POSTHARVEST LOSSES AND EVALUATION OF THE BIOEFFICACY OF *Chromolaena odorata* AND *Jatropha gossypiifolia* AGAINST *Sitophilus zeamais* MOTSCH AND *Tribolium castaneum* HERBST IN THE AWUTU-SENYA DISTRICT OF THE CENTRAL REGION OF GHANA

BY

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DECLARATION

I, IRENE SEPEYA KARGBO, do hereby declare that except for the references cited which have been duly acknowledged, this thesis is the result of my own research undertaken by me towards the award of Master of Philosophy degree in Entomology in African Regional Postgraduate Programme in Insect Science (ARPPIS), University of Ghana, Legon. This work has never been presented anywhere either in part, or in whole for the award of any degree.

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ABSTRACT

A survey was conducted within five maize farming communities namely: Ahentia, Bontrase, Chochoe, Kroebogyir and Kwai-Blagu in the Awutu-Senya District in the Central Region of Ghana to determine the perception of maize farmers with respect to grain losses in their storage structures. The two major insect pests of maize encountered in the district namely *Sitophilus zeamais* Motschulsky and *Tribolium castaneum* Herbst were used as test insects. Bio-efficacies of diethyl-ether and methanol extracts of dried *Jatropha gossypiifolia* L. and *Chromolaena odorata* (L.) King and Robinson leaf and bark were evaluated as bio-insecticidal agents against the beetles using topical application and grain treatments under laboratory conditions. A conventional grain storage insecticide, pirimiphos-methyl (Actellic 25 EC) was used as a reference product. The assays were run in complete randomized design with three replications. The effect of the methanol and diethyl-ether leaf and bark extracts of the two plant species at different concentrations (20%, 50% and 100%) on the adult insects in grain treatment was also determined in the laboratory. The survey showed that about 80%, 12% and 8% of farmers reported insects, rodents and moulds, respectively, to cause damage to maize grains stored in these traditional storage structures. *Sitophilus zeamais* was the major insect pest identified by farmers and ranked as the most destructive, followed by *T. castaneum*. Most of the farmers (52%) applied either chemicals such as actellic or phostoxin or dried the maize frequently (28%) to control maize grains against pest infestation. Other post-harvest practices such as dehusking and shelling (8%) to prevent further damage were also commonly used by farmers. The laboratory assays of the two plants' parts showed varying levels of toxicity to the two insects, but comparatively the leaf extracts were more toxic than the bark extracts against *S. zeamais* and *T. castaneum*. Both plant products were not as effective as Actellic 25 EC. The methanolic leaf extracts of *C. odorata* and *J. gossypiifolia* were effective at 20% and significantly increased the mortality of *T. castaneum* and *S. zeamais* to 66.1% and 77.7%, respectively. Percentage mortality of the insects was significantly increased at higher concentration of the extracts. The highest mortality of 90% was recorded at 4 ml/L of Actellic for *S. zeamais*. A repellency of 83.3% was recorded for 20% diethyl-ether leaf extract of *J. gossypiifolia* against both insects compared to 100% repellency produced by Actellic against *T. castaneum*. The methanolic leaf extracts of *C. odorata*, diethyl-ether leaf extracts of *J. gossypiifolia* at 20% and reference product completely inhibited the development of both insects (0.0%) as no adults emerged in these treatments. Grains treated with the plant extracts significantly reduced damage caused by *S. zeamais* and *T. castaneum* compared with the untreated grains. The current findings showed that extracts of *C. odorata* and *J. gossypiifolia* could potentially be used in IPM programmes as environmentally friendly products for the management of stored-product beetles and may be exploited for the development of botanical insecticides for grain protection. This would, however, require further field studies to establish levels that would produce consistent and acceptable results.

DEDICATION

This thesis is dedicated to my parents Mr. & Mrs. Alfred C. Kargbo, Sr., for their prayers, encouragement and support, in all my endeavours; especially my daddy who so lovingly and unselfishly cared for my kids during the course of this study, my daughters-Angel, Nenneh and Uche for their patient love, and my siblings who always wished the best for me.

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Plate

LIST OF ABBREVIATIONS

AEO ……………………………………………………Agricultural Extension Officers

a.i ……………………………………………………Active ingredient

BCFM …………………………………………………..Broken Corn and Foreign material (USDA)

CFP……………………………………………………..Brazilian Financing Commission

°C………………………………………………………Degree Celsius

cm………………………………………………………centimeters

CO_2…………………………………………………… carbondioxide

COG……………………………………………………cost of grain

E.g………………………………………………………example

FAO……………………………………………………Food and Agriculture Organization

Fig………………………………………………………Figure

FW……………………………………………………...final weight

g………………………………………………………...grams

GDP……………………………………………………Gross Domestic Product

GH¢……………………………………………………Ghana cedis

GISD…………………………………………………..Global Invasive Species Database

GLSS…………………………………………………..Ghana Living Standard Survey

ha………………………………………………………hectares

HGCA …………………………………………………Home Grown Cereal Association

IITA……………………………………………………International Institute of Tropical Agriculture

IPCS INCHEM……………………………………..International Programme on Chemical Safety

IPM……………………………………………………Integrated Pest Management

ISSER …………………………………………………Institute of Statistical Social and Economic Research

kg……………………………………………………...kilograms

LSD……………………………………………………Least Significant Difference

m………………………………………………………meter

MC……………………………………………………..Moisture content

ml……………………………………………………...millimeter

MoFA……………………………………………….Ministry of Food and Agriculture

MT………………………………………………….metric tonnes

OPs……………………………………………….Organophosphates

ppm……………………………………………....parts per million

rpm………………………………………………..revolutions per minute

SPSS……………………………………………..Statistical Package for Social Sciences

spp…………………………………………………species

SRID……………………………………………..Statistics, Research and Information Directorate of MoFA

SVW……………………………………………..Standard Volume Weight

TROPICOS……………………………………..Botanical Garden Information System

TGM……………………………………………..Thousand Grain Mass

TND……………………………………………..Total number of destroyed and missing grains

UW………………………………………………..undamaged weight

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Introduction

Grains constitute the most important staple food for the growing population in most parts of the world and are usually stored to provide food reserve and seeds for planting (Niber, 1994). Maize is a very important crop of the world after wheat and rice (Purseglove, 1992).

Maize (*Zea mays*) originated in America, and is now the principal cereal crop in the tropics and sub-tropics (FAO, 1992). In Ghana, maize is the largest staple crop and is the mainstay of the diet of the majority of Ghanaians, because it is the base for several traditional food preparations (such as *banku*, *kenkey*, *tuozafi*) (Morris *et al*., 1999). Additionally, it represents the second largest commodity crop in the country, after cocoa (ISSER, 2012). Maize is also the main component for poultry and livestock feed (Asiedu *et al*., 2002).

Maize accounts for 50 – 60% of the total cereal production in Ghana (Egyir, 2003; ISSER, 2012). The total average annual maize production in Ghana between 2007 and 2012 was 1.5 million MT (MoFA, 2012), which indicates that maize supply in Ghana has steadily been increasing over the past few years. It is estimated that Ghana is about 99% self-sufficient in domestic maize production, therefore proper storage practices should be done in order to reduce postharvest losses to major storage insect pests which has been recognized as an increasingly important constraint to food security.

Many factors including biotic (insect pests, mites, rodents and micro-organisms) and abiotic (high moisture content, relative humidity and temperature) account for the post-harvest losses of maize both in the field and storage and are responsible for the decline in quality, nutrition and germination potential in storage (Forsyth, 1962; Devereau *et al*., 2002).

Stored maize is attacked by 20 different species of insect pests (Mould, 1973; Ayertey, 1979). Some of the major insect pests of stored maize are *Sitophilus zeamais* Motsch (Coleoptera: Curculionidae), *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) and *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae). In Africa the estimates of maize grain losses in storage vary but are known to be in the range of 20–30% (Markham *et al*., 1994; Van Gastel *et al*., 1999; Lamptey, 2000; Nyanteng and Asuming – Bempong, 2003; Egyir, 2003). In Ghana, there are reports of losses averaging 30% or more of grain dry weight in maize stored on farm due to infestation by *Tribolium castaneum* (Herbst), *Sitophilus zeamais* (Motsch) and *Sitotroga cerealella* (Olivier) (IITA, 1995; Egyir *et al*., 2008); and out of an estimated total annual harvest of 250,000-300,000 tonnes of maize about 20-25% is lost to *S. zeamais* alone (Ayertey, 1982; Obeng-Ofori and Amiteye, 2005). Such losses lower both the incomes and standard of living of farmers and also lead to wastage of a large proportion of the contribution to the nation's food supply and can pose a serious threat to the nation's food security (Asiedu and Van Gastel, 2001; FAO, 2004). Apart from the actual nutrient losses, kernels damaged by insects may be contaminated with dangerous levels of aflatoxins (IITA, 1995). Additionally, there is contamination by dead beetles, pupae and larval cocoons, some of which contain highly dangerous substances (IITA, 1995).

Storage losses may be the major cause of maize price variability in Ghana. Agricultural produce either of plant or animal origin, durable or perishable begins to deteriorate as soon as they are harvested. This deterioration may commence within few minutes after harvest resulting in partial or complete loss (Boxall *et al*., 2002). It may also take place very slowly making the crop retain some essential quality for months (Setamou *et al*., 1998).

Currently, insect control in stored food products relies heavily on the use of fumigants and residual chemical insecticides. These synthetic insecticides have made a tremendous impact over the years in stored product protection. However, misuse of these chemicals has promoted faster evolution of resistant forms of pests, destroyed natural enemies, turned formerly innocuous species into pests, harmed other non-target species and contaminated food (Obeng-Ofori *et al*., 1997). These concerns have stimulated the search for cheap, easily biodegradable and readily available natural products for stored product protection (Owusu, 2001; Obeng-Ofori, 2007). The use of locally available plant materials to protect stored products against pest damage is a common practice in traditional farm storage systems in most developing countries (Poswal and Akpa 1991; Boeke *et al*., 2004). A bulk of information is available on the effectiveness of insecticidal plants to control storage pests (Obeng-Ofori and Coaker, 1990; Owusu, 2001; Owusu *et al*., 2008; Boateng and Kusi, 2008; Udo *et al*., 2009).

Jatropha gossypiifolia and *Chromolaena odorata* are plants with medicinal value that have long been known to contain some insecticidal properties (Weaver *et al*., 1995; CIAT, 2001; Talukder, 2006).

1.2 Justification

The study sought to assess the postharvest losses in some selected traditional maize grain storage structures in the Awutu-Senya District of Ghana and to evaluate the bio-efficacy of *C. odorata* and *J. gossypiifolia* for the control of *S. zeamais* and *T. castaneum* in stored maize.

This is because effective storage stimulates both production and consumption of grains. Despite the widespread and continuous use of traditional storage practices by small scale farmers in the Awutu-Senya District, no quantitative information on maize grain losses is available. Also based on the fact that information of post-harvest losses is about 20 years out of date, there's a need to assess the losses in these selected storage structures to update the quantitative information of maize grain losses that lower both the incomes and standard of living of farmers and can pose a serious threat to the nation's food security (Asiedu and Van Gastel, 2001; FAO, 2004). Considering the importance of maize in providing daily calorie needs and an ingredient for poultry and livestock feed, protecting maize from stored product pests is of utmost importance. Therefore, there is need to determine the causes, types and level of losses of grains that occur during storage. This will help make suggestions that will lead to the effective and efficient storage of grains in the selected storage structures in the Awutu-Senya District. Such information is essential to increase the overall quantity and quality standards of maize grain, income and standard of living of farmers. Furthermore, the study would add to the body of knowledge on botanical insecticides that are environmentally safe and friendly to control storage pests making food available to man, his livestock and the industries, and thus providing gainful employment.

1.3 Objectives

The main objective of the study was to assess storage losses in traditional storage structures in the Awutu-Senya District of Ghana and to evaluate the bio-efficacy of extracts of *J. gossypiifolia* and *C. odorata* against *S. zeamais* and *T. castaneum* in stored maize. The specific objectives were:

I. To survey and determine the causes and types of grain losses that occurs in the different traditional storage structures.

II. To identify the most potent part(s) of *C. odorata* and *J. gossypiifolia* against *S. zeamais* and *T. castaneum* infesting maize using Pirimiphos-methyl (Actellic) as a reference.

III. To determine the toxicities and repellencies of the methanol and diethyl-ether extracts of the most potent plant parts against *S. zeamais* and *T. castaneum.*

IV. To determine the effect of these extracts on the emergence of adult *S. zeamais* and *T. castaneum* in treated grains.

V. To assess the effect of these extracts on grain damage by adult *S. zeamais* and *T. castaneum* that occurs in the different traditional storage structures.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and uses of maize

Maize is a member of the grass family, Gramineae, and an important grain crop in the world after wheat and rice (Purseglove, 1992). Maize (*Zea mays*) originated in America, and is now the principal cereal crop in the tropics and sub-tropics (FAO, 1992). Maize is grown on every continent and in many countries and has almost replaced cereals such as sorghum and millet (FAO, 1992). It is an important crop in the economy of Ghana, and is grown by the vast majority of rural households in all parts of the country, except for the Sudan savannah zone of the far north, and it is a leading staple in the Southern Central, Volta and Northern Regions (Morris *et al*., 1999). Maize is prepared and consumed in many ways depending on region or ethnic group. For example in Ghana, *kenkey, tuozaafi* and *banku,* and Nigeria, meals such as *eba* and *eko* are prepared from maize (Morris *et al*., 1999). In some parts of Africa, maize is mainly consumed as thick porridge (*ugali* in East Africa and *sadza* in Zimbabwe). A thin porridge (*uji* in East Africa, *ogi* in Nigeria, *koko* in Ghana) is also commonly eaten, especially as a weaning food (Morris *et al*., 1999).

2.2 Maize production in Ghana and its contribution to the economy

Agriculture continues to be the bedrock of Ghana's economy accounting for more than 48% of GDP in 2011, at a growth rate of 13. 5% and contributed to about 50% of foreign exchange earnings (GLSS, 2008; ISSER 2011). In terms of sales value, maize is an important cash crop in Ghana.

Maize is produced in all the ecological regions in Ghana, namely the Forest, Coastal Savannah, Forest Savannah transition, Guinea Savannah, Sudan Savannah and Sahel Savannah (Egyir, 2003).

According to the Ghana Living Standard Survey (GLSS, 2000), climatically, there are three ecological zones, the northern savannah, coastal savannah and forest zones. In the forest zone the climate is dominated most of year by moist air and conventional rainfall is frequent. The rainfall is usually between 1000 and 2000 cm per annum, falling in two seasons with only a short dry season of reduced rainfall between them. In Southern Ghana, where this condition is prevalent, two cropping seasons of maize are possible. The savannah areas may have two short rainy seasons and a pronounced intervening dry season, as in the coastal areas, or a medium, lengthy rainy season and a long dry season as found in most parts of Northern Ghana.

Although, maize production cuts across all the 10 regions of Ghana, the Eastern, Ashanti, Central, Brong-Ahafo and the Northern Regions are the five major growing areas (SRID of MOFA, 2011).

Maize is produced mostly by small-scale farmers using simple hand tools such as hoe and cutlass. Very few commercial maize farms are in operation presently in Ghana (e.g.Ejura Farms). The level of production on individual farms is very low, hence the need to minimize postharvest losses. The common varieties cultivated in Ghana include *Obaatanpa*, *Abasa, Okomasa*, *Abrotia, Dobidi, Abeleehi and Dodzi* (Aikins *et al*., 2010). The harvested maize cobs in sheath are either stored inside the room either in loose piles, traditional barns or the crib.

Table 2.1 shows the quantity (in metric tonnes) of maize produced from 2002-2010 in the 10 regions of Ghana. The total area planted and quality of maize produced in Ghana from 2006 – 2010 is also shown in Table 2.2.

While there is no recent reliable data for corn used in animal feed, the COG estimates that 85% of all corn grown in Ghana is destined for human consumption and the remaining 15% is used for animal feeding sector (mainly poultry) (Grain and Feed Annual Grain Report, 2011). Thus, to meet the increasing demands of maize, farmers may have to adopt improved production and handling systems. In the Central Region of Ghana, the total maize production in the years 2008, 2009, and 2010 were 182,000, 187,383 and 195,394 MT, respectively (www.ghananation.com).

Table 2.1: Quantity of maize produced in the different regoions of Ghana from 2002-2010 (in Metric Tonnes)

Regions	2002	2003	2004	2005	2006	2007	2008	2009	2010
Western	86,520	86,520	159,622	72,135	73,210	75,406	77,553	75,210	74,191
Central	247,110	247,110	159,622	164,398	166,847	176,222	182,000	187,383	195,394
Eastern	218,900	244,000	241,621	206,467	209,542	227,505	280,806	303,400	380,505
Gt. Accra	2,610	2,610	2,714	2,103	2,134	2,775	2,882	3,210	3,584
Volta	58,630	58,630	53,868	47,577	48,286	49,978	72,858	78,868	93,887
Ashanti	187,000	193,920	183,032	161,816	164,226	169,383	182,848	186,830	253,374
Brong-Ahafo	295,680	295,680	281,267	358,259	363,595	381,435	402,688	453,816	510,172
Northern	79,050	79,050	74,566	96,717	98,157	88,037	131,857	162,622	202,316
Upper-West	60,710	60,710	60,801	47,422	48,128	40,104	55,223	73,610	96,018
Upper-East	20,370	20,370	14,650	14,496	14,712	8,756	27,528	51,143	62,256
Total	1,256,580	1,288,600	1,157,621	1,171,390	1,188,836	1,219,601	1,416,243	1,576,092	1,871,697

Source: Statistics, Research and Information Directorate (SRID), MoFA (2002-2010)

Table 2.2: Total Area planted and quality of maize produced in Ghana (2006-2010)

2006	2007	2008	2009	2010
		Area planted (000, ha)		
793	790	846	954	992
		Quality produced('000, tonnes)		
1188	1220	1470	1620	1872

Source: ISSER, 2006-2011; The World Bank Group, 2011

2.3 Classification of grain quality

To facilitate marketing and to identify the best uses for the various types of maize produced throughout the world, measures of grain quality have been determined, although they may not be accepted by all maize - producing countries (FAO, 1992). In the United States maize is classified into five different grades, based on several factors (FAO, 1992). The maximum permitted amount of broken maize and foreign material (BCFM) varies from 2 percent for Grade 1 to 7% for Grade 5. Maize is also classified as yellow, white or mixed maize. Yellow maize must have not more than 5 percent white kernels and white maize must not have more than 2 percent yellow grains. The mixed class contains more than 10 percent of the other grain (Schuler *et al*., 1978; FAO, 1992).

Moisture content of maize is an important part of its chemical composition and it is fundamentally important in establishing safe storage conditions (Devereau *et al*., 2002). Changes in moisture content also cause a change in overall weight of a commodity, and as products are often traded by weight this has obvious financial implications (Devereau *et al*., 2002). Although the moisture content of maize is not considered a quality factor, it has much influence on composition, quality changes during storage and processing (Golob *et al*., 2004). High moisture content in maize with a soft texture is easily damaged in storage, while maize with low levels of moisture becomes brittle. The most commonly accepted moisture level for marketing purposes is 15.5% (FAO, 1992). Density of maize (weight per unit volume) is important in storage and transportation since it establishes the size of container for test weight are related; the higher the moisture level the lower the specific density test weight and this affects milling (Devereau *et al*., 2002).

Another important quality characteristic of maize is its hardness, which influences grinding power requirements, dust formation, nutritional properties, processing for food products and the yield of products from dry and wet milling operations (FAO, 1992). Hardness of maize is genetically controlled, but it can be modified by both cultural practices and post-harvest handling conditions (FAO, 1992). Many investigators have proposed methodologies for measuring hardness for a number of different applications (Pomeranz *et al*., 1984; 1985; 1986). Maize varieties with a horny endosperm such as flint and popcorn types have hard kernels, while starchy and opaque maize varieties are soft. Some flint types are intermediate (FAO, 1992).

2.3.1 Grain losses

Food grain losses may be direct or indirect. A direct loss is disappearance of food by spillage, or consumption by insects, rodents and birds (Schuler *et al*., 1978). An indirect loss is the lowering of food quality to the point where people refuse to eat it (Mejia, 2003). Post-harvest crop losses occur at different stages: - from the moment when crops are harvested until they are sold at the market. These stages include field handling, on-farm storage, processing, packaging, transportation and market handling (Mejia, 2003). Post-harvest crop losses, especially in grains are due to insect, rodent damage and fungal infection (Adesuyi, 1982; Farrell *et al*., 2002).

Post-harvest losses in grain, in the developing countries are estimated at 25-40% of the total crop harvested (Salunkhe *et al*., 1985; Voices Newsletter, 2006). This means more than one-quarter of what is produced never reaches the consumer for whom it was grown, and the effort and money required to produce it are lost forever. Estimates of maize grain loss in storage vary but are known to be in the range of 20% - 30% (Lamptey, 2000; Egyir, 2003).

Post-harvest losses can have very serious implication for farmers, consumers and the environment (Golob *et al*., 2002). Farmers' financial and food security can be severely affected, while consumers face hunger if post-harvest losses of important staple crops occur on a wide scale in the area where they live. Consumers also risk illness if they eat food that has been infected by fungi or other contaminants (Voices Newsletter, 2006).

Losses may be qualitative or quantitative, or a combination of both, and result from the inability of the host to limit biological damage (Thompson, 1996). In addition, produce may be predisposed to further attack because points of entry for secondary insect pests and saprobic fungi have been created by the existing damage (Waller, 2001). Produce with surface blemishes, such as discoloration, blotches or signs of insect activity, may be rejected by graders or consumers and hence give rise to qualitative losses (Cantwell and Kader, 2006). Qualitative losses are particularly important in the international trade, where emphasis is placed on visual quality, and where even a small cosmetic defect may render the produce unsaleable (Waller, 2001). Quantitative losses arise when stored produce is directly consumed by primary insect pests and rodents, or from the rapid and extensive decay caused by the action of micro-organisms (Wills *et al*., 1998).

Attack usually begins with one or a few species, followed by invasion of a broad range of non-specific micro-organisms or secondary insect pests (Golob *et al*., 2002). The feeding habits of primary pests may lead to quality losses, since some insects exhibit a preference for feeding on the germ region of the seed, leading to a loss in nutritive value and seed viability in cereal grains (Farrell *et al*., 2002).

2.3.2 Estimates of post-harvest losses

Losses may occur at all stages in the post-harvest system; during transportation to the home, in storage and at processing, but it is very difficult to assess losses which occur at each of these stages (Boxall *et al*., 2002). The ability to accurately assess the losses during grain storage in different structures is essential in determining the extent of losses and protection a given structure can provide for the grains over a certain period. Most estimates have focused on measuring weight loss during storage. In Malawi, losses in stored local maize were found to be 3% or less for maize stored up to 10 months in the Lilongwe Plain and Lower Shire Highlands (Golob, 1981) and similar losses have been recorded in Zambia (Adams and Harman, 1977) and Kenya (De Lima, 1979). Over the past 25-30 years various levels of postharvest losses, especially grain have been quoted as between 25-30% (Lamptey, 2000). Estimates of losses in Ghana have been given at one time or the other as 12% (1951), 25% (1968), 10-30% (1976) 25.3% (1985) and 20% (1998) (Bani, 1991a & b).

The estimated loss of maize, sorghum, millet and rice are approximately 18%, 7.5%, 6.6% and 5.5% respectively (Egyir *et al*., 2008). For the cereals, most losses occur during harvesting, temporary processing, packaging, storage, transportation and loading. The minor season losses appear lower for all the cereals, except rice. Egyir *et al*. (2008) estimated the average losses of maize to be 13.95%. Most of these losses have been attributed to damage caused by insects, rodents, rainwater, birds, fire, moulds, and ground water (Farrell *et al*., 2002).

2.3.3 Factors and causes of grain loss

Perishable and durable stored food may be considered to be an ecosystem (Multon, 1988; Sinha, 1995). The interactions between the physical, climatic, chemical and biological factors within the ecosystem lead to changes in the quality and nutritive value of the stored product (Saucer, 1992; Jayas, 1995; HGCA, 1999).

Knowledge of these factors is necessary if the quality and quantity of stored products are to be maintained. The physical factors which are most important during storage are temperature, moisture content of the crop, relative humidity of the atmosphere and concentration of atmospheric gases (oxygen, carbondioxide) (HGCA,1999). All living things, including the stored product itself, insects, mites and micro-organisms within the store are affected by these factors. Control of losses and maintenance of desirable quality traits depends to a great extent upon the measurement and control of these physical factors (HGCA, 1999). Physical factors do not exist in isolation. There are defined relationships between many of them, influenced by the presence and type of stored product. A change in one physical factor may lead to changes in another, and may lead to conditions which either promote or prevent spoilage (Mejia, 2003). Physical factors are those that directly affect the nature and appearance of the stored commodity, thereby determine its susceptibility to pest attack (Mejia, 2003). Climatic factors include temperature, humidity and moisture content. Biological factors include insects, mites, rodents and fungi. Many aspects of insect development and behavior are controlled by physical and environmental conditions of both the stored grain and the storage premises (HGCA, 1999; Mejia, 2003; Golob *et al*., 2002). Since most of these factors are quantitative, it therefore can affect insect biology in proportion to their intensity, while others trigger or control behavior (Saucer, 1992).

The magnitude of storage losses in a given instance is, therefore due to the combined effects of the physical and biological factors. The losses could be minimal in cool dry areas, high in cool damp conditions, marked in hot, dry areas and very high in hot damp climates (Golob *et al*., 2002). The type of storage structures used during storage and the storage management can regulate the effects of these factors (Hoseney and Faubion, 1992).

