EFFECTIVENESS OF CULTURAL PRACTICES AND SWEET POTATO VARIETIES (*Ipomoea batatas* Lam) IN MANAGING SWEET POTATO WEEVIL (*Cylas* spp) IN ZANZIBAR

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ABSTRACT

Field experiments were conducted simultaneously from April to July 2012 at agro-ecologies; Bambi (Latitude 06°09'S, Longitude 039°16'E; and Altitude 20m above sea level) Central District and Kizimbani (Latitude 05°54'S, Longitude 039°16'E; and Altitude 20 m above sea level) Western Unguja district. The aim was to investigate the effectiveness of selected cultural practices (weeding and hilling-up once, twice and thrice), vine portions (apical, middle and basal) and variety (Mbirimbi, Shangazi and Mayai) on damage due to sweet potato weevil. The experiments were laid out in split-split in a randomized complete block design with three replications. The main plot factor was three varieties, the sub plot factor was three vine portion and the sub-sub plot factor was cultural practices. The main plots were consisted of twenty seven, sub plots nine while sub-sub plot three ridges. The vines were planted at a spacing of 0.3 m apart on a ridge of six metre long and one metre apart. Weeding and hilling-up the soil were done simultaneously at four weeks, eight weeks and twelve weeks after planting. Data collected were sweet potato weevil incidence (weevil/m^2), severity (1-5 scale) and number of infested tubers. The data were subjected to Analysis of Variance (ANOVA) at $p \leq 0.05$ and GENSTAT statistical package. Tukey's test was used for mean separation. The results show that varieties, vine portion and cultural practices have significant effect on sweet potato weevil incidence and severity. With regard to variety, Mayai was significantly ($p<0.05$) had higher weevil incidence (LSD 0.397) than Mbirimbi and Shangazi. Using apical vine portion significantly ($p<0.05$) had low weevil severity (LSD 0.115) than middle and basal vine portions. Weeding and hilling-up thrice (12 WAP) significantly ($p<0.05$) had low weevil damage (LSD 0.768).

DECLARATION

I, SALUM ABDULLAH SALUM, do hereby declare to the Senate of the Sokoine University of Agriculture that the content of this dissertation is a result of my own original work done within the period of registration and has neither been submitted no being concurrently submitted in any other institution.

____________________________ ____________________

Salum Abdullah Salum **Date**

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The above declaration confirmed by;

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Prof. Mwatawala, M.W. **Date**

(Supervisor)

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DEDICATION

This work is dedicated to: My parents, Mr. Abdullah Salum Ali and Mrs Mwanajuma Mgeni Khamis for taking me to school.

And

My wife Wanu. Sons Abdullah, Yassir, Nabil, Ahmad and daughter Farhiya for supporting me. I always love you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATION, SYMBOLS AND ACRONYMS

%	-	percentage
<	-	less than
>	-	greater than
≤	-	less than or equal to
a. i.	-	active ingredient
a.s.l	-	above sea level
ANOVA	-	Analysis of Variance
AVRDC	-	Asian Vegetable Research and Development Centre
CIP	-	Center of International Potato
cm	-	centimeter
CV	-	Coeffiecient of variation
DM	-	Dry matter
E	-	East
et al.,	-	and others
FAO	-	Food and Agriculture Organization
g	-	gram
ha	-	hectare
IITA	-	International Institute of Tropical Agriculture
IPM	-	Integrated Pest Management
kg	-	kilogram
KSP	-	Kadulaw Sweet potato
LSD	-	Least Significant Difference

m	-	meter
m^2	-	meter square
MANR	-	Ministry of Agriculture and Natural Resources
ml	-	milliliter
mm	-	millimeters
^oC	-	Degrees centigrade
p.a	-	per annum
S	-	South
S.E	-	Standard Error
spp	-	species
SPW	-	Sweet potato weevil
TIS	-	Tropical Institute Sweet potato
WAP	-	Weeks after planting
ZARI	-	Zanzibar Agricutural Research Institute
ZATI	-	Zanzibar Agricultural Tranformation Initiative

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Sweet potato weevil, *Cylas* spp (Coleoptera: Curculionidae) is the most destructive insect pest of sweet potato, *Ipomoea batatas* (L.) in Zanzibar (Saleh and Mohammed, 2001). Although the extent of damage caused by sweet potato weevils has never been quantified in Zanzibar, Chalfant *et al*., (1990) reported that losses often reach 60 to 100 percent in low input agricultural systems. Surveys which have been conducted elsewhere in Tanzania indicate that, sweet potato weevil is the major insect pest of sweet potato crop in almost all major sweet potato growing areas (Kapinga, 1992; Kapinga *et al*., 1995).

Although the importance of sweet potato has been realized by farmers in Zanzibar, its expansion in acreage for several years and yield per unit area in farmers field is still low (Saleh and Mohammed, 2001). The total area under sweet potato cultivation is estimated at 3800 ha in Unguja and 1430 ha in Pemba (ZATI, 2010). This low expansion rate in acreage and low root yield is caused by the crop being highly susceptible to sweet potato weevils (Saleh and Mohammed, 2001). Sweet potato weevils become more abundant during periods of drought. Hahn and Leuschner (1982), noted that weevil populations increase more easily and rapidly on a dry compared to wet season crop. Thus, one of the recommendations was to plant sweet potato and harvest early when the soil moisture is still high. Several methods of sweet potato weevil control have been tried with varying degrees of success (Stathers *et al.,* 2005). The objective has been to search for better and sustainable methods of sweet potato weevil control which can be adopted by small holder sweet potato growers so as to reduce losses due to *Cylas* damage. Examples of control methods include effective weed control, appropriate hilling up of soil around the plant and crop rotation (Stathers *et al.,* 2003).

1.2 Justification

Sweet potato is an important food security crop in Zanzibar particularly during the dry season when other foods are scarce. Sweet potato weevil is the most serious pest of sweet potato in Zanzibar reported to cause great loss of more than 60 percent (Saleh and Mohammed, 2001). Prolonged dry season experienced in sweet potato growing areas lead to shortage of planting material forcing farmers to use any available planting materials (Stathers *et al.,* 2005).

Most farmers rely in indigenous pest management approaches to manage pest infestation in their farms (Abate *et al.,* 2000). Cultural practices such as hilling up twice, earthing-up during weeding and selection of deep rooting cultivars with long necks between the roots and stem are not practiced (Nair, 2006). The yield quality and quantity of sweet potato have declined despite the use of selected high yielding varieties due to infestation by sweet potato weevils and inadequate clean planting materials (Pinense, 2001).

Sweet potato weevil, *Cylas* spp. is the biggest constraint to the production of sweet potato in the world (Chalfant *et al.*, 1990). Even very low populations reduce the quality of the roots and possible yield (Proschold, 1983) and the crop produces bitter tasting and toxic sesquiterpenes, which render stored roots unfit for human consumption (Akazawa *et al*., 1960). Generally, the average fresh root yield at farm level in Tanzania is only eight tonnes per hectare as compared to the potential yield of 20 tonnes per hectare. Such low yield is attributed by the use of poor yielding local varieties which are also susceptible to *Cylas* spp. (ZATI, 2010).

Previous studies (Ali *et al*., 1996) reported that the average yield of sweet potato was as low as five to eight tonnes per hectare. In a recent research priority setting survey carried out by Fuglie (2007), management of weevils was highest ranked need in relation to improved sweet potato crop management. Among the most important constraints reported to cause the low yield were poor soils because of continuous cropping on the same piece of land and the use of poor quality vines which are susceptible to *Cylas* spp. The use of poor quality vines is due to the fact that farmers lack good sources of planting materials and knowledge on selection of high quality and good planting materials (Ali *et al*., 1996).

Mullen, (1984) studied infestation of sweet potato weevil in 12 sweet potato lines. The study did not compare local varieties which are available in Zanzibar. The study also did not compare susceptibility to sweet potato weevils of local varieties available in Zanzibar. The study also did not compare effect of cultural practices on incidence and infestation of the pest. Thus a study to determine effect of cultural practices on incidence and infestation rate is necessary for formulating ecologically based IPM of sweet potato weevils.

1.3 Objectives

1.3.1 Overall objective

To investigate appropriate management of reducing sweet potato weevils (*Cylas* spp) infestation in local sweet potato varieties grown in Zanzibar.

1.3.2 Specific objectives

(i) To establish incidence of sweet potato weevils in selected sweet potato varieties

(ii) To determine severity of sweet potato weevils in selected sweet potato varieties

(iii) To determine effect of cultural practices on sweet potato weevils in selected sweetpotato varieties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description, Diversity, Biology and Distribution of *Cylas* spp

2.1.1 Description of cylas spp

Sweet potato weevils is in the genus Cylas (Coleoptera: Apionidae) (Chalfant *et al.,* 1990; Smit, 1997a). Contains three species namely *Cylas brunneus* (Olivier), *Cylas puncticollis* (Boheman) and *Cylas formicarius* (Fabricius) (Wolfe, 1991). Adult weevils are elongeted smooth and shine with ant like snouted beak but species can be differentieted by size and colour (Smit, 1997a). *C. formicarius* are small with a bluish black abdomen and a red thorax, *C. puncticollis* are black and large, *C. brunneus* are small either black or brown (Wolfe, 1991).

2.1.2 Diversity of sweet potato weevils

Both *C. puncticollis* and *C.brunneus* are the most common species in East Africa (Parker *et al*., 1990). On the other hand, *Cylas formicarius* is the main pest species in Asia, the United States and Oceania, but in Africa it has been found in Natal, South Africa and on the coast in Kenya (Parker, 1990).

