KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF AGRICULTURE AND NATURAL RESOURCES

FACULTY OF AGRICULTURE

DEPARTMENT OF HORTICULTURE

LABORATORY STUDIES TO DEVELOP CASSAVA BAIT TO CONTROL INSECT INFESTATION OF COCOA BEANS USING COFFEE BEAN WEEVIL, *ARAECERUS FASCICULATUS* (DE GEER) (COLEOPTERA; ANTHRIBIDAE), AS MODEL SPECIES.

BY

AKPAH EDUKU

JUNE, 2014

LABORATORY STUDIES TO DEVELOP CASSAVA BAIT TO CONTROL INSECT INFESTATION OF COCOA BEANS USING COFFEE BEAN WEEVIL, *ARAECERUS FASCICULATUS* (DE GEER) (COLEOPTERA; ANTHRIBIDAE), AS MODEL SPECIES.

BY

AKPAH EDUKU

THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF PHILOSOPHY (M. PHIL.) POST-HARVEST TECHNOLOGY

JUNE, 2014

DECLARATION

I, Akpah Eduku, hereby declare that, except for specific references, which have been duly acknowledged, this project is the result of my own research and it has not been submitted either in part or in whole for any other degree elsewhere.

AKPAH EDUKU Student No. PG418610	……………………….. Signature	…………………… Date
Dr. B. K. MAALEKUU (Main Supervisor)	……………………….. Signature	…………………….. Date
Ms. P. D. KALEDZI (Co – Supervisor)	….…………………… Signature	…………………….. Date
Dr. BEN KWAKU BANFUL (Head of Department)	……………………….. Signature	…………………….. Date

DEDICATION

After rains comes sunshine,

After darkness comes the glorious dawn.

There is no joy without its admixture of misfortune,

There is no misfortune without its alloy of joy.

Behind the ugly terrible mask,

Lies the beautiful countenance of prosperity.

So, tear the mask.

Awolowo (Nigerian)

To God be the glory for the great things he has done. This work is dedicated to Him, The Almighty God, and then to my only daughter, Lucina Akpah.

ACKNOWLEDGEMENTS

My foremost thanks go to the Almighty God for giving me the dream, strength and wisdom to pursue this postgraduate course to its conclusive end, for in him there is light that shines to the success of men.

Secondly, I wish to extend my warmest thanks to my supervisors, Dr. B. K. Maalekuu (Main supervisor) and Ms. P. D. Kaledzi (Co- Supervisor) for their invaluable help, encouragement, guidance, useful criticisms and suggestions at various stages of this research. I am deeply grateful to them.

In addition, I owe much to Dr. E. A. Osekre, of the Entomology Department, who offered special and technical advice. All I can do is to thank him dearly.

Indeed, special thanks goes to the entire Senior Members of the Horticulture Department who offered useful suggestions and criticisms during my seminars to straighten the rough edges.

It is necessary for me to mention Miss Josephine Mends in appreciation of her inputs in various forms, but most importantly as the ‘primary editor’ of all write-ups. I must thank her for that.

Finally, I am indebted to the Management of Quality Control Company Limited (COCOBOD) for granting me the permission to do this study and by topping it up with some financial support.

I have to express my sincere gratitude to all my friends and my family for their help, encouragement and good wishes. May the Almighty God bless you.

ABSTRACT

An experiment was conducted at the Laboratory of the Horticulture Department of Kwame Nkrumah University of Science and Technology between January and March, 2012 within temperature and humidity ranges of 18 – 32 °C and 63 – 85 %, respectively. The purpose of the investigation was to develop an effective insecticidal cassava bait to control insect pests of cocoa in storage using *Araecerus fasciculatus* (De Geer) as model species. The experiment was conducted in a five-roomed glass cage of 60 cm x 60 cm x 200 cm with the backside made of a net to improve aeration in the cage. It was observed that *A. fasciculatus* preferred sun-dried chips to fresh chips, fermented dough, flour and cocoa beans and that soaking of sun-dried chips in brown sugar solution of 500 g per litre of water further enhanced the preference. Deltamost emerged superior to Fastrack and Confidor insecticides by registering 4 – 6 minutes of lethal time, 21 – 30 days persistence and attract-and-kill potential of 76.7 – 86.7 % of infested bagged cocoa beans. However, cassava bait at 25 % of Deltamost insecticide was at equal strength ($p < 0.05$) with the 50 and 75 % of the label dosage and should be the obvious choice for the insecticidal cassava bait preparation.

TABLE OF CONTENTS

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

LIST OF TABLES

LIST OF PLATES

PLATE **PAGE**

LIST OF ABBREVIATIONS

Msc.	Master of Science
ANOVA	Analysis of Variance
BHC	*Benzene hexa chloride*
COCOBOD	Ghana Cocoa Board
DDT	*Dichloro-diphenyl-trichloroethane*
EC	Emulsifiable Concentrate
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organization
NMD	Nutritional Metabolic Disrupter
OSU	Oregon State University
PVC	Polyvinyl Chloride
SC	Suspension concentrate
WP	Wettable product
ULV	Ultra low volume

CHAPTER ONE

1.0 INTRODUCTION

Cocoa contributes immensely to the economy of Ghana and has been the major export crop (Tracy, 2009). The production of cocoa has been a multi-billion dollar activity and it is the mainstay of over 60 percent of farm-families (Ntiamoah and Afrane, 2008) with its production in six out of the ten regions of Ghana. Ghana is so dependent on cocoa such that it is often said that 'Ghana is cocoa and cocoa is Ghana'.

Though Ghana is the second leading producer, the quality of Ghana's cocoa is the best on the international market, which attracts high premiums (Tracy, 2009). According to Osei (2007), a good quality cocoa is one devoid of insect infestation and high levels of chemical residues in the produce. The sale of cocoa that has any of these attributes may suffer outright rejection by the buyer or may be subjected to high arbitration cost to the country.

Bateman (2010) reported that insect infestation and chemical residues in cocoa beans are major challenges confronting the cocoa industry in Ghana and according to Jonfia-Essien *et al*. (2008), fumigating cocoa beans with methyl bromide and phosphine is the current method of controlling insect pests of stored cocoa.

The use of methyl bromide however, was banned in developed countries in 2005 and it was to take effect in developing countries in 2015 because of its depleting effect on the ozone layer (USDA, 2006). On the other hand, the EPA proposed a ban or restrictive use of phosphine because it is highly toxic and insects rapidly build resistance to it (Hodges and Graham, 2008).

Environmental concerns, chemical residues, insect resistance and worker safety issues have increased interest in alternative, safer, selective and ecologically acceptable toxophores and novel methods of application including the use of insecticidal baits (Renju, 2007).

Though dry cassava chips have been found to be preferred by a primary pest of stored cocoa, *Araecerus fasciculatus* De Geer (Boateng and Chijindu, 2008), much work has not been done in the use of baits to control insect pests of cocoa beans as well as using cassava as an attractant in insecticidal bait formulation.

Objectives:

The purpose of this investigation, therefore, was to develop an effective insecticidal cassava bait to control insect pests of cocoa in storage using *A. fasciculatus* as model species with the following specific objectives:

- To determine the cassava preparation that is most preferred by *A. fasciculatus;*
- To determine the effect of brown sugar on the preference of *Araecerus* to cassava;
- To identify the most effective chemical for the cassava bait preparation and
- To determine the efficacy of insecticidal cassava bait in controlling *Araecerus* infestation of bagged cocoa beans under cage.

CHAPTER TWO

2.0 LITERATURE REVIEW

Extensive studies and applications have been made in the use of insecticidal baits to control pests of field crops. Many insect species have been controlled successfully with various forms of baits while some attempts were faced with challenges to achieve desired results.

2.1 Storage Pests of Cocoa Beans

Until now, 26 insect species have been recorded on cocoa beans as pests (Moermans *et al.*, 1998). However, they reported that in Ghana, the most common insects infesting stored cocoa are *Ephestia cautella* (Walker), *Lasioderma serricorne* (Fabricius), *Araecerus fasciculatus* (De Geer) *and Tribolium castaneum* (Herbst).

Olsson (2001) reported that cocoa is the main food preference for *Plodia interpunctella* (Hubner), *Ephestia elutella* (Hubner) and *E. cautella*.

Finkelman *et al.* (2003) stressed on *E. cautella, P. interpunctella, T. castaneum* and *Oryzaephilus surinamensis* (Linnaeus) as major pests of stored cocoa beans.

Jonfia-Essien (2004) reported that in Ghana, dry cocoa beans in storage were monitored from 1995 to 2000 and *L. serricorne, T. castaneum, Cadra cautella* (Walker) and *Corcyra cephalonica* (Stainton) were among the eleven species identified as the most important pests of the crop.

According to Rajendran (2005), insect species that have visible indicators of infestation of cocoa beans include *Stegobium panecium* (Linnaeus), *L. serricorne, Rhizopertha dominica* (Fabricius), *Sitophilus* spp., *Sitotroga cerealella* (Olivier), *Amyelois transitella* (Walker), *E. cautella, P. interpunctella, A. fasciculatus* and *Callosobruchus* spp.

Navarro *et al*. (2007) reported that insect populations found in fermented cocoa in the Makassar, Indonesia, consisted of *Carpophilus* spp., *Ahasverus advena* (Waltl), *Cryptolestes* spp. and Psocids. They further intimated that the most common storage pests in cocoa beans from Indonesia to South America is the cocoa moth or the tropical warehouse moth, *E. cautella*, whereas the dominant species in cocoa beans from West Africa is the rice moth, *C. cephalonica*. In addition, they recorded that several storage insect species are known to infest cocoa beans; among them are the storage beetles such as the floor beetle (*Tribolium castaneum* Herbst).

However, in the attempt to employ hermetic storage in controlling insect pests and preserving the quality of cocoa beans as an alternative to chemical treatment, cocoa was found to be infested with live adults of *Cryptolestes ferrugineus* (Stephens), *Cryptolestes pusillus* (Schoenherr), *L. serricorne*, *A. fasciculatus and E. cautella* and some fruit flies (Jonfia-Essien *et al.*, 2010).

Bateman (2010) asserted that the storage pests likely to infest cocoa beans include the warehouse moths, *E. cautella* and *E. elutella;* beetles such as *L. serricorne, Carpophilus dimidiatus* (Fabricius), *C. ferrugineus and A. fasciculatus* and rodents (Rattus species) also attack stored cocoa.

2.2 Importance of *Araecerus fasciculatus* (De Geer) as a pest of cocoa

Back in the 1930's, *A. fasciculatus* was a pest of stored cocoa, which attacked undamaged cocoa bean on the drying tray and opened the bean up for infestation by other lepidopteran pests (Cotterell, 1934). Entwistle (1972) reported that there were a number of weevil-like beetles that had been recorded on cocoa mainly in West Africa, but it was only the larvae of *A. fasciculatus* that could bore into the outer coat of the cocoa bean. This, according to Dennis (1983), creates avenues for infestation by other pests.

Arbogast *et al*. (2002) also classified *A. fasciculatus* as a tropical pest that is capable of attacking a host of the most high value agricultural stored products of the tropics including cocoa, coffee, dried cassava chips and yams, maize, groundnuts, Brazil nuts, nut megs, etc.

Rees (2007) confirmed *A. fasciculatus* as a primary pest that could attack an undamaged bean and open it up for other pests to attack, but Adu-Mensah *et al.* (2007) explained the predominance of *A. fasciculatus* on cassava chips which is produced throughout the year. However, the suitability of cassava chips to the development of *A. fasciculatus* makes the insect an important pest of cocoa because both cocoa and cassava chips are dried together on the same drying platform or on different platforms in the same area. The production of the two crops together by farmers makes cocoa more vulnerable to attack by the pest.

According to Rees (2007), *A. fasciculatus* has a relatively short life cycle within 22 – 66 days, which requires an optimum temperature of 28 - 32°C and relative humidity greater than 60 %. He reported that the maximum population growth rate of the insect is 40 offspring per month. He stated further that the female adult lays eggs onto the bean and the larvae upon hatching, bores into the commodity and completes development inside the bean. The adult on emergence, leave neat exit hole and fly away.

From Rees (2007), the relatively short life cycle and high fecundity of the pest implies that several generations in high numbers could emerge in a year, which may not auger well for a stored produce like cocoa that is stored for several months or even years before processing.

Obeng-Ofori (2008b) mentioned *A. fasciculatus* as a major pest of stored coffee and cocoa world-wide and stressed that the contamination caused by the presence of the beetle on these high-value commodities is usually of greater importance than the actual direct damage it causes.

Yuekai *et al*. (2011) described the coffee bean weevil (*A. fasciculatus*) as a worldwide important pest in the storehouse, which is prevalent in tropical and sub-tropical regions. According to them, with *A. fasciculatus* identified on *Jetropha curcas* (Linnaeus) as a new host, both in the field and in storage, potential damage including direct feeding on seeds, spreading diseases and damage on several economic crops could occur.