2.4 Insect pests of stored maize

Stored produce is at risk from problems not faced by crops in the field because seeds and fruits are essentially dormant structures; their cells are physiological different from those of the growing plant (Golob *et al*., 2002). In addition, bulking of produce, in store or transit, gives rise to conditions very different from those in the field (Wheeler, 1969). A wide range of biological factors influence stored products. Any organic product that is not kept in a sterile manner is liable to be degraded by some biological agent, if it is kept long enough (Golob *et al*., 2002). Insects of the Orders Coleoptera and Lepidoptera are known to cause most damage to stored grains and grain products throughout the world (Fatope *et al*., 1995; Abate *et al*., 2000). These may occur on commodities as primary or secondary pests and the extent of damage depends on the stage of the development or growth of the insect. In Ghana, the most frequently encountered storage insect pests of cereals including maize are *Sitophilus zeamais* (Motsch.), *Sitophilus oryzae* (L.), *Tribolium castaneum* (Herbst), *Callosobruchus maculatus* (F.), and *Prostephanus truncatus* (Horn) (Fatope *et al*., 1995; Abate *et al*., 2000). The major moth pests include *Ephestia cautella* (Walker), *Ephestia kuehniella* (Zeller), *Ephestia elutella* (Hubner), *Plodia interpunctella* (Hubner), *Corcyra cephalonica* (Stainton) and *Sitotroga cerealella* (Olivier). In Africa, maize production is generally low because of the incidence of insect pests. According to FAO (1985) and Golob *et al*., (1999), the greatest loss of maize occurs during storage and is caused by four agents: moulds, mites, vertebrate and insect pests. *Sitophilus* species have been implicated as the major insect pests of stored maize particularly in the tropics, and cause 50% of the total damage of stored maize worldwide. In Ghana, out of an estimated total harvest of 250,000-300,000 tonnes of maize about 20% are lost to *Sitophilus zeamais* (Obeng-Ofori and Amiteye, 2005).

2.4.1 Damage caused by insect pests of stored maize

Insects that attack stored cereals and grain legumes can be described as either primary or secondary pests. Primary pests are those species that are capable of successfully attacking undamaged grain and establishing an infestation; they breed in previously undamaged solid grains, for example, whole cereal and pulse grains (Obeng-Ofori, 2008a). This means that they are capable of penetrating an undamaged seed coat and sometimes also a pod in order to feed on the embryo, endosperm or cotyledons of the seed. Such pests are capable of feeding on other solid, but non-granular commodities, for example, dried cassava (Belmain, 2002). Secondary pests only attack and breed in commodities that have been previously damaged by some other agency: a) other pests, especially primary pests, b) bad threshing, drying, handling, etc., or c) intentional processing of the commodity (Farrell *et al*., 2002).

Sitophilus spp: They are the largest order of insects and the most largely researched (Obeng-Ofori, 2008a). Three species are well known as pests of stored grain: *Sitophilus zeamais* known as the maize weevil, *S. oryzae* often called the rice weevil, and *S. granaries* referred to as the granary weevil. Adult *Sitophilus* feed especially on grain endosperm that has been exposed by breakage or by entering emergence holes. *S. zeamais* and *S. oryzae* are commonly found throughout the world in the tropical and subtropical regions (Longstaff, 1981; Belmain, 2002).

S. zeamais and *S. oryzae* thrive best at warm temperatures (27^{o}C) and in grain with not much less than 13% moisture content (Karma, 2000).

Rhyzopertha dominica (Fabricius) and *P. truncatus* (Horn): Most members of the Bostrichidae are wood-boring insects, but two species, the lesser grain borer, *R. dominica* and the larger grain borer *P. truncatus*, are able to thrive in stored products such as cereals and dried cassava roots and are important primary pests (Obeng-Ofori, 1995; 2008). *Prostephanus truncatus* is a serious pest of maize stored on the cob and can tolerate dry conditions breeding on maize with 9% moisture content. Its ability to develop in grain at low moisture content may be one of the reasons for its success (Pederson, 1992; Belmain, 2002). It has been shown to cause about 34% and 70% weight loss in maize and cassava stored for 3-6 months and 4 months, respectively in Tanzania. In Nicaragua, weight losses of up to 40% had been recorded from maize cobs stored on farms for six months (Farrell *et al*., 2002). Adult and larvae *R. dominica* and *P. truncatus* bore into whole cereals and feed throughout their lives, producing large quantities of dust and frass containing a high proportion of undigested fragments, which can support larval development if sufficiently compacted (Nang'ayo *et al*., 1993; Farrell *et al*., 2002). *Prostephanus truncatus* infest maize cobs with intact sheaths, the adult initiate their attack through the maize cobs gaining access to the maize by the apex of the cob. *Rhyzopertha dominica* and *Prostephanus truncatus* are adapted to rather higher temperatures and lower moisture contents and are therefore the dominant pests in hot, drier areas (HGCA, 1999).

Tribolium castaneum: *Tribolium castaneum* feeds on a range of commodities, especially cereals, but also groundnuts, nuts, spices, coffee, cocoa, dried fruit and occasionally pulses (Obeng-Ofori, 1991). They also feed on animal tissues, including the bodies of dead insects and attack and eat small or immobile stages of living insects, especially eggs and pupae. Heavy infestations by *T. castaneum* can produce disagreeable odours and flavours in commodities due to the production of benzoquinones from the abdominal and thoracic defence glands of the adults (Leconti and Roth, 1953; Obeng-Ofori, 1991).

Sitotroga cerealella: *Sitotroga cerealella* is an important primary pest of cereals and can infest grain in the field before harvest, especially maize and sorghum. The adults are good fliers and cross-infestation occurs easily. Infestations in bulk grain are generally confined to the outer, most exposed layers (Belmain, 2002). However, quite serious infestations can develop in cereals stored in bag stacks, especially if the pre-harvest infestation has been heavy. Infestations of the pest are most frequently encountered in farm storage since the larvae compete with those of *Sitophilus* spp (Karma, 2000).

2.4.2 Storage losses caused by insect pests of maize

Insect pests damage to stored grain results in major economic losses to farmers throughout the world (Obeng-Ofori *et al*., 1997). These losses are diverse and intense, and it is estimated that approximately one-third of the world's food crop is damaged or destroyed by insect pests during growth, harvest and storage (Jacobson, 1985). Insect pests constitute a single most important cause of post-harvest losses in the tropics (Prempeh, 1971), which have been estimated at 20-30% (Dick, 1988).

In Africa, where subsistence grain production supports majority of the population, grain losses caused by storage insect pests such as *Sitophilus* and *Callosobruchus* can be critical (Golob and Tyler, 1994). Furthermore, approximately 70% of agricultural products in Africa are stored on-farm for periods extending from one harvest to the next and sometimes longer (Golob, 1997). During storage, the produce is susceptible to attack by many different pests of which insects are the most important. In Ghana, about 20% of annual maize and cowpea production of 750 and 300 metric tonnes respectively are lost to insects (Owusu-Akyaw, 1991).

In the Sahel region, post-harvest losses are significant for bagged maize and sorghum because of damaged caused by insects and rodents (Alzouma, 1990). On the other hand, beetles can cause up to 40% loss of the region's legume production. Despite the fact that cereal production in North Africa is insufficient, this problem is compounded due to losses during post-harvest operations, particularly because of pest infestation in storage (Bartali, 1990). In spite of major technological advances in agriculture, the world food deficit situation remains serious (Anon, 1982).

Stored product beetles and moths can cause losses to grain in storage, either directly through consumption of grain, or indirectly by producing 'hot spots,' causing loss of moisture, and thereby making grain more suitable for other pests (Longstaff, 1986; Talukder and Howse, 1994). The ability to detect insect pests is fundamental to most recent strategies of stored product insect pest control (Giga and Canhao, 1992). Early warning of pest presence can be used to prevent damage and an efficient detection programme can lead to a reduction in losses and pesticide use.

2.5 Biology and behaviour of the maize weevil, *Sitophilus zeamais*

Sitophilus zeamais is found in all warm and tropical parts of the world (Hill, 1983). The weevil has a characteristic rostrum, which is a forward snout-like extension of the head and carries the mouth parts in a position that is ideal for penetrating plant tissues (Plate 2.1). The antennae are elbowed and eight segmented and always carried in an extended position when the insect is walking. There are four pale reddish-brown or orange-brown oval markings on the elytra, which cover the entire abdomen (Hill, 1983).

Plate 2.1: Adult *S. zeamais* (Source: CABI, CPC)

Sitophilus zeamais belongs to the Family Curculionidae, which is a large family of beetles that attack a range of plant tissues, with their larvae always being borers in roots, stems or seeds of plants. They are good fliers that are able to infest grains prior to harvesting (Caswell, 1962). Adults live from several months to one year and about 150 eggs can be laid throughout their adult life. The eggs are laid individually in small cavities chewed into grains by the female, each cavity is sealed and the egg protected by a gelatinous waxy secretion usually referred to as an 'egg-plug' produced by the female. The incubation period of the egg is about six days at 25^{o}C (Howe, 1952). Temperature and moisture content are the chief factors determining the abundance of *S. zeamais* and the pest fails to develop when the moisture content of the grain is below 9%. Upon hatching, the larva begins to feed inside the grain, excavating a tunnel as it develops. There are four larval instars and at 25^{o}C and 70% relative humidity, pupation takes place within the grains in about 25 days (Haines, 1991). The newly developed adult chews its way out leaving a characteristic emergence hole. Total developmental period ranges from about 35 days under optimal conditions to over 110 days in unfavourable conditions (Haines, 1991).

2.6 Biology and behaviour of the red rusty flour beetle, *Tribolium castaneum*

Tribolium castaneum is thought to have originated from India, but is now found throughout all tropical, sub-tropical and warm temperate areas of the world. The beetle is red-brown in colour with 11-segmented antennae, which are distinct club-like in shape (Plate 2.2).

Plate 2.2: Adult *T. castaneum* (Source: CABI, CPC)

Tribolium castaneum lives on a wide range of commodities and also feeds as a predator on other insects. It has been reported as one of the most destructive secondary stored product beetle pests in the world (Boateng and Obeng-Ofori, 2008) attacking milled cereals and animal feeds, and does not multiply rapidly on dry cereal grains if these are undamaged and free of grain fragments or other dockage (Haines, 1991). The larvae and adults feed on a wide range of durable commodities and are important secondary pests of cereals having a preference for the embryo. It also feeds on groundnuts, nuts, spices, coffee, cocoa, dried fruit and occasionally, peas and beans. They can penetrate deeply into the stored commodity.

Cannibalism and predation play a very important role in the nutrition of *T. castaneum* with the eggs and pupae often consumed by the adults. The females, which may copulate many times, lay their rather sticky eggs in the commodity throughout their adult lives. However, the number of eggs laid depends on the temperature. Under optimum conditions of 35^{o}C and 75% relative humidity, larvae emerge from eggs approximately three days after oviposition. The upper and lower temperature limits for development are 40 and 33^{o}C (Haines, 1991). Under optimum conditions, *T. castaneum* has a very short life cycle which contributes to its high rate of increase, calculated as reaching 70 times per lunar month (Haines, 1991). However, cannibalism, parasitism, predation, disease and limitations of space and food curtail the high rate of increase, even though these density-dependent controls may be eased by emigration of the active flying adults. *T. castaneum* is a colonizing species (Dawson, 1977) and in shelled groundnuts for example, it is often the first stored-product pest to appear after harvesting and shelling. In late afternoons many individuals fly from the surfaces of infested sacks, especially when infestation is heavy. Their long life span and long reproductive period enable the insect to spend a considerable time searching for new food sources.

2.7 Maize handling and storage

At harvest time there is much more to eat than required, hence the need to store for future use.

Various storage structures have been designed using different materials (natural and artificial) for the storage of maize in Ghana (Lamptey, 2000). Crop storage may be defined in simple terms as the process of taking the crop at its point of maximum palatability and nutritive values whilst maintaining these values without allowing them to deteriorate over an indefinite period of time (Lamptey, 2000). In storage, however, the inherent qualities of the produce are seldom maintained and these may reduce to unacceptable levels. This is in part due to the inability of selected storage structures and methods to hold the commodity, keep out moisture, dry, control enzymatic activity and microbial growth and keep off rodents, insects and thieves (Lamptey, 2000). Structures for the purpose of grain storage have been designed and constructed with the objective of carrying out such controls. Varying degrees of success in applying the basic principles involved in the storage of grains have been achieved.

Maize is stored at three main levels; these are farmer level, trader or middleman and depot or commercial stores. Structures used for maize storage depend on the form in which the produce is handled after harvest, the production level of the producer/farmer and therefore the quantity handled, duration of storage and intended end use of the produce (FAO, 1994a; World Resources, 1998; Mijinyawa, 2002; Dlamini, 2003). At the farm level, maize is stored dry on the cob with or without the sheath and in simple and inexpensive structures. Quantities of stored maize are taken from these structures periodically and hand shelled for outright sale or bagged for sale at a later date (Lamptey, 2000).

2.8 Maize storage methods and structures

Maize storage technologies are diverse among farmers and these variations have economic implications (Adetunji, 2007). Traditional methods of storage still predominate in most parts of Africa (Brice, 2002). They have been developed to suit the needs of a simple, subsistence farming system. However, as production systems become modernized, these storage methods are not able to cope with increases in production. Modern storage techniques are the best because they have the highest difference in gross margin and highest marginal rate of return (Adetunji, 2007). Nyanteng (1972), Igbeka and Olumeko (1996) and Adetunji (2007) have outlined various traditional storage structures. These include farmhouses, cribs, barns, platforms, warehouse, silos, pens, yards and sheds, deep litter houses; palm fronts woven baskets, hutches and cages.

Although a number of materials are available for construction, cost is found to be a major factor in the selection of materials. There is extensive use of locally sourced materials such as wood, natural fibers and earth for the construction of these structures. The factors which tend to reduce the service life and efficiency of these facilities include rainfall, temperature and insects. The probability of using local storage is enhanced by farmer's age, semi modern structures is influenced by quality of maize stored while the probability of using modern storage structures is increased by years of experience, educational level of the farmers and quantity of maize stored (Adetunji, 2007). Farmers store their food crops in various traditional structures including barns, baskets, sacks, rooms and open sheds. Middlemen in grain trade, package grain in sacks and store them in their warehouses or storerooms in the market whilst sales go on (Adetunji, 2007). These traditional grain storage systems may provide some storage security for traditional farmers. However, this is normally for a limited period and losses can be high. The traditional storage structures provide limited protection against fungal growth, insects and rodents damage, especially in areas where the climate is warm and humid or where grain is stored for extended periods (Mejia, 2003). The increasing demand for cereals has meant that traditional farming systems be improved by introducing and producing high yielding varieties of grains by farmers. However, because of the increased production, the traditional storage system is proving inadequate not only in capacity, but also in protecting grain from damage, since the new varieties may be more susceptible to insect attack. It has therefore become necessary to improve the traditional small-scale, on-farm storage methods.

A storage structure plays a single decisive role in maintaining grain quality after the grain has been properly conditioned and put into storage (Lamptey, 2000). The functions of a storage structure therefore include bearing its own and weight of the produce, creation of appropriate environment within itself for the safe keeping of the produce and resisting any adverse effects of the environment on it and also on the produce (Golob *et al*., 2002). The pre-storage handling of the grain and the structure in which the grain is stored and finally the environment within which the structure is sited are all decisive factors for safe keeping of grain. The effectiveness of the storage structure in fulfilling its function depends on such factors as the choice of structure materials, the design, the constructional details and the initial status of the produce before going to store (Farrell *et al*., 2002).

2.9 Description of traditional storage structures

2.9.1 Temporary grain storage methods

These methods are quite often associated with the drying of the crop, and are primarily intended to serve this purpose. They assume the function of storage if only the grain is kept in place beyond the drying period.

The Traditional Ewe barn: This consists of radiating sticks constructed on legs of wooden stalks of ten to fifteen feet (Plates 2.3 and 2.7). The barn commonly referred to as Ewe barn is mainly used for storing maize. The maize cobs are stacked into a compact cylinder with pointed ends of the maize directed inwards and at an angle. This is an automatic arrangement following the shape of the barn. This arrangement provides some sort of drainage system for rain water falling on the maize. Bark of trees, raffia leaves are sometimes used to cover the stack of maize to prevent rainfall reaching it. Instead of being horizontal and flat, it may be conical in shape which is pointed at the bottom. The platforms are usually between 2 and 3 m in diameter, but some may be more than 6 m wide, with a maximum height of 2.5 m at the centre and 1.5 m at the periphery. Such structures facilitate drying because of their funnel shape (Boxall *et al*., 2002). This is a common practice in Southern Benin, Togo and Ghana.

Aerial storage: Maize cobs, sorghum or millet panicles are sometimes tied in bundles, which are then suspended from tree branches, posts or tight lines, or inside the house. This precarious method of storage is not suitable for very small or very large quantities and does not provide protection against the weather if outside, from insects, rodents or thieves (Plate 2.4).

Open platforms: A platform essentially consists of a number of relatively straight poles laid horizontally on a series of upright posts with a flat top (Plate 2.5). They are mainly used to store unshelled maize in the forest zones. The maize cobs are stacked into a compact cylinder on top of the platform. The peripheral cobs are built up very carefully to form a wall, the inner cobs being loosely packed. The stack of cobs is girdled at intervals with ropes or twines made from the bark of trees to give physical support. If the platform is constructed inside a building, it may be raised at least 1 meter above ground level. They are usually rectangular in shape, but circular or polygonal platforms are common in some countries. In humid countries fires may be lit under elevated platforms to dry the produce and deter insects or other pests (Plate 2.5).

Storage on the ground, or on drying floors: This method can only be provisional since the grain is exposed to all pests, including domestic animals, and the weather. Usually it is resorted to, only if the producer is compelled to attend to some other task, or lacks means for transporting the grain to the homestead.

2.9.2 Long-term grain storage methods

Traditional crib: The traditional crib differs in having a roof and wall(s). It may even be elevated at least one meter above ground levels allegedly, to reduce insect infestation. However, such cribs (especially the larger ones) are more commonly raised only 40 to 50 cm above ground level. These cribs are square or rectangular in shape, being constructed with open or open weave sides to allow extensive air flow. They may be raised up to 2 m off the ground to allow cooking beneath or if very large they may be located directly on the ground (Plate 2.6). Large bamboo or sisal poles are often used in their construction. Cribs have sealable gaps in the wall for the removal of grain.

Storage baskets: Baskets with an open weave are suitable for drying grain, e.g. sorghum heads and maize cobs, especially without husks. They are used in certain parts of the country for storage of cereals especially in the form of grains. Whereas the grains on the head are normally stored on a platform covered with thatch, the threshed grains are normally put in large baskets which are kept on the platform and covered with thatch. These are used in humid countries, where grain cannot be dried adequately prior to storage and needs to be kept well ventilated during the storage period (Plate 2.8). Under prevailing climatic conditions most plant material rots fairly quickly, and most cribs have to be replaced every two or three years, although bamboo structures may last up to 15 years, with careful maintenance (Nyanteng, 1972).

Mud or clay silos: Mud or clay silos are usually round or cylindrical in shape, depending on the materials used (Plate 2.9). Rectangular – shaped bins of this type are less common, because the uneven pressure of the grain inside causes cracking, especially at the corners. Clay, which is the basic material, varies in composition from one place to another; that which is most commonly used for such construction work is obtained from termitaries, because the termites add a secretion which gives it better plasticity. To give it added strength, certain straw materials such as rice straw may be mixed with it to make it almost as durable as concrete. The diversity of materials used explains why the capacity of such silos can vary from 150 kg to 10 tonnes. Such grain stores are usually associated with dry climatic conditions, under which it is possible to reduce the moisture content of the harvested grain to a satisfactory level simply by sun-drying it.

The base of a solid wall bin may be made of timber (an increasingly scarce resource), earth or stone. The roof is usually made of thatched grass, with a generous overhang to protect the mud wall(s) from erosion and a side door is provided for access to the bin.

Grounds, earthenware pots: These small capacity containers are most commonly used for storing seeds and pulse grain, such as cowpeas (Plate 2.10). Having a small opening, they can be made hermetic, by sealing the walls inside and out with a liquid clay and closing the mouth with stiff clay, cow dung, or a wooden bung reinforced with cloth. If the grain is dry (less than 12% moisture content) there is usually no problem with this kind of storage.

Bag storage: Bag storage is a convenient way of keeping threshed grain and pulses. The need to thresh or shell grain may deter farmers from using bags if labour is in short supply at harvest time. These difficulties may be overcome by the use of shellers or threshers. Bags are usually made from jute or woven polypropylene, but hemp, sisal, grass and polythene sacks are also available. Durability of bags will depend on their quality and how they are handled. Jute sacks are more expensive but last longer than woven polypropylene ones, which are liable to degrade in sunlight. With careful use and repair, bags should last for several seasons. Bags provide the flexibility to store different types and different quantities of cereals and pulses. The storage capacity is limited only by the number of bags available and the size of the storeroom. Small numbers of bags may be kept in the farmer's house or in a separate store. This might include a room attached to the house, a simple pole and thatch shelter or a separate building made from traditional or non-traditional materials (bricks and cement).

Bags of grain may also be stored in maize cribs. Ideally, one room or store should be kept for use entirely as a grain store. It is important that bags of grain are never placed directly on the floor. They should be stored on small storage platforms made from wooden poles (dunnage) (Plate

2.11). This will allow air to flow under the stacks and will stop the bags getting wet from the uptake of moisture from the ground. If no wood is available the bags should be stacked on a plastic sheet. The area around the stack should be kept clear of household items that might provide hiding places for insects and rodents. The stack should be well constructed to prevent collapse and kept away from the walls of the store if possible. In the house the stack should be kept away from the kitchen and fireplace.

Underground storage: This method of storage is used in dry regions where the water table does not endanger the contents (Plate 2.12). Conceived for long term storage, pits vary in capacity (from a few hundred kilograms to 200 tonnes). Their traditional form varies from region to region; they are usually cylindrical, spherical or amphoric in shape, but other types are known (Gilman and Boxall, 1974). The entrance to the pit may be closed either by a stone sealed with mud or by heaping earth or sand onto a timber cover. The advantages of this method of storage are: few problems with insects and rodents; low cost of construction compared to that of above-ground storage of similar capacity; hardly visible, and therefore relatively safe from thieves; no need for continuous inspection; ambient temperatures are relatively low and constant; the disadvantages are: storage conditions adversely affect viability; the grain can acquire a fermented smell after long storage; digging and construction are laborious; the stored grains can only be used for consumption; removal of the grain is laborious and can be dangerous because of the accumulation of carbondioxide in the pit, if it is not completely full; inspection of the grain is difficult; risks of penetration of water and the grains which are at the top and are in contact with the walls are often mouldy, even if the rest of the stock is healthy.

Plate 2.3: Traditional Ewe barn with polythene cover

Plate 2.4: Maize cobs stored in roof space of house (Aerial storage)

Plate 2.5: Storage platform (open)

Plate 2.6: Traditional crib

Plate 2.7: Thatched structure (Ava)

Plate 2.8: Woven basket store

Plate 2.9: Mud storage structure

Plate 2.10: Ground/earthenware pot

Plate 2.11: Bags stored on dunnage

Plate 2.12: Opening of under-ground pit store

2.10 Assessment of post-harvest storage losses

Hodges and Farrell (2004) indicated that loss may generally be considered in terms of quantity or quality, each of which will have economic implications. Quantitative loss is a physical loss of produce that can be measured as a reduction in weight and can be measured and valued most readily. Qualitative loss is more difficult to assess since it is frequently based upon subjective judgments and is perhaps best identified through comparison with locally accepted quality standards. It may include the presence of contaminants, and changes in appearance, taste and texture that may cause the produce to be rejected by consumers. Loss of nutritional value may be considered as an aspect of quality loss (Bressani, 1990). Weight loss (loss of quantity) is a reduction in weight and it is easily detected but it may not necessarily indicate a loss of food material. In the case of grains, for example, it may be due to reduced moisture content (Siriacha *et al*., 1998). This is recognized and allowed for commercial transactions by a 'shrinkage factor.'

True weight loss may result from feeding by insects, rodents and birds or from growth of micro-organisms (Siriacha *et al*., 1998).

2.11 Methods of assessing grain losses in storage

Boxall (1986) outlined different methods for assessing grain losses and these methods are described below:

The volumetric method

This method is also known as the bulk density or the standard volume weight (SVW) method. It is based upon the use of equipment for measuring the bulk density of a clean, sieved sample of grain. At the beginning of a storage period a baseline SVW is determined from a representative sample of the grain put into store. Losses are recorded by following changes in the SVW on subsequent occasions throughout the storage period. Although the method strictly records changes in bulk density, the change in weight over time is taken to reflect the weight loss due to the damage caused by grain-boring insects. The difference in moisture content in grain samples collected at different times will affect the weight of grain in the standard volume container. This effect can be excluded by expressing all weight measurements in terms of constant moisture content, usually the dry weight. However, changes in moisture content also affect the volume and frictional properties of grain.

There are several shortcomings in this method. An increase in moisture content will increase the volume of the grain and cause it to pack more loosely, leading to a decrease in the dry weight of a given volume. To allow for the effect of moisture on the volume of the grain it is necessary to calculate, by experiment, the dry weight of a standard volume of a reference sample of grain at different levels of moisture content. The dry weight of the grain filling the standard volume container for subsequent samples, taken at the prevailing moisture content, can then be related to the dry weight of the reference sample at the same moisture content by reference to a specially prepared graph or chart. The procedure requires a great deal of care and time and an adequately equipped laboratory (Adams and Schulten, 1978). Another factor affecting the weight of a standard volume of grain is the addition of insecticide dust. The dust adheres to the surface of the grain, causing an increase in the volume and a change in the frictional properties. Sieving the grain is unlikely to remove all the dust where insecticides have been applied; therefore, the volumetric method is less useful since it will tend to lead to overestimates of loss.