2.1.3 Biology of sweet potato weevils

All three species have a similar life history. The adult female lays eggs singly in cavities excavated in vine or in roots, preferring the latter. The egg cavity is sealed with a protective, gray fecal plug. The developing larvae tunnel in the vine or root. Pupation takes place within the larvae tunnels. A few days after eclosion, the adult emerge from the vine or roots because the female weevil cannot dig, she finds soil cracks. Alternate host of sweet potato weevils are *Ipomoea* spp. weeds (Ames *et al.,* 1996).

2.1.3.1 Eggs

The egg is oval, and yellowish-white (Schimutterer, 1969). Eggs are deposited in small cavities created by the female with her mouthparts in the sweet potato root or stem. The female deposits a single egg at a time, and seals the egg within the oviposition cavity with a plug of fecal material, making it difficult to observe the egg. Eggs will hatch after three to seven days depending on the environmental conditions (Otto *et al.,* 2006).

2.1.3.2 Larvae

The larvae have head, thorax and abdomen. The head is pale brown with darker brown mandibles, one pair of ocelli (stemmata), each containing two contiguous pigment spots (Allard, 1990). The thorax is divided into prothorax and mesothorax whereby mesothoracic spiracle located on a lobe very close to the prothorax. The abdomen is whitish, legless, slightly curved, approximately 10 millimetres length maximum width two millimetres cuticle speculate. Larvae has three instars, first larval instar, second larval instar, and third larval instar. Total larvae period varies from 10 – 25 days (Otto *et al.,* 2006).

2.1.3.3 Pupae

The pupa of sweet potato weevil is white and approximately six millimetres in length; pronotal width one metre, cuticle glabrous. The head and rostrum are provided with setiferous tubercles, one pair between the eyes at base and two pairs on the rostrum. The posterior pair being close to the eyes and the anterior behind the middle. Pupation occurs inside the vine or root and takes eight days for adults to emerge (Otto *et al.,* 2006).

2.1.3.4 Adults

The pest is black, with a faint, metallic blue luster, and not with a distinctly shiny, copper-like sheen, body length is eight millimetres. The length of male antennal club is equal to or greater than combined length of all preceding segments. Eyes close together in dorsal view; distance between eyes is about one sixth of minimum width of rostrum.

At an optimal temperature of 27-30^{o}C, *C. formicarius* completes development (from egg to adult) in about 33 days. Adult longevity is two to three months and females lay between 100 and 250 eggs in this period. Female's (*C. puncticollis)* lay 90 -140 eggs in their life time, whereas *C. brunneus* lay 80 – 115 eggs (Ames *et al.,* 1996). The male and female adult sweet potato weevils can be told apart by the shape of their antennae. The antennae of the males are straight while those of the female are round or club-shaped. Under favourable conditions, sweetpotato weevils can produce 13 generations a year and can live for three to four months (Okonyo, 2013).

2.1.4 Distribution

The sweet potato weevil is one of the major pests of sweet potato worldwide. Three species have been identified in Africa. Their distribution in Africa is being surveyed and it appears that all the three species have a similar life history, making all of them difficult targets for conventional pest control measures (Parker *et al.,* 1990). Among the three, *C. formicarius* is an important pest in India, South East Asia, Oceania, the United States and the Carribean. Several studies have shown that only *C. puncticollis* and *C. brunneus* have been confirmed to commonly occur in Kenya (Nderitu *et al.,* 2009).

2.2 Economic Importance of Sweet Potato Weevils

Sweet potato weevil is one of the most important biotic factors limiting sweet potato production in Africa (Chalfant *et al.,* 1990; Pfeiffer, 1982; Smit and Matengo, 1995). Sweet potato is the sixth most important food crop in the world (Vietmeyer, 1986) and both adults and larvae cause serious damage to leaves and stems. Adults attack the leaves of sweet potatoes, but the larvae are more injurious boring into the stems and causing serious mortality to seedlings (Daiber, 1994).

Adults of all three *Cylas* species feed on the epidermis of vines and leaves, scraping oval patches off petioles, young vines and leaves. Yield loss is seldom serious (Wolfe, 1990). Adults also feed on the external surfaces of roots causing round feeding punctures which can be distinguished from oviposition sites by their greater depth and the absence of a faecal plug. The developing larvae tunnel in the vines and roots causing significant damage. Frass is deposited in the tunnels (Wolfe, 1990). In response to the damage, the root produces terpenes which render the infested root part inedible (Sato *et al.*, 1981).

Allard *et al.,* (1991) report on serious larval infestations disrupting sweet potato nurseries in Ethiopia, on established plants, the larvae feed in the tubers and stems producing larvae tunnels and later, pupal chambers stem damage is believed to be the main reason for yield loss, although damage to the vascular system caused by feeding, larvae tunnel secondary rots reduce the size and number of roots. In Eastern Africa both C. *puncticollis* and *C. brunneus* can be found infesting the same root. When a root is exclusively infested by *C. puncticollis,* the core of the root might still be untouched; *C. brunneus* larvae seem to tunnel further inside the root. First severe infestations render the crop unpalatable and therefore inedible to humans. Pest damage usually continues during storage, therefore infested tubers cannot be stored for a long time. In conjunction with other coleoptera pests, sweet potato weevil can completely destroy sweet potato plantations (Geisthardt and van Harten, 1992). Weevil feeding on storage roots induces terpenoid production that makes even slightly damaged root unpalatable (Uritani *et al*., 1975; Sato *et al.,* 1981). Thus low weevil densities may cause devastating crop losses of up to 60 -100% (Chalfant *et al.,* 1990).

2.3 Management of Sweet Potato Weevils

2.3.1 Cultural control

Cultural practices aimed at preventing infestation proved to be effective way of reducing weevil damage. Stathers *et al.* (2005) reported different successful cultural practices used in experiments conducted in East Africa, Taiwan, Philippines, Vietnam, America, India, Cuba and Indonesia.

a) Field sanitation

A survey of farmer's cultural practices in Kenya by Smit and Matengo (1995) suggested that crop protection workers should concentrate their research and extension efforts on crop sanitation and the avoidance of adjacent planting of successive crops.

- Removal and destruction (through burning or feeding to livestock) of infested vine and root remains. If vines are left in the field to maintain soil fertilily, care should be taken to ensure they are dead or dry and not able to sprout and than provide food for weevils. If peace meal harvesting of the crop is practiced, care should be taken to remove and destroy any infested roots that are found (Stathers *et al.,* 2005).
- Removal of volunteer sweet potato plant and wild morning glories as these may be alternative hosts (Sato *et al.,* 1981). Removal of alternate host plants like *Calystegia soldanella,* C. *hederacea* and *Ipomoea indica* reduced the sweet potato weevil infestation in Japan (Komi, 2000).
- Crop rotation with other crops for two to three seasons appears to be the most effective method of preventing infestations of weevils (Geisthardt and van Harten, 1992).
- In a large ecosystem area or community burying can help to reduce weevil infestation. Infested roots must be buried >15 cm underground (Stathers *et al.,* 2005).

b) **Hilling up**

Collection of soil around the base of plants to prevent or fill soil cracks. This practice not only protects the plants from weevil attack but can also result in increased crop yield (Allard *et al.,* 1991). Re-ridging the crop at tuber formation stage prevents the weevil from laying the eggs and the entry of the grubs into the tuber. The efficacy of re-ridging in sweet potato crop, as a cultural practice for reducing weevil incidence was investigated over two seasons at Vellayani, Kerala, India. Five re-ridgings between 50 and 90 days after planting, at 10 days interval, significantly reduce the weevil damage to the tubers (Palaniswami and Mohandas, 1994). Deep planting into the hill, and planting into the furrow and earthing after six weeks offers protection against weevils (Macfarlane, 1987).

c) Mulching

Application of dry leaves on the soil to keep it moist, prevent cracks and provide a more favourable place for natural enemies. Care should be taken to make sure the weevils can not feeds or develop on the mulching material (Geisthardt and van Harten, 1992). Mulching with rice straw or black plastic reduced the infestation by SPW in the root zone (AVRDC, 1987). The availability of mulch is a problem especially in dry-lands coupled with higher temperatures. Termites are a problem during summer as they completely devour the dried grasses and other shrubs in dry lands.

d) Early harvesting

Harvesting two weeks earlier reduce the loss due to weevil from greater than 30 percent to less than five percent (Ebregt *et al.,* 2005). Early harvesting of the crop is practiced to ensure that infested roots are removed and destroyed. Vines left in the field should not be allowed to sprout and than provide food for weevils (Powell *et al.,* 2001). Timely harvesting to remove the largest storage root most at risk from weevil attack and subsequent hilling up of the soil arround the remaining root to prevent weevils from accessing the root through cracks in the soil (Stathers *et al.,* 2005).

e) Flooding

Sweet potato weevils can be controlled by flooding of fields before planting (Stathers *et al*., 2003). Flooding of the field for more than 48 hours kill the weevil larvae present in roots that have been left in the field (Otto *et al.,* 2006). Also Talekar (1987) reported that, flooding of infested field for at least 48 hours after completing harvest drown weevils and induces rotting of the left over plant materials and thereby reduces weevils' densities from one planting to the next. This is an option in areas where rotation is not possible. Flooding of fields between two consecutive sweet potato crops may reduce the immediate source of weevil from the field (Otto *et al.,* 2006).

f) Intercropping

In Taiwan, 103 different crops were tested as intercrops for sweet potato weevil control, the best result were obtained with coriander (*Coriandrum sativum* L.)

