laborious to perform. Traps prepared from the proximal end of the pseudostem may be most attractive (Mestre and Rhino, 1997). Braimah and Van Emden (1999) have reported that dead banana leaves and other non-host plants are more attractive than pseudostem and corm materials. The major attractive kairomone substances are unknown (Budenberg *et al.*, 1993b, Braimah, 1997), but mono- and sesquiterpenes (Ndiege *et al.*, 1991) and 1, 8 cineole (Ndiege *et al.*, 1996a) have been suggested as attractants.

Budenberg *et al.*, (1993a) provided evidence of a male aggregation pheromone to which both male and female *C.sordidus* respond. Beauhaire *et al.*, (1995) detected six male-specific compounds with Electroantennogram activity in volatile collections. Sordidin (2, 8-dioxa-1-ethyl-3, 5, 7-trimethylbicyclo [3.2.1] octane) as the most abundant volatile was identified and synthesized to provide Cosmolure pheromones. Pheromones have been used for monitoring population of crop pests and orchard pests (Wall, 1989). Monitoring can assist in detecting the arrival and migration of insect pests, timing of control measures, risk assessment and population density estimates (McVeigh *et al.*, 1990; Howse *et al.*, 1998). Infochemical, particularly pheromones, have been widely used in pest management and is reported to have the advantage of being non-toxic to humans and arthropods (David and Birch, 1986; Ridgway *et al.*, 1990; Agelopoulos *et al.*, 1999). Pheromones perform most effectively when used with other methods in an integrated control programme, where they are either used indirectly for monitoring (Wall, 1989), or directly to manipulate pest populations (Griffiths *et al.*, 1991). They offer prospects for attracting pests to microbial control agents in environments where these agents might be best

preserved. This can apply to fungal pathogens, mobile insect predators and parasitoids (Pickett, 1988).

Pheromone trap effectiveness is influenced by a number of factors such as pheromone dose and release rate and thus determine how well they attract insects (Muirhead-Thompson, 1991; De Groot and De Barr, 1998). In most cases trap catches correlate to environmental factors such as wind direction and speed, rainfall and temperature (Jansson *et al.*, 1989; Sappington and Spurgeon, 2000). Wind speed and direction may change pheromone plume shape and size, and create pheromone concentration gradients within the plume.

2.7.2: Economic threshold

According to Vilardebo (1960), if more than 10% of the plants examined show signs of peripheral weevil damage then economic threshold is reached, and greater than 25% of coefficient of infestation is equivalent to 30-60% yield loss (Vilardebo, 1973). With the coefficient of infestation method, economic threshold in Cameroon is attained when one of the 20 plants sampled per hectare is attacked (Fogain *et al.*, 2002). According to ChemTica International, S. A, trap catch threshold levels for plantain weevil borer are low, <5 adults per week; medium, 5-10 adults per week; high, >10 adults per week. In South Africa the economic threshold of the plantain weevil borer were 1-2 adults per trap (Govender and Viljoen, 2004).

2.7.3: Cultural control

Cultural control is an important strategy, especially for subsistence and organic farmers. It is based on the manipulation of the weevil habitat to adversely affect the pest and promote growth of the plantain plant. Cultural control practices are considered important and under certain conditions have been reported to keep weevil populations and damage at significantly low levels

(Simmonds, 1959). Using clean planting material (pest and disease free planting material) is reported to significantly minimize the spread of plantain weevil borer and plant parasitic nematodes (Prasad and Seshu-Reddy, 1994; CRBP, 1996; Speijer *et al.*, 1999; Masanza, 2003). Pared suckers treated with hot water at 53°C for 20 min is found to be effective in the elimination of pests such as plantain weevil borers and nematodes. Using clean planting material is the most popular cultural technique. A combination of several cultural techniques is the best available approach to resource-poor farmers as it is likely to reduce plantain weevil borer and nematode pressure (InfoMusa, 2003). In Cameroon, different techniques are employed by both large-scale commercial plantations and small to medium sized farms. These materials include plantlets produced from rapid multiplication techniques (the PIF technique- production of small plantlets from stem bits), tissue-cultured plants and pared suckers (Courrier du CRBP, 1996b; CRBP, 1997; Messiaen, 2002).

It is reported that removal of plant debris and destruction of old pseudostems help to reduce snapping as a result of plantain weevil borer damage. A practice in Ghana is paring (removal of the outer layer of the corm of a sucker using sharp knife or machete). According to Messiaen (2002), this method helps to expose larval galleries which allow the farmer to reject heavily damaged suckers.

Another important technique is the use of traps to either catch and destroy or poison adult weevils. Classical split pseudostems are the commonly used traps (Price, 1993, 1995; Messiaen, 2002). Most small scale farmers find it very difficult to adopt this technique, whilst most large scale farmers adopt it but soon abandon it because it is labour intensive or demanding and time consuming.

2.7.4: Host plant resistance

Nutrient composition, secondary plant substances and other host quality characteristics govern resistance and influence herbivore feeding. Host quality has been defined as physical and chemical plant attributes that contribute either negatively or positively to the fitness of an insect population or individual that feeds upon the plant's tissues (Leather, 1994). Physical factors include colour, texture, hairiness and hardness; chemical factors include water, nutrients and secondary plant metabolites. Nutrient levels influence palatability and acceptance as well as development rates of insects (Price *et al.*, 1990). Allelochemicals may influence feeding (Slansky, 1992), through pre-ingestive (as feeding stimulants or deterrents) or post-ingestive effects.

The long term and more sustainable control strategy to the plantain weevil borer is the development of resistance cultivars. The difficulty in conventional breeding of bananas and plantains has prompted efforts towards the use of genetic transformation for banana and plantain improvement.

Considerable work has been done in screening diverse *Musa* germplasms for weevil resistance in Africa and Asia (Fogain and Price, 1994; Kiggundu *et al.*, 2003). In Cameroon, the cultivar *Kedong kekang* (AAB) is resistant to the plantain weevil borer (Fogain and Price, 1994). The highland banana cultivars such as *Tereza*, *Nalukira* and *Nsowe* had intermediate resistance to plantain weevils (Kiggundu *et al.*, 2003). The diverse variability in the response of the weevils observed in *Musa* germplasm and hybrid testing suggested the availability of useful source of weevil resistance in *Musa* germplasm (Kiggundu *et al.*, 2003). Candidates for use in conventional breeding for weevil resistance have been selected on the basis of very low levels of weevil damage in the field.

Classical resistance mechanisms (Painter, 1951) have been investigated in *Musa* germplasm, and antibiosis (factors affecting larval performance), rather than antixenosis (attraction), appears to be the most important resistance mechanism in banana (Ortiz *et al.*, 1995; Abera *et al.*, 1999; Kiggundu, 2000).

2.7.5: Biological control

Biological control represents the combined effects of a natural enemy complex in suppressing pest populations. This involves the manipulation and/or use of natural agents and mechanisms to keep pest populations below economic damage or in tolerable balance (Pedigo, 1999; Norris *et al.*, 2003; Okolle, 2008). Natural agents for the management of the weevils include predatory arthropods (e.g. histerid beetles and ants), parasitoids, entomopathogens (*Beauveria bassiana*, *Metarrhizium anisopliae*) and fungal endophytes or *mycorrhizae* (Neuenschwander, 1987; Koppennenhofer *et al.*, 1992; Gold and Speijer, 1997; Haysim and Gold, 1999). The histerid beetle (*Plaeus javanus*) has been successfully introduced in the pacific region and Trinidad (Waterhouse and Norris, 1987), but failed to establish in Australia, Cameroon, Jamaica, Japan, Samoa, Tanzania and Uganda.

In laboratory infectivity tests conducted using different isolates of *B. bassiana* isolated from dead banana weevil and soil samples in East Africa (Nankinga, 1994) and in West Africa (Godonou *et al.*, 1998), weevil mortality of up to 100% was obtained. *B. bassiana* therefore, represents a promising alternative for the management of *C. sordidus* in Africa. In Ghana, pathogenicity tests conducted by Godonou (1999) on *B. bassiana* isolate IMI330194 (ex International Mycological Institute, UK) was identified as a possible biocontrol agent for *C. sordidus* based on its virulence against the insect pest and potential for mass production. Subsequent pot experiments undertaken to evaluate different formulations of *B. bassiana* isolate IMI330194 demonstrated that conidial

powder only and conidial powder plus oil palm kernel cake (a waste product obtained after extraction of oil from oil palm kernel) were the most effective, giving 75% mortality as compared to the 1% in untreated control (Godonou *et al.*, 2000). These experiments were undertaken to determine the performance of these formulations under field conditions in Ghana, firstly using artificial weevil release and secondly, under conditions of natural weevil infestation. Entomopathogenic fungi such as *Beauveria* spp and *Metarhizium* spp. have the potential to grow, multiply and persist on the insect they kill. Moreover, infected hosts can move away from the infection point, thereby spreading the pathogen throughout the pest's habitat.

Possibilities and considerations for classical biological control of plantain weevil have been reviewed (Greathead *et al.*, 1989; and Koppenhofer, 1993) while Schmitt (1993) provides a partial list of arthropod natural enemies. Koppenhofer *et al.*, (1992) and Koppenhofer (1993) found that endemic natural enemies of the weevil in Kenya did not show much promise. In contrast, ants (i.e. *Tetramorium guinense* (Mayr), *T. bicarinatum* (Nylander) and *Pheidole megacephala* Fabricius) contribute to control of banana weevil in Cuba (Roche and Abreu, 1983, Castineiras and Ponce, 1991). Based on the weevil's biology, Greathead *et al.* (1989) gave a 30% chance for a complete success in biological control. In Asia, a large number of beneficial organisms (parasites, predators and pathogens) occur naturally in banana plantations and may provide some degree of pest control. Predatory spiders, coccinellids, reduviids, ants, and parasitic flies and wasps are the most important beneficial insect groups active in banana plantations. Many natural enemies appear small and insignificant, or are nocturnally active, and may go largely unnoticed. Their real value is only appreciated when they are destroyed by inappropriate use of insecticide and there is pest resurgence. Nevertheless, exploration for

plantain weevil natural enemies in Asia followed by selection, quarantine and release of suitable species could establish herbivore equilibrium below economic threshold levels.

2.7.6: Chemical control

Chemical control of the weevil has been employed since the early 20th century. The chemicals were usually applied with baits such as flour and other substances (Froggatt, 1925; Cuille, 1950; Treverrow *et al.*, 1992), and this method was very effective (Simmonds, 1966). The persistent cyclodienes, dieldrin and aldrin, showed high efficacy against the plantain weevil as a soil treatment (Braithwaite, 1958). In the 1950's cyclodienes were widely used around the world (Edge, 1974) and was found to be effective for up to 2 yrs after application (Braithwaite, 1967). As early as 1970, the weevil has developed resistance to cyclodienes (Vilardebo, 1967; Shanahan and Goodyer, 1974).

The search for alternative chemicals (mainly organophosphates and carbamates) showed chlordecone (organochlorine), pirimiphos-ethyl, chlorpyrifos, prothiophos and ethoprophos as viable for biannual applications, but Diazinon was unsuitable because of its short residual action (Wright, 1977; Smith, 1995). Dipping corms in insecticide solution were found to be more effective than hot water treatment in the control of the plantain weevil borer in planting materials (Cardenas Murillo *et al.*, 1986). Chemical application is commonly recognized in planting holes (Franzmann, 1972; Fogain *et al.*, 2002), to plant traps (bait spraying) (Treverrow *et al.*, 1992) and to the bases of banana plants (butt sprays) (Braithwaite, 1958; Smith, 1995; Fogain *et al.*, 2002).

Systemic insecticides (dimethoate, omethoate, aldicarb, carbofuran, fenamiphos, fosthiazate, isazofos, monocrotophos, oxamyl, phorate and terbufos) absorbed by banana and plantain roots

can potentially control larvae following soil application (Gold *et al.*, 2003). Systemic insecticides offer protective treatment for plants, but have relatively shorter residual actions (Treverrow *et al.*, 1992).



CHAPTER THREE

3.0 METHODOLOGY

3.1: General procedures

3.1.1: Study location

The study was carried out at the Forest and Horticultural Crops Research Center (FOHCREC), Kade of the University of Ghana, which lies within latitude $6^{\circ} 09'$ and $6^{\circ} 06'$ N and longitude $0^{\circ} 55'$ and $0^{\circ} 49'$ W in the Kwaebibirem District of the Eastern Region. The Centre which is located in the semi-deciduous forest agro-ecological zone of Ghana is 135.9 m above sea level. The study location is characterized by a bimodal rainfall pattern with peaks in June and October with a short break in August and a dry season from December to March. The area has a thirty year average annual rainfall amount of 1284 mm and annual average temperature of 26.1°C (GMA, 2010). The total annual rainfall amount during the experimental period was 1327 mm.

3.1.2: Site description

Field studies to examine the attractiveness of host plant volatiles and pheromone (Cosmolure[®]) to *C. sordidus* and the effect of trap size on weevil catches were conducted on a plantain and cocoa intercrop farm ($06^{\circ} 08'\text{-N}$, $0^{\circ} 54'\text{-W}$). Selection of field was based on a preliminary survey using split pseudostem traps (Simmonds, 1966) to determine *C. sordidus* population. The field had steep slope topography with highest elevation of 693 ft and lowest elevation of 601 ft.



Plate 3.1: Study site (Plantain-cocoa intercrop field)

3.1.3: Farm history

The field which has a total size of 10 hectares was established in May 2011 on a land previously cropped to cocoa. Suckers of different cultivars were obtained from farmers' fields in Awaham, a farming community which is about 40 km from FOHCREC. Prior to planting, the suckers were pared. The plantains which were intercropped with cocoa to provide shade for the cocoa were planted at a spacing of 3 x 3 m. The most common cultivars were Apantu pa and Apem which are the False horn and French plantain respectively. Manual weeding using cutlass was done along the rows and when necessary hand irrigation using watering can was carried out during the dry season. The cocoa plants were mulched at the plant base with rice husk to conserve soil moisture.

3.1.4: Meteorological data

Data on weather conditions such as temperature, relative humidity, and dew point were obtained with the use of a thermohygrometer (Plate 3.2) whereas the monthly rainfall data was obtained from the Center's weather station.