2.3 Control of Storage Pests of Cocoa

2.3.1 Use of non- baits

Bateman (2010) enumerated various chemical treatment methods employed in the control of insect pests on cocoa beans. These include; mixture of insecticidal dusts with the produce before packaging, application of liquid insecticide sprays or dusts to successive layers of sacks as the stack is built, fumigating the sacks under gas–proof sheets and introduction of fogs into enclosed spaces. However, some of these techniques are likely to give rise to health hazards and are no longer recommended for use. According to Bateman (2010), it is upon consideration that non-chemical insect pest control methods, which include general sanitation, maintaining low moisture content below 8 %, using modified atmospheres such as reducing oxygen availability and controlling temperatures have gained prominence lately.

Jonfia-Essien *et al.* (2010) mentioned fumigation as one control method that has widely been used for pest control in both cocoa beans and other stored products to prevent qualitative and quantitative losses caused by insects. They said insect infestation is a major problem affecting cocoa in storage and therefore the beans are frequently fumigated using phosphine or mythyl bromide. However, increased public concern over the adverse effects of pesticide residues in food and the environment has led to their partial substitution with alternative control methods. Consequently, non-chemical and environmentally user-friendly methods of pest control in the post-harvest sector are becoming increasingly important (Bateman, 2010). Methyl bromide should have been phased out in developed countries by 2005 and will be phased out in developing countries by 2015, because of its contribution to the atmospheric ozone depletion (Casanova, 2002).

In contrast, phosphine remains popular, particularly in developing countries because it is easier to apply than methyl bromide. However, some insects have developed resistance to phosphine in some countries over the last decade (Savvidou *et al.,* 2003). According to Navarro (2006), hermetic storage has provided a new successful storage method for the protection of high value commodities such as cocoa and coffee without using fumigants or refrigeration for insect control and quality preservation. Furthermore, Finkelman *et al.* (2003) reported that the use of a low pressure of 50 mmHg at 30°C for 3 days in PVC storage enclosures termed “Volcani Cubes” or “Grain Pro Cocoons” provide effective insect control for quarantine or in-transit storage pending the satisfaction of technical and commercial criterion.

Wahyudi (2003) admitted that as fumigation was used as the rapid method to control storage pests of cocoa beans, methyl bromide and phosphine are the most currently used fumigants for treatment prior to storage and export of cocoa beans. Alternatively, he confirms the potency of carbon dioxide gas as the alternative fumigant in controlling stored-product insect pests. According to him, carbon dioxide concentration of 40, 60 and 80 % were effective in controlling *Ephestia cautella* (Walker) and *Araecerus fasciculatus* (De Geer) within one to three months exposure.

Rajendran and Sriranjini (2007) in their studies on plant essential oils and their constituents as fumigants against stored- product insect pests with their focus on beetle pests, found adult insects generally susceptible. They found some of the plant compounds having toxicity comparable to methyl bromide or chloropicrin.

Since methyl bromide under the Montreal Protocol was phased out, restrictions on the use of fumigants have resulted in efforts to develop new technologies as alternative control methods. Ethyl formate in combination with some other compounds or in vacuum may be most promising fumigant for grains and all other stored and fresh products (Haritos *et al*., 2006).

2.3.2 Use of baits

Examination of scientific literature shows that not much headway has been made with the use of baits in controlling insect pests of cocoa beans. However, according to Champion *et al.* (1987), small-scale trials were conducted to evaluate pheromone formulations to control the warehouse moth, *Ephestia cautella* Walker, as a pest of stored cocoa in Brazil. Penninger (1990) indicated that the earliest use of food-baited traps was for surveys of *Trogoderma* and other beetle species in the USA and India. Development of food-filled plastic mesh traps in the UK led to the use of those traps for monitoring infestation levels in addition to surveys. The challenge with the performance of food-derived lures as trap components is the insect's perception of food volatiles when in competition with other odours in the environment.

There was a comparison between traps baited with food attractants and pheromones and Olsson (2001) reported that food attractants are multi-specific, attract sexes, adults and larvae alike, simple and cheap. He further stated that food attractants are less potent when they are in competition with surrounding food sources.

Rees (2004) documented that *Cryptolestes* species are easily caught in pitfall traps inserted into commodity bulks. According to him, crevice traps are also effective and their efficacy can be improved with addition of food bait. In addition, a number of proprietary bait and trap systems are available which would be attractive to storage pests.

According to Trematerra and Sciarretta (2004), food- baited traps are sometimes used in combination with pheromone-baited traps to determine distribution of stored- product pests. However, insect traps, utilized alone or in combination with pheromones or food attractants or both, have been used in pest location and monitoring in food stores (Rajendran, 2005).

2.4 Efficacy of Pesticides in Baits

Chemicals used in baits have varying lethal effects on pests. A brief review of the efficacy of pesticides employed in formulating baits has been presented below.

2.4.1 Non-pyrethriods

Before the advent of conventional pesticides, various attempts were made to control insect pests with baits. Fernald (1914) had an excellent result with baits prepared from paris green, molasses and water against *Heliophila unipuncta* (Haworth).

The incorporation of pesticides into bait preparation started with the advent of DDT in the late 1930's (Shortwell, 1942). The development of baits continued with the evolution of various classes of pesticides. Most of the developed baits became efficacious but with the advent of pesticide appliances and different formulations to suit those appliances, the use of baits almost disappeared (Mukerji *et al.*, 1981).

Dahms and Fenton (1942) reported that using a mixture of sodium arsenate, wheat bran and water gave good control of armyworms and Scott (1945) used parisgreen on bran to reduce infestation of *Cirphis unipuncta* (Haworth) by 90 %.

Tublad (1947) reported that bait consisting of wheat bran, cryolite, sugar and water were used to achieve over 90 % mortality of the larvae of *Agrotis segetum* (Schiff.).

Sechriest (1968) found trichlorfon, abate, ethyl parathion, mirex TFD and carbaryl as effective toxicants in bait formulations against *Agrotis ipsilon* (Hufnagel) infesting corn farm.

Morgan and French (1971) tested 15 pesticides in bait formulations and found that abate, monocrotophos, dursban, dyfosate, trichlorfon, mythomyl and monitor all gave over 90 % control of cutmorms within 24 hours after application.

Devaiah (1973) employed several non-pyrethroids in the preparation of baits and found the toxicants abate, carbaryl, endosulfan, methomyl and trichlorfon as equally effective giving 90 % mortality in the instar larvae of *Spodoptera litura* (Fabricius).

Creighton *et al.* (1973) applied methomyl bait and found that it was effective against *Helicoverpa zea* (Boddie) on tomatoes in South Carolina. Sechriest and Sherrod (1977) found biothion, tonofos, methomyl, chlorpyriphos, trichlorfon and carbaryl in pelleted bait formulations against the control of the larvae of *Agrotis ipsilon* (Hufnagel) effective soon after maize seedling emergence.

Abdulkareem and Vishwanathan (1980) recommended carbaryl poison baiting for the control of *S. litura* when 100 % mortality was achieved in less than 16 days in the control of *S. litura* with 0.1 % chlorpyrifos bait.

Kepner and Yu (1987) in an attempt to develop an optimal toxic bait for the control of molecrickets (*Scapteriscus acletus* Rehn and Hebard) in Florida came up with commercial preparations of 20 % carbaryl, 0.5 % chlorpyriphos, 5 % trichlorfon and 4 % malathion baits as equally effective.

Giraddi and Kulkarni (1987) worked on insecticidal baits of fenthion, endosulfan, monocrotophos and quinalphos, but found quinalphos more effective followed by monocrotophos. Ramana *et al.* (1988) reported the effectiveness of a combination of chlorpyrifos and monocrotophos in the control of *Spodoptera litura* (Fabricius) in groundnut fields.

Records of an impressive control of *S. litura* in a severely infested cauliflower fields with BHC 50 WP, carbaryl 50 WP, fenthion 80 EC and malathion 50 EC Bait pellets were also made (Mohan *et al.,* 1989). Ramaprasad *et al.* (1989) reported of the effective control of *S. litura* in tobacco nurseries of the latter instar stages with baits prepared from endosulfan or monocrotophos or chorpyrifos or fenvalerate or quinalfos at one third of their recommended doses.

Hiremath *et al.*(1990) found monocrotophos bait superior to 0.05 % sprays of monocrotophos, endosulfan, chlorpyrifos and decammethrin or BHC dust or carbofuran in suppressing army worm, *Mythimna seperata* (Walker) populations in Dharwad.

In another study, Hiremath *et al.* (1992) found out the mass trapping technique for the armyworm moths by using fermented bait of monocrotophos (stored for 48 hours). Application of such bait resulted in 98 % kill of larvae and 70 % of adult moths.

Further studies made by Hiremath (1993) found poison baits consisting of 250 ml. monocrotophos significantly superior to endosufan spray in suppressing the larval population of *M. seperata* on sorghum and maize, *S. litura* on groundnut and sunflower and *Helicoverpa armigera* (Hubner) on bengalgram and cotton. The bait was effective in killing the adults of these pests.

In an experiment to test the efficacy of some chemicals and bioagents against *M. seperata* by applying them through bait formulations, fenvalerate exhibited its superiority over the others such as monocrotophos and chlorpyriphos and achieved between 87 to 100 % control of the pest (Mallapur, 1993).

Foster *et al.* (1999) in a study to determine if high dosages and multiple applications of insecticidal baits could be used to increase mortality of rangeland grasshopper, single application of high dosage carbaryl bran bait had a significant effect than single applications of lesser dosages.

Chacon and Jaramillo (2003) studied the effects of boric acid, fipronil, hydromethylnon and diflubenzuron baits on laboratory colonies of ghost ants (*Tapinoma melanocephalum* Fabricius) and concluded that 100 % mortality was achieved at varied number of days.

2.4.2 Synthetic pyrethriods

Modern pesticide use involves a host of factors including better pesticides that are not only selective and applied at a lower rate, but also have lower inherent toxicity and thus a lower impact on human health and the environment (Renju, 2007). Pyrethroids are meant to fill this gap in the application of pesticides and have been tried in various bait formulations.

Metcalf *et al.* (1987) evaluated dry curcubitacin containing baits for controlling diabroticide beetles in sweet corn and curcubits and found that methomyl, carbofuran, carbaryl and bendiocarp baits at 0.1 % were more effective than the pyrethroids permethrin, cypermethrin, fenvalerate and flucythrinate at 0.01 %. Isofenphos was the most effective of the organophosphorus insecticides.

Hiremath *et al*. (1990) took advantage of an armyworm outbreak at Dhawad and carried out poison bait experiments using monocrotophos, endosulfan, chlorpyyriphos and decamethrin. It was found that monocrotophos was superior but decamethrin was able to control 73.2 % of the larval populations of *Mythimna seperata* (Walker).

Metaweh *et al.* (2002) compared the effectiveness of baits of lambda cyhalothrin, carbosulfan and fenithrothion and concluded that lambda cyhalothrin revealed higher toxicity and was more effective against fourth nyphal instars of grasshoppers *Euprepocnemis plorans* (Charpentier) and *Heteracris annulosa* (Walker).

According to Renju (2007), with the invention of organic insecticides, investigations were carried out to substitute the inorganic compounds. However, pyrethroids such as fenvarelate, permethrin and insect growth regulators such as diflubenzuron and chlorfluazuron were found to give good control of various insect pests. However, in the evaluation of new insecticidal poison baits against lepidopterous crop pests, he found baits prepared from chlorpyriphos, monocrotophos, protenofos more effective than lamda cyhalothrin (a synthetic pyrethriod) and indaxocarb in the control of the larvae of *Spodoptera litura* (Fabricius).

2.4.3 Synergists of pyrethroids, bioallethrine and piperonyl butoxide

There was no information through the search for the three pesticides in a mixture of bait formulation. However, some information concerning the synergistic effects of the mixture on insect pest control has been illustrated below.

Nita (2001) reported of baits in dust formulations used in cracks and voids against the Argentine ants by combining pyrethroids and an activator, piperonyl butoxide.

Mani *et al.* (2005) evaluated the efficacy of indoor and peridomestic thermal fog applications of deltacide, a synergized mixture of pyrethroids (S-bioallethrin 0.7 % w/v, deltamethrin 0.5 % w/v and piperonyl butoxide 8.9 % w/v) against adult populations of *Aedes aegypti* (Linnaeus) in Chennai, Tamil Nadu, India. Bioassay mortalities recorded indicated that the knockdown and killing effect was greater when fogging was applied inside houses rather than around them and that indoor fogging suppressed adult population for 5 days.

Srinivasan and Kalyanasundaram (2006) researched into the effectiveness of the combination of deltamethrine, bioallethrine and piperonyl butoxide under the trade name Deltacide. They found the synergy to be effective in preventing resistance development and that it rendered all species of mosquitoes inactive and completely knocked them down in 60 minutes of exposure to all dosages (0.005, 0.01, 0.02, 0.04 ml/M^2) of ULV application and mortality was 100 % after 24 hours of exposure.