(Stathers *et al*., 2005). Mixed cropping systems with sweet potato and other crops (ginger, okra, maize, colocasia and yam) are practiced by farmers in North Eastern Region of India. Low incidence of *C. formicarius* was noticed in these systems and the interaction of intercrops and several insect pests of tuber crops, including sweet potato weevil, in these multiple cropping systems are described by Rajasekhara Rao (2005) and Rajasekhara Rao *et al.,* (2006).

g) Use of clean planting material

Weevils tend to lay eggs in the older woodier parts of the vine, so if the tender tips are used for planting they are less likely to be infested by weevils (Nair, 2006). Allard *et al*. (1991) described the following techniques that have been used in the management of sweet potato weevils. Planting only in fields that have had no weevil infestations within the last 12 months and preferably more than 1 km away from any infested land; planting resistant or tolerant cultivars; selecting deep-rooting cultivars, with long necks between the roots and the stems (which are less susceptible because the adult weevil cannot burrow downwards more than one centimetre); planting early-maturing cultivars which can escape serious damage; earthing up of plants (hilling), particularly those cultivars with the tendency to push out of the ground; removal of all plant debris and volunteer plants after harvest; re- ridging approximately 30 days after planting as this places the roots deeper and out of reach of the weevils; planting non-infested material; and use of intercropping.

2.3.2 Biological control

2.3.2.1 Parasitoids

Maeto and Uesato (2007) reported a new species of braconid, *Bracon yasudai* from the south-west islands of Japan. It is a solitary idiobiont ectoparasitoid of the larvae of the West Indian sweet potato weevil, *Euscepes postfasciatus*, and the sweet potato weevil, *C. formicarius,* both feeding on *Ipomoea batatas* (L.). Palaniswami and Rajamma (1986) reported the braconids *Rhaconotus* spp. and *Bracon* spp. and an unidentified hymenopterous parasitoid on the larvae of sweet potato weevil. Jansson and Lecrone (1991) reported *Euderus purpureas*, an eulophid parasitizing on *C. formicarius* in Southern Florida. Nevertheless, the success of all these parasitoids at field conditions is doubtful since they are recorded in a very few numbers.

2.3.2.2 Predators

The use of ants against weevils is another component of the control strategy adopted for the sweet potato weevil in Cuba. Two species of predatory ants, *Pheidole megacephala* and *Tetramorium guineense* (*Pheidole guineensis*), are common inhabitants of banana plantations. Rolled banana leaves were used as "temporary nests" to transport the ants from their natural reservoir to sweet potato fields, where they prey upon weevils and other insects. Setting up ant colonies in the field 30 days after planting with 60-110 nests has reduced weevil infestation from three to five percent (Lagnaoui *et al.,* 2000).

The subterranean habitat of *C. puncticollis*, whilst making it less accessible to predators and parasitoids may enhance the impact of fungal pathogens which require a protected cool, humid environment for survival and reproduction; conditions generally found under dense foliage of sweet potato. The eggs are also well protected as they are laid within vines, or in tubers and egg cavity is sealed with a feacal plug that preserves moisture, disguises location and protects the eggs from predatory mites. Potential candidates for use as biological insecticides include *B. bassiana* and *M. anisopliae.* Isolates of the former have been collected from laboratory-reared adults originally collected in Kenya (Allard *et al.,* 1991).

2.3.2.3 Entomopathogenic nematodes

Entomopathogenic nematodes (EPN) have beneficial interaction with sweetpotato within the roots and are promising for the control of sweet potato weevils (Jansson and Lecrone, 1997). Among different species, Heterorhabditis was found to be most effective, infective and pathogenic than Steinernematids (Mannion and Jansson, 1992). Heterorhabditid nematodes were more pathogenic to pupae, than were Steinernematid nematodes. Weevil adults were the least susceptible to nematode infection. The number of applications of bacteriophora did not significantly reduce numbers of *C. formicarius* but consistently reduced damage to sweet potato tubers (Jansson *et al.,* 1991).

Nematode application rate had no effect on densities of *C. formicarius* or damage caused suggesting that a single application early in the growing season is adequate (Jannson *et al.,* 1991). Weevil damage to plants treated with insecticides is intermediate to that on nematode-treated and untreated plants weevils (Jansson and Lecrone, 1997). Jannson *et al.* (1991) indicated that bacteriophora, is more infective than *Steinernematids* c*arpocapsae* ('All' strain). Subsequent field tests showed that one application of bacteriophora has found effective at protecting sweet potato tubers from weevil damage. This nematode persisted for over 130 and 250 days after application in two separate experiments, respectively.

2.3.2.4 Entomopathogenic fungi

Most effective entomopathogenic fungi infecting sweet potato weevil has been identified as *Beauveria bassiana* (Bals.) Vuill, which can be applied as a foliar spray or in combination with pheromone trap, for its successful infection and dispersal. Spraying of *B. bassiana* solution (isolated from *C. formicarius*) at a concentration of $1.6x10^4$ conidia ml^{-1} at planting and rootstock formation, and broadcasting soybeans containing *B. bassian*a into the rows at planting controlled *C. formicarius* effectively (Su, 1991a).

Application of *B. bassiana* isolated from honey bees at a concentration of $1x10^6$ conidia ml^{-1} at planting and rootstock formation also gave the best results. The success of infection of *B. bassiana* on sweet potato weevil is dependent on the type of soil (Su, 1991b). Thirteen different soils were pernicious to sweet potato weevil out of eighty soils collected from central and southern Taiwan because when they were added to the row at planting, mortality caused to the sweet potato weevil by *B. bassiana* was >80%. Environmental factors also govern the successful infection of sweet potato weevil by entomopathogenic fungi. Low relative humidity (<43%) and low temperatures below (<15^{o}C) were not conducive for *B. bassiana* infection of adults of sweet potato weevil (Yasuda *et al.,* 1992).

Yasuda (1995) developed an auto-infection system consisting of a modified sex pheromone trap and a bottle with exit holes containing conidia of *B. bassiana* ($9.3 x 10^{10}$ g^{-1} medium) successfully tested to control *C. formicarius* in Japan. Male weevils were attracted to the system by the action of pheromone and exited the bottle were found infected with *B. bassiana.* Formulations of *B. bassiana* conidia in a 10% corn oil mixture showed more superior infectivity in both sexes of *C. formicarius* than the formulation of conidia (Yasuda *et al.,* 2004). Low cost and effective technology of production of *B. bassiana* at a cottage industry level to control sweet potato weevil was successfully established and adopted by many farmers in Cuba (Lagnaoui *et al.,* 2000). Use of the fungus is particularly attractive because it relieves farmers from the high cost of chemical pesticides.

Incubation of entomopathogenic fungi in different growth media results in production of several metabolites with insecticidal activity. Squamulosone (aromadendr-1(10)-en-9-one) was isolated in large quantity from the plant *Hyptis verticillata* and incubated with the fungus *Curvularia lunata* in two different growth media (potato dextrose broth and beef extract medium) (Collins et *al.,* 2001). *C. lunata* is well known for its efficient 11a-hydroxylation of steroids (Holland and Reimland, 1985; Chen and Wey, 1990) and also has been used to transform a number of terpenes (Azerad, 2000). *B. bassiana*, the fungus which is responsible for the muscardine disease in insects, was also known to affect the bioconversion of many substrates including alkaloids, steroids and terpenes. This strain, formerly known as *B*. *sulfurescens* or *Sporotrichum sulfurescens* has been used to effect the reduction of various carbonyl compounds (Davies *et al.,* 1989).

B. bassiana is also known to selectively hydroxylate non-activated carbon atoms (Lamare *et al.,* 1991; Holland, 1992). Incubation of cadina-4,10(15)-dien-3-one with *B. bassiana* results in the production of nine novel sesquiterpenes which are effective against *C. formicarius elegantulus* (Buchanan *et al.,* 2000). Labo-Lima (1990) conducted bioassays to evaluate the pathogenicity of the fungal pathogens *M. anisopliae* and *Beauveria bassiana* against *C. puncticollis.* Mortality rates obtained were encouraging for further research on the control of *C. puncticollis* with these fungi.

2.3.3 Chemical Control

Sweet potato weevil is a difficult target for conventional pest control measures as the larvae feed in the storage roots in the found, or inside the woody base of the stems. This means that with the possible 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, nor of the other stages found within the plant tissue (Allard *et al.,* 1991). In Ethiopia, insecticidal screening trials tested the use of foliar sprays applied three months after planting, followed by four applications at fortnightly intervals, and also root dipping prior to planting. Deltamethrin and pirimiphos methy1 gave good control of sweet potato pests (Allard, 1990). Recommendations for the use of 19 insecticides for the control of sweet potato weevils are provided by Kasasian (1978).

Several insecticides were tested for the management of sweet potato weevil by using them after planting, either by foliar spray or basal granular applications (Rajamma and Pillai, 1991). Some of the insecticides are also used for vine dipping for successful control of sweet potato weevil. Fenvalerate, permethrin and deltamethrin each 0.003% are the most effective insecticides to *C. formicarius* (Rajamma, 1990). Rajamma and Pillai (1991) showed that 0.05% fenthion or endosulfan spray at monthly intervals with or without running or soil application of carbofuran or phorate granules each 1 kg a.i. ha^{-1} 45 days after planting days after planting are all effective in reducing infestation by *C. formicarius* resulting in greater marketable tuber yields.