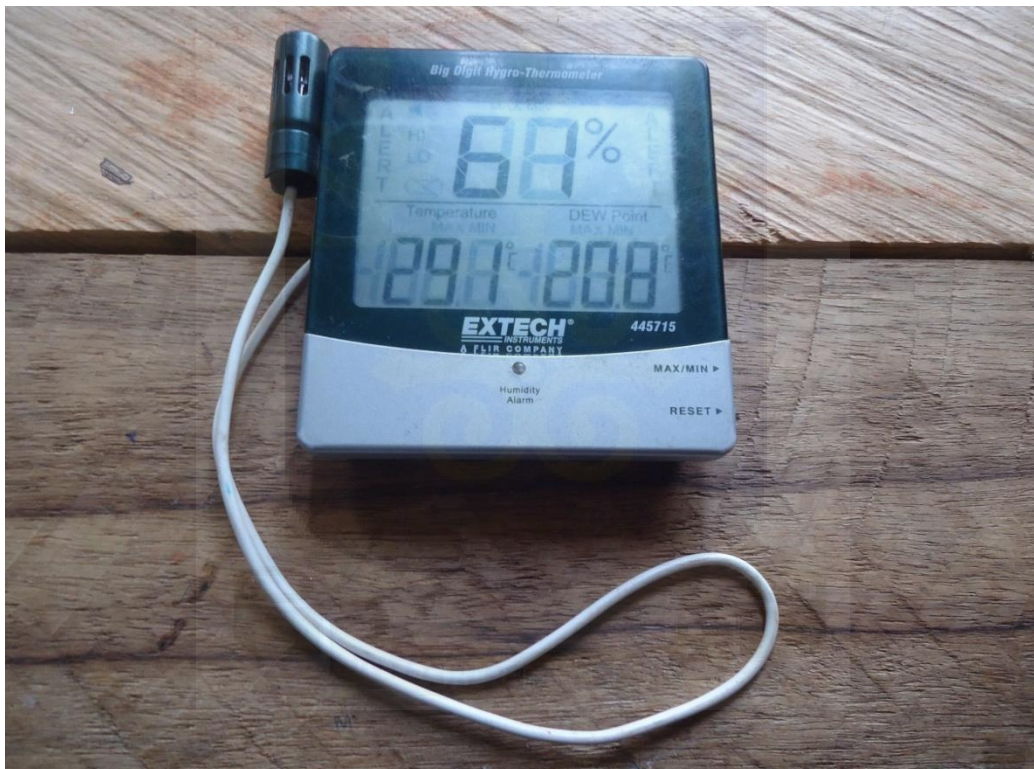
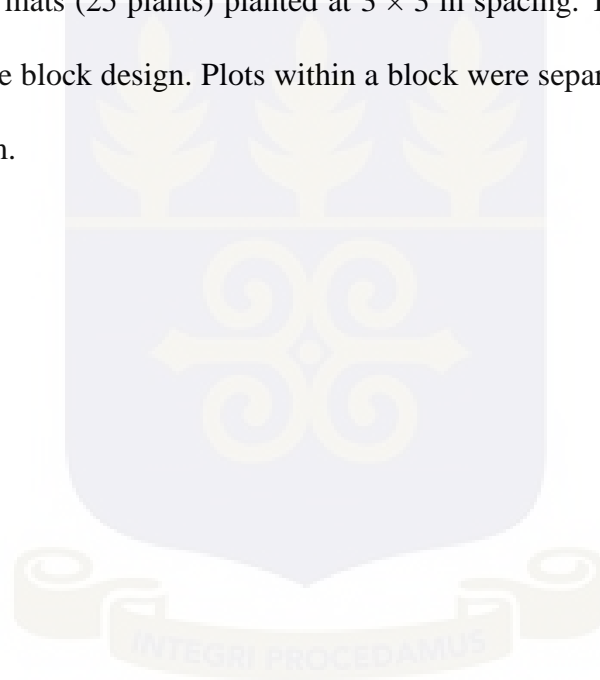


Plate 3.2: Thermohygrometer used to collect data on temp, humidity and dew point

3.2 Experiment 1: Evaluation of corm, pseudostem and pheromone traps for the monitoring of the plantain weevil borer, *C. sordidus* in Kade.

3.2.1: Treatments and experimental design

The trial comprised of three treatments (three different odour sources) and a control. The treatments were: 1) corm 2) pseudostem 3) pheromone (Cosmolure[®]) and 4) pitfall (control). The field trial consisted of four (4) blocks and each block was considered a replicate. Each block was divided into four plots and treatments allocated to the plots at random. Each plot measuring 144 m²: 5 rows of 5 plantain mats (25 plants) planted at 3 × 3 m spacing. Treatments were arranged in a randomized complete block design. Plots within a block were separated by 9 m and distance between blocks was 18 m.

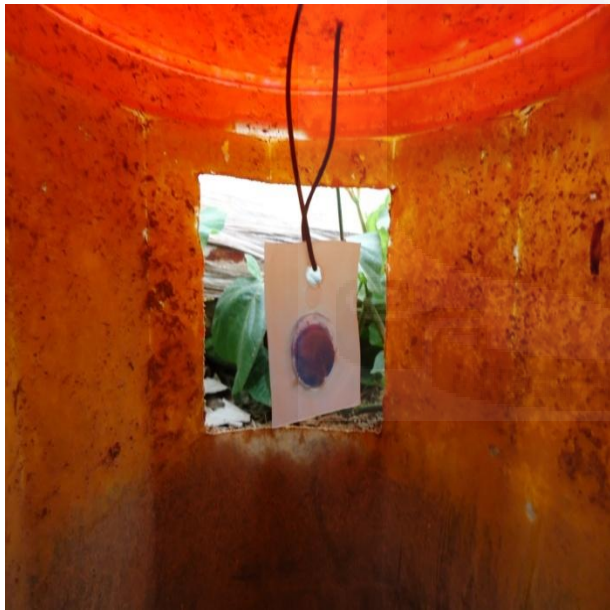




A-corm



B-pseudostem



C-pheromone



D-pitfall (control)

Plate 3.3: Treatments used in the study (A, B, C and D)

3.2.2: Trap preparation and design

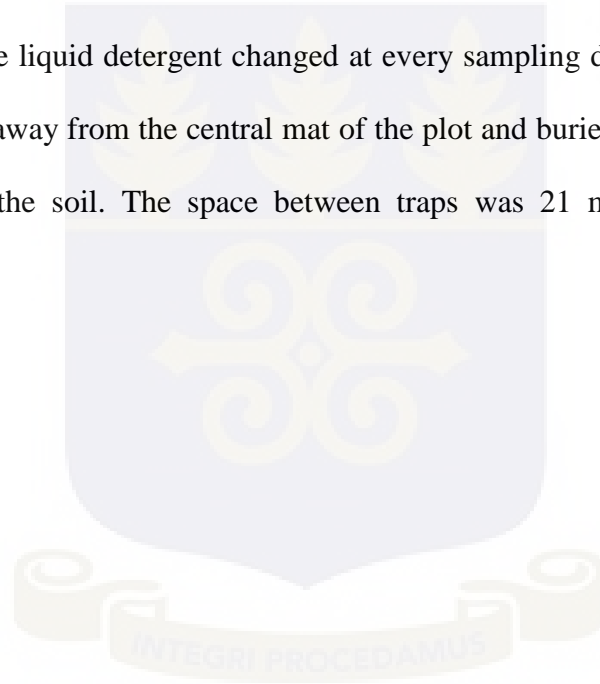
Pitfall traps were made from 8-liter plastic buckets (24 cm height, 22 cm rim diameter) purchased from a local market in Accra. Two cut windows of 10 × 10 cm were made at opposite sides of the bucket at a height of 10 cm from the bottom, to allow adult *C. sordidus* to enter the traps (Tinzaara *et al.*, 2000). The buckets were then filled with a liquid detergent and buried such that the windows are the same level with the soil. The liquid detergent solution (0.5 liter) was placed in the trap as a killing agent and was changed during each sampling. In each pheromone trap, a single pheromone lure was suspended by a metal wire in the middle of the cut windows from top end of the trap. The pheromones were obtained from ChemTica International, San Jose, Costa Rica. These were shipped in closed polythene bags delivered through courier services and it was stored in a freezer until use. The pheromones were used within 30 minutes after removal from the freezer so as to minimize the loss of potency. The pitfall traps (control) had only liquid detergent.

Pseudostem plant materials were selected from freshly harvested plants of not more than one week. Only one trap was prepared from each plant and pseudostems with internal necrosis/damage/tunnels were discarded. Pseudostem traps were 30 cm length (obtained from 30-60 cm above the collar), bisected longitudinally and each half placed ventrally and directed next to the mat of the plant (Simmonds, 1959; Gowen, 1995). Corm disk traps (selected from the widest part of the corm) were prepared from plants used for pseudostem traps and corms with internal damage/necrosis/tunnels were discarded. Each corm had an average circumference of at least 60 cm and cut to a thickness of 5 cm.

3.2.3: Trap placement and replacement

Traps prepared from pseudostems were split into two halves and placed 5 cm on opposite sides of the central mat of the plot and regarded as a single trap. Traps prepared from the corm were also placed 5cm away from the central mat of a plot. Traps prepared from pseudostem and corm was replaced every two weeks.

The pheromone-baited pitfall traps were placed 30 cm away from the centre of the plot and buried 10 cm into the soil such that the cut windows flush against the soil. Pheromone lures were replaced monthly and the liquid detergent changed at every sampling day. Pitfall traps (control) were also placed 30 cm away from the central mat of the plot and buried 10 cm such that the cut windows flush against the soil. The space between traps was 21 m to minimize treatment interference.



3.2.4: Sampling and data collection

At each sampling, the maximum and minimum temperatures, relative humidities and dew point at every individual treatment were recorded using a thermohygrometer. At the end of every week the data on weather conditions was averaged as the weekly total. The collected *C. sordidus* (target) and other insects (non-target) were put in vials containing 70% alcohol for preservation until sex determination.

Treatments were sampled every third and seventh day of the week (INIBAP, 1988) for twelve weeks during the three periods (Major rainy season, Minor rainy season and Dry season). Trap inspection commenced at 6:00 a.m and the number of weevils collected was recorded on a data sheet. The stored weevils in vials were labelled with treatment name, block name, and date of sampling. These vials were kept in the laboratory for sex determination. The data sheet contained information on treatment, block, temperature, humidity, dew point, number of weevils (target) and number of insects (non-target). Both *C. sordidus* and other insects (non-target) were sampled and collected to provide information on insect diversity in plantain fields and predators associated with the *C. sordidus*.

Weevils



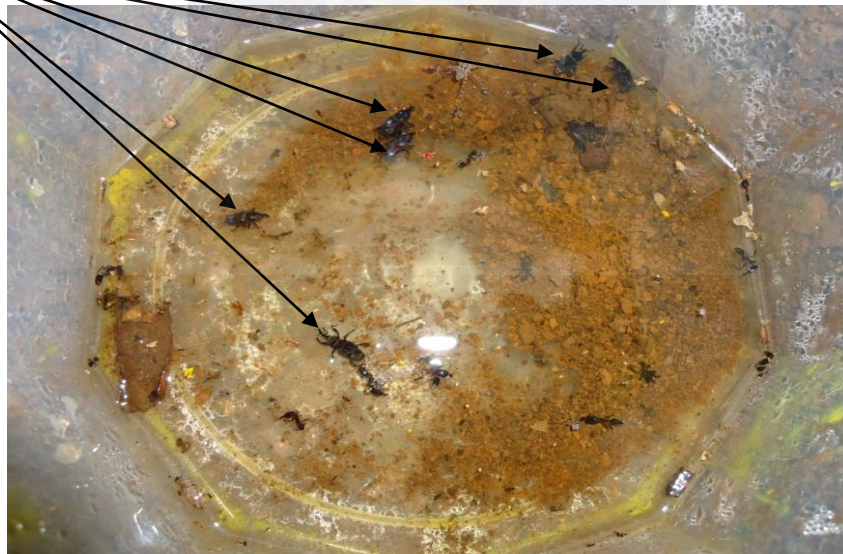
A (fermented pseudostem)

Weevils



B (corn)

Weevils



C (pheromone trap)

Plate 3.4: Captured weevils on different treatments. A= pseudostem, B= corn, and C= pheromone

3.2.5: *Cosmopolites sordidus* sex determination

Weevils collected from traps were stored in vials containing 70% alcohol and kept in a cool dry place until the end of each trial. Morphological identification keys by Cuille (1950), Gold *et al.*, (1999c), Longoria (1968) and Roth and Willis (1963) were used to distinguish males and females. This was done with the help of Mr. Davies, the curator/lab technician at ARPPIS. The major characters used to sex were the shape of the last abdominal sternite which in males, is sharply curved downwards than in females (Roth and Willis, 1963). Also punctuations on the rostrum of the females do not extend beyond the antenna as is the case of the males (Longoria, 1968). The females tend to be mostly larger than the males (Cuille, 1950; Gold *et al.*, 1999c). Non-target insects were also identified to family level with the intention of determining the insect diversity within plantain farms and *C. sordidus* predators.



Plate 3.6: Male *C. sordidus* (last abdominal sternite sharply curved)



Plate 3.5: Female *C. sordidus* (last abdominal sternite not sharply curved)



Plate 3.7: Weevils preserved in 70% alcohol

3.2.6: Corm damage assessment

After the 9 months trial *C. sordidus* damage was assessed on corms of selected plants from the sixteen experimental plots as an estimate of peripheral and cross sectional damage from the central cylinder and outer cortex using the methods developed by Gold *et al.* (1994b). A plant was selected from each of the sixteen plots for damage assessment, representing four plants for each treatment (corm, pheromone, pitfall and pseudostem). The pseudostem of each plant was cut 10 cm above the collar and the corm uprooted and thinly pared 10 cm below the collar and estimating the percentage surface area that was damaged by *C. sordidus* larvae (in galleries). Cross sections were made at the collar and 5 cm below the collar. For each cross section, *C. sordidus* damage was estimated as the percentage of damaged tissue (in galleries) in the central cylinder and in the cortex.



Plate 3.8: Damaged corm with internal galleries

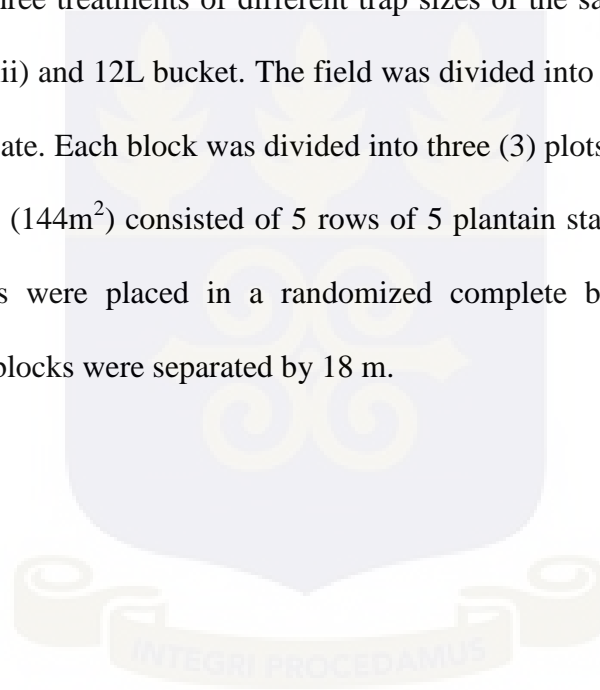


3.3: Experiment 2: Effect of trap size on plantain weevil borer catches in pheromone-baited pitfall traps.