Fakoorziba *et al.* (2009) confirmed the effectiveness of the synergist of deltamenthrin with piperonyl butoxide in the ratio of 1:6 in the control and reduction in the ability to build resistance of five species of field collection of mosquitoes from the grand pools of Mysore.

2.4.4 Nitroguanidines

Nitroguanidines are derivatives used as insecticides having a comparable effect to nicotine. The derivatives are systemic insecticides used for crop protection purposes and include clothianidine, dinotefuran, imidacloprid and thiamithoxam, which have acclaimed worldwide patronage (Kanne *et al.*, 2005). On the use of nitroguanidines in bait preparations for insect pest control, contrasting results have been recorded.

Appel and Tanley (2000) conducted an experiment with imidacloprid gel bait in a laboratory and field studies against the German cockroach, *Blattella germanica* (Linnaeus). When they applied the bait at 15 – 45 g per kitchen, the bait significantly reduced German cockroach trap catch in infested homes during a four-week period. The experiment revealed a 50 % reduction after a week and 80 % reduction four weeks after treatment.

White *et al.* (2006) reported that spinosad and methomyl were superior to imidacloprid baits against house fly (*Musca domestica* Linnaeus). According to them, imidacloprid was affected by temperature and that flies knocked down by it could recover after a while.

A new imidacloprid sprayable fly bait formulation was compared against two commonly used dry scatter baits in the laboratory and against granular imidacloprid paint-on bait in a controlled field setting. The sprayable imidacloprid bait proved effective, reduced fly count by over 82 %, and was recommended for fly management programmes in urban, agriculture and military setting (Hertz, 2007).

The effectiveness of imidacloprid was evaluated against the house fly *Musca domestica* (Linnaeus) by scatter and paint-on applications. Though comparable mortalities of not up to 80 % were registered in 48 hours, from the dosage used and mortality rates obtained, paint-on application was more efficient than scatter (Bong *et al.*, 2008).

Wiltz *et al.* (2009) evaluated activities of bifenthrin, clorfenapyr, fipronil and thiamethoxam against the Argentine ants and found bifenthrin and thiamethoxam with the lowest median lethal time.

Wasserberg *et al.* (2011) studied the effectiveness of imidacloprid as a systemic control agent. They fed adult female *Phlebotomus papatasi* (Scopoli) with imidacloprid-treated rabbit blood and had 89.9 % mortality with a higher dose (5 mg/ml) and 81.3 % with a lower dose (1 mg/ml).

2.5 Carriers and Attractants

Carriers and attractants used in bait preparations have varied influence on the bait in terms of performance, attractiveness and effectiveness, selectivity and sustenance of the bait for longer periods as presented below.

2.5.1 Non-cassava products

Lofgren *et al.* (1963) tested wheat bran, various plant products, vermiculite and various clay granules in Mississippi as carriers in oil baits for use against *Solenopsis saevissima richteri* Forel. According to them, the attractive formulation consisted of 85 % maize cob grits, 15 % soybean oil and 0.07 % mirex.

Devaiah (1973) conducted studies in the laboratory using the last instar larvae of *Spodoptera littoralis* (Boisduval). He prepared the bait with wheat bran, jaggery and toxicants, namely, abate, carbaryl, endosulfan, methomyl and trichlorfon. Among these, carbaryl, methomyl and trichlorfon were equally effective and gave 90 % mortality.

Moustafa (1983) carried out experiments using different carriers on the performance of baits with fenvalerate and chlorpyriphos for the control of *Agrotis ipsilon* (Hufnagel). Maize cob pith was more attractive and effective carrier than groundnut shell or wheat bran.

Parasuraman *et al.* (1985) evaluated the effectiveness of different baits to attract the fourth instar larvae of *S. litura.* Wheat flour with 20 % molasses attracted more larvae and could maintain their feeding.

Viswanadham *et al.* (1986) in an experiment under laboratory conditions on different insecticidal baits against *S. litura* reported rice bran as the most effective carrier, with high mortalities followed by rice fine husk, jowar flour and ragi flour. They later reported that rice bran and jaggery were the most attractive.

Pellets made of rice bran and jaggery with BHC 50 WP, carbaryl 50 WP, fenthion 80 EC and malathion 50 EC pesticides were all effective in attracting and killing the larvae of *S. litura* (Mohan *et al.*, 1989).

In a research to develop a new type of bait using the German cockroach as a model insect, a non-toxic composition of the compounds oxiparinol and xanthine were used as the active ingredients of a nutritional metabolic disrupter (NMD). Field-trial results confirmed that the baits were equally effective against large populations of the German cockroaches compared with known toxic baits (Wren, 1996).

The use of carriers to formulate baits started since the late 1800's to suppress grasshoppers and the mommon crickets (Foster *et al.,* 2010). However, in the early to mid 1970's, carbaryl on wheat bran was the most commonly used bait on Western United States rangeland as the level of acceptance by the different rangeland grasshopper species to wheat bran bait was documented (Jech *et al.*, 1993).

Barbara and Capinera (2003) assessed grain-based baits (rolled oats, wheat bran, oat bran, yeast, corn meal, cornflakes) and vegetable oils (canola, corn, peanut, soybean), for eastern lubber grasshopper, *Romalea guttata* (Houttuyn). They concluded that adult *R. gutatta* preferred bait consisting of wheat bran carrier with corn oil as an added phagostimulant. According to them, addition of flavorings (peppermint, anise, lemon, and banana) resulted in few significant effects and carbaryl, wheat bran, and oil bait developed in the study was effective at causing mortality in field-cage studies.

Chacon and Jaramillo (2003) studied the effects of boric acid, fipronil, hydromethylnon and diflubenzuron baits on laboratory colonies of ghost ants (*Tapinoma melanocephalum* Fabricius) and administered sugar solution containing fipronil caused 100 % mortality even after ninth week.

Mangan *et al.* (2005) reported that hydrolyzed protein edible insecticide bait (GF-120), made up of a mixture of spinosad , microbial hydrolyzed protein, sugars, adjuvants and a series of conditioners was effective against tropical fruit fly (Tephritidae) in a laboratory cage test experiment .

Foster *et al.* (2006) did a study of field cage comparisons of carbaryl bait prepared from wheat bran, apple pumice and food waste against rangeland grasshopper species. According to them, results obtained from apple pumice and food waste baits could be compared to the standard wheat bran bait.

Sackmann and Corley (2007) tested the attractiveness of protein (fresh and freeze-dried beef) and carbohydrate (corn syrup and honey) baits (alone and mixed) and three pesticides commonly employed to control terrestrial domestic arthropods (hydramethylnon 2%, permethrin 0.3% and chlorpyrifos 0.25%). Their results showed that beef was the most attractive bait tested for the wasps *Vespula germanica* (Fabricius) in North Western Patagonia. Honey and corn syrup alone or mixed with beef did not attract foraging wasps as did baits made of beef only throughout the wasp season.

2.5.2 Cassava products

Cassava, *Manihot esculenta* (Crantz), has been utilized in only few instances as bait or substrate, which illustrates that to some extent, cassava possesses some amount of ingredients capable of attracting some organisms.

According to Etejere and Ramakrishna (1985), pealed cassava chips fried in red palm oil was used as bait to catch farm rodents.

FAO (1990) recommended that in attracting bees to the beehive, a little bee wax, dry cassava flour, sweet syrup such as palm wine or molasses, granulated sugar, sweet-scented lavender, limes, cow-dung, intestinal waste, lemon grass and a dish of water could be used.

Borgemeister *et al.* (1999) reported that sticky traps, baited with cassava chips harbouring male *Dinoderus bifoveolatus* (Wollaston), set up in two regions of southern Benin, consistently caught considerable numbers of insects belonging to the same species. Low numbers of two other bostrichids i.e., *Prostephanus truncatus* (Horn) and *Rhyzopertha dominica* (Fabricius) were also recorded in the traps.

2.6 Efficacy of Insecticidal Baits

2.6.1 Under storage conditions

Cox and Collins (2001) attributed influences that conflict with intended response to attractive lures in grain store environment to include origin of the storage pest, behaviour associated with beetle movements and distribution within the grain bulk, response to food and other multi-species attractants and semiochemicals in grains with hot spots.

In field studies on the ecology of *Sitophilus oryzae* (Linnaeus) and *S. zeamais* (Motsclusky), 19 species of stored-product Coleopterans were caught on sticky traps and corn-baited packets placed in grain storage sites in South Carolina (Throne and Cline, 1994).

Trials were conducted to evaluate the efficacy of protein-enriched pea flour against common stored-grain insects, *Sitophilus oryzae* (L.), *Tribolium castaneum* (Herbst) and *Cryptolestes ferrugineus* (Stephens). Six 30-tonne farm granaries were filled with 11 tonnes of barley. In the experiment, four kinds of traps; flight, surface pitfall, probe pitfall and sticky-bar were placed at different locations in the granaries to estimate movement of insects. It was found that the 0.1 % protein enriched pea flour treatment reduced adult numbers of S. oryzae by 93 %, *T. castaneum* by 66 % and *C. ferrugineus* by 58 % and reduced the emerged adults by 87, 77, and 77 %, respectively (Hou and Fields, 2003).

On the other hand, food-based lures have been used to detect and monitor the presence of mites under storage conditions. A trap called the BT mite trap was developed for the detection and monitoring of mites in food, animal feed and associated industries. This trap was made up of a mixed food-based lure held in a robust adjustable housing. The trap's performance was assessed in four different warehousing conditions and a total of 17 genera or species of storage and predatory mites were detected (Thind, 2005).

Pheromone traps were used in silos, mills and warehouses to estimate the effectiveness in direct control of Indian meal moth (*Plodia interpunctella* Hubner) using mass trapping methods. It was found that there was no significant difference between low and high densities of traps in the control of the insect (Drosu *et al.*, 2011).

2.6.2 Under laboratory conditions

Delrivero and Planes (1966) carried out laboratory tests in Spain to evaluate the effectiveness of various insecticides suitable for use in baits against larvae of *Spodoptera littoralis* (Fabricius). The insecticides that gave complete mortality were trichlorfon, methidathion, phosalone, aminocarb, diazinon, fenthion, BHC, carbaryl, sodium fluosilicate and barium fluosilicate. Out of these, the last two were used as standard toxicants in bait formulations in Spain against pests.

Viswanadham *et al.* (1986) experimented under laboratory conditions on different insecticidal baits against *Spodoptera litura* (Fabricius) and noticed the superiority of chlorpyriphos bait over monocrotophos, quinalphos, undosulfan and carbaryl baits.

Testing the persistence and effects of dilution of a hydrolyzed protein edible insecticidal bait (GF-20) as effective against tropical fruit fly (Tephritidae) in a laboratory-cage-test experiment had been reported (Mangan *et al.*, 2005).

A strain of *Beauvaria bassiana* (Bb) was evaluated as a biopesticide for the control of shore flies. Bb was grown on autoclaved millet seed and was used as bait for the control of shore flies. In cages at the laboratory containing only adult shore flies, the entire population was dead within 10 – 12 days in the Bb-treatment (Stanghellini and El-Hamalawi, 2005).

Renju (2007) performed an experiment to evaluate new insecticidal poison baits for their efficacy and preference under laboratory conditions. He found chlorpyriphos at 75 % the recommended dosage to be more superior to other treatments, recording 100 % mortality at 48 hours after exposure of larvae of *Mythimna seperata* (Walker) to the baits.

2.6.3 Against Non-Coloepteran Pests

Mohan *et al.*, (1989) reported that pellets made of rice bran and jaggery with BHC 50 WP, carbaryl 50 WP, fenthion 80 EC and malathion 50 EC pesticides were all effective in attracting and killing the larvae of *Spodoptera litura* (Fabricius).

Prokopy *et al.* (2003) conducted a field study in Hawaii, in which colour-marked protein-deprived and protein-fed female melon flies, *Bactrocera cucurbitae* (Coquillett), were released within canopies of unsprayed sorghum plants (a non-host of melon flies) outside of a border area of unsprayed or bait-sprayed sorghum plants or open space that surrounded cucumbers, a favoured host of melon flies. According to them, application of bait spray to sorghum or sugarcane surrounding host plants of melon flies is a common practice for melon fly control in Hawaii. They reported that GF-120 Fruit Fly Bait spray proved very effective in preventing protein-deprived females from alighting on cucumbers, but proved less effective in suppressing protein-fed females. Their combined findings suggested that either application of GF-120 Fruit Fly Bait spray to non-host plants for melon fly control be made often enough to overcome loss of attractiveness of bait spray droplets to females or that bait spray be applied to non-host plants that are themselves attractive to the females.

Barry and Polavarapu (2004) conducted an experiment on blueberry maggot (*Rhagolettis mendax* Curran) using three protein baits, ammonium acetate and sucrose. According to them, flies fed significantly longer on concentrations of 25 and 50 % solbait than any of the concentrations tested. They also observed that higher concentrations (8, 16 and 32 %) sucrose elicited greater feeding responses than lower concentrations (4 %) and water. They concluded that solbait is a superior protein bait based on attraction and feeding and that alternative baits should contain at least 8 % sucrose, as a significant feeding stimulant and some amount of ammonium acetate as an attractant.

