EVALUATION OF SOME SWEET POTATO VARIETIES FOR SUSCEPTIBILITY TO THE WEEVIL, *CYLAS* SPP. (COLEOPTERA: BRENTIDAE).

BY

MEDETISSI ADOM

(10509049)

B.Sc. (HONS) CROP SCIENCE, UNIVERSITE DE LOME (TOGO)

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DECLARATION

I hereby declare that this thesis is the result of the original work personally done by me for the award of a Master of Philosophy Degree in Entomology at the African Regional Postgraduate Programme in Insect Science (ARPPIS) in the University of Ghana. All the references to other people's work have been duly acknowledged and this thesis has not been submitted in part or whole for the award of a degree elsewhere.

Signature…………….....................Date……………………..

MEDETISSI ADOM

(STUDENT)

Signature…………………………..Date………………………

DR. DAVID D. WILSON

(PRINCIPAL SUPERVISOR)

Signature……………………….... Date………………………

DR. KEN O. FENING

(CO-SUPERVISOR)

Signature…………………………Date………………………..

DR. ROSINA KYEREMATEN

(ARPPIS COORDINATOR)

DEDICATION

To my beloved mother, ***Georgette Adjoa KEGBENG,*** *and to the memory of my beloved late father,* ***Innocent Kossi ADOM****.*

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TABLE OF CONTENTS

LIST OF ACRONYMS

ARPPIS:	African Regional Postgraduate Programme in Insect Science.
B$_{t:}$	*Bacillus thuringiensis.*
CABI:	Centre of Agriculture and Biosciences International.
CIP	International Centre of Potato.
CSIR-CRI:	Council for Scientific and Industrial Research-Crops Research Institute.
GLM	General Linear Model.
FAO:	Food and Agriculture Organization of the United Nations.
FAOSTAT:	Food and Agricultural Organization Corporate Statistical Database.
IPM:	Integrated Pest Management.
MoFA:	Ministry of Food and Agriculture.
SPSS	Statistical Package for the Social Sciences.
SNK	Student Newman-Keuls.

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABSTRACT

Sweet potato (*Ipomoea batatas* Lam.) is a staple food crop for a large proportion of the population in sub-Saharan Africa. One important factor limiting its production and utilisation is infestation by weevils belonging to the genus *Cylas*, commonly known as sweetpotato weevils. The use of host plant resistance is an essential component for the integrated pest management of sweetpotato weevils. In this study, the susceptibility of some Ghanaian sweet potato varieties to infestations by *Cylas* spp. was assessed under both field and laboratory conditions. Natural levels of infestation and yield loss due to sweetpotato weevil attack of 7 sweet potato varieties (Apumoden, Ligri, Faara, Bohye, Dadanyui, Okumkom and Sauti) were determined and plant root characteristics were measured under field conditions during two rainy seasons in 2015. In the laboratory, feeding and oviposition preferences of *Cylas puncticollis* (Coleoptera: Brentidae) for eight (8) varieties (the first six mentioned above plus Red skinned and white skinned varieties) through no choice and choice tests were determined at 30.09 ± 1.50^{o} C and 76.12 ± 3.75 % RH. The effect of sweet potato variety on some bionomic parameters of *C. puncticollis* was also determined. During the major and minor rainy seasons of field experiments, Apumoden and Ligri scored the highest levels of infestation (1.80 and 1.77, 1.84 and 1.96, respectively) and yield loss (43.41% and 41.85%, 23.84% and 23.87%, respectively). While Faara and Okumkom scored the lowest infestation levels (1.20 and 1.24, respectively) and yield loss (9.60% and 8.09%, respectively) in the major rainy season. However in the minor rainy season, there was no significant difference between Faraa, Okumkom, Bohye and Dadanyui with regards to the infestation level and yield loss. The storage root infestation appeared to have a strong negative correlation (r = -0.82 and -0.75, in the major and minor rainy seasons, respectively) with the shortest weevil distance, a strong positive correlation (r = 0.75; and 0.71 in the major and minor rainy seasons, respectively) with the root size index and a weak negative correlation (r = -0.45 and -0.36 in the major and minor rainy seasons, respectively) with root neck length. The highest yield was recorded on Ligri (22.25 and 22.49 t/ha in the major and minor rainy season, respectively). In the laboratory studies, *C. puncticollis* preferred Apumoden and Ligri for feeding and oviposition more than other varieties in both no choice and choice tests, while Okumkom was the less preferred. Faara was preferred for feeding but not for oviposition. The effect of sweet potato variety on *C. puncticollis* bionomic parameters appeared to be significant on female fecundity ($P < 0.0001$), oviposition ($P < 0.0001$) and post-oviposition ($P = 0.0160$) periods, female longevity ($P < 0.0001$), developmental period ($P = 0.0190$), larval survival ($P = 0.0050$) and adult emergence rate ($P = 0.0190$) but not significant on female pre-oviposition period, egg incubation period ($P = 0.7260$) and survival ($P = 0.8880$), larval development period ($P = 0.0560$), pupal survival ($P = 0.2510$) and development time ($P = 0.190$) and sex ratio ($P = 0.8970$).

CHAPTER ONE

INTRODUCTION

1.0 Background information

Sweet potato (*Ipomoea batatas* Lam.) is an important food and industrial crop worldwide. Its production as a food crop is increasing unceasingly in many sub-Saharan Africa countries (Korada *et al*., 2010). Sweet potato is grown for both home consumption and to supplement household income when sold in local markets and in some urban centers (Stathers *et al*., 1999). FAO (2012) reported that over one hundred (100) developing countries cultivate sweet potato and in more than fifty (50) of these countries, the crop is among the five most important. In the tropics, sweet potato is planted at any time from vines. It is a low input crop that can almost always offer some yield, and can be harvested at almost any time, from 4 to 6 months after planting (Ray *et al*., 1983). Unlike most of the other major staple food crops, sweet potato can produce comparatively higher yields under relatively adverse conditions. Moreover, apart from the high caloric content of the storage roots, sweet potato is also one of the cheapest source of vitamin A. Vitamin A alleviates the problem of blindness and infant mortality, from which millions of children from sub-Saharan Africa suffer (West, 2002). Sweet potato therefore holds many desirable traits that positively contribute to food security and improvement of farmers' livelihood in developing countries.

In Ghana, the harvested area of sweet potato in 2013 was about 74,000 hectares (FAOSTAT, 2015), which comes after cassava and yam in order of importance among root crops. Sweet potato is cultivated mainly for the carbohydrate-rich storage roots although the foliage has the potential for use as vegetable and animal feed (Otoo *et al.*, 2001). Though sweet potato leaves are very rich in minerals and vitamins, the roots are more widely consumed in Ghana where the crop is particularly important in the Central, Greater Accra, Volta, Eastern and Upper East regions (MoFA, 2012).

Considering the importance of sweet potato in poor – resource farmers' livelihood, a lot of research has been done in order to enable producers to increase the productivity and the quality of the crop (Kihurani *et al.*, 1995; Kabi *et al.*, 2001; Rukarwa *et al*., 2013; Baafi *et al.*, 2015). Unfortunately some key constraints specific to sweet potato are still hindering its production. For example in sub-Saharan Africa, sweetpotato weevil management was reported by Fuglie (2007), as a key need among other challenges that face farmers. Indeed sweetpotato weevil, *Cylas* spp. is by far the most important pest of sweet potato and is widely distributed (Hill and Waller, 1988; Austin *et al.*, 1991; Ames *et al.*, 1997). It has been reported as a major pest in Uganda (Muyinza *et al.*, 2007; Mwanga *et al.*, 2009; Okonya and Kroschel, 2013), Kenya (Nderitu *et al.*, 2009), Nigeria (Tewe *et al.*, 2003), Ghana (Darko, 2000) and is also present within 20 other countries in Africa (CABI, 2005). The other sweet potato pests such as the sweetpotato butterfly**,** *Acraea acerata* Hew**.** (Lepidoptera: Lymphalidae)**,** and rough potato weevil *Blosyrus* spp. (Coleoptera: Curculionidae) are only relatively important according to ecological area (Okonya *et al.*, 2014).

Sweetpotato weevil species were reported to damage every harvestable part of the plant with devastating consequences for resource-poor farmers with yield losses up to 80% (Smit *et al.*, 2001; Rees *et al.*, 2003). Infestation by sweetpotato weevil to sweet potato storage, causes not only direct injury and quantitative loss, but also can cause qualitative loss, reducing the product marketability because of the unpalatable terpenoids produced by the plant in response to infestation caused by the weevil (Stathers *et al.*, 2003a).The consumers therefore pay only reduced prices for damaged roots (Ndunguru *et al.*, 1998). The damaging stages of sweetpotato weevil are the larvae and the adults which prefer to feed on the tuber, causing extensive damage in the field and in storage. Sweetpotato weevil is then also considered as post-harvest insect pest as it reduces both economic and nutritional value of the root during storage and can reduce its shelf life. The principal damage of the pest is the mining of the tubers by larvae (Stathers *et al.*, 1999).

Therefore, to achieve food security and improve livelihoods of poor-resource sweet potato farmers across the world, especially in sub-Saharan Africa, there is a need to put in place effective strategies that will lead to sustainable control of sweetpotato weevil. Insecticides have been used to control insect pests in agriculture to reduce yield losses by insect damages. Unfortunately, the control of sweetpotato weevils by insecticides is quite ineffective due to the cryptic feeding habit on the tubers in the ground, or inside the woody base of the stems (Ames *et al.*, 1997). This means that with the exception of systemic insecticides, which are costly and pose the risk of residual contamination of the tubers, there is no effective chemical control of the larvae, or of the other stages found within the plant tissue. The cryptic feeding habit reduces the effect of biological insecticides and natural enemies as well (Smit *et al.*, 2001). Alternative means to manage the weevils are adherence to good agricultural practices and the use of host plant resistance/tolerance

(Stathers *et al*., 2003a; Mansaray *et al*., 2013, 2015) which are seen as essential components in the integrated sweetpotato weevil management.

1.1 Justification

Sweetpotato weevils are the most important sweet potato pests in Sub-Saharan Africa. Sustainable management of these insect pests could certainly increase the production and would impact positively on the livelihoods of millions of resources- poor farmers across sub-Saharan Africa (Muyinza *et al.,* 2012). The lack of appropriate farm-level control options following the concealed nature of feeding habit of sweetpotato weevils, the use of resistant varieties would therefore be a practical and economical method of their control (Collins and Mendoza 1991, Stathers *et al*., 2003a). This has led researchers across the world to search for varieties with resistance to sweetpotato weevil and which may provide valuable material for breeding programmes (Stathers *et al*., 2003a). Although studies have not yet shown any reliable resistant sweet potato variety that is immune to sweetpotato weevil attack, significant difference in levels of susceptibility in sweet potato germplasm have been reported in field and laboratory studies across the world (Darko, 2000, Stathers *et al*., 2003a, 2003b, Jackson and Bohac, 2006, Stevenson *et al*., 2009, Muyinza *et al*., 2012).

Many factors have been reported to be responsible for the differences in the level of susceptibility to *Cylas* spp. among sweet potato varieties. These factors include plant morphology, especially root structure and root chemical composition. The former factors were reported to provide an "escape" form of resistance while the latter, a "dynamic" form of resistance (Wilson *et al.*, 1988; Kabi *et al*. 2001, Stathers *et al*., 2003a, 2003b). Unfortunately, those factors can vary for the same variety in different ecological zones and seasons (Mao *et al.*, 2001; Stathers *et al.*, 2003a). Therefore inconsistent performance of selected varieties by breeding, to different locations is often encountered, limiting the successful development of useful resistant sweet potato genotypes (Collins and Mendoza, 1991). A successful variety resistance - based management of sweetpotato weevil requires then an assessment of available varieties at the local level in order to select the less susceptible ones. Since it is logical to expect plants to maximize their chances of avoiding insect damage by using a number of different resistance traits, assessing resistance among a number of sweet potato varieties must therefore, incorporate both field and laboratory investigations and endeavor to measure every potential attribute which may confer resistance. Moreover the elucidation of factors determining susceptibility of varieties may be helpful in providing strategies towards the breeding of less susceptible varieties (Stathers *et al.*, 2003b).

To improve sweet potato production in Ghana, breeding programmes have always been based principally on improvement in yield and with the purpose of meeting consumers' preference (Baafi *et al.*, 2015). Little attention has been to the ability of the crop to withstand attack from diseases vectors and insect pests especially the most destructive pest, sweetpotato weevil. Therefore, only meager information exists on the susceptibility of available sweet potato varieties in Ghana to weevil infestation. The need to assess Ghanaian released sweet potato varieties for their susceptibility to weevils then becomes urgent for a successful resistance - based weevil management system to improve sweet potato production.

1.2 Objectives

The main objective of this work was to determine the extent to which some improved sweet potato varieties presently available in Ghana differ in their susceptibility to infestation by sweetpotato weevil.

Specifically the aims of the work were to:

1. Assess the level of natural infestation by the weevils and yield loss of the different sweet potato varieties in the field.
2. Determine if there is a correlation between rooting characteristics and levels of infestation of sweet potato storage root.
3. Assess the susceptibility of sweet potato varieties in the laboratory to the sweetpotato weevil, *C. puncticollis*.
4. Determine the effect of sweet potato variety on the bionomic parameters of *C. puncticollis*.

CHAPTER TWO

LITERATURE REVIEW

2.1 Systematic botany of sweet potato

Sweet potato is a hexaploid plant with a basic chromosome number of x=15. The total number of chromosomes in the sweet potato plant is 2n=6x=90 (Huamàn and Zhang, 1997). Sweet potato was first described by Linnaeus (1753) as *Convolvulus batatas*. However, based on the stigma shape and surface of the pollen grains, Lamarck classified sweet potato within genus *Ipomoea* in 1791. Therefore, the name was changed to *Ipomoea batatas* (L.) Lam. The systematic classification of the sweet potato is as follows:

Kingdom: Plantae

Phylum: Magnoliophyta

Class: Eudicotyledones

Order: Solanales

Family: Convolvulaceae

Tribe: Ipomoeae

Genus: *Ipomoea*

Sub - genus: Uamoclit

Section: Batatas

Species: *Ipomoea batatas* (L.) Lam.

2.2 Origin and distribution of sweet potato

The exact origin of sweet potato is still not well- documented. However, the historical evidence suggests that the crop originated from the New World Central or South American lowlands. Wolfe (1992) stated that South American indigenous communities have probably cultivated the crop since 3,000 BC. Therefore, sweet potato is believed to have originated from the region between Yucatan Peninsula of Mexico and Orinoco River in Venezuela and spread to the rest of the world (Zhang *et al*., 2004). Columbus introduced the sweet potato into Europe after voyages of discovery, while Spanish and Portuguese explorers and traders subsequently introduced it into Asia and Africa by the 16th century (FAO, 1994). Sweet potato is mainly grown today in developing countries, which account for over 95% of world output. With annual production of about 8 million tonnes, China is ranked the first sweet potato producer worldwide. Nigeria is ranked first producer in Africa with an annual production of 3,400,000.00 tonnes followed by Tanzania. Roughly about 80% of the world's sweet potatoes are grown in Asia, about 15% in Africa, and only 5% in the rest of the world. In 2013, the cultivated area of sweet potato in Ghana was about 7,400 ha with an annual production of 135,000.00 tonnes (FAOSTAT, 2015).

2.3 Biology and morphology of sweet potato plant

2.3.1 Growth Habit

Although sweet potato is an herbaceous and perennial crop, it is grown as an annual plant by vegetative propagation using either storage roots or stem cuttings. The growth habit varies among varieties but it is mainly prostrate with a vine system expanding horizontally on the soil. The growth habit can also be spreading or very spreading, erect and semi - erect (Huamàn *et al.*, 1999).

2.3.2 Root system

Two types of roots are observed in the sweet potato root system: the fibrous root and storage root. The fibrous roots absorb nutrient and water, and anchor the plant while storage roots are enlarged true roots where the plant stores photosynthetic products and are the main organ used for human consumption (Kays *et al*., 1992; Huamàn *et al.*, 1999).The formation of storage root in sweet potato occurs between the period 7 to 91 days after transplanting and varies among varieties (Ravi and Indira, 1999). The process of storage root formation is very complex and involves various steps such as stopping of root elongation, initiation of first and second vascular cambia, development of anomalous and interstitial cambia, increasing of radial growth, cell proliferation and expansion, and massive accumulation of starch and proteins. A number of endogenous phytohormones such as Cytokinines control the whole process of storage root formation. Storage root increases in size through accumulation of photosynthetic products and the multiplication of cells (Desai, 2008; Ravi *et al.*, 2009). The accumulation of dry matter is associated with the ability of the root to attract photo-assimilated products from photosynthetic organ especially from the leaves. The photosynthesized sucrose migrates from leaves through the stem, towards underground parts including storage roots (Li, 2008). In the storage root, the sucrose is transformed into starch through a polymerase reaction and stored in the amyloplasts. The shape and size of the storage root varies among varieties and depend on environmental and edaphic conditions. The storage root can be round, long or curved

(Wolfe, 1992). The smooth storage root skin ranges from white to dark purple and the flesh colour vary from white to orange depending on variety (Laurie and Niederwieser, 2004).

2.3.3 Stem

The sweet potato stem is described as cylindrical. The length of the stem as well as the internodes depend on the growth habit of the varieties and of the availability of water in the soil. Somda and Kays (1990) reported that stem length may range from 1 m to 6 m. Internode length may also range from a few centimeters up to more than 12 cm. Stem diameter can be thin or very thick and varies approximately between 4 to 12 mm. The erect varieties are approximately 1m long, while the very spreading ones can reach 5m long. Some varieties have stems with twining characteristics. Stem colour varies from green to totally pigmented with anthocyanins (red-purple color) depending on the type of variety. Hairiness in the apical shoots, and in some varieties also in the stems, varies from glabrous (without hairs) to very pubescent (CIP *et al*., 1991). Sweet potato plants produce three types of branching normally namely primary, secondary and tertiary at different periods of growth. The total number of branches varies between 3 and 20 among varieties. Spacing, photoperiod, soil moisture and nutrient supply influence the branching intensity of sweet potato (Somda and Kays, 1990).

2.3.4 Leaves and Petioles

The shape, the colour of leaves, the size, the veins, the degree of hairiness of leaves and the petiole can be used to differentiate sweet potato varieties (Huamàn *et al*., 1999). Sweet potato plant has simple leaves which are spirally arranged on the stem in a pattern known as 2/5 phyllotaxis. The edge of the leave may be entire, toothed or lobed and the shape, rounded, reniform, cordate, triangular, hastate, lobed and almost divided. In lobed leaves, the number of lobes generally range from 3 to 7. However there is a variation in leaf shape on the same plant in some varieties. The leaf colour, the leaf veins and petiole may be green-yellowish, green or may be completely or partially pigmented in purple. Petiole length varies widely with genotype and may range from approximately 10 to 40 cm (CIP *et al*., 1991).

2.3.5 Flowers, fruits and seeds

All sweet potato varieties don't have the ability to produce flowers equally. Under normal condition in the field, some produce very few flowers while others flower profusely. The inflorescence is generally a cyme and bisexual. The fruit is a capsule, more or less spherical with a terminal tip and containing two to four seeds. It can be pubescent or glabrous. The capsule turns brown when mature (Huamàn *et al.*, 1999).

2.4 Sweet potato production

Sweet potato is the seventh most important food crop in the world in terms of production (Loebenstein, 2009). Sweet potato is grown on about 8.2 million hectares producing about 11.7 million tonnes with 13.43 tons/ha as an average yield (FAOSTAT, 2015). It is one of the most widely grown root crops in Sub-Saharan Africa (Low *et al.*, 2009) and it is particularly important in countries surrounding the Great Lakes in Eastern and Central Africa; Malawi, Angola, Mozambique and Madagascar in Southern Africa and Nigeria in West Africa (Wolfe, 1992). In Ghana, sweet potato is ranked between first and tenth important food crops out of 24 among the communities. It is ranked first in Brong Ahafo and Central Regions but tenth in the Greater Accra Region (Baafi *et al.*, 2015). Sweet potato production is constantly increasing in Ghana. The annual production has passed from about 122000 tonnes in 2009 to 135 000 tonnes in 2013 (FAOSTAT, 2015). The most important area of sweet potato production is the Upper East region while Ashanti region is the lowest production area (Table 1). The yield varies from one region to another and is affected by cultural practices. Studies by Bidzakin *et al.*, (2014) showed that Northern and Upper East Regions reported higher yields ranging from about 7.5 - 9 tonnes/hectare of fresh sweet potato if fertilizer is applied.