Thousand grain mass method

This method is similar to the standard volume weight method but instead of comparing weights of a fixed volume of grain, the weights of a fixed number of grains are compared. The thousand grains mass (TGM) is the mean grain weight multiplied by 1000 and corrected to a dry weight, and is calculated by counting and weighing the number of grains in a given sample. A baseline TGM is determined from a sample of grain collected in a representative manner as the grain is put into store. It does not involve separating damaged from undamaged grains or standardization of grain samples to an exact weight/volume before analysis. Subsequent measurements of the TGM made throughout the season are compared to the baseline value.

The count and weigh method

The count and weigh method provides an estimate of loss where a baseline sample cannot be obtained at the beginning of the storage season (Anon, 1999). It uses a sample of about 1000 grains. The method, which is applied to a single sample, involves separating the damaged and undamaged grains and then counting and weighing each fraction. The data are then substituted into the following equation:

Percentage weight loss = $\frac{(U\ X\ Nd - D\ x\ Nu}{U\ (Nd + Nu)}\ x\ 100$

Where: U = Weight of undamaged grain; D = Weight of damaged grain; Nu = Number of undamaged grains; Nd = Number of damaged grains.

The method uses a single sample and it is considered unnecessary to determine the moisture content of the separate fractions, on the assumption that the differences are likely to be small. This method assumes that insects choose grains at random, which may not be true. It also does not account for hidden infestation, because grains containing such infestation are classed as undamaged (Adams and Harman, 1977). Both factors may cause misleading, or even negative, results at very low levels of infestation. At very high levels of infestation, misleading results occur because of multiple infestations in large grains such as maize, beans, and in some sorghum varieties. However, it is a useful, quick field method if allowance is made for the problems occurring at the extremes. Refinements to the technique have been addressed to solve, preferential attack of large or small grains, differences in moisture content between damaged and undamaged grains, and the presence of hidden infestation. The refinements include separating grains into size categories before counting and weighing (Boxall, 1986), separating superficially from severely attacked grains (Ratnadass *et al*., 1994) and making a second assessment after the emergence of hidden infestation (Ratnadass and Fleurat-Lessard, 1991).

Modification of the count and weigh method

A modification of the count and weigh method has been developed for use in the situation where insects completely destroy grains on maize cobs. If such missing grains are not taken into account when assessing losses of cob maize, the count and weigh method is likely to underestimate the loss (Compton *et al*., 1998). The method was developed to handle the larger grain borer, *P. truncatus*, a pest of cob-stored maize which reduces many grains to powder. It is recommended that a sample of about 30 maize cobs is used and that each cob is shelled separately. The number of destroyed grains are counted for each cob and then summed over all cobs in the sample to give the total number of destroyed and missing grains (TND). The shelled grains from all cobs are pooled and weighed and the final weight recorded (FW). Two sub-samples, each of about 500 grains, are extracted and the grains in each are then sorted into damaged and undamaged groups and counted and weighed as in the conventional method. The weight loss is calculated separately for the two sub samples and the average taken as the weight loss in the cob sample.

The percentage weight loss is then derived from the formula below:

$$\frac{TND \quad D + U \;\; U \quad + FW \; (Nd\, U - Nu\, D)}{TND \quad D + U \;\; U \quad + FW \quad Nd + Nu \;\; U)} \; x\, 100$$

Where: U = Weight of undamaged grain; D = Weight of damaged grain; Nu = Number of undamaged grains; Nd = Number of damaged grains; TND = Destroyed and Missing grains; FW = Final Weight

Derivation of the equation

The percentage weight loss in the sample defined as: The final weight (FW), is explained above. The undamaged weight (UW) is the estimated sample weight in the absence of destroyed and damaged grains and is estimated by applying the same assumptions used in the conventional count and weigh method (damage is equally distributed over large and small grains in the sample). On this basis the average weight of undamaged grains in the original cob sample will be equal to the average unit weight of the remaining undamaged grains in the grain sub-sample. The undamaged weight of the whole original cob sample is calculated as the product of the total number of grains estimated to be in the original sample and the unit weight of undamaged grain in the sub-sample. The total number of grains is the sum of the destroyed and missing grains and the number of grains (damaged and undamaged) in the pooled sample of shelled maize. This last parameter has to be estimated and is obtained from the final sample weight divided by the average unit weight of all grain.

The modified count and weigh method suffers less from systematic bias associated with destroyed grains than the conventional count and weigh method, which seriously underestimates true weight loss when grains are destroyed by insects. Hence, the modified count and weigh method is recommended for studies where destroyed grains are likely to be significant (Compton *et al*., 1998).

The converted percentage damage method

This method is suitable where a quick assessment of loss caused by grain-boring insects is required, without the need for equipment, for example, during a rapid field appraisal. Weight losses in samples of grain may be estimated by reference to the percentage of damaged grains in a sample. A laboratory study must be undertaken first to establish the relationship between damage and weight loss. A conversion factor can then be calculated and subsequently used to determine weight losses in other samples of the same type of grain. It is usual to determine the conversion factor from the results of the count and weigh method and so this technique will be subject to the same sources of error. The conversion factor is calculated from the following formula:

Conversion factor = $\frac{\%\, damaged\ grain}{\%\, weight\ loss}$

In order to avoid some of the sources of error arising from the use of the count and weigh-technique to derive a conversion factor, it is recommended that a sample of grain with 10% or more damaged grains be used in the first step. This is because the count and weigh method tends to underestimate loss at low levels of infestation. The sample size should never be less than 500 grains. When a subsequent sample of grain is collected, the number of insect-damaged grains in a sub-sample (of not less than 500 grains) is counted and expressed as a percentage of the total grains present. This figure is converted to a weight loss using the predetermined conversion factor. They are only approximate and should be regarded as rough guides; it is preferable to determine conversion factors for the particular grains being studied.

Rapid loss assessment technique based on grain damage/weight loss relationships

A rapid field assessment technique for predicting weight loss in grains has been developed based on the relationship of grain damage to weight loss. Although specifically developed for cowpea and Bambara groundnut, the technique could be used for any grain, especially larger types such as maize. The technique requires the use of standard graphs relating percentage damage and weight loss for the commodities under study. When preparing the reference graphs, at least 10 working samples consisting of around 500 grains are required for the preliminary laboratory work. The weight loss of each sample is calculated using the count and weigh method, and the percentage of damaged grains.

Rapid loss assessment using visual scales

All of the above loss assessment techniques (with the exception of the last described) are, to a greater or lesser extent, time-consuming, require well-trained personnel and appropriate equipment. These shortcomings can be overcome by using visual scales. Visual scales are used routinely for assessing damage in field crops and are ideal for field use, rapid to use, require nothing beyond reference scales (for example, photographs), and have low levels of operator bias (Compton *et al*., 1998). A technique has been developed for cob maize and dried cassava pieces in which sampling and scoring can take less than 15 minutes. This enables increased sampling and wider coverage or reduced sample error. A loss estimate is obtained on the spot, leading to a reduced risk of spoilage, and anomalous results can be double-checked before leaving the site.

After analysis, the cobs or cassava pieces can be handed back to the owner intact, avoiding the common problem of how to compensate farmers for any samples removed (Compton and Sherington, 1999).

Difficulty in measuring losses

Loss assessment methods tend to be slow and to require skilled field and laboratory staff. They are often under taken on experimental sites, making it difficult to relate the results to on-farm situations. There are a number of factors which tend to lead to an upward bias in the loss estimates. Firstly, extremes may be taken rather than averages. Ideally, the sample size and standard deviation should be quoted with the loss estimated to avoid this. Secondly removals from store over the season are not always accounted for. Where removals do occur, percentage losses calculated on the basis of grain remaining in store will be overestimates.

Another source of over estimates lies in treating partial damage as a total loss, when in fact the damaged grain would be used by farmers for home consumption or animal feed. A fourth source of upward bias lies in the potential for double counting losses at different stages in the post-harvest system. Losses at one level are related to those at other levels.

Another difficulty in using estimates of losses to justify technical change is the problem of assigning to the losses a value which makes sense to the potential user of the technology. The most common form in which losses are expressed is as a percentage weight loss. But from the farmers' points of view what is important is the use that the grain can be put to, or the market price that will be received. Grain intended for sale may be consumed, or that intended for consumption used as animal feed. A rapid loss assessment method for estimating storage losses in maize and cassava has recently been developed in Togo (Compton *et al*., 1998).

2.12 Detection of hidden infestation

Insect infestation is a common problem for stored grain. Insects can cause quantitative losses as they consume the kernels. A number of insect pests such as *Sitophilus*, *Callosobruchus*, *Rhyzopertha*, *Prostephanus* and *Sitotroga* species have their immature stages (e.g. eggs, larvae, pupae) inside grains (FAO, 1985). Also, the appearance and organoleptic properties can be altered through physical damage and contamination by faeces, webbing and body parts of insects, respectively.

Most of the damage and weight loss caused by insects on grain are inflicted by the primary grain feeders. They are capable of penetrating sound whole kernels of grain and their life cycle is completed entirely within the kernel in which the egg is laid or entered by the first instar larva. The absence of any live adults of storage insects in grain samples does not necessarily mean the absence of an infestation and consequently many methods have been devised to identify individual kernels that have become the home of the immature stages of the major insect pests. Therefore, due to their presence inside the grains, several detection techniques, including the following have been developed and applied to stored grains:

Egg-plug staining technique (Milner *et al*., 1950): This is a more rapid method of detecting the presence of weevil infestation within grain using different staining techniques outlined below:

Acid-fuchsin method procedure: Prepare a dye solution by adding 0.5 g acid fuchsin to a mixture of 50.0 ml of glacial acetic acid and 950.0 ml of distilled water. This dye solution can be stored for a long time and may be used repeatedly until it becomes murky. Soak the grains to be treated for five minutes in warm water; drain off water and cover grain with acid-fuchsin solution for two minutes in warm water. If left longer, the kernels may absorb enough solution to make the identification of the egg plugs difficult; pour off the dye solution (retain for future use) and wash grain in tap water to remove excess dye; examine the kernels to locate the gelatinous egg plugs, which stains a deep cherry red. Note that the feeding punctures and mechanical injuries stain a lighter colour than egg plugs. The egg plugs are about the size of an ordinary pin prick and can readily be seen with the naked eye. The degree of internal infestation can be then estimated by the number of egg plugs observed. This method is not particularly accurate; it is time-consuming, gives no indication on the stage of insect development and is only useful for weevil infestation.

This procedure was later modified to ensure more uniform staining of the egg plugs as follows: Prepare the stain solution following the procedure outlined above; place approximately 100 ml of stain solution in a 600-ml beaker; place about 25 g of grain in a tea strainer and hold it under warm running water until thoroughly wetted and dust and frass are washed away; allow excess water to drain from the grains, and then pour them into the stain solution; swirl the grain into the stain solution intermittently for two minutes; pour stain solution into second 600-ml beaker, catching the grain in the tea strainer; rinse the grain in the tea strainer under cool running water to remove excess stain; place the wet grain on a paper towel and examine using an illuminated lens to detect cherry red-stained egg plugs.

Berberine sulphate solution: A soluble fluorescent dye (berberine sulphate) is used to stain the gelatinous plug secreted by female *Sitophilus* spp. to cover the egg cavity in the grain. Grains are soaked in a dilute (aqueous) solution of 20 ppm of alkaloid berberine sulphate for one minute followed by rinsing and examining the kernels under ultra-violet light for the greenish-yellow plugs. The degree of internal infestation can then be estimated by the number of egg plugs observed. This method is not particularly accurate; it is time-consuming, gives no indication on the stage of insect development and is only useful for weevil infestation. The stained egg plugs will fluoresce intense yellow; feeding punctures and mechanical injuries do not fluoresce.

Gentian violet stain (Goosens, 1949): Prepare 1% gentian violet aqueous stock solution; soak 5 g of grain in warm water containing a wetting agent or detergent for 30 seconds; drain by placing the sample in a wire container, wash, and then put the wet grain on a dry paper towel for a few seconds; place the grain for two minutes in a staining solution that contains 10 drops of 1% gentian violet aqueous stock solution in 50 ml of 95% ethanol; pour off the staining solution and wash the grain in clear water for 20 seconds; the egg plugs are purple and very easily seen while the kernels are still wet or in the water. Gentian violet does not stain the endosperm.

Grain dissection: The grain is cut vertically and examined with a microscope to reveal the presence of insects or parts of insects, and gives a valuable indication of the stage of development of an infestation relevant for any impending control method. It is best done under a binocular microscope and dissected with a sharp scalpel after the grains have been presoftened by soaking for 2 hours.

X-ray technique: The use of X-rays, discovered in 1895 by Roentgen, was generally restricted to the examination of high density materials. This is described the most accurate and rapid method of determining internal insect infestation in samples of grain. By this method X-ray machines are used to take radiographs of 100 g samples of grain. These radiographs reveal the presence of insects' forms within the grain. X-ray manufacturers have now developed X-ray units specifically for this purpose. Several researchers at Kansas State University (Katz *et al*., 1950; Milner *et al*., 1950; 1952) pioneered radiography in its application to agriculture, and developed a method for detecting hidden infestation that was marketed by the General Electric Company known as the "grain inspection unit". It suffered from being time-consuming (approximately 15 minutes) and was not suitable for routine inspection of grain. The equipment is expensive but is used extensively by large milling factories.

Carbondioxide production method: This method gives an accurate measurement of the total metabolic rate of the grain, and therefore cannot be specifically applied to insects. The method requires enclosing a quantity of grain in a gas tight bottle at 35°C for 24 hours, then drawing a sample of intergranular air and analyzing it for percent CO_2 evolved. Dry uninfested grain is normally < 0.25%, between 0.3-0.5% suggests a light insect infestation (or a MC> 15%), and if the CO_2 evolution is > 0.5% in 24 hours, the grain is definitely unsuitable for storage without any further treatment (Howe and Oxley, 1944).

2.13 Control of stored product insect pests

Stored product insect pests population tend to increase exponentially under favourable conditions and availability of food, and this eventually lead to substantial losses in stored produce (Talukder, 1995). Throughout history, man has employed a variety of preventive and curative measures against pests of stored food, designed either to prevent infestation or to inhibit pests in their development by repelling or destroying them (Zehrer, 1994).

Most crops become infested with insects before they are harvested, thus introducing the pests into storage. The basic requirement for effective pest management is a good knowledge of the pest (such as biology, ecology and population dynamics), its host and the environment in which the pest lives. These can be manipulated to make conditions unfavourable for the development of the pest (Talukder, 1995). In addition, a number of active pest control methods are designed to destroy, repel or inhibit reproduction of pests. Below are some of the control methods:

2.13.1 Use of traditional methods

The use of locally available plant materials for insect pest control is a common practice in traditional farm storage in developing countries (Poswal and Akpa, 1991). Traditional storage practice throughout most African countries involves mixing grains with wood ash, laterite dust or sand, or suspending crop over fireplaces.

Drying grains by exposing them to the hot sun rids produce of pests. In historical times, farmers used a number of substances from animal origin such as bile, urine and droppings to preserve and disinfest seed grains. Substances of vegetable origin have also been employed in pest control over several decades. The plant kingdom, being very large, offers a wealth of resources for pest control, the study of which had been seriously neglected at the advent of synthetic insecticides. Commonly, picking of pests by hand and destroying them before storage is an active mechanical pest control method, and is still practised in various parts of Africa. In West Africa, insect pests of stored cereals and legumes are mostly sorted by hand to increase marketability. Special sieves are also used for sifting out pests and this represents a substantial improvement over hand sorting. Winnowing to remove insect pests and other unwanted materials is also employed. Since a decade or two ago, however, more scientific investigations into the insecticidal efficacy of a number of different plant products have been carried out by a number of scientists at different research institutes worldwide. The investigations reported here are further contributions to this area of research.

2.13.2 Use of physical control

This involves manipulating the physical environment of the pest making it inimical for its growth and survival (Fields and Muir, 1995). By doing so, the insect population does not increase, but rather is reduced and eliminated. This physical attributes relate to temperature, relative humidity, moisture content of grains, storage structures, forces in commodity (compression and impaction), irradiation and the use of inert dust. For about thousands of years now, stored product insects have been controlled by using physical means. In Africa, in the Neolithic times this method was employed in the Nile Delta by placing seeds to be stored in glass jars underground to keep them cool and dry (Fields and Muir, 1995). Temperature regulation is one aspect of physical control mostly used in stored product protection. Some insects are susceptible to high temperatures, while others to low temperatures. Some are also susceptible to extreme high and low temperatures. For example, in general, *Tribolium* spp. are most susceptible to high and low temperatures of $>45^{o}$C and $<13^{o}$C, respectively (Kirkpatrick and Tilton, 1972; Fields and Muir, 1995).

Another aspect of physical control deals with controlled or modified atmospheres. Examples are the underground storage in Egypt and grains stored in sealed containers in most African countries (example Senegal). The term usually refers to the process of changing the atmosphere of a facility by introducing carbondioxide or nitrogen creating an environment that will not support the growth and development of the insect. The hermetic storage of grains is one form of modified atmospheres (Obeng-Ofori, 2008a).

2.13.3 Use of chemical control

Insecticides used in storage generally combine high toxicity of insects with low mammalian toxicity. Insects take up insecticides by external contact or ingestion of treated material. Most insecticides act by disruption of the nervous system, but mineral dusts and ashes exert a physical effect, damaging the exoskeleton and the insects' moisture control mechanism by abrasion, absorption or by blocking the surface (Anon, 1983).

According to Obeng-Ofori (2006) all insecticides used on or near stored food must meet certain criteria and intense regulatory review to ensure human safety. An ideal insecticide must rapidly kill the insect without killing non-target organisms, must be easily degradable with low residual activity, must be easily handled and prepared with low mammalian toxicity, must be cheap and readily available for the farmers to use (Boateng and Obeng-Ofori, 2008).

Currently, the classes of contact insecticides used on or near stored products include organophosphates and synergized pyrethroids. These synthetic chemical insecticides are available in a wide variety of compounds and formulations and are applied using different methods including spraying, fumigation, dusting, smoking, sprinkling, fogging and evaporation (Billups, 1980). These insecticides may cause neurological poisoning, desiccation, suffocation or other complex physiological abnormalities in the target pests (Obeng-Ofori, 2008b).

Organophosphorus insecticides act by inhibiting enzyme cholinesterase, thus preventing nerve impulse transmission resulting in eventual death of the insect (Walker, 1994).

Organophosphorous (OP) compounds are effective against most storage pests, although less against the Bostrichidae (*R. dominica* (F.), *P. truncatus* (Horn), *Dinoderus* spp.) Organophosphorous compounds such as pirimiphos-methyl (Actellic) with effective dose as 10g ai/tonne of grain is a broad spectrum insecticide with remarkable knock down effect and is persistent for several months, and is used in the control of stored product beetles and moths. Other OPs used include Etrimfos, Chloropyrifosmethyl (Reldan) and Methacrifos (Damfin) (Obeng-Ofori, 2010) (Table 2.3).

Pyrethroids are synthetic substitutes for pyrethrum obtained from the plant *Chrysanthemum cinerareaefolium* Trev. They are most active either for knockdown or kill and have low persistence (Billups, 1980). Pyrethroids are very effective against Bostrichidae, though less against other species of beetles. Synthetic pyrethrins/pyrethroids used in the control of stored product insect pests include Bioresmethrin, Deltamethrin, Permethrin and Phenothrin (Table 2.4). Almost all the economically important stored product insect pests throughout the world are resistant to most of the insecticides commonly used to protect commodities against insect infestation and damage (Subramanyam and Hagstrum, 1995). In view of this, two or more insecticides known as "cocktails" are combined to control certain storage pests. For example, Fenitrothion (OP) + Bioresmethrin (pyrethroid) are combined to control *Rhyzopertha dominica* (F). Fenitrothion + Permithrin + Resmethrin can be mixed to control grain weevils, beetles and borers (Table 2.5) (Obeng-Ofori, 2008b).

Fumigants are gases used to disinfest commodities either in stacks under gas-proof sheets or in sealed silos, warehouses, containers and ships (Walker, 1994). The commonly used fumigant is phosphine. Phosphine is highly toxic and is available as tablets, pellets, plates or sachets of aluminum or magnesium phosphide, which can be kept in gas tight packs. Although fumigants can penetrate masses of material to kill all forms of storage insects, and produce maximum effect within hours of application if done properly, they do not give subsequent or residual protection. Moreover, some insect pests such as *R. dominica* (Fab.) and *T. castaneum* (Herbst) are reported to have developed resistance to fumigants (Walker, 1994).

Although chemical control is the fastest method of pest control, problems of insecticide residues which may be detrimental to the consumer, buildup of insecticide resistance by the pest, as well as the destruction of non-target pests are major drawbacks to its use. However, if appropriate application techniques are employed, these problems may be reduced (Koomson, 2003).

Table 2.3: Common organophosphorous insecticides used for stored product pest control

Active Ingredients	Brand Names
Pirimiphos-methyl	Actellic
Dichlorvos (DDVP)	Nuvan, Vapona
Fenitrothion	Folithion, Sumithion
Iodofenphos	Nuvanol
Malathion	Malathion, Malagrain
Methacrifos	Damfin
Phoxim	Baythion
Chlorpyrifos-methyl	Reldan
Tetrachlorvinphos	Gardona

Source: FAO/WHO, 1994b

Table 2.4: Common pyrethroids insecticides used for stored product pest control

Active Ingredients	Brand Names
Cyfluthrin	Baythriod
Deltamethrin	K-Othrin
Fenvalerate	Sumicidin
Permethrin	Permethrin

Source: FAO/WHO, 1994b

Table 2.5: Combined contact insecticides commonly used against mixed insect infestation in storage

Active Ingredients	**Brand Names**
Fenitrothion + Cyfluthrin Baythroid Combi	Baythroid Combi
Fenitrothion + Fenvalerate	Sumi Combi
Pirimiphos-methyl /+ Deltamethrin	K – Othrine Combi
Pirimiphos – methyl + Permethrin	Actellic Super

Source: FAO/WHO, 1994b

2.13.4 Use of biological control

All insect populations tend to increase exponentially as long as there is adequate food and suitable environment, and no predators or parasites (Fields and Muir, 1995). Biological control employs the use of natural enemies such as parasites, predators or pathogens to suppress pest populations. Natural enemies can be classified into two types (predators and parasites) based on their life history, ecology and population dynamics (Brower *et al*., 1995). Generally, predators prey on individuals who are smaller than they are and feed on many preys during their life time. Parasites are generally smaller than their hosts and can be classified into parasitoids and micro parasites. Parasitoids are insects whose immature stages develop as a parasite on or in another insect. Microparasites are microbial pathogens such as viruses, bacteria, fungi, protozoa which cause contagious diseases in target pests (Brower *et al*., 1995). Some organisms used as biological control agents include: The female of the Pteromalids *Anisopteromalus calandrae* (Howard) and *Choetospila elegans* (Westwood) forage through stored grains, select a kernel that contains a larva or pupa of a grain beetle (such as the rice weevil or the lesser grain borer) (Brower *et al*., 1995). Pirate bugs such as the warehouse pirate bug, *Xylocoris flavipes* (Reuter), and the larger pirate bug, *Lyctocoris campestris* (Fabricius) are generalist predators whose adults and nymphs feed on any life stage of pests that can be subdued (Billups, 1980). *Trichrogramma* species lay their eggs in the caterpillar of moths, e.g. *C. cephalonica* and *Ephestia* spp. (Obeng-Ofori, 2008a). *Teretrus nigriscenes* (Lewis) has been effectively used to control *P. truncatus* in most countries. Females of the parasitoid wasp, *Bracon hebetor* (Say) seek out and sting wandering-stage larvae of Pyralid moth pests such as the Indian meal moth and the Mediterranean flour moth (Brower *et al*., 1995).

Insect pathogens (microbial agents) are facultative pathogens that kill by means of insecticidal proteins (toxins). Infections are acute and cause rapid mortality. For example, formulations containing *Bacillus thuringiensis* (Bt) kill the caterpillar stage of a wide array of moths such as *P. interpunctella*, *Ephestia* spp., *C. cephalonica* as well as the lesser grain borer *R. dominica* (Taura *et al*., 2004).

2.13.5 Use of phytochemicals/botanicals

The plant kingdom is a vast storehouse of chemical substances manufactured and used by plants for defence against attack by insects. These substances may elicit strong physiological responses in various stages of an insect's life. Since these naturally occurring phytochemicals are usually biodegradable and non-toxic to plants and animals, they offer the potential for safe and effective control of stored product pests (Rembold, 1994). More than 30,000 secondary metabolites have been reported from plants (Wink, 1988), and the major group of compounds with insecticidal activity are alkaloids, amines, non-protein amino acids, cyanogenic glycosides, glucosinolates, lectins, protease inhibitors; all of which are nitrogen containing allelochemicals. Other allelochemicals are monoterpenes, sesquiterpenes, diterpenes, triterpenes/steroids, tetraterpenes, polyketides, polyacetylenes, flavonoids and phenylpropanoids (Wink, 1993).

The use of locally available plant materials for stored product protection is a common practice and has more potential in subsistence and traditional farm storage conditions in developing and underdeveloped countries (Golob and Webley, 1980; Obeng-Ofori, 2007).