Pheromone efficacy is influenced by parameters such as trap colour, size and distance. This experiment was aimed at evaluating the influence of trap size on the efficacy of pheromone-baited pitfall traps in the field.

3.3.1: Treatments and experimental design

The trial comprised of three treatments of different trap sizes of the same design and colour: i) 4L bucket ii) 8L bucket iii) and 12L bucket. The field was divided into three (3) blocks and each block considered a replicate. Each block was divided into three (3) plots and treatments allocated to plots at random. Plots (144m²) consisted of 5 rows of 5 plantain stands planted in a 3 × 3 m arrangement. Treatments were placed in a randomized complete block design. Plots were separated by 9 m whilst blocks were separated by 18 m.





4L pitfall trap



8L pitfall trap



12L pitfall trap

Plate 3.9: different sizes of pitfall traps set in the field

3.3.2: Trap preparation and design

Pitfall traps were made from 4L, 8L, and 12L plastic buckets purchased from a local market in Accra. Two windows of sizes 10×10 cm were created on two sides of each of the buckets. The purpose was to allow adult *C. sordidus* to enter the traps (Tinzaara et al., 2000). The buckets were then filled with a liquid detergent and buried such that the cuts flush against the soil. The liquid detergent solution (0.5L) was placed in the trap as a killing agent and was changed on

every sampling. In each pitfall trap, a single pheromone lure (Cosmolure) was suspended by a metal wire in the middle of the cut windows from top end of the trap. Each lure contained 90 mg of pheromone based on manufacturer's recommendation. The lures were used within 30 minutes after removal from the freezer, to minimize the influence of weather conditions on the pheromone potency.

3.3.3: Trap placement and replacement.

The pheromone-baited pitfall traps (4L, 8L, and 12L) were placed 30 cm away from the central mat of the plot and buried 10 cm into the soil such that the cut windows flush against the soil, the cut windows were faced towards the plantain mat. Pheromone lures were replaced monthly and traps were separated by 21 m in order to minimize treatment interference.

3.3.4 Sampling and data collection.

The materials used for data collection were thermohygrometer and data sheet. The thermohygrometer was used to take data on the maximum and minimum temperatures, relative humidities and dew point at every individual treatment. At the end of every week these data on weather conditions were averaged as the weekly total.

Treatments were sampled twice a week (Tuesday and Saturday) for eight weeks period. Trap inspection began at 6:00 a.m and ended at 7:00 a.m. and collected weevils were recorded. The following data were collected: number of weevils (target), temperature, humidity, dew point.

3.4: Experiment 3: Varietal preference of *C. sordidus* to three major plantain cultivars.

This experiment was aimed at finding a variety that could potentially be used by farmers as trap crops and also search for most suitable cultivars for the trapping of the plantain weevil borer in plantain farms.

3.4.1: Experimental site

This study was conducted as an outdoor cage experiment behind the main administrative block of the Forest and Horticultural Crops Research Center, Kade to evaluate the preference of the plantain weevil borer Germar, *C. sordidus* for three plantain cultivars (*Apem*, *Apantu pa*, and *Brodewuio*). These cultivars were selected because of their importance as the most preferred cultivars based on (longevity, sucker production and suitability for ‘fufu’ preparation). Suckers obtained from the centre were established in June 2012. The suckers were nursed in 5L polythene bags filled with soil and mulched with rice husk for a three month period before being used in the trial. Conditions at the nursery were similar for all cultivars in terms of amount of water, mulching, weeding.

3.4.2: Insect trapping and rearing

Adult weevils were trapped from neighboring plantain fields at the Center using split pseudostems (Simmonds, 1966). The size and shape of the pseudostem traps were similar to those described previously. The pseudostem were bisected longitudinally and each half placed (with the cut surface ventral) and directed next to the mat of the plant. Traps were inspected every three days for weevils (INIBAP, 1988). Collected weevils were reared in wooden cages (45×35×35cm) with nylon screen net on all sides on fresh *Musa* pseudostems at room temperature. The pseudostem in the cages was changed weekly.



Plate 3.10: Pseudostem traps set to collect weevils for cage experiment

3.4.3: Treatments and experimental procedure

Large cube-shaped PVC-frame, fabric netting cages (125 × 125 × 125 cm) with zips on one side to facilitate easy access to experimental plants were used in this experiment (Plate 3.11). The cultivars (treatment) evaluated were i) *Apem* ii) *Apantu pa* iii) *Brodewuio* and iv) Yam (control). The three plantain (AAB) cultivars used in this study were collected from the FOHCREC, Kade *Musa* collection. The three Ghanaian cultivars had been classified using their local names, the *Brodewuio*, *Apantu pa* and *Apem* (Karikari, 1971). This trial was conducted in four experiments with four cages in sixteen replicates at monthly intervals. In every trial the cages were divided into five sections (four corners and a middle section) and the plantain cultivars with height and girth of about 0.75 m and 25 cm respectively and yam (control) were randomly allocated to the four corners. Part of the exposed corm of these cultivars was slightly cut to serve as source of volatiles (kairomones). The cultivars were tagged with cultivar name, replicate number and plot number (corner) for easy data collection. In each replicate (cage), 10 weevils of both sexes, previously starved for 12 hrs were released from a Petri dish placed at the center of a cage at night (since the weevils have been shown to be active at night). Water was

sprinkled on the plants every 48 hrs to maintain the moisture level, as the plantain weevil borer is susceptible to desiccation.



Plate 3.11: Experimental cage setup with three plantain cultivars.

3.4.4: Sampling and data collection

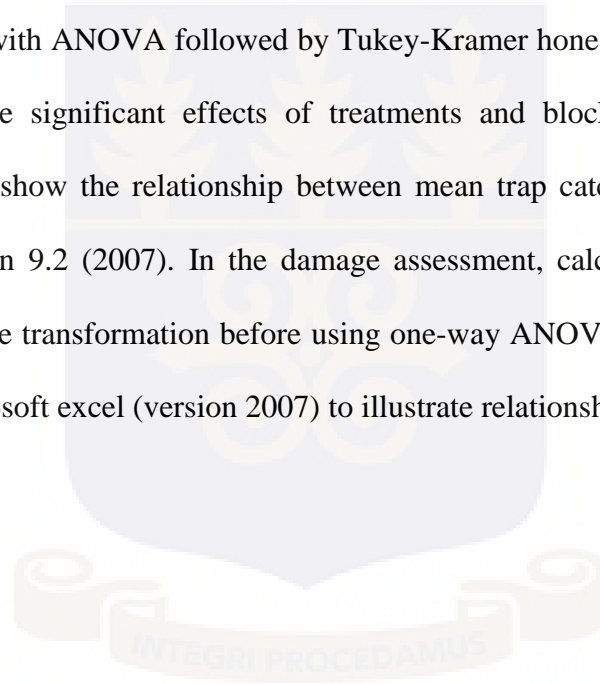
Destructive sampling was carried out after one week of the start of the experiment on all the cultivars and weevils found on each plant were collected counted and recorded. The thermohygrometer was set inside the cages to record daily weather conditions.



Plate 3.12: Destructive Sampling of plantain cultivars after a week

3.5: Statistical analyses

Data for each season was analysed and presented separately. Trap capture data were not normally distributed and thus were transformed using the square root transformation method. The data were first analyzed using standard least square (JMPIN version 10.0, SAS Institute 2010) to determine the effect of treatment, weeks and week*treatment interaction. Because the week*treatment interaction was not significant the data was pooled and analyzed using one-way ANOVA for both treatment, trap size and cultivar preference evaluation. Seasonal mean trap captures were analysed with ANOVA followed by Tukey-Kramer honestly significant difference (HSD) test to determine significant effects of treatments and blocks. Pearson correlation coefficient was used to show the relationship between mean trap catches and weather factors using GENSTAT version 9.2 (2007). In the damage assessment, calculated percentages were transformed using arcsine transformation before using one-way ANOVA. Linear and bar graphs were plotted using Microsoft excel (version 2007) to illustrate relationship among variables.



CHAPTER FOUR

4.0 RESULTS

4.1: Evaluation of trap performance for the monitoring of *C. sordidus*

During the major rainy season (June – Aug, 2012), 327 weevils were captured from all traps in a 12 week trial. A total of 257 (78.59%) weevils were attracted by pheromone-baited pitfall traps, 43 (13.15%) weevils were attracted by corm traps, 27 (8.26%) weevils were attracted by pseudostem traps and unbaited pitfall traps (control) attracted 0 (0%). The standard least square ANOVA did not show any significant difference among the weeks ($F= 0.57$; $d.f= 11, 144$; $P= 0.8517$) and week*treatment interaction ($F= 0.45$; $d.f= 33, 144$; $P= 0.9956$), however a significant difference existed among the treatments for total number of weevils attracted ($F= 39.13$; $d.f= 3, 185$; $P<0.0001$) (Appendix 5). The pheromone-baited traps attracted significantly more weevils than the corm traps ($P<0.0001$), pseudostem traps ($P<0.0001$) and pitfall traps ($P<0.0001$), however the other traps were not significantly different from each other. Corm attracted a similar number of weevils as pseudostem ($P= 0.9323$) and pitfall traps ($P= 0.3758$), pseudostem and pitfall also attracted a similar weevil number ($P= 0.7434$). Comparing the means, the results showed that pheromone-baited traps attracted mean of 5.4 ± 0.7 weevils per week, followed by corm traps (0.9 ± 0.2) weevils per week, and pseudostem traps (0.6 ± 0.1) weevils per week. No weevils were captured by the pitfall traps (Fig. 4.2). The weevil catches were similar among the weeks for corm except for week 10 with a mean of 3.3 ± 1.8 weevils while pheromone traps have similar catches among the weeks except for week 1, 4, and 12 with means of 2.8 ± 0.7 , 2.8 ± 1.2 and 3.0 ± 1.4 respectively. The performance of pseudostem traps was similar throughout the 12 weeks trial (Appendix 2).

During the minor rainy season (Sept – Nov, 2012) 298 weevils were collected. A total of 156 (52.35%) weevils were captured by pheromone-baited traps, corm traps captured 91 (30.54%) weevils, pseudostem traps captured 51 (17.11%) weevils and 0 (0%) weevils were captured from the pitfall traps (control). The standard least square ANOVA showed no significant difference among the weeks ($F= 0.72$, $d.f= 11, 144$; $P= 0.7198$) and the week*treatment interaction ($F= 0.73$; $d.f= 33, 144$; $P= 0.8505$). However, the result showed a significant difference among the treatments for total number of weevils attracted ($F= 20.58$; $d.f= 3, 185$; $P<0.0001$) (Appendix 6). The pheromone-baited traps attracted significantly more weevils than the corm traps ($P<0.0001$), pseudostem traps ($P< 0.0001$) and pitfall traps ($P< 0.0001$). The effectiveness of corm traps and pseudostem traps was similar ($P= 0.211$), but corm traps were significantly different from pitfall traps ($P< 0.001$), whereas there was no significant difference between pseudostem and pitfall ($P= 0.0658$). Pheromone-baited traps were more effective and attracted a mean of 3.3 ± 0.5 weevils per week, corm traps attracted a mean of 1.9 ± 0.3 weevils per week, pseudostem traps attracted a mean of 1.1 ± 0.2 weevils per week, while no weevils were attracted by pitfall traps (Fig. 4.3). The weekly total catches of weevils were similar in all the treatments except for week eleven and twelve, where catches by corm and pheromone traps were significantly different from catches by pitfall and pseudostem traps. Pheromone trap catches were also significantly different from the corm trap catches (Appendix 3).

During the dry season (Dec 2012 – Feb 2013) a total of 456 weevils were captured. Pheromone-baited traps captured 326 (71.49%) weevils, corm traps captured 62 (13.60%) weevils, pseudostem traps captured 68 (14.91%) weevils, and 0 (0%) weevils were captured from the pitfall traps (control). The standard least square ANOVA showed that there were no significant differences among the catches in the various weeks ($F= 0.94$; $d.f= 11, 144$; $P= 0.5068$) and the

week*treatment interaction ($F=0.99$; d.f= 33, 144; $P= 0.4939$), however the result showed a significant difference among the treatments for the total number of weevils attracted ($F= 53.58$; d.f= 3, 185; $P<0.0001$) (Appendix 7). The pheromone-baited traps attracted significantly more weevils than the corm traps ($P<0.0001$), pseudostem traps ($P<0.0001$) and pitfall traps ($P<0.0001$), but the effectiveness of corm was not significantly different from pseudostem traps ($P= 0.9965$) and pitfall traps ($P= 0.1220$). During the trial, pheromone traps were more effective and attracted a mean of 6.79 ± 0.73 weevils per week, corm traps attracted a mean of 1.29 ± 0.24 weevils per week, pseudostem traps attracted a mean of 1.42 ± 0.26 weevils per week, while no weevils were attracted in the pitfall traps (Fig.4.4). The pheromone traps showed significant increase in weevil collections (relative to week 1-6) with very high numbers from the seventh to the tenth week, whereas corm, pseudostem and pitfall traps captured a similar number across the weeks (Appendix 4).

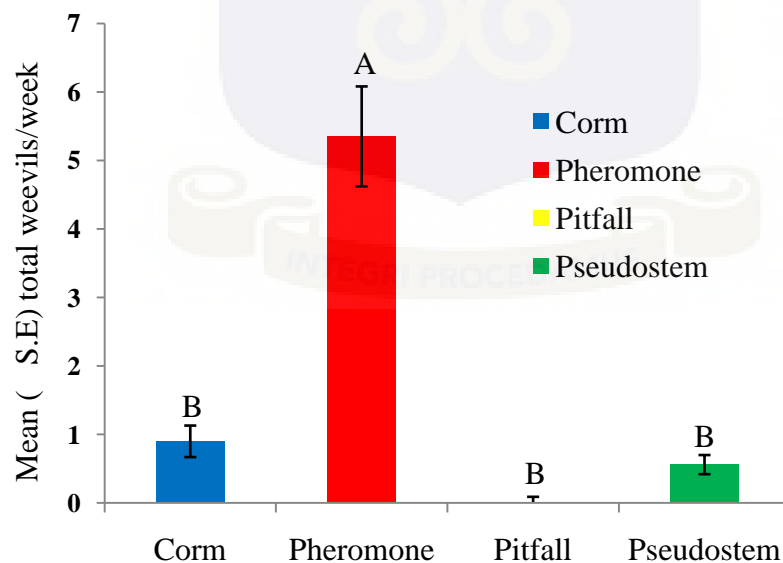


Figure 4.2: The mean (\pm S.E) total weevils/week attracted by different traps during June-Aug 2012 (major rainy season). Levels not connected by same letter are significantly different.