In a field cage development of myco-insecticidal bait to control mormon cricket, *Anabrus simplex* Helderman (Orthoptera: Tettigoniidae), Foster *et al.* (2010) failed to achieve their objectives and attributed it to unexpected bait aversion.

Conway and Forrester (2011) in an eradication programme of the Mexican fruit fly, *Anatrepha ludens* (Loew) (Diptera: Tephritidae) in citrus, used bait sprays of malathion Nu-Lure and GF-120 to enhance the sterile to wild fly ratio, thereby increasing the effectiveness of the sterile insect release programme. They recommended that bait spray option using ground spray equipment to apply ultra-low rates of either malathion Nu-Lure or GF-120 spinosad at high rate is a viable cost effective treatment method to treat small acreages for *A. ludens*.

2.6.4 Against Coleopteran Pests

Metcalf *et al.* (1987) evaluated dry curcubitacin containing baits for controlling diabroticide beetles in sweet corn and curcubits and found that methomyl, carbofuran, carbaryl and bendiocarp baits at 0.1 % were more effective than the pyrethroids permethrin, cypermethrin, fenvalerate and flucythrinate at 0.01 %. Isofenphos was the most effective of the organophosphorus insecticides.

Traps have been developed for aerial insects (mainly pyralid moths and anobiids), for crawling stages of Coleoptera (*Trogoderma*, *Tribolium* and *Oryzaephilus* spp.) and for insertion into bulk grain for a complex of grain-infesting Coleoptera. However, food-baited traps have been used for crawling Coleoptera (Barak *et al.,* 1990).

Schroder *et al.* (2001) took an extract from Hawkesbury watermelon and used it as the primary component of water-soluble bait that could be combined with toxins for adult diabroticide beetle control. The bait was efficacious against spotted and striped cucumber beetles.

Weinzierl *et al.* (2005) used can- or baglike traps for Japanese beetles, which contained a feeding attractant, sold under claims that they could reduce beetle numbers. Although the lure was indeed very attractive to adult Japanese beetles, the use of the lure did not reduce damage to plant foliage. In contrast, areas where the Japanese beetle densities were low, traps placed several yards away from valuable plants could reduce the damage caused by adult beetle feeding on foliage or flowers. Traps in areas where the Japanese beetle was prevalent had increased beetle numbers and damage to host plants in the area around the trap. That outcome apparently resulted from the fact that the lure attracted many beetles, but were not captured by the trap. In areas where the Japanese beetle was a serious pest, only very widespread use of many traps was likely to reduce damage caused.

Mahroof and Phillips (2007) made an observation in a research to investigate the responses of adult *Stegobium panecium* (Linnaeus) and *Lasioderma serricorne* (Fabricius) to different commercially available or prototype fabrications of their female-produced sex pheromones. They saw that the number of beetles captured in traps baited with a combination of serricornin and chilli volatiles were significantly higher than traps baited with pheromones or chilli volatiles alone. This indicated that potential exist for improved monitoring or mass trapping of *L. serricorne* by combining pheromone with plant-derived volatiles present in *Capsicum* species.

Alderman (2010) developed trap-and-kill technology for cucumber beetle (*Diabotrica undecimpunctata* Mannerheim) and Western striped cucumber beetle (*Acalymma trivittatum* Mannerheim) with a bait component of cucubitacin used in the trap. A round trap design called OSU Lab trap was efficient in the capture of both beetles.

2.6.5 As broad-spectrum insecticides

According to Wakefield (2006), the use of a lure based on food attractants holds promise as a basis for a multi- species lure to allow for expansion of the number of target species to include those for which the attractant pheromones are unknown. For him, food baits contain complex mixture of volatiles, only some of which will be detected by the insect to elicit a behavioural response. A few instances where food bait has been used for broad-spectrum pest detection or control purposes have been listed below.

In field studies on the ecology of *Sitophilus oryzae* (Linnaeus) and *S. zeamais* (Motsclusky), 19 species of stored-product Coleopterans were caught on sticky traps and corn-baited packets placed in grain storage sites in South Carolina (Throne and Cline, 1994).

Borgemeister *et al.* (1999) reported that sticky traps, baited with cassava chips harbouring male *Dinoderus bifoveolatus* (Wollaston), set up in two regions of southern Benin, consistently caught considerable numbers of conspecifics. The sex ratio of the trapped *D. bifoveolatus* was significantly female biased. Low numbers of two other bostrichids i.e., *Prostephanus truncatus* (Horn) and *Rhyzopertha dominica* (Fabricius) were also recorded in the traps.

Roesli *et al.* (2002) found pitfall traps with food as effective in sampling adult beetles and moths to evaluate heat treatment effectiveness of storage facilities. Some of the insects sampled included *Cadra cautella* (Walker), *Lasioderma serricorne* (Fabricius), *Cryptolestes pusilus* (Schoenherr), *Plodia interpunctella* (Hubner) *and Tribolium castaneum* (Herbst).

According to Stanley (2004), protein-based matrices of hydramethylnon and fipronil are highly attractive and give effective control of ant populations of several species. However, Wakefield *et al.* (2006) reported that insect lures based on food attractants have the potential to attract more than one species of insects and therefore have the advantage over pheromone–based lures. According to their report, food-attractant-based lures used to date have tended to use natural products resulting in batch-to-batch variation in composition and hence performance.

The production of a multi-species lure was examined using a mixture of volatiles obtained from kibbled carob and peanuts to attract three principal beetles, *Oryzaephilus surinamensis* (Linnaeus), *Sitophilus granaries* (Linnaeus) and *Cryptolestes ferrugenius* (Stephens), in the United Kingdom. For 180 volatile compounds detected, only two elicited a response from the three species of insects (Wakefield, 2006).

Commodities may be attacked by a multitude of pest species simultaneously and so to be cost-effective any lure must be attractive to a range of target species. The attractant effect of the multi-species lure formulation was tested using two types of dispensers with populations of the three principal grain beetle pests in the UK (*O. surinamensis*, *S. granarius* and *C. ferrugineus*). The trials were performed over a period of six weeks with the lures tested in traps. The second lure dispenser released the attractant volatiles more consistently over six weeks and exerted significant attraction to *O. surinamensis* and *C. ferrugineus* in the traps in the grain bulk and to *O. surinamensis* and *S. granarius* in floor traps (Collins *et al.,* 2008).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental site

The experiment was conducted at the laboratory of the Horticulture Department of the Kwame Nkrumah University of Science and Technology between January and March, 2012. The experiment was performed within temperature and humidity ranges of 18 - 32°C and 63- 85 %, respectively.

3.2 Culturing of experimental insects

Culture of *Araecerus fasciculatus* (De Geer) was raised from a field strain of parent stock obtained from Ashanti Bekwai. An insect haven was created in a garden behind the Quality Control (COCOBOD) office by drying cassava chips on a raised platform and any *A. fasciculatus* that was attracted was captured with a pooter.

The culture was prepared using ten Kilner jars with dry cassava chips sterilized in an oven at a temperature of 60°C for 24 hours. The moisture content of the sterilized chips was reduced to 9 %, measured using an Aqua Boy. The jars were filled with the sterilized cassava chips to three-quarters full before introducing the insects (Plate 1). The insects were secured in the jars with meshed covers to provide adequate aeration in the bottles. The jars were then placed on plastic trays containing industrial oil to prevent contamination of the culture by other insects. The insects were sieved off 12 days after introduction and the contents kept for fresh insect immergence.

Plate 1: Culture of *A. fasciculatus*

3.3 Experimental cage

A transparent glass cage of 60 cm x 60 cm x 200 cm was constructed with the backside of the cage made of a net to improve aeration. The top had four breaks at 40 cm interval where partition glasses inserted created five equal cabins. Each cabin had a sliding door on the front side and the base was made of a transparent glass (Plate 2).

Plate 2: Glass cage for determining the preference of *A. fasciculatus*

3.4 Evaluation of the preference of *A. fasciculatus* for four cassava preparations

The four partitions of the cage were removed and 300 g each of four cassava preparations (fresh chips, sun-dried chips, fermented dough and flour) from the Yebesi local variety and cocoa beans as the control were simultaneously placed on the floor of the cage. Twenty five day-old insects were introduced and the cage closed. The four partitions were inserted after 24 hours and insects present on each cassava preparation and the cocoa used were counted. This was repeated three times by randomizing the arrangement of the treatments in the cage and the number of *A. fasciculatus* attracted to each treatment 24 hours after introduction into the cage was recorded.

Plate 3: Comparison of the preference of *A. fasciculatus* to four cassava preparations in the cage

3.5 Experiment to determine the preference of *A. fasciculatus* to dry cassava chips and chips immersed in brown sugar solution.

A solution was prepared using 500 g of brown sugar and one litre of water. One kilogram of dry chips was soaked in the solution and the mixture was transferred into a black polyethylene bag and kept for 12 hours. A comparison was made by placing 300 g each of dry cassava chips, soaked chips and cocoa as the control in the cage and twenty day-old *A. fasciculatus* were introduced. The experiment was repeated three times by randomizing the arrangement of the treatments in the cage. The number of *A. fasciculatus* attracted to dry cassava chips, chips immersed in brown sugar solution and cocoa beans 24 hours after introduction into the cage were recorded.

Plate 4: Comparison of the preference of *A. fasciculatus* to dry cassava chips and cassava chips immersed in brown sugar solution

3.6 Preparation of insecticidal cassava bait

The cassava bait was prepared using 500 g of brown sugar dissolved in one litre of water (Hiremath *et al*., 1990) and varied concentrations (25 %, 50 % and 75 % of manufacturer's application rate) of the three chemicals (Renju, 2007) each added separately and mixed thoroughly. One kilogram of dry cassava chips of sweet tasting variety (Yebesi) was soaked in each of the prepared solution and kept in black polyethylene bags for 12 hours. The chips were then picked out of the solution, air-dried for 30 minutes, and used as bait.

The various concentrations of chemicals used in preparation of the bait are shown in Table 3.1.

Table 3.1: Application rates of pesticides used for the preparation of cassava bait

PESTICIDE	Manufacturer's application rate/ L (Water)	25% of application rate/ L (Water)	50% of application rate/ L (Water)	75% of application rate/ L (Water)
Confidor 20 SC/ml.	2.50	0.63	1.25	1.88
Deltamost/ml.	111.00	27.75	55.50	83.25
Fastrack 10 SC/ml.	15.00	3.75	7.50	11.25

Note: Deltamost contains 2.5 % deltamethrine, 0.3 % bioallethrine and 11% piperonyl butoxide while Confidor contains 20 % Immidachloprid and Fastrack, 10 % Alpha-cypermethrine.

3.7 No-choice test to determine the efficacy of the cassava insecticidal bait

Thirty grams each of the cassava baits prepared with three different concentrations of the three insecticides were placed in transparent plastic jars with meshed lids and day-old *A. fasciculatus* was introduced. The time of insect coming into contact with the bait and the time it dropped dead (lethal time) were taken and the experiment repeated three times for each bait.

On the other hand, 30 g of each of the cassava bait with cassava chips soaked in only brown sugar solution as the control were also put into separate transparent plastic jars, three of day-old insects were introduced to each treatment at 24 hourly intervals and insect mortalities were recorded. This was repeated until further introduction of day-old insects did not result in any mortality and the number of days was recorded. The experiment was repeated three times for each treatment.

Plate 5: Transparent plastic jars containing baits for determination of persistence of pesticides

3.8 Experiment to evaluate insecticidal cassava bait for efficacy against *A. fasciculatus* on infested bagged cocoa beans under cage.

Cassava baits at three different concentrations of each of the three pesticides (Fastrack 10 SC, Confidor 20 SC and Deltamost) were prepared using sun-dried cassava chips. The baits weighing 100 g each were introduced into each partition of the cage containing a stack of five bags of cocoa beans in miniature jute sacks. The jute sacks with dimensions of 7 cm wide and 16 cm deep were filled with 1.5 kg each of cocoa. Both the bait and the cocoa were placed in the cage and twenty day-old *Araecerus* were introduced. The number of *Araecerus* attracted and killed by the bait after 12, 24, 48 and 72 hours were counted. A partition containing cocoa with dry cassava chips immersed in brown sugar solution was used as the control since there was no standard bait to compare with and the experiment was repeated three times.

Plate 6: Set-up to determine efficacy of insecticidal cassava bait in the control of *A. fasciculatus* on bagged cocoa beans

CHAPTER FOUR

4.0 RESULTS

4.1 Evaluation of the preference of *A. fasciculatus* among four cassava preparations

There were significant differences ($p < 0.05$) between the preferences for cassava preparations by *A. fasciculatus***.** Dry cassava chips were most preferred by *A. fasciculatus*, which was significantly different, attracting 14 of the insects representing 57.2 % (Table 4.1). This was followed by fermented dough, which scored an average preference of 21.3 %. There were however no significant differences ($p > 0.05$) between the cassava dough and the fresh cassava chips in terms of their preference by the insect. The least preferred cassava preparation was the flour, which scored an average preference of 2.8 %. However, it was not statistically different from that of cocoa beans (1.2 %), which served as the control.