Teli and Salunkhe (1994) tried dipping cuttings in insecticide solution before planting and spraying the crop one month after planting, and further three times, at three week intervals, subsequently with cypermethrin or fenvalerate each 375 g a.i. ha^{-1}, was most effective in reducing damage caused by the insect. Similar works on the use of several other insecticides to achieve better control of sweet potato weevil are available (Mason *et al.,* 1991; Sinha, 1994).

Soil drenching at 50 and 80; 60 and 90; and 50, 65 and 80 days after planting were equally effective in suppressing the incidence and intensity of weevil damage (Palaniswami and Mohandas, 1996). Among the single soil drenching, application on the 65th day was assessed to be the most effective against the weevil. Misra *et al*. (2001) reported that combination of vine dipping of 0.05% monocrotophos and three foliar sprays with 0.05% endosulfan proved very effective than that of basal application of phorate granules followed by vine dipping of 0.05% monocrotophos. Palaniswami *et al*. (2002) reported that endosulfan, fenthion and fenitrothion each at

0.05% applied as soil drench at 50 and 80 days after planting were effective against. *formicarius* and their residues in tubers at harvest were lower than the detectable levels. Chlorpyrifos and fensulfothion granules are more toxic to sweet potato weevil adults than the other insecticides, while their persistence was about 10 months (Hwang and Hung, 1991).

2.3.4 Host Plant resistance

Plant resistance provides a pivotal role in the management of insect pests (Rajasekhara Rao, 2002, 2005). The physical attributes of the tuber namely, the shape, length, neck length, colour of the skin, flesh colour and thickness plays in important role in preference by *C. formicarius* apart from the inherent nutritional quality of the sweet potato plant and tuber. Round tubers are preferred by more than elongate and spindle-shaped ones. Teli and Salunkhe (1996) reported that round and oval tubers of sweet potato were more infested in the field by *C. formicarius* than long stalked, spindle and elongate ones. Pink and red coloured tubers are considered less susceptible than white and brown coloured ones. Cultivars with thin foliage and lobed leaves with purple coloration at emergence were found less susceptible.

Search for plant resistance in sweet potato to environmental stress is underway in many parts of the world to fulfil the requirements of farmers situated in arid and semi arid tropics (Stathers *et al.,* 2003). Only a limited success has been achieved, because of the inconsistent expression of the resistance (Rajasekhara Rao, 2002). Drought stress may increase the activity of oviposition stimulant present in the genotypes because weevils deposited more eggs on drought-stressed plants (Mao *et al.,* 2004). Some of the plant metabolites are produced and influenced by environment, which would have a bearing on resistance or tolerance. Recent analyses showed that the levels of resin glycosides and caffeic acid vary between sweet potato genotypes and within genotypes among years or areas of production (Harrison *et al.,* 2003) and have shown insecticidal activities (Jackson and Peterson, 2000). This may indicate a relationship between the quantity of these two compounds and the antibiosis of sweet potato.

Host plant nutritional parameters are also believed to affect incidence of sweet potato weevil. The relationship between potash and silica in sweet potato stems is negatively correlated with *C. formicarius* infestation (Singh *et al.,* 1993). Nitrogen and potassium influence the storage root-surface chemistry of sweet potato genotypes which have a bearing on resistance to sweet potato weevil (Marti *et al.,* 1993).

Selection of sweet potato genotypes with decreased volatile attractants (kairomones) and/or increased deterrents may significantly facilitate developing resistance to sweet potato weevil. Plant resistance can also be induced through alterations in nutritional regimes of the crop (Rajasekhara Rao, 2002). A triterpenol acetate was identified in the root surface on a sweet potato weevil susceptible genotype ‘Centennial’, but not in more resistant genotype (Nottingham *et al.,* 1989). Wilson *et al.* (1988) demonstrated that a methylene chloride surface extract of the periderm of tubers of the susceptible ‘Centennial’ stimulated oviposition of *C. formicarius elegantulus*.

Nottingham *et al.,* (1987) also showed that ovipositional stimulant resided in the tuber periderm, not in the core of the tuber.

Considerable research has been done on breeding and evaluating sweet potato germplams for resistance. The development of insect- resistance is seen as a viable component of integrated pest management programes. Mechanisms of resistance to sweet potato weevil in sweet potato include antibiosis, antixenosis (non – preference) and escape (for example, long and thin storage roots set deep in he soil and scattered within growing hills). Resistance characters identified as under polygenic inheritance include fleshy root density, dry matter and starch content, root depth, vine thickness and tuber chemistry (Allard *et al.,* 1991).

Anota and Odebiyi (1984) found no evidence that nitrogen, starch, dry matter, or moisture content played a role in tuber resistance of five resistant sweet potato cultivars tested in Nigeria, but carotene content was identified as a major factor. No oviposition preference for tubers or vines was apparent. There was a lower survival rate in all life stages, smaller body weights and a longer developmental period of *C. puncticollis* raised on resistant cultivars.

Two orange fleshed and 18 white fleshed cultivars evaluated in he field for resistance to *C. puncticollis.* Cultivars (TIS 3053 and TIS 3030) exhibited the least root damage, whereas Cultivars (TIS 2532, TIS 3017 and TIS 3030) showed the least shoot damage (all white – fleshed) (Hahn and Leuschner, 1981). Cheng (1981) identified 14 sweet potato lines resistance to *C. puncticollis*, but their yields were lower than those of the majority of susceptible lines (Cheng, 1981). Screening of 700 cultivars of sweet potato in Nigeria revealed low resistance levels to *C. puncticollis* (Hahn and Leuschner, 1981).

Shakoor *et al.* (1984) identified seven resistant sweet potato lines, including KSP 20, KSP1K, SP 19 and KSP 20 following screening of 93 accessions of diverse origin. In trials conducted in the Philippines by Petro *et al*. (1986), local cultivars Karingkit and Kadulaw gave the highest yields, whereas the improved cultivars tested exhibited undesirable agronomic characteristic and susceptibility to *C. puncticollis.*

2.3.5 Pheromonal control

Observations of behaviour in both the laboratory and the field indicate that there is probably a sex pheromone for *C. puncticollis*, as is the case for *C. formicarius*. In rearing rooms, gregarious clumping behaviour has been noted, as well as the obvious attraction of males towards the females (Downham *et al.,* 2001). In the field, males are predominantly found under the foliage, presumably seeking females. Simple laboratory tests have shown that males are attracted to females. The feasibility of using virgin, unmated females as baits for males in simple traps was investigated in Kenya (Allard, 1990).

Precise decision tool to assess the time of sweet potato weevil incidence on sweet potato, suggest the use of sex pheromones (boehmeryl acetate). Soon after the identification of female sex pheromone of *C. formicarius* by Heath *et al.* (1986), the course of weevil management in different parts of sweet potato growing countries around the world changed dramatically. The success of sweet potato weevil control in these countries is unequivocally assigned to the sex pheromone. The sex pheromone, alone contributed to significant reductions in weevil populations and tuber damage, which resulted in greater marketable tuber yield.

The sex pheromone (Z)-3-dodecen-1-ol (E)-2-butenoate, proved to be a successful mating disruptant for the control of C. *formicarius* (Mason and Jansson, 1991; Yasuda, 1995; Yasuda *et al.,* 1992). It is also used to trap both sexes of sweet potato weevil. With 100 mg of sex pheromone, the attraction was 60.88%. Entrapment of weevils differs significantly during different parts of the day (Yasuda *et al.,* 1992). Pheromone traps installed close to the ground trapped more males than those set above the ground (Yasuda *et al.,* 1992). Most of the males approached the traps by walking. Different types of traps used for monitoring and mass trapping. When the sex pheromone discovered and synthesized, various designs and types of traps used for the weevil management viz. Light, sticky, water, plastic funnel live trap etc. Talekar and Lee (1989) reported that female sex pheromone identified in *C. formicarius elegantulus* was also active in *C. formicarius*.

Sweet potato weevil sex pheromone traps each 30 hectares with a distance of 15 m between traps reduced the tuber damage by 10.1% and controlled the sweet potato weevil up to 53.1-58.2% in China (Li, 1998). Pillai *et al.* (1996) reported that trap containing synthetic sex pheromone (100 traps per hectare) is highly effective for mass trapping the male sweet potato weevil which significantly reduced population build-up, consequently resulted in greater marketable tuber yield. Pheromone traps each 40 per hectare reduced sweet potato tuber damage by 65% by sweet potato weevil and use of chlorpyrifos each two kilogrammes active ingredient per hectare in addition to the pheromone reduced the damage by an extra 10% over the pheromone treatment (Hwang and Hung, 1991).

Integration of sex pheromone traps with insecticides or entomopathogenic fungi are practiced successfully. Yasuda *et al.* (2004) developed a new pheromone formulation to increase exposure time to insecticide for control of the sweet potato weevil. The formulation was a combination of sex pheromone, butenoate, and an insecticide impregnated into blue ball made of the diatomaceous soil. The male weevils were attracted to the visual stimulation in addition to the sex pheromone (Smit *et al.,* 2001). The attracted males located and tried to mate with the ball. They were thereby efficiently exposed to the insecticide for a longer time. The concentration of the new formulation was extremely low compared to the conventional formulations, and therefore, lowers the cost of application (Yasuda *et al.,* 2004).