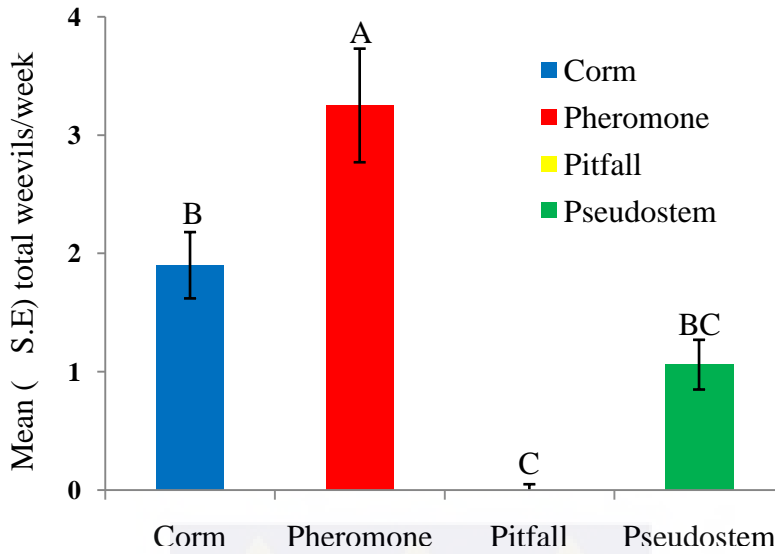


Figure 4.3: The mean (± S.E) total weevils/week attracted by different traps during Sept-Nov 2012 (Minor rainy season). Levels not connected by same letter are significantly different.

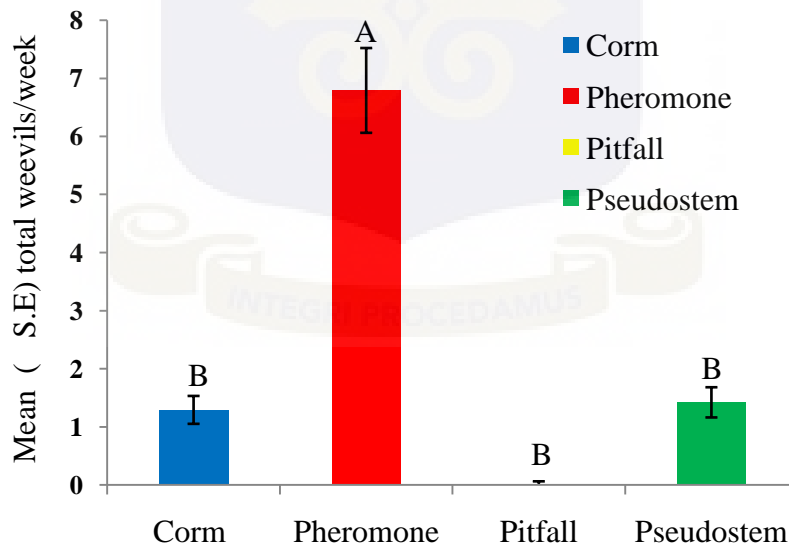


Figure 4.4: The mean (± S.E) total weevils/week attracted by different traps during Dec-Feb 2013 trial (dry season). Levels not connected by same letter are significantly different.

4.2: Sex ratio determination of *C. sordidus* from the different traps

A total of 327 weevils were captured by the traps during the major rainy season. Out of this number, 233 weevils were females and 94 were males, giving a ratio of 2.5:1 respectively. There was a significant difference among the treatments in the total number of female ($F= 34.94$; $d.f= 3, 185$; $P<0.0001$) and male ($F= 12.25$; $d.f= 3, 185$; $P<0.0001$) weevils attracted. Pheromone-baited traps attracted significantly more females than corm traps ($P<0.0001$), pitfall traps ($P<0.0001$) and pseudostem traps ($P<0.0001$). Pheromone-baited traps attracted a mean number of female weevils of 4.21 ± 0.61 , corm traps attracted a mean of 0.52 ± 0.13 and pseudostem traps attracted a mean of 0.31 ± 0.09 (Fig. 4.5). Corm traps attracted a similar number of female weevils to pitfall traps ($P= 0.6556$) and pseudostem traps ($P= 0.9671$), pseudostem traps and pitfall traps also attracted a similar female number ($P= 0.8995$). Pheromone-baited traps attracted the highest percentage of female weevils (75.10%), followed by corm and pseudostem traps which attracted 58.14% and 55.56% females, respectively. Male weevils attracted by pheromone-baited, corm and pseudostem traps were 24.90%, 41.86% and 44.44% respectively.

In the minor rainy season, a total of 298 weevils were sampled, consisting of 190 female weevils and 108 male weevils in the ratio 1.8:1, respectively. There were significant differences among the treatments in respect of total number of females ($F= 20.07$; $d.f= 3, 185$; $P<0.0001$) and male ($F= 11.20$; $d.f= 3, 185$; $P<0.0001$) weevils attracted. Pheromone traps attracted significantly more females than corm ($P<0.0001$), pitfall ($P<0.0001$) and pseudostem ($P<0.0001$). The number of female weevils attracted was not significantly different from those by corm and pseudostem traps; but corm was significantly different from pitfall (control). Pheromone traps were significantly more effective attracting a mean total of 2.29 ± 0.36 compared to 1.10 ± 0.19 , 0.56 ± 0.14 and 0.00 ± 0.03 by corm, pseudostem and pitfall respectively (fig. 4.6). Generally,

attraction of females by the different traps was as follows; Pheromone 110 females (70.52%), corm 53 females (58.24%), pseudostem 27 females (52.94%), and pitfall 0 females (0%). The percentage of males attracted were 29.48%, 41.76%, 47.06% and 0% by pheromone, corm, pseudostem and pitfall respectively.

Of the 456 weevils captured in the dry season, there were 306 female weevils and 150 male weevils, giving a female to male ratio of 2:1 respectively. There was a significant difference among the treatments in the total number of female ($F= 54.32$; $d.f= 3, 185$; $P<.0001$) and male ($F= 21.38$; $d.f= 3, 185$; $P<.0001$) weevils attracted. Pheromone traps attracted significantly more females than corm ($P<.0001$), pitfall ($P<.0001$), and pseudostem ($P<.0001$). Pheromone traps were significantly more effective, attracting a mean total weevil of 4.83 ± 0.54 female compared to 0.73 ± 0.15 , 0.81 ± 0.18 and 0.00 ± 0.06 by corm, pseudostem and pitfall respectively (Fig. 4.7). The number of female weevils attracted was not significantly different among corm, pseudostem and pitfall. The pheromone traps attracted the highest percentage of female weevils (71.17 %), followed by corm and pseudostem traps which attracted 56.45 % and 57.35 % females respectively. The percentage of males attracted were 28.83 %, 43.55 %, 42.65 % and 0% by pheromone, corm, pseudostem and pitfall respectively.

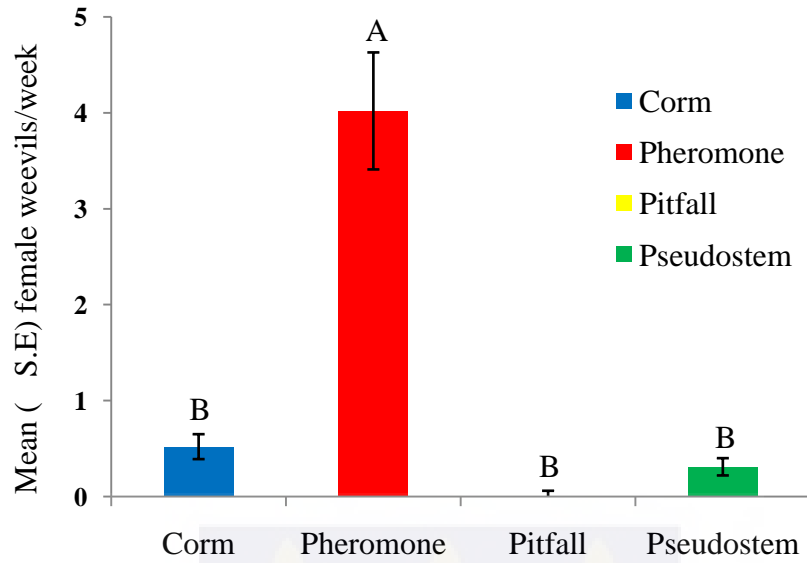


Figure 4.5: The mean (\pm S.E) female weevils/week attracted by different traps during June-Aug 2012 trial (major rainy season). Levels not connected by same letter are significantly different.

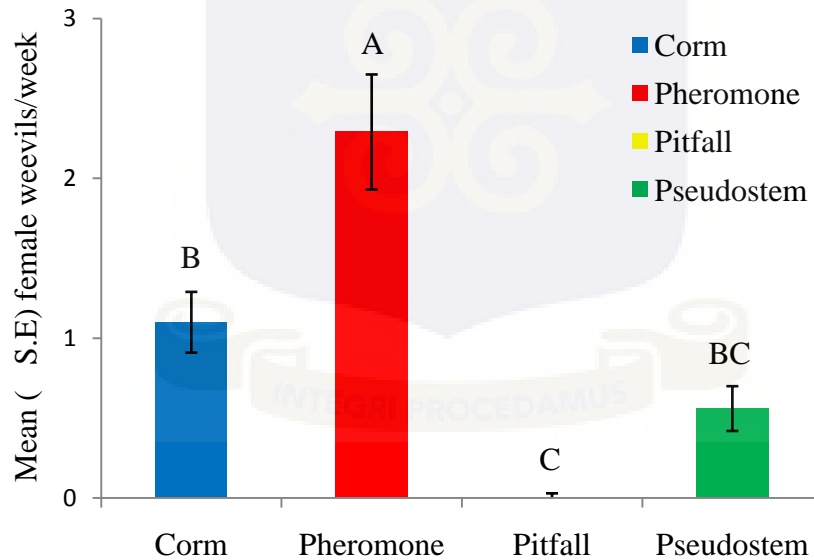


Figure 4.6: The mean (\pm S.E) female weevils/week attracted by different traps during Sept-Nov 2012 (minor rainy season). Levels not connected by same letter are significantly different.

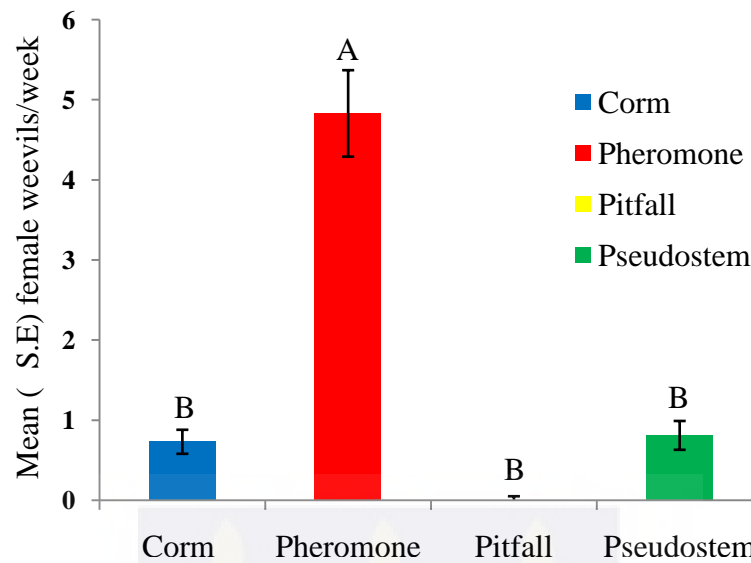


Figure 4.7: The mean (\pm S.E) female weevils/week attracted by different traps during Dec-Feb 2013 trial (dry season). Levels not connected by same letter are significantly different.

4.3: The effect of rainfall, temperature and relative humidity on trap catches

A multiple correlation analysis was used to determine the effect of some environmental factors (rainfall, temperature, humidity and dew point) on weekly trap catches during the period June-August 2012. The results show no significant relationship between environmental factors and weekly trap catches. Rainfall, humidity, and dew point have a weak negative relation with trap catches by corm, pheromone and pseudostem traps, while temperature has a weak positive relation with trap catches of corm, pheromone and pseudostem (Table 4.5).

The Sept-Nov trial (Minor rainy season) indicated no significant relationship between the environmental factors and the weekly trap catches. Humidity had a weak positive relation with pheromone trap catches and a negative relation with corm and pseudostem. Rainfall showed a weak positive relation with corm and pseudostem but had a weak negative relation with pheromone. Temperature had a weak negative relation with catches by the pheromone and corm traps whilst catches by pseudostem had a weak positive relation with temperature (Table 4.6).

The Dec 2012-Feb 2013 (Dry season) trial did not show any significant relationship between environmental factors (rainfall, temperature, humidity and dew point) and weekly trap catches. There was a weak positive correlation between catches by corm and pseudostem with rainfall, whilst rainfall had a negative correlation with catches by pheromone. Catches by the corm, pseudostem and pheromone traps showed negative correlation with humidity, temperature, and dew point (Table 4.7). During the trials temperature, humidity and dew point showed a significant relationship among themselves.

Table 4.5: Pearson correlation coefficient between trap catches of corm, pheromone and pseudostem and weather factors (rainfall, temperature, humidity and dew point) from June-August 2012 (Major rainy season).

Temp	-						
Rainfall	0.340	-					
Humidity	-0.929*	0.004	-				
Dew point	0.814*	0.629*	-0.583*	-			
Corm	0.061	-0.302	-0.110	-0.079	-		
Pheromone	0.196	-0.309	-0.326	-0.138	0.246	-	
Pseudostem	0.277	-0.050	-0.288	-0.348	0.301	-0.078	-
	Temp	Rainfall	Humidity	Dew point	Corm	Pheromone	Pseudostem

*Significant at $P < 0.05$

Table 4.6: Pearson correlation coefficient between trap catches of corm, pheromone and pseudostem and weather factors (rainfall, temperature, humidity and dew point) from Sept-Nov 2012 (Minor rainy season).