Table 4.1: Mean preference of *A. fasciculatus* to cassava preparations

Cassava preparation	Mean no. of insects
Dry chips	14.30 a (57.2%)
Fermented dough	5.30 b (21.2%)
Fresh chips	4.40 b (17.6%)
Flour	0.70 c (2.8%)
Control (Cocoa)	0.30 c (1.2%)

Notes: Percentage of insects attracted in parenthesis.

Means followed by same letter does not differ significantly at $p < 0.05$.

4.2 Comparison of the preference of *A. fasciculatus* between dry cassava chips and chips immersed in brown sugar solution

There were significant differences (P < 0.05) in the attraction of day-old *Araecerus* to dry cassava chips and that of chips immersed in brown sugar solution. Chips immersed in brown sugar solution attracted 81.2 % of the insects as compared with 16 % for the dry cassava chips, which was also significantly different from those attracted to cocoa (2.8 %), which was used as the control for the experiment.

Table 4.2: Mean preference of *Araecerus* to dry cassava chips and chips in brown sugar solution

Product	**Mean no. of insects**
Chips in brown sugar sol.	20.30 a (81.2 %)
Dry chips	3.70 b (16 %)
Control (Cocoa)	0.30 c (2.8 %)

Notes: Percentage of insects attracted in parenthesis.

Means followed by same letter does not differ significantly at p < 0.05.

4.3 Determination of the lethal mean time for *A. fasciculatus* on insecticidal cassava bait at varied concentrations of three insecticides

Table 4.3: Mean lethal time taken to record insect mortality

Pesticide concentration	Mean lethal time/ minutes.
Fastrack 50%	30.33 a
Confidor 75%	14.33 b
Fastrack 75%	10.67 bc
Deltamost 25%	6.33 cd
Deltamost 50%	6.00 cd
Deltamost 75%	4.00 d

Notes: Mean lethal time followed by same letter does not differ significantly at $p < 0.05$.

From Table 4.3 there was varied efficacy among the insecticide-prepared baits towards *A. fasciculatus*. Most of the baits killed *Araecerus* between 4 and 30.3 minutes after it had fed on it, but baits prepared with 25 and 50 % Confidor and 25 % Fastrack of the recommended application rates took two to three days to cause mortality and were, therefore, dropped in subsequent investigations.

However, six treatments in addition to the control were used in subsequent experiments.

From Table 4.3, there were significant differences ($p < 0.05$) in the lethal time for the various insecticidal bait preparations. Deltamost at 75 % recorded the shortest lethal time of 4 minutes which was significantly different from those of Confidor at 75 %, and Fastrack at 50 and 75 %, but not insignificantly different ($p > 0.05$) when compared with Deltamost at 25 and 50 % of the recommended concentrations. Fastrack at 50 % of the recommended application rate recorded the longest lethal time of 30.33 minutes which was significantly longer than all the other bait preparations. There were no significant differences ($p > 0.05$) between the confidor at 75 % and fastrack at 75 % with both recording 14.33 and 10.67 minutes, respectively. The differences between deltamost at 50 % and 25 % and fastrack 75 % were also statistically insignificant.

4.4 Comparison of persistence of insecticides at varied concentrations in cassava bait

Table 4.4: Persistence of pesticides in baits

Pesticide concentration	Mean persistence/ days.
Deltamost 75%	29.67 a
Deltamost 50%	25.33 b
Deltamost 25%	21.00 c
Fastrack 75%	13.00 d
Fastrack 50%	9.33 e
Confidor 75%	5.33 f
Confidor 50%	2.67 f

Notes: Mean persistence followed by same letter does not differ significantly at $p < 0.05$.

From Table 4.4 the persistence of the various levels of the insecticide on the baits varied significantly at $p < 0.05$. Generally, Deltamost recorded longer number of days (above 20 days) for all the three levels with Deltamost at 75 % of the recommended level having the longest persistency of 29.67 days which was significantly longer than the other pesticide concentrations. Deltamost at 25 and 50 % followed respectively with 21.00 and 25.33 days of persistence, which were individually significantly different from each other. The two levels of Confidor recorded the least number of days for persistency with 50 % concentration recording the shortest persistency of 2.67 days whilst 75 % followed with 5.33days. They were however not statistically different at $P > 0.05$ from each other. On the other hand, Fastrack 50 and 75 % recorded 9.33 and 13 days of persistence respectively which were different from each other.

The control (dry chips immersed in brown sugar solution) did not register any mortality during the test period and was, therefore, excluded in the statistical analysis.

4.5 Evaluation of insecticidal cassava bait for efficacy against *Araecerus*-infested bagged cocoa beans under cage

At 12 hours of introducing insects to treatment, Deltamost treated baits performed significantly better ($p < 0.05$) than the other pesticides. From Table 4.5, Deltamost at 75 % killed the highest number (40 %) of insects introduced and it was however not significantly different ($p > 0.05$) from Deltamost at 50 % and Deltamost at 25 % which recorded 36.7 % and 35.0 % insect mortality, respectively. Fastrack at 75 % and Confidor at 75 % recorded 11.7 % and 5.0 % mortality rates respectively which were not significantly different from each other, though they were different from the three levels of Deltamost baits. Fastrack at 50 % also recorded 5.0 %

mortality rating. The control (dry chips soaked in brown sugar solution) recorded 0.0 % mortality rate but was not different from Deltamost at 50 % and Confidor at 75 %.

At 24 hours after treatment, Deltamost generally continued to perform significantly better ($p < 0.05$) than the two other chemicals, but in this case, Deltamost at 50% recorded 60% insect mortality, which was not different statistically ($p > 0.05$) from Deltamost at 75 % (58.3 % mortality) and Deltamost at 25 % (51.7 % mortality) the recommended rates. These were followed by Dastrack at 75 % the recommended dosage, which recorded an average insect mortality of 33.3 %, but was not significantly different from Confidor at 75 % the recommended rate (28.3 % mortality). Confidor at 75 % was also not different statistically ($p > 0.05$) from Fastrack at 50 % the recommended rate, which recorded insect mortality of 15 %. However, the performance of Fastrack at 50 % the recommended dosage was not different from the control, which recorded 1.7 % mortality of *Araecerus* introduced into the cage.

Table 4.5: Evaluation of cassava bait for efficacy against *A. fasciculatus* on infested bagged cocoa beans under cage

Treatment	**Conc. of bait (%)**	**Time (Hours)**			
		12	**24**	**48**	**72**
Deltamost	75	40.00 a	58.35 a	81.65 a	86.65 a
	50	35.00 a	60.00 a	73.35 a	76.65 ab
	25	36.65 a	51.65 a	83.35 a	85.00 a
Fastrack 10 SC	75	11.65 b	33.35 b	53.35 b	63.35 bc
	50	5.00 bc	15.00 cd	36.65 c	55.00 c
Confidor 20 SC	75	5.00 bc	28.35 bc	45.00 bc	48.35 c
Control (Chips + B.Sugar Solution)	-	0.00 c	1.65 d	1.65 d	1.65 d

Notes: Percentage insect mortalities recorded followed by same letter does not differ significantly at $p < 0.05$.

There was a general increase in the mortality with increasing time. At 48 hours after introduction of the insects, Deltamost continued to perform significantly better ($p < 0.05$) than the other pesticides. Deltamost at 25 % the recommended rate recorded the highest mortality of 83.3 %, but that was not significantly different ($p > 0.05$) from Deltamost at 75 % and 50 %, which recorded 81.7 and 73.3 % mortalities respectively. On the other hand, Fastrack at 75 % of the recommended rate was not statistically different ($p > 0.05$) from Confidor at 75 % the recommended dosage. However, it performed significantly better than Fastrack at 50 %, which in turn was not different from Confidor at 50 %. The control was the least performer with 1.7 % mortality.

After 72 hours of exposure, Deltamost at 75 % of the recommended dosage emerged the best (86.7 % mortality), but that performance was not significantly different ($p > 0.05$) from Deltamost at 25 % and 50 % which recorded mortality rates of 85 and 76.7 % respectively (Table 4.5). However, Deltamost at 50 % did not show significant differences from Fastrack at 75 % of the recommended dosage with 63.3 % insect mortality. On the other hand, there were no significant differences between Fastrack at 75 %, Fastrack at 50 % and Confidor at 75 % of the recommended dosages. Only 1.7 % mortality was recorded in the control, which was the least mortality recorded.

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Evaluation of the preference of *A. fasciculatus* to four cassava preparations

The four preparations were from the same source of cassava (Yebesi local variety) however, their attractiveness to the insect varied significantly, making sun-dried chips the obvious choice.

According to Metcalf (1992), the development and processing of plants and plant parts produce chemical compounds, which generate olfactory or gustatory stimuli that convey specific behavioral messages to specific species involved in ecological interrelations of the food web. In his assertion, insects have sensory receptors, which are used to perceive semiochemicals in the form of volatiles from food. It could, however, be inferred that the sun-dried cassava chips emitted compounds that attracted *A. fasciculatus* more than the other cassava preparations. Chijindu and Boateng (2008) reported that *A. fasciculatus* preferred fermented and sundried chips probably because of their lower densities, which make it easier to penetrate as well as olfactory cue emitted.

The difference between the attractiveness of dry cassava chips and the flour is striking and needs to be explained. Producing flour from the same chips and for the chips to be more attractive implies that breaking the cassava into powder might have reduced the critical signals that stimulate behavioral patterns leading to preferred oviposition sites, satisfactory food supplies and aggregation with receptive mates or shelter (Metcalf, 1992).

Furthermore, Viswanadham *et al.* (1986) found rice bran more preferred by *Spodoptera litura* (Fabricius) than rice fine husk, jowar flour, and ragi flour. Adu-Mensah *et al*. (2007) also reported the suitability and preference of sun-dried cassava chips by *A. fasciculatus*, which supports the result obtained from this study.

According to Wakefield (2006), food baits contain complex mixture of volatile, only some of which will be detected by the insect to elicit a behavioral response. No work has been done on food bait comparisons involving cocoa beans and cassava chips. However, it could be inferred that the dry cassava chips produced volatiles that attracted *A. fasciculatus* more than the cocoa beans. This could be likened to a food bait experiment by Foster *et al.* (2006) who compared wheat bran, apple pumice and food waste using rangeland grasshopper species and found apple pumice and food waste superior.

5.2 Effect of brown sugar on the preference of *A. fasciculatus* to dry cassava chip

In comparing the preferences of *Araecerus* to cassava and chips immersed in brown sugar solution, dry cassava chips immersed in brown sugar solution was preferred to dry cassava chips.

Generally, several researchers have reported that sugars are good insect attractant. Tublad (1947) reported that sugar added to wheat bran, creolite and water could achieve over 90 % attract-and-kill of the larvae of *Agrotis segetum* (Schiff). Devaiah (1973) added jaggery to wheat bran to make effective bait against *Spodoptera littoralis* (Boisduval). Twenty per cent molasses was added to wheat flour to attract the fourth instar larvae of *S. litura* (Parasuraman *et al.*, 1985). Hiremath *et al.* (1990) standardized bait preparation by the addition of jaggery to water and rice bran. Müller *et al.* (2010) formulated attractive toxic sugar bait, which caused a decline of 90 % in mosquitoes in the Bandiagara district of Mali. Barry and Polavarapu (2004) observed that higher concentrations (8, 16 and 32 %) of sucrose in baits elicited greater feeding responses in blueberry maggot (*Rhagolettis mendax* Curan) than lower concentrations (4 %) and no sugar and concluded that alternative baits should contain at least 8 % sucrose, as a significant feeding stimulant and some amount of ammonium acetate as an attractant. In the preparation of attractive toxic sugar bait for the control of *Phlebotomus papatasi* (Scopoli), Muller and Schlein (2011) prepared baits with 10 % brown sugar, which made effective sprays on barrier fences. These results confirm the attractiveness of the dry chips immersed in brown sugar solution to *A. fasciculatus* than dry cassava chips and cocoa beans.

The chips immersed in the brown sugar solution were so attractive that most of the insects were attracted to it thereby making the dry chips unattractive and as such making it have the same effect as the control (cocoa beans).

5.3 Comparison of the mean lethal time for *Araecerus* on insecticidal cassava bait at varied concentrations of three pesticides

In this study, Deltamost (deltamethrin synergist with bioallethrin and piperonyl butoxide) in cassava bait was superior at the three levels to both confidor (imidacloprid) and fastrack (alpha-cypermethrin) (Appendix A).