In a survey in Benin, West Africa, out of 33 plants collected and tested, the powders of *Nicotiana tabacum* L, *Tephrosia vogelii* (Hook) F and *Securidaca longepedunculata* Fres significantly reduced progeny production of *C. maculatus* in stored cowpea, while *Clausena anisata* (Willd) Hook, *Dracaena arborea* (Willd) Link, *T. vogelii* (Hook) F., *Momordica charantia* Linn and *Blumea aurita* (Linn) F. were repellent to beetles (Boeke *et al*., 2004). Similarly, in a survey of plants used as traditional insecticides in 12 districts in forest areas of the Ashanti Region of Ghana involving about 500 farmers, 26 different plant species were found to be used as grain storage protectants (Cobbinah *et al*., 1999). The most common were *Chromolaena odorata* L., *Azadirachta indica* A. Juss., and *Capsicum annum* commonly used by subsistence farmers as dry powder and admixed with grains in the Northern Region of Ghana to protect stored maize, cowpea, bambara groundnut, millet and sorghum is *Cassia* species (Belmain *et al*., 1999; 2001). Niber (1994) also investigated the bioactivity of 10 indigenous plant species reputed to have both medicinal and insecticidal properties by local herbalists in Ghana against *P. truncatus* and *S. oryzae.* Based on the above research in Ghana, Belmain *et al*. (2001) reported 16 different plant species the Ministry of Food and Agriculture (MoFA) of Ghana has adopted to be used by farmers for stored product protection (Table 2.6).

Table 2.6: Plant species adopted by the Ministry of Food and Agriculture of Ghana to be used by farmers for stored product protection in Ghana

1. *Azadirachta indica* (Neem tree)	9. *Lippia multiflora* (Bush tea)
2. *Capsicum annum* (Chilli pepper)	10. *Mitragyna inermis* (False abura)
3. *Cassia sophera* (Coffee pod)	11. *Ocimum americana* (American Basil tree)
4. *Chamaecrista nigricens* (Partridge pea)	12. *Pleiocapa mutica* (Kanwene-taste bitter)
5. *Chromolaena odorata* (Siam weed)	13. *Pterocarpus erinaceus* (Barwood)
6. *Citrus sinensis* (Sweet orange)	14. *Securidaca longepeduncata* (African Violet tree)
7. *Cymbopogon schoenanthus* (Lemon grass)	15. *Synedrella nodiflora* (Cinderella weed)
8. *Khaya senegalensis* (Mahogany tree)	16. *Vitellaria paradoxa* (Shea Butter tree)

2.13.6 Use of plant products in stored product protection

Application of crude extracts from many plants against pests has a long tradition in farming (Wande *et al*., 1992). Different plant products (leaves, ash, seeds, essential oils, plant oils, etc.) are mixed with different food stuffs to protect them against insect pest damage (Schmutterer, 1995; Hassanali *et al*., 1990; Niber, 1994; Obeng-Ofori *et al*., 1997). One of the best known examples is the neem tree, *A. indica*. Many parts of the neem tree including the leaves, bark and the seeds are used for plant protection purposes in many parts of the tropical world. The seed kernels are rich in oil, which even at extremely low concentration as a water emulsion, deter insect larvae from feeding and interfere with reproduction, growth and development (Schmutterer, 1995; Addae-Mensah, 1998).

Other plants that have shown promise for the control of storage pests include the Siam weed, *Ocimum* plant species, Mahogany tree, Candlewood, *Jatropha*, etc., (Bekele *et al*., 1997; Obeng-Ofori and Akuamoah, 2000; Udo, 2000) vegetable oils like groundnut, coconut oil are mixed with grains as protectants before storage, thus protection is offered by inhibiting oviposition and damaging the eggs of pests (Zehrer, 1980; Obeng-Ofori, 1995). Use of jute bags impregnated with 10% of aqueous extract from *Chenopodium ambrosiodes* L. and *Lantana camara* L. were found to be very effective in reducing infestation for more than six months (Obeng-Ofori, 2007). Owusu (2001) reported that out of 4 solvent extracts of the roots of *Z. xanthoxyloides* Lam., the methanol (MeOH) extract caused 100% mortality of *S. zeamais* and *C. maculatus* in the laboratory. Yadava (1973) found that 2 and 4% emulsion of essential oil of *Acorus calamus* L. in kerosene oil, water and absolute oil were effective against *Callosobruchus chinensis* L. Shay and Ikan (1980) found that the fractionated cotton seed oil processed insecticidal activity against *C. chinensis* when applied at a concentration of 400 g/ton of stored chick peas. The fractions were also active against *S. oryzae* on stored wheat.

2.14 The Bellyache bush, *Jatropha gossypiifolia* L.

2.14.1 Taxonomy, distribution and ecology

Jatropha gossypiifolia belongs to the Family Euphorbiaceae. The genus name *Jatropha* combines the Greek iatros, meaning physician, with tropheia, meaning mother's milk, hinting at the medicinal properties of the plant (Parsons and Cuthbertson, 2001). The species name 'gossypiifolia' is a combination of the Latin gossypium, meaning cotton, and folium, suggesting that the leaves appear similar to those of the cotton plant (Parsons and Cuthbertson, 2001). Overseas, *J. gossypiifolia* common names include ‘cotton-leaf physic nut’(Australia), ‘cotton-leaved jatropha’, ‘purging nut’, ‘American purging nut’, ‘wild cassava’, ‘red fig-nut flower’ (Africa), ‘damar merah’ (Indonesia) and ‘castor oil plant’ (erroneous), bellyache bush, black physic nut, castor bean, red physic nut, Spanish physic nut tree, wild physic nut; local common names include, lapalapa pupa (Africa), aburokyi-raba, akandedua, babatsi, dkrakpoti, edmebii, gbomagboti, kaagya, kiti-gbleteo, kpitikpiteo (Ghana).

Jatropha gossypiifolia is native to Brazil and tropical America from Mexico to Paraguay and the Caribbean region (Gardner and Bennetts, 1956). The Missouri botanical garden’s ‘TROPICOS’ database holds 84 records of the plant from Central America (Costa Rica, Honduras and Nicaragua), South America (Bolivia, Colombia, Ecuador, Paraguay, Peru and Venezuela), the Caribbean (Dominican Republic, Puerto Rico and Leeward Islands) and West Africa (Cameroon and Ghana) (Irvine, 1961; Chadhokar, 1978; Holm *et al*., 1979; Dehgan, 1982; Swarbrick, 1997). It was imported into Australia in the late 1800’s, probably as a garden ornamental and had naturalized in Queensland by 1912. It is a major weed in Australia grown as fence, and also found in waste places, by the road sides and fallow lands. It occurs throughout tropical Africa, except the dry regions in southern Africa, but including South Africa. Introduced to southern Africa, the plant has spread from Mozambique through Zambia to the Transvaal and Natal. In West Africa, it is listed in the exotic flora of Chad (Brundu and Camarda, 2004), Cameroon and Ghana (Csurhes, 1999).

It is a bushy, gregarious shrub up to 1.8 m, 3-5 lobed, approximately 20 cm long and wide with leaves having a long petiole, covered with glandular hairs from the euphorbiaceous family. The stem is hairy and nonwoody. Flowers are red-crimson of purple in corymbs, with greenish seed in smooth, glabrous, oblong capsule (Plate 2.13). The plant's leaves are arranged alternately along the stem. Leaf petioles are 2-7 cm long and the leaf blades are palmately 3-5-lobed, 45-90 x 50-130 mm; the lobes are more or less elliptic (Wheeler, 1992). Immature leaves are deep purple and sticky (Plate 2.14). Older leaves are generally glossy green although some may have a purple colouration (Pitt and Miller, 1991). Petioles and leaf margins are covered with coarse, gland-tipped, sticky brown hairs. Because of its deep purple immature leaves, this weed tends to be readily noticed by landholders.

Plate 2.13: Older leaves with seeds and flowers of *J. gossypiifolia*

Plate 2.14: Immature leaves of *J. gossypiifolia*

2.14.2 Uses

The major benefits of *J. gossypiifolia* are associated with its medicinal attributes. Roots, stems, leaves, seeds, and fruits have been widely used in traditional folk medicine in many parts of western Africa (de Padua *et al*., 1999; IPCS INCHEM, 2004). Extracts from the plant have been used to treat a number of human ailments, ranging from anaemia, vertigo, worms, leprosy, leukaemia, dysphonia, urinary complaints, ulcers, itches, conjunctivitis, dermatitis, gout, snakebite and venereal diseases (Irvine, 1961; Kupchan *et al*., 1976; Morton, 1981; Liogier, 1990; Das and Das, 1994; Horsten *et al*., 1996; de Padua *et al*., 1999). The leaves are purgative; applied to boils, carbuncles, eczema and itches. Sap exudates taken from leaf petiole is mixed with molasses and given to cure dysentery. Seed oil is used in skin diseases and as an external stimulant in rheumatism and paralytic affections. Regular brushing with the twigs keeps the teeth and gum disease free and cures toothache (Yusuf *et al*., 2009). Dried residue of MeOH extract of fruits is mollucidal. Seed, leaf and bark extracts are active against stored-grain pest (Asolkar *et al*., 1992). In parts of Africa, the plant is the object of superstition and is believed to ward off lightning (Dalziel, 1948; Ogbobe and Akano, 1993).

Since the 1970s, various parts of the plant have been studied as a source of novel medicinal drugs, including potential anticancer drugs (Biehl and Hecker, 1985; de Padua *et al*., 1999). For example, anti-leukemic compounds have been isolated from the plant's roots (Taylor *et al*., 1983). Other potential uses that have been investigated include a source of oil for energy (Forni-Martins and Cruz, 1985), a source of plant food for human and animal consumption, an additive for plastic formulations (Ogbobe and Akano, 1993) and a source of insecticides (Prasad *et al*., 1993; Chatterjee *et al*., 1980). In Asia, the plant is used for lamp oils and dye (Smith, 1995). In Peru the leaves and latex are used to treat abscesses, tonsillitis, asthma, diarrhoea, toothache, fever, gingivitis, fungal skin infections, inflammations, burns and coughs (Pinedo *et al*., 1997).

In certain African countries, people are accustomed to chewing seeds of *J. gossypiifolia* when in need of a laxative (IPCS INCHEM, 2004). The seeds are oily, purgative and emetic (Irvine, 1961). Tea made from bark is used in Nigeria to cure intestinal worms (Irvine, 1961). The leaves are boiled up and used as a bath for fever and the leaves are used as a purgative in Jamaica (Irvine, 1961; de Padua *et al*., 1999). Roots of *J. gossypiifolia* have been used for treatment of leprosy (Das and Das, 1994; Baxter, 2000). Plant parts used for healthcare in India include the young stem, root, bark and latex (Das and Das, 1994). These parts are used either alone or with other components for the treatment of abdominal discomfort, bone fracture, toothache, conjunctivitis, open wounds, diarrhoea, dysentery, haemorrhoids, intra-uterine death, muscular pain, rheumatism, tongue sores and infections around fingernails and toenails (Banerji *et al*., 1993; de Padua *et al*., 1999).

Crude hot water extract of *J. gossypiifolia* exhibited anti-malarial properties. It was capable of 100% inhibition of the malaria agent *Plasmodium falciparum* (Gbeassor *et al*., 1989). Extracts of *J. gossypiifolia* have a reputation as a cancer cure (Biswanth and Ratna, 1995; Biswanth *et al*., 1996; Morton, 1981, 1982; Taylor *et al*., 1983). For example, on the island of Aruba, people believe that a decoction of the stems from *J. gossypiifolia* cures throat cancer (Morton, 1982). Derivatives of the diterpene jatrophone were also isolated from roots of *J. gossypiifolia* and shown to have anti-tumour properties in vitro (Taylor *et al*., 1983). Oil extracted from *J. gossypiifolia* seeds are also used as an illuminant in Africa (Burkill, 1994).

In drier regions of West Africa, *J. gossypiifolia* is used as a hedge around villages to protect them against bush fires (Irvine, 1961; Ogbobe and Akano, 1993). Some West Africans also believe that *J. gossypiifolia* has magical powers that protect against snakes, lightning, and violence (Burkill, 1994). In Senegal a decoction of the leaves is taken to treat colic, stomach-ache and fever, including malaria. In Ghana the leaves are used as a purgative, and the leaf sap is applied to the tongue of babies to treat thrush and to inflamed tongues of adults. The pith of old stems is inserted into the nostril to cause sneezing to cure headache. In the Caribbean the plant sap is traditionally used in the treatment of cancer. In the West Indies an infusion of the stem is taken to treat hypertension.

Since the plant has excited considerable interest because of its medicinal activity and novel metabolites (Das and Das 1994), biochemical companies, or other private interests, in Australia may eventually seek to cultivate the plant. Most parts of the *J. gossypiifolia* plant contain toxins of various concentrations, posing a serious human health risk. Detrimental effects on human health include seed poisoning (Kingsbury, 1964), dermatitis (Souder, 1963) and sneezing (Irvine, 1961). Whilst numerous cases of severe poisoning have been reported from the plant's native range, no human deaths were recorded (Begg and Gaskin, 1994). Although all parts of *J. gossypiifolia* are considered toxic, the seeds are especially so (Gardner and Bennetts, 1956; Oakes and Butcher, 1962; Kingsbury, 1964; Marcano-Fondeur, 1992; Wheeler *et al*., 1992; IPCS INCHEM, 2004). Main toxins include purgative oil and curcin, which is found mainly in the seeds and also in the fruit and sap (Chopra and Badhwar, 1940; Simonsen, 1945; Gardner and Bennetts, 1956; Morton, 1981; Joubert *et al*., 1984; Marcano-Fondeur, 1992; Burkill, 1994; Parsons and Cuthbertson, 2001; IPCS INCHEM, 2004). Curcin is similar to ricin, the toxic protein of castor oil plant (*Ricinus communis*). Leaves contain flavonoids, a saponin, a resin, tannin and triterpenes. They also contain flavonoids, vitexin, isovitexin and apigenin. Roots contain antileukemic and tumour-inhibitor macrocyclic diterpene, jatrophone and jatropholones A and B. Bark contain β-sitosterol. Roots, stems and seeds contain arylnaphthalene lignan and the lignan prasanthaline. Cyclogossine, a cyclic heptapeptide, had been isolated from the latex of the plant. Stem contains a novel lignan; jatrodien (Ghani, 2003; Rastogi & Mehrotra, 1993). It has toxic content ricinine and jatrophin. It is used for toothache, leprosy, ulcers, skin itches etc. When consumed in excess it produces abdominal pain, ptosis, and hind-limb paralysis.

2.15 The Siam weed, *Chromolaena odorata* (L) King and Robinson

2.15.1 Taxonomy, distribution and ecology

Chromolaena odorata is a species of flowering shrub in the Sunflower Family, Asteraceae. The genus name "*Chromolaena*" is (Latin for 'fragrant, smelling nice', referring to smell the plant emits when damaged). The common names of the plant include agonoi, hagonoy (Philippines), Bitter bush, Christmas bush, Chromolaena (Swarbrick, 1997), Common floss flower, Jack in the bush (Vander Velde, 2003), Siam weed, Triffid (English), Siam-raut (German), Herbe du Laos (French), Rumput belalang, Rumput golkar, Rumput putih (Indonesia) (U.S. Dept. Agr. Res. Serv., 2011). There are several local names of *C. odorata* in Ghana. However, one, 'Acheampong', is most commonly used in areas where it occurs. This is probably because the weed became prominent during the military regime (1972-78) of General I.K. Acheampong. It is also known as 'Busia' especially in the Western and Central regions. Dr. K.A. Busia was a head of state in Ghana around 1969, when the weed was first discovered at Legon Botanical Gardens.

It is native to North and Central America, from Florida through the West Indies and from Texas to Mexico and the Caribbean (Howard, 1989; Liogier, 1997) and has been introduced to tropical Asia, West Africa, and parts of Australia where it was first identified in 1994 with infestations along the Tully River and near Mission Beach, in North Queensland (Pacific Island Ecosystems at Risk, 2001). In its native range, it is frequently seen on roadsides, riverbanks, vacant lots, abandoned farmland, and neglected pastures. Christmas bush has found a particular niche in the slash-and-burn agriculture cycle (Ohtsuka, 1999). The species is not shade tolerant and will not grow under a closed forest stand (Binggeli, 1999).

In the tropics of Africa and Asia Siam weed is a major pest of crops such as coconuts, rubber, tobacco and sugar cane. Siam weed is now a serious weed in Mauritius, India, Sri Lanka, south-east Asia, China, the Philippines and Guam. It was first reported in Africa in the 1940s. Today, it is a major weed in Nigeria, Ghana, Cameroon, Zaire and South Africa. It has become a major weed in parts of Asia and West, Central and South Africa (Muniappan, 1988). It was introduced to Nigeria in the 1940's, and by the late 1960s, *C. odorata* had become an important weed. It has since spread to Ghana, Cote d'Ivoire and Cameroon (Cruttwell, 1988). In Ghana, the weed was first discovered in February 1969, in old abandoned experimental plots in the Legon Botanical Gardens (Hall *et al*., 1972). By 1972 it had spread to the Greater Accra, Central and Western regions. The plant can be poisonous to livestock killing more than 3000 cattle annually in the Philippines, as it has exceptionally high level of nitrate in the leaves and young shoots; the cattle feeding on these die of tissue anoxia. The toxin also causes abortions in cattle and is suspected of being a fish poison (Sajise *et al*., 1974).

Siam weed is recognized as one of the world's worst tropical weeds due to its quick invasion and establishment. It invades and out-competes pastures, crops and native vegetation. It has an extremely fast growth rate (up to 20 mm a day) and prolific seed production producing up to 87,000 seeds per plant. It also has the potential to increase the fuel load in bushfires and it can cause allergic reactions.

Siam weed is an erect or sprawling fast-growing perennial shrub, forming dense tangled thickets from 1.5 metres to seven metres high. It is also known to grow up to 20 metres high as a climbing plant. Its leaves are almost triangular, 5-12 cm long, with forward facing serrations on the margins (Plate 2.15). They emit a pungent odour when crushed. The stem has soft pith. White to pale lilac flowers occur in flat-topped clusters during winter. Seeds are brown to black, 4-5 mm long, with parachute-like white hairs (pappus) at the top of the seed. They also contain fine barbs, which mean they readily stick to clothing, equipment and animals. The seed is very light and is subject to widespread dispersal by wind and water.

Plate 2.15: Leaves, flowers and stem of *C.odorata*

2.15.2 Uses

Despite the menace caused by *C. odorata* (Timbilla, 1996) it is claimed to be of some use in agriculture, land conservation and medicine. As a herbal medicine, the young leaves are crushed and used to treat skin wounds in Indonesia. The leaf extracts with salt are used as a gargle for sore throats and colds. It is also used to scent aromatic baths (Liogier, 1990). Extracts of Christmas bush have been shown to inhibit or kill *Neisseria gonorrhoeae* (the organism that causes gonorrhoea) in vitro (Caceres *et al*., 1995) and to accelerate blood clotting (Triratana *et al*., 1991). The liquid extract is used primarily for treating fresh wounds. Old wounds and boils are also treated with the weed. Another important use of the weed is preservation (embalming) of dead bodies in villages in Ghana. Diseases like malaria and jaundice are also said to be cured by drinking the boiled extract of *C. odorata*.

Abdominal pains are said to be treated with liquid extracts of the weed as an enema. The weed is known to be effective in cleaning teeth and treating certain eye problems. It is also claimed that it effects abortion when used as an enema during the early stages of pregnancy, a disadvantage in religious circles. Additionally, the weed is said to repel mosquitoes and snakes, and is used to preserve maize from rodents. Other advantages include using it to prevent soil erosion, as firewood especially in the western and central regions of Ghana, and as bait for trapping crabs when *C. odorata* leaves are combined with other chemicals. It has been reported to have antispasmodic, antiprotozoal, antitrypanosomal, antibacterial and antihypertensive activities. It has also been reported to possess anti-inflammatory, astringent, diuretic and hepatotropic activities (Watt and Brandwijk, 1962; Feng *et al.*, 1964; Weniger and Robinean, 1988; Iwu, 1993). Some specific phenolic compounds have been isolated from the plant (Metwally and Ekejuba, 1981). The medicinal values of plants lie in their component phytochemicals such as alkaloids, tannins, flavonoids and other phenolic compounds, which produce a definite physiological action on the human body (Hill, 1952).

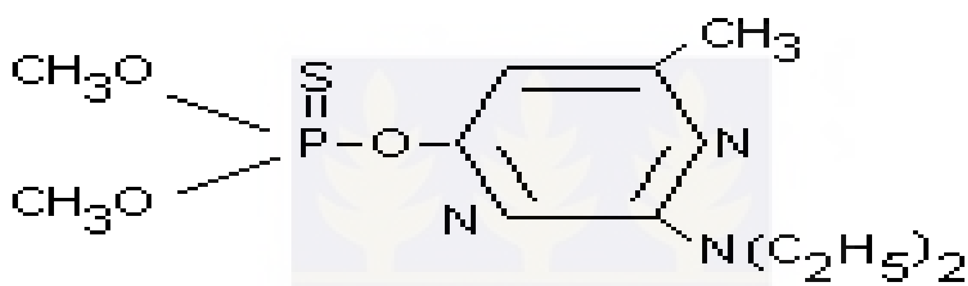
As an ornamental plant, it is sometimes used in shifting slash-and-burn agriculture to compete with *Imperata cylindrica*, which is harder to control. *Chromolaena odorata* can be used as a green manure and it possess insecticidal properties (GISD, 2006). During fallows between cultivation, Christmas bush adds copious amounts of organic matter to the soil and may reduce the populations of nematodes (M’Boob, 1991). It is also useful as mulch for row crops (Swennen and Wilson, 1984). Fallow lands under *C. odorata* produce higher yields of crops such as maize and cassava. This is probably due to the recycling of nutrients and higher litter fall which improves organic matter and soil structure. This has also been reported in the Philippines (Torres and Paller, 1989). Farmers welcome the weed in some grassland areas because it suppresses grass growth.

2.16 Pirimiphos-methyl (Actellic)

Pirimiphos-methyl is a phosphorothioate used as an insecticide. It was originally developed by Imperial Chemical Industries Ltd., now Syngenta , United Kingdom in 1967.

2.16 .1 Structural Formula of Pirimiphos-methyl ($C_{11}H_{20}N_3O_3PS$)

Pirimiphos-methyl is a related insecticide in which the methyl groups are replaced with ethyl groups.



Other names include Phosphorothioic acid, O-[2-(diethylamino)-6-methyl-4-pyrimidinyl] O,O-dimethyl ester; Actellic; ENT 27699Gc; Methylpirimiphos; Methylpyrimiphos; Pirimiphos Me; Plant Protection PP511; Pyridimine phosphate; PP 511; Pyrimiphos-methyl; Actelic; Actellifog; Blex; 2-Diethylamino-6-methylpyrimidin-4-yl dimethyl phosphorothionate; O-(2-(Diethylamino) -6-methyl-4-pyrimidinyl)O,O-dimethyl phosphorothioate; O-(2-Diethylamino-6-methylpyrimi-din-4-yl) O,O-dimethyl phosphorothioate; OMS 1424; Pirimifosmethyl; Silosan; Sybol 2; O-[2-(Diethylamino)-6-methyl-4-pyrimidinyl] O,O-dimethyl thiophosphate.

2.16.2 Identity and Properties of Pirimiphos-methyl

Pirimiphos-methyl is a pale straw coloured liquid. It melts at 15-18°C and decomposes above 100°C. It has a vapour pressure of approximately 1×10^{-4} Torr at 30°C and a density of 1.157 g/ml at 20°C. Pirimiphos-methyl is stable for up to six months at room temperature. It is hydrolysed by strong acid or alkali. Pirimiphos-methyl is miscible with most organic solvents: methanol, ethanol, chloroform, acetone, benzene, toluene, and xylene (IPCS INCHEM, 2006).

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2.16.3 Uses

Pirimiphos-methyl is a fast-acting broad-spectrum organophosphorus insecticide with both contact and fumigant action. As a post-harvest insecticide, pirimiphos-methyl is the active ingredient in a number of insecticides used to control insect pests in stored cereal grain, seeds and peanuts (Obeng-Ofori and Amiteye, 2005). It can be applied as a complete admixture treatment directly to the grain and a seed of wheat, barley and oats or as a surface admixture to the same crop and does not affect the flavor, color, texture or aroma of grain. Treated grain may be used immediately for any feed or food purpose.

It provides complete control of all of the following cereal pests: flour or mill moth (*Ephestia kuhniella*), grain weevil (*Sitophilus granarius*), saw-toothed grain beetle (*Oryzaephilus surinamensis*), cosmopolitan food mite (*Glycyphagus destructor*), rust-red grain beetle (*Cryptolestes ferrugineus*), common flour mite (*Acarus siro*), warehouse moth (*Ephestia elutella*), and flour beetles (*Tribolium* spp.).

Pirimiphos-methyl has been used in many situations against stored product pests. The minimum effective dose against a wide range of insects is lower than most other OP on use or under development as grain protectant. It is potent against beetles, weevils, moths and mites, but not sufficiently effective against some strains of *Rhyzopertha dominica*. It is useful against immature stages within the individual grains and it appears quite effective against many lindane-malathion resistant strains. In the Philippines, pirimiphos-methyl was found to be an effective protectant of corn grains against a variety of pests especially *Sitophilus* spp. for 6 months. Pirimiphos-methyl is more persistent in maize than in sorghum. Pirimiphos-methyl impregnated sacks are more effective than malathion for the control of storage pests of shelled corn (U.S. EPA, 2003).

The efficacy of pirimiphos-methyl in controlling coleopteran pests in stored wheat has been reported in a number of publications. Huang and Subramanyam (2005) reported damage caused by coleopteran insects in the range of 9 to 99 % in non-treated wheat grains and that doses from 4 to 8 ppm of pirimiphos methyl have reduced the damages to less than 1 %. Chawla and Bindra (1976) cited the existence of eight species of grain pests, resistant to the malation and that from seven organophosphorated insecticide and two pyrethroids tested for the control of *Trogoderma granarium* and *Sitophilus* spp in wheat, the best result was obtained with pirimiphos-methyl and phoxim. Bitran *et al*. (1991) reported that, from the tested insecticides for *S. zeamais* in maize, for *S. oryzae* in rice and wheat, and *R. dominica* in wheat, pirimiphos- methyl was the best treatment to protect maize against *S. zeamais*.