Temp.	-						
Humidity	-0.707*	-					
Dew point	0.609*	-0.093	-				
Rainfall	-0.036	0.333	0.278	-			
Pheromone	-0.333	0.283	-0.214	-0.017	-		
Corm	-0.280	0.412	0.056	0.297	0.148	-	
Pseudostem	0.526	-0.460	0.051	0.048	-0.024	-0.441	-
	Temp.	Humidity	Dew point	Rainfall	Pheromone	Corm	Pseudostem

*Significant at $P < 0.05$

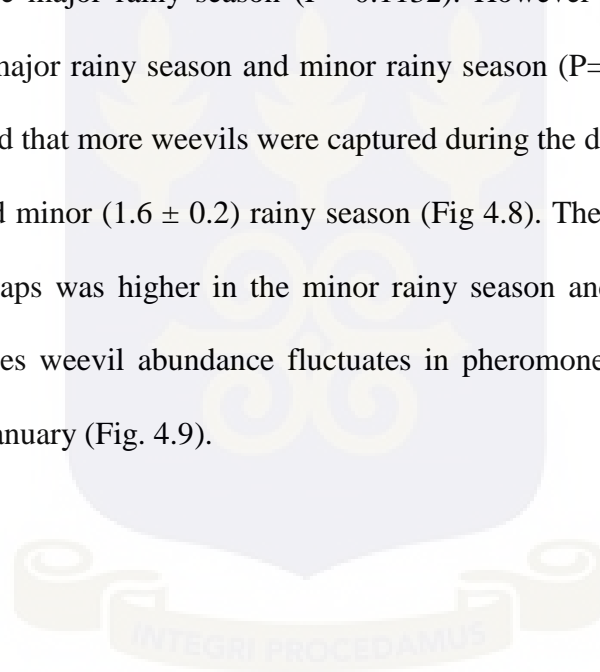
Table 4.7: Pearson correlation coefficient between trap catches of corm, pheromone and pseudostem and weather factors (rainfall, temperature, humidity and dew point) from December 2012-February 2012.

Temp.	-						
Humidity	0.487	-					
Rainfall	0.111	0.395	-				
Dew point	0.958*	0.712*	0.220	-			
Corm	-0.278	-0.035	0.039	-0.223	-		
Pheromone	-0.043	-0.378	-0.394	-0.182	-0.353	-	
Pseudostem	-0.552	-0.102	0.115	-0.552	0.516	0.141	-
	Temp.	humidity	rainfall	Dew point	corm	pheromone	Pseudostem

*Significant at $P < 0.05$

4.4: Distribution and seasonal abundance of *Cosmopolites sordidus* in the field.

A total of 1081 plantain weevil borers were captured by the traps during the study period, out of which 327 weevils were captured in the major rainy season representing 30.25%, 298 weevils were captured in the minor rainy season representing 27.57% and 456 weevils were captured in the dry season representing 42.18%. There was a significant difference in the total number of weevils collected among the seasons ($F= 3.40$; $d.f= 2, 570$; $P< 0.034$) (Appendix 14). Catches during the dry season were significantly different from that of the minor rainy season ($P< 0.0388$) but not from the major rainy season ($P= 0.1132$). However there was no significant difference between the major rainy season and minor rainy season ($P= 0.8946$). Comparing the means, the results showed that more weevils were captured during the dry season (2.4 ± 0.3) than the major (1.7 ± 0.3) and minor (1.6 ± 0.2) rainy season (Fig 4.8). The weevil abundance in the corm and pseudostem traps was higher in the minor rainy season and dry season than in the major rainy season while weevil abundance fluctuates in pheromone traps and was lower in October and highest in January (Fig. 4.9).



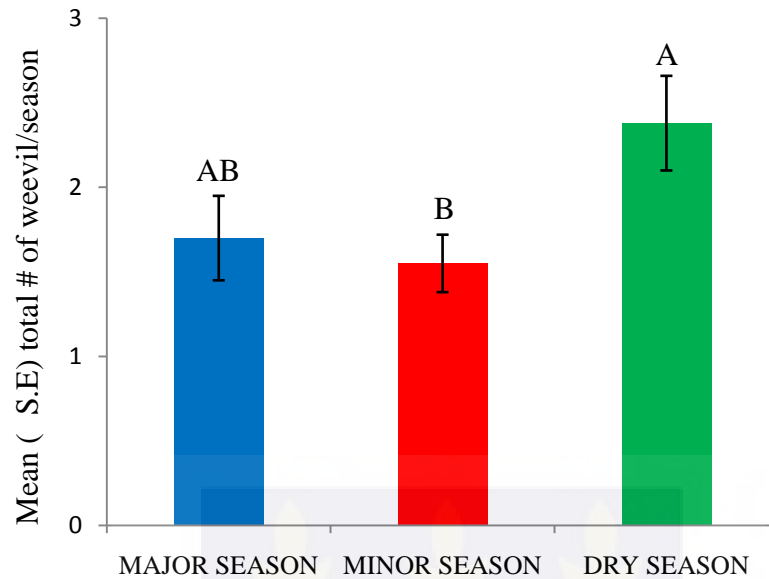


Figure 4.8: The mean (\pm S.E) total number of weevils attracted by all traps in the major rainy season (Jun-Aug), minor rainy season (Sept-Nov) and dry season (Dec-Feb). Levels not connected by same letter are significantly different.

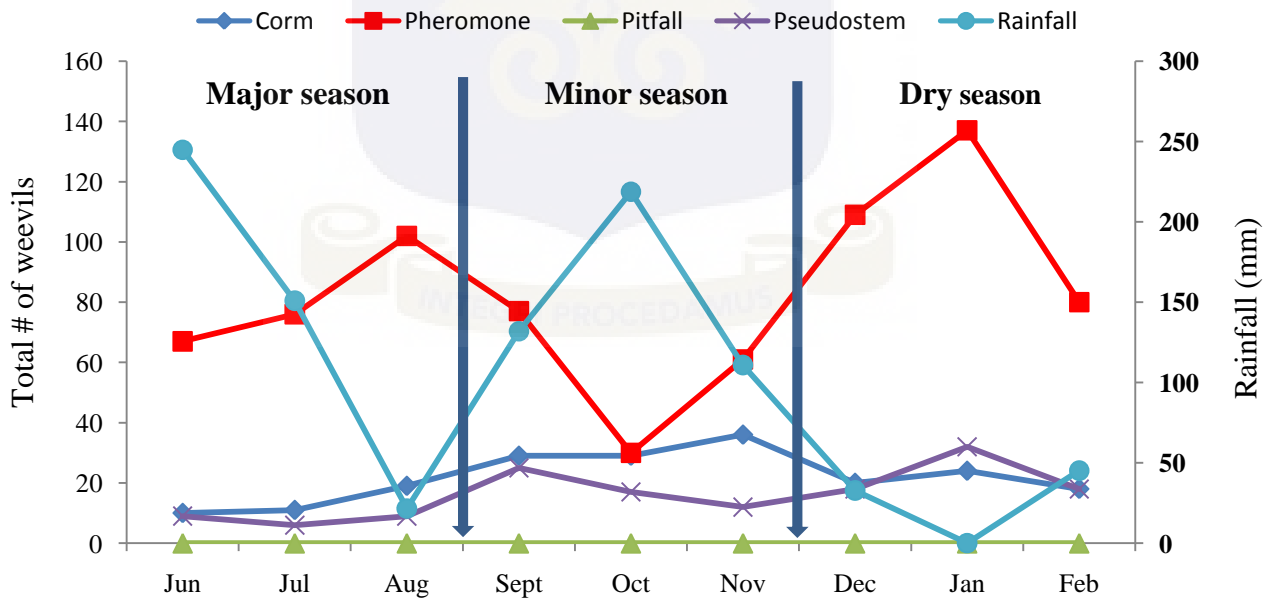


Figure 4.9: plot of treatment catches in the major rainy season (June-August, 2012), minor rainy season (September-November 2012) and dry season (December 2012-February 2013) in relation to rainfall patterns.

4.5: Relative population density fluctuation of *C. sordidus* in different seasons.

The One way ANOVA of mean adult populations between months showed no significant difference ($F= 1.70$, $d.f= 8$, 564 , $P= 0.095$). The plantain weevil borer, *C. sordidus* occurred throughout the sampling period from June 2012 to February 2013. The regression analysis indicated significant effects of monthly rainfall on *C. sordidus* abundance. The population density of the *C. sordidus* increased from December 2012 to January 2013 (highest peak) (Fig.4.10) corresponding to the driest months in Kade. However, the population gradually declined in February 2013 at the beginning of the rains. *C. sordidus* abundance was lowest in June and October corresponding with the highest rainfall peaks in Kade. The monthly population abundance was significantly related to rainfall ($R^2= 0.69$) and the average monthly temperatures ($R^2= 0.58$), with the population at its peak in January corresponding with the lowest temperatures (Fig. 4.11). The months of June and October with the highest temperatures had lower *C. sordidus* population abundance. The monthly *C. sordidus* population abundance was not significantly related to the average monthly relative humidity ($R^2= 0.20$). However, the highest populations in December and January corresponded to lower relative humidities (Fig. 4.12).

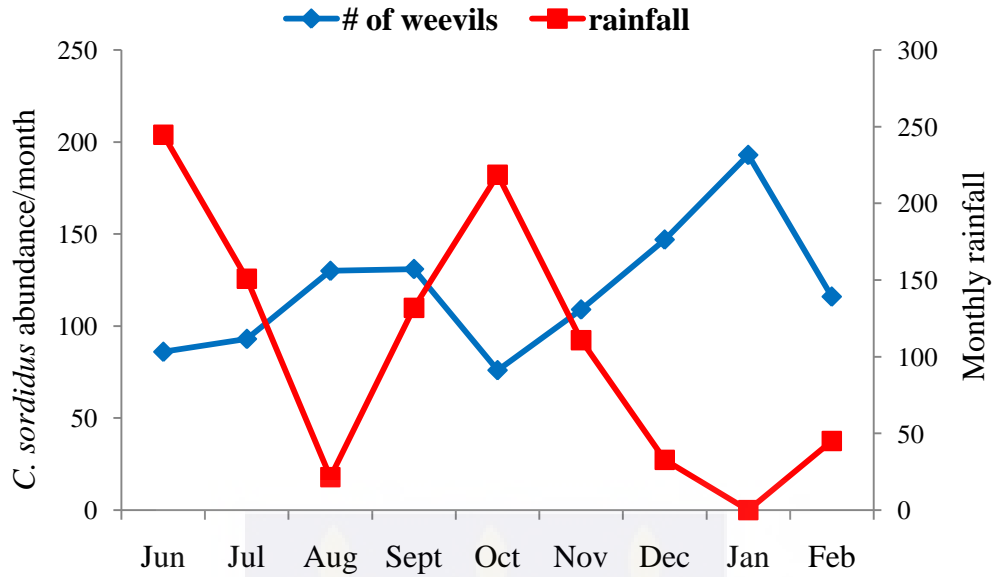


Figure 4.10: The effect of rainfall on monthly population abundance of *C. sordidus* during June 2012-Feb 2013. Abundance was determined using values from all traps (corn, pheromone, and pseudostem).

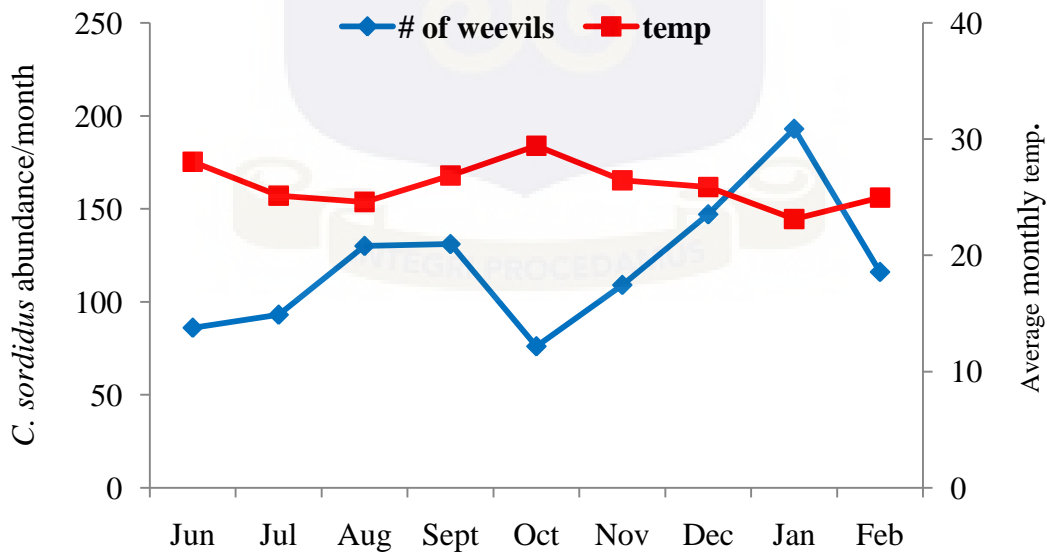


Figure 4.11: The effect of temperature on monthly population abundance of *C. sordidus* during June 2012-February 2013. Abundance was determined using values from all traps (corn, pheromone and pseudostem).