Obeng- Ofori (2008a) reported of the potency of deltamethrin in the control of stored product beetles where organophosphates are ineffective. However, deltamost at 75 % the recommended dosage had a mean lethal time of 4.0 minutes, which was not matched by any of the treatments. Rint (1989) impregnated sacks with deltamethrin at 75 % dosage and recorded 100 % mortality of *A. fasciculatus* while cypermethrin at 75 % dosage was ineffective.

Generally, higher concentrations of the pesticides used in this experiment had shorter knockdown time compared with those of lower concentrations. This could be compared with a laboratory trial conducted by Barry and Polavarapu (2004) in which fly survivorship on six insecticides (acetamiprid, clothianidin, deltamethrin, fipronil, imidacloprid and spinosad) incorporated at 4, 40 and 400 parts per million in protein baits had higher concentrations of insecticides resulting in increased fly mortality. Similarly, Renju (2007) in the evaluation of new insecticides in baits found higher dosages more potent than lower dosages.

All the dosages at 75 % strength were more toxic which supports observations made by Viswanadham *et al.* (1986) who tested different levels of chlorpyriphos (0.5, 1.0, 1.5 and 2.0 %) in bait formulation and recorded higher insect mortalities with higher than lower concentrations.

These results might explain why lower concentrations of Confidor at 25 and 50 % and Fastrack at 25 % the recommended dosages were not potent enough to cause insect mortality within a comparable time.

The control (dry chips soaked in sugar solution only) did not record any insect mortality which suggests that the mortalities recorded in the treatments with insecticides in the cassava bait were due to the insecticide in the cassava. Rint (1989) recorded 100 % survival rate of *Araecerus* in the control of the experiment to impregnate sacks with pesticides where there was no pesticide in those bags used as the control of the experiment.

5.4 Evaluation of the persistence of the pesticides in the cassava bait

Deltamost was more persistent than Confidor and Fastrack in the cassava bait against *Araecerus* with the 25 % of the approved dosage of Deltamost being capable of causing mortality of *Araecerus* within 24 hours for 21 days in a no-choice experiment while the 75 % of the approved dosage recorded the highest with 29.7 days. There is no similar finding in literature to support this finding. However, according to Mangan *et al.* (2005), spinosad bait at different concentrations maintained toxicity against the tropical fruit fly for at least three weeks, which could be compared with the persistence of Deltamost cassava bait against *Araecerus*.

Dilution of the insecticides affected the potency of the bait with time and the higher the concentration of the insecticide in the bait, the more it lasted against *A. fasciculatus*. With respect to each pesticide, 75 % strength lasted longer in toxicity than the 50 % and that was more potent than the 25 % the recommended dosages. Similarly, Revis *et al.* (2004) assessed the effects of concentration and ageing on the attractiveness and toxicity of GF-120 fruit fly bait to melon flies, *Bactrocera cucurbitae* (Coquillett). They tested dilutions of 20, 40, and 80 parts per million of active ingredient (spinosad) against water controls and found baits containing higher concentrations more persistent than those containing lower concentrations of spinosad.

The control (dry chips immersed in brown sugar solution only) did not register any mortality during the test period. This meant that the pesticides were potent enough to cause mortality of *A. fasciculatus* in the specified periods.

5.5 Evaluation of insecticidal cassava bait for efficacy against *Araecerus*-infested bagged cocoa beans under cage

In this study, insect mortalities caused by the addition of the pesticides to the cassava bait were significantly higher than the control (dry chips soaked in brown sugar without pesticide). The high insect mortalities recorded could be attributed to the use of the pesticides in the bait because no mortalities were recorded in the control experiment.

Deltamost was the fastest and most potent attract-and-kill cassava bait, in that at 12 hours after the treatment, more than 35 % of the insects introduced had been killed by the bait while the highest performance for both Fastrack and Confidor cassava baits was 12.7 %. According to de Groot (2004), Deltamethrin (an active ingredient of Deltamost) is very effective against grain weevils and could be the reason why Deltamost proved much more potent even at lower concentrations and within short exposure time periods.

Cassava bait prepared with Deltamost at 25 % the recommended dosage was the most effective in attracting and killing *Araecerus* in bagged cocoa beans since at that low rate, the performance was not different from the 75 % the recommended dosage within the period of the experimentation. Preparing the cassava bait with Deltamost at 25 % the recommended dosage meant reducing cost and load of the chemical in the working environment.

Apart from Deltamost pesticide which did not differ among the different concentrations used in the experiment, both Fastrack and Confidor had lower concentrations causing lower mortalities for short periods, but eventually the lower concentrations ended up causing comparable mortalities with higher concentrations. Though both pesticides have not been applied in a similar work before, this observation could be compared with the findings of Bong *et al.* (2008). In evaluating the effectiveness of imidacloprid (Confidor) against strains of the house fly, *Musca domestica* (Linnaeus), they reported that mortalities due to scatter and paint-on applications increased with increased time of exposure.

The study revealed that between the 50 and 75 % the recommended dosages of fastrack, 75 % the recommended dosage was superior at attracting and killing the insect at 12 hours after treatment than the 50 %, but at 72 hours after treatment, however, their ability to cause mortality were not different. This finding could be compared with the test of persistence and effects of dilution of hydrolyzed-protein-edible-insecticide bait conducted by Mangan *et al.* (2005) for the control of tropical fruit flies. They reported that lower concentrations of spinosad (80 ppm) killed fewer flies when measured over short periods than higher concentrations (200 ppm), but fly mortalities were not different in four days.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In the test conducted among four cassava preparations (sun-dried chips, fresh chips, fermented dough, and flour) with cocoa beans as the control, sun-dried chips was the most attractive to *A. fasciculatus* and thus the obvious choice for the preparation of the bait. Soaking the chips in brown sugar solution and fermenting for 12 hour further enhanced the attractiveness of sun-dried chips to *A. fasciculatus*.

Deltamost, amongst Fastrack and Confidor pesticides, emerged superior with the least mean lethal time at the three different concentrations, knocking down the insect 4-6.33 minutes after exposure to the bait with higher concentration of pesticide having lower mean lethal time and vice versa.

In addition, another comparison to determine the persistence of the three pesticides in cassava bait at three different levels of concentration showed Deltamost as the most persistent pesticide maintaining potency 21 - 30 days; higher concentration being more potent for a longer period than lower concentration.

Furthermore, cassava containing Deltamost insecticide was the most effective attract-and-kill bait for the control of *Araecerus*-infested bagged cocoa beans under cage, in that, at 72 hours after introduction of the insects, 76.7 - 86.7 % had been attracted and killed by the bait.

In all, cassava bait at 25 % of the recommended dosage of Deltamost pesticide was at equal strength at $p > 0.05$ with the 50 and 75 % and could, therefore, be used for the insecticidal cassava bait preparation to make the bait much safer and cheaper.

6.2 Recommendations

Though the development of the cassava bait gave promising results, the performance of the cassava bait could further be improved by exploring the synergy between that and pheromones of storage pests as recommended by Wakefield (2006).

Additionally, the effect of longer fermentation of the bait mixture (0-48 hours) should be investigated to determine an optimal period of fermentation to produce the desired effect of attracting the pests.

Cassava, in combination with pesticides, produces different attract- and-kill results. It however, will be important to investigate into several other classes of pesticides to come up with a more effective combination. More so, the formulation, that is, paint-on, chips, scatters, extract spray, etc. could also be compared to select the best.

Nevertheless, the application of attractants, phagostimulants, conditioners and flavorings, which have positive effect on the attractiveness of baits to the insect (Mangan *et al*., 2005) must be looked into to formulate the best cassava bait additives.

The objective of the investigation was to produce cassava bait to control insect pests of stored cocoa. Therefore, it will be important to determine the effect of the bait on other storage beetles and lepidopterous pests in applied storage conditions.

7.0 REFERENCES

Abdulkareem, A. and Vishwanathan, T. (1980). A general account of the integrated approach for the control of bollworms on cotton. Andhra Agric. J., 27: 123 – 124.

Adu-Mensah, J., Owusu-Akyaw, M. and Mochiah, M. B. (2007). Insect pest of dried cassava (kokonte) in the Ashanti and Brong Ahafo regions of Ghana. Journal of the Ghana Science Association. Vol. 9, No. 2(2007): pp. 9 – 17.

Alderman, K. (2010). Developing trap and kill technologies to improve management of the Western spotted cucumber beetle *(Diabotrica undecimpunctata*) and the Western striped cucumber beetle (*Acalymma trivittatum*). An undergraduate thesis submitted to Oregon State University. http://ir.library,oregonstate.edu/xmlui/bitstream/handle/1957/16202/KatieAlderman_Thesis.pdf?sequence=1.

Appel, A. G. and Tanley, M. J. (2000). Laboratory and field performance of an imidacloprid gel bait against German cockroaches (Dictyoptera: Blattelidae). Journal of Economic Entomology, 93 (1): pp. 112 – 118 (2000).

Arbogast, T. R., Kendra, P. E., Mankin, W. R. and McDonald, R. C. (2002). Insect infestation of a botanicals warehouse in North-central Florida. Journal of Stored Product Research, 38(2002): pp. 349 – 363.

Barak, A. V., Burkholder, W. E. and Faustini D. L. (1990). Factors Affecting the Design of Traps for Stored-Product Insects. Journal of the Kansas Entomological Society, Vol. 63, No. 4, (1990), pp. 466 – 485.

Barbara, K. A. and Capinera J. L. (2003). Development of a toxic bait for control of eastern lubber grasshopper (Orthoptera: Acrididae). Journal of Economic Entomology (2003). Volume: 96, Issue: 3, Pages: 584-591

Barry, J. D. and Polavarapu, S. (2004). Feeding activity and attraction of blueberry maggot (Diptera: Tephritidae) to protein baits, ammonium acetate and sucrose. Journal of Economic Entomology, 97(4), pp1269 – 1277, 2004.

Bateman, R. (2010). Revised Ed. Pesticide use in cocoa, A guide for training administrative and research staff. [Available on line] http://www.dropdata.org/cocoa/cocoa _pesticide manual_Ed2.pdf. 20TH September, 2011.

Boateng, B. A. and Chijindu, E. N. (2008). Presence of and damage to processed cassava chips by Araecerus fasciculatus (De Geer). [Available on line] http://www.aensionline.com/jasr/2008/939 -944.pdf.

Bong, L. J., Sulaiman, S. and Othman, H. F. (2008). Evaluation of imidacloprid against the house fly Musca domestica (L.) in the laboratory. Journal of Tropical Medicine and Parasitology, Vol. 31 (No. 1), (2008), pp. 23 – 27.

Borgemeister, C., Schafer, K,, Goergen, G. , Awande, S., Setamou, M., Poehling, H. M. and Scholtz, D. (1999). Host-finding behavior of Dinoderus bifoveolatus (Coleoptera: Bostrichidae), an important pest of stored cassava: the role of plant volatiles and odors of conspecifics. Annals of the Entomological Society of America, (1999) Volume: 92, Issue: 5, Publisher: Entomological Society of America, Pages: 766-771.

Casanova, J. L.(2002). An overview of scientific aspects of ozone depletion and their impact on the environment. In: Batchelor, T. A., Bolivar, J. M. (Eds.), Proceedings of International Conference on Alternatives of Methyl Bromide, Sevilla, Spain, March 5 – 8, 2002, pp. 23 – 27.

Chacon, P. and Jaramillo, G. I. (2003). Effect of boric acid , Fipronil, Hydramethylnon and Diflubenzuron baits on colonies of ghost ants (Hymenoptera: Foemicidae). J. Econ. Entomol., 96: 856 – 862.

Champion, D. G., Hall, D. R. and Prevatte, P. F. (1987). Use of pheromones in crop and stored products pest management: International Journal of Tropical Isect Science, 1987. No. 8: pp 737 – 741.

Chijindu, E. N. and Boateng B. A. (2008). Reference of and damage to processed cassava chips by Araecerus fasciculatus (Degeer). Journal of Applied Sciences Research, 4(8): pp 939 – 944 (2008).

Collins, L.E., Bryning, G.P., Wakefield, M.E., Chambers, J., Fennah, K., Cox, P.D. (2008). Effectiveness of a multi-species attractant in two different trap types under practical grain storage conditions. Journal of Stored Products Research, Volume 44, Issue 3, 2008, Pages 247-257.

Conway, H. E. and Forrester , O. T. (2011). Efficacy of Ground Spray Application of Bait Sprays with Malathion or Spinosad on Mexican Fruit Fly (Diptera: Tephritidae) in Texas Citrus. Journal of Economic Entomology 104(2):452-458. 2011.

Cotterell, G. S. (1934). Infestation of stored cocoa by weevil (*Araecerus fasciculatus*) and moth (*Ephestia cautella*). Bull. Dept. of Agric. Gold Coast. No. 28, pp. 14.

Cox, P. D. and Collins, L. E. (2001). Factors affecting the behavior of beetle pests in stored grain with particular reference to to the development of lures. Journal of Stored Product Research. Vol. 38, Issue 2, 2002, pp. 95 – 115.