In some African countries, grains are protected from insects during storage by chemical (mainly synthetic organic insecticides), non-chemical (including extremes of temperature, admixtures with oils, powders and extracts from plants) and often the integration of these control measures in a compatible manner to reduce their individual negative effects (Delobel and Malonga, 1987; Makanjuola, 1989; Don-Pedro, 1989; Denloye and Makanjuola, 1997; Ogendo *et al*., 2004). Many of these non-chemical methods are cheap, locally available and easily applicable without need for technical expertise. However, they are slow acting and not standardized, their use depending mainly on experience and tradition (Delobel and Malonga, 1987; Belmain and Stevenson, 2001). They are mainly used by subsistence farmers. In addition, the superiority in efficacy of synthetic compounds over non-chemical methods has been shown by recent studies. Okunade *et al*. (2002) reported that Pirimiphos-methyl was more potent against *Rhyzopertha* *dominica* on sorghum in comparison to 12 natural plant products. Similarly, Obeng-Ofori and Amiteye (2005) reported that only pirimiphos- methyl showed effective control of *S. zeamais* on stored maize grains when its efficacy was compared with products from three plant species. The foregoing increases support for the use of synthetic chemicals, which are often quick-acting and persistent in the stored grain, thus ensuring long-term protection.

2.16.3.1 Use pattern

Pirimiphos-methyl shows activity against a wide spectrum of insect pests, including ants, aphids, beetles, caterpillars, cockroaches, fleas, flies, mites, mosquitoes, moths and thrips. It possesses only limited biological persistence on leaf surfaces but gives long lasting control of insect pests on inert surfaces such as wood, carpets, sacking and masonry. It retains its biological activity when applied to stored agricultural commodities including raw grain and nuts. Commercial uses of pirimiphos-methyl are now developing in a wide variety of outlets, including growing crops, public health and stored products. The most important potential use appears to be as a grain protectant and for use in the control of insect pests in stored products. When used for the control of stored product pests, pirimiphos-methyl is effective as a spray on structural surfaces and on the outside of bagged produce and as an admixture treatment. The recommended rates of application to bagged grain to control a complex of beetles, weevils, moths and mites are normally in the range 20-50 mg/kg. For admixture with small grains the recommended rate of application is 4 ml/L (10 ppm) except where *Rhyzopertha dominica* is present when a rate of 6 ml/L is required. These are the maximum international limits for insecticide residues in grains that result from postharvest application set by FAO/WHO of the United Nations (Smith, 1990). Since the widespread development of strains of stored product pests resistant to malathion (Pieterse *et al*., 1972; Waterhouse, 1973) there has been considerable interest in pirimiphos-methyl which has proved effective against all known strains of malathion-resistant stored product insects. Pirimiphos-methyl is regarded as more than a replacement for malathion. At recommended rates, it is effective against a wider spectrum of insect pests, having an ability to destroy all forms other than eggs and to confer long-term protection. It is effective at lower rates of application and for much longer periods than is malathion. Malathion is also registered for use on coarse and small grains. However, this insecticide is not a suitable grain protectant because it breaks down rapidly and many stored-grain insects have developed high levels of resistance to the insecticide (Subramanyam & Hagstrum, 1995).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study area

The study area was the Awutu-Senya District in the Central Region of Ghana. The district capital is Awutu-Breku, which shares boundaries at the North with the Agona District, the West with Gomoa District, both in the Central Region, at the East with Ga District in the Greater Accra Region, whilst at the South it is bothered by the Gulf of Guinea (Fig 3.1). According to the Ghana Statistical Service (2011), the current population of the district is about 274,584. Out of this population, 47.9% are males and 52.1% are females.

There are two main vegetation zones namely the Savanna and forest zones in the district. The district experiences a five-month dry season starting from November to March during which period the dry North-East trade winds dominate the area. The dry season is followed by a seven-month rainy season from April to October during which the South-West monsoon winds dominate the area. The rainfall figures of the district are low (40-50 cm) along the coast, but are higher in the inland with the mean annual rainfall ranging between 50 and 70 cm. The mean annual minimum and maximum temperatures are 22°C and 28°C, respectively. The major cash crops cultivated in the district are maize, yam, pineapple and cassava (Sackey, 2006; Awutu-Senya District Profile, 2008). The topography and cropping patterns of the Awutu-Senya District were studied so that a representative selected area could be included after expert consultation with the District Director of the Ministry of Food and Agriculture (MoFA). By stratified random sampling, five farmers were selected from each of the five selected villages and interviewed, giving a sample size of twenty-five (25) maize farmers. The selected communities were Ahentia, Bontrase, Chochoe, Kroebogyir (Senya) and Kwai- Blagu.

3.2 The survey

A formal survey based on a written questionnaire was conducted for five weeks. The questionnaire (Appendix 1) was pre-tested and modified to suit farmers' understanding and to make it easier to analyze.

During the first time visit when the maize was harvested, samples were taken and the moisture content determined before produce was put in stores. The questionnaires and observations from the field were used to obtain information on the causes of losses. Questionnaires comprised both open and closed ended questions. Questions asked included: household demographics, farm sizes, agronomic practices (weeding, thinning, fertilizer application), harvesting period, storage volumes and losses, causes of losses (insect, rodent and mould damage) and marketing. The questionnaires were administered to twenty-five (25) farmers in the selected villages using stratified random sampling. Secondary information was obtained from the MoFA office at Awutu-Senya District (Breku) in the Central Region.

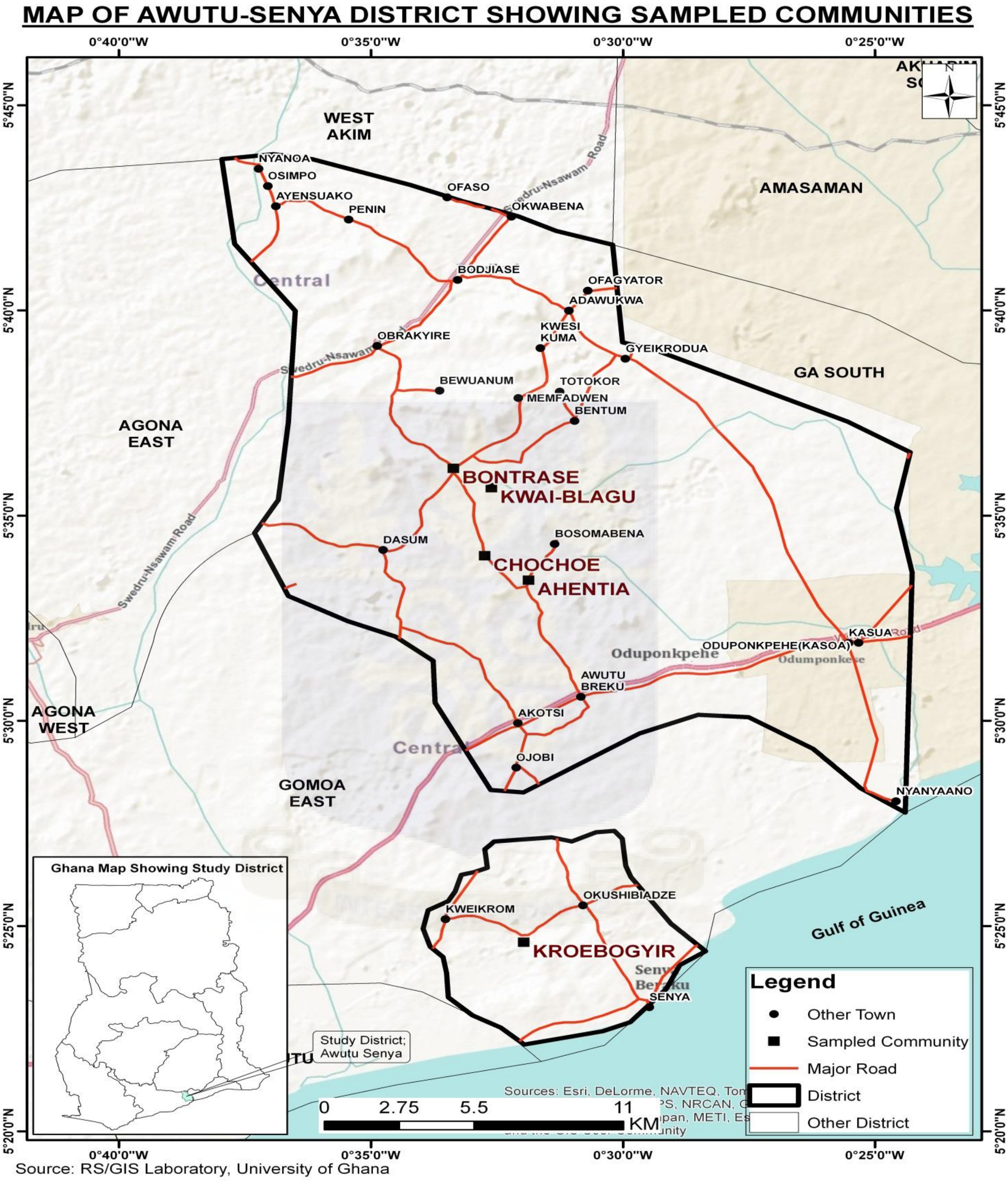

Fig. 3.1: A map of Awutu-Senya District showing sampled communities

3.3 Determination of baseline data

For the complex method, a baseline data covering all the moisture condition for the grains was determined to serve as reference point for the working samples to be used in the subsequent determination of losses using one of the complex methods, the Thousand Grain Mass method (TGM).

The procedure used was as follows:

About 1 kg (1000 g) maize sample was taken at the start of the storage and sieved to remove all unwanted materials to obtain a working sample. The moisture content was determined using the Protimeter Grain Master (GE Sensing, EMEA Shannon Company). The remaining working sample was divided into three replicate sub- samples and each counted and weighed using KERN 572 electronic weighing scale. The baseline data or initial TGM was calculated using the following formula (Boxall, 1986):

$$TGM_1 = \frac{10\ W\ (100 - MC)}{N}$$

Where: TGM_1 = initial Thousand Grain Mass

W = wet weight of sample

MC = Moisture Content

N = No. of grains in the sample

3.4 Determination of grain moisture content

Moisture content was determined from 10-15 maize cobs of varying sizes that were randomly selected from different parts of the maize stacks from each storage structure within the five communities. The maize was shelled and the moisture content was determined using the moisture meter (Protimeter Grain Master). The remaining grains were kept frozen for subsequent bioassays.

3.5 Chemical used as standard insecticide check

A liquid formulation of Pirimiphos-methyl (Actellic 25 EC) containing 4 ml (10 ppm a.i.) /L was obtained from AGRIMAT HOUSE, Madina (a suburb of Accra, Ghana), since there is no plant product that has been recommended for use in controlling stored product pests. Insecticide was diluted in distilled water to make solutions of different concentrations for the various bioassays.

3.6 Assessment of the bio-efficacy of *C. odorata* and *J. gossypiifolia* against major insects encountered during the survey

The major storage insect pests observed during the survey were *Sitophilus zeamais* and *Tribolium castaneum*.

3.6.1 Culturing of insects for laboratory bioassays

Sitophilus zeamais were collected from naturally infested stock of maize cobs at the five selected farming communities in the Awutu-Senya District, Central Region and reared on whole grains in controlled environment at 28±2°C, 65% relative humidity and 12L: 12D photo regime (Osafo, 1998; Weaver *et al*., 1998; Udo *et al*., 2009) in the Research Laboratory at the African Regional Postgraduate Programme in Insect Science (ARPPIS) Centre, University of Ghana (Plate 3.1). Grains were sterilized in an oven at 60°C for three hours (Santhoy and Rejesus, 2004). Adult weevils (100) of mixed sexes were placed in glass jars containing 500 g of sterilized grains to allow oviposition. After two weeks the parent adults were removed by sieving to enable the emergence of same age progeny that were used for the different bioassays (Udoh *et al*., 2009).

The initial stock of *Tribolium castaneum* was obtained from naturally infested cobs from the five selected farming communities, and wheat bran culture from the Entomology Laboratory Insectary of the Department of Crop Science, University of Ghana. One hundred adult insects of mixed sexes were placed in glass jars containing 500 g of sterilized grains to allow oviposition.

The culture was maintained in a controlled environment room at 28±2 °C, 65% relative humidity and 12L: 12D photo regime. After one week the parent adults were removed to enable the emergence of same age progeny that were used for the different bioassays (Plate 3.1).

Plate 3.1: *S. zeamais* and *T. castaneum* culture

3.7 Plant materials used for the assays

The leaves and bark of *Jatropha gossypiifolia* and *Chromolaena odorata* were used for the different bioassays. The leaves and bark of the plant species were collected from the wild at Legon, and further identified at the Department of Botany, University of Ghana.

The plant materials were air-dried at room conditions in the screenhouse at the Sinna Garden, Department of Crop Science for 10 days (Plate 3.2). The materials were chopped into smaller pieces and milled using Retsch Verder Company (German) Milling Machine. The milled materials were sieved using impact test sieve with a mesh size of 710µ to obtain a fine powder which was used for the bioassays.



Plate 3.2: Leaves and bark of plants being dried in the screenhouse

3.8 Preparation of extracts

Methanol and diethyl-ether solvents (100%) were used for the preparation of extracts. About 40 g of *C. odorata* bark, 100 g of *C. odorata* leaves, 100 g each of *J. gossypiifolia* bark and leaves were mixed with 500 ml of both solvents separately and shaken using Stuart Scientific Flask Shaker at 200 OSC/MIN (timer 60) at the Teaching Laboratory of the Crop Science Department, University of Ghana for three days (Plate 3.3). Each solution was filtered and concentrated using Buchi Waterbath Rotary Evaporator (B-480) at 60-70°C for methanol with rotary speed of 3-6 rpm for an hour, and 20-30°C for diethyl-ether with rotary speed of 2-6 rpm for 30 minutes according to the procedure of Godefroot *et al*. (1981) (Plate 3.4). After complete evaporation, the residues obtained were separately re-dissolved in acetone and were used for the different bioassay. Preliminary screenings were done using 20%, 50% and 100% concentrations of the extracts and the 20% was selected for the different bioassays based on the results obtained. The extracts were stored in the refrigerator at 8°C (Ofuya and Okuku, 1994) until ready for use.

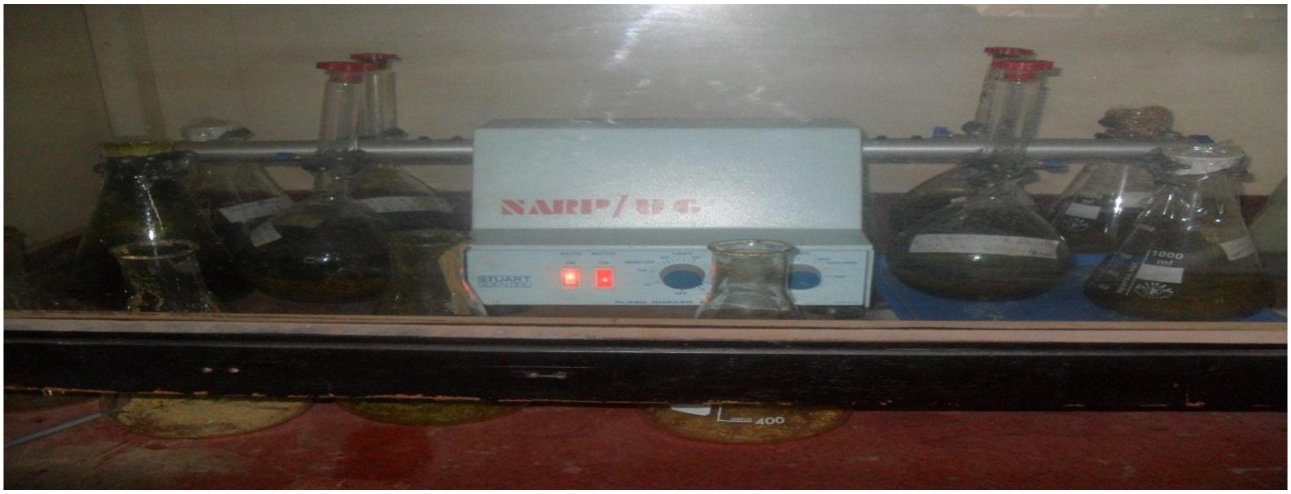

Plate 3.3: Stuart Scientific Flask Shaker shaking plant materials mixed with solvents

Plate 3.4: Rotary evaporator

3.9 Contact toxicity by topical application

Ten adults of *S. zeamais* (7-14 days old) and *T. castaneum* (3-7days old) were used for this study. The insects were chilled for three minutes to immobilise them and transferred into petri dishes lined with moist filter paper. One micro litre of 20% concentration of the methanol and diethyl-ether extracts was applied to the dorsal surface of the thorax of each insect using a micro-pipette. Pirimiphos-methyl (1µL) of the 4 ml/L was used as a reference. Acetone was applied to the control insects and each treatment was replicated three times. Insects that did not move by responding to three prods of a blunt probe were considered dead (Lloyd, 1969). Mortality was recorded after two days.

3.10 Repellency test

The area preference test method described by McDonald *et al*. (1970) was used to determine the repellent action of the extracts to *S. zeamais* and *T. castaneum.* Whatman No.1 filter papers (11.0 cm) were cut in halves (treated) and halves (untreated) – control. Concentrations (20%) of the extracts in acetone were uniformly applied to half of the filter paper discs with a pipette. The other halves of the filter paper were treated with acetone only and air-dried to evaporate the solvent completely (Obeng-Ofori and Reichmuth, 1997). Pirimiphos-methyl was used as reference product. Full discs were remade, by attaching treated halves to untreated halves of the same dimensions with cellotape. Each full filter paper was placed in a petri dish and 10 adult insects each of *S. zeamais* and *T. castaneum* of mixed sexes were released at the centre of each filter paper and covered (Plate 3.5). For each plant extract, there were three replicates, and the number of insect present on control (Nc) and treated (Nt) strips were counted and recorded after 3 hours (Talukder and Howse, 1994). Percentage repellency (PR) values were computed as

% PR = [(Nc - Nt) / (Nc + Nt)] x 100 (McDonald *et al*., 1970);

Where: Nc = number of insects on control

Nt = number of insects on the extract sides

All negative PR were treated as zero.

Plate 3.5: Insects being tested for repellence against plant extracts

3.11 Toxicity of extracts on adult insects in treated grains

The toxicity of methanol and diethyl-ether extracts against the beetles in maize grains was tested in the laboratory by applying 0.5 ml of extracts of dry leaves and bark at 100% concentration, 0.25 ml each of extracts and acetone at 50% concentration and 20% concentration. Pirimiphos-methyl (0.25 ml) was used as a reference. Sterilized maize grains (10 g) were placed into each petri dish and extracts were applied to grains and stirred to ensure uniform mixing and allowed to dry for one hour. Ten insects each of *S. zeamais* and *T. castaneum* were introduced into the treated and control grains and left in the controlled environment room at 28±2°C, 65% relative humidity and 12L: 12D photo regime. The control was treated with acetone. For each treatment, there were three replicates. Mortality was recorded after 4 days. Insects were considered dead when they did not move by responding to three prods of a blunt probe.

3.12 Oviposition test

Unsexed *S. zeamais* and *T. castaneum* adults (20) were selected at random and added to 50 g of maize grains in glass jars and sealed with muslin cloth. They were incubated at 28±2°C ambient temperature and 65% relative humidity for 7 days. After this period the parent adults were sieved out and 20 grains were randomly selected from each glass jar in the egg stage of both insects to detect grains with eggs deposited in them; that is if the insects actually laid eggs, before the treatment was applied using the egg-plug staining technique described by Milner *et al*. (1950). A dye solution was prepared by adding 0.5 g acid fuchsin to 5% glacial acetic acid solution. Grains to be treated were soaked for five minutes in warm water. The water was drained off and the grains were stained for two minutes (Plate 3.6). The dye solution was poured off and grains were washed in tap water to remove excess dye. The grains were examined to determine kernels with eggs deposited in them. These were identified by the presence of cherry-red stained gelatin on the grains (Plate 3.7). It was assumed that all grains containing eggs were plugged with gelatin. The number of egg plugs observed was counted and percentages of infestation level were recorded.

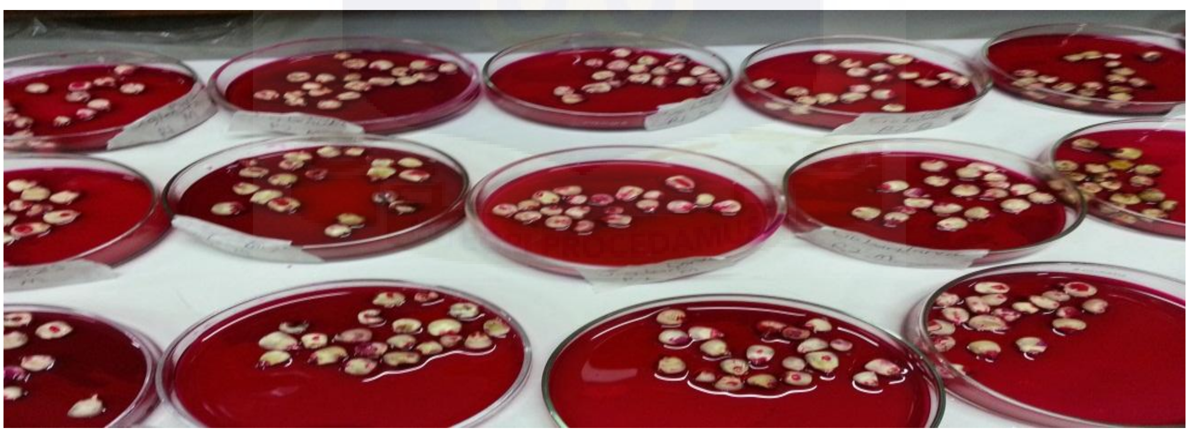

Plate 3.6: Grains covered with acid-fuchsin solution

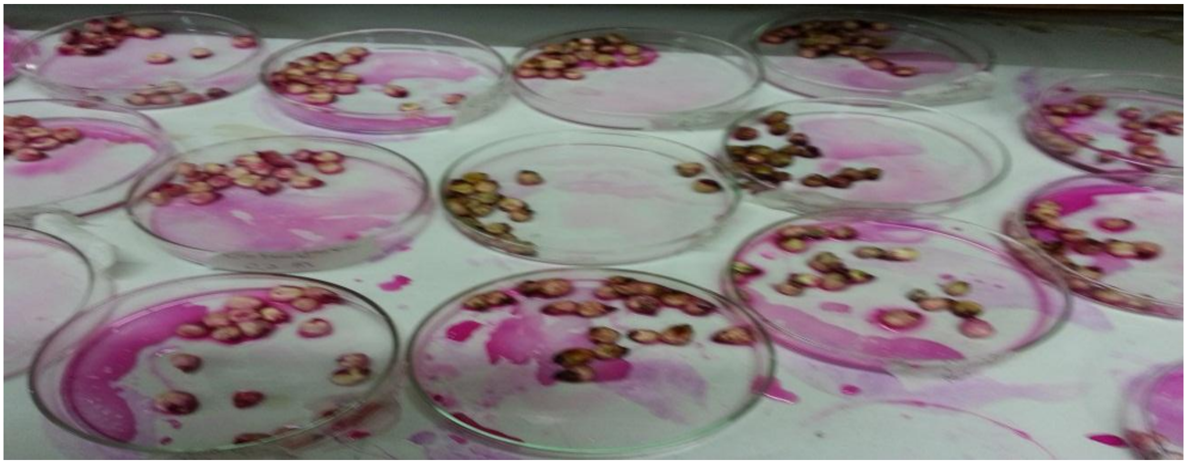

Plate 3.7: Grains examined to detect the presence of egg plugs

3.13 Effect of extracts on immature stages of *S. zeamais* and *T. castaneum*

In this experiment, ninety glass jars were filled with 50 g of maize grains each and 20 *S. zeamais* and *T. castaneum* adults were introduced into each jar for seven days to allow for oviposition, after which the parent adults were sieved out. The jars were grouped into three batches of thirty units. One day after the adults' removal, the first batch was treated with 20% of the methanol and diethyl-ether extracts of *C. odorata* and *J. gossypiifolia* in acetone to assess the effect of the extracts on the eggs using the method adopted by Udo (2000) (Plate 3.8). Pirimiphos-methyl (0.5 ml) was used as a reference. These treatments were replicated three times. To determine the toxicity of the treatments on the larval and pupal stages, the treatments were applied to the second and third batches one week and two weeks after adult removal, respectively. This follows the duration of the various developmental stages of the insects after (Hodges, 1986; Obeng-Ofori, 2008). Grains treated with acetone served as control for each batch, and there were three replications for each treatment. The number of adults that emerged after five weeks of adult removal were counted and recorded for *S. zeamais* and *T. castaneum*.

Plate 3.8: Extracts being tested on immature stages of *S. zeamais* and *T. castaneum*

3.14 Grain dissection to detect dead immatures

This was done for the larval and pupal stages, after the treatments were applied to the second and third batches one week and two weeks after adult removal, respectively. Twenty grains were randomly selected from each glass jar to detect the presence of larva and pupa. The grains were pre-softened by soaking for two hours, then dissected with a sharp scalpel and examined under a microscope that revealed the presence of insects. The numbers of larva and pupa observed that didn't emerge were counted and percentages were recorded for both *S. zeamais* and *T. castaneum*.

3.15 Assessment of grain weight loss

The loss assessment methodology based on that described by Boxall (1986) was carried out. Losses could be due to mouldiness of grains, attack by micro-organisms and rodents, discolouration of grains, and insect infestation, which appear to be the major cause of grain loss. Observations of rodent activity were recorded. The samples of maize in the various storage structures were analyzed to obtain estimates of weight loss. Damage caused by the insects was assessed for the treated and the control grains using the setup in Section 3.14. Before the experiment on the effect of extracts on immature stages, a baseline data was obtained after which the initial TGM was calculated (Sec.3.3).