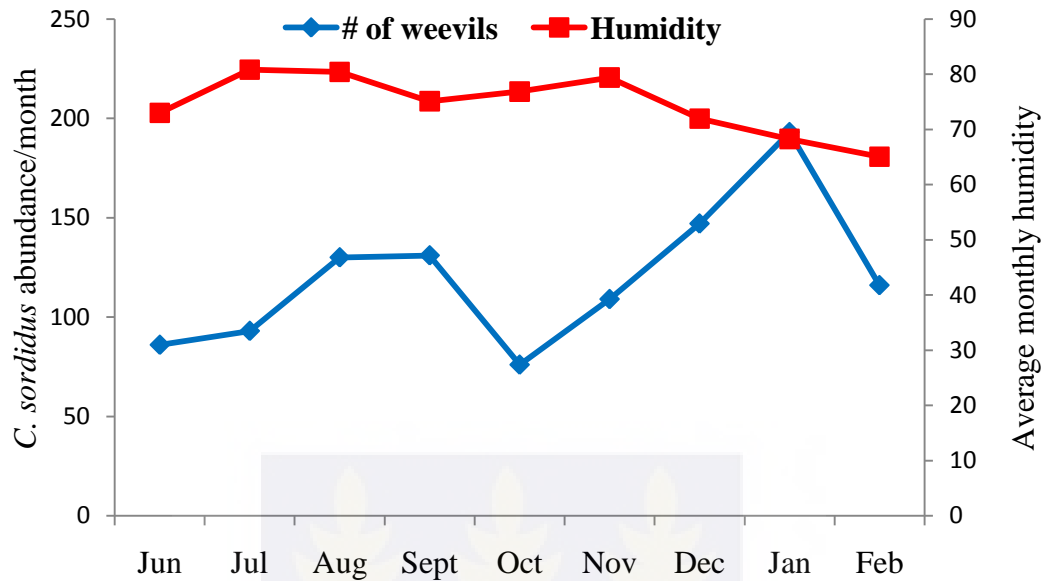
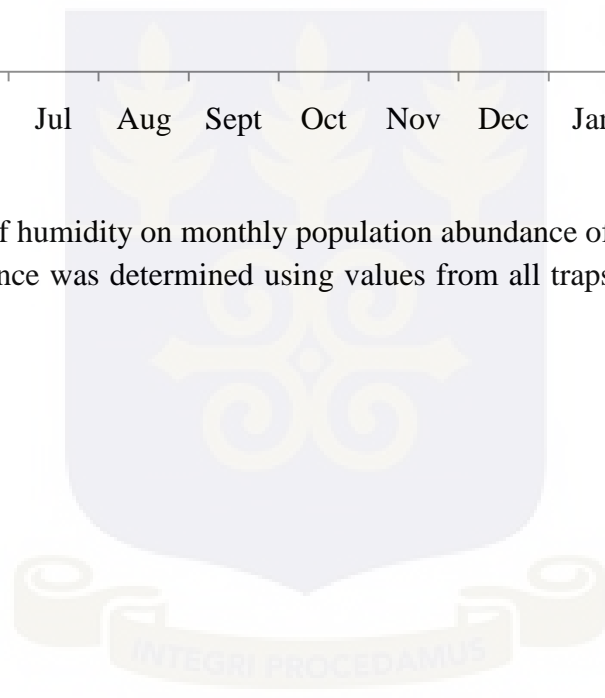


Figure 4.12: The effect of humidity on monthly population abundance of *C. sordidus* during June 2012-Feb 2013. Abundance was determined using values from all traps (corn, pheromone, and pseudostem).



4.6: Corm damage assessment

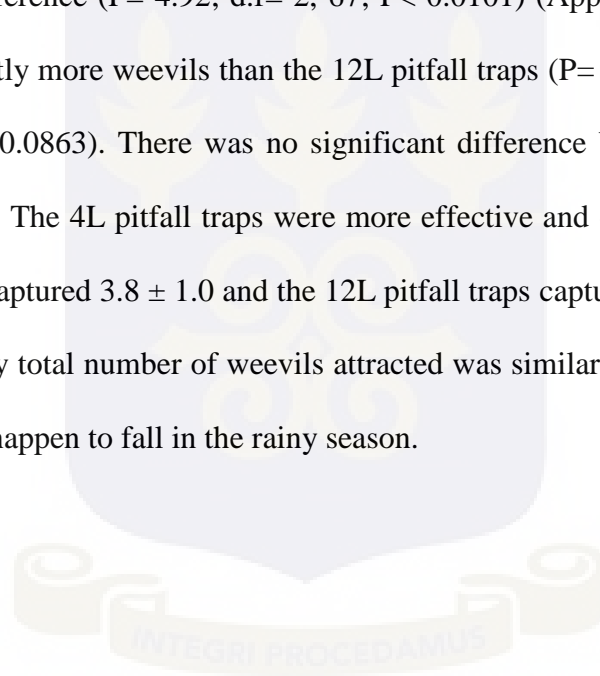
The data obtained from the assessment was pooled and analysed for peripheral and cross sectional damage. There was no significant difference in the level of corm damage between the treatment plots, that is in the peripheral corm and the cross-sectional corm damage assessment (Table 4.8). Plants from pheromone plots had less peripheral and cross-sectional corm damage with mean percentage of 12.25 and 15.50 respectively, whereas plants examined from pitfall trap plots had the most peripheral and cross-sectional percentage corm damage of 15.25 and 17.75 respectively. There was a significant difference between the peripheral and cross sectional corm damage ($F= 15.10$, $d.f= 1, 30$, $P< 0.001$), there was more percentage cross-sectional corm damage than peripheral corm damage with percentage means of 16.56 and 13.69 respectively (table not shown).

Table 4.8: Mean percentage (\pm S.E) number of galleries in plants assessed from different treatment plots.

Treatment plot	% Peripheral corm damage	% Cross sectional corm damage
Corm	13.00 \pm 1.08	16.00 \pm 1.47
Pheromone	12.25 \pm 0.63	15.50 \pm 1.19
Pitfall	15.25 \pm 0.48	17.75 \pm 1.11
Pseudostem	14.25 \pm 0.85	17.00 \pm 0.91
LSD (P= 0.05)	NS	NS

4.8: Effect of trap size on the attractiveness of pheromone-baited pitfall traps to *Cosmopolites sordidus*.

A total of 308 weevils were captured in an 8 week trial. The 4L pitfall traps captured 155 weevils representing 50.33%, the 8L pitfall traps captured 90 weevils representing 29.22%, and the 12L pitfall traps captured 63 weevils representing 20.45%. The standard least square ANOVA showed that there was no significant difference among the weeks ($F= 2.19$; $d.f= 7, 14$; $P= 0.053$) and the week*treatment interaction ($F= 0.62$; $d.f= 14, 46$; $P= 0.830$). However, the treatments showed a significant difference ($F= 4.92$; $d.f= 2, 67$; $P< 0.0101$) (Appendix 17). The 4L pitfall traps attracted significantly more weevils than the 12L pitfall traps ($P= 0.009$) but was similar to the 8L pitfall traps ($P= 0.0863$). There was no significant difference between the 8L and 12L pitfall traps ($P= 0.6448$). The 4L pitfall traps were more effective and captured a mean of 6.5 ± 1.0 , the 8L pitfall traps captured 3.8 ± 1.0 and the 12L pitfall traps captured 2.6 ± 0.6 weevils per week (Fig. 4.13). Weekly total number of weevils attracted was similar among the weeks except for week 6 and 8 which happen to fall in the rainy season.



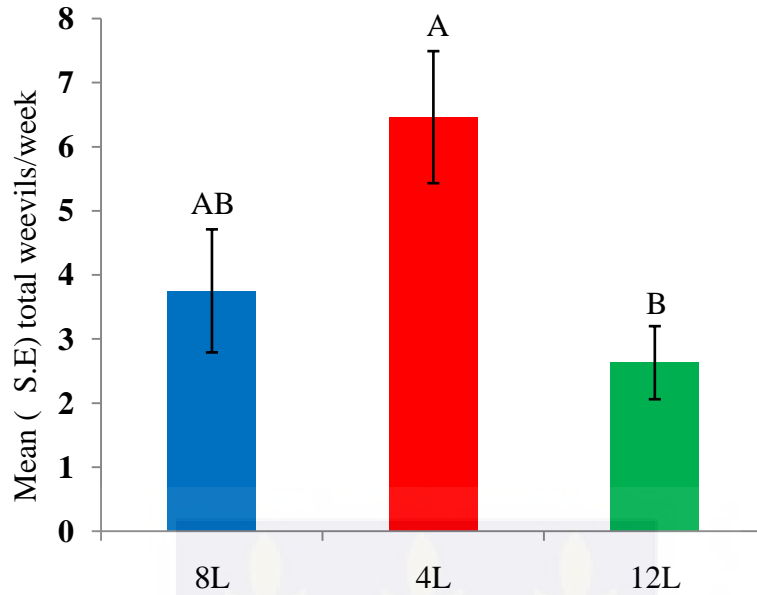


Figure 4.13: The mean (\pm S.E) total weevils/week captured by different trap sizes during Jan-Feb 2013 trial. Levels not connected by same letter are significantly different.

4.9: The effects of rainfall, temperature and relative humidity on different trap catches.

A multiple correlation analyses showed no significant relation between weather factors (temperature, rainfall, dew point and humidity) and weekly catches by various trap sizes during the period Jan-Feb 2013. Rainfall was positively related to the 12L and 4L traps whilst temperature was negatively related to 12L and 4L traps. The 8L traps had a negative and positive relation with rainfall and temperature respectively. Humidity was negatively related to the 12L and 8L traps and positively to the 4L traps (Table 4.9)

Table 4.9: Pearson correlation coefficient between trap catches of 12L, 4L and 8L with environmental factors (rainfall, temperature, humidity and dew point) between Jan-Feb 2013.

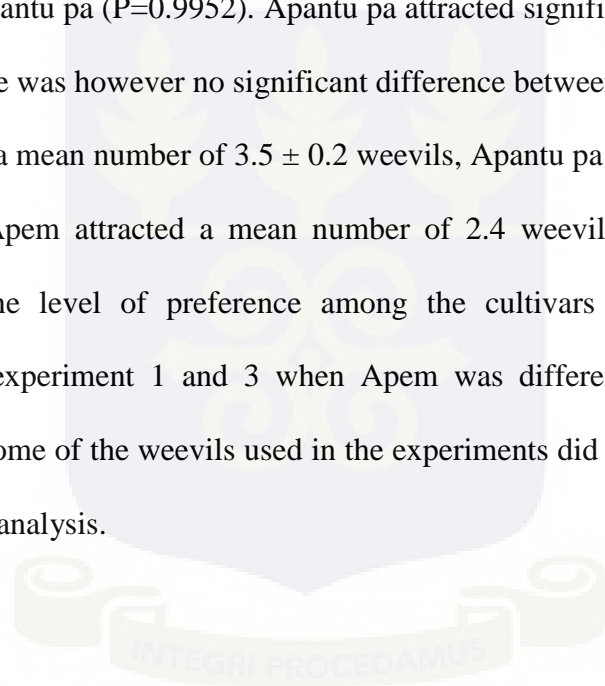
12L	-						
4L	0.675	-					
8L	0.722*	0.316	-				
Temp.	-0.051	-0.391	0.413	-			
Rainfall	0.227	0.163	-0.444	-0.361	-		
Dew point	-0.216	-0.383	0.160	0.658	-0.337	-	
Humidity	-0.043	0.067	-0.156	-0.331	0.066	0.468	-
	12L	4L	8L	Temp	Rainfall	Dew point	Humidity

*Significant at $P < 0.05$



4.1.0: Preference test of Apem, Apantu pa, and Brodewuio cultivars to *C. sordidus*.

A total of 160 plantain weevil borers, *C. sordidus* were used in four experiments to evaluate the preference of the weevil to Apem, Apantu pa and Brodewuio cultivars. Brodewuio attracted 55 weevils representing 37.16%, Apantu pa attracted 54 weevils representing 36.49%, Apem attracted 39 weevils representing 26.35% and Yam (control) attracted no weevils. There was a significant difference among the cultivars ($F= 75.47$, $d.f= 3, 57$, $P< 0.0001$) (Appendix 18). Brodewuio attracted significantly more weevils than Apem ($P= 0.0018$), but attracted a similar number of weevils as Apantu pa ($P=0.9952$). Apantu pa attracted significantly more weevils than Apem ($P= 0.0038$). There was however no significant difference between Brodewuio and Apantu pa. Brodewuio attracted a mean number of 3.5 ± 0.2 weevils, Apantu pa attracted a mean number of 3.4 ± 0.3 weevils, Apem attracted a mean number of 2.4 weevils and Yam attracted no weevils (Fig. 4.14). The level of preference among the cultivars was similar in all the experiments except in experiment 1 and 3 when Apem was different from Brodewuio and Apantu pa (Fig. 4.15). Some of the weevils used in the experiments did not make any choice and were not included in the analysis.



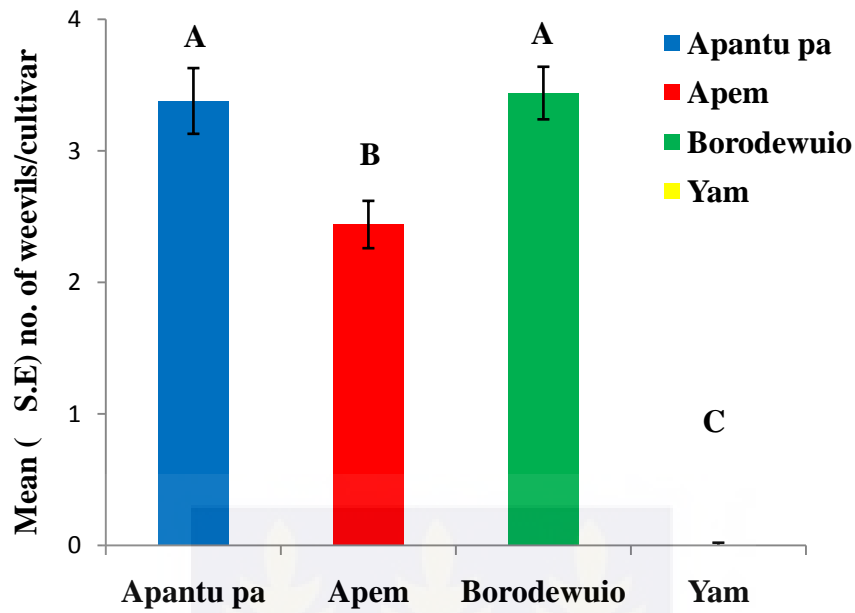


Figure 4.14: The mean (\pm S.E) total number of weevils attracted to different cultivars in all experiments. Levels not connected by same letter are significantly different.

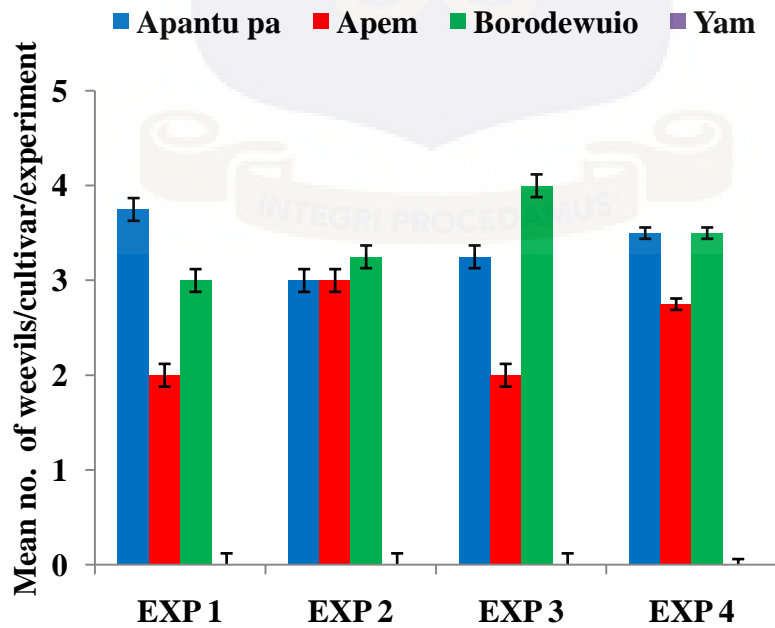


Figure 4.15: The mean (\pm S.E) number of weevils attracted by different cultivars per experiment.