2.4 Constraints to Sweet Potato Weevil Management

Chemical control is not effective because the weevils are protected for, at least part of their life cycle by their development within roots or stems, where they are not easily reached by pesticides (Mason *et al.,* 1991). Pesticides kill natural enemies that under natural circumstances quite effectively control weevil populations, and can also present health, risks for human and animals (Stathers *et al.,* 2005). In some countries planting materials are dipped into on synthetic pesticide before planting, which can delay pest infestation for several months, however, most pesticides are expensive and highly toxic therefore dipping is only likely to be economical for large scale commercial root production or vine multiplication nurseries (Stathers *et al.,* 2005). Breeders have spent many years trying to develop varieties that are resistant to the weevil. So far they have not been successful (Stevenson *et al.,* 2009). However, varieties that form root relatively deep in the soil are less attacked because the weevils cannot easily reach the roots to lay eggs (Kays *et al.,* 1993) Other varieties escape weevil damage because their storage roots mature quickly and can be harvested early (Stathers *et al.,* 2005).

The larvae feed on storage root in the ground or inside the woody base of the stems. This means with the possible exception of systemic insecticides, which are costly and pose risk of residual contamination of the roots there is no effective chemical control of all stages of the pest found within the plant tissues (Kabi *et al.,* 2001). This subterranean habitat also makes the insect less accessible to predator and parasitoids but increases the impact of pathogens and nematodes, natural enemies which requires a protected, cool and humid environment for survival and reproduction (Stathers *et al.,* 2005).

CHAPTER THREE

3.0 MATERIAL AND METHODS

3.1 Location and Duration

The studies on effectiveness of cultural practices and sweet potato varieties in managing sweet potato weevil (*Cylas* spp) were conducted at two locations: Kizimbani Agricultural Research Station (05 54'S,039 E; 20 m a.s.l) and Bambi Agricultural Research Station (06° 09'S, 039°16' E; 20m a.s.l) in Zanzibar (Fig. 1), during the April – July growing season in 2012. Kizimbani is located in agro-ecological zone two, which has deep clay soil and high rainfall. Bambi is located in agro- ecological zone five (Table 1) which is dominated by shallow clay soil and moderate rainfall (MANRZ, 2004).

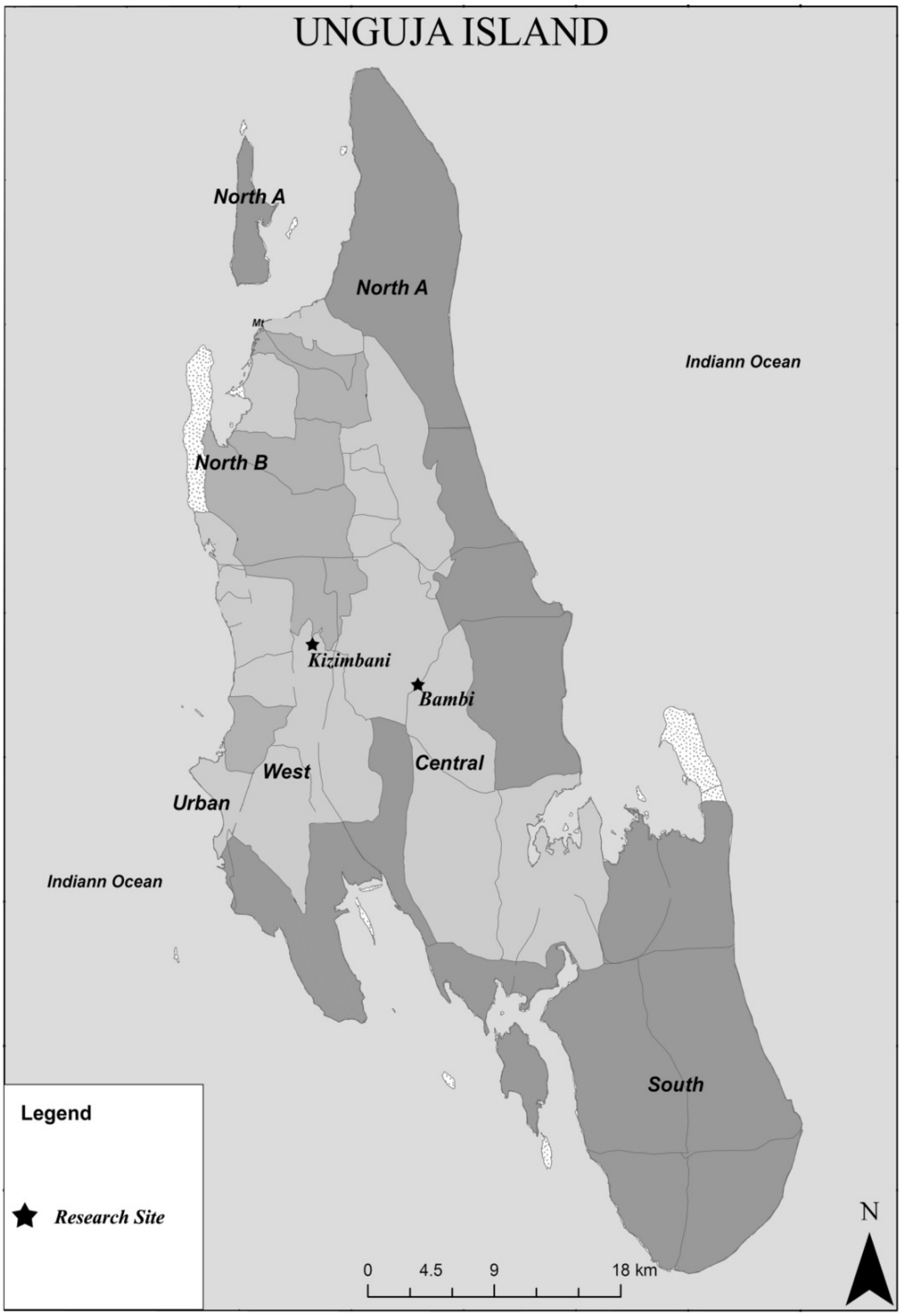

Figure 1: Location of Kizimbani and Bambi in Unguja Island.

Table 1: Description of Unguja Agro-ecological zones

Zone	Characteristics
Zone one-Peri – Urban	The zones covers all urban and adjacent area of Zanzibar town. It is characterized by having intensive livestock and vegetable production. For example Fuoni, Bububu, Zanzibar municipal etc.
Zone two – Central – North	About 80% of the soil is deep clay soil suitable for plantation crops and food crops. For example Kizimbani, Dole, Machui etc.
Zone three- Mangapwani	Sandy soil dominated by cassava and coconut intercroppping systems. For example Selem, Mfenesini and Mangapwani.
Zone four – Coral Rag	The zones covers most of the southern, northen and eastern coast. The area is constrained by decreasing fallow periods and declining soil fertility. Short rains are unreliable. For example Kajengwa, Mtende, Nungwi, Uroa etc.
Zone 5- Central South	This area is dominated by shallow clay soils. suitable for food and cash crops examples, Bambi, Cheju, Ndijani and Dunga.

Source: MANR, Zanzibar (2004).

3.2 Weather and Soil Patterns

Both locations receive bimodal rainfall (Appendix 1). Therefore the wet season is divided into short rainy season (October - December) and long rainy season (March - May). The short rains are usually erratic; the remaining months fall under dry season. (January - February and June - September). The long rainy season (Fig. 2) is for sweet potato growing.

Kizimbani is characterized by having deep clay soil. This has the tendency of expanding during dry season, which resulting into the formation of cracks. Soil cracking exposes the upper parts of storage roots to damage by sweet potato weevils as reported by Hahn and Leuschner (1981). Bambi is dominated by shallow clay soil. The shallowness of this soil exposes the upper parts of storage roots to damage by sweet potato weevils.

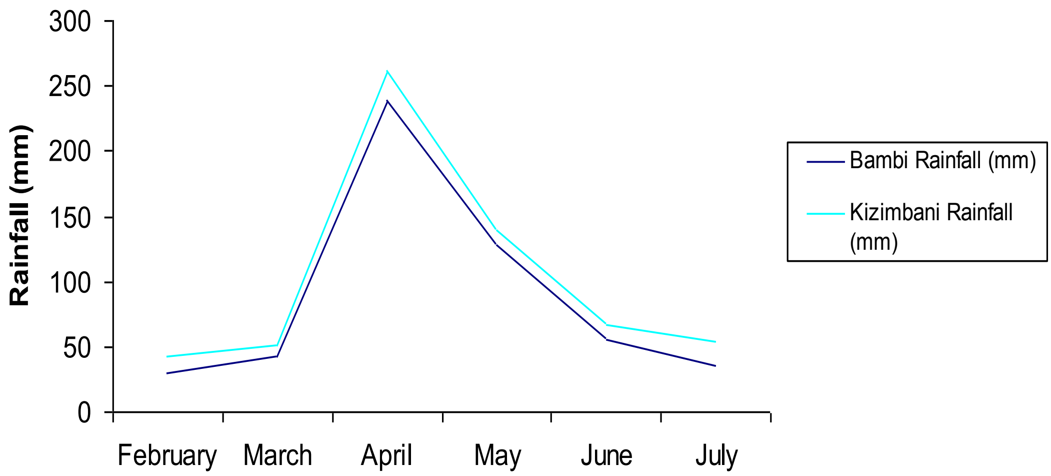

Figure 2: Rainfall distribution during the growing period in both locations

3.3 Experimental Design and Treatments

3.3.1 Experiments one

3.3.1.1 Establishment of incidences of sweet potato weevil in selected sweet potato varieties

Three sweet potato varieties (Table 2) namely: Mayai, Shangazi and Mbirimbi were grown at Bambi and Kizimbani research stations between April and July 2012. Mayai was used as a control since is orange fleshed and susceptible to sweet potato weevils (Pinese, 2001).