After 5 weeks of storage, the final TGM (TGMx) was calculated using the procedure as follows: The number of grains in each glass jar was counted and weighed (Plate 3.8) and the MC was obtained electronically using the Protimeter Grain Master.

The Thousand Grain Mass method (TGM) described by Boxall (1986) was used to assess weight loss in maize for each treatment of the egg and larval stages. The final TGM (TGMx) was calculated using the formula:

$$TGM_x = \frac{10\ W\ (100 - MC)}{N}$$

Where: TGMx = TGM of the grain at time x.

W = wet weight of sample;

MC = moisture content (wet weight basis);

N = number of grains in the sample.

The percentage weight loss was determined by using the formula as follows:

$$\text{Percentage wt loss} = \frac{TGM_1 - TGM_X}{TGM_1} \times 100$$

Where: TGM_1 = initial TGM (normally determined at the beginning of the storage season, also called the reference sample)

TGM_x = TGM of the grain at time x.

3.16 Data analysis

Different analytical tools were used for various sections of the work. Statistical Package for Social Sciences (SPSS version 17) was used to analyze qualitative data and data obtained from questionnaire. Quantitative data such as moisture content and weight loss were analyzed using ANOVA (Genstat Version 9) and the Least Significant Difference (LSD) was used to separate the means.

The laboratory data collected were analyzed using Genstat Statistical Package 9.2 (9^{th} Edition) in which case Analysis of Variance (ANOVA) was run using LSD at 95% confidence level. Data involving counts were transformed using square root ($y=\sqrt{x}$) transformation, while those involving percentages were transformed using arcsine ($y = \sin^{-1}\sqrt{x/100}$) transformation before analysis. Correction for natural mortality in control treatment was done using Abbott's (1925) formula:

$$M_x = \frac{(M_t - M_c)}{100 - M_c} \times 100$$

Where: Mx = corrected mortality (%)

Mt = mortality in treatment

Mc = control mortality

CHAPTER FOUR

4.0 RESULTS

4.1 Farmers' knowledge and perception concerning postharvest losses in maize

4.1.1 General background of maize farmers in the Awutu-Senya District

The general background of maize farmers indicated that majority (68%) of the farmers were males and 32% were females (Fig. 4.1).

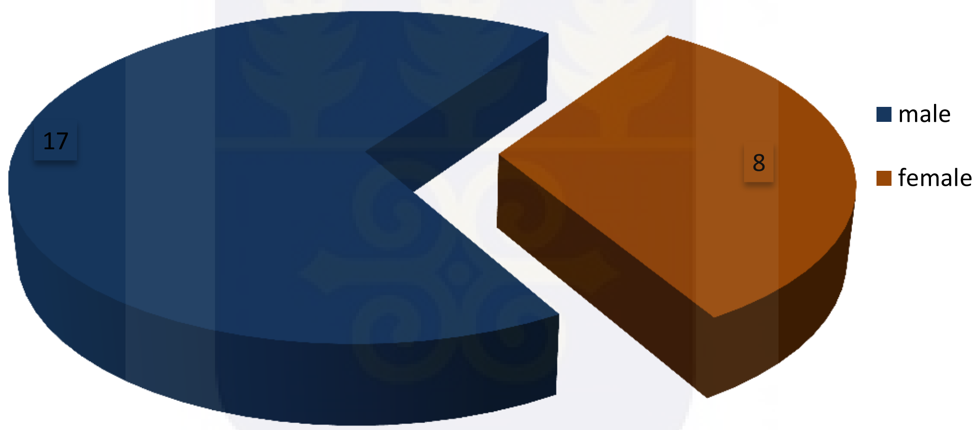

Fig. 4.1: Gender of maize farmers in Awutu-Senya District

Figure 4.2 indicates that majority of the farmers (60%) were in the age range of 41-60 years and 8% were less than 20 years old.

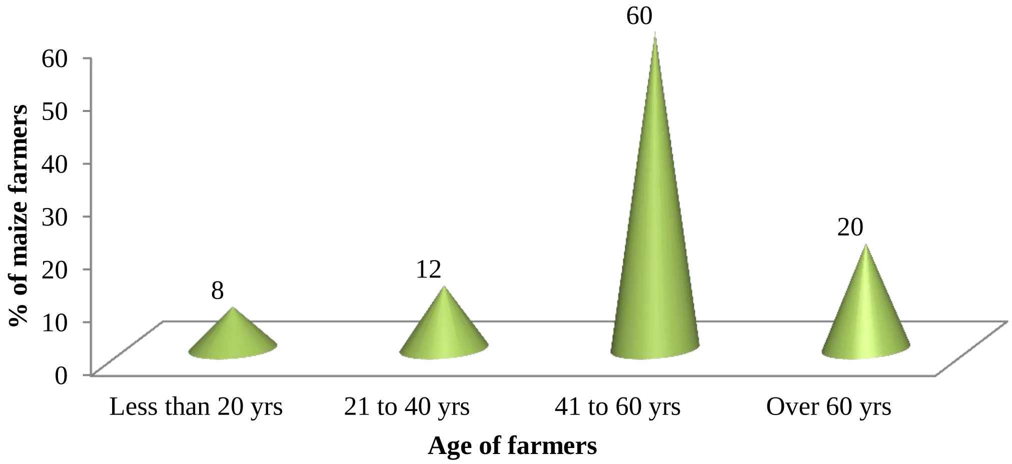

Fig. 4.2: Age of maize farmers in the Awutu-Senya District

On the level of education, 24% had no formal education, 44% of the farmers were educated up to the primary level, and 12% had Senior High School (SHS) education (Fig 4.3).

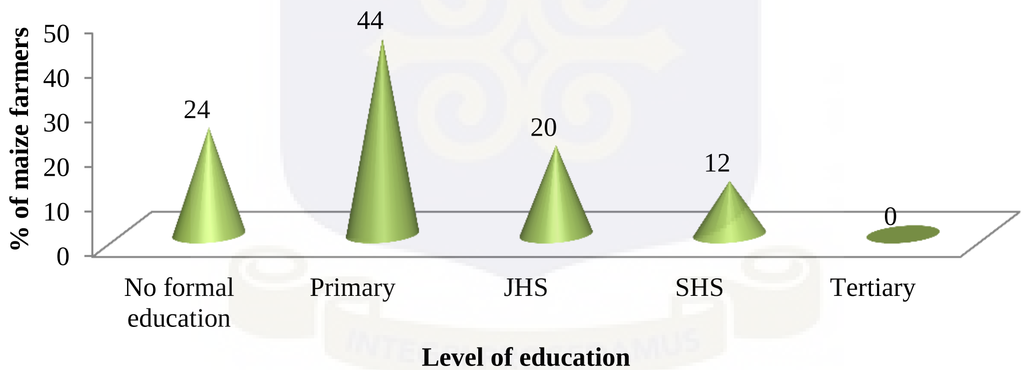

Fig. 4.3: Educational level of maize farmers in the Awutu-Senya District

A greater percentage of the farmers (44%) have been in maize farming for 6-10 years and about 32% of them have been farming for 11 years and above (Table 4.1).

Table 4.1: Farmers' farming experience in the Awutu-Senya District

Farming experience (years)	Percentage of maize farmers
1-5	24
6-10	44
11-25	16
26 and above	16
Total	100

4.2 Production, harvesting and postharvest practices

4.2.1 Maize varieties grown by farmers

Maize was the predominant crop grown as farmers used more than 50% of their land for its production. In order to minimize risk, the farmers also grew other crops including cassava, pineapple and yam. However, most (48%) of the farmers in the district produced maize in larger quantities, while the least produced was beans.

Farmers, when asked to indicate their reasons for cultivating maize, majority (96%) of them were farming to sell the produce, and the remaining respondents (4%) cultivated maize for household consumption.

Most of the farmers had the intention of cultivating maize for commercial purposes, but the ability to expand their production was affected by some factors. These included availability of land (40%) as the major challenge to them all. Other factors were longer experience, improved varieties, availability of funds from previous harvest and availability of labour.

The survey report indicated that 60% of the farmers cultivated the hybrid maize variety known as Obaatanpa and only 8% cultivated the mixed maize (Akpossoi) variety (Fig.4.4).

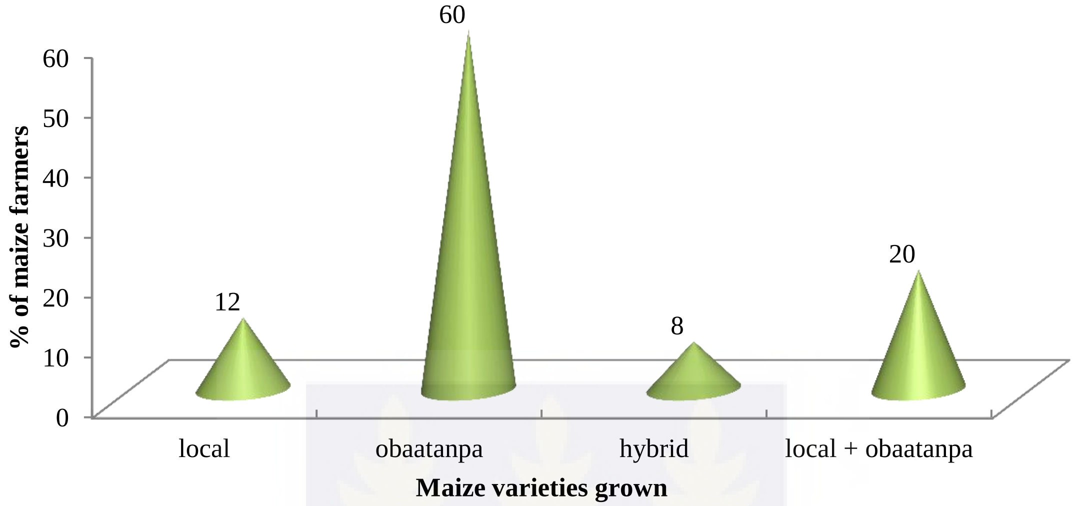

Fig. 4.4: Varieties of maize grown by the farmers in the district

4.2.2 Varieties of maize grains stored

There were three types of varieties of maize stored within the five farming communities: (i) Obaatanpa (hybrid), (ii) Abasa (local) and (iii) mixed maize (Akpossoi-not common) (Plates 4.1-4.3). Samples of the different varieties of maize were collected from the five villages and shelled to determine the moisture content.

Plate 4.1: Obaatanpa (hybrid)

Plate 4.2: Abasa (local)

Plate 4.3: Mixed maize (Akpossoi)

4.2.3 Training of farmers by AEOs

About 72% of the farmers indicated that they have been visited by Agricultural Extension Officers, and have received training on when to harvest, dry and store their maize, while 28% of them have never received any training (Table 4.2). Four out of 25 farmers indicated that they do not plant their maize in rows using recommended spacing (Table 4.2). Twelve (48%) of the farmers used sticks to prepare their land and about 28% of them used a tractor for tilling their land for cultivation.

Table 4.2: Visit by AEOs and farm training

	Visit by AEOs	Planting in rows with recommended spacing	Receive training on when to harvest, how to dry and store maize
Yes	18	21	18
No	7	4	7
Total	25	25	25

AEO- Agricultural Extension Officer

4.2.4 Harvesting and storage

The time for harvesting maize from the field varied from farmer to farmer depending on the availability of labour. However, the average time for harvesting was between 4-5 months after planting (Table 4.3). Nineteen (19) out of 25 farmers harvested their crop 4 months after planting. Only 3 farmers left their crops in the field for up to 5 months after planting to dry before harvesting. The remaining 3 farmers harvested their crops between 4 and 5 months after planting. The survey report also indicated that 56% of the farmers stored the hybrid maize variety (Obaatanpa) while only 44% of them stored the local variety (Abasa) (Fig 4.5).

Table 4.3: Farmers' time of harvesting

Months after planting	Freq.	Percentage of maize farmers
4 months	19	76
4 .5 months	3	12
5 months	3	12
Total	25	100

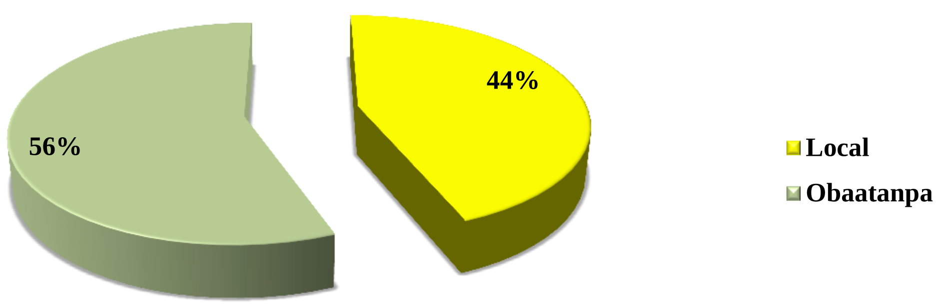

Fig. 4.5: Maize varieties stored by the farmers in the Awutu-Senya District

4.2.5 Postharvest practices before storage

Postharvest practices in the production of maize include harvesting, transporting of grain from the field to the house, dehusking, drying, threshing, shelling and drying before the maize were put into store. Majority (64%) of the farmers stored the maize with husks while some (32%) shelled the grains before storage. However, a few (4%) of the farmers stored in cobs (without husks) (Table 4.4).

Table 4.4: Nature of stored grains

Maize stored in cobs or shelled	**Frequency**	**Percentage of maize Farmers**
cobs (with husks)	16	64
cobs (without husks)	1	4
shelled grains	8	32
Total	25	100

Most (52%) of the farmers kept some of the maize for seed while about 48% of them did not. About 52% of the farmers kept between 6 to 18 kg of the Obaatanpa maize variety for seed and stored none of the other maize varieties (Table 4.5).

Table 4.5: Maize kept for seed

Maize kept as seed		Varieties of maize kept as seed		Cumulative percent
Yes	13	Obaatanpa	13	52
No	12	None	12	48
Total	25	Total	25	100

About 28% of the farmers stored surplus maize due to high cost of seed maize and available number of traditional cribs. Others stored for other reasons (Table 4.6).

Table 4.6: Reasons for storing surplus maize in the district

Reasons	Percentage of maize farmers
High cost of seed maize	28
Good germination assessment	4
Support to grow more maize	16
Successful harvest	8
Available number of traditional cribs	28
Adequate land	16
Total	100

The maize farmers (44%) indicated that they stored their maize to obtain good price, and few of them (12%) attributed it to avoiding shortage of food (Table 4.7).

Table 4.7: Reasons for storing maize

Reasons for storage	Frequency	Percentage of maize farmers
Avoid spoilage	5	20
High price	11	44
Food	6	24
Avoid shortage of food	3	12
Total	25	100

Some of the farmers (76%) do not store enough maize due to lack of funds and insect infestation (Table 4.8).

Table 4.8: Reasons for storing low quantity of maize in the district

Reasons	Percentage of maize farmers
High insect infestation	24
Lack of funds	76
Total	100

4.3 Storage structures

The types of storage structures commonly used by maize farmers in the district are shown in Plates 4.4-4.6. Plate 4.7 shows the general arrangement of maize cobs in the storage structures. Table 4.9 indicates that among the common storage structures existing in the study area, the room stores, traditional ewe barns with polythene cover and cribs were used for maize storage by majority of the local farmers. The bonko and agbalugu were the least (8%) used by the farmers.

Plate 4.4: Room storage

Plate 4.5: Traditional crib

Plate 4.6: Traditional Ewe barn with polythene cover

Plate 4.7: Arrangement of maize cobs in storage

Table 4.9: Types of storage structures commonly used by maize farmers in the district

Type of storage structure	Percentage of maize farmers
Bonko	8
Agbalugu	8
Traditional barn	28
Crib	24
Room	32
Total	100

4.3.1 Characteristics of the three storage structures

4.3.1.1 Room storage

The height of this structure ranges between 21.5 to 22.6 m, 32.8 to 33.7 m in diameter, 36 to 40 m in length, and 32.8 to 33.7 m in width (Plate 4.4). Maize cobs were usually stacked with the husk-on in a semi-circular form. The larger cobs were carefully stacked on the exterior with the remaining cobs filling the inside column into a compact cylinder. The roofing used on the building was made of iron sheets which protects the maize against sun and rain (Plate 4.4).

4.3.1.2 Traditional crib

The height of this structure ranges between 22.5 to 25 m, 1 to 0.96 m in height above ground, 23 to 25 m in length (Plate 4.5). The structure is supported by a 2.5 m × 2.5 m, 4 wooden legs on the exterior. Maize cobs were usually stacked with the husk-on in a squared-form in the crib. The larger cobs were carefully stacked on the exterior with the remaining cobs filling the inside column into a compact square as on the platform. The crib is normally covered with metal roof to protect the maize against sun and rain (Plate 4.5).

4.3.1.3 Traditional Ewe barn with polythene cover

In this structure the height ranges between 19.2 to 20 m, 6.7 to 10 m in height above ground, 72.5 to 97.6 m in circumference and 21.0 to 33 m in diameter (Plate 4.6). The structure is supported by a 0.2 cm×0.2 cm split bamboo of 20-25 wooden stands. Maize cobs are stacked with the husk-on in a circular form. The larger cobs are carefully stacked on the exterior with the remaining cobs filling the inside column into a compact cylinder. A polythene sheet was used as cover (Plate 4.6).

4.3.2 Types of materials used for construction of storage structures

Materials used for the construction of the various storage structures included mud, wood slaps, bamboo, sand, cement and aluminum roofing sheets (especially for the traditional cribs and room stores). All the traditional cribs and traditional barns were raised on 4-10 wooden stands, at least 1 m above the ground. The materials used for construction of stores in all the five communities were all obtained locally, except in the few cases where stores are constructed using cement and galvanized zinc sheets.

4.3.3 Age of grain stores

The various storage structures currently used by farmers in the district were room stores, traditional cribs and traditional Ewe barns with polythene cover. These are presented in Plates 4.4- 4.6. Plate 4.7 shows the conditions under which maize are stored which make them liable to rodent attack.

Although the age of farmers' stores in the area of study ranged from 1-25 years, most of them were 1-5 years old, and 12% of the maize farmers indicated that their stores were over 11 years (Table 4.10).

Table 4.10: Age of farmers' stores in the district

Age of stores	Percentage of maize farmers
1-5yrs	56
6-10yrs	20
11-15yrs	12
16 yrs and above	12
Total	100

4.3.4 Maize storage efficiency

The storage efficiency was based on the level of losses of the weight of the grains. According to the farmers, the traditional cribs had the highest storage period (24 months) and showed the lowest level of storage losses (5.0%) (Table 4.11). The room stores were almost comparable to the traditional cribs in terms of storage period and levels of losses according to farmers' estimates. However, the Traditional Ewe barns were reported to have higher levels of storage losses and shorter storage periods when compared to the other structures (Table 4.11).

Table 4.11: Storage efficiency based on grain loss and storage length

Storage type	Average storage length (months)	Average grain loss reported by farmers(%)
Traditional Ewe barns	7	15.00
Room stores	15	7.50
Traditional cribs	24	5.0

4.5 Storage losses

4.5.1 Farmers' assessment of storage losses

During the study, local farmers were given the opportunity to identify common postharvest loss problems and the agents involved. For the causes of losses or damage to their grains in store, farmers mentioned insects, moulds and rodents as the most important factors (Fig 4.6). Majority of the farmers (80%) said insect infestation caused most of the damage to the maize. Some farmers (12%) mentioned rats which are mostly found in the Traditional Ewe barns, while some respondents (8%) said mould infection was a problem (Fig 4.6).

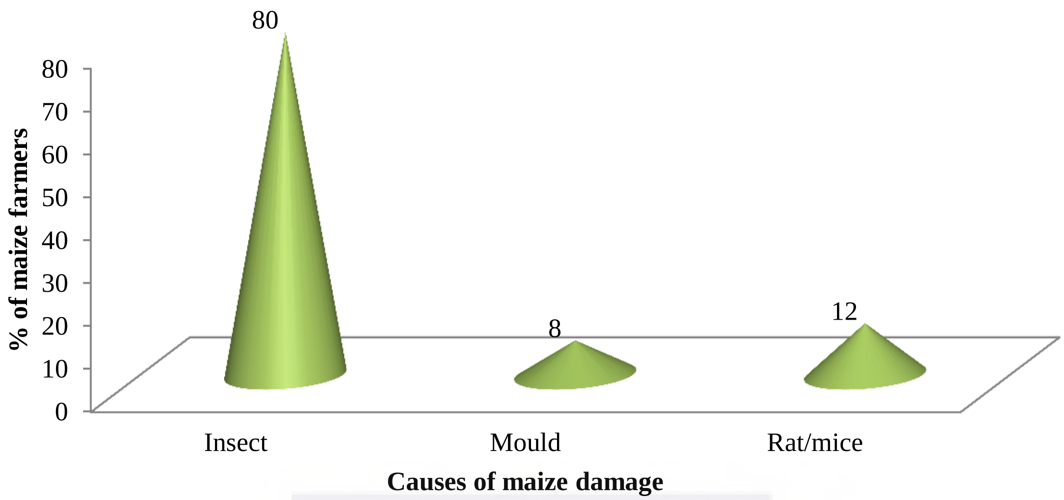

Fig 4.6: Causes of losses to maize during storage

4.5.2 Visual observation of storage losses

Most of the on-farm stores had old, infested grains stored next to new, clean grains. This practice exposed new grains to insect infestation very early during the storage period. In addition, most farmers did not clean their stores before storing new harvested maize. Insect infestation, exit holes, frass and dead insects' bodies were observed in the grains and stores. Few of the stores had moulded grains, holes in the grains caused by insects, grains turned into powder by insects, the presence of rodents, and webbing of grains by moths. The most important insect pests found to be causing qualitative and quantitative losses included the grain weevil (*Sitophilus* spp.) and the red flour beetle (*Tribolium* spp.). Others included the larger grain borer (*P. truncatus*), the lesser grain borer (*R. dominica*) and the grain moth (*S. cerealella*) (Plates 4.8-4.12).

Losses caused by moulds were regarded as minimal, because they only occurred during the rainy season when the weather was wet and farmers were not able to dry the maize to the required moisture content either on the farm or in the open after harvest before storage.

Plate 4.8: Maize weevil, *S.zeamais*

Plate 4.9: *Red flour beetle, T. castaneum*

Plate 4.10: The larger grain borer, *P. truncatus*

Plate 4.11: Lesser grain borer, *R. dominica*

Plate 4.12: Angoumois grain moth,
S. cerealella

4.6 Pests control measures by farmers

Most of the farmers either applied chemical (52%) such as Actellic or Phostoxin to control pests. Drying the maize frequently, dehusking and shelling to prevent further damage by pests were also commonly used by farmers (Table 4.12).

Table 4.12: Pest control measures used on stored maize

Control measures	**Percentage of maize farmers**
Spraying the barn	12
Use of chemical to control the insect pests	52
Drying the maize frequently	28
Dehusking and shelling to prevent further damage	8
Total	100

4.7 Contact toxicity of extracts on insects by topical application

The effect of the methanol and diethyl-ether extracts of *J. gossypiifolia* and *C. odorata* leaves and bark applied topically on adults *S. zeamais* and *T. castaneum* is summarized in Table 4.13. There was no significant difference in the percentage mortality of the beetles for all plants extracts used for the treatment. However, there was a significant ($P \leq 0.05$) difference between beetles treated with methanol and diethyl-ether extracts of both plants and the control. Pirimiphos-methyl treatment induced 90% mortality in both insects after 48 hours (Table 4.13). The methanolic extract of the leaves of *C. odorata* against *T. castaneum* and *J. gossypiifolia* against *S. zeamais* gave 66% and 77% mortality, respectively after 48 hours. No mortality was recorded in the acetone control treatment after 48 hours exposure (Table 4.13).

Table 4.13: Contact toxicity of 20 % methanol and diethyl-ether extracts of *C. odorata* and *J. gossypiifolia* by topical application on *T. castaneum and S. zeamais*

	Mean % mortality ±SE	
Plant part/ Extraction solvent	*T.castaneum* 48 hours	*S. zeamais* 48 hours
C. odorata leaves Diethyl-ether	59.0 ± 2.2	57.0 ± 3.7
C. odorata leaves Methanol	66.1 ± 2.7	68.8 ± 2.7
C. odorata bark Diethyl-ether	57.0 ± 3.7	54.7 ± 2.0
C. odorata bark Methanol	57.0 ± 3.7	52.7 ± 2.0
J.gossypiifolia bark Diethyl-ether	47.0 ± 5.2	41.1 ± 1.9
J.gossypiifolia bark Methanol	54.7 ± 2.0	52.7 ± 2.0
J.gossypiifolia leaves Diethyl-ether	59.0 ± 2.2	61.2 ± 2.2
J.gossypiifolia leaves Methanol	63.9 ± 4.3	77.7 ± 6.1
Actellic	90.0 ± 0.0	90.0 ± 0.0
Acetone control	0.0	0.0
LSD ($P \leq 0.05$)	8.99	8.30

4.8 Repellency assays

The repellent effect of *C. odorata* and *J. gossypiifolia* extracts is summarized in Table 4.14. Both plants were repellent against the insects; however, the extracts were more repellent to *S. zeamais* than *T. castaneum*. Leaf extracts gave better repellency to the beetles than the bark extracts. The highest repellency (83.3%) was recorded for diethyl-ether extracts of *J. gossypiifolia* leaves against *T. castaneum* and *S. zeamais*. At the same concentration, the diethyl-ether extracts of *C. odorata* bark gave the lowest repellency for *T. castaneum. Tribolium castaneum and S. zeamais* were significantly (P<0.05) repelled, 100% and 93%, respectively by the reference product (Table 4.14).