Creighton, C. S., Mcladden, T L., and Cuthbert, R. B. (1973). Tomato fruit worm control in South Carolina with chemical and microbial insecticides. J. Econ. Entomol., 66: 473 – 475.

Dahms, R. S. and Fenton, F. A., 1942, Experiments with poisoned bait to control armyworms in wheat. *J. Econ. Entomol*., 35 : 439-440.

de Groot, I. (2004). Protection of stored grains and pulses. Agrodok Series 18, (5^{th} Ed.), pp. 39 – 47.

Delrivero, J. M. and Planes, S. (1966). Tests on the control of *Spodoptera littoralis* in the laboratory. Boln Patrol Veg. Entomol. Agric., 29: 293- 305.

Dennis, S. H. (1983). Agricultural insect pests of the tropics and their control; 2^{nd} Edition. Pp.621. Cambridge University Press.

Devaiah, M. A. (1973). Studies on cutworm in Mysore state and their control. M. Sc. (Agn) Thesis, University of A gric. Science, Bangalore (India).

Drosu, S., Ciobanu, M., Opera, M., Tudorache, M. and Fatu, V. (2011). Alternative methods of stored grains protection against pests agents. Analele Universitatii din Craiova, seria Agricultura- Montanologie-Cadastrru Vol. XLI 2011/2, pp. 142 – 148. [Available on line] www.cabi.org/isc/ShowPDF.aspx?PAN=20123109042.

Entwistle, P. F. (1972). Pests of cocoa in storage. In: Pests of cocoa. Pp.662 – 665. Longman Group Limited, London.

Etejere, E. O. and Ramakrishna, B.B. (1985). Traditional preparation and uses of cassava in Nigeria. Economic Botany, 39 (2), 1985, pp 157- 164.

Fakoorziba, M. R., Eghbal, F., Vijayan, V. A. (2009). Synergist efficacy of piperonyl butoxide with deltamethrin as pyrethroid insecticide on Culex tritaeniorhynchus (Diptera: Culicidae) and other mosquitoe species. Journal of Environmental Toxicology 2009 Feb;24(1):19-24.

FAO (1990). Bee Keeping in Africa. Agricultural Services Bulletin. [Available on line] (http://www.fao.org/docrep/t0104e/T0104E08.htm)

Fernald, H. T. (1914). The armyworm *Heliotis unipuncta* (Haw.). Massacusette State Bd. Agric, 22: 1 – 13.

Finkelman, S., Navarro, S., Rindner, M., Dias, R., Azrieli, A. (2003). Effect of low pressure on the survival of three cocoa pests at 30°C. Journal of Stored Product Research. 40 (2004) 499 – 506

Foster, R. N., Jeronski, S., Reuter, K. C., Black, R. L. and Schlothauer, R. (2010). Explaining mycoinsecticide activity: poor performance of spray and bait formulation of *Beauveria bassiana* and *Metarhizium brunneum* against mormon cricket in field cage studies. Journal of Orthoptera Research, 2010, 19(2), pp. 303 – 313.

Foster, R. N., Reuter, K. C., Black, R. L., Helbig, B., Kozel, L. and Schuetzle, V. L. (2006). Field cage comparisons of wheat bran, apple pumice and food waste baits containing carbaryl against rangeland grasshopper species with varying susceptibilities to standard wheat bran baits. USDA/APHIS/PPQ/CPHST/DS&PMSL, Report 2006. 33 pp.

Foster, R. N., Quinn, M. A., Reuter, K. C., Colleto, D., Houston, R., Puclick, M. J., Scott, A. and Radsick, B. (1999). Comparison of single and multiple applications of an insecticidalbait for controlling grasshoppers (Orthoptera: Acrididae) on mixed-grass Prairie. Journal of the Cansas Entomological Society, 72(2), 1999, pp. 181- 189.

Giraddi, R. S. and Kulkani K. A. (1987). Efficacy of insecticidal baits and granules against armyworm , *Mythimna seperata* (Walker) in sorghum. Pesticides, 21: 27 – 31.

Haritos, V., Damcevski, K. and Dojchinov, G. (2006). Improved efficacy of ethyl formate against stored grain insects by combination with carbon dioxide in a ‘dynamic’ application. Pest Management Science, 62, pp. 325 – 333.

Hertz J. C. (2007). Potential of insecticide-treated cords and sprayable baits for control of houseflies (diptera: muscidae). A thesis presented to the graduate school of the university of florida in partial fulfillment of the requirements for the degree of master of science university of florida, 2007, PP 68 – 70.

Hiremath, I. G., Bhuti, S. G. and Lingappa S. (1992). Ecobiology and management of Mythinma seperata (Walker). Karnataka J. Agric. Sci., 3: 128 – 130.

Hiremath, I. G., Bhuti, S. G., Kachapur, M. D., Viraktamath, S. and Lingappa, S. (1990). Mass killing of moths- A new approach in the management of armyworm, *Mythimna seperata* (Walker), Karnataka J. Agric. Sci., 3: 128- 130.

Hiremath, K. G. (1993). Evaluation of poison baits against lepidopterous pests of economic importance in Karnataka. M. Sc. (Agric.) Thesis, Uni. Agri. Sci., Dhawad (India).

Hodges, R. and Graham, F. (2008). Crop Post-Harvest: Science and Technology, Durables case studies in the handling and storage of durable commodities. Vol.2, pp 92 – 95.

Hou, X. and Fields, P. G. (2003). Granary trial of protein-enriched pea flour for the control of three stored product insects in barley. Journal of Economic Entomology, Vol. 96 (3), 2003, pp. 1005 – 1015.

Jech, L. E., Foster, R. N., Colletto, D., Walgenbach, D. D., Roland, T. J., Rodriquez, G. D., Bohls, R., Houston, R. D., Meeks, W. K., Queener, R. L., Jackson C. L., Dines J. L., Puclik, M. J. and Scott, A. K. (1993). Field evaluation of diflubenzeron and carbaryl bran baits against grasshopper (Orthoptera: Acrididae) populations in South Dakota. Journal of Economic Entomology, No. 86, pp. 557 -565.

Jonfia-Essien, W. A. (2004). Cocoa storage in Ghana. In: Hordges, R. J. and Farell, G. (Eds.), Crop Post-harvest: Science and Technology Vol. 2.; Durables. Blackwell Science Ltd., UK., pp. 274.

Jonfia-Essien, W. A., Navarro, S. and Dator, J. V. (2008). Effectiveness of hermetic storage in insect control and quality preservation of cocoa beans in Ghana. [Available on line] http://www.worldcocoafoundation.org/scientific-research/research-library/documents/Jonfia-Essien 2008D.pdf

Jonfia-Essien, W. A., Shlomo, N. and Villars, P. (2010). Hermetic Storage: A novel approach to the protection of cocoa beans. African Crop Science Journal. Vol. 18, No. 2, pp. 59 – 68.

Kanne, D. B., Dick, R. A., Tomizawa, M. and Casida, J. E.(2005). Neonicotinoid nitroguanidine insecticide metabolites: synthesis and nicotinic receptor potency of guanidines, aminoguanidines, and their derivatives. Journal of Chemical Research Toxicology. 2005 Sep;18(9):1479-84.

Kepner, R. L. and Yu, S. J. (1987). Development of toxic bait for control of mole crickets (Orthoptera: Gryllotalpidae). J. Econ. Entomol., 80: 659 – 665.

Lofgren, C. S., Bartlett, F. J. and Stringer, C. E. (1963). Imported fire ants toxic studies: Evaluation of carriers for oil baits. Journal of Economic Entomology, 56, pp. 62 – 63.

Mahroof, R. M. and Phillips, T. W. (2007). Responses of stored-product Anibiidae to pheromone lures and plant-derived volatiles. Journal of Applied Entomology, 132 (2008), pp. 161 – 167.

Mallapur C. P. (1993). Studies on ecobiology and management of armyworm, Mythimna separata Walker (Lepidotera: Nuctuidae) on sorghum. Ph. D. Thesis. Uni. Agri. Sci., Dhawad (India).

Mangan, R. L., Moreno, D. S., and Thomson, D. G. (2005). Bait dilution, spinosad concentration and efficacy of GF-20 based fruit fly sprays. Crop protection, 25 (2006), pp. 125 – 133.

Mani, T. R. Arunachalam, N. Rajendran, R. Satyanarayana, K. and Dash, A. P. (2005). Efficacy of thermal fog application of deltacide, a synergized mixture of pyrethroids, against Aedes aegypti, the vector of dengue. Journal of Tropical Medicine and International Health, Vol. 10, No. 12, pp 1298 – 1304, December 2005.

Metaweh, H. H., Gomma, E. A. A., Sherif, R. M. and Abdel-Fattah, T. A. (2002). Toxicity and persistence of some poison baits against fourth nymphal intars of two species of grasshopper. Egypt J. Agri. Res., 80: 73 – 78.

Metcalf, R. L. (1992). Plant kairomones in insect ecology and control. Chapman and Hall Publishers, 2-6 Boundary Row, London SEI 8HN., pp.1 – 23.

Metcalf, R. L., Ferguson, J. F., Lampman, R. and Rinderson, J. F. (1987). Dry curcubitacin containing baits for controlling diabroticide beetles. Journal of Economic Entomology, No. 80: pp. 870 -875.

Moermans, R., Casteels, H. and Van Hecke, P. (1998). Evolution of cocao-pests over six year period. Anzeiger fur Schaelingskunde Pflanzenschutz Umweltschutz 71, pp. 149 -151.

Mohan, S., Varadhajan, N. and Balasubramanian, M. (1989). Development and testing of pesticide bait pellets of tobacco cutworm, *Spodoptera litura* Fab. Pestology, 13: 22 – 23.

Morgan L. W. and French J. C. (1971). Granulate cutworm control in peanuts in Georgia. J. Econ. Entomol., 64; 937 – 939.

Moustafa, O. K. (1983). Effects of carrier and soil moisture on the performance of baits used for the control of greasy cutworm, *Agrotis ipsilon*. Bull. Entomol. Soc. Egypt, 11, pp. 271 – 274.

Mukerji, M. K., Ewen A. B., Craig, C. H. and Ford, R. J. (1981). Evolution of insecticide treated bran baits for grasshopper control in Saskatchewan (Orthoptera; Acrididae). Can. Entomol., 113: 705- 710.

Müller, G. C. and Schlein, Y. (2011). Different methods of using attractive toxic sugar bait (ATSB) for the control of *Phlebotomus papatasi*. Journal of Vector Ecology, Vol. 36, pp. 64 – 70.

Müller, G. C., Beier J. C., Traore, S. F., Toure, M. B., Traore, M. M., Bah, S., Doumbia, S. and Schlein, Y. (2010). Successful field trial of attractive toxic sugar bait (ATSB) plant-spraying methods against malaria vectors in the *Anopheles gambiae* complex in Mali, West Africa. *Malaria Journal* 2010, 9:210, pp.1475-2875. [Available on line] http://www.malariajournal.com/ content/9/1/210

Navarro, S. (2006). Modified atmospheres for the control of stored product insects and mites. In: Insect Management for food storage and processing. Secocnd Edition. Heaps, J. W. (Ed.), AACC International, St. Paul, MN. Pp. 105 – 146.

Navarro, S., deBruin, T., Montemayor, A. R., Finkelman, S.,Rindner, M. and Dias, R. (2007). Use of biogenerated atmospheres of stored commodities for quality preservation and insect control with particular reference to cocoa beans. Integrated Protection of Stored Products, IOBC/wprs Bulletin Vol. 30 (2), 2007, pp. 197 – 204.

Nita, A. D. (2001). Pest Management Assessment. Least- toxic alternatives for the Argentine ants, fleas and white grubs of lawns. Califonian Environmental Protection Agency Report Number Pm- 01 -02, pp 8 – 10. [Available on line] http://apps. cdpr.ca.gov/schoolipm/managing_pests/74_antgrub.pdf. (Date accessed) 2pm. 5th October, 2012.

Ntiamoah, A. and Afrane G. (2008). Environmental impacts of cocoa production and processing in Ghana: life cycle assessment approach. Journal of Cleaner Production , 16 (2008): pp. 1735 – 1740.

Obeng-Ofori, D. (2008a). Management of Stored Product Arthropod Pests. In: Post-Harvest Science and Technology (Eds.: Cornelius, E. W. and Obeng-Ofori, D. 2008). Pp : 92 - 145.

Obeng-Ofori, D. (2008b). Major Stored Product Arthropod Pests. In: Post-Harvest Science and Technology (Eds.: Cornelius, E. W. and Obeng-Ofori, D. 2008). Pp : 67 – 91.

Olsson, C. (2001). The function of food volatiles: insect behavior and pest control. www.lu.se./upload/biologi/pheromone/introlsson.pdf.

Osei, I. (2007). Challenges of Quality Standards in the cocoa Industry. A Presentation at the African Cocoa Summit. 3- 5 September, 2007.

[Available on line] http://www.mofep.gov.gh/documents/cocoasummit_p3.pdf.

(Date assessed) 19th October, 2011.