Many varieties of sweet potato are grown in Ghana including the improved ones. The new variety adoption is complexly related to field yield performance as well as consumer taste acceptability (Sugri *et al.*, 2012). A field survey carried out by CIP Ghana, (2012) showed that sweet potato varieties grown in Ghana vary in their susceptibility to pests and diseases.

Table 1: Production and Area involved in sweet potato in Ghana.

Region	Area (Ha)	% contribution	Production (tonnes)	% contribution
Central	371	3.9	6,490	4.9
Volta	880	9.1	15,340	11.6
Eastern	1,030	10.7	34,910	26.4
Greater Accra	38	0.4	640	0.5
Ashanti	37	0.4	620	0.5
Brong Ahafo	145	1.5	2,390	1.8
Northern	414	4.3	6,070	4.6
Upper East	5,550	57.7	46,000	34.9
Upper west	1, 157	12.0	19,530	14.8
Total	9,622	100.0	131,990	100.0

Source: MoFA, 2012.

2.5 Importance and uses of sweet potato

Sweet potato is considered as a food security crop in sub-Saharan Africa where it is mainly grown on subsistence scale and provides compliant source of food before other crops mature. Laurie and Niederwieser (2004) reported that in some African countries, starchy crops such as sweet potato are staple food whereas other countries utilise it as an additional or food security crop. Sweet potato contains carbohydrates, protein, dietary fibre, minerals, vitamins and antioxidants (Van Jaarsveld *et al.*, 2006; Kim *et al.*, 2007; Yildirim *et al.*, 2011). The storage root of sweet potato provides considerable amount of carbohydrates compared to other root crops but has lower protein content. It provides comparatively high calorie at 152 MJ ha^{-1} day^{-1} while other crops such as cassava, wheat, rice and maize provide 121, 135, 151, and 159 MJ ha^{-1} day^{-1} calorie, respectively (Horton and Fano, 1985; Scott *et al.*, 2000). The orange fleshed sweet potato has high levels of beta-carotene which is precursor of vitamin A, contributing much to improve human health and nutrition especially for children (Wolfe, 1992). Purple flesh sweet potatoes are rich in anthocyanins (Philpott *et al.*, 2004; Terahara *et al.*, 2004). Anthocyanins are natural soluble food pigments and have applications in pharmaceutical and cosmetic industries due to their bright colour and non - poisonous nature, rich nutrition, safe and health care function (Rice - Evans and Packer, 1998). Bassa and Francis (1987) first noted that anthocyanins from sweet potato are effective natural food colorants for preparation of beverages. Therefore, purple fleshed sweet potatoes are used in juices, alcoholic beverages, jams, confectioneries, bread, snacks, and noodles. The recent findings of the radical scavenging, antimutagenicity and efficacy of sweet potato anthocyanins against liver disease, indicated that purple flesh sweet potato may contribute to maintaining good health of humans (Terahara *et al.*, 2004).

Sweet potato contains high concentration of phenolics that have been showed to have potential for consumption as a functional food for improving human health. The sweet potato phenolics are found to inhibit the growth of human colon, leukaemia and stomach cancer cells (Kurata *et al.*, 2007), to inhibit growth of viruses and fungi in vitro (Peterson *et al.*, 2005) and to ameliorate diabetes in humans (Ludvik *et al.*, 2008). Consuming or processing sweet potato with the skin may enhance its nutraceutical potential because the content of some antioxidants is higher in the peel than in the flesh (Salawu *et al.*, 2015).

Sweet potato has versatility in Ghana and it is used in various food preparations in place of rice, cassava, yam, plantain and other staples (Ellis *et al.*, 2001; Meludu *et al.*, 2003; Zuraida, 2003). In spite of this it does not have the same importance in the Ghanaian diet as other root and tuber crops, such as yam, cassava or cocoyam (Adu-Kwarteng *et al.*, 2002; Opare-Obisaw *et al.*, 2000). It is reported that about 39% of consumers eat sweet potato two or three days per week while about 28% consumed it at least six days per week and only about 12% of the respondents consuming sweet potato at most only once a week according to a survey conducted by Baafi *et al.*, (2015). Sweet potatoes were mainly consumed by frying or boiling in the form of *ampesi*. Other uses of sweet potato were stew preparation from the leaves and as herb for jaundice (in the Eastern Region), and the use of the storage roots as a source of sugary flour for porridge in the Northern Region. One of the oldest uses was sweetening porridges and maize products, such as *Aboloo* (steamed or baked sweetened fermented maize dough) (Osei-Opare and Adjei-Poku, 1977).

2.6 Sweet potato cultivation

2.6.1 Climate and Soil

Though sweet potato is an easy-to-grow crop with good adaptability in diverse environmental conditions (Ravindran *et al.*, 1995), it grows best in the tropical and warm temperate regions wherever there is sufficient sunlight, water and moderate temperature (21-26^{o} C). It requires warm days and nights for optimal yields and is sensitive to low temperatures. It is then planted and harvested every month in one part or other part of the world. A well distributed rainfall of 750 – 1500 mm is sufficient for sweet potato cultivation (Nedunchezhiyan *et al.*, 2012a). Very high rainfall leads to excessive vine development (Obigbesan, 2009). Sunshine is important for sweet potato development and excessive shade leads to yield reduction (Nedunchezіyan *et al.*, 2012a). Sweet potato can tolerate drought to some extent but cannot withstand water logging and requires for its production well drained loam and clay loam soils. Heavy clay soils prevent the formation of large storage roots while sandy soils favour the formation of pencil like roots. Soil pH of 5.5 – 6.5 is found to be optimum. High soil pH invites pox and scurf diseases in sweet potato, whereas at low pH sweet potato suffers from aluminum toxicity (Nedunchezіyan and Ray, 2010). The tolerance of sweet potato to soil salinity may vary among varieties and the higher levels of salt can cause a decrease in number of leaves, number of shoots, number of roots, length of plantlets and length of roots and consequently reduction of the yield (Dasgupta *et al*., 2008).

2.6.2 Propagation

Generally sweet potato is propagated asexually from vine cuttings, though propagation from seed is possible and is only part of breeding programme (Wolfe, 1992). In the tropics, sweet potato is normally propagated from vine tip cuttings from fields, which are ready for harvest. This practice doesn't affect the yield but enhances the severity of weevil infestation compared to cuttings obtained directly from storage root in nursery (Ray *et al.*, 1983). In vegetative reproduction, green vines of approximately 30 cm length with at least three leaf nodes are planted on ridges, mounds or even on flat land on sandier soils (Obigbesan, 2009).

The land preparation varies according to sweet potato production system and depends on soil type, fertility and drainage condition. Sweet potato vine can be planted on mounds or ridges, and occasionally on raised beds or on the flat. Planting on flat, is commonly observed on the sandier soils and raised beds are mostly found in wet areas. Deep cultivation enhances root growth and bulking of the sweet potato roots. Mounds and ridges promote adequate drainage and ease of harvesting (Low *et al*., 2009).

Planting space varies from one country to another but a closer spacing is generally recommended for sweet potato to achieve maximum root yield (Nedunchezhiyan *et al.*, 2012a). In India, a plant density of 83,000 per hectare is recommended. In Uganda a plant density of 25, 000 to 125 000 is suggested. A significant reduction in yield was observed when the plant population was dropped 12,000 ha^{-1} (Kaggwa *et al.*, 2006). In Cameroon, where sweet potato clones are grown at plant densities of 10,200 and 300,000 ha^{-1}. Plant vigor and root number increases, and weevil infestation and root size decrease with increase in plant density (Wolfe, 1992).

2.6.3 Cropping pattern

Sweet potato is commonly monocroped in small patches scattered around the farm or the farm hut. It is also sometimes inter or relay cropped with other crops such of rice, ragi, maize and red gram. Strip cropping of sweet potato along with those crops improves soil moisture storage in the soil and increase crop yields (Neduncheziyan *et al.*, 2012a). However Singh *et al.*, (1984) reported that yield of sweet potato grown in mixed cropping system is generally below those grown in monoculture. This is due, in part, to the shading effect of upper storey crops on the lower storey sweet potato crop. Robert-Nkrumah *et al.*, (1986) reported that tuberization can be almost suppressed in sweet potato for 73 % shade.

Therefore, in case of higher weevil infestation, damage could be more devastating to shaded plants due to the reduced ability of the plant to compensate for weevil feeding.

2.7 Sweet potato production constraints

A survey conducted by the International Center of Potato (CIP) in order to identify the most important constraints facing poor and small scale sweet potato growers showed that there were a few key challenges facing farmers in all major sweet potato producing areas, but there were also other very important challenges specific to certain regions. Virus attack, lack of enterprise for sweet potato processing, lack of improved planting material and varieties exhibiting high stable potential were the major common constraints in all or most of the major sweet potato producing areas. An additional major constraint for sub-Saharan Africa include damage by sweetpotato weevil (Fuglie, 2007). Sweetpotato weevil is the biggest threat to sweet potato production, and some species are particularly problematic in sub-Saharan Africa. Okonya *et al.* (2014) conducted a survey on farmer's perception in the major sweet potato growing areas of Uganda and found that insect pests were the major constraints to sweet potato production. Apart from a few localities, ninety three percent (93%) of farmers perceived sweetpotato weevil to be the most important pest. Others insect pests such as the sweetpotato butterfly and leaf miner and vine borers were of minor importance.

In Ghana, sweet potato production is hindered by many factors. Lack of planting material, attack by diseases and insect pests and lack of good market, poor rainfall pattern, and poor storability are major limiting factors to the expansion of sweet potato production (Darko, 2000; Bidzakin *et al.*, 2014).

2.8 Sweet potato insect pests

A large number of insect species damage sweet potato and their importance varieties among different agro ecological zones. Ames *et al.*, (1997) classified sweet potato insect pests into storage root feeders, stem borers and feeders and leaf feeders (Table 2). Among all sweet potato insect species, sweetpotato weevil is the cosmopolitan insect and most serious insect of the pests (Darko, 2000; Kabi *et al.*, 2001; Okonya *et al.*, 2014).

2.9 Sweetpotato weevil

2.9.1 Distribution of Sweetpotato weevils

Three *Cylas* species are reported pests of sweet potato: *Cylas formicarius* , *C. puncticollis*, and *C. brunneus* (Ames *et al.*, 1997) and are all found in Africa. *Cylas brunneus* and *C. puncticollis* have originally been associated with other Convolvulaceae before the introduction of sweet potato in Africa and are currently the most abundant (Austin *et al.*, 1991). *Cylas puncticollis* occurs only in Africa while *C. formicarius* is found across the tropical zone, from west Africa, through to east Africa, southern Africa, Madagascar, Mauritius, Seychelles, India, Bangladesh, Sri Lanka, south east Asia, China, Philippines, Indonesia, USA, West Indies, Mexico, northern South America, and several other locations around the world (Hill and Waller, 1988).

Table 2: Sweet potato insect pest groups**.**

Pest groups	Insect pest species
Storage Root Feeders	Sweetpotato Weevils (*Cylas* spp.), West Indian Sweetpotato Weevil (*Euscepes postfasciatus*), Rough Sweetpotato Weevil (*Blosyrus* sp.), Clearwing Moth (*Synanthedon* spp.), Peloropus Weevil (*Peloropus batatae*); White Grubs (*Phyllophaga* spp.)
Stem borers and Feeders	Clearwing Moth (*Synanthedon* spp.); Sweetpotato Stemborer (*Omphisia anastomasalis*); Striped Sweetpotato Weevil (*Alcidodes* spp.); Sweetpotato Weevils (*Cylas* spp.) Peloropus Weevil (*Peloropus batatae*) Sweetpotato Bug (*Physomerus grossipes*); Long-Horned Beetle.
Leaf feeders	Sweetpotato Butterfly (*Acraea acerata);* Tortoise shell Beetles (*Aspidomorpha* spp. and others), Sweetpotato Hornworm *(Agrius convolvuli*); Armyworms (*Spodoptera eridania, S. exigua, S. litura*); Leaf Folders (*Brachmia convolvuli, Herpetogramma hipponalis*); Strobiderus Beetle (*Strobiderus aequatorialis*); Rough Weevil (*Blosyrus* sp.); Sweetpotato Weevils (*Cylas* spp.)

Source: Ames *et al.*, (1997).

2.9.2 Morphology and Biology of *C. puncticollis*

Cylas species are holometabolous like any other coleopteran insects with four main developmental stages: the egg, lava, pupa and the adult. The eggs which are oval, and yellowish-white (Schmutterer, 1969), are laid singly at the base of the vines, or in roots and then plugged with faecal matter (Moyer *et al.*, 1989). The female excavates a hole in the potato's tuber or stem with its mouthparts. The egg is then placed within the cavity, and the entrance is plugged with fecal matter which turns dark brown or black on hardening. The fecal plug serves to keep the egg in a moistened condition by sealing the hole and also protects the egg from mechanical injury, predators and parasites. Egg incubation period in the laboratory varies from 4 to 5 days (Darko, 2000).

The larva is of the typical curculionid form. They are crescent-shaped, subcylindrical, white, and legless. Darko (2000) reported three (3) larval stages and the mean length of first, second and third are 1.41 mm, 2.27 mm and 5.91 mm, respectively. The second instar is not well sclerotized as the third instars. Larval development is completed in 10 – 12 days and depends on the sweet potato variety. The pupal stage is preceded by a pre-pupal stage which last for 1 - 2 days. The pre-pupa is an immobile stage, creamy white and measures 5.43mm. The pupa is an immobile stage as well but when disturbed, it can shake the abdominal section in a circular manner. It is whitish when it first appears with eyes, head and the snout folded ventrally to partially cover part of the thoracic region. The pupal stage lasts between 6 - 8 days and can measure 5.41mm (Darko, 2000). The pupation occurs in the root or stem within a small pupal chamber prepared by the larva.

The adult (Plate 1) has an elongated ant – like body, black with a narrow head and thorax and the average body length from the tip of the snout to tip of the abdomen in a female and male are 7.35 mm and 7.15 mm (Ames *et al*., 1997; Darko, 2000). The sexes can be readily determined by an examination of the shape of antennae. In the male, shape of the distal antennal segment is filiform while female has club like shape (Smit *et al*., 2001). The adult emergence time varies considerably and depends on the temperature and the sweet potato variety. Darko (2000), reported between 21-24 and 24-27 days on red and white skin varieties, respectively.

Plate 1: Female (left) and male (right) of *C. puncticollis.*

Source: Photo Camille Locatelli.

2.9.3 Dissemination of sweet potato weevil

Cylas species have well-developed wings but cannot fly that much. The maximum distance *C. formicarius* has been observed to fly in the laboratory was about 20 feet. Flight is by then probably only a minor way of dissemination for *Cylas* spp. (Sherman and Tamashiro, 1954). Infestation of a field probably occurs primarily by means of infested sweet potato cuttings (Cisneros *et al.*, 1995), adults crawling from adjacent infested fields, and by other mechanical means. The planting of infested cuttings in a field will result in the development of a high weevil population within one season. Normally, however, if clean planting material is used in a field that has never been planted with sweet potato, the build-up of the weevils is slow. In cases where sweet potato is grown in an isolated area in which this crop had previously not been grown, the weevils probably move in from one of the alternate hosts; and, after several seasons, the population may increase to a very high level. Allowing volunteer growth of sweet potatoes does much to maintain and increase a weevil population within a field. They are probably able to survive for several months in a field from which sweet potatoes have been harvested. This has very serious implications, since it emphasizes the fact that sweet potatoes planted in the same field during this period would be readily attacked by the weevils (Sherman and Tamashiro, 1954).

2.9.4 Damage and yield loss by sweetpotato weevil

Sweetpotato weevils constitute a major constraint to sweet potato production and utilisation worldwide (Lenne, 1991). The damage is similar for the three different species. The adult stage of *Cylas* spp. feed on the epidermis of vines by scraping oval parches of young vines and petiole. Feeding inside the vines causes malformation, thickening, and cracking of the affected vine (Ames *et al.*, 1997). They feed as well on external surfaces of storage root resulting in round feeding punctures. The female sweetpotato weevil lays eggs singly in cavities excavated in either the vine or exposed/easily accessible roots of sweet potato. The tunnels may be partially filled with frass. The feeding punctures can be distinguished from oviposition sites by their greater depth and the absence of a fecal plug (Sato *et al.*, 1982). The developing larvae tunnel while feeding within the vine and root, and this is the most destructive damage (Plate 2). The main portion of the stem will usually have a heavier infestation than the younger vines. The crown end of the root is probably attacked more readily than any other portion of the root. Plant may wilt or even die as a result of extensive stem damage, and damage to the vascular system can reduce the size and the number of storage roots. While external damage to roots can affect their quality and marketable value, internal damage lead to complete loss (Chalfant *et al.*, 1990).

Plate 2: Sweet potato storage root severely infested by the weevil.

Yield losses as a result of the weevil damage as high as 60-97% have been reported (Smit, 1997). Even low infestation can reduce root quality and marketable yield because the plants produce unpalatable terpenoids in response to weevil feeding (Burns, 1999) and consumers pay only reduced prices for weevil damaged roots. Sweetpotato weevils are particularly serious under dry conditions, because the insects, which cannot dig, can reach roots more easily through cracks that appear in the soil as it dries out. It is for this reason that during the dry season, unlike cassava, sweet potato roots cannot be stored in the ground for any significant period of time.

2.10 Sweetpotato weevil management strategies

The control of sweetpotato weevil has been done with some degree of difficulty. The larva, which is the most destructive stage of the insect, feed on stem and storage roots. Their presence inside the various parts of the plant protects them from contact insecticides and most natural enemies. Despite their taxonomic differences, the mode of infestation and nature of damage by sweetpotato weevils are quite similar. Hence control measures devised to combat them are also practically identical.

2.10.1 Cultural methods

At present, under conditions where the use of insecticides is not effective, cultural methods have been then recommended since the early 1900's as the most suitable means of controlling sweetpotato weevils (Talekar, 1987). Crop rotation, sanitation, use of clean cuttings, intercropping, planting time manipulation and re- hilling are some of those cultural practices that contribute to reduce weevil infestation. Escape is a form of resistance encountered in sweet potato to weevil attacks. Therefore early planting and early harvesting may avoid high weevil population and reduce consequently infestation level. Mansaray *et al.* (2013) reported that early harvesting at 104th days after planting coupled with other good cultural practices resulted in increased number of tubers and reduced sweetpotato weevil infestation.

As stated earlier, sweetpotato weevil cannot dig the soil and readily reaches storage roots through cracks that appear in the soil when it dries out. Higher levels of infestation are reported to occur during the dry season than the rainy season when the soil is wet (Stathers *et al.*, 2003a). This is presumed to be due to the absence of soil cracks due to adequate soil moisture in the wet season as opposed to the dry season. Therefore prevention of soil cracking by re-hilling the area around the plant or irrigating frequently, are suggested as effective strategies of reducing weevil damage. Emana (1990) reported that earthing up of soil around the plant three times at monthly intervals starting from the second month after planting significantly reduced infestation of tuberous roots and this practice could enable one to delay harvesting for more than six months. Mulching is another way to prevent formation of cracks in the soil and this reduces weevil infestation to the sweet potato. Mulching at the rate of 5t/ ha has reduced infestation level three times compared to unmulched plots (Mansaray *et al.*, 2015).

Similarly, sweetpotato weevils survive in roots and stem after harvesting and their population can easily build up from residues of the previous season. Therefore, destruction of crop residues is very important and helps to avoid a source of infestation for the next season (Dalip, 2000). Flooding of harvested sweet potato farm is seen as a safe and cost-effective method to destroy sweetpotato weevils in leftover plant materials. It induces the rotting of leftovers and then reduces the chances of weevil infestation in neighboring plants (Komi, 2000).

Research works on crop rotation and intercropping of sweet potato with other crops have shown that they reduce sweet potato infestation by the weevils and increase crops yields (Mansaray *et al.*, 2013). Strip intercropping in sweet potato reduces the root infestation by sweetpotato weevil. Lower percentage of weevil damaged roots was found in strip intercropping of sweet potato along with maize compare to with other crops (red gram, rice, ragi) (Nedunchezhiyan *et al.*, 2012b). In Kerala, India, Pillai *et al.*, (1996) reported that intercropping of sweet potato along with colocasia, rice, or cowpea resulted in up to tenfold reduction in the infestation of sweetpotato weevil compared to monocrop of sweet potato. Crop rotation was found to be effective in controlling weevil infestation. The work conducted by Alvarez *et al.*, (1996) showed that the number of weevils captured by sex pheromone traps in areas with monoculture of sweet potato exceeded exponentially that in areas planted with sweet potato rotated with Irish potato.

The nature and level of soil fertility contribute significantly to the sweet potato plant's susceptibility to the weevil. A negative correlation was established between the potash and silica content in sweet potato stems and the level of infestation by the weevils (Singh *et al.*, 1984). Nitrogen and potassium content in the soil may affect the chemical composition of the storage roots especially chemicals contributing to resistance to weevil attack such as oviposition stimulants (Marti *et al.,* 1993). Therefore sweet potato plant resistance can be altered through alterations in nutritional regimes of the crop (Korada *et al*, 2010**)**. Other cultural methods include clean planting material (weevil- free vines), removal of volunteer plants, timely planting and prompt harvesting especially piecemeal harvesting (Ebregt *et al.*, 2007), removal of wild host plants and planting isolated fields (Ames *et al*., 1997).

2.10.2 Varietal resistance for sweetpotato weevil

Though several research indicated the possibility that an adequate source of resistance to the weevil may not exist in sweet potato germplasm, there is a variability among sweet potato varieties for susceptibility to sweetpotato weevil (Mao *et al.*, 2001; Anioke and Ogbalu, 2003). However, some of the materials reported to be resistant succumb under high weevil population pressure. Many factors are responsible for the different levels of susceptibility observed among sweet potato varieties. Plant morphological characters such as root depth, root shape, root arrangement and plant canopy (Kabi *et al.,* 2001, Stathers *et al.*, 2003a). Stathers *et al.*, (2003b) reported sweet potato varietal differences in attraction/deterrence and antibiosis for *Cylas* spp. which may affect oviposition, egg incubation time and larval mortality.

Therefore selection of varieties exhibiting characters that cause escape from weevil attacks and/or adversely affect survival or development of *Cylas* spp. may drastically affect the dynamics of the weevil population (Mullen *et al.*, 1980). Sweet potato varietal resistance can be improved as well by introduction of foreign genes which confer resistance to the plant. A lot of research has been done on genetically modified sweet potato especially on sweet potato Bt. It has been shown that under controlled conditions weevil damage on tubers was up to 5 times lower in transgenic sweet potato compared with control plants (García *et al*., 2000).

2.10.3 Use of pheromones

Due to the cryptic behaviour of sweetpotato weevils, pheromone traps provide an effective monitoring tool for use in resistance breeding trials and in community level IPM projects. It has been suggested that mass trapping of weevils in nurseries for the production of clean planting materials could be an effective control strategy (Downham *et al*., 1998). Studies conducted by Jenn-Sheng (2000), showed that the use pheromone baited traps placed at a density of 4 traps/0.1 ha reduced damage to tubers caused by sweetpotato weevil by 57-65%. Sex pheromone specific to each *Cylas* species have been isolated, identified and synthetized. Pheromone lures of *C. formicarius* are commercially available and pheromone traps are used as monitoring, training, and management tools. Traps are so sensitive that their failure to catch weevils is a good indication that the pest is not present (Ames, 1997).

2.10.4 Biological control

Biological control is an environmentally sound method to reduce pest densities and is most suitable for all types of cropping systems wherein pesticides are not used (Korada *et al.*, 2010). Biological control involves the use of parasitoids, entomopathogenic fungi and nematodes, among others. Several parasitoids have been found to parasitize sweetpotato weevils all over the world. Palaniswami and Rajamma (1986) and Maeto and Uesato

(2007), reported *Bracon yasudai* in south-west islands of Japan, *Rhaconotus* sp. and *Euderus purpureas* in southern Florida, respectively parasitising sweetpotato weevils. Nevertheless, the success of all these parasitoids at field conditions is doubtful since they are recorded in a very few numbers.

2.10.5 Chemical control

Chemical control of *Cylas* species has been done by the application of inorganic fluorine and arsenical insecticides. However because of the concealed nature of the feeding habit, the use of contact insecticide has been ineffective (Collins and Mendoza 1991). Work carried out by Rajamma and Pillai (1991) showed that 0.05% fenthion or endosulfan spray at monthly intervals with or without pruning or soil application of carbofuran or phorate granules at 1 kg a.i. ha^{-1} 45 days after planting (DAP) were all effective in reducing infestation by sweetpotato weevils resulting in greater marketable tuber yields. In another study, dipping sweet potato cuttings in diazinon 60 % EC at the rate of 1ml of chemical per 200 ml of distilled water, before planting improved the yield and reduced the level of infestation (Tesfaye, 2002).

2.10.6 Integrated management of sweetpotato weevil

When weevil populations are high, a single control method may not provide a suitable control. There is a need to combine, harmoniously and based on cost/benefit analysis, different methods emphasizing on prevention that will help to achieve a suitable crop protection (Ames, 1997). The integration of early planting, insecticides and earthing up three times starting from one month after planting highly reduced the percentage of infestation by the sweetpotato weevil and increased root yield of sweet potato (Mesele *et al.*, 2005). Work carried out by Worku *et al.*, (2014) with the aim to identify effective control tools by integrating two cultural practices: earthing up and harvesting time indicated that prompt harvesting significantly reduced number of damaged tubers, sweetpotato weevil density, damage percentage, unmarketable yield and yield losses.

2.10.7 Released varieties of sweet potato in Ghana

Officially released varieties in Ghana are all selections from exotic introductions. Eight varieties of sweet potato have been released by the CSIR-Crops Research Institute and one released by KNUST. Okumkom, Sauti, Faara and Santom Pona were released in 1998 (CSIR-CRI, 1998). In 2005, Hi-Starch, Ogyefo, Otoo and Apomuden were also released. These are high yielding, resistant to pests and diseases and good for food and industrial products. According to a study done in CSIR, Apomuden recorded the highest mean fresh tuber yields followed by Otoo, Ogyefo and High-Starch (CSIR-CRI, 2005). Cemsa 74-228, NingShu, Kemb 37, Mohc, TekSantom, Ligri, Dadanyui and 199062.1 are also some varieties that were introduced into Ghana. The improved sweet potato varieties in Ghana are shown in Table 3.

Table 3: Some characteristics of Ghanaian improved sweet potato varieties.

Varieties	Colour		Maturity (months)	Yield (tons/ha)	Some characteristics and uses
	Tuber skin	Flesh			
CRI-Sauti	Cream	Yellow	4	19	High dry matter, excellent for ampesi and fried chips, less sugary, good for flour and its products
CRI- Santom pona	Dark cream	Light yellow	4	17	Early maturing, high foliage, high dry matter, good for ampesi, tastes like pona- a local yam variety
CRI- Okumkom	Light pink	White	4	20	Early maturing, moderate dry matter, good for ampesi and fufu, fried chips.
CRI- Faara	Pink	White	4	22	High dry matter, high foliage, highly preferred and excellent for chips and ampesi
CRI- Apomuden	Purple red	Dark orange	3.5 – 4	30	High beta carotene levels; highly preferred by exporters; excellent industrial and confectionery products. E.g. beverages, custard, baby -foods; local dishes e.g. mpotompoto and TZ; flesh colour orange very appealing to children
CRI- Otoo	Pale cream	Cream with interspersed orange	4	23	Medium beta- carotene levels; excellent when boiled (Ampesi) and deep fried as chips (highly rated excellent for chips); flour products (pasteries); high foliage production (good for livestock); and highly preferred by exporters.

Source: MoFA, (2014)

Table 3 Cont'd: Some characteristics of some sweet potato varieties.

Varieties	Colour		Maturity (months)	Yield (tons/ha)	Some characteristics and uses
	Tuber skin	Flesh			
CRI- Histarch	Dark cream	Cream	4	18	High starch content (21%) and excellent starch properties, mild sweetness, excellent for fufu and ampesi, good quality flour
CRI-Ogyefo	Purple-red	White	4	20	Very high dry matter, highly preferred for ampesi and fried chips; very aggressive with high foliage (very good for weed control and livestock feed)
CRI- Patron	Dark yellow	Dark yellow	4-5	22	High dry matter and starch content, moderate beta-carotene level, high foliage, excellent for ampesi and fried chips, good for starch and flour production, foliage for animal feed and weed control
CRI-Ligri	Pale yellow	Cream	4-5	20	High dry matter and starch content , excellent for ampesi and fried chips, starch and flour production, high foliage for weed control and livestock feed
CRI-Bohye	Purple	Pale orange	4-5	22	High beta- carotene content, high starch and moderate dry matter content, excellent for ampesi and fried chips, good for starch and flour production
CRI-Dadanyui	Dark purple	White	4-5	18	High dry matter , high starch content and excellent starch properties, excellent for ampesi and fufu, flour and industrial starch

Source: MoFA, (2014)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Field evaluation of natural infestation of different sweet potato varieties by the potato weevil

3.1.1 Description of Study site

The field experiments for assessing the susceptibility of the different sweet potato varieties to weevil damage were carried out at the University of Ghana farm, Legon. University of Ghana is located at 05^{o} 39 03 N, 00^{o} 11 13 W in Accra which lies in the costal savannah zone with two rainy seasons per annum from April to July (major rainy season) and September to November (minor rainy season). Accra is subjected to an average 787 mm of rainfall per year with an average annual temperature of 26.5^{o} C. Almost all the food crops grown in the southern Ghana (vegetables, cereals, legumes, root crops) are cultivated in the University farm. Sweet potato has been cultivated every year during the major rainy season.

3.1.2 Plant material

A total of seven (7) improved Ghanaian sweet potato varieties, Apumeden, Bohye, Dadanyui, Faara, Ligri, Okumkom and Sauti were assessed for their susceptibility to the weevil in the field. The vine cuttings of these sweet potato varieties were received from CSIR/ Crops Research Institute - Kumasi (Ghana). Some of their characteristics are mentioned in Table 3.

3.1.3 Land preparation

The land used for the experiments were initially used to grow vegetables. The plots were ploughed and then ridges were made with a tractor drawn plow. The ridges were 0.5 m wide and 1m apart (distance between middles of ridges).

3.1.4 Experimental design and planting

The experiment was carried out during the major and minor seasons 2015. During the major rainy season six (6) sweet potato varieties: Apumeden, Bohye, Dadanyui, Faara, Ligri and Okumkom, were evaluated. The major rainy season trial was set up towards the end of the season in July near to an infested sweet potato farm to ensure the presence of the weevils. In the minor rainy season, one more variety, Sauti, was added to the six varieties initially evaluated during the major rainy season. This was established late in the season in November. The minor and major rainy seasons plots were separated from each other by about 250 m. Both trials were laid in a randomized complete block design with four replications in the major and three replications in the minor rainy seasons. Vine cuttings of 30 cm long of all the varieties were planted singly in the middle of each ridge in 4 cm deep holes and spaced 0.3 m. The established plot is shown in plate 3.

In the major rainy season, the experimental unit was made by two ridges of 3m each, spaced 1m with 10 plants each making 20 plants per experimental unit. During the minor rainy season each had 7 plants making 14 plants per experimental unit. The number of replications and plants per experimental unit was reduced in the minor rainy season trial because of lack of vine cuttings. Experimental units were 1m apart. To avoid excessive drought, supplementary irrigation was done during the time of drought and especially in the earlier stages of plant development. No fertilizers or insecticides were applied. For weed control hand weeding using a hoe was done three times, 4, 8 and 14th weeks after planting. Harvesting was done after 18 weeks after planting with hoes and machete.

Plate 3: Established sweet potato plot at the early stage of plant development.

3.1.5 Assessment of plant establishment rate

After planting, a weekly survey was done in the experimental plot for six weeks to check for plant establishment. The number of plants which failed to establish was recorded in all experimental units. The stem base of these plants which failed to establish were dissected to check for the presence of weevil adults, larvae or larval tunneling (Plate 4). The failure of establishment of the plant in which weevil and/or larval tunneling were found was attributed to weevil infestation. The failure of establishment of dissected plants without any sign of weevil infestation at the stem base were attributed to factors such as cutting quality, virus attacks, lack of water and attack by other insect pests especially termites.

distance from top of the ridge to top-most part of each root and the horizontal distance (H), from the side surface of the ridge to closest part of the root (Plate 5) using Pythagoras' theorem.

RD= (V x H)/ R with R= $(V^2+H^2)^{1/2}$ (Kabi *et al*., 2001). The measurements were done with a 30 cm ruler.

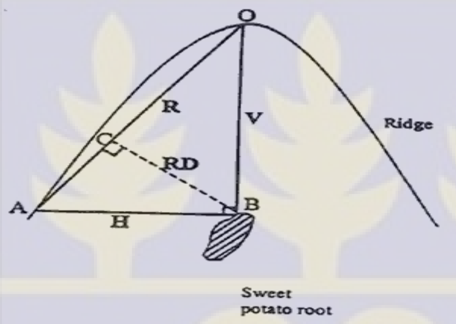


Figure 1: Cross section of sweet potato ridge showing how vertical and horizontal (V and H) positions of roots in relation to the surface of the ridge to the root were measured.

Source: (Kabi *et al*., 2001).

Root neck length, is the distance between the top of the root tuber and the point of attachment to the mother vine. It was measured by stretching the root neck along a tape measure.

Root tuber length, was measured from one end of the root to the other.

Root tuber girth, was derived from measurement of the circumference at three different points along the root tuber, namely the middle point (C_1), and then the middle of each half (C_2 and C_3). From this, an average root girth measurement was calculated.

The root tuber size index was obtained by multiplying the average root girth by the root length.

3.1.7 Determination of yield

At the harvesting, storage roots from the all surviving plants on each plot were carefully dug up, collected and weighed using a scale (Salter Metal-body Kitchen Scale) (Plate 6) to obtain the overall root weight per plot. The yield was expressed as weight of fresh storage root weight in tonne per hectare**.**

Plate 5: Weighing the storage root for yield determination.

3.1.8 Assessment of infestation level and yield loss by the weevils

The level of infestation was assessed on the stem base and the storage root as well.

3.1.8.1 Assessment of external and internal stem base infestation

Stem bases measuring 15 cm (cut off from the crown) of five plants were collected randomly in each experimental unit (plants previously used for root characteristic measurements) and scored for weevil damage levels on the stem surface and inside them. Weevil damage was identified by the presence of dark scarred spots, a typical symptom of weevil penetration and feeding (Plate 7). Internal damage of the stem was obtained by splitting the stem lengthwise with a knife. The infestation level was scored on a scale of 1-5 for weevil damage, whereby 1= 0 - 20%, 2 = 21 - 40%, 3 = 41 - 60%, 4=61-80% and 5=81-100% stem surface damage (Muyinza *et al.*, 2007).

1. Adult weevil emergence hole. 2. Destruction of internal stem base by weevil larval feeding.

Plate 6: Stem bases showing external (a) and internal damage (b).

3.1.8.2 Assessment of storage root infestation

After harvesting**,** storage roots from each plot were sorted into unmarketable (< 100g) and marketable (≥ 100g). Only marketable storage roots were assessed for weevil infestation. Roots were assessed for weevil infestation using a scale of 1 to 5; whereby; 1= 0-20%, 2=21-40%, 3=41-60%, 4=61-80% and 5=81-100% root surface damage (Stathers *et al.*, 2003a). A root was considered to be weevil - damaged if it showed characteristic dark scarred spots on the surface of the root a typical symptom of weevil penetration and feeding. Those roots lacking any surface damage were considered to be non-infested (Stathers *et al.*, 2003a).

3.1.8.2 Determination of yield losses by weevil

Yield losses due to weevil damage were evaluated by firstly sorting the marketable storage roots harvested from each plot into three different groups namely:

1. **Totally clean storage roots**, bearing no sign of weevil infestation (Plate 8a);

2. **Clean portion of infested storage roots** (edible part of infested storage roots), obtained by cutting off the damaged part of the storage root (Plate 8b). This group of storage roots can be used by households, but will not be kept for long.

3. **Infested portions of infested storage roots,** useless for most purposes (Plate 8c).

Both totally clean storage roots and clean portions of infested roots were put together as the total clean storage roots harvested. Yield loss was then expressed as percentage of infested roots using the equation used by Kabi *et al.* (2001).

$$\text{Yield loss} = \frac{\text{Total storage root weight} - \text{total clean storage root weight}}{\text{Total tuber weight}} \text{ x } 100$$

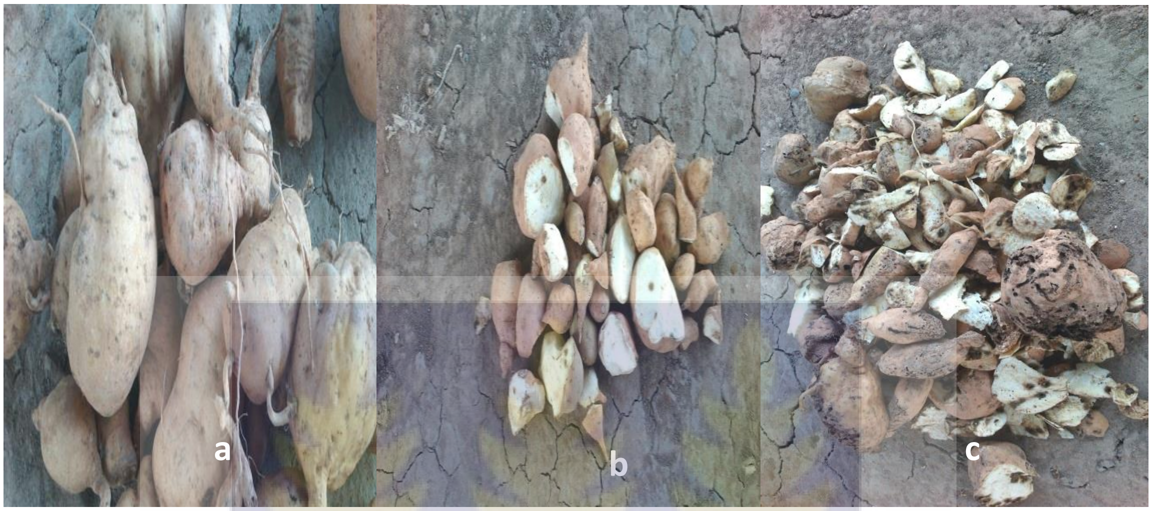


Plate 7: Sweet potato sorted based on the level of infestation; totally clean (a), clean portions of infested storage roots (b) and infested portions of infested storage roots.

3.2 Laboratory study

Experiments were carried out in the laboratory of African Regional Postgraduate Programme in Insect science (ARPPIS), University of Ghana, Legon. The preference of *C. puncticollis* for eight (8) different varieties was determined through no choice and choice tests. These varieties included six that were used for field evaluation during the major rainy season and two other varieties bought from Madina market in Accra. One had a yellowish skin and flesh (yellowish-yellowish) while the other one had red skin and yellowish flesh (red-yellowish). In addition, the laboratory study consisted of the determination of some bionomic parameters of *C. puncticollis* developing on four different varieties: Apumeden, Ligri, Bohye and Okumkom. The storage roots used for the laboratory study were, excepted the ones bought from the market for which growing conditions were unknown, the others were harvested from the field experimental plots. The harvested storage roots were cured in the sun, and stored in paper bags in the laboratory. The experiments were carried out under ambient conditions in the laboratory at 30.09 ± 1.50^{o} C and 76.12 ± 3.75 % RH.

3.2.1 Insect culture

Colony of sweetpotato weevil was established in the laboratory from infested sweet potato storage roots bought from farmers in Akatsi in the Volta region of Ghana. The infested storage roots were incubated in boxes. These were 17.0 x 17.0 x 9.5 cm^3 rectangular plastic containers fitted with a mesh cover at the top to allow ventilation and to prevent adult from escape when emerged (Plate 9a). Before infested storage roots were kept in the box for incubation, paper towels were used to line its base to suck excess moisture resulting from storage root transpiration. The incubation boxes were checked daily for adult emergence. Upon emergence, adults were removed from the incubation boxes and, both sexes of adult weevils (unsexed population), were kept in infestation boxes with a paper towel in the base and several uninfested clean storage roots. Infestation boxes were 40 cm x 26 cm x 26 cm rectangular plastic containers and were fitted with a mesh cover at the top (Plate 9b). The infested storage roots in the infestation boxes were replaced weekly with clean uninfested ones to assure continuous weevil production for experimental purposes. The infested roots were then kept in a new incubation boxes for adult emergence. All the emerged adults were collected and the infested roots were thrown away.

Plate 8: Incubation box (a) and infestation box (b).

3.2.2 Studies of weevil preference of sweet potato varieties for feeding and oviposition: no choice and choice tests

The experiment was conducted according to the technique developed by Mullen *et al.* (1980) and adapted by Mao *et al.* (2001) with slight modifications. One to two week-old gravid females were used in both no choice and choice tests to enhance egg laying capability (Wilson *et al.*, 1988). The sexing of adult weevils was done under stereomicroscope (Vernon Hills, Illinois 60061, Cole Parmer®) and based on the shape of the distal antennal segment; males have a filiform shape and females have club like shape (Smit, 1997). A 24-well tissue culture plate (Plate 10a) containing sweet potato storage root cores was placed in rectangular clear plastic container. Cores were cut from selected storage roots with a cork borer (Plate 10b) and inserted into the wells (Ø = 1.6 cm; h = 2.0 cm) such a way that only the root periderm was exposed (Plate 10c). The cores cut had the same diameter as the wells, providing a close fit. Selected females for experiment (1- 2 week-old) were starved for 12 hours prior to use for experiments. They were introduced into the experimental containers (17.0 x 17.0 x 9.5 cm^3) at the rate of two (2) females per root core. A wet paper towel in the base of the container maintains a humid environment and prevents excessive desiccation of the root cores. The weevils were allowed to feed and oviposit for 48 h and then were removed from experimental container.

In a no-choice test: cores from only one variety was presented to the weevils in the culture tissue plate while in choice test, three (3) cores from each one of eight sweet potato varieties were randomly arranged on the plate and presented. The feeding punctures, eggs laid were counted and recorded under stereomicroscope for both no choice and choice test and the number of frass from weevil feeding were recorded only for no choice to give an indication of the level of feeding, oviposition activities and digestibility which may be factors of susceptibility of sweet potato to the weevil infestation (Wilson *et al.*, 1988, Stathers *et al.*, 2003b).

Plate 9: Empty 24-well tissue culture plate (a); a cork borer (b) and tissue culture plate with sweet potato cores (c).

3.2.3 Determination of bionomics and life of *C. puncticollis*

3.2.3.1 Developmental period and survival rate of immature stages and sex ratio

Ten un-infested storage roots of each variety were washed and wiped dry and provided to gravid female weevils for 24 hours for them to oviposit upon. Twenty (20) cubes of various sizes each containing one egg was cut from infested sweet potato storage roots for each variety. A small slit was made on each cube just to make the egg visible inside the hole. The cubes were kept in containers (17.0 x 17.0 x 9.5 cm^3) and were then were observed daily under a stereomicroscope for (10) days to determine the egg incubation period and egg survival. The un-hatched eggs after ten (10) days were considered as nonviable eggs.

On hatching, each young larva (≤ 24 h - old) was transferred in about 3 mm deep well made on a new fresh sweet potato cube (1.5 x 1.5 x 2.0 cm^3). This was done by using a needle nosed forceps and a fine brush. The egg plugs on infested sweet potato storage root were opened with the needle nosed forceps and using a fine brush, the young larva was taken out and transferred gently and with a lot of care, into the well. The well was then covered with a glass slide and the cube held between two slides with rubber bands (Plate 11). One day after infestation, dead larvae which didn’t show signs of having fed before they have died were discarded. It was assumed the death was caused by the transfer procedure and not due to varietal effect. The remaining cubes were observed daily until the larvae have pupated and then emerged into adults. Cube was changed, when there were signs of contamination by fungi or got dried.

Larval period and larval survival were determined as the time it took for a larva to turn into a pupa and the proportion of larvae which pupated, respectively.

Pupal period and pupal survival were determined as the time for a newly formed pupa to emerge into adult and the proportion of pupae which emerged into adults, respectively.

Emerged adults were sexed under stereomicroscope to determine the proportion of each sex in the emerged population. Sex ratio was determined as following:

$$\text{Sex} - \text{ratio} = \frac{\text{Total number of emerged females}}{\text{Total number of emerged adults}} \text{ x } 100$$

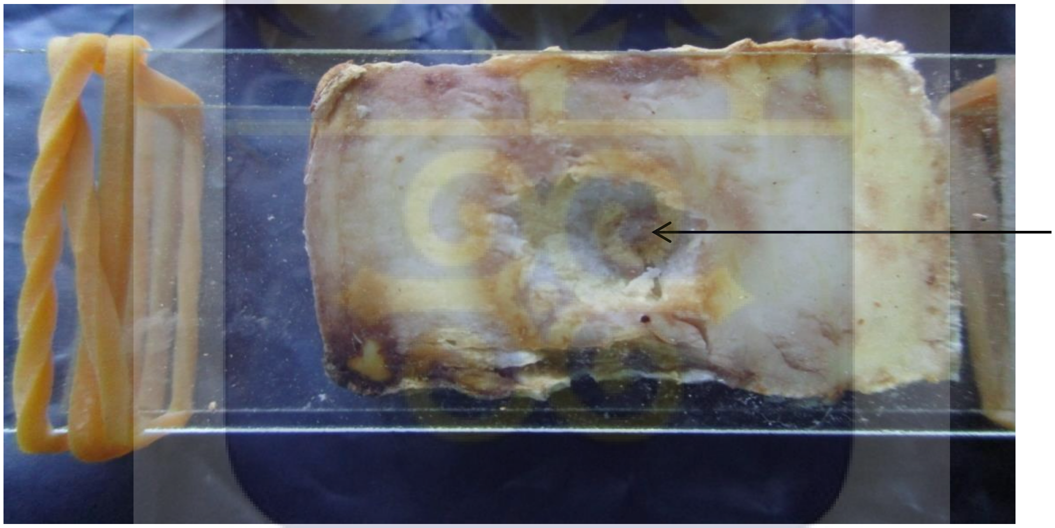


Plate 10: The larva of *C. puncticollis* in sweet potato cube held between two slides.

3.2.3.2 Determination of adult longevity and female fecundity

A pair (female and male) of newly emerged weevils (< 24 h-old) obtained from incubated pupae was kept in a transparent plastic jam- jar (Ø = 6.3 cm; h = 10.5 cm) closed with muslin – cloth. One fresh, uninfested sweet potato storage root piece cut almost flat (5cm x 2cm) was provided daily to the paired weevil until the last individual died. Male was replaced if it died before the female. The storage root piece was placed in the jam – jar with the periderm facing upwards. Used, infested storage root piece was removed and examined closely under a stereomicroscope for presence of eggs. For each variety, fifteen pairs, each pair representing one replication, were observed. From this experiment the following parameters were determined:

Female fecundity: number of eggs laid by a female during her life time. The fecundity was determined by counting the located eggs on each daily infested root piece and the number recorded on all storage root pieces provided to a female were summed up to obtain the fecundity.

Pre -oviposition, oviposition and post - oviposition periods are the age at which a female is mature enough to lay egg, the period during which it lays eggs and the period between the times the female stops laying eggs and its death, respectively.

Longevity was determined for both the females and males**.**

3.3 Statistical analysis

Data collected from both field and laboratory experiments were summarized and subjected to univariate analysis of general linear model (GLM) using SPSS 16.0 software. Where significant differences were found, means were separated by the post hoc test of Student Newman-Keuls Tests (SNK), at 0.05 level of significance. Pearson correlation was run to check the relationship between root characteristics and level of infestation and also between crown (stem base) infestation and root infestation. Percentage and count data (number of eggs, feeding punctures and frass) were prior to analysis subjected to arcsine square root and square root transformations, respectively. .

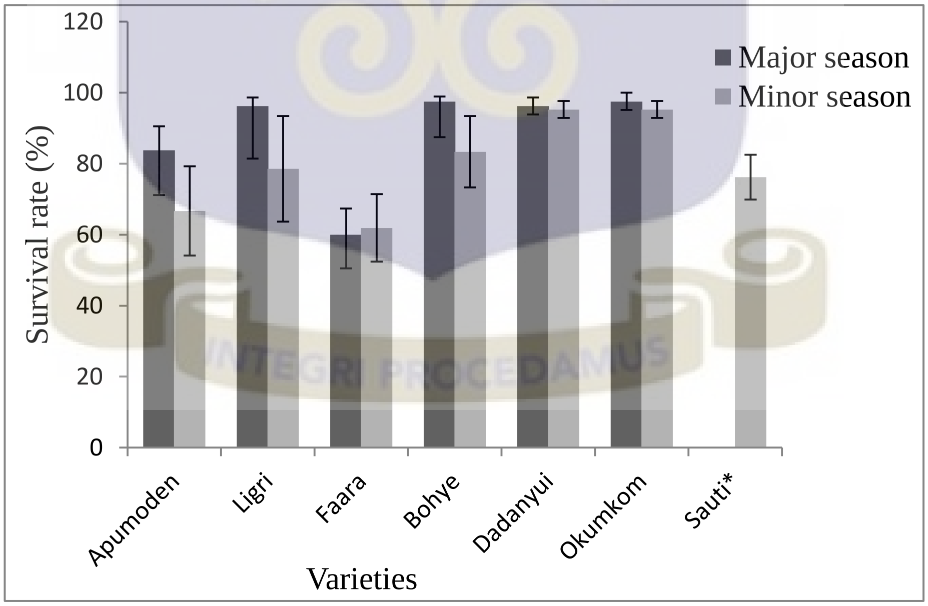
CHAPTER IV

RESULTS

4.1 Evaluation of natural infestation of different sweet potato varieties by the sweetpotato weevil

4.1.1 Plant survival

The percentage of transplanted sweet potato cuttings that survived varied significantly ($F_{5, 23} = 8.63$; $P < 0.0001$) among varieties during the major rainy season with Faara showing the lowest survival rate of 60.00% and Okumkom the highest survival of 97.50%. However, during the minor rainy season, the survival was statistically similar among varieties ($F_{6, 20} = 1.83$; $P = 0.1510$) with means varying from 61.90% to 95.24% recorded on Faara and Dadanyui, respectively (Figure 1). There was no significant difference in plant survival across the seasons in all varieties (Appendix 1).

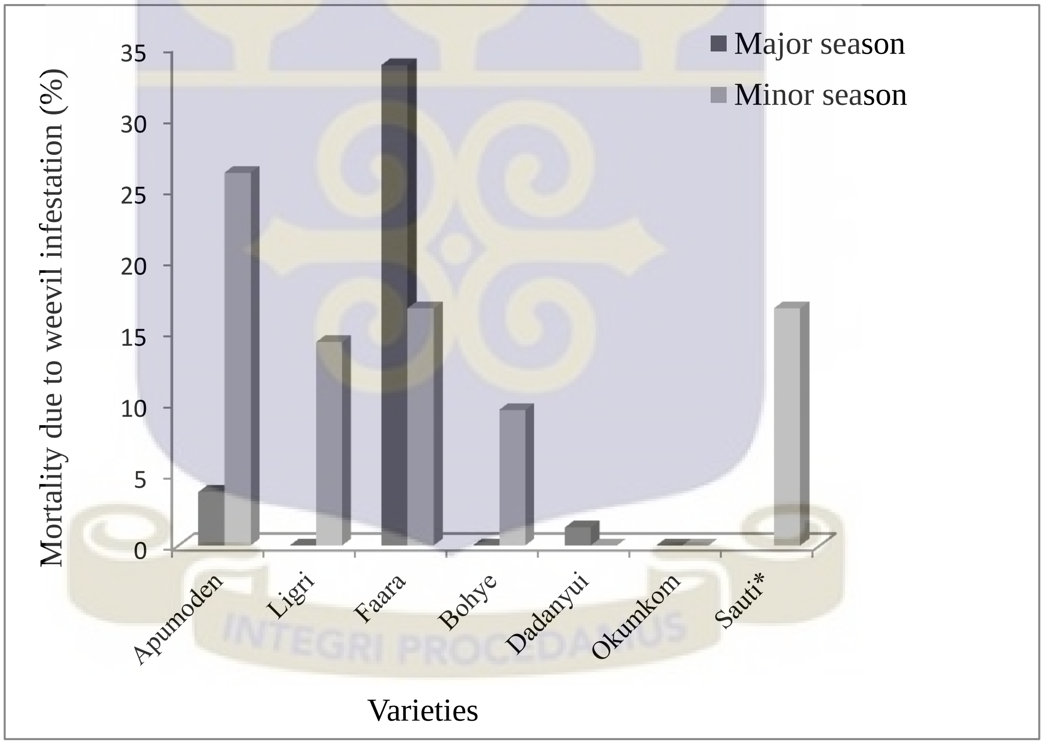


***** Sauti was not assessed during the major rainy season

Figure 2: Survival rate of different varieties in the major and minor rainy seasons.

4.1.2 Mortality of cuttings due to weevil infestation

The mortality in sweet potato cuttings due to weevil infestation varied significantly ($F_{5,\ 23} = 6.44$; $P = 0.0010$) among varieties during the major rainy season, with Faara showing the highest level of 33.75%. However, during the minor rainy season, the mortality didn't vary significantly among varieties ($F_{6,\ 20} = 2.28$; $P = 0.0870$). Among all the assessed varieties, only Apumoden showed a significant difference ($t_{(5)} = -3.73$; $P = 0.0120$) across the seasons with means ranging from 3.7 % in the major rainy season to 26.19% mortality due to weevil infestation in the minor rainy season (Figure 2).



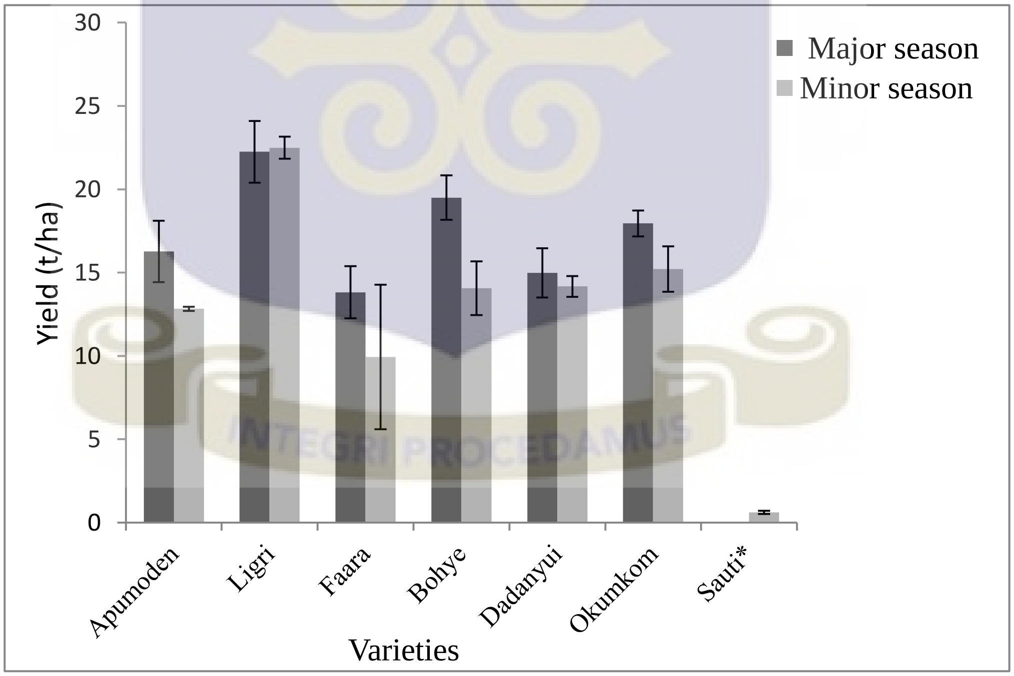
***** Sauti was not assessed during the major rainy season

Figure 3: Mortality due to weevil infestation of different varieties in the two seasons**.**

4.1.3 Evaluation of yield

- **Total yield**

The total yield varied significantly among varieties during the major rainy season ($F_{5,\ 23}$ = 5.08; P = 0.0040) and highly significant in the minor rainy season ($F_{6,\ 20}$ = 41.26; P < 0.0001). Ligiri gave the highest yield (22.25 and 22.49 t/ha in the major and minor rainy season, respectively) while Faara had the lowest yield (13.82 t/ha) in the major rainy season and Sauti (0.61 t/ha) in the minor rainy season. Apart from Ligri, the yield decreased in all varieties in the minor rainy season but it was significant only in Apumoden (t_5 = 3.2; P = 0.0230) and Bohye (t_5 = 2.62; P = 0.0470) and not significant in Faara (t_5 = 1.77; P = 0.1380), Dadanyui (t_5 = 0.45; P = 0.6730) and Okumkom (t_5 = 1.79; P = 0.1410) (Figure 3).

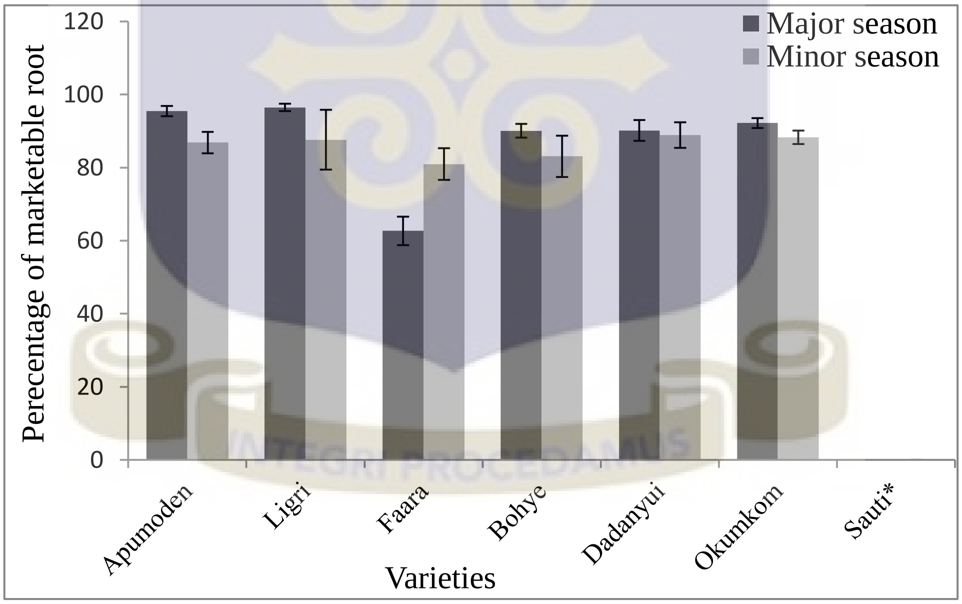


* Sauti was not assessed during the major rainy season

Figure 4: Total yield of different varieties in the major and minor rainy seasons.

- **Marketable root yield**

The difference in the proportion of marketable root among varieties was highly significant during the major rainy season ($F_{5,\ 23} = 23.08;\ P < 0.0001$) with Faara giving the least marketable root yield of 62.69 %. In the minor rainy season, the new variety, Sauti introduced in the trial didn't produce any marketable root at all and the difference in the marketable root proportion among varieties was highly significant ($F_{6,\ 20} = 45.90;\ P < 0.0001$) (Figure 4). The marketable root yield recorded by Faara increased significantly ($t_5 = -3.11;\ P = 0.0260$) from 62.69 during the major rainy season to 80.96 % in the minor rainy season while that recorded on Apumoden decreased significantly ($t_5 = 2.90;\ P = 0.0340$) from 95.49 to 86.88%. However there was no significant difference in the marketable yield of other varieties between the two seasons (Appendix 1).



* Sauti was not assessed during the major rainy season

Figure 5: Marketable root yield of different varieties in the major and minor rainy seasons.

4.1.4 Evaluation of infestation by weevil and yield loss

4.1.4.1 Evaluation of stem base infestation

There was no significant difference in external stem base infestation among varieties in the major and minor rainy seasons, respectively, ($F_{5, 23} = 1.19$; $P = 0.3500$; $F_{6, 20} = 0.72$; $P = 0.6420$) (Table 4). Regarding internal stem base infestation, there was a significant difference among varieties in the major rainy season ($F_{5, 23} = 5.21$; $P = 0.0040$) with Faara having the highest internal stem base infestation (4.40) whilst Okumkom had a mean of 2.60. However there was no significant difference ($F_{6, 20} = 1.07$; $P = 0.4260$) during the minor rainy season (Table 4). The stem base infestation level in Okumkom increased significantly ($t_5 = -5.06$; $P = 0.0040$) to 4.28 in the minor rainy season while no significant difference was found in other varieties across seasons (Appendix 1).

4.1.4.2 Evaluation of storage root infestation

Storage root infestation differed significantly among varieties in the major and minor rainy seasons, respectively ($F_{5, 23} = 6.02$; $P = 0.0250$; $F_{5, 17} = 8.07$; $P = 0.0020$). In both seasons, Apumoden recorded the highest infestation (1.80 and 1.84, respectively in the major and minor rainy seasons) and Ligri (1.77 and 1.84, respectively in the major and minor rainy seasons) though there was no significant difference in the infestation level among other varieties, Okumkom and Faara appeared to be less infested (Figure 5). There was no significant difference in the storage root infestation recorded on different varieties across the seasons (Appendix 1).

Table 4: Mean (±SE)[1] external and internal stem base infestation level in the major and minor seasons.

Variety	External stem base infestation		Internal stem base infestation	
	Major season	Minor season	Major season	Minor season
Apumoden	3.22 ± 0.43 Aa	2.53 ± 0.24 Aa	4.30 ± 0.37 Aa	4.13 ± 0.18 Aa
Ligri	2.55 ± 0.23 Aa	2.50 ± 0.15 Aa	4.15 ± 0.22 Aa	4.60 ± 0.20 Aa
Faara	3.47 ± 0.25 Aa	2.80 ± 0.48 Aa	4.40 ± 0.35 Aa	4.00 ± 0.29 Aa
Bohye	2.79 ± 0.46 Aa	2.35 ± 0.13 Aa	3.45 ± 0.25 ABa	4.10 ± 0.26 Aa
Dadanyui	3.20 ± 0.28 Aa	2.66 ± 0.37 Aa	3.35 ± 0.35 ABa	4.40 ± 0.12 Aa
Okumkom	2.57 ± 0.34 Aa	2.93 ± 0.20 Aa	2.60 ± 0.25 Ba	4.31 ± 0.17Ab
Sauti	*	2.70 ± 0.12 Aa	*	4.28 ± 0.79A
F	1.19	0.72	5.21	1.07
P	0.3500	0.6420	0.0040	0.4260

[1] Means within a column followed by the same lower-case letter and in a row followed by the same upper-case letter are not significantly different (Student–Newman–Keuls, $P < 0.05$).

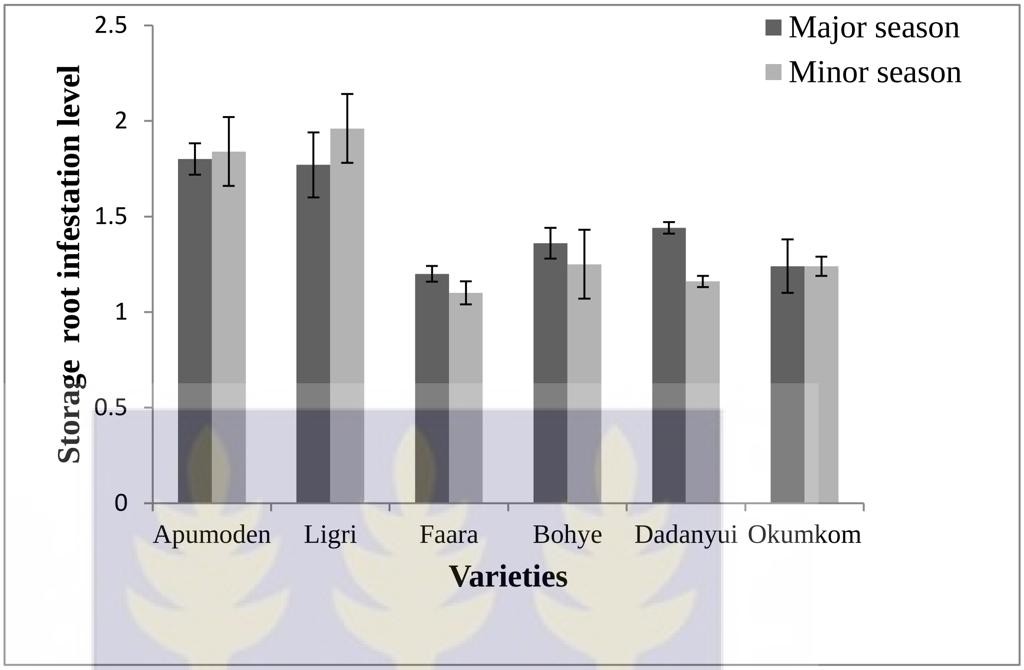


Figure 6: Storage root infestation level of different varieties in the major and minor rainy seasons.

4.1.4.3 Evaluation of yield loss

The storage root yield loss due to weevil infestation was highly significant among the varieties in the major rainy season ($F_{5,\ 23} = 34.89$; $P < 0.0001$) and significant in the minor rainy season ($F_{5,\ 17} = 20.08$; $P = 0.00200$). The highest yield losses were recorded on Apumoden (43.41%) and Ligri, followed by Bohye and Dadanyui and the lowest yield losses were recorded on Faara and Okumkom (8.09%). In the minor rainy season, Apumoden and Ligri had the highest yield losses (23.84% and 23.87%, respectively) but there was no significant difference among other varieties. The yield loss due to the weevil infestation decreased significantly in the minor rainy season compared to the major rainy season in Apumoden ($t_5 = 4.90$; $P = 0.0040$), Ligri ($t_5 = 5.87$; $P = 0.0020$), Bohye ($t_5 = 5.08$; $P = 0.0040$), and Dadanyui ($t_5 = 3.10$; $P = 0.0270$) and not significantly in Faara ($t_5 =$

0.34; P = 0.7460), but increased though not significantly in Okumkom (t_5 = -1.02*; P* = 0.3550) (Figure 6).

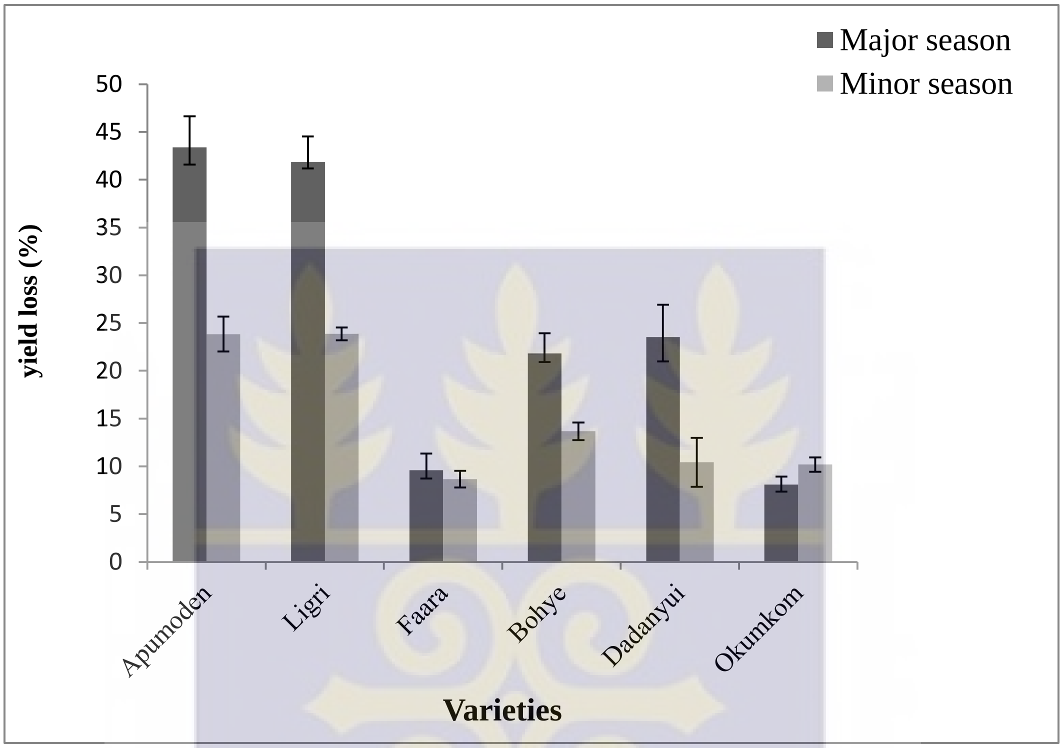


Figure 7: Yield loss of different varieties in the major and minor rainy seasons.

4.1.5 Relationship between stem base infestation and storage root infestation by weevils

There was a non-significant negative correlation between external stem base infestation and storage root infestation in the major and minor rainy seasons ($r_{(5)}$= -0.13; $F_{1, 5}$ = 0.08, *P* = 0.8032; $r_{(5)}$= 0.18*;* $F_{1, 5}$ = 0.01, *P* = 0.9221, respectively). However a moderate non-sgnificant positive correlation was found between the internal stem base infestation level and storage root infestation level in both the major and minor seasons ($r_{(5)}$ = 0.46; $F_{1, 5}$ = 1.23; *P* = 0.3312 and $r_{(5)}$ = 0.47; *F* = 1.17; *P* = 0.3490, respectively) (Figures 7 and 8).

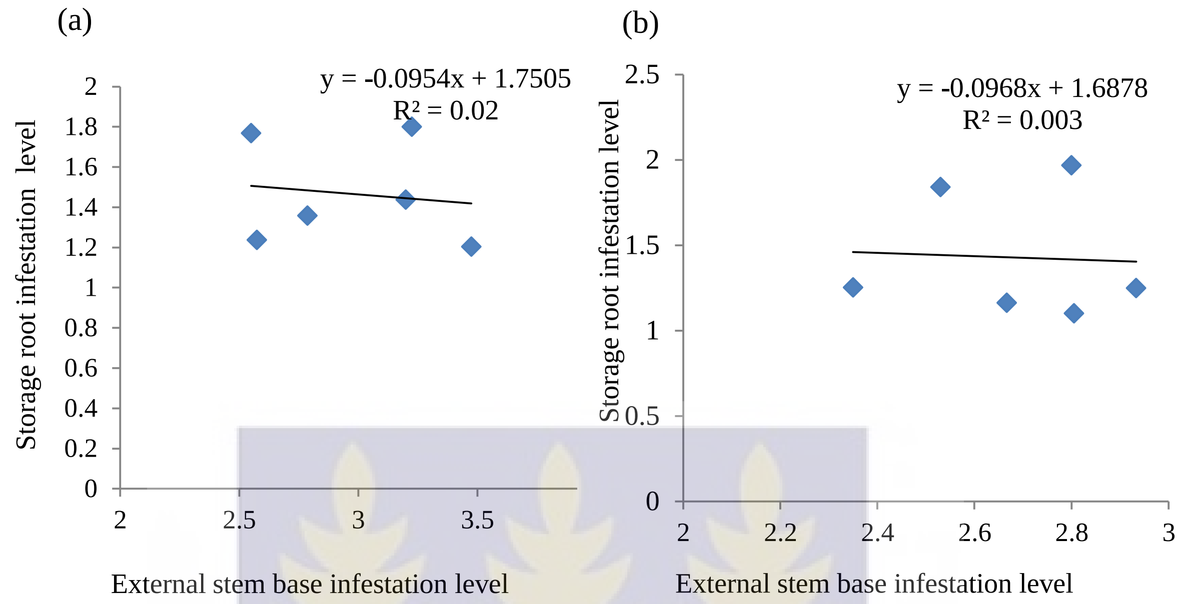


Figure 8: Relationship between the external stem base infestation and storage root infestation level in the major (a) and the minor (b) rainy seasons.

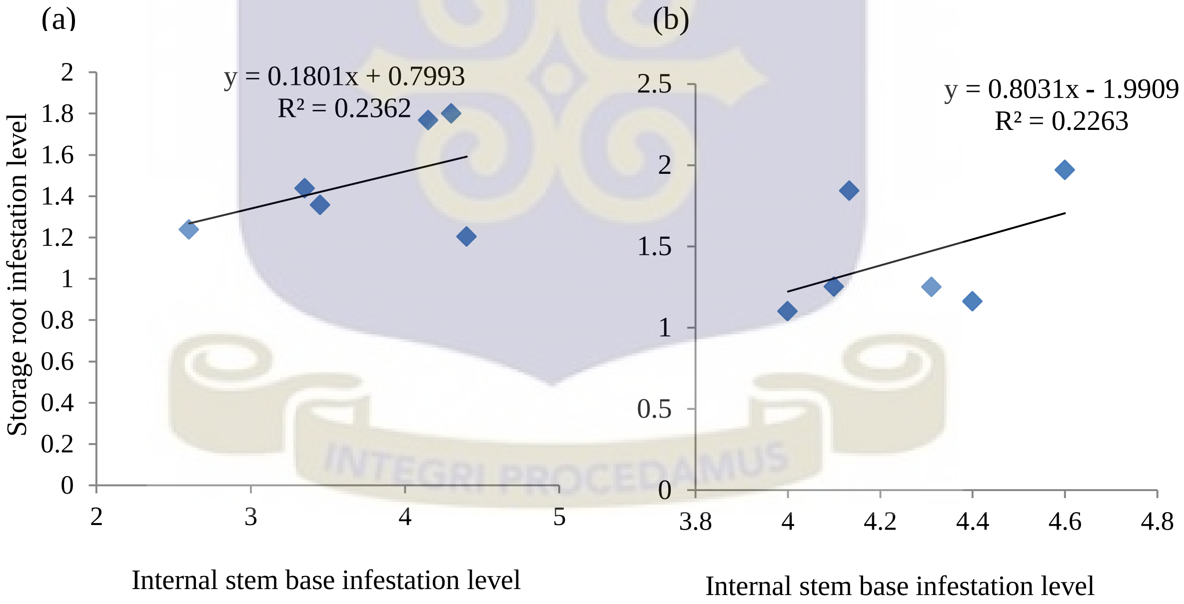


Figure 9: Relationship between the internal stem base infestation and storage root infestation level in the major (a) and minor rainy (b) seasons.

4.1.6 Rooting and root characteristics of different sweet potato varieties

4.1.6.1 The shortest weevil distance

The shortest weevil distances of different varieties were computed using vertical and horizontal distances corresponding values (Appendix 2). The shortest weevil distance varied significantly in both the major and minor rainy seasons ($F_{5,\ 23} = 5.31$; $P = 0.0040$, $F_{5,\ 17} = 5.44$, $P = 0.0080$, respectively) among varieties with Faara having the highest (Table 5), while Apumoden, Ligiri and Bohye had the least in both seasons. A *t*- test, revealed a consistency of these root characteristics across seasons in all the varieties (Appendix 1).

4.1.6.2 Root neck length

The root neck length varied significantly among varieties in the major and minor rainy seasons ($F_{5,\ 23} = 7.36$; $P = 0.0010$ and $F_{5,\ 17} = 6.55$; $P = 0.0040$). For both seasons, Faara had the longest root neck length (5.73 and 11.82 cm) (Table 5). The root neck length varied significantly between seasons in all varieties except Bohye (Appendix 1).

Table 5: Mean (± SE)[1] of the shortest weevil distance and root neck length for different sweet potato varieties in the minor and major rainy seasons.

Variety	Shortest weevil distance (cm)		Root neck length(cm)	
	Major season	Major season	Minor season	Minor season
Apumoden	5.11 ± 0.28Ba	2.09 ± 0.37Ab	3.72 ± 0.33Ba	4.95. ± 0.60Ba
Ligri	5.18 ± 0.54Ba	3.40 ± 0.62Bb	6.59 ± 0.72Ba	4.41 ± 0.61Ba
Faara	7.36 ± 0.33Aa	5.73 ± 0.90Ab	11.82 ± 1.14Aa	10.68 ± 1.72Aa
Bohye	5.50 ± 0.3Ba	2.08 ± 0.24Ba	3.48 ± 1.51Ba	6.58 ± 0.52Ba
Dadanyui	6.57 ± 0.44ABa	2.29 ± 0.12Bb	5.31 ± 0.59Ba	5.55 ± 0.89Ba
Okumkom	6.48 ± 0.19 ABa	3.13 ± 0.44Bb	6.93 ± 1.99Bb	7.04 ± 0.55Ba
F	5.31	5.44	7.36	6.55
P	0.0040	0.0080	0.0010	0.0040

[1] Means within a column followed by the same lower-case letter and in a row followed by the same upper-case letter are not significantly different (Student–Newman–Keuls, $P < 0.05$).

4.1.6.3 Root girth, root length and root size index

The root girth differed significantly among varieties ($F_{5, 23} = 12.72$; $P < 0.0001$, $F_{5, 17} = 3.60$; $P = 0.0030$ in the major and minor rainy seasons, respectively). For both seasons, Ligri produced the largest storage roots (14.46 and 17.40 cm) while Faara storage roots were the smallest with means of 7.22 and 9.99 cm. The storage root length varied significantly among varieties during the major and minor rainy seasons ($F_{5, 23} = 4.53$; $P = 0.0070$ and $F_{5, 17} = 3.23$; $P = 0.0390$). Like the storage root girth and length, the storage root size index also varied significantly among the varieties during the major and minor rainy seasons ($F_{5,\ 23}$ = 4.16; P = 0.0120 and $F_{5,\ 17}$ = 4.02; P = 0.0220). In both seasons, Ligri produced storage roots with highest storage root size index (173.69 and 278.87 cm^2) while Faara had the least storage root index (68.66 and 121.95 cm^2) (Table 6).

Table 6: Mean (± SE) root girth, root length and root size index of different varieties in major and minor rainy seasons.

Variety	Root girth (cm)		Root length(cm)		Root size index (cm^2)	
	Major season	Minor season	Major season	Minor season	Major season	Minor season
Apumoden	11.05 ± 0.39Ba	12.75 ± 0.62Aba	13.97 ± 0.79Aa	12.93 ± 0.30Aba	155.55± 12.93Aa	165.51 ± 4.13Ba
Ligri	14.46± 1.27Aa	17.40 ± 2.40Aa	11.79± 0.90Aba	15.50± 1.86Aa	173.69 ± 26.57Aa	278.87 ± 58.61 Aa
Faara	7.22 ± 0.71Bb	9.99 ± 0.29Ba	9.55 ± 0.41Ba	12.2 ± 0.50ABb	68.66 ± 8.85Bb	121.95 ± 4.67Ba
Bohye	10.92 ± 0.34Ba	12.70 ± 1.05Aba	11.02 ± 0.67Ba	10.39 ± 0.53Ba	120.73 ± 9.3Aba	131.30 ± 16.11Ba
Dadanyui	12.20 ± 0.33Bb	13.34 ± 0.64Aba	11.93 ± 0.26Aba	13.96 ± 1.00Aba	145.79 ± 24.51Aa	193.68 ± 24.74ABa
Okumkom	11.40 ± 0.31Ba	12.94 ± 1.32Aba	12.41 ± 0.86Aba	11.40 ± 1.05Aba	141.89 ± 11.71Aa	149.12 ± 24.81Ba
F	12.72	3.60	4.54	3.26	4.16	4.02
P	< 0.0001	0.0030	0.0070	0.0390	0.0120	0.0220

Means within a column followed by the same lower-case letter and in a row followed by the same upper-case letter are not significantly different (Student–Newman–Keuls, $P < 0.05$).

4.1.7 Relationship between root characteristics and storage root infestation by sweetpotato weevil

4.1.7.1 Shortest weevil distance and storage root infestation level

The shortest weevil distance was negatively and strongly correlated with storage root infestation in both the major ($r_{(5)}$ = -0.82) and minor ($r_{(5)}$ = -0.75) rainy seasons (Figure 9). The analysis showed a significant correlation in the major rainy season ($F_{1,\ 5}$ = 8.64; P = 0.0461) but not in the minor rainy season ($F_{1,\ 5}$ = 5.15; P = 0.0822).

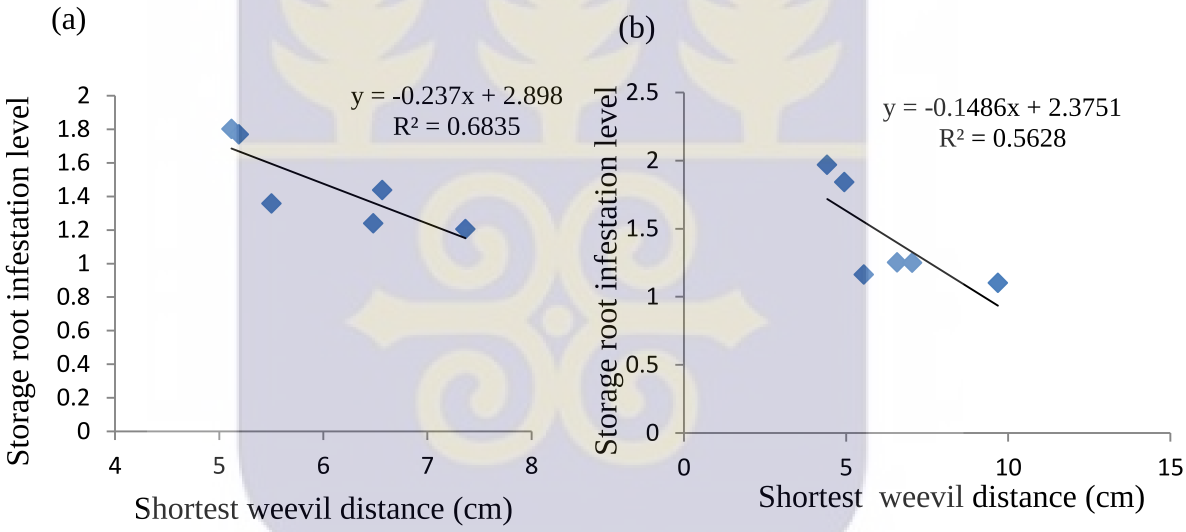


Figure 10: Relationship between the shortest weevil distance and storage root infestation level in the major (a) and minor (b) rainy seasons.

4.1.7.2 Root size length, root girth and root size index

There was a non–significant strong positive correlation between the storage root girth and the storage root infestation level in both the major ($r_{(5)} = 0.63$; $F_{1,5} = 2.7$; $P = 0.1820$) and minor ($r_{(5)} = 0.72$; $F_{1,5} = 4.37$; $P = 0.1172$) rainy seasons (Figure 10). The same correlation was found with root length ($r_{(5)} = 0.66$; $F_{1,5} = 3.06$; $P = 0.1602$ and $r_{(5)} = 0.60$; $F_{1,5} = 2.31$; $P = 0.2722$ in major and in the minor rainy seasons, respectively) (Figure 11) and root size index ($r_{(5)} = 0.75$; $F_{1,5} = 5.18$; $P = 0.0837$ and $r_{(5)} = 0.71$; $F_{1,5} = 4.36$; $P = 0.1110$ in the major and minor rainy seasons, respectively) (Figure 12).

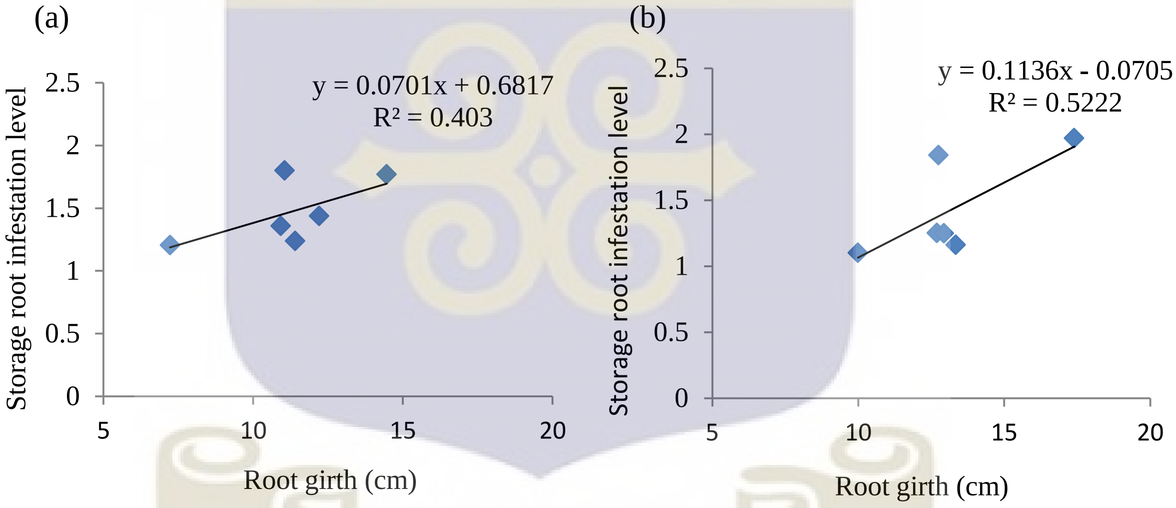


Figure 11: Relationship between root girth and storage root infestation level in the major (a) and minor (b) rainy seasons.

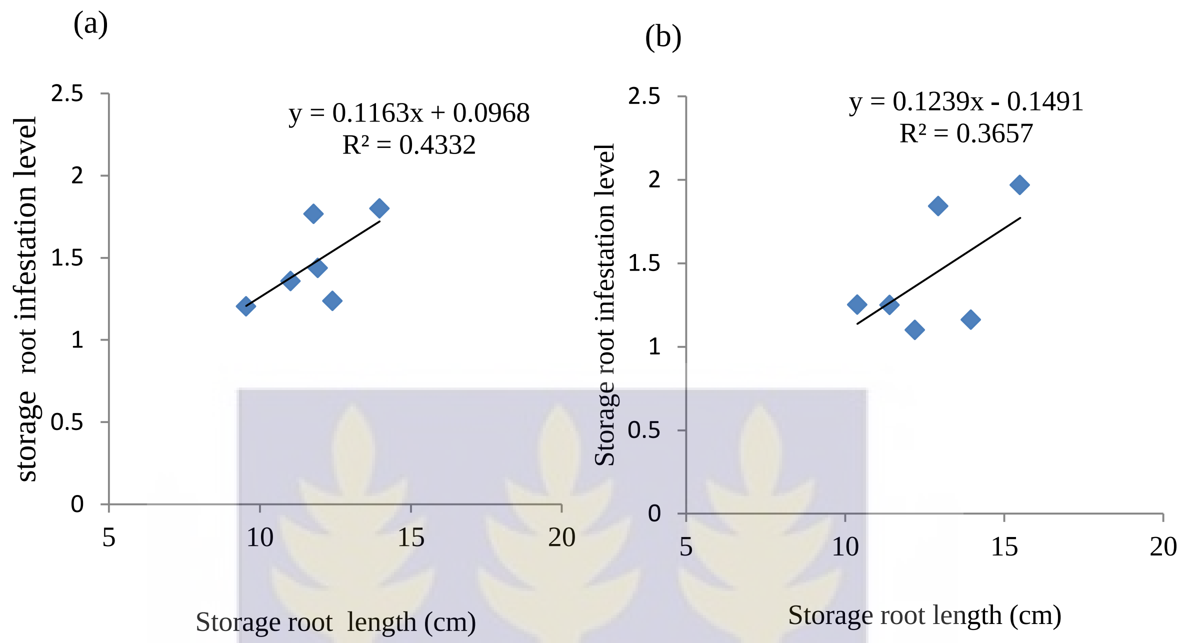


Figure 12: Relationship between root length and storage root infestation level in the major (a) and minor (b) rainy seasons.

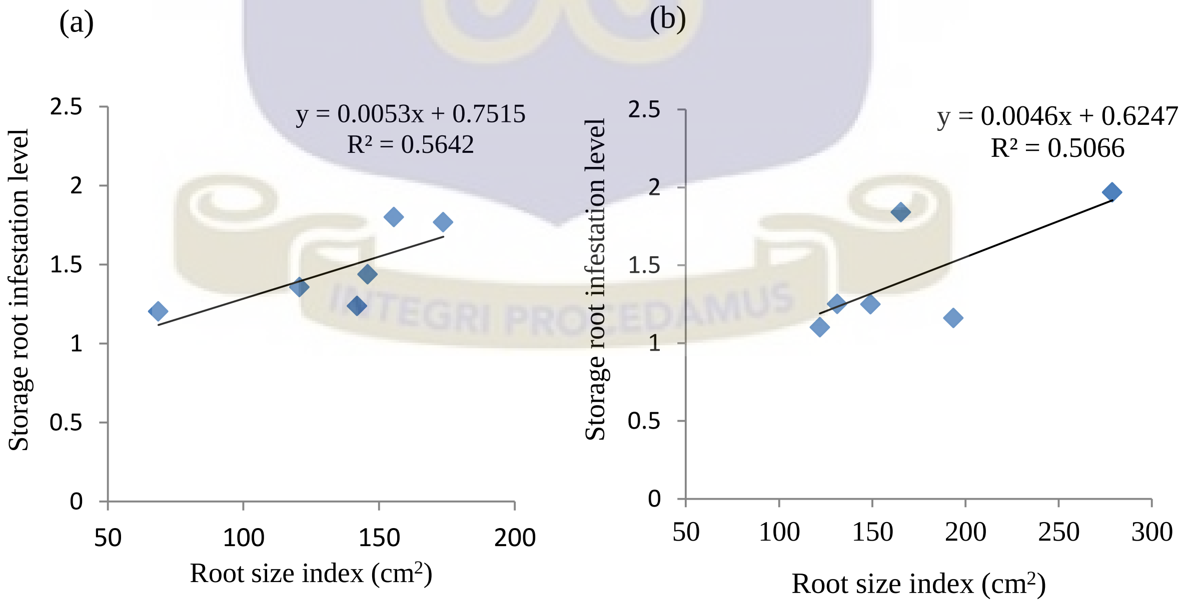


Figure 13: Relationship between storage size root index and storage root infestation level in the major (a) and minor (b) rainy seasons.

4.1.7.3 Root neck length

A non significant negative corrrelation was found between the root neck length and storage root infestation in both major ($r_{(5)} = -0.45$; $F_{1,5} = 1.01$; $P = 0.3720$) and minor seasons ($r_{(5)} = -0.36$; $F_{1,5} = 0.60$; $P = 0.4813$).

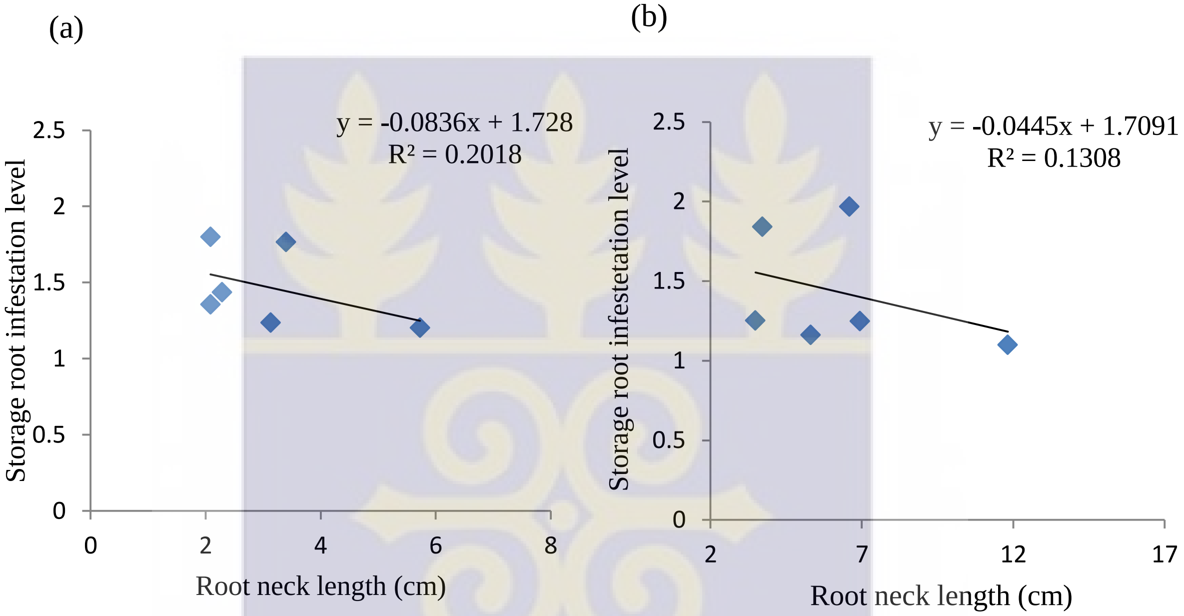


Figure 14: Relationship between root neck length and storage root infestation level in the major (a) and minor (b) rainy seasons.

4.2 Laboratory experiments

4.2.1 Feeding and oviposition preferences of *C. puncticollis* for storage roots of eight (8) different sweet potato varieties

- **No choice test**

The number of feeding punctures made by female of *C. puncticollis* differed significantly ($F_{7,\ 63} = 4.97$; $P < 0.0001$) among sweet potato varieties with Ligri having the highest mean number of 15.62 ±1.07 punctures / root core which was statistically similar to that recorded on Apumoden and Faara. The lowest number of feeding punctures was recorded on Okumkom (8.98 punctures / root core), which was statistically similar to that recorded on Dadanyui and Red skinned variety (Table 7). Like the feeding punctures, the oviposition level differed significantly among varieties ($F_{7,\ 63} = 10.63$; $P < 0.0001$). The highest number of eggs / root core was recorded on Apumoden with a mean of 5.32 ± 0.38, while the lowest was recorded on Faara which was statistically similar to that on Okumkom (Table 7). Regarding the number of frass, the mean number varied from 110.37 ± 12.09 to 218 ± 25.94 / tissue culture plate recorded on Apumoden and Faara, respectively but there was no significant difference ($F_{7,\ 63} = 1.21$; $P = 0.3050$) among varieties (Table 7).

- **Choice test**

In the free choice experiment, the number of feeding punctures recorded was significantly high ($F_{7,\ 287} = 25.473$; $P < 0.0001$) on Apumoden (14.31 ± 1.24 feeding punctures / root core) which was statistically similar to that recoded on Ligri and Red skinned variety. Okumkon was the variety which received the lowest mean number of feeding punctures with 3.11± 0.52 per core (Table 8). The oviposition level differed highly significantly ($F_{7, 287} = 10.48$; $P < 0.0001$) among sweet potato varieties. More eggs were laid on Apumoden (3.83 ± 0.53 eggs / root core), but no significant difference was found among Apumoden, Ligiri and red skinned variety. Faara had an oviposition rate of 0.83 ± 015 which was statistically similar to that recorded on Okumkom (Table 8).

Table 7: Feeding punctures and oviposition on storage root cores of different sweet potato varieties in a no choice test[1].

Variety	Feeding punctures / root core	Eggs / root core	Frass / tissue culture plate
Apomuden	15.17 ± 0.73a	5.32 ± 0.38a	110.37 ± 12.09a
Ligri	1.62 ± 1.07a	4.89 ± 0.64ab	176.38 ± 34.99a
Faara	14.63 ± 2.00a	1.08 ± 0.255c	218.13 ± 25.94a
Bohye	12.12± 0.99ab	3.33 ± 0.51b	155.50 ± 27.42a
Dadanyui	9.79 ± 0.99b	3.31 ± 0.57b	155.75 ± 35.74a
Okunkom	8.98 ± 1.10b	1.35 ± 0.42c	116. 25 ± 31.46a
Red skin	9.91 ± 1.07b	3.42 ± 0.42b	160.50 ± 39.36a
Yellow skin	12.02 ± 1.01ab	3.33 ± 0.28b	150.75 ± 28.94a
$F_{7, 64}$	4.97	10.63	1.21
P	< 0.0001	< 0.0001	0.3050

[1] Means (± SE) within a column followed by the same letter are not significantly different (Student–Newman–Keuls, $P < 0.05$).

Table 8: Feeding punctures and oviposition on storage root cores of different sweet potato varieties in choice test[1].

Variety	Feeding punctures / root core	Eggs / root core
Apomuden	14.31 ± 1.24a	3.83 ± 0.53a
Ligiri	13.19 ± 1.02a	3.53 ± 0.41ab
Faara	7.47 ± 0.75b	0.94 ± 0.15d
Bohye	5.31± 0.75bc	2.06 ± 0.25c
Dadanyui	5.39 ± 0.68bc	1.94 ± 0.22c
Okunkom	3.11 ± 0.52c	0.83 ± 0.17d
Red skin	13.08 ± 0.93a	2.64 ± 3.68abc
Yellow skin	5.44 ± 6.43bc	2.31 ± 0.33bc
$F_{7,\,288}$	25.47	10.48
P	< 0.0001	< 0.0001

[1] Means (± SE) within a column followed by the same letter are not significantly different (Student–Newman–Keuls, $P < 0.05$)

4.2.2 Relationship between storage root infestation in the field and laboratory

The ranking of susceptibility to the weevil infestation of different varieties based on laboratory and field evaluation is summarized in Table 9. Correlation analysis showed that results from laboratory and field experimentations were correlated but the preference for oviposition was more correlated ($r = 0.96$ and 0.98 in no choice and choice tests, respectively) than preference for feeding with field infestation level (Table 10).

Table 9: Ranking of susceptibility of different varieties based on laboratory and field evaluation[*].

Variety	Laboratory evaluation				Field evaluation	
	No choice test		Choice test			
	Feeding punctures	Oviposition	Feeding punctures	Oviposition	Major season	Minor season
Apumoden	1	1	1	1	1	1
Ligri	1	1	2	1	1	1
Faara	1	4	2	4	3	2
Bohye	2	3	3	3	3	2
Dadanyui	3	3	3	3	2	2
Okumkom	3	4	4	4	3	2

[*] The ranking was based on different groups given by Student–Newman–Keuls, ($P < 0.05$) post hoc analysis. Only varieties that were investigated both in the field and laboratory were ranked.

Table 10: A summary of the relationship between laboratory experiments and field trial[1].

Laboratory parameters		Coefficient of correlation
No choice test	Feeding punctures	0.59 NS
	Oviposition	0.96*
Choice test	Feeding punctures	0.88*
	Oviposition	0.98*

NS Non-significant; * Significant, $P < 0.05$

[1] Correlation analysis was done with field infestation recorded in major rainy season.

4.2.3 Effect of sweet potato varieties on bionomic parameters of *C. puncticollis.*

4.2.3.1 Developmental period and survival of immature life stages, and sex ratio

- **Egg period and survival rate**

Eggs were laid singly in punctures and covered with root plug by the female and took three (3) to five (5) days for them to hatch into larvae on Apumoden, Ligri, Bohye but delayed to 6 days on Okumkom (Appendix 3). However the difference was not significant among varieties ($F_{3, 15} = 0.44$; $P = 0.7260$) (Table 11). For all varieties, the egg hatching reached a peak on the 4th day of egg incubation, with about 60% of eggs hatched (Figure 14). Egg survival rate ranged from 90 - 96.25% on Okumkom and Ligri, respectively but it didn’t vary significantly among the different varieties ($F_{3, 15} = 0.21$; $P = 0.8880$) (Table 11).

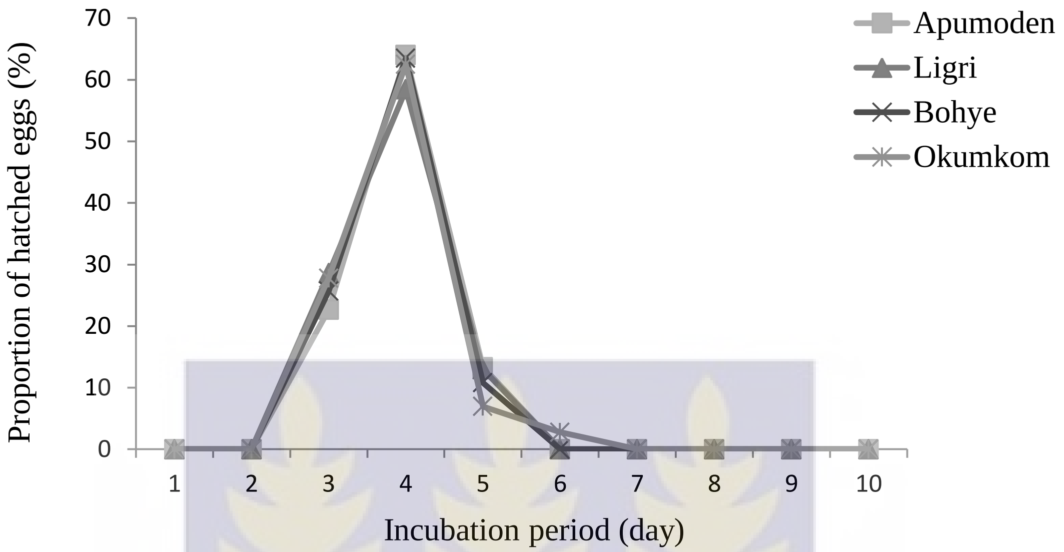


Figure 15: Daily egg hatching rate of *C. puncticollis* on different varieties.

- **Larval development period and survival rate**

Larval development was completed in about two weeks on all varieties. It varied from 14.87 ± 0.33 to 16.33 ± 0.23 days on Apumoden and Okumkom. However the effect of variety on the larval development period was not significant ($F_{3,\ 15}$ = 3.33; P = 0.0560) (Table 11). The larval survival rate was significantly higher ($F_{3,\ 15}$ = 7.18; P = 0.0050) on Ligri (82.63 ± 1.20 %) but statistically similar to that recorded on Apumoden. The lowest larval survival rate, 66.70 ± 4.04 was recorded on Bohye (Table 11).

Table 11: Mean (±SE)[1] developmental period and survival rate of immature life stages of *C. puncticollis* on different sweet potato varieties.

Parameters	Variety			
	Apumoden	Ligri	Bohye	Okumkom
Development period (day)				
Egg – larva	4.00 ± 0.00a	3.87 ± 0.13a	3.75 ± 0.14a	3.97 ± 0.24a
Larva – pupa	14.87 ± 0.33a	15.14 ± 0.42a	15.51 ± 0.38a	16.63 ± 0.23a
Pupa- adult	4.17 ± 1.87a	3.74 ± 0.27a	4.47 ± 0.33a	3.98 ± 0.18a
Egg – adult	22.80 ± 0.54a	22.68 ± 0.35a	23.28 ±0.25a	24.70 ± 0.46b
Survival rate (%)				
Egg	93.75 ± 4.73a	96.25 ± 3.7a	92.50 ± 4.78a	90. 00 ± 7.07a
Larva	79.65 ± 2.24a	82.73 ± 1.20a	66.70 ± 4.04b	72.28 ± 2.92ab
Pupa	94.74 ± 3.25a	93.66 ± 4.18a	94.07 ± 3.71a	100. 00 ± 0.00a
Emergence rate (%)	70.78 ± 3.24a	74.86 ± 3.40a	57.92 ± 1.69b	64. 53 ± 4.11ab
Sex – ratio (♀/(♀+♂))	49.46 ± 2.23a	47.81 ± 2.41a	49.11 ± 2.40a	51. 33 ± 5.13a

[1] Means within a row followed by the same letter are not significantly different (Student–Newman–Keuls test, $P < 0.05$)

- **Pupal development period and survival rate**

On average, the pupal stage lasted for 3 to 5 days on all varieties. It varied from 3.74 ± 0.27 to 4.47 ± 0.33 days on Ligri and Bohye, respectively. The period was however statistically similar ($F_{3, 15} = 1.56$; $P = 0.2510$) among varieties (Table 11). The pupal survival was not significantly ($F_{3, 15} = 0.95$; $P = 0.4490$) affected by the variety and could reach up to 100% (Table 11).

- **Life cycle period, emergence rate and sex ratio.**

The developmental period of *C. puncticollis* was significantly shorter ($F_{3, 15} = 4.90$; $P = 0.0190$) on Ligri (22.68 ± 0.35 days), while Okumkom (24.70 ± 0.46 days) had the longest period. The difference among Ligri, Apumoden and Bohye was statistically similar. Moreover, the daily adult emergence showed that, to 22nd day of developmental period, about 45% of adult emerged from Apumoden and Ligri, while 25% emerged from Bohye, and only about 15% emerged from Okumkom (Figure 15; Appendix 4). The proportion of eggs that developed to adult stage was significantly ($F_{3, 15} = 4.90$; $P = 0.0190$) affected by the sweet potato variety. Only 57.92 ± 1.69% of eggs reached adult stage on Bohye, while up 74.86 ± 3.40 % was recorded on Ligri. The proportion of females in the emerged population was about 50% on all varieties and there was no significant difference ($F_{3, 15} = 0.20$; $P = 0.8970$) among different varieties (Table 11).

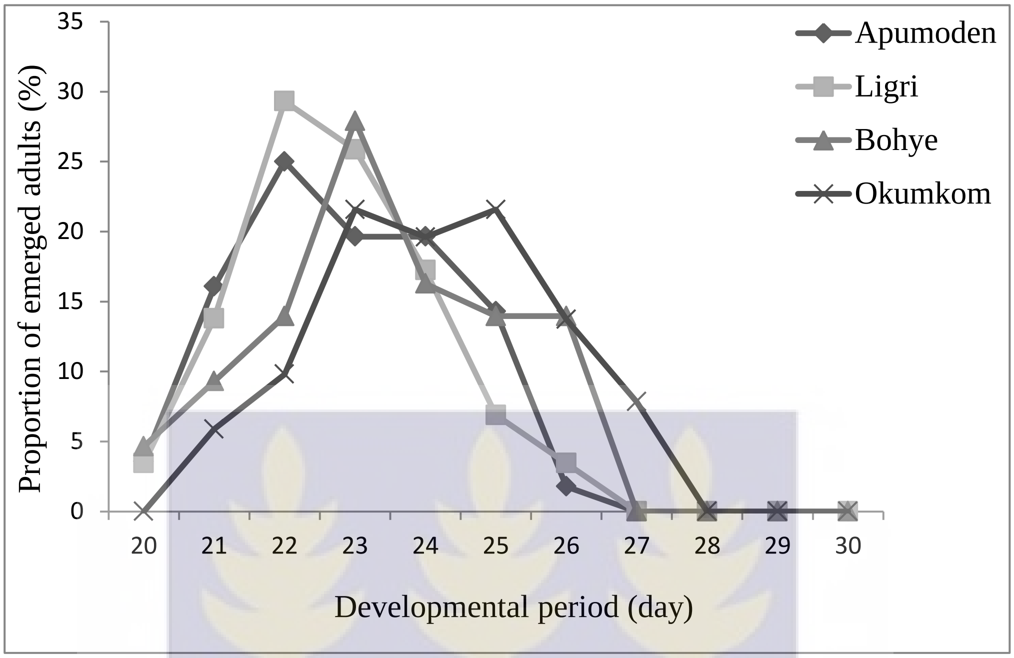


Figure 16: Daily emergence rate of *C. puncticollis* adult on different sweet potato varieties.

3.3.1.1 Determination of adult longevity and female fecundity

- **Adult longevity**

The pre – oviposition period of *C. puncticollis* female was on the average five (5) to six (6) days on different sweet potato varieties. But the effect of variety was not significant ($F_{3, 59}$ = 0.54; P = 0.6560) (Table 12).

The oviposition period was affected by the sweet potato variety ($F_{3, 59}$ = 12.73; $P <$ 0.0001). A female laid eggs during an average period of 88 ± 4.25 days when provided with the variety Apumoden which was the highest oviposition period but statistically similar to that recorded on Ligiri (81.40 ± 4.56). The lowest oviposition period was recorded with females feeding on Bohye with an average of 57.73 ± 4.40 (Table 12). The post - oviposition period of *C. puncticollis* female differed significantly among varieties

($F_{3,\,59} = 3.75$; $P = 0.0160$). It took an average of 13.30 ± 2.48 days for a female to die after oviposition period on Ligri which was statistically similar to that recorded on Apumoden. The lowest, 6.69 ± 0.83 days was recorded on Okumkom which was about three days lower than that recorded on Bohye (Table 12).

- **Longevity**

As a result of the difference in oviposition and post-oviposition and oviposition period among different varieties, the longevity of *C. puncticollis* female was affected by the variety. The female lived significantly longer ($F_{3,\,59} = 17.00$; $P < 0.0001$) on Apumoden with an average of 106.8 ± 4.48, which was about 6, 32 and 34 days longer than that recorded on Ligri, Okumkom and Bohye, respectively. Daily female survival was shown in Figure 16. Generally, *C. puncticollis* female lived longer than the male on all varieties but the difference was only highly significant on Apumoden ($t_{28} = 5.6$; $P < 0.0001$) and Ligri ($t_{28} = 3.99$; $P < 0.0001$) but not significant on Bohye ($t_{28} = 0.87$; $P = 0.3900$) and Okumkom ($t_{28} = 0.44$; $P = 0.2080$). There was no significant difference in male longevity among varieties ($F_{3,\,59} = 0.46$; $P = 0.7090$). The male longevity ranged from 73.86 ± 4.03 to 66 ± 3.76 days on Apumoden and Bohye, respectively (Table 12).

- **Fecundity**

The fecundity differed significantly ($F_{3,\,59} = 14.85$; $P < 0.0001$) among varieties. The highest number of egg was laid on Ligri (242.13 ± 17.72) and the lowest was recorded on Bohye. The daily oviposition during the oviposition period was statistically similar ($F_{3,\,59} = 1.59$; $P = 0.2010$) among different varieties ranging from 2.37 ± 0.28 to 3.07 ± 0.26 eggs per day on Bohye and Ligri, respectively (Table 12). Figure 16, shows that the age-specific fecundity on different varieties were partly similar in pattern as started in the range of 3 to 6th days after adult mergence , peaked few days later and declined gradually till zero.

Table 12: Mean **(**± SE**)**[1] pre-oviposition, oviposition, post-oviposition periods, fecundity and longevity of *C. puncticollis* on the different varieties.

Parameters	Variety			
	Apumoden	Ligri	Bohye	Okumkom
Pre-oviposition period (day)	5.07 ± 0.37a	6.00 ± 0.70a	5.33 ± 0.63a	5.20 ± 0.51a
Oviposition period (day)	88.80 ± 4.22a	81.40 ± 4.56a	57.73 ± 4.40b	63.47 ± 3.09b
Post-oviposition period (day)	12.93 ± 1.58a	13.20 ± 2.31a	8.60 ± 1.74ab	6.60 ± 0.72b
Fecundity (egg/ female)	233.27 ± 13.90a	242.13 ± 17.72a	125.67 ± 11.69b	194. ± 10.65ab
Daily fecundity	2.69 ± 1.19a	3.07 ± 0.26a	2.37 ±0.28a	3.00 ± 0.28a
Longevity (day)				
Female	106.80 ± 4.48a	100.60 ± 4.38a	71.67 ± 5.00b	75. 27 ± 3.07b
Male	73.87 ± 4.03a	69.47 ± 6.46a	66.20 ± 3.77a	68. 93± 3.83a

[1] Means within a row followed by the same letter are not significantly different (Student–Newman–Keuls, $P < 0.05$)

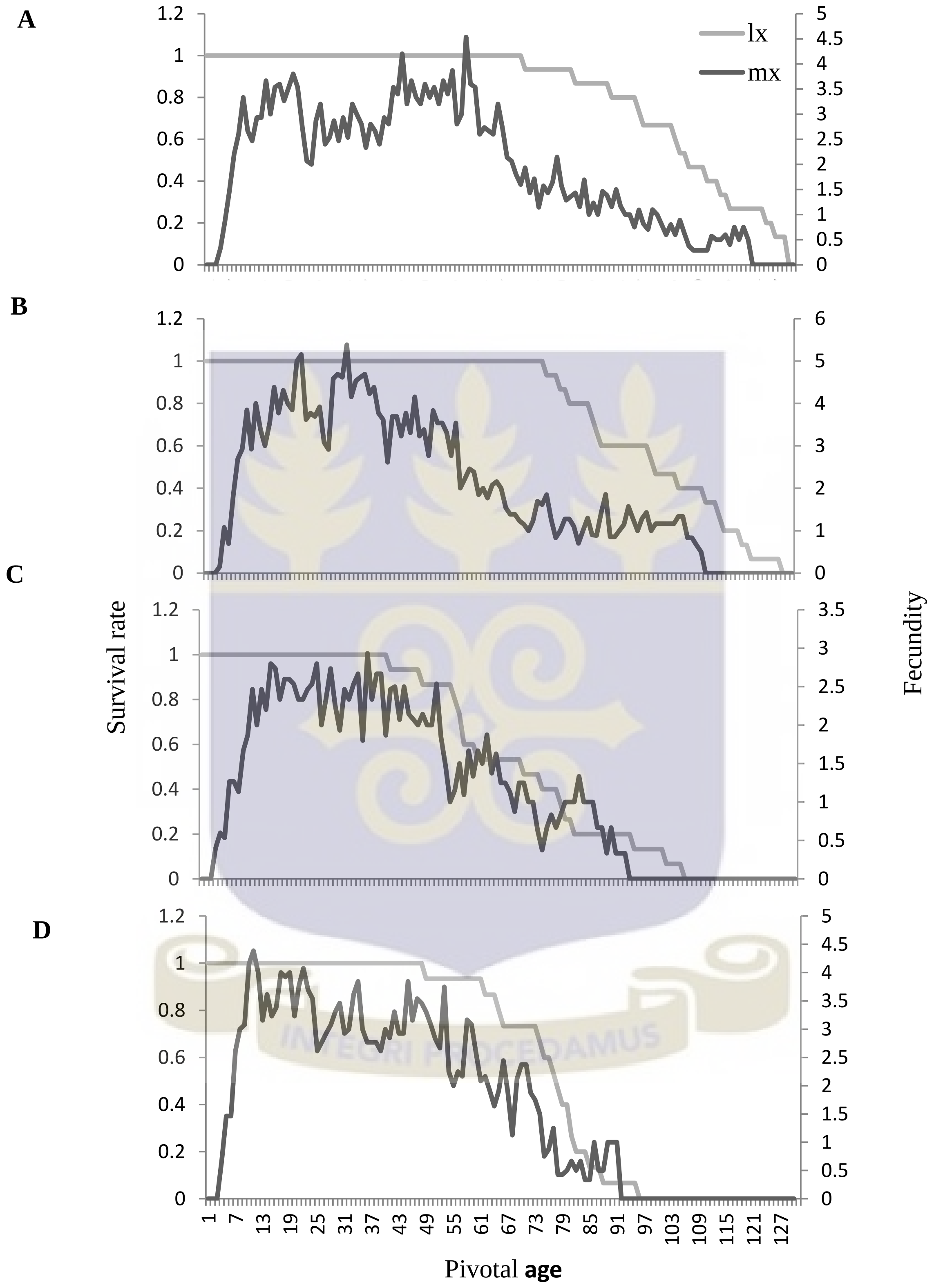


Figure 17: Daily fecundity and female survival on different varieties: (A) = Apumoden, (B) = Ligri, (C) = Bohye and (D) = Okumkom.

CHAPTER V

DISCUSSION

Total and marketable root yield.

The total root yield of the seven sweet potato varieties assessed in this study differed significantly. In the major and minor rainy seasons, Ligri had the highest yield while Faara and Sauti recorded the lowest. The range of values for the yield among varieties in this study correlated well with previous studies carried out in sweet potato production zones across the world (Kabi *et al.*, 2001; Stathers *et al.*, 2003a; Tigabu and Tilahun, 2013; Amare *et al*., 2015; Mansaray *et al.*, 2015). The yield obtained varied from 0.61 to 22.25 t/ha which was not much different from 0 - 21.20 t/ha found by Amankwaa, (2012) among some released and elite Ghanaian sweet potato varieties. However the yields obtained for some varieties in this study were far lower than their potential yields (ranging from 18 to 30 t/ ha) reported by CSIR-Crops Research Institute (MoFA, 2014). The highest gaps in the yield were recorded with Sauti, Apumoden and Faara. Nevertheless the yields found in this study were by far higher than the findings of Bidzakin, *et al.*, (2014) on various sweet potato varieties in rural areas in Ghana, which ranged from 3.50 to 9 t/ha. The difference in the root yield between seasons recorded in this study and other studies might be due to environmental effects, soil types, and the farming practices. In this study, fertilizers were not applied. This probably contributed to the low yields observed, compared to the potential yields of some varieties. Ligri was the variety that performed best with about 22 tons/ha. This record was higher than the previously reported potential yield, 20 t/ ha (MoFA, 2014). These results showed that each sweet potato variety might have specific conditions conducive for its development. These conditions may vary among for all the varieties investigated in this study. Among the assessed varieties, the total yield varied significantly only in Apumoden and Bohye across the study seasons. This variation might partly be due to climatic conditions (Osiru *et al.*, 2009; Mwololo *et al*, 2012).

With respect to marketable yield, Faara gave significantly lower proportion of marketable roots in the major rainy season but in the minor rainy season only Sauti differed significantly from other varieties. Amankwaah, (2012), earlier on, reported differences not only in the total yield, but also in the marketable yield among varieties. The lowest marketable root yield found in Faara in this study might be due to the extensive vine infestation by the weevil during the early stage of plant development since it was reported that the extensive infestation of stem caused reduction in the size and number of storage root (Chalfant *et al.*, 1990).

Survival and plant mortality due to the weevil infestation

The plant survival and the mortality due to weevil infestation varied significantly among varieties in the major rainy season but not in the minor season. During the major rainy season, Faara had the highest mortality due to the weevil infestation and the lowest survival rate. The difference in survival rate observed may be largely attributed to variations in the level of stem infestation by the weevil since in the minor rainy season, no difference was observed in the survival and mortality rates due to weevil infestation. In fact, sweet potato cannot withstand early infestation by weevils. The feeding of adult weevils and larval infestation on easily accessible stem bases can could plant wilting and loss of planting materials (Allard *et al.*, 1991; Smit, 1997).

The relatively higher infestation of Faara and Apumoden leading to death of planted cuttings during the early developmental stage might be attributed to the flowers that were produced by these two varieties. Indeed all sweet potato varieties do not have the ability to produce flowers (Huamàn *et al.*, 1999) and among evaluated varieties, only Apumoden and more abundantly Faara blossomed, especially during the early stage of development. The flowers produced by these two varieties may have attracted insects, especially weevils and other flower feeding insects.

In laboratory studies, volatile compounds released by sweet potato storage roots and flowers appear to be more attractive to female weevils than volatiles from other parts of the plant (Korada *et al.*, 2013). Thus, in a situation whereby plants have not produced storage roots yet, flowers might be the sole sweet potato plant organ that will attract female weevils for feeding and oviposition. Moreover, plant mortality due to the weevil infestation decreased from 33.75 in the major rainy season to 16.66% in the minor rainy season and increased from 3.75 to 26.91% in Faara and Apumoden, respectively. The difference in survival rate as a consequence to differences in the level of stem infestation reported with Faara and Apumoden across seasons might also be due to differences in the level of flower production. Contrarily to the major rainy season, Apumoden produced more flowers than Faara. Previous studies have showed that in general plant physiology is affected by ecological conditions and flower production is seasonal (Parolo and Rossi, 2008).

Evaluation of infestation level

In this study, the difference in the susceptibility of sweet potato varieties to weevil infestation was manifested not only through the mortality of sweet potato plants at the early developmental stage but also through stem base, storage root infestation and yield loss. In the major rainy season, the internal stem base infestation varied significantly among the varieties, but the external stem infestation did not. However, no significant difference was observed in either the external stem base or the internal stem base infestation among the varieties in the minor rainy season. In contrast, Muyinza *et al.*, (2007) found significant differences in Uganda sweet potato germplasm assessed during two different seasons. This contradiction may be due to difference in varietal attributes, environmental conditions and weevil infestation pressure.

Moreover, it was found that the external damage appeared to be lower than the internal damage. Two reasons may explain this difference. The first is the nature of infestation that occurs in the sweet potato plant. External damage is a result of adult feeding punctures and adult emergence holes which is less disastrous than continuous tunnels made by larvae when feeding inside the stem. This confirms the findings of Daiber *et al.*, (1994), who reported that though adult weevils damage the plant, larvae are more injurious. The second reason is the ability of the sweet potato plant to repair weevil - damaged stem tissue, with adventitious growth resulting in thicker crown (Talekar, 1982). As the external surface is not continuously damaged like the internal stem, the external damage may be repaired faster than the internal damage. This difference in how fast the plant could repair weevil infestation between the internal and external stem might contribute to the differences in the level of infestation found in this study.

The storage roots of all varieties assessed were infested but the level of infestation and yield loss varied significantly among varieties. This is in agreement with a number of studies on field evaluation of sweet potato susceptibility to the weevil infestation. In Ghana, an earlier study carried out by Darko, (2000) revealed differences in the level of infestation between two sweet potato varieties, the red skinned and white skinned varieties. In Sierra Leone, Mansaray *et al.* (2015) reported different levels of infestation among three different cultivars with Slipot 2 having the highest level of infestation. Kabi *et al.*, (2001) and Stathers *et al.*, (2003a) found differences in the level of infestation among Uganda and Tanzania sweet potato varieties. This study confirmed the conclusion made by previous workers that though there is no sweet potato variety that is immune to *Cylas* spp. attack, there is a significant difference in levels of susceptibility among sweet potato varieties in natural infestation (Stathers *et al.*, 2003a, Darko, 2000; Jackson and Bohac, 2006, Stevenson *et al.*, 2009, Muyinza *et al.*, 2012). In both seasons, Apumoden and Ligri were the most infested while similar levels of infestations were found among other varieties namely Faara, Bohye, Dadanyui and Okumkom. The consistency among sweet potato varieties over seasons with respect to infestation level found in this study is in agreement with previous research carried out by Stathers *et al.*, (2003a) and Muyinza *et al.*, (2012) who worked with East African and Ugandan cultivars, respectively. But this finding is in contradiction to Talekar (1987) who found an inconsistency among varieties not only across the seasons but also among replicates of the same trial and among seasons. Though the level of infestation was not different among varieties across the season, there was significant difference in the yield loss. It appears that the determination of infestation level by scoring the storage root surface damage do not give much idea of the internal damage which contributes to yield loss. Stathers *et al*., (2003a) reported it in another way, stating that storage roots without much external damage often have greater internal damage as a result of burrowing and feeding by developing larvae.

Relationship between stem base infestation and storage root infestation

Very weak negative and positive correlations were found between the external stem base infestation and storage root infestation in the major and minor seasons, respectively. This showed that there might be no correlation between both parameters. A moderately positive correlation was however found between the internal stem base and storage root infestation. Large disparities were found among previous works with respect to the relationship between the stem infestation and storage root infestation by the sweetpotato weevil. Cockerham and Deen (1947) found no correlation between both parameters, while Stathers *et al*, (2003a) found a negative correlation just as Mullen *et al.* (1980) who described a negative correlation between crown damage and adult emergence from infested roots. However a strong positive correlation was found by Mohamed, (2005) and Muyinza *et al*., (2007). These disparities imply that factors contributing to the stem infestation may not always be the same affecting the storage root infestation. Some varieties may be predisposed to stem base infestation by the weevil. For example, the big size of stem (Kabi *et al.*, 2001) or the presence of flowers can enhance stem infestation, but the storage roots might escape the infestation because of their depth. Other factors such as timing and severity of the infestation (Mullen *et al*., 1985) and variation in the environmental conditions (Stathers *et al*., 1999) may also contribute to these disparities. In summary, Talekar *et al*., (1982) reported that though heavy infestation in stems is correlated with storage root infestation, this correlation did not occur always. Those authors highlighted that knowing the number of insects feeding in the crown cannot be used to predict the root damage. Therefore the suggestion by Muyinza *et al*. (2007) to use the stem base infestation as an index for quick selection of sweet potato varieties resistant to weevil infestation in field evaluation might not be the accurate method if the storage root infestation level is the only factor of selection that is considered. But considering the total yield as an additional factor which is also important, this suggestion can be used without any doubt of mis - selection since heavy stem base infestation results in yield reduction (Sutherland, 1986).

Correlation between root characteristics and storage infestation

Phenotypic and molecular characterization of released and elite sweet potato varieties in Ghana showed differences among varieties with respect to plant morphological parameters (Amankwaa, 2012). However, this author did not look at the attributes relating to the root. This study showed that there be differences in rooting and root characteristics as well among Ghanaian sweet potato varieties and this might be useful for breeding for host plant resistant to *Cylas* spp. infestation.

The level of storage root infestation positively correlated with root length, root girth and root size index but negatively correlated with the shortest weevil distance and root neck length. However only the shortest weevil distance significantly correlated with storage root infestation. The strong positive correlation found between the root girth, length and size index and storage root infestation might be explained by the fact that when increasing in size or in length during the growth process, the storage roots make cracks in the soil or appear at the soil surface which increases their accessibility to the weevil. *Cylas* weevils are not able to dig through the soil and so they use cracks that appear in the soil to reach storage root underground (Smit, 1997). In the current study, varieties such as Ligri and Apumoden with bigger storage roots had higher level of infestation. The relationship between root length, girth and size index with storage root infestation is in agreement with the findings of Kabi *et al*. (2001) and Stathers et *al.*, (2003a).

The negative correlation between the shortest weevil distance and storage root infestation found is also in agreement with the findings by Kabi *et al.* (2001) and Stathers *et al.*, (2003a). These authors described the shortest weevil distance as a parameter that reflects how accessible the roots are to be infested by sweetpotato weevils. The more the storage root is formed deeply in the ground, the less accessible it is to weevil infestation. In this study, Faara produced the deepest storage root and this resulted in lower infestation compared to Apumoden and Ligiri which produced the shallowest storage roots and sometimes with these appearing at the soil surface. The results showed that deep-rooted tubers are not easily accessible by the weevils for feeding and oviposition. This finding confirms the importance of some cultural practices especially re-hilling in the management of sweetpotato weevil (Pardales and Cernas, 1994; Tarekegn *et al.*, 2014). Stathers *et al.* (2003a) reported that an increase in shortest weevil distance of only one centimeter could reduce the infestation levels by several per cent.

Moderately negative correlation was found between the root neck length and the storage root infestation. This finding is not much far from that of Teli and Salunke (1994) and Mohamed (2005) who found weak negative correlation between root neck length and storage root infestation. Burdeos and Gaspin (1980) found that the root neck length is the root characteristic that determines how deeply the storage roots develop below the soil surface. Based on this, it was expected to find a strong negative correlation between root neck length and storage root infestation since the shortest weevil distance (root depth) is strongly correlated with storage infestation. But it was not the case in this study. This showed that the root neck length does not always determine the storage root depth which is in agreement with Stathers *et al.* (2003a) who reported that the measurement of root neck length do not give any indication of whether storage root have gone straight down into the soil or spread sideways. The root neck could be curve – shaped which may prevent roots going deeply in soil but tend to come upwards. Therefore breeding for long root neck to reduce weevil infestation may not be realistic.

Feeding and oviposition preferences of *C. puncticollis* for storage root of different sweet potato varieties

The present study showed that, though *C. puncticollis* females fed and oviposited on the storage root of all varieties that were investigated, it exhibited varietal preference for both feeding and oviposition. In both no choice and choice tests, Apumoden and Ligri appeared to be the most preferred and Okumkom, the least preferred for feeding and oviposition. This finding is consistent with previous studies carried by Darko (2000) and Parr *et al.* (2016) with Ghanaian and Cameroonian sweet potato varieties, respectively. The preference exhibited by *C. puncticollis* in this study suggests the presence of different level of xenobiotic effects among sweet potato varieties that were investigated (Wilson *et al.*, 1988; Stathers *et al.*, 2003b; Mao *et al.*, 2004). Different substances such as boehmeryl acetate and boehmerol, occurring in the storage root surface were identified to act as oviposition stimulants for *C. formicarius* and the levels of these chemicals in root differ among sweet potato varieties (Nottingham *et al.*, 1989; Wilson *et al.*, 1990; Son *et al.*, 1991). Although not tested in the current study, the level of these chemicals may therefore vary among the investigated varieties, and may have contributed to determining the preference of *C. puncticollis* for oviposition.

In this study Faara, appeared to be preferred for feeding and not for oviposition especially in no choice test. This suggests that factors that contribute or stimulate oviposition in *C. puncticollis* may not be the same controlling the feeding behaviour which is in agreement with Mao *et al.* (2004) who reported that chemicals in the sweet potato storage root periderm do not affect the feeding preference. This is possible because of the feeding behavior of the weevil, in which it chews through the periderm and feed primarily on the tissue beneath it, thereby avoiding the periderm layer. Parr *et al.* (2016) therefore suggested that the feeding preference by *C. puncticollis* may depend mainly on the texture of storage root.

In this study a slight difference in ranking of varieties for susceptibility was based on either feeding punctures or oviposition sites between choice and no choice tests. The Red skinned variety for example showed relatively low number of feeding punctures in no choice test but relatively high in choice test. These disparities between choice and choice tests were earlier found by Tingey, (1986) and Mao *et al.* (2001). The first author even observed that sometimes, results from no choice and choice appear to be contradictory. This implies that the behavior of *C. puncticollis* may not be the same in presence of either one or many different varieties.

The quantity of frass from *C. puncticollis* did not differ significantly among different sweet potato varieties. This finding is in contradiction with Anyanga *et al.* (2013) who reported significantly lower number of fecal droppings of *C. puncticollis* on varieties with reduced feeding punctures. This contradiction might be due to the experimental methods used. The frass recorded in this study might not be from the digested food eaten only during the experimental period but affected by the one eaten before the experiment.

Effect of sweet potato variety on the bionomic parameters of sweetpotato weevil

Understanding the biology of an insect pest is the cornerstone for developing an environmentally friendly pest management strategy (Reddy and Chi, 2015). The results of this study showed how sweet potato variety could influence the development and survival of *C. puncticollis*. The total developmental period (egg to adult) of *C. puncticollis* was affected by sweet potato variety in this study. It took 20 to 26 days for the sweetpotato weevil to complete its development on Apumoden, Ligri and Bohye but reached up to 27 days on Okumkom. The most significant varietal effect was the time of adult emergence peak. By the 22nd day of the developmental period, about 45% of the adults emerged from Apumoden and Ligri while 25% emerged from Bohye and only about 15% emerged from

Okumkom. This implied that the development of immature stages of *C. puncticollis* was faster on Apumoden and Ligiri than it was on other varieties. The effects of sweet potato variety on the developmental period of *C. puncticollis* were reported earlier by Darko, (2000) working on two different Ghanaian varieties, and by Yamaguchi *et al.*, (2006) using four different Japenese varieties. Like the developmental period, the adult emergence rate was affected by the variety which was in an agreement with Kabi *et al.*, (2001) and Stathers *et al.* (2003b). These authors reported that the effect of variety on the developmental period and emergence rate of *C. puncticollis* suggests the presence of antibiosis mechanism in sweet potato which affects its development. It is therefore assumed that the difference in developmental period and emergence rate of the weevils among tested varieties in this study might be due to different levels of an antibiosis effect. Resin glycosides and caffeic acid in the latex of sweet potato storage root were found to have insecticidal effect on sweet potato weevil and could affect its survival and development (Jackson and Peterson, 2000). The proportion of female of *C. puncticollis* populations that emerged from all varieties was close to 50% which is not far from the findings of Smit and Van Huis (1999) and Mohamed (2005).

The effect of variety was not significant on pre - oviposition period but was significant on the oviposition and post - oviposition periods. Various studies found different pre - oviposition periods in female of *C. puncticollis*, but the average pre - oviposition period recorded in this study on the different sweet potato varieties were not far from the findings of Mohamed (2005). However, Moyer *et al.*, (1989) found about 3 days less and Smit and Van Huis, (1999) found 6 days more than the current findings. The variations in results of different studies could be the result of differences in experimental conditions. The oviposition period in this study varied from 88.8 days on Apumoden to 54.6 days on Bohye. Smit and Van Huis (1999), found an oviposition period of 110 days with one Kenyan variety ‘’Kalamba Nyerere’’while on a Ghanaian red skinned variety, Darko (2000) found 42 days less than that found by Smit and Van Huis (1999). Like the oviposition period the female fecundity was affected by the variety. The average fecundity varied from 241.64 to 121.60 eggs/female on Ligri and Bohye, respectively. As it was stated earlier, the difference in the fecundity might be due to the difference in the content of oviposition stimulants that occur in the periderm of different varieties (Wilson *et al.*, 1988; Mao *et al.*, 2001). However, the levels of *C. puncticollis* female fecundity found on different varieties in this study fell in the range reported in different studies undertaken previously. Anota and Leuschner (1983) found that the fecundity of C. puncticollis can reach up to 329 eggs/ female; Darko (2000) found 299.5 eggs/ female, while Smit and Van Huis (1999) reported only 103 eggs / female. The highest female fecundity was observed with females that had the longest oviposition period. This suggests that the stimulation of oviposition in *C. puncticollis* may also lengthen the oviposition period and even the post-oviposition period as hypothesized by Darko (2000). Moreover previous experiments found that, the susceptible varieties, upon which the highest number of egg were laid were also in most cases the most consumed by the female weevil (Mao *et al.*, 2001; Parr *et al.*, 2016). The increased longevity of females on the varieties which were most susceptible for egg laying as observed in this study might also be attributed to the abundant food obtained by the female weevil. The similar mean daily fecundity recorded on different varieties might be due to the fact that the oviposition rate dropped in females with great longevity in the later stages of the oviposition period.

On all varieties, females of *C. puncticollis* lived longer than the males. This is in agreement with Darko (2000). Difference in longevity between males and females are commonly observed across many insect species, depending on the genetic make - up of insect species, and also on the environmental effects especially quality of the composition of diets (Partridge *et al.*, 2005; Tower and Arbeitman, 2009). Accordingly, the difference obtained here might have been due to the effect of weevil genetics or nutritional composition of sweet potato which might enhance the longevity of the females.

Bionomic parameters of phytophagous insect pest is inherently tied to the host it exploits (Kohno and Thi, 2005; Yamaguchi *et al.*, 2006; Muli *et al.*, 2009). Reddy and Chi (2015) found that the growth rate of *C. formicarius* differed depending on whether it exploits its major host *Ipomea batatas* or the alternative host *I. triloba*. The effect of the sweet potato variety on the bionomic parameters of *C. puncticollis* in this study showed the importance of sweet potato variety in the population build - up and infestation level in sweet potato farm. It is therefore possible to reduce weevil populations by choosing varieties on which the weevil population grows less rapidly (Jansson *et al.*, 1990).

Correlation between field and laboratory results

The correlation between laboratory experiments and field trials to determine the level of susceptibility to weevil infestation among different sweet potato varieties was strong. This is in agreement with Nottingham *et al.* (1989) who found that a highly susceptible variety ‘’ centennial’’ in field plot experiments, was most preferred for feeding and oviposition by

C. formicarius among four different cultivars. In contrast, Stathers *et al.* (2003b) reported no correlation between field experimentation and laboratory bioassay. These contradictions might arise from the difference in methods used to assess the level of infestation especially in the laboratory bioassays. Therefore, it appears that the laboratory method suggested by Wilson *et al.* (1988) and used in this work may be more reliable. It was also found that the preference for oviposition more correlated with field infestation level than preference for feeding in agreement with Wilson *et al.* (1988) who reported that an oviposition assay would be better indicator of plant resistance than feeding assay.

CHAPTER VI

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The use of resistant host plants as a component in integrated pest management requires a priori the selection of resistant or at least the less susceptible varieties to the target pest. Field evaluation of seven (7) Ghanaian sweet potato varieties (Apumoden, Ligri, Faara, Bohye, Dadanyui, Okumkom and Sauti) for susceptibility to *Cylas* spp. infestation showed that Apumoden and Ligri appeared to be more susceptible than Faara, Bohye, Dadanyui and Okumkom. The infestation level was found to be negatively correlated with the shortest weevil distance but positively correlated with the storage root size. These root characteristics may therefore contribute to the susceptibility to sweetpotato weevil infestation. Regarding the yield, Ligri appeared as a high yielding variety but unfortunately the most susceptible variety, while Faara gave the lowest yield.

A Moderately positive correlation was found between stem base infestation and storage root infestation and therefore using stem base infestation as an index to screen for resistant sweet potato varieties may not always be realistic. The production of flowers was found to be one of the factors that may contribute to increased stem base infestation level in sweet potato but the storage roots may escape the infestation. The varieties producing flowers abundantly shouldn't then be used to avoid high infestation level due to migration of sweetpotato weevils from neighbouring sweet potato farms. Laboratory studies confirmed the relatively high susceptibility of Apumoden and Ligri to *C. puncticollis* and Okumkom appeared to be less susceptible compared to the other varieties assessed. However, compared to the Apumoden, Ligri and Okumoom, Bohye may be the most appropriate for storage since it slows weevil population growth. The host plant exploited by *C. puncticollis* can affect its bionomic parameters.

The analysis of findings of field trial and laboratory study of preference for feeding and oviposition by *C. puncticollis* implies that the model/level of susceptibility of sweet potato varieties encountered in the field is mainly biochemical. This may be through production of either kairomones (weevil oviposition stimulant) or allomones (insecticidal effect of latex). Favorable root characteristics may only contribute to infestation level by reducing the possibility of contact between storage roots with the weevil and thereby delay the infestation time. Therefore, though sweet potato physical root characteristics may help to escape the infestation, breeding for resistance to sweetpotato weevil should rather focus on the biochemical basis than other root characteristics. Thus, breeding for new resistance based on root size may not be beneficial since reduction of root size may negatively affect the total yield and marketability. Moreover such an escape tactic provided by root characteristics in sweet potato can be achieved through the use of appropriate farming practices such as re- hilling.

With regard to inconsistency in susceptibility level to *Cylas* spp. encounted most of the time in sweet potato germaplasm, further studies are needed to confirm the results of this study. These studies should be carried out using not only improved varieties but also the local ones and to look for source of resistance for breeding purposes. Chemical analysis of Ghanaian sweet potato varieties to understand chemical basis of resistance and investigation on the role of sweet potato flowers in contributing to weevil infestation are two important aspects on which future studies could focus on.

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APPENDICES

Appendix 1: Summary of t- test analysis comparing different parameters on each variety between the major and minor rainy seasons.

Varieties	Plant survival		Plant mortality		ESB[1]		ISB[2]		Total yield		Marketable yield	
	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*
Apumoden	1.33	0.2410	-3.75	0.0170	1.29	0.2610	0.35	0.7440	3.22	0.0230	2.90	0.0340
Ligri	1.20	0.2950	-2.23	0.0760	1.33	0.9050	-1.45	0.2130	-0.11	0.9200	1.26	0.2630
Faara	-1.61	0.8180	0.82	0.4580	1.34	0.2420	0.84	0.4420	1.77	0.1380	-3.11	0.0260
Bohye	1.32	0.2420	-2.04	0.0919	0.78	0.4720	-1.76	0.1470	2.61	0.0470	1.28	0.2670
Dadanyui	0.69	0.7400	-0.85	0.4450	-2.47	0.0630	1.17	0.3010	0.45	0.6730	0.26	0.8110
Okumkom	0.63	0.5580	0.82	0.5490	-0.82	0.4600	-5.06	0.0040	1.79	0.1310	1.75	0.1410

Appendix 1 cont'd.

Varieties	Root infestation		Yield loss		RD[3]		RL[4]		RG[5]		RSI[6]		RNL[7]	
	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*	t_5	*P*
Apumoden	-2.30	0.8390	4.90	0.0040	0.28	0.7910	1.06	0.3420	-2.45	0.5850	-0.64	0.5550	-314	0.0310
Ligri	-0.79	0.4740	5.87	0.0020	0.95	0.3990	-1.98	0.1190	-1.17	0.3010	-1.79	0.1370	-3.38	0.0210
Faara	1.51	0.1940	0.34	0.7460	-1.91	0.1150	-4.18	0.0090	-3.15	0.2510	-4.78	0.0050	-4.26	0.0080
Bohye	0.36	0.7320	5.08	0.0040	-1.78	0.1450	0.71	0.5120	-1.83	0.1340	-0.61	0.5720	-1.08	0.3220
Dadanyui	1.71	0.1550	3.10	0.0270	4.08	0.3390	-1.18	0.3090	-2.97	0.0310	-2.08	0.1000	-3.06	0.0270
Okumkom	-0.07	0.9500	-1.02	0.3550	-0.69	0.5230	0.57	0.6030	-0.63	0.5530	0.69	0.5220	-2.77	0.0340

[1] External stem base infestation, [2] Internal stem base infestation, [3] Shortest weevil distance, [4] Root length, [5] Root girth, [6] Root size index, [7] Root neck length.

Appendix 2: Vertical and horizontal distances (mean ± SE) of different varieties in major and rainy seasons.

Variety	Vertical distance (cm)		Horizontal distance (cm)	
	Major season	Minor season	Major season	Minor season
Apumoden	5.28 ± 030	5.16 ± 0.67	20.97 ± 064	21.84 ± 0.73
Ligri	5.35 ± 058	4.81 ± 0.86	21.87 ± 0.87BC	21.04 ± 1.20
Faara	7.73± 0.38	10.98± 2.32	24.32 ± 0.31	20.63 ± 1.21
Bohye	5.69 ± 0.38	7.21 ± 0.44	21.74 ± 071	22.86 ± 0.99
Dadanyui	6.85 ± 0.48	5.81 ± 0.94	23.44 ± 0.53	23.40 ± 1.51
Okumkom	6.74 ± 0.40	7.64 ± 0.39	24.08 ± 0.19	24.72 ± 0.84

Appendix 3: Egg incubation period in days of *C. puncticollis* on different sweet potato varieties (N=80).

Variety	No. of eggs hatched after (days)							Total No. of eggs hatched
	1	2	3	4	5	6	7	
Apumoden	0	0	17	48	10	0	0	75
Ligri	0	0	22	45	10	0	0	77
Bohye	0	0	19	47	8	0	0	74
Okumkom	0	0	20	45	5	2	0	72

Appendix 4: Development period (egg to adult) in days of *C. puncticollis* on different sweet potato varieties (N=80).

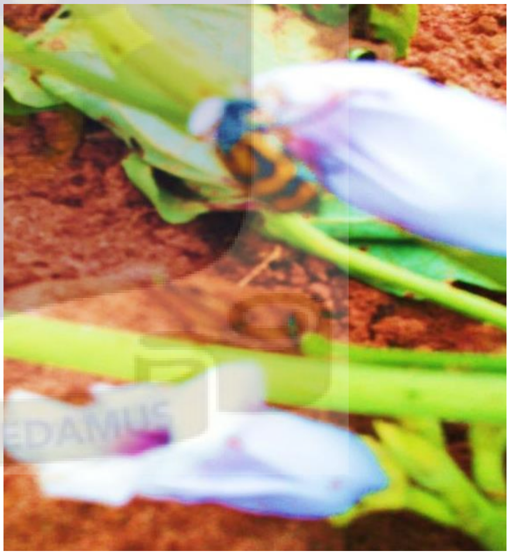
Variety	No. of adults emerged after (days)										Total No. of Adult emerged
	19	20	21	22	23	24	25	26	27	28	
Apumoden	0	2	9	14	11	11	8	1	0	0	56
Ligri	0	2	8	17	15	10	4	2	0	0	58
Bohye	0	2	4	6	12	7	6	6	0	0	43
Okumkom	0	0	3	5	11	10	11	7	4	0	51

Appendix 5: Pictures of sweet potato insect pests recorded in the field experiments.

Adult of *Cylas puncticollis*
(Coleoptera: Brentidae)

Adult *of Alcidodes* spp.
(Coleoptera: Curculionidae)

Pupa of *Agrius convolvuli*
(Lepidoptera: Sphingidae)



Adult of *Mylabris* spp.
(Coleoptera: Mylabridae)

Nymph of *Zonocerus variegatus*
(Orthoptera: Pyrgomorphidae)