Table 4.14: Mean % repellency of 20% of methanol and diethyl-ether extracts of *C. odorata* and *J. gossypiifolia* against *T. castaneum* and *S. zeamais*

Plant part/Extraction solvent	Mean % repellency ± SE	
	T. castaneum	*S. zeamais*
C. odorata leaves Diethyl-ether	60.0 ± 5.8	83.3 ± 3.3
C. odorata leaves Methanol	66.7 ± 8.8	76.7 ± 14.5
C. odorata bark Diethyl-ether	53.3 ± 16.7	80.0 ± 0.0
C. odorata bark Methanol	56.7 ± 18.6	73.3 ± 3.3
J. gossypiifoila bark Diethyl-ether	56.7 ± 3.3	73.3 ± 8.8
J. gossypiifolia bark Methanol	63.3 ± 17.6	66.7 ± 13.3
J. gossypiifolia leaves Diethyl-ether	83.3 ± 6.7	83.3 ± 8.8
J. gossypiifolia leaves Methanol	70.0 ± 5.8	73.3 ± 3.3
Actellic	100.0 ± 0.0	93.3 ± 6.7
LSD (P ≤ 0.05)	33.3	24.7

4.9 Toxicity of extracts on adult insects in treated grains

The toxicity of diethyl-ether and methanol extracts of the plants species on insects in treated grains is presented in Tables 4.15, 4.16 and 4.17. Percentage mortalities of both insects were low at lower concentrations of the diethyl-ether extracts of the bark of the plants. There was no significant difference in mortalities among the treatments. As the concentration of the extracts increased, the mortality of the insects also increased. The highest mortality (68%) was recorded for *S. zeamais* after four days grain treatment with 100% diethyl-ether and methanolic leaf extracts of C. *odorata*. The same concentration caused 68% mortality in *T. castaneum* after four days (Table 4.17). On the other hand, grains treated with 50% concentration of the leaf extract of *J. gossypiifolia* caused the highest mortality of 66.1% against *T. castaneum* after four days treatment (Table 4.16), while 20% and 50% diethyl-ether leaf extracts of *C. odorata* induced 66.1% mortality (Tables 4.15 and 4.16). There was no mortality in the control. Grains treated with actellic caused 90% mortality in the weevils.

Table 4.15: Mean % mortality of *T. castaneum* and *S. zeamais* exposed to grains treated with 20% extracts of *C. odorata* and *J. gossypiifolia* after 96 hours

Plant part/ Extraction solvent	Mean% mortality *T. castaneum* Day 4	*S.zeamais* Day 4
C.odorata leaves Diethyl-ether	57.0 ± 6.3	66.1 ± 4.7
C.odorata leaves Methanol	59.0 ± 3.8	59.0 ± 3.8
C.odorata bark Diethyl-ether	46.9 ± 3.3	48.8 ± 3.3
C.odorata bark Methanol	48.8 ± 3.3	50.8 ± 5.9
J.gossypiifolia bark Diethylether	46.9 ± 3.3	46.9 ± 3.3
J.gossypiifolia bark Methanol	48.8 ± 3.3	50.8 ± 5.9
J.gossypiifolia leaves Diethyl-ether	59.0 ± 3.8	63.4 ±0.0
J.gossypiifolia leaves Methanol	61.2 ± 3.8	59.0 ± 3.8
Actellic	77.7 ± 10.6	90.0 ± 0.0
Acetone control	0.0	0.0
LSD ($P \leq 0.05$)	8.37	6.44

Table 4.16: Mean % mortality of *T. castaneum* and *S. zeamais* exposed to grains treated with 50% extracts of *C. odorata* and *J. gossypiifolia* after 96 hours

Plant part/ Extraction solvent	Mean % mortality *T. castaneum* Day 4	*S. zeamais* Day 4
C.odorata leaves Diethyl-ether	61.2 ± 3.8	66.1 ± 4.7
C.odorata leaves Methanol	63.4 ± 0.0	57.0 ± 6.3
C.odorata bark Diethyl-ether	48.8 ± 3.3	50.8 ± 5.9
C.odorata bark Methanol	52.7 ± 3.5	52.7 ± 3.5
J.gossypiifolia bark Diethyl-ether	46.9 ± 3.3	48.8 ± 3.3
J.gossypiifolia bark Methanol	50.7 ± 0.0	52.7 ± 3.5
J.gossypiifolia leaves Diethyl-ether	66.1 ± 4.7	63.4 ± 0.0
J.gossypiifolia leaves Methanol	63.4 ± 0.0	59.0 ± 3.8
Actellic	77.7 ± 10.6	83.8 ± 10.6
Acetone control	0.0	0.0
LSD ($P \leq 0.05$)	7.31	8.68

Table 4.17: Mean % mortality of *T. castaneum* and *S. zeamais* exposed to grains treated with 100% extracts of *C. odorata* and *J. gossypiifolia* after 96 hours

Plant part/ Extraction solvent	Mean % mortality	
	T. castaneum	*S. zeamais*
	Day 4	Day 4
C.odorata leaves Diethyl-ether	68.8 ± 4.7	68.8 ± 4.7
C.odorata leaves Methanol	68.8 ± 4.7	68.8 ± 4.7
C.odorata bark Diethyl-ether	57.0 ± 6.3	59.0 ± 3.8
C.odorata bark Methanol	50.7 ± 0.0	54.7 ± 3.5
J.gossypiifolia bark Diethyl-ether	54.7 ± 3.5	56.7 ± 0.0
J.gossypiifolia bark Methanol	50.7 ± 0.0	54.7 ± 3.5
J.gossypiifolia leaves Diethyl-ether	68.8 ± 4.7	66.1 ± 4.7
J.gossypiifolia leaves Methanol	68.8 ± 4.7	59.0 ± 3.8
Actellic	77.7 ± 10.6	90.0 ± 0.0
Acetone control	0.0	0.0
LSD ($P \leq 0.05$)	8.57	5.89

4.10 Detection of hidden infestation

The degree of internal infestation was due to the presence of insects feeding inside the grains. Grains stained with acid-fuchsin solution and the grains dissected showed the degree of infestation by the number of egg plugs observed and the presence of larva and pupa respectively, compared with the control.

4.10.1 Oviposition

The mean total number of eggs laid per 20 grains by *S. zeamais* and *T. castaneum* after 7 days oviposition period before treating the grains with extracts is summarized in Table 4.18. It was observed that *T. castaneum* laid more eggs than *S. zeamais* though the observed differences in the number of eggs laid by both insects were not significantly different.

Table 4.18: Mean total number of eggs laid by *S. zeamais* and *T. castaneum* per 20 grains using the acid fuschin egg staining technique

Plant part/ Extraction solvent	Mean number of eggs laid ±SE	
	S. zeamais	*T. castaneum*
C. odorata leaves Diethyl-ether	72.6 ± 11.5	73.5 ± 8.3
C.odorata leaves Methanol	75.0 ± 7.9	78.1 ± 6.6
C. odorata bark Diethyl-ether	58.9 ± 7.7	63.2 ± 6.3
C. odorta bark Methanol	55.3 ± 6.0	58.3 ± 4.8
J.gossypiifolia bark Diethyl-ether	63.2 ± 6.3	60.7 ± 5.5
J.gossypiifolia bark Methanol	75.0 ± 7.9	72.8 ± 9.6
J. gossypiifolia leaves Diethyl-ether	63.9 ± 4.3	79.5 ± 5.5
J.gossypiifolia leaves Methanol	68.1 ± 11.6	68.9 ± 2.7
Actellic	85.7 ± 4.3	85.7 ± 4.3
Acetone control	76.3 ± 7.0	79.5 ± 5.5
LSD ($P \leq 0.05$)	23.07	18.27

4.11 Effect of extracts on immature stages of *T. castaneum* and *S. zeamais*

4.11.1 Effect of extracts on eggs

The *C. odorata* and *J. gossypiifolia* extracts reduced the emergence of adult *S. zeamais* and *T. castaneum* in grains containing eggs of the insects (Table 4.19). A few adults emerged at 20% concentration of diethyl-ether and methanolic bark extracts of both *C. odorata* and *J.*

gossypiifolia, while there were no emergence recorded for the same concentrations of leaf extracts of both plant species, just as the reference product (Table 4.19). There was a significant (P <0.05) difference between the extract treated grains and the control. The highest mean adult emergence of 15.0 was recorded in the control.

Table 4.19: Mean adult emergence (%) of *T. castaneum* and *S. zeamais* after treating eggs with 20% extracts of *C. odorata* and *J. gossypiifolia*

Plant part/ Extraction solvent	Mean adult emergence±SE	
	T. castaneum	*S. zeamais*
C.odorata leaves Diethyl-ether	0.0	0.0
C.odorata leaves Methanol	0.0	0.0
C.odorata bark Diethyl-ether	1.0 ± 0.7	1.0 ± 1.0
C.odorata bark Methanol	1.0 ± 1.0	1.0 ± 0.6
J. gossypiifolia bark Diethyl-ether	2.0 ± 0.9	1.0 ± 0.3
J. gosypiifolia bark Methanol	0.0	1.0 ± 0.3
J. gossypiifolia leaves Diethyl-ether	0.0	0.0
J. gossypiifolia leaves Methanol	1.0 ± 0.7	0.0
Actellic	0.0	0.0
Acetone control	15.0 ± 0.6	15.0 ± 0.9
LSD ($P \leq 0.05$)	1.61	1.42

4.11.2 Effect of extracts on larvae

The effect of methanol and diethyl-ether extracts of *C. odorata* and *J. gossypiifolia* on the developing larvae of *S. zeamais* and *T. castaneum* is summarized in Table 4.20. Generally the products had detrimental effect on the developing larvae as no adult emerged in all treatments though few adults emerged from the methanolic bark extracts of *J. gossypiifolia* and *C. odorata*, and diethyl-ether extracts of *J. gossypiifolia* but there were no significant difference among treatments.

Table 4.20: Mean adult emergence (%) of *T. castaneum* and *S. zeamais* after treating larvae with 20% extracts of *C. odorata* and *J. gossypiifolia*

Plant part/ Extraction solvent	Mean adult emergence ±SE	
	T. castaneum	*S. zeamais*
C.odorata leaves Diethyl-ether	0.0	0.0
C.odorata leaves Methanol	0.0	0.0
C.odorata bark Diethyl-ether	0.0	0.0
C.odorata bark Methanol	1.0 ± 1.0	1.0 ± 0.7
J. gossypiifolia bark Diethyl-ether	1.0 ± 0.3	1.0 ± 1.0
J. gosypiifolia bark Methanol	1.0 ± 0.6	1.0 ± 0.7
J. gossypiifolia leaves Diethyl-ether	0.0	0.0
J. gossypiifolia leaves Methanol	0.0	0.0
Actellic	0.0	0.0
Acetone control	14.0 ± 0.6	17.0 ± 0.3
LSD ($P \leq 0.05$)	1.24	1.31

4.11.3 Effect of extracts on pupae

The *C. odorata* and *J. gossypiifolia* extracts were effective against pupae and significantly ($P<0.05$) reduced the emergence of *T. castaneum* and *S. zeamais* (Table 4.21). Only 1 adult *S. zeamais* emerged in the diethyl-ether leaf extracts treatment of *J. gossypiifolia*. Leaf and bark extracts of *C. odorata* completely inhibited the development of *T. castaneum and S. zeamais.* The methanolic leaf extract of *J. gossypiifolia* also caused complete mortality of pupae and no adult beetle emerged in treated grains.

Table 4.21: Mean adult emergence (%) of *T. castaneum* and *S. zeamais* after treating pupae with 20% extracts of *C. odorata* and *J. gossypiifolia*

Plant part/ Extraction solvent	Mean adult emergence ±SE	
	T. castaneum	*S. zeamais*
C.odorata leaves Diethyl-ether	0.0	0.0
C.odorata leaves Methanol	0.0	0.0
C.odorata bark Diethyl-ether	0.0	0.0
C.odorata bark Methanol	0.0	0.0
J. gossypiifolia bark Diethyl-ether	0.0	0.0
J. gosypiifolia bark Methanol	1.0 ± 0.7	0.0
J. gossypiifolia leaves Diethyl-ether	0.0	0.0
J. gossypiifolia leaves Methanol	0.0	0.0
Actellic	0.0	0.0
Acetone control	16.0 ± 1.5	15.0 ± 1.5
LSD ($P \leq 0.05$)	1.52	1.42

4.12 Grain dissection to detect dead immatures

The mean number of larvae and pupae per 20 grains by *S. zeamais* and *T. castaneum* after the treatments were applied one and two weeks after adult removal is summarized in Table 4.22. It was observed that both insects treated with the diethyl-ether extract of the bark of *J. gossypiifolia* had higher percentages of pupae within the grains next to the control. The larvae of both insects treated with methanolic leaf extract of *C. odorata* and *J. gossypiifolia* significantly ($P<0.05$) reduced the number of larvae and pupae hatchability.

Table 4.22: Mean number of larvae and pupae of *S. zeamais* and *T. castaneum* dissected from stored grains

Plant part/ Extraction solvent	Mean % dissected larvae and pupae ± SE			
	T. castaneum		*S. zeamais*	
	Larva	Pupa	Larva	Pupa
C.odorata leaves Diethyl-ether	50.8 ± 3.4	42.1 ± 1.7	45.03 ± 4.4	36.2 ± 1.7
C.odorata leaves Methanol	56.8 ± 1.8	45.0 ± 1.7	45.9 ± 2.5	39.2 ± 1.7
C.odorata bark Diethyl-ether	53.7 ± 1.7	44.0 ± 3.5	50.7 ± 1.7	44.0 ± 3.5
C.odorata bark Methanol	51.8 ± 3.5	37.2 ± 1.0	49.8 ± 2.6	37.2 ± 2.6
J.gossypiifolia bark Diethyl-ether	55.8 ± 2.7	51.7 ± 1.0	55.8 ± 2.7	45.0 ± 3.3
J. gosypiifolia bark Methanol	53.7 ± 1.7	38.2 ± 1.0	45.9 ± 2.5	39.2 ± 1.7
J. gossypiifolia leaves Diethyl-ether	47.8 ± 1.7	38.2 ± 1.0	55.8 ± 2.7	38.2 ± 1.0
J. gossypiifolia leaves Methanol	53.7 ± 1.7	37.2 ± 1.0	55.8 ± 2.7	39.2 ± 0.0
Actellic	66.2 ± 3.4	64.1 ± 5.4	73.4 ± 1.8	64.9 ± 1.3
Acetone control .	65.0 ± 3.4	58.0 ± 3.8	70.1 ± 1.5	47.8 ± 1.7
LSD ($P \leq 0.05$)	7.78	7.55	7.77	6.19

4.13 Damage assessment

Damage assessment in terms of percentage weight loss due to the feeding activities of the insects is presented in Table 4.23. Grains treated with the plant extracts significantly (P<0.05) reduced damage caused by *S. zeamais* and *T. castaneum* compared with the untreated grains. Leaf extracts of *C. odorata* and *J. gossypiifolia* were more potent than the bark extracts as the lowest weight loss caused by both insect species was recorded in those treatments compared to bark extracts. The methanol extract of the bark of *J .gossypiifolia* was the least effective after the control in protecting grains from damage by *S. zeamais* and *T. castaneum* (Table 4.23.). Maize grains were protected by the extracts for 37 days in storage with no significant difference (P<0.05) between the leaf extracts and Actellic, though the plant materials was generally less effective than Actellic.

Table 4.23: Mean % weight loss caused by *S. zeamais* and *T. castaneum* on grains stored for 37 days with 20% extracts of *C. odorata* and *J. gossypiifolia*

Treatment	Mean % weight loss ±SE			
	S. zeamais		*T. castaneum*	
	Egg	Larva	Egg	Larva
C. odorata leaves Diethyl-ether	1.46 ± 0.1	1.14 ± 0.1	0.77 ± 0.4	0.48 ± 0.2
C. odorata leaves Methanol	1.00 ± 0.1	0.68 ± 0.1	0.66 ± 0.3	1.15 ± 0.2
C. odorata bark Diethyl-ether	1.07 ± 0.1	0.79 ± 0.1	1.15 ± 0.2	1.13 ± 0.3
C. odorata bark Methanol	1.38 ± 0.4	0.94 ± 0.1	0.77 ± 0.2	0.49 ± 0.0
J. gossypiifolia bark Diethyl-ether	0.68 ± 0.1	1.38 ± 0.4	0.61 ± 0.2	0.79 ± 0.1
J. gosypiifolia bark Methanol	1.15 ± 0.1	1.07 ± 0.1	1.05 ± 0.2	0.67 ± 0.2
J. gossypiifolia leaves Diethyl-ether	0.79 ± 0.1	0.99 ± 0.1	0.71 ± 0.2	0.86 ± 0.1
J. gossypiifolia leaves Methanol	0.94 ± 0.1	1.46 ± 0.1	1.11 ± 0.3	0.71 ± 0.1
Actellic	0.32 ± 0.0	0.26 ± 0.0	0.16 ± 0.0	0.14 ± 0.0
Acetone control	6.83 ± 0.9	6.57 ± 0.5	4.47 ± 0.7	2.79 ± 0.3
LSD (P ≤ 0.05)	0.98	0.65	0.96	0.55

CHAPTER FIVE

5.0 DISCUSSION

5.1 Socio-economic characteristics of farmers

Farmers' decision to use any storage structure was influenced by factors such as sex, age, educational level, household size and the capacity to store (Antle *et al*., 1993). This study however revealed that the choice of the storage structures and the postharvest practices used by farmers was not influenced by their age, sex, educational level or household size. This could be related to the fact that some of them had not received any training from Agricultural Extension Officers in production and postharvest practices. The only social factor that influenced the choice of any of the storage structures was years of farming experience. For example, the use of traditional cribs was mostly used by experienced farmers since they knew that cribs might have the highest storage period (24 months) and the lowest storage losses (5.0%). Other inexperienced farmers use Traditional Ewe barns and room stores.

5.2 Production, harvesting and postharvest practices

Post-harvest practices include harvesting, gathering, transportation of grains from the field to homes, drying, threshing, shelling, cleaning and packaging (Golob *et al*., 2002). Most of the farmers (64%) in the Awutu-Senya District store their maize on cobs with the sheath (husks) on. Therefore activities such as shelling, drying, threshing and cleaning are not properly done before storage. Traditionally, cereal grains are stored in the dry form (Marsland and Golob, 1999). Drying is normally effected by leaving the matured crops in the field to dry in the sun before harvesting. It is noted that the cereals are harvested with a high moisture content ranging between 21-25% (Boxall *et al*., 2002). Grains are further dried in the sun (either in the field or at home) after harvesting to avoid heating and fungal growth (Marsland and Golob, 1999), unlike what is practiced in certain parts of Ghana, especially in the Ashanti and Brong-Ahafo Regions, where the sheath of the maize may be removed and the cobs sorted into two lots; damaged and undamaged (Nyanteng, 1972). Similar differences in post-harvest practices have been reported in other parts of Africa (Golob *et al*., 2002). These differences in post-harvest handling between areas in a country reflect mostly farming experience and ethnicity and are not necessarily a result of economic or technical influences (Golob *et al*., 2002).

The two major forms of storing maize have advantages and disadvantages. Insect infestation starts on the field (Farrell *et al*., 2002), thus removal of sheath makes it possible to select and store the cobs which have not been infested. The presence of long tight husks is known to reduce weevil infestation in the field (FAO, 1969; Kossou *et al*., 1993), and the protective function of husks can carry over into the maize storage period. Another advantage is that fungal growth is reduced as a result of a decrease in weevil infestation. Weevils facilitate the growth of *Aspergillus flavus* and aflatoxin production in maize by increasing surface area susceptible to fungal infection and increasing moisture content as a result of the weevil metabolic activity (Beti *et al*., 1995). Also, re-infestation can be facilitated in store where cobs are stored without sheaths (Farrell *et al*., 2002). However, storing in sheath does not allow selection to be done and hence both damaged and undamaged cobs are stored together.

5.2.1 Area under maize cultivation

The land under cultivation by participating farmers was approximately 1.2 (ha) and 83% of them expressed the willingness of increasing the quantity of maize they grow, though they were constrained by several factors including availability and size of land, sale of previous season and current market price of the crop. These factors make it difficult for farmers to decide the area of maize to be grown and quantity that would be stored per season. This was a contradiction to findings of Mijinyawa *et al*. (2006) who reported that the quantity of maize to be stored depended on the quantity harvested. In view of these, farmers have resolved to farming on small lands as they could not get enough land to increase their productivity.

5.3 Varieties of maize stored and farmers' knowledge on modern farm practices

Farmers in the Awutu-Senya District mainly store three types of maize varieties. The survey showed that 60% of the farmers cultivated the hybrid maize variety known as the Obaatanpa and only 8% cultivated the mixed maize (Akpossoi) variety. The local variety, Abasa, was also common in the district.

Technology is the accumulation of knowledge that lowers cost of production and helps in increased output (Hill, 1990). For example, in storage-loss control, the uses of appropriate protectants, which reduce loss and lengthen shelf-life of grains, reduce the vulnerability to pest infestation (Egyir, 2003). Farmers in the study area have knowledge on improved farming methods such as growing of improved maize varieties, planting in rows with correct spacing and practising postharvest activities such as dehusking, shelling, cleaning and drying before storage. Rogers (1995) asserted that an individual's knowledge of an activity depends on factors such as educational level, participation in training programmes, accessibility to mass media and accessibility to change agent. Oloruntoba and Adegbite (2006) contended that the provision of extension services coupled with other factors have significant positive influence on decision to adopt introduced technologies with attendant improvement in productivity and the well-being of farmers. Thus, for a farmer to get access to a new technology the important factors are the change agent and the farmers' willingness to accept the technology. Therefore, the lack of knowledge on such pertinent agricultural practices could have resulted from the absence of these change agents. In effect an individual's adoption and use of good agricultural practices is influenced by their ability to utilize the information, as well as the structures made available by relevant institutions (Oloruntoba and Adegbite, 2006).

5.3.1 Types of materials used for construction of storage structures

The materials used for the construction of stores in the district included mud, wood slaps, bamboo, sand, cement and aluminum roofing sheets, especially for traditional cribs and room stores. These materials were not different from those described by Nyanteng (1972) for traditional storage structures in Ghana. These materials were obtained locally, except in a few cases where stores were constructed using materials such as cement and galvanized zinc sheets. One of the key factors affecting efficient storage of produce is the availability of the structure to hold the produce, depending on the type of produce, volume of storage, technical and economic situations of the individuals involved in the storage (FAO, 1994b; World Resources, 1998; Mijinyawa, 2002; Dlamini, 2003). The effectiveness of storage structures in any farming communities is related to the availability and affordability of its construction materials as well as the appropriateness of the technology and its efficiency (Itto and Wongo, 2002).

Out of the different types of storage structures, the Traditional Ewe barns, room stores and traditional cribs were the three commonly used storage types in all the sample communities. With the exception of room stores, the other two structures do not last very long since the roofs require replacement every season. The traditional storage structure systems and practices used by farmers in the study area have evolved over many generations to keep grains cool, dry and safe from pests attack. Despite adaptations, pests often find their way to the stored grain, so farmers have to ensure good grain conditions and quality through sun-drying, spraying or applying chemical, dehusking and shelling to prevent further damage against pests and rodents.

These materials were observed to be non-resistant to one form of deterioration or the other. Walls of some of the rooms used as grain stores were constructed from either mud or bricks, and as such, they were subject to rain erosion and in some cases cracks on the walls induced water getting into the rooms. Natural fibers are prone to fire hazards. They are also liable to decay due to weathering and insect attack. Wood products were substantially used for construction because of their local availability and ease of use though breakages and decay were some problems identified with their usage. Some of the wood species were claimed to be naturally durable and were often used untreated. They were therefore often attacked by insect pests since no attempt was made to apply any preservatives. Those used as columns for traditional cribs were prone to either buckling or breakage due to overloading. Where metal roof is used, corrosion is a common problem, especially around the nail points, which may lead to leakage.

5.3.2 Maize storage efficiency

The efficiency of storage systems was determined by storage length and losses that are incurred. Maize storage methods used by households were inefficient except for traditional cribs and the room stores. The majority of the farmers using the various storage structures said they did not intend to change the type of storage method used despite the problems associated with their usage. The average storage length stated by farmers varied and ranged from 5 to 8 months, indicating that the grain is commonly sold or consumed prior to or by the time new season's maize is ready for harvesting. Maize storage has the potential to smoothen food supply between harvests (Thamaga-Chitja *et al*., 2004), but seemingly insufficient produce is stored to take households through to the next season. Some of the farmers in the study area reported purchasing additional maize to take them to the next crop harvest, and this highlights the inadequacy of production and storage systems. Farmers could not accurately estimate storage losses making it difficult to determine the proportion of maize lost due to deterioration in storage. However, respondents reported maize losses in storage to be ranging from 7-15%. It is therefore difficult to determine if food supply is constrained by inadequate production or if production is constrained by storage potential and if storage potential is limited by maize deterioration.

FAO (1994a) reported that there had been a tendency to over-estimate storage losses, and to base estimates on extreme cases or guess-work rather than on sound empirical testing. Figures of 30% or more are not uncommon for grains, 50% for roots and tubers and 100% for perishable crops such as fruit and vegetable crops (FAO, 1994a). Ghana's crop loss level has been estimated at a global 30 percent or more (Egyir *et al.*, 2008). Even if these figures are exaggerated, FAO (1994a) suggests that food losses as low as 5% should not be ignored. This is because such losses are usually accompanied by qualitative losses which affect the whole mass of the grain in store. Moreover, the losses are mainly experienced during the lean season before the new harvest is ready, thereby having an adverse effect on the food security of farming families at a particular critical period.

The Traditional Ewe barns were comparatively cheap to construct, maintain and easily accessible to respondents, and hence widely used. Although these structures can store grain for more than six months, higher losses make this storage method inefficient. The average storage length for Traditional Ewe barns was much lower than that of the traditional cribs. Thus, increased use of traditional cribs could extend the availability of maize for households in the district. Therefore, traditional cribs may increase household food security but it is less accessible to poorer households because of the high cost and labour involved in their construction. The storage length of maize in room stores was almost comparable to the average storage length of maize in traditional cribs. However, respondents using this structure reported losses higher than those of the traditional cribs.

5.4 Maize losses incurred by farmers

Losses' estimates reported by the farmers in the district varied widely. The estimates could hardly be correlated with the length of storage. While the estimated losses tend to vary, it was noted that there was similar range within which most of the estimated figures fell. While it is now generally accepted that the traditional local storage systems are usually well-adapted to local conditions and losses from grain are generally low and acceptable to farmers (Compton, 1992), farmers surveyed estimated between 5 to 15% of maize stored in the various storage structures. The farmers using the Traditional Ewe barns reported higher losses and the lowest was reported by farmers using the traditional cribs. These estimates are consistent with those reported by Reusse (1968), Rawnsley (1969), Nyanteng (1972), Armah and Asante (2003) and Egyir *et al*. (2008). However, the estimates reported by these farmers were higher than those obtained by this author using standard laboratory methods. Most farmers in the area of study considered storage losses caused by insects and rodents as serious, and those caused by moulds as minimal. The two commonest insects reported by the farmers were the maize weevil, *S. zeamais* and the red rusty flour beetle, *T. castaneum*, though *S. zeamais* is a key pest since farmers appear to be more familiar with it than *T. castaneum.* Other insect pests reported by farmers were *P. truncatus*, *S. cerealella* and *R. dominica.* The farmers' opinion that *S. zeamais* was the most destructive corroborates reports in Ghana, that out of an estimated total annual harvest of 250,000-300,000 tonnes of maize about 20-25% is lost to *S. zeamais* alone (Ayertey, 1982; Obeng-Ofori and Amiteye, 2005).

It was observed that farmers did not store new, clean grains separately from old, infested grains in their stores. Additionally, farmers did not clean their stores before storing new harvested maize. All these bad post-harvest practices contributed to maize losses in the stores.

5.5 Pests control measures by farmers

Most of the farmers in the Awutu-Senya District use different pest control measures such as treatment with Actellic or phostoxin, drying the maize frequently, dehusking and shelling to prevent further damage. It was also observed that most of the farmers (52%) in the study area applied chemicals for preservation. However, sampled grains showed to a larger extent the presence of insects. It was observed that most of the farmers had been trained in the past by MoFA Extension Officers on the use of insecticides (synthetic and botanicals). However, the farmers were not applying the chemicals as recommended by the manufacturers. Most of the farmers could not read the label and apply the recommended chemical at the required quantity. Some of the farmers have been made to believe by the chemical peddlers that these chemicals are not toxic to humans. Furthermore, respondents believed the liquid does not get into the maize itself since it is just sprayed on the grains or around the sacks.

5.6 Contact toxicity of extracts on insects by topical application

The concentration of the methanol and diethyl-ether extracts of the leaves and bark of *C. odorata* and *J. gossypiifolia* were bioactive against *S. zeamais* and *T. castaneum* when applied topically on them and monitored for 48 hours, though the leaves of both plants were significantly more potent than the bark. The extracts in the present study were more toxic to *T. castaneum* than *S. zeamais.* The effectiveness of the extracts indicates a positive contact action of the active constituents in *C. odorata* and *J. gossypiifolia*. In a similar study leaf extracts of *J. gossypiifolia* were shown to be toxic to *T. castaneum* (Herbst) (Coleoptera: Tenebrionidae) and *Phenacoccus* *herreni* William & Cock (Sternorrhyncha: Pseudococcidae) (Dev and Koul, 1997; CIAT, 2001). Using *Jatropha curcas* L. (Euphorbiaceae) extracts, a 20% concentration was required to cause 70 to 90% mortality in beetles (Asmanizar and Idris, 2012). Thus, insect susceptibility to the extracts may depend on mode of administration, chemical composition of the constituent compounds and their structural features (Bell, 1986).

5.7 Repellent effect of extracts on insects

The various plant extracts were repellent to *S. zeamais* and *T. castaneum* relative to the control. The diethyl-ether leaf extract of *J. gossypiifolia* gave the highest repellent effect of 83.3% against both insects, while the least repelled was the bark of *C. odorata* against *T. castaneum*. The treatments were more repellent against *S. zeamais* as compared to *T. castaneum*. Studies by Ogendo *et al*. (2004) found similar repellency against maize weevil using leaf extracts from *Lantana camara* L. and *Tephrosia vogeli* (Hook). These findings indicate good potential of *C. odorata* and *J. gossypiifolia* for the use as repellent and toxic agents in the management of the maize weevil. Since plant derived pesticides are biodegradable and safer to higher animals, they offer a viable alternative to synthetic agrochemicals (Bouda *et al*., 2001; Soon-II *et al*., 2003). The degree of repellency to the two insects may depend on the habit of the insect species. *Tribolium castaneum* is always confined to closed habitats in the stored product environment while *S. zeamais* is often in close association with crops in the field, as well as in stores, and this tends to expose them to secondary compounds of botanicals. Furthermore, the results may be attributed to the presence of several secondary compounds from *J. gossypiifolia* leaves and its implication in the toxicity, including flavonoids (e.g. apigenin, isovitexin, vitexin) and diterpenoids (e.g. jatrophone) (Kupchan *et al*., 1970; Subramanian *et al*., 1971) that have both attractants and repellent properties. The repellent action increases the protectant potential of the plants against storage insect pests since the treatment with high repellency reduced damage caused by the insects in stored grains. However, a detailed investigation of the effects of the individual constituent of the plant needs to be further studied.

5.8 Toxicity of extracts to adult insects in treated grains

The methanol and diethyl-ether extracts *of C. odorata* and *J. gossypiifolia* on the adult insects in treated grains after 4 days period increased the mortality and decreased the feeding activity of *S. zeamais* and *T. castaneum* with the highest concentration yielding the highest percentage mortality compared to the control. This could be due to the presence of the β-sitosterol, tanins and other saponins found in the leaves and bark of the plants which might act as antifeedants (GISD, 2006; Talukder, 2006). The leaf extracts protected the grain against damage than the bark. The lower protection observed in the bark extract could be attributed to the loss of toxic volatile secondary constituents during the drying and extraction process (Bekele *et al*., 1997). Asawalam *et al*. (2006) found that *C. odorata* leaf extracts caused 69% mortality of *S. zeamais* in treated grains. Stoll (2000) used 20% of lime to treat 1 kg of maize and was found to be very potent against *S. zeamais* in the treated maize. The test insecticide at the different concentrations was more toxic to *S. zeamais* than *T. castaneum* which further demonstrates that pirimiphos-methyl, the active compound in Actellic was effective for the control of *S. zeamais* on maize grains at the recommended dose (Obeng-Ofori and Amiteye, 2005).

5.9 Oviposition test

The results obtained from the oviposition test using the acid fuschin egg-staining technique (Milner *et al*., 1950) detected that *S. zeamais* laid less number of eggs than *T. castaneum*. In a similar study by Ashford (1970) it was reported that a healthy *Tribolium* fertile female lays no egg in the first three days of adult life, and then lays egg at an increasing rate up to 18 per day.

The females of these insects laid eggs individually in small cavities chewed into grains and each cavity sealed and the egg protected by an egg-plug that was distinctly stained cherry-red. Once eggs were laid there was a high chance of survival irrespective of the further nutritional status of the grains (Frimpong, 2004). This detection of eggs on grains was done with the aim of testing if the insects actually laid eggs before treating the grains to determine the effect of extracts on the immature stages of the test insects. This method, however, revealed the efficacy of the extracts with low adult emergence though there were many eggs laid.

5.10 Effect of extracts on immature stages of *T. castaneum* and *S. zeamais*

The extracts of *C. odorata* and *J. gossypiifolia* reduced the number of adults of *S. zeamais* and *T. castaneum* that emerged in grains containing the egg and inhibited the development of larvae and pupae of both beetle species. Significant reductions in egg hatchability revealed the harmful effect of extracts of the plant species towards the eggs of the test insects. This observation is in agreement with that of Khanam *et al*. (2008) who reported that food treated with *J. gossypiifolia* leaf extract strongly inhibits the fecundity of *T. castaneum* compared with *T. confusum*. The leaf extracts of both plant species caused complete inhibition of emergence of the immature stages. The high activity of the leaf extract may confirm the presence of secondary compounds as reported by Taponjou *et al*. (2002). The high mortality induced by the leaf extracts of the plants indicates that they could be used for the control of grain storage insect pests. Similar investigations carried out by Okonkwo and Okoye (2006) revealed 50% mortality in adult *S. zeamais* and reduced adult emergence by *Monodora myristica*. The complete inhibition of the development of eggs and immature stages within grain kernels suggests the presence of ovicidal properties in the plant (Taponjou *et al*., 2002), and this increases the protectant potential of *C.*

odorata and *J. gossypiifolia* against insect damage in storage.

5.11 Damage assessment

The Thousand Grain Mass (TGM) method was used to assess percent weight loss on grain caused by *S. zeamais* and *T. castaneum*. *Tribolium castaneum* caused less damage to the stored grains throughout the storage period. Generally, beetle damage was significantly reduced in all treatments. The leaf extracts of both plant species significantly reduced damage more than the bark extracts. This is evidenced by the high repellency and low number of adult emergence in such treatments. The methanol extract of the bark of *J. gossypiifolia* was the least effective after the control in protecting grains from damage by *S. zeamais* and *T. castaneum*. The low percent weight losses reported occurred when the insects were feeding during the oviposition period prior to the treatment of the grains. Udo (2011) indicated that damage to grain by these insects was reduced in grains with treatments which exhibited high repellency to insects. The active compounds in these plants acted as deterrents and toxicants to the insects. These inhibited feeding on the grains by rendering them unattractive or unpalatable to the insects (Saxena *et al*., 1988). At 37 days after infestation, the results showed that the differences in weight losss among the leaf extracts of the botanical pesticides were not significant for all the bioassays in this study even though each of the plant materials was generally less effective than Actellic applied to the grains. This resulted in the lowest percentage weight loss, perhaps on account of the fact that this product is a conventional synthetic insecticide specifically formulated with high insecticidal activities on stored product pests (Anon, 1993).

Botanical pesticides represent an important component of integrated pest management (IPM) systems in traditional grain storage, as they are broad spectrum in action, based on local materials and potentially less expensive (Obeng-Ofori *et al*., 1997). Many are also safe to the environment and harmless to man and other mammals (Talukder and Howse, 1995). However, farmers in the Awutu-Senya District were not using botanicals for grain protection, because they do not have the know-how to actually apply botanicals to protect their stored produce against pest infestation. Also, many of these non-chemical methods are slow acting and not standardized, their use are mainly dependent on experience and tradition (Delobel and Malonga, 1987; Belmain and Stevenson, 2001). In addition, the superiority in efficacy of synthetic compounds over non-chemical methods has been shown by recent studies. Okunade *et al*. (2002) reported that Pirimiphos-methyl was more potent against *R. dominica* on sorghum in comparison to 12 natural plant products. Similarly, Obeng-Ofori and Amiteye (2005) reported that only pirimiphos-methyl showed effective control of *S. zeamais* on stored maize grains when its efficacy was compared with products from three plant species. Synthetic chemicals, are often quick acting and persistent in the stored grain, thus ensuring long term protection. Most trials using botanicals are usually laboratory- based and of short duration. There is therefore, the need to build on farmers' experience and traditional methods in developing more cost-effective and sustainable storage-pest control strategies based on locally available botanicals for small-scale farmers in the Awutu-Senya District of Ghana.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Maize is the most important crop grown in the Awutu-Senya District of Ghana. Farmers store their maize for 7-8 months, generally to provide a food reserve, sale for better price as well as seed for future planting. However, maize storage conditions are inappropriate and farmers experience postharvest grain losses mainly due to insect attack. The maize weevil, *S. zeamais* was identified by farmers as a key pest of maize whose infestation starts in the field before harvest and extends throughout the storage period predisposing them to attack by the secondary pest, *T. castaneum.* The population of *T. castaneum* persisted throughout storage with the population increasing as storage duration was prolonged, making it a major pest. Owing to the economic importance attached to maize in Ghanaian agriculture there is the need to protect the crop against damage by the insecs during storage.

It was observed that farmers in the district have been using pirimiphos-methyl (Actellic) as one of the pest control measures but was undermined by their low level of education in reading the labels for handling and application procedures and storage practices. Researchers and extension officers also need to educate maize farmers continuously in adopting suitable pest control methods since some of their activities can either promote pest outbreaks or reduce their infestation.

The study has shown the bio-efficacies of the Siam weed, *C. odorata* and the Bellyache bush, *J. gossypiifolia* against *S. zeamais* and *T. castaneum* with insecticidal, antifeedant, ovicidal and repellent properties.

Extracts of dry leaf and bark of *C. odorata* and *J. gossypiifolia* were toxic to *T. castaneum* and *S. zeamais* when applied topically.

The diethyl-ether leaf extracts of *C. odorata* and *J. gossypiifolia* repelled the insects, as well as reduced adult emergence in treated grains.

Grains treated with the methanol and diethyl-ether leaf extracts of the two plant species reduced damage caused by *S. zeamais* and *T. castaneum* with resultant decrease in weight loss.

Both solvents performed equally well on the average, but in terms of the effectiveness of the plant parts, the leaf extracts of both plants were more potent than the bark.

All the laboratory bioassays showed that pirimiphos-methyl (Actellic) used at the current registered rate 4 ml/L (10 ppm) on maize was very effective against *S. zeamais* and *T. castaneum* adults, perhaps on account of the fact that this product is a conventional synthetic insecticide specifically formulated with high insecticidal activities on stored product pests.

The results obtained from the study suggest good potential for the use of *C. odorata* and *J. gossypiifolia* in stored product pest management system, in view of the relative safety of the plants which are used to cure diseases like malaria and jaundice by drinking the boiled extract of *C. odorata*. In Ghana, the leaves of *J. gossypiifolia* are used as a purgative, and the leaf sap is applied to the tongue of babies to treat thrush and to inflamed tongues of adults.

The results of this study have also established the scientific bases of the practice by farmers in northern Ghana in which the leaf of C. *odorata* is pounded and mixed into stored grain. The leaf extracts of *C. odorata* and *J. gossypiifolia* could therefore be used as a component of Integrated Pest Management in stored product protection if further field studies are undertaken.

6.2 Recommendations

Based on the findings of the study, the following recommendations can be made:

- Farmers should improve on postharvest practices to reduce losses of grain by harvesting early, sorting, drying and carrying out regular inspection of grains to be able to detect damage early;
- Further studies should be carried out to assess postharvest losses attributed to insects in the traditional storage structures;
- Researchers and extension officers need to involve maize farmers in finding and adopting suitable pest control methods since some of their activities can either promote pest outbreaks or reduce their infestation;
- Extensive studies should be carried out on the biologically active compounds in *C. odorata* and *J. gossypiifolia* for the control of stored product pests to determine the precise mode of action of the active compounds;
- Chemical residue analysis on maize and the effect of the extracts on non-target organisms should be carried out to enable its full incorporation into IPM practices;
- Other solvents should be used for the extraction process to evaluate the efficacy in controlling insect pests; and
- Studies should be carried out to determine the persistence of solvents on stored products and results should be validated in the field.
- In so doing, a cheap readily available and environmentally friendly pest control agent can be developed for grain protection.

REFERENCES

Abate, T. A., Van Huis, A. and Ampofo, J. K. O. (2000). Pest Management Strategies in Traditional Agriculture: An Ethiopian Agricultural Research Organization, Nazareth Research Center. African perspective. *Annual Review of Entomology* **45**: 631-659.

Abbott, W. S. (1925). A method for comparing the effectiveness of an insecticide. *Journal of Economic Entomology* **18**: 265-283.

Adams, J. M. and Harman, G.W. (1977). The evaluation of losses in maize storage on a selection of small farms in Zambia with particular reference to the development of methodology. Tropical Products Institute G109, Slough, UK, 160 pp.

Adams, J. M. and Schulten, G. G. M. (1978). Losses caused by insects, mites and micro - organisms. *In*: K.L .Harris and C.J. Lindbald (eds.) Post-harvest Grain Loss Assessment Methods. American Association of Cereal Chemist, U.S.A, 135 pp.

Addae- Mensah, I. (1998). The uses of the neem *Azadirachta indica* A.Juss in Ghana and their relationships to the chemical constituents and biological activities. *In*: The potentials of Neem Tree in Ghana. *Proceedings of a seminar held in Dodowa, Ghana*. GTZ, Eschborn, 11-26 pp.

Adesuyi, S.A. (1982). Field trials with permethrin dust for the control of insects' infestation in stored products in Southern Nigeria. *Journal of Stored Product Research* **18**: 125-130.

Adetunji, M. O. (2007). Economics of maize storage techniques by farmers in Kwara State, Nigeria. *Pakistan Journal of Social Sciences* **4(3)**: 442-450.

Aikins, S. H.M., Bart- Plange, A. and Opoku- Baffour, S. (2010). Performance evaluation of Jab Planters for maize planting and inorganic fertilizer. *ARPN Journal of Agriculture and Biological Science* **5(1)**: 29-33.

Alzouma, I. (1990). The post- harvest situation on Sahel. *In*: Post Recolte en Afrique, Abidjan (Cote d' Ivoire), 29th January, 1990. *Proceedings- AUPELP- UREF*, Paris (France) 9: 22-28.

Anon. (1982). Plant Protection Legislation. FAO, Rome, 165 pp.

Anon. (1983). Food storage manual (2nd ed.) World Food Programme */ TDRI*, London.263 pp.

Anon. (1993). Zeneca Agrochemical Product Specifications. Imperial Chemical House, Millbank, London, p. 4.

Anon. (1999). New Technologies for Grain Storage. Department of Warehouses and Storage, China National Grain Reserve Bureau, Beijing, P. R. China. *In*: Crop Post-harvest Science and Technology Volume 2: Durables. Blackwell Publishing, Oxford, UK, pp. 26-51.

Antle, B., John, M. and Tom, M. (1993). Technological innovation agricultural productivity and environmental resources. *In*: G.A. Carlson, D. Zilbberman and J.A.Miranowski (eds.), *Agricultural and environment resource economics*. Oxford University Press, New York, pp. 175-217.

Armah, P. and Asante, F. (2003). Traditional maize storage systems and staple-food security in Ghana. *Journal of Food Distribution Research* **37(1)**: 40-45.

Asawalam, E.F. and Emosairue, S.O. (2006). Comparative efficacy of *Piper guineense* (Schum and Thonn) and Pirimiphos-methyl on *Sitophilus zeamais* (Motsch.). Tropical and Subtropical Agroecosystem 6: 143-148.

Asawalam, E.F., Emosairue, S.O., Ekeleme, F. and Wokocha, R.C. (2006). Insecticidal effects of eight Nigerian plant species against maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). pp. 106-113.

Ashford, R.W. (1970). Some relationships between the red flour beetle, *Tribolium castaneum* (Herbst)(Coleoptera:Tenebrionidae) and *Lymphotropha trioli* (Neogregarinidae: Schizocystidae). *Acta Protozool* **7**: 513-529.

Asiedu, E.A. and Van Gastel, A.G.J. (2001). Dehumidifying drying: a viable option for long term seed storage in humid tropics. Impact, challenges and prospects of maize research and development in West and Central Africa. *In*: Economics of Maize Techniques by Farmers in Kwara State, Nigeria. *Pakistan Journal of Social Sciences* **4(3)**: 442-450.

Asiedu, E.A., Adusei-Akowuah, P., Van Gastel, A.G.J. and Sallah, P.Y.K. (2002). Effect of dehumidifiers drying on storage life of maize. *Crop Research Institute* **42**: 196-199.

Asmanizar, A.D. and Idris, A.B. (2012). Evaluation of *Jatropha curcas* and *Annona muricata* seed crude extracts against *Sitophilus zeamais* infesting stored rice. *Journal of Entomology* **9**: 13-22.

Asolkar, L.V., Kakkar, K.K. and Chakre, O.J. (1992). Glossary of Indian medicinal plants with active principles. Part I. New Delhi, India, *P & I Directorate*, *CSIR*, pp. 232-233.

Awutu-Senya District Profile (2008). 71pp.

Ayertey, J.N. (1979). The control of some pests of stored maize using methyl bromide or phosphine. *Ghana Journal of Agricultural Science* **12**: 113-124.

Ayertey, J.N. (1982). Development of *Sitotroga cerealella* on whole cracked or ground maize. *Entomologia Experimentalis et Applicata* **31**: 165-169.

Banerji, J., Das, B., Bose, P., Chakrabarti, R. and Chatterjee, A. (1993). Traditional medicine, Mukherjee, (ed.), New Delhi, India: Oxford and IBH Publishing, 352 pp.

Bani, R. J. (1991a). Reduce Grain Postharvest Losses Agriculture Mechanization in Asia, African and Latin America 22(2): 67-70.

Bani, R. J. (1991b). The significance of post-harvest food losses in Ghana: *The Legon Agricultural Research and Extension Journal* **3(1)**: 43-46.

Bartali, E.H. (1990). The post-harvest situation in Northern Africa. *In:* Post Re'colte en Afrique, Abidjan, Cote d'Ivoire) 29th January, 1990. *Proceedings-AUPELF-UREF*, Paris (France), pp. 17-21.

Baxter, P. (2000). Deadly weeds on Leper Island. Northern Territory News, November 8: 19.

Begg, J. and Gaskin, T. (1994). *Jatropha gossypiifolia* - poisonous information. Ontario: *IPCS INCHEM*, unpaginated. [Monograph 643.]

Bekele, A.J., Obeng- Ofori, D. and Hassanali, A. (1997). Evaluation of *Ocimum kenyense* (Ayobangira) as source of repellents, toxicants and protectants in storage against three major stored product insect pests. *Journal of Applied Entomology* **121**: 169-173.

Bell, E.A. (1986). Plants as sources of novel pest and disease control agents. *In*: British crop protection conference-pests and diseases. BCPC publications, Brighton, England. pp. 661-667.

Bellyache bush Pest Status Review (1999). 29 pp.

Belmain, S.R., Golob, P., Andan, H.F. and Cobbinah, J.R. (1999). Ethobotanicals- future prospects as post-harvest insecticides. *Agro- Food Industry Hi- Tech* **10**: 34-36.

Belmian, S.R., Neal, G.E., Ray, D. E. and Golob, P. (2001). Insecticidal and vertebrate toxicity associated with ethnobotanicals used as post- harvest protectants in Ghana. *Food and Chemical Toxicology* **39:** 287-291.

Belmain, S. and Stevenson, P. (2001). Ethnobotanicals in Ghana: Reviving and modernizing age-old farmer practice. Pesticide Outlook 12: 233-238.

Belmain, S. R. (2002). Botanicals. *In*: P. Golob, G. Farrell and J.E., Orchard (eds.). Crop-Post-Harvest. Science and Technology, Volume 1 Principles and Practice. Blackwell Publishing, Oxford, U.K, 37 pp.

Beti, J.A., Phillips, T.W. and Smalley, E.B. (1995). Effects of maize weevils (Coleoptera: Curculionidae) on production of aflatoxin B1 by *A. flavus* in stored corn. *Journal of Economic Entomology* **6**: 1776-1782.

Biehl, J. and Hecker, E. (1985). On the isolation of *Macrocyclic diterpenes* from roots of *Jatropha gossypiifolia* Euphorbiaceae. *Acta Agronomica Academiae Scientiarum Hungaricae* **34**: 78.

Billups, J.L. (1980). Fumigants and their application, *In*: Post-harvest problems. *Documentation of OAU /GTZ Seminar*. GTZ, 291 pp.

Binggeli, P. (1999). *Chromolaena odorata* (L.) King & Robinson (Asteraceae). http://members. tripod. co.uk/WoodyPlantEcology/docs/web-sp4.htm,4 pp.

Biswanth, D. and Ratna, D. (1995). Gossypifan, a lignan from *Jatropha gossypiifolia*. *Phyto-chemistry* **40**: 931-932.

Biswanth, D., Rao, S.P. and Srinivas, K.V. (1996). Isolation of isogadain from *Jatropha gossypiifolia*. *Planta Medica* **62**: 90.

Bitran, E.A., Campos, T.B., Suplicy-Filho, N. and Chiba, S. (1991). Avaliação da ação residual de alguns inseticidas na proteção de grãos de milho, trigo e arroz contra pragas de armazenamento (Evaluation of the residual efficacy of some insecticides in the protection of corn, wheat and rice grains against the stored products pest). *Arquivosdo Instituto Biológico São Paulo* **58**: 43-50.

Boateng, B.A. and Kusi, F. (2008). Toxicity of Jatropha seed oil to *Callosobruchus maculatus* (Coleoptera: Bruchidae) and its parasitoid, *Dinarmus basalis* (Hymenoptera: Pteromalidae). *Journal of Applied Sciences Research* **4(8)**: 945-951.

Boateng, B.A. and Obeng- Ofori, D. (2008). Post-harvest Science and Technology, Smartline Publishing Limited, Ghana, pp.1-46.

Boeke, S. J., Baumgart, I. R., Loon, J.J.A., van Huis, A., Dicke, M. and Kossou, D.K. (2004). Toxicity and repellency of African plants traditionally used for the protection of stored cowpea against *Callosobruchus maculatus*. *Journal of Stored Products Research* **40**: 423-438.

Bouda, H., Tapondjou, L.A., Fontem, A.D. and Gumedzoe, D.Y.M. (2001). Effects of essential oils from leaves of *Ageratum conyzoides*