CHAPTER FIVE

5.0 DISCUSSION

5.1: Trap evaluation for the monitoring of *C. sordidus*.

With the threats posed to plantain fields by *C. sordidus*, it is important to determine and deploy the most effective monitoring tools possible to detect populations early in the establishment of the crop. A wide range of monitoring methods exist for trapping *C. sordidus* adults and determining the most effective technique is critical to monitoring success. The results from the research indicated differences in weevil numbers trapped and collected from the different traps. The pheromone-baited traps were most effective in trapping *C. sordidus* in all the seasons and this confirms work done by Alpizar *et al.*, (1999) in Costa Rica, Tinzaara *et al.*, (1999, 2003) in Uganda and De Graaf *et al.*, (2005) in South Africa, in which the aggregation pheromone was more effective than pseudostem traps. In this study pheromone-baited traps were also more effective in the dry season (December 2012-February 2013) than in the major rainy (June-August 2012) and the minor rainy seasons (September- November 2012). This might be due to the strong winds associated with the rains, high diversity of insect population in the field, sloppy nature of the study area and weather conditions in the different seasons. For example during the rainy seasons a lot of plantains (20 %) were either toppled or snapped in the field (Appendix 19A) as a result of the winds associated with the early rains. These toppled or snapped plants emitted volatiles (kairomones) into the field which might have interfered with the pheromone-baited trap volatiles thereby limiting their attractiveness. The sloppy nature of the study field introduced run-off during heavy rainfall and this run-off destroyed the connection of the trap entry windows and the ground thereby creating gaps that makes it difficult for the plantain weevils to enter the pheromone-baited traps. The insect diversity was higher in the wet seasons (major and minor

rainy season) than in the dry season and some of these insects which included predators of the plantain weevil could suppress population and thereby limit their movement. Hasyim and Harlion (1998) observed that weevil numbers were negatively related to predator densities in the field. In the tropics, conditions are drier in the dry season and this supports the volatility and diffusion of the pheromone thereby increasing trapping efficiency in the field.

Pseudostem traps were also more effective in the dry season (December 2012-February 2013) than in the wet season (June-November 2012). This was because pseudostem traps were observed to ferment towards the second week of trapping due to the dry weather experienced in the dry season and this fermentation increased the spectrum of odorants that were significantly different from those released by healthy plants (Braumah and Van Emden, 1999). This could also be due to the fact that the plantain weevil was susceptible to desiccation and would prefer hiding under newly cut or fermented plant materials with wet surfaces. During field sampling in the dry season we had to place our fingers deep into the rotten pseudostem to catch weevils that had managed to bore deep into the pseudostem trap. Generally, pseudostem traps were not found to be very effective as compared to other methods of trapping the weevil and this confirms the reports by Ssenyonga *et al.*, (1999), who earlier had observed that pseudostem traps are ineffective and cannot be recommended for effective monitoring of the plantain weevil. This observation was however in conflict with observations by Gold *et al.*, (2002) that pseudostem trapping reduced the population of plantain weevils. Probably, these conflicting reports could be attributed to variation in the *Musa* cultivars used as pseudostem traps, diversity in weather conditions and management practices of the study location.

Corm performance was the same between the dry season and the minor rainy season, but the major rainy season was significantly different from the dry season and this could be due to trap

interference from volatiles emitted by toppled plants in the field and the prevalence of predators in the wet season that could suppress adult weevil movement in the field. Generally corm and pseudostem traps were not significantly different from one another but corm traps attracted more weevils than pseudostem traps. This confirms work done by Masanza (2003) that showed similar effectiveness between corm and pseudostem traps.

This study has shown that pheromone trapping was more advantageous than corm and pseudostem trapping which were more labourious and normally lasted for between 7-14 days (Schmitt *et al.*, 1992), and required regular sampling to remove and destroy adult weevils (Gold *et al.*, 2001). Pheromone trapping has the advantage of lasting for one month and killing adult weevils attracted to the traps. The efficiency of pheromone trapping is based on the assumptions that; in one month the traps would remove a high population of adult weevils within 21 metres relative to the traps. Generally adult weevils are sedentary and migration from one part of the field to another is very limited. In addition their low reproductive potential limits population build-up. Thus, the results from this study suggest that pheromone lures of the plantain weevil could offer an effective means of monitoring and managing the population of the plantain weevil in Ghana because it was 4 and 5 times more effective in attracting the weevils than corm and pseudostem traps, respectively. The observation in this study that fermented pseudostems were very attractive to the *C. sordidus* is an indication that harvested plantain residues could serve as breeding grounds for fecund adult weevils. Consequently, these should be removed from the field and destroyed after harvest as a management strategy.

5.2: Sex ratio determination of *C. sordidus* from the different traps and seasons.

More females than males were captured in all three trials in a ratio of 2:1. This might be because female *C. sordidus* are known to be more active and move greater distances than the male in

search of oviposition sites and mates (Gold *et al.*, 2001). A greater proportion of female *C. sordidus* were captured in the dry season than in the major and minor rainy seasons. The number of female *C. sordidus* peaked in January and August which occurred in the dry season and short dry spell after the major rainy season respectively. Thus, these two months are the driest in the trial period (fig 4.9). A laboratory study earlier conducted at the research center (FOHCREC) showed that the female *C. sordidus* laid more eggs in the dry season than the wet seasons and a greater percentage of these eggs hatched in the dry season (Afreh-Nuamah, 1993). This suggests that the female weevils are more active in the dry season in search of breeding grounds. This probably explains the reason why they are captured more by traps during this time. Pheromone-baited traps were most effective than corm and pseudostem and captured a greater proportion of female *C. sordidus* in the trials. This confirmed the work of De Graaf *et al.*, (2005), who reported more females in pheromone-baited traps than plant material traps (corm and pseudostem) in South Africa. In a recapture trial, Tinzaara *et al.*, (2004c) found that more female than male *C. sordidus* responded to pheromone-baited traps at different distances. Based on the findings in this study, *C. sordidus* management could be improved with the use of pheromone-baited traps in the dry season when female weevils are more active and trap efficiency is increased. This is because the female weevils are the reproductive adults and populations can increase where we have few males and large female populations (one male can inseminate many females).

5.3: Distribution and seasonal abundance of *Cosmopolites sordidus*.

The study indicates that rainfall has a significant negative effect on population of *C. sordidus* with the highest number of *C. sordidus* trapped being in the dry season (December 2012 to February 2013). This confirmed earlier work by Gold *et al* (2001, 2002), who reported higher numbers of *C. sordidus* from traps during drier periods in Uganda. High soil moisture in the

rainy season potentially leads to an increased number of suitable 'resting sites' for adult *C. sordidus* and this would reduce the movement of high proportion of *C. sordidus* in the field; this was demonstrated in a similar work on *C. sordidus* dispersal (Vinatier *et al.*, 2011). Earlier work conducted by Nkakwa *et al.*, (2006) showed a decrease in weevil catches after heavy rains at the research center in Kade. Temperature greatly affects the distribution and population abundance of insects because it affects their metabolism (Birch, 1948). This study indicates a significant negative relationship between temperature and monthly population abundance with the highest temperatures in October (29°C) and June (28°C) corresponding to the lowest population abundance (fig. 4.10). A work by Rhino *et al* (2010) showed that when temperatures were higher than 23°C, the catches decrease. Cuille (1950), Lescot (1988) and Traore *et al.*, (1993) estimated the minimal thermal threshold for adult activity between 15-18°C, and the optimal temperature at 25°C. Uzakah (1995) found weevil activity in the laboratory to be negatively correlated with temperature. This could be due to the fact that *C. sordidus* move less at temperatures higher than 25°C and seek refuge under the crop residues. Henderson and Roitberg (2006) showed that *Exophthalmus jekelianus* (Coleoptera: Curculionidae) preferred a shaded microhabitat when the temperature increases. Generally, the distribution and population abundance of the *C. sordidus* were more widespread in the dry season than in the rainy season due to the above observed factors. Relative humidity showed a weak negative relationship with monthly abundance of *C. sordidus*. *C. sordidus* abundance peaks in the months of December and January corresponding to the lowest humidity values during the trial period showing that *C. sordidus* catches decreased when relative humidity increased. In a laboratory study, Roth and Willis (1963) showed that *C. sordidus* tended to aggregate at higher humidities. It is common to have large fluctuations in trap counts from one sample (weekly, biweekly and monthly) to another (Jansson *et al.*, 1989) and

these fluctuations could be attributed to environmental conditions, such as temperature, rainfall, humidity and wind speed and direction.

5.4: Damage assessment.

Generally, the level of damage on evaluated plants was <18% after 9 months of trapping and this according to the threshold set by ChemTica International would be medium as per their quotation for threshold between low (< 5 adults per week), medium (5-10 adults per week), and high (> 10 adult per week) (Unpublished data). Economic thresholds are not available for *C. sordidus* in Ghana, so relying on these threshold provided by ChemTica International, the weekly trap densities in this study would be medium (6.8 adults per week) to low (3.3 adults per week) in the dry and minor rainy season respectively. The study also showed similar percentage proportion of peripheral and cross sectional corm damage in the different treatment plots, but plants assessed from control plots incurred more damage (17.75%) than plants from plots with pheromone traps (15.50%). This may be due to the attraction of the weevils away by the pheromones from the plants, this result in minimising damage. In a study to assess the effect of pheromone trapping on plantain yield, Dahlquist (2008) recorded cross sectional damage decrease from 5.1% in 2006 to 3.4% in 2007 in farms where pheromones were used with a 20.6% bunch weight increase, whereas in the control farms a damage increase from 5.1% in 2006 to 7.2% in 2007 was recorded. The insignificant damage level between the treated plots and the control plots in this study could be due to the limited trapping period in the study and *C. sordidus* migration from neighbouring plantain fields. Damage levels between the peripheral and cross sectional corm damage was found to be different, with the cross sectional corm damage being higher than the peripheral corm damage. This is attributed to the fact that the larvae which is responsible for these damages resides within the central cylinder after emerging from the eggs laid by the adult

at the periphery of the corm. At the central cylinder it creates galleries from its feeding activities until pupation. Plantain weevil borer indirectly affects the harvested bunch by interfering with nutrient transport and distribution to aboveground tissues.

5.6: The effect of pheromone-baited trap's size on weevil catches.

With the threats posed to plantain fields by *C. sordidus*, it is important to deploy the most effective monitoring tools possible to detect populations early in the establishment stage of the pest. A wide range of monitoring methods exist for trapping *C. sordidus* insects and determining the most effective technique is critical to monitoring success. The ease and cost effectiveness of semiochemical baited traps have made them the primary choice for *C. sordidus* monitoring, but information on trap parameters that may help maximize their effectiveness is still lacking. Pheromone trap capture should be considered as the result of interactions between the behaviour and spatial distribution of insects and trap parameters, such as pheromone dosage, design and size, as well as trap location. In using linear funnel traps Miller and Crowe (2009) got mixed results. They found that more *Arhopalus rusticus* (LeConte) (Coleo: Cerambycidae) were caught in 16 unit traps than in 8 unit traps but catches of *Hylobius pales* (Herbst) (Coleo: Curculionidae) in 16 unit traps were 54% lower than those in 8 unit traps.

Trap size affects the efficacy of *C. sordidus* pheromone traps. The results of this study indicated that 4 litre buckets (21 by 19 cm) were the most effective sizes for trapping *C. sordidus* adults. The 4 litre bucket traps (21 by 19 cm) were 1.72 and 2.26 times more effective than the catches in the 8 litre bucket traps (24 by 22 cm) and 12 litre bucket traps (28 by 25 cm) respectively. This higher numbers captured indicated that using 4 litre bucket traps (21 by 19 cm) could almost double the trapping efficacy of *C. sordidus* by pheromone traps. According to (Howse *et al.*, 1998) trap captures increase with increasing release rate but usually up to a limit, beyond

which the number of insects caught either decreases due to a repellent effect or remains unchanged, thus indicating the optimal release rate for mass trapping. This possibly could be a cause for the difference in weevils between the trap sizes in this study but we were unable to evaluate the release rates of the different trap sizes. Nevertheless, for economy, ease of handling and efficiency, 4 litre bucket traps are preferable for monitoring and studies of the weevil in the semi-deciduous rainforest zone.

From the management of the insect, this observation is an improvement in weevil trapping which significantly could reduce the population size and improve the monitoring system of this pest in Ghana.

5.7: Preference of Apem, Apantu pa, and Brodewuio cultivars by *C. sordidus*.

All the plantain cultivars evaluated in this study were observed to be attractive to the adult *C. sordidus*. *Brodewuio* attracted the highest number of *C. sordidus* followed by *Apantu pa* and *Apem*, but *Brodewuio* and *Apantu pa* had a similar level of infestation. A trial by Nkakwa *et al.*, (2006) for oviposition preference, egg hatchability and larval survivorship, *Brodewuio* and *Apantu pa* showed no significant difference in these parameters confirming the similarity in infestation observed between *Brodewuio* and *Apantu pa* in this study.

Budenberg and Ndiege (1991) suggested that the quantity and types of semiochemicals produced by *Musa* cultivars could result in greater weevil attraction and consequently bring about susceptibility variations among the cultivars. The result from this study has shown that *Brodewuio* is most susceptible to the weevil and can serve as a possible trap crop and source of trapping material in plantain fields. Plantains investigated by Nkakwa *et al.*, 2006, indicates more corm damage on *Brodewuio* and *Agbagba* due to weevil attack than the rest of the cultivars

(*Apantu pa, Obino L'Ewai, Asamienu, Osoboaso*) and this accounts for the short cropping cycles of *Brodewuio* and *Agbagba*.



CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1: Conclusion

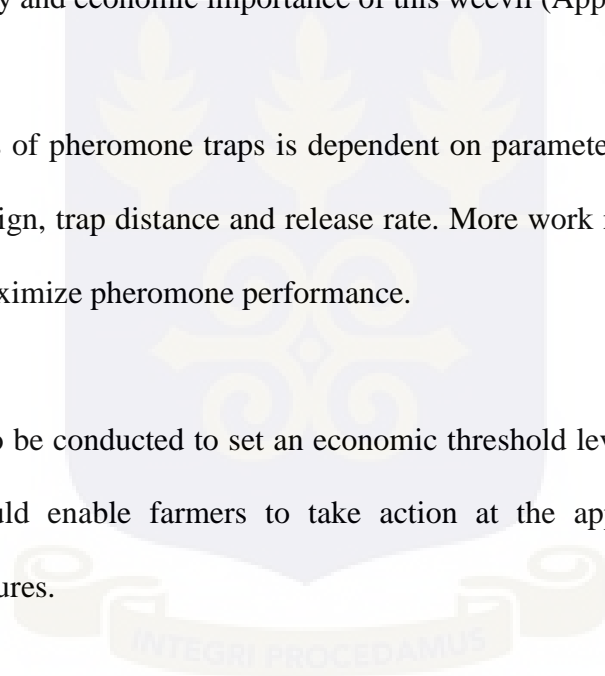
This study shows that pheromone-baited traps are more effective for monitoring *C. sordidus* in plantain fields and has the advantage of detecting *C. sordidus* in both newly established and old plantations it also suppresses the population of the *C. sordidus* to manageable levels thereby improving plant health and yield.

The distribution and abundance of the *C. sordidus* vary with season; the dry season recorded the highest populations than the two wet seasons (major and minor). Consequently, management strategies should be implemented in the dry season when populations are high and traps are most efficient. Trapping in the dry season when female populations are higher and most active would greatly reduce *C. sordidus* populations over time by reducing the population of the reproductive adult.

The 4 litre trap bucket should be used in pheromone trapping to maximize trap efficiency which is both cost effective and efficient and is readily available in the local markets in the country. Traps set in the field for monitoring should be regularly checked to ensure that the entry windows are level with the ground so as to allow *C. sordidus* to enter the traps. It was observed that heavy rains damaged trap entry windows which hinder *C. sordidus* access to traps. Farmers should also try the idea of trap crops using *Brodewuio* (the most attractive cultivar) in plantain production and this might go a long way in suppressing populations of *C. sordidus*. This might be done with other management strategies in an integrated management programme.

6.2: Recommendation.

- ❖ Studies should be carried out to determine the species composition and relative abundance of predators associated with the *C. sordidus* in plantain fields in Ghana.
- ❖ During the trial a different species (*Polytus mellerbergi*) that attack pseudostem of plantain and banana was discovered, it is recommended that a thorough survey be conducted in plantain fields in all districts in the Eastern region to check distribution and population density and economic importance of this weevil (Appendix 19c).
- ❖ The effectiveness of pheromone traps is dependent on parameters such as trap size, trap location, trap design, trap distance and release rate. More work need to be done on these parameters to maximize pheromone performance.
- ❖ Work should also be conducted to set an economic threshold level for the *C. sordidus* in Ghana; this would enable farmers to take action at the appropriate time with the appropriate measures.



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APPENDICES

APPENDIX 1: Summary of mean (\pm S.E) total, female, and male number of weevils collected weekly by different traps in three seasons (9 months) at FOHCREC. For each dependent variable, means with a common letter in the same row indicate no significant difference ($P < 0.05$).

Dependent variable	Season	Treatment			P value	
		Corm	Pheromone	Pitfall (control) Pseudostem		
Total	Major season	0.90 \pm 0.23b	5.35 \pm 0.73a	0.00 \pm 0.09b	0.56 \pm 0.14b	<.0001
	Minor season	1.90 \pm 0.28b	3.25 \pm 0.48a	0.00 \pm 0.05c	1.06 \pm 0.21bc	<.0001
	Dry season	1.29 \pm 0.24b	6.79 \pm 0.73a	0.00 \pm 0.06b	1.42 \pm 0.26b	<.0001
Female	Major season	0.52 \pm 0.13b	4.02 \pm 0.61a	0.00 \pm 0.06b	0.31 \pm 0.10b	<.0001
	Minor season	1.10 \pm 0.19b	2.29 \pm 0.36a	0.00 \pm 0.03c	0.56 \pm 0.14bc	<.0001
	Dry season	0.73 \pm 0.15b	4.83 \pm 0.54a	0.00 \pm 0.06b	0.81 \pm 0.18b	<.0001
Male	Major season	0.38 \pm 0.12b	1.33 \pm 0.30a	0.00 \pm 0.03b	0.25 \pm 0.07b	<.0001
	Minor season	0.79 \pm 0.13a	0.95 \pm 0.17a	0.00 \pm 0.02b	0.50 \pm 0.12a	<.0001
	Dry season	0.56 \pm 0.14b	1.96 \pm 0.29a	0.00 \pm 0.02b	0.60 \pm 0.14b	<.0001

APPENDIX 2: Mean number (\pm s.e) of weevils sampled weekly from different traps in the major rainy season. Means with a common letter in the same row indicate no significant difference ($P < 0.05$).

Date	Corm	Pheromone	Pitfall	Pseudostem
16/06/12	1.00 \pm 0.40 ab	2.75 \pm 0.72 a	0.00 \pm 0.19 b	1.00 \pm 0.45 ab
23/06/12	1.00 \pm 0.23 ab	5.25 \pm 1.45 a	0.00 \pm 0.59 b	0.75 \pm 0.95 ab
30/06/12	0.50 \pm 1.29 a	8.75 \pm 3.22 a	0.00 \pm 1.05 a	0.50 \pm 0.92 a
7/7/2012	0.25 \pm 0.40 a	2.75 \pm 1.20 a	0.00 \pm 0.36 a	0.25 \pm 0.53 a
14/07/12	0.75 \pm 1.71 a	6.25 \pm 4.55 a	0.00 \pm 1.39 a	0.50 \pm 1.55 a
21/07/12	1.25 \pm 0.48 b	4.25 \pm 0.66 a	0.00 \pm 0.12 b	0.25 \pm 0.33 b
28/07/12	0.50 \pm 0.77 ab	5.75 \pm 1.92 a	0.00 \pm 0.64 b	0.50 \pm 0.62 ab
4/8/2012	0.50 \pm 1.09 a	6.25 \pm 3.08 a	0.00 \pm 0.90 a	0.75 \pm 1.34 a
11/8/2012	0.25 \pm 0.33 b	5.75 \pm 1.17 a	0.00 \pm 0.44 b	0.50 \pm 0.53 b
18/08/12	3.25 \pm 1.80 ab	7.50 \pm 1.80 a	0.00 \pm 0.44 b	0.75 \pm 0.33 b
25/08/12	0.75 \pm 0.43 b	6.00 \pm 1.67 a	0.00 \pm 0.61 b	0.25 \pm 0.66 b
1/9/2012	0.75 \pm 0.59 a	3.00 \pm 1.43 a	0.00 \pm 0.38 a	0.75 \pm 0.72 a

Means with a common letter in the same row indicate no significant difference ($P < 0.05$).

APPENDIX 3: Mean number (\pm s.e) of weevils sampled weekly from different traps in the minor rainy season. Means with a common letter in the same row indicate no significant difference ($P < 0.05$).

Date	Corm	Pheromone	Pitfall	Pseudostem
8/9/2012	1.50 \pm 1.08 a	6.00 \pm 2.05 a	0.00 \pm 0.39 a	1.25 \pm 1.02 a
15/9/2012	0.75 \pm 0.73 a	3.5 \pm 1.56 a	0.00 \pm 0.39 a	1.25 \pm 0.70 a
22/9/2012	1.25 \pm 1.07 a	1.75 \pm 1.22 a	0.00 \pm 0.26 a	1.50 \pm 0.86 a
29/9/2012	3.00 \pm 0.79 a	5.00 \pm 2.70 a	0.00 \pm 0.71 a	1.50 \pm 1.46 a
6/10/2012	1.75 \pm 0.88 a	1.75 \pm 0.97 a	0.00 \pm 0.26 a	2.00 \pm 1.18 a
13/10/2012	1.25 \pm 0.52 a	2.50 \pm 0.69 a	0.00 \pm 0.45 a	1.50 \pm 0.37 a
20/10/2012	2.50 \pm 1.38 a	1.00 \pm 0.53 a	0.00 \pm 0.48 a	0.00 \pm 0.48 a
27/10/2012	1.75 \pm 0.98 a	2.25 \pm 0.83 a	0.00 \pm 0.21 a	0.75 \pm 0.91 a
3/11/2012	2.75 \pm 1.29 a	5.25 \pm 2.62 a	0.00 \pm 0.70 a	0.25 \pm 0.75 a
10/11/2012	2.50 \pm 0.87 a	1.75 \pm 0.74 a	0.00 \pm 0.57 a	1.00 \pm 0.19 a
17/11/2012	1.75 \pm 0.53 ab	4.00 \pm 0.74 a	0.00 \pm 0.21 b	1.00 \pm 0.41 b
24/11/2012	2.00 \pm 0.32 ab	4.25 \pm 0.74 a	0.00 \pm 0.52 b	0.75 \pm 0.35 b

Means with a common letter in the same row indicate no significant difference ($P < 0.05$).

APPENDIX 4: Mean number (\pm s.e) of weevils sampled weekly from different traps in the dry season. Means with a common letter in the same row indicate no significant difference ($P < 0.05$).

Date	Corm	Pheromone	Pitfall	Pseudostem
1/12/2012	0.00 \pm 0.54 b	6.00 \pm 1.82 a	0.00 \pm 0.54 b	0.50 \pm 0.82 b
8/12/2012	0.75 \pm 0.92 a	4.75 \pm 2.03 a	0.00 \pm 0.54 a	1.50 \pm 0.68 a
15/12/2012	2.00 \pm 0.89 a	4.25 \pm 1.48 a	0.00 \pm 0.41 a	1.00 \pm 0.74 a
22/12/2012	1.00 \pm 0.94 a	5.75 \pm 2.58 a	0.00 \pm 0.71 a	0.50 \pm 0.97 a
29/12/2012	1.25 \pm 0.57 b	6.50 \pm 0.54 a	0.00 \pm 0.48 b	1.00 \pm 0.93 b
5/1/2013	2.00 \pm 0.94 ab	4.75 \pm 1.04 a	0.00 \pm 0.80 b	2.25 \pm 0.57 ab
12/1/2013	1.75 \pm 1.77 a	8.25 \pm 2.85 a	0.00 \pm 0.81 a	2.25 \pm 0.70 a
19/1/2013	1.00 \pm 1.30 a	10.25 \pm 3.53 a	0.00 \pm 0.97 a	2.25 \pm 1.60 a
26/1/2013	1.25 \pm 0.44 b	11.00 \pm 1.25 a	0.00 \pm 0.33 b	1.25 \pm 1.41 b
2/2/2013	0.75 \pm 0.84 b	11.25 \pm 2.70 b	0.00 \pm 0.70 b	1.25 \pm 1.21 b
9/2/2013	1.75 \pm 0.70 a	4.50 \pm 1.66 a	0.00 \pm 0.19 a	1.50 \pm 1.00 a
16/2/2013	2.00 \pm 0.73 a	4.25 \pm 1.70 a	0.00 \pm 0.64 a	1.75 \pm 0.71 a

Means with a common letter in the same row indicate no significant difference ($P < 0.05$).

APPENDIX 5: ANOVA for the evaluation of trap performance (major rainy season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	872.81	290.94	39.13	<0.0001
Rep	3	79.72	26.58	3.57	0.0151
Error	185	1375.55	7.44		
Total	191	2328.08			

Appendix 6: ANOVA for the evaluation of trap performance (minor rainy season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	271.19	90.40	20.58	<0.0001
Rep	3	25.69	8.56	1.95	0.1232
Error	185	812.60	4.39		
Total	191	1109.48			

Appendix 7: ANOVA for the evaluation of trap performance (dry season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	1307.50	435.83	53.58	<0.0001
Rep	3	38.79	12.93	1.59	0.1934
Error	185	1504.71	8.13		
Total	191	2851.00			

Appendix 8: ANOVA for female sex determination from different treatments (major rainy season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	510.97	170.33	34.94	<0.0001
Rep	3	35.31	11.77	2.41	0.0681
Error	185	901.96	4.88		
Total	191	1448.24			

Appendix 9: ANOVA for male sex determination from different treatments (major rainy season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	49.06	16.35	12.25	<0.0001
Rep	3	35.31	3.30	2.47	0.0633
Error	185	901.96	1.34		
Total	191	1448.24			

Appendix 10: ANOVA for female sex determination from different treatments (minor rainy season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	137.77	45.92	20.07	<0.0001
Rep	3	10.94	3.65	1.59	0.1925
Error	185	423.27	2.29		
Total	191	571.98			

Appendix 11: ANOVA for male sex determination from different treatments (minor rainy season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	25.42	8.47	11.20	<0.0001
Rep	3	3.88	1.29	1.71	0.1670
Error	185	139.96	0.76		
Total	191	169.25			

Appendix 12: ANOVA for female sex determination from different treatments (dry season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	690.85	230.29	54.32	<0.0001
Rep	3	31.23	10.41	2.46	0.0645
Error	185	784.23	4.24		
Total	191	1506.31			

Appendix 13: ANOVA for male sex determination from different treatments (dry season)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	99.60	33.20	21.38	<0.0001
Rep	3	3.94	1.31	0.85	0.4707
Error	185	287.27	1.55		
Total	191	390.81			

Appendix 14: ANOVA for the distribution and seasonal abundance of *C. sordidus*

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
season	2	73.69	36.85	3.40	0.0341
Rep	3	109.96	36.65	3.38	0.0180
Error	570	6178.59	10.84		
Total	575	6362.25			

Appendix 15: ANOVA for PCI for peripheral corm damage from sixteen plots (pooled analysis)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	21.19	7.06	2.80	0.085
Error	12	30.25	2.52		
Total	15	51.44			

Appendix 16: ANOVA for PCI for peripheral corm damage from sixteen plots (pooled analysis)

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	12.19	4.06	0.72	0.559
Error	12	67.75	5.65		
Total	15	79.94			

Appendix 17: ANOVA effect of trap size on the attractiveness of pheromone-baited pitfall traps

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	2	186.36	93.18	4.92	0.0101
Rep	2	34.19	17.10	0.90	0.4100
Error	67	1267.89	18.92		
Total	71	1488.44			

Appendix 18: ANOVA for weevil preference on three plantain cultivars in outdoor experiment

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Prob.
Treatment	3	124.13	41.38	75.47	0.0001
Rep	3	0.38	0.13	0.23	0.8765
Error	57	31.25	0.55		
Total	63	155.75			





A: Toppled premature plantain



B: *Cosmopolites sordidus* pupa



C: new species discovered during sampling



D: *Beauveria bassiana* infested *C. sordidus*



E: Adult *C. sordidus* on dry plantain leaves

APPENDIX 19: Picture gallery (A, B, C, D, E)