Table 2: Description of sweet potato varieties

Variety	Characteristics
Mayai	High yielding local variety, medium maturing (three to four months), orange fleshed, moderate dry matter, narrow leaves, thin wood stem, medium white-skinned storage roots, short necked, very susceptible to sweet potato weevils (Fig. 3).
Shangazi	It is a moderate yielding local variety, early maturing (three to months), white fleshed, high dry matter, broad leaves, thick woody stem, small red-skinned storage roots, short necked and speculated by farmers to have low susceptibility to sweet potato weevils (Fig. 4).
Mbirimbi	A high yielding local variety, medium maturity (three to four months), white fleshed, high dry matter, broad leaves, thick woody stem, large brown-skinned storage roots, long necked and speculated by farmers to have low susceptibility to sweet potato weevils (Fig. 5).

Source: (ZARI, 2011)

Figure 3: Mayai variety (Orange fleshed)

Figure 4: Shangazi variety (White fleshed)

Figure 5: Mbirimbi variety (White fleshed)

A randomized complete block design in a split split plot arrangement with three replications was used. The main plot factor was variety, the subplot factor was three vine portions (Apical, middle and basal portions) and the sub sub-plot factor was cultural practices (which were weeding and hilling up once, weeding and hilling up twice and weeding and hilling up thrice).

The vines were planted at a spacing of 0.3 m apart on a ridge of six metre long and one metre apart between ridges. The gross plot size was 30 m^2. The cultural practices were implemented simultaneously. The first weeding and hilling up the soil was done at fourth week, the second was done at eigth week and the third was done at twelveth week after planting.

Data of infestation in the vines and crowns were counted at fourth week, eigth week and twelveth week after planting. The sweet potato were harvested once they reached three to four months (Fig. 6). Data of effect on sweet potato weevils infestation were collected at a time of weeding and hilling up where two middle ridges one metre square for each treatment were randomly uprooted for sampling. During sampling, five vines, crowns and storage roots were selected were sliced longitudinally and weevils life stages (larva, pupa and adult) were removed and counted. Data on number of tubers and crowns, with adult weevil were recorded.

The incidences of sweet potato weevil were obtained by counting number of crowns and tubers with sweet potato weevil per meter square. The sources of variation were sweet potato varieties, vine portions and cultural practices.

Figure 6: Harvesting of sweetpotatoes

3.3.2 Experiment two

3.3.2.1 Determination of severity of sweet potato weevil in selected sweet potato varieties

Experimental layout and treatment allocation were as in section 3.2.1. Sweet potato weevils severity class was recorded by externally and internally visual observation of severity level of randomly uprooted five crowns from one metre square area in the middle ridges. Data collection started at fourth week, eighth week and twelveth week after planting and continue up to harvesting (i.e. three to four months). Severity of sweetpotato weevils in each treatment were determined following the scale of 1 to 5 (Rangi *et al.,* 1990) where as:

Class 1: indicate no damage

Class 2: 1- 20% damage to crown

Class 3: 26 – 50% damage to crown

Class 4: 51 – 75 damage to crown

Class 5: 76- 100% of the crown damaged

3.3.3 Experiment three

3.3.3.1 Determination of effect of cultural practices on sweet potato weevil in selected sweet potato varieties

Experimental layout and treatment allocation were as in section 3.2.1. Data were collected during harvesting, whereby Mbirimbi harvested four months, Mayai and Shangazi were harvested three months after planting. Data of effect of cultural practices on sweet potato weevils infestation were collected in the two middle ridges one metre square for each treatment were randomly uprooted for sampling. During sampling, five vines, crowns and storage roots were selected, sliced longitudinally and weevils life stages (larva, pupa and adult) were removed and counted. Data on number of storage roots with adult weevil were recorded.

3.4 Data Analysis

The collected data on weevils incidence and severity were analysed by GEN-STAT statistical package according to (Payne, 2011). Tukey's test was used for mean separation and analysis of variance (ANOVA) at $p \leq 0,05$.

Statistical model: for split -split plot design using the model below.

$$Yijk = \mu + R_i + Vj + (Ea)_{ij} + (F)k + (VF)_{jk} + (Eb)_{ik} + (W)_l + (VW)_{jl} + (FW)_{kl} + (VFW)_{jkl} + (Ec)_{ijkl} \quad \text{......} 1$$

Where; Y_{ijkl} = Response,

μ = General mean,

R_i = Replication effect (ith)

$(V)_j$ = jth effect of sweet potato varieties,

$(Ea)_{ij}$ = Main plot error (error a),

$(F)_k$ = ith effect of sweet potato vine portions,

(VF)jk = Interaction of sweet potato varieties and sweet potato vine portions,

$(Eb)_{ik}$ = sub-plot error (error b)

(W)l = Cultural practices effect,

$(VW)_{jl}$ = interaction of sweet potato varieties and cultural practices

$(FW)_{kl}$ = Interaction of sweet potato vine portions and cultural practices,

$(VFW)_{jkl}$ = Interaction of sweet potato varieties, sweet potato vine portions and cultural practices.

$Ec)_{ijkl}$ = Experimental error (error c).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Incidences of Sweet potato Weevil in Selected Sweet Potato Varieties

Results show significant differences on incidence of sweet potato weevils among sweet potato varieties ($F = 37.01$; $df = 2$; $p = 0.003$), sweet potato vine ($F = 392.04$; $df = 2$; $p < 0.01$) and cultural practices ($F = 23.89$; $df = 2$; $p<0.01$) at Bambi (Appendix 3). Similarly the incidence of the pests were significant among sweet potato varieties ($F = 141.09$; $df = 2$; $p < 0.001$), sweet potato vine ($F = 182.92$; $df = 2$; $p < 0.001$) and cultural practices ($F = 49.55$; $df = 2$; $p< 0.001$) at Kizimbani location. (Appendix 6). There was a significant ($p = < 0.05$) interaction between variety and vine portion in both location where Mbirimbi had low weevils incidence on all vine portion. Mayai had higher weevils incidence on all vine portions.

The highest incidence of sweet potato weevil at Bambi were observed in Mayai variety using basal vine portion (Fig. 7) under weeding and hilling up once while the lowest were recorded in Mbirimbi using apical vine portion under weeding and hilling up thrice (Table 3). At Kizimbani site the highest incidence of sweet potato weevil was observed in Mayai variety using basal vine portion under weeding and hilling up once while the lowest were recorded in Mbirimbi using apical vine portion under weeding and hilling up thrice (Table 4).

Table 3: Incidence (weevil/m^2) of sweet potato weevil in selected sweet potato varietes at Bambi

Variety	Vine portion	Cultural practice	Mean	S.E.
Shangazi	Apical	1	8.198	1.531
		2	5.531	0.691
		3	2.864	0.840
	Middle	1	5.160	0.284
		2	3.160	0.173
		3	2.827	0.457
	Basal	1	4.309	1.247
		2	3.309	0.864
		3	2.642	0.383
Mayai	Apical	1	13.309	2.691
		2	8.642	0.642
		3	6.309	2.049
	Middle	1	15.049	0.272
		2	5.716	0.605
		3	2.049	0.877
	Basal	1	17.309	2.420
		2	9.160	1.247
		3	2.975	1.173
Mbirimbi	Apical	1	2.827	1.160
		2	6.494	0.049
		3	1.642	1.210
	Middle	1	6.790	0.012
		2	3.123	0.432
		3	3.123	0.420
	Basal	1	5.716	1.173
		2	3.049	0.383
		3	3.383	0.790

LSD =0.397, CV=16.8

1= Weeding and hilling up once, 2=Weeding and hilling up twice, 3= Weeding and hilling up thrice

Table 4: Incidence (weevil/m^2) of sweet potato weevil in selected sweet potato varieties at Kizimbani

Variety	Vine portion	Cultural practice	Mean	S.E.
Shangazi	**Apical**	1	2.333	0.630
		2	1.333	0.667
		3	2.667	0.037
	Middle	1	3.259	0.778
		2	1.926	0.630
		3	2.593	0.148
	Basal	1	6.407	1.407
		2	5.407	1.296
		3	3.407	0.111
Mayai	Apical	1	5.185	1.741
		2	3.185	0.519
		3	4.185	1.222
	Middle	1	6.000	1.704
		2	4.333	1.111
		3	3.667	0.593
	Basal	1	16.481	3.444
		2	3.148	1.630
		3	1.815	1.815
Mbirimbi	Apical	1	1.815	1.111
		2	0.815	0.148
		3	0.741	1.259
	Middle	1	2.407	0.926
		2	1.481	0.481
		3	2.407	0.444
	Basal	1	4.778	2.037
		2	3.111	0.333
		3	5.111	1.704

LSD =0.242, CV =9.9

1= Weeding and hilling up once, 2=Weeding and hilling up twice, 3= Weeding and hilling up thrice.