Parasuraman, S., Jayaraj, S., Gopalan, M. and Kamaraswami, T. (1985). Attraction of *Spodoptora litura* (Fabr.) larvae to baits. Indian Journal of Agric. Science, 55, pp. 773 -774.

Penninger, D. B. (1990). Food-baited traps; past, present and future. Journal of the Kansas Entomological Society. Vol. 63, No. 4 (Oct., 1990), pp 533 – 538.

Prokopy, R. J., Miller, N. W., Piñero J. C., Barry, J. D., Tran, L. C., Oride, L. and Vargas R. I. (2003). Effectiveness of GF-120 Fruit Fly Bait Spray Applied to Border

Area Plants for Control of Melon Flies (Diptera: Tephritidae). Journal of Economic Entomology, 96(5):1485-1493. 2003.

Ramaprasad, G., Joshi, B. G., Sitaramaiah, S. and Chari, M. S. (1989). Efficacy of insecticides in bait formulations for control of fourth instar larvae of Spodoptera litura Fab. in tobacco nurseries. Indian Journal of Plant Protection, 17: 53 – 57.

Ramana, V. V., Reddy G. P. V. and Krisha- Murphy, M. M.(1988). Synthetic pyrethroids and other bait formulations in the control of *Spodoptera litura* Fab. Attacking rabi groundnut. Pesticides , 22: 13 – 16.

Rajendran, S. (2005). Detection of Insect infestation in stored food commodities. Journal of Food Science and Tecnology Mysore(1999). Vol. 36, Issue 4, pp. 238 – 300.

Ranjendran, S. and Sriranjini, V. (2007). Plant products as fumigants for stored-product pest control. Journal of Stored Product Research. Vol. 44, Issue 2(2008), pp. 126 -135.

Rees, D. (2007). Insects of stored grain, a pocket reference. Second (Ed.). Pp. 12.

Rees, D. (2004). Insects of stored products. CSIRO Publishing. Pp. 78.

Renju, T. (2007). Evaluation of newer insecticidal poison baits against lepidopterous crop pests. Msc. Thesis, July 2007, Department of Agricultural Entomology, University of Agricultural Sciences, Dharwad.

Revis, H.C., Miller, N.W. and Vargas, R.I. (2004). Effects of aging and dilution on attraction and toxicity of gf-120 fruit fly bait spray for melon fly control in Hawaii. Journal of Economic Entomology, 97 (5), pp.1659-1665.

Rint, J. R. (1989). Biology of the coffee bean weevil, *Araecerus fasciculatus* de Geer (Coleoptera: Anthribidae) and its susceptibility to insecticides. In: Naewbanji, J. O.

(Ed.). Advances in grain postharvest technology generation and utilization, Bankok (Thailand); Asean Grain Poastharvest Programme, 1988, pp. 143 – 157.

Roesli, R., Subramanyam, B., Fairchild, F. J., and Behnke, K. C. (2002). Trap catches of stored-product insects before and after heat treatment in a pilot feed mill. Journal of Stored Product Research. 39(2003), pp 521 – 540.

Sackmann, P. and Corley, J. C. (2007), Control of *Vespula germanica* (Hym. Vespidae) populations using toxic baits: bait attractiveness and pesticide efficacy. Journal of Applied Entomology, 131: 630–636.

Savvidou, N., Mills, K. A., and Pennington, A. (2003). Phosphine resistance in Lasioderma serricorne (F.) (Coleoptera: Anobiidae). In: Credland, P. F., Armitage, D. M., Bell, C. H., Cogan, P. M., Highly, E. (Eds.), Pp. 702 – 712. Advances in stored product protection, Proceedings of the 8th International Working Conference on Stored Product Protection, York, CAB international, Oxon, UK.

Schroder, R. F. W. , Martin, P. A. W. and Athanas, M. M. (2001). Effect of a Phloxine B-Cucubitacin Bait on Diabrotricide Beetles (Coleoptera: Chrysomelidae). Journal of Econ. Entomol. 94 (4) 2001: pp. 892 – 897.

Scott, L. B. (1945). Arsenic residues in straw and grain from wheat dusted by airplane or treated with poison bait. Journal of Economic Entomology, 32: 165 -169.

Sechriest, R. E. (1968). Greenhouse experiments with baits for control of the black cutworm. Journal of Economic Entomology, 61 : 591-593.

Sechriest, R. E. and Sherrod, D. W. (1977). Pelletted bait for control of the black cutworm in corn. J. Econ. Entomol., 70; 699 -700.

Shortwell, R. L. (1942). Evaluation of baits and bait ingredients used in grasshopper control. United States Department of Agriculture. Tech. Bull. No. 12, pp.1 – 7.

Srinivasan, R. and Karyanasundaram, M. (2006).Ultra Low Volume Aerosol Application of Deltacide (Deltamethrine 0.5% w/v, S- Bioallethrine 0.71% w/v and Piperonyl Butoxide 8.9% w/v) Agaist Mosquitoes. Indian Journal of Medical Research, 123, January 2006, pp 55 – 60.

Stanghellini, M. E. and El-Hamalawi, Z. A. (2005). Efficacy of *Beauvaria bassiana* on colonized millet seed as a biopesticide for the control of shore flies. HortScience Vol. 40 (5), 2005, pp. 1384 – 1388.

Stanley, M. C. (2004). Review of efficacy of baits used for ant control and eradication. Landcare Research Contract Report : LC0405/044, 78pp.

Thind, B. B. ((2005). Anew versatile and robust mite trap for detection and monitoring of storage mites in the cereal and allied industries. Experimental and Allied Acalorogy, (2005), 35; pp. 1 – 15.

Throne, J. E. and Cline, D. L. (1994). Seasonal Flight Activity and Seasonal Abundance of Selected Stored-Product Coleoptera Around Grain Storage Sites in South Carolina. Journal of Agricultural Entomology, 11(2), (October, 1994), pp. 321 -338.

Tracy, W. (2009). An African success story: Ghana's cocoa marketing system. IDS working paper vol. 2009, No. 318.

[Available on line] http://www.ids.ac.uk/gdr/cfs/pdfs/Wp318.pdf.

Trematerra, P. and Sciarretta, A. (2004). Spatial distribution of some beetles infesting a feed mill with spacio-temporal dynamics of *Oryzaephillus surinamensis*, *Tribolium castaneum* and *Tribolium confusum*. Journal of stored product research.

Tublad, B. (1947). Poison bran against cutworms in a nursery. Vaxtskyddsnotiser, 4: 53 -55.

USDA (2006). Agricultural Research Service, National Program 308. Methyl Bromide Alternatives Action Plan 2007 – 2012.

Viswanadham, J. K., Punnaiah, K. C. and Rao, C. R. S. (1986). Studies on certain bait compositions against tobacco caterpillar, *Spodoptera litura* Fabricus (Noctuidae; Lepidoptera). Andhra Agric. J., 33: 16 – 19.

Wahyudi, T. (2003). Effects of carbon dioxide concentration on stored product insects, afflatoxin production and storage quality changes in cocoa beans. Thesis submitted to the school of Graduate Studies, Universiti Putra Malaysia, in fulfillment of requirement for the degree of Doctor of Philosophy. Pp. 4.

Wakefield M. E. (2006). Storage arthropod detection-current status and future directions. 9th International Conference on Stored Product Protection. Pp. 371 – 384.

Wakefield, M. E., Collins, L. E., Bryning, G. P., Chambers, J., Cox, P. D., Fennah, K., Al-Zaidi, S., Cross, D. and Braithwaith, M. (2006). Improved detection and monitoring of beetle pests in stored grain through use of a multi-species lure. [Available on line] http://publications.hgca.com/publications /documents/cropresearch/ PR396_Final_Project_Report.pdf. (Date accessed) 9th March, 2012

Wasserberg, G., Poche, R., Miller , D., Chenault, M., Zollner, G. and Rowton, E. D. (2011). Imidacloprid as a potential agent for systemic control of sand flies. Journal of Vector Ecology, Vol. 36, Supplement 1, pp. 148 – 156.

Weinzierl, R., Henn ,T., Koehler, P. G. and Tucker, C. L.(2005). Insect Attractants and Traps. http://edis.ifas.ufl.edu.

White, W. H., McCoy, C. M., Meyer, J. A., Winkle, J. R., Plummer, P. R., Kemper, C. J., Starkey, R. and Snyder, D. E. (2006). Knockdown and mortality comparisons among spinosad-, imidacloprid-, and methomyl-containing baits against susceptible *Musca domestica* (Diptera: Muscidae) under laboratory conditions. Journal of Economic Entomology 100(1):155-163. 2007.

Wiltz, B. A., Suiter, D. R. and Gardner, W.A. (2009). Activity of bifenthrin, chlorfenapyr, fipronil and thiamethoxam against Argentine ants (Hymenoptera: Formicidae). Journal of Economic Entomology, 102(6), 2009, pp. 2279 – 2288.

Wren, H. N.(1996). Discovery and development of a new bait for control of pests insects. Proceedings of the second international conference on urban pests. Pp. 235 – 243.

Yuekai, W., Chen, B. T. and Teng, O. G. (2011). Damage of coffee bean weevil (*Araecerus fasciculatus* De Geer) on its new host Jetropha curcas L. Journal of plant diseases and pests, Cranston, USA. Vol. 2, No.2, pp. 22- 24.

8.0 APPENDICES

APPENDIX **PAGE**

Appendix A: Active ingredients of pesticides used in the preparation of cassava bait

PESTICIDE	ACTIVE INGREDIENT(S)	QUANTITY OF ACTIVE INGREDIENT
Confidor 20 SC	Immidacloprid	20% (200g/L)
Deltamost	Deltamethrin	2.5% (25g/L)
	Bioallethrin	0.3% (3g/L)
	Piperonyl butoxide	11% (110g/L)
Fastrack 10 SC	Alpha-cypermethrin	10% (100g/L)

Appendix B: Table of time between feeding on insecticidal cassava bait at varied concentrations of three pesticides and knockdown of *Araecerus*

Treatments	**Concentration of insecticidal bait (%)**	**Time of first *Areacerus* to drop dead/ mins**			**Total**	**Mean/min**
		1	**2**	**3**		
Confidor 20 SC	25	*	*	*	-	-
	50	*	*	*	-	-
	75	14	16	13	43	14.3
Fastrack 10 SC	25	*	*	*	-	-
	50	37	29	25	91	30.3
	75	10	9	13	32	10.7
Deltamost	25	6	7	6	19	6.3
	50	5	6	7	18	6.0
	75	5	3	4	12	4.0
Control (chips in sugar sol.)		*	*	*	-	-

* Time not applicable.

Appendix C: ANOVA table for preference of *Araecerus* to cassava preparations

Source	DF	SS	MS	F	P
Product	4	462.667	115.667	66.73	0.0000
Error	10	17.333	1.733		
Total	14	480.000			

Grand Mean 5.0000 CV 26.33

Appendix D: ANOVA table for Comparison of the preference of *A. fasciculatus* to dry cassava chip and chips immersed in brown sugar solution.

Source	DF	SS	MS	F	P
Product	2	688.889	344.444	206.67	0.0000
Error	6	10.000	1.667		
Total	8	698.889			

Grand Mean 8.1111 CV 15.92

Appendix E: ANOVA table for Speed of knock-down

Source	DF	SS	MS	F	P
Treatment	5	1426.28	285.256	36.94	0.0000
Error	12	92.67	7.722		
Total	17	1518.94			

Grand Mean 11.944 CV 23.27

Appendix F: ANOVA table for persistence of pesticide in bait

Source	DF	SS	MS	F	P
Treatment	6	1917.90	319.651	72.96	0.0000
Error	14	61.33	4.381		
Total	20	1979.24			

Grand Mean 15.190 CV 13.78

Appendix G1: ANOVA table for attract-and-kill potential of insecticidal cassava bait at 12 hours

Source	DF	SS	MS	F	P
Treatment	6	217.905	36.3175	21.79	0.0000
Error	14	23.333	1.6667		
Total	20	241.238			

Grand Mean 3.8095   CV 33.89

Appendix G2: ANOVA table for attract-and-kill potential of insecticidal cassava bait at 24 hours

Source	DF	SS	MS	F	P
Treatment	6	360.476	60.0794	25.23	0.0000
Error	14	33.333	2.3810		
Total	20	393.810			

Grand Mean 7.0952   CV 21.75

Appendix G3: ANOVA table for attract-and-kill potential of insecticidal cassava bait at 48 hours

Source	DF	SS	MS	F	P
Treatment	6	614.286	102.381	42.16	0.0000
Error	14	34.000	2.429		
Total	20	648.286			

Grand Mean 10.714 CV 14.54

Appendix G4: ANOVA table for attract-and-kill potential of insecticidal cassava bait at 72 hours

Source	DF	SS	MS	F	P
Treatment	6	622.476	103.746	35.14	0.0000
Error	14	41.333	2.952		
Total	20	663.810			

Grand Mean 11.905 CV 14.43