Figure 7: Infested basal vine portion

The highest mean of sweet potato weevil incidence was observed in Mayai variety at Bambi. Lowest weevil incidence was recorded in Mbirimbi variety. Mbirimbi variety has long neck between the roots and the stem which make difficult for adult weevil to burrow downwards more than one centimeter. Sweet potato varieties with long neck between the roots and the stems are less susceptible to weevil (Allard *et al*., 1991). Mayai variety has short neck with orange fleshed colour. According to Pinese (2001) concluding that flesh colour is the most reliable indicator for determining sweet potato weevil resistance. Orange fleshed variety (Mayai) is generally more susceptible to sweet potato weevils than white fleshed varieties.

Studies indicate that there is a consistence difference in susceptibility to *Cylas* among different varieties (Odongo *et al.,* 2003). This is attributed to Mayai variety having thin woody stems that could easily be infested (Nair, 2006). The type of planting material had an effect on number of tubers infested by sweet potato weevils in both locations. Basal vine is woody and could easily be attacked while middle and apical vines have young vegetative parts that produce more latex thus reduced weevils damage (Belehu, 1991).

The incidence of sweet potato weevil in selected sweet potato varieties using different cultural practices show that the highest incidence was observed under weeding and hilling-up once. According to Stathers *et al*. (2005) hilling-up of soil around the base of plant prevent or fill soil cracks hence protect the plant from weevil attack. The result of planting materials show that the basal portions are more susceptible to sweet potato weevils followed by the middle and apical portion. The incidences of apical vine portion was low followed by middle and basal portions for Kizimbani. At Bambi, the lowest incidence recorded in apical vine portion was followed by middle and basal portion. The result conforms to the findings obtained by Belehu (1991) who pointed out that, apical vine portion is normally free from sweet potato weevils and recomended to be the best planting material.

High levels of weevil incidence generally correspond with lower rainfall levels. Weevils fail to penetrate wet soils but can penetrate dry soils (Otto *et al.,* 2006). The highest mean score of sweet potato weevil incidence at Bambi was greater than that of Kizimbani because of differences in amount of rainfall. Bambi received lower rainfall than Kizimbani during the study period (Appendix 1) which favours weevil infestation. According Hahn and Leuschner (1982) weevil populations increase more easily and rapidly on a dry compared to wet season.

4.2 Severity of Sweet Potato Weevil in Selected Sweet Potato Sweet Potato Varieties

Results show highly significant differences on severity of sweet potato weevils among sweetpotato varieties ($F = 6.34$; $df = 2$; $p = 0.058$), sweet potato vine ($F = 36.50$; $df = 2$; $p < 0.01$) and cultural practices ($F = 2.09$; $df = 2$; $p = 0.03$) at Bambi (Appendix 2). There was also significantly ($p = < 0.05$) interaction effect between vine portion and cultural practices on severity of damage in both location, where all vine portion had low damage at twelveth week after planting than high damage at eighth week after planting and finally higher severity at fourth week after planting. At Kizimbani, the highest severity of sweet potato weevil were observed in Mayai variety using basal vine portion under weeding and hilling-up once, while the lowest were recorded in Mbirimbi using apical vine portion under weeding and hilling-up thrice (Table 5).

Table 5: Severity (weevil/m^2) of sweet potato weevil in selected sweet potato varieties at Kizimbani

Variety	Vine portion	Cultural practice	Mean	S.E.
Shangazi	Apical	1	1.951	0.086
		2	1.951	0.012
		3	1.951	0.099
	Middle	1	1.840	0.136
		2	1.840	0.012
		3	1.840	0.123
	Basal	1	2.210	0.049
		2	2.210	0.025
		3	2.210	0.025
Mayai	Apical	1	3.099	0.062
		2	2.099	0.025
		3	2.432	0.086
	Middle	1	2.654	0.049
		2	2.321	0.025
		3	2.321	0.025
	Basal	1	3.580	0.012
		2	2.580	0.049
		3	2.247	0.062
Mbirimbi	Apical	1	1.951	0.025
		2	1.951	0.012
		3	1.951	0.012
	Middle	1	1.840	0.086
		2	1.840	0.012
		3	1.840	0.099
	Basal	1	2.210	0.062
		2	2.210	0.025
		3	2.210	0.086

LSD = 0.115, CV =16.8

1= Weeding and hilling up once, 2=Weeding and hilling up twice, 3= Weeding and hilling up thrice.

The highest mean severity of sweet potato weevil at Bambi was greater than of Kizimbani. At Kizimbani the severity of the pests were also significant among sweet potato varieties ($F = 36.57$; $df = 2$; $p = 0.003$), sweet potato vine ($F = 14.52$; $df = 2$; $p < 0.001$) and cultural practices ($F = 4.15$; $df = 2$; $p < 0.001$), (Appendix 3). The highest severity of sweet potato weevil at Bambi were observed in Mayai variety using basal vine portion under weeding and hilling-up once, while the lowest were recorded in Mbirimbi using apical vine portion under weeding and hilling-up thrice (Table 6). The highest mean severity score of sweet potato weevil was observed in Mayai variety at Bambi. Lowest weevil severity score was observed in Mbirimbi variety.

The severity of sweet potato weevil in selected sweet potato variety using different cultural practices show that the highest severity score was observed under weeding and hilling-up once. Therefore, these favour more weevil infestation. According to Stathers *et al*. (2003) hilling-up more soil around the base of plant reduce weevil infestation.

Table 6: Severity (weevil/m^2) of sweet potato weevil in selected sweet potato varieties at Bambi

Variety	Vine portion	Cultural practice	Mean	S.E.
Shangazi	Apical	1	2.605	0.012
		2	2.272	0.049
		3	1.938	0.062
	Middle	1	2.494	0.099
		2	2.160	0.062
		3	2.160	0.160
	Basal	1	2.568	0.086
		2	2.235	0.012
		3	1.901	0.099
Mayai	Apical	1	3.494	0.210
		2	2.494	0.049
		3	2.494	0.160
	Middle	1	2.457	0.346
		2	2.383	0.062
		3	2.049	0.284
	Basal	1	4.049	0.136
		2	3.457	0.012
		3	2.457	0.123
Mbirimbi	Apical	1	2.568	0.198
		2	1.901	0.099
		3	1.901	0.099
	Middle	1	2.123	0.247
		2	2.123	0.123
		3	2.123	0.123
	Basal	1	2.309	0.049
		2	1.975	0.025
		3	1.975	0.025

LSD = 0.134, CV = 8.5

1= Weeding and hilling up once, 2=Weeding and hilling up twice, 3= Weeding and hilling up thrice.

The result of planting material show that the basal portion are more succeptible to sweet potato weevil followed by middle and apical portion. Geisthardt and van Harten (1992) reported that middle and basal vine portions are more prone to weevils infestation since female sweet potato weevils prefer to lay eggs in small hollows which are eaten into those vine parts or in tubers.These findings are also similar to those obtained by Daiber (1994), who reported that lavae of sweet potato weevils are more injurious, boring into basal and middle vine portions causing serious mortality to seedlings. The severity of apical portion was low followed by middle and basal portion for Bambi. At Kizimbani the lowest severity recorded in middle vine portion followed by apical and basal portion. Severity of weevil damage among varieties differ in both locations. Mayai was more damaged than Mbirimbi and shangazi in both locations (Table 5 and 6). This was because the variety was shallow rooted, thin stemmed and orange fleshed thus easily infested with weevils (Nair, 2006).

4.3 Effect of Cultural Practices on Sweet Potato Weevil in Selected Sweetpotato Varieties

Results show highly significance differences on cultural practices of sweet potato weevil control among sweet potato varieties ($F=39.96$, $df=2$, $p=0.002$), sweet potato vine ($F=188.38$, $df=2$, $p<0.01$) and cultural practices ($F=7.21$, $df=2$, $p<0.01$) at Bambi (appendix 4). For Kizimbani the effect of cultural practice were also significant of sweet potato varieties ($F=46.42$, $df=2$, $p=0.002$), sweet potato vine ($F=47.555$, $df=2$, $p<0.001$) and cultural practices ($F=2.93$, $df=2$, $p=0.003$) (Appendix 7). The highest damage caused by sweet potato weevil at Bambi were observed in Mayai variety using basal vine portion under weeding and hilling up once. While the lowest were recorded in Mbirimbi using apical vine portion under weeding and hilling-up thrice (Table 7). For Kizimbani the highest damage of sweet potato weevils were also observed in Mayai using basal vine portion under weeding and hilling-up once. While the lowest damage were recorded in Mbirimbi variety using apical vine portion under weeding and hilling-up thrice (Table 8).

Table 7: Effect of cultural practices on sweet potato weevils in selected sweetpotato varieties at Bambi

Variety	Vine portion	Cultural practice	Mean	S.E.
Shangazi	Apical	1	12.42	1.05
		2	10.09	1.06
		3	5.75	0.01
	Middle	1	8.98	0.17
		2	6.31	0.16
		3	5.64	0.01
	Basal	1	7.94	0.88
		2	6.94	0.90
		3	5.94	0.02
Mayai	Apical	1	18.98	1.95
		2	15.64	1.27
		3	7.64	0.68
	Middle	1	18.64	0.06
		2	9.98	0.60
		3	6.31	0.54
	Basal	1	20.38	2.01
		2	7.38	1.88
		3	5.72	0.14
Mbirimbi	Apical	1	14.94	0.90
		2	12.27	0.21
		3	4.60	0.69
	Middle	1	12.05	0.23
		2	6.72	0.77
		3	7.05	0.53
	Basal	1	10.35	1.14
		2	8.35	0.98
		3	5.68	0.16

LSD = 0.95, CV =6.5

1= Weeding and hilling up once, 2=Weeding and hilling up twice, 3= Weeding and hilling up thrice.

Table 8: Effect of cultural practices on sweet potato weevils in selected sweetpotato varieties at Kizimbani

Variety	Vine portion	Cultural practice	Mean	S.E.
Shangazi	Apical	1	7.02	0.09
		2	4.36	0.27
		3	5.69	0.36
	Middle	1	8.10	0.77
		2	6.10	0.25
		3	4.10	1.01
	Basal	1	10.21	0.68
		2	7.88	0.02
		3	6.21	0.65
Mayai	Apical	1	12.91	0.20
		2	8.25	0.05
		3	6.25	0.25
	Middle	1	11.99	1.35
		2	9.32	0.20
		3	7.32	1.54
	Basal	1	18.43	1.54
		2	11.77	0.25
		3	4.43	1.79
Mbirimbi	Apical	1	6.06	0.28
		2	4.06	0.32
		3	4.06	0.60
	Middle	1	6.58	0.58
		2	4.91	0.05
		3	3.91	0.53
	Basal	1	8.69	0.86
		2	6.69	0.27
		3	6.02	1.14

LSD = 0.768, CV = 8.4
1= Weeding and hilling up once, 2=Weeding and hilling up twice, 3= Weeding and hilling up thrice.

The results of this study reveal that location, variety, cultural practices and vine portion are significantly influence sweet potato weevil damage at Kizimbani and Bambi. The infestation was significantly higher on weeding and hilling-up once; and improper selection of planting material (vine portion). This is in support to the finding of Odongo *et al.* (2003), that appropriate and timely hilling up reduces weevil infestation. The infestation was reduced in plots that were weeded and hilled-up thrice. Therefore hilling up can be seen as a control method with direct effect. Soil cracks are filled and exposed tubers are covered, blocking the way for weevils. In both locations, infestation was significantly higher in Bambi than Kizimbani. This may be as a result of interplay of climate and edaphic factors as noted by Ehisianya *et al.* (2011). Kizimbani had more rainfall compared to Bambi (Appendix 1) which might favour low level of infestation.

However, the varieties are well suited for both location (Saleh and Mohammed, 2001). Varieties Mbirimbi and Shangazi were less susceptible to sweet potato weevils in both locations. Mbirimbi and Shangazi are white fleshed while Mayai is an orange fleshed variety. Pinese (2001) confirms that varieties with orange fleshed are the most susceptible to weevil infestation.

Mbirimbi had the least infestation and was the most resistant to the weevil infestation in both locations. Level of infestation and severity score were significantly lower at Kizimbani compared to Bambi. This may be due to the availability of rainfall which increase in developmental period and reduced rate of fecundity attributable to higher moisture. Dryness of soil and bulking of roots causes cracking of soil which exposes the roots and allows weevil asses to the roots for oviposition (Ehisianya *et al.,* 2011).

The result obtained from vine portion show that, the infestation on apical portion is low in all three varieties. Moreover, high infestation observed in basal portion followed by middle portion. These finding revealed that, the basal portion normally habour pest while the apical portion are free from sweet potato weevil. According to Nair (2006) there is a great chance of weevil incidence in basal portion due to proximity with the crown portion where sweet potato weevil multiplies.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Result from the experiment revealed that Mayai; the orange- fleshed variety is more susceptible to sweet potato weevil as compared to Mbirimbi and Shangazi; white – fleshed and deep rooted varieties. The apical portion of the vine is better than the middle or basal portions. This portion is less likely to carry sweetpotato weevils and has been found to establish faster than other portions. Basal vine portion is more susceptible to weevil infestation as compared to apical and middle vine portions.

On cultural practices, appropriate thrice hilling up and effective thrice weeding regimes reduce weevil infestation. It appears that infestation by sweet potato weevil can be minimized through adoption of agronomic practices. These are appropriate hilling-up and weeding regimes. The usefulnes of any agronomic practice depend upon its effective in preventing the continous multiplication of weevil population and preventing the accessibility of the developing tuber to the weevil.

5.2 Recommendations

a. As per results of this study, white fleshed varieties (Mbirimbi and Shangazi) are good for Kizimbani and Bambi because they are tolerant to sweet potato weevil.

b. In the area where the infestation of sweet potato weevil is high, the best planting material are apical vine. The middle vines portion could just as well be used as planting materials, when the apical portions are in short supply. This should be carried out with great care since improper selection of middle vine portion may influence to use weevil infested planting materials.

c. In order to control infestation, keeping moisture content is recommended and therefore the crop should be planted during rain or irrigation should be applied.

d. More detailed studies on the effects of temperature, moisture regimes and sweet potato varieties rooting depth on incidence and severity of sweet potato weevils are recommended.

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APPENDICES

Appendix 1: Climatic data during the study period of February - July 2012 at Bambi and Kizimbani

Months 2012	Bambi			Kizimbani		
	Rainfall (mm)	Temperature ^{0}C Min	Max	Rainfall (mm)	Temperature ^{0}C Min	Max
February	30	22.2	32.2	42.0	23.1	31.4
March	42.4	24.1	33.1	50.8	25.2	33.4
April	239.2	23.0	30	261.7	23.9	30.3
May	128.1	23.1	29.9	139.1	23.4	30.0
June	55.1	21	27.2	67.1	21.7	28.8
July	35.3	20.7	29.5	53.5	20.7	29.9
	T*530.1	A*24.01	A*30.32	T*614.2	A*24	A*30.63

T= Total, A= Average

Source: MANR (2012).

Appendix 2: ANOVA table, severity of sweet potato weevils in sweet potato varieties at Bambi

Source of variation	Df	s.s	m.s	v.r.	Fpr.
Rep	2	2.2469	1.1235	1.92	
Variety	2	7.4321	3.7160	6.34	0.058
Residual	4	2.3457	0.5864		
Rep	2	0.0247	0.0123		
Variety x vine portion x	20	1.6790	0.0840		
Cultural practices					
Residual	4	4.2963			
Vine portion	2	8.6173	4.3086	36.50	<0.01
Cultural practices	20	4.9383	0.2469	2.09	0.030
Residual	32	3.7778	0.1181		
Total	80	35.3580			

Appendix 3: ANOVA table, incidence of sweet potato weevil in seleted sweet potato varieties at Bambi

Source of variation	df	s.s	m.s	v.r.	Fpr.
Rep	2	17.3580	8.6790	2.73	
Variety	2	235.2840	117.6420	37.01	0.003
Residual	4	12.7160	3.1790		
Rep	2	70.5432	35.2716		
Variety x vine portion x	20	3.7531	0.1877		
Cultural practices					
Residual	4	15.0370			
Vine portion	2	593.5062	296.7531	392.04	<0.01
Cultural practices	20	361.6049	18.0802	23.89	<0.01
Residual	32	24.2222	0.7569		
Total	80	1334.0247			

Appendix 4: ANOVA table, cultural practice on sweet potato weevil in selected sweet potato varieties at Bambi

Source of variation	df	s.s	m.s	v.r.	Fpr.
Rep	2	22.840	11.420	3.01	
Variety	2	302.914	151.457	39.96	0.002
Residual	4	15.160	3.790		
Rep	2	132.914	66.457		
Variety x vine portion x	20	20.864	1.043		
Cultural practices					
Residual	4	62.000			
Vine portion	2	832.025	416.012	188.38	<0.01
Cultural practices	20	318.642	15.932	7.21	<0.01
Residual	32	70.667	2.208		
Total	80	1778.025			

Appendix 5: ANOVA table, severity of sweet potato weevil in sweet potato at Kizimbani

Source of variation	Df	s.s	m.s	v.r.	Fpr.
Rep	2	0.17284	0.08642	1.00	
Variety	2	6.32099	3.16049	36.57	0.003
Residual	4	0.34568	0.08642		
Rep	2	1.95062	0.97531		
Variety x vine portion x	20	3.90123	0.19506		
Cultural practices					
Residual	4	0.14815			
Vine portion	2	1.20988	0.60494	14.52	<0.001
Cultural practices	20	3.45679	0.17284	4.15	<0.001
Residual	32	1.33333	0.04167		
Total	80	18.83951			

Appendix 6: ANOVA table, incidence of sweet potato weevil in sweet potato at Kizimbani

Source of variation	Df	s.s	m.s	v.r.	Fpr.
Rep	2	20.9630	10.4815	25.73	
Variety	2	114.9630	57.4815	141.09	<0.001
Residual	4	1.6296	0.4074		
Rep	2	136.5185	68.2593		
Variety x vine portion x	20	111.8519	5.5926		
Cultural practices					
Residual	4	3.6296			
Rep	2	119.4074	59.7037	182.92	<0.001
Cultural practices	20	323.4815	16.1741	49.55	<0.001
Residual	32	10.4444	0.3264		
Total	80	842.8889			

Appendix 7: ANOVA table, cultural practice on sweet potato weevil in selected sweet potato varieties at Kizimbani

Source of variation	Df	s.s	m.s	v.r.	Fpr.
Rep	2	21.432	10.716	3.43	
Variety	2	289.951	144.975	46.42	0.002
Residual	4	12.494	3.123		
Rep	2	89.654	44.827		
Variety x vine portion x	20	69.160	3.458		
Cultural practices					
Residual	4	39.407			
Vine portion	2	301.136	150.568	47.55	<0.001
Cultural practices	20	185.531	9.277	2.93	0.003
Residual	32	101.333	3.167		
Total	80	1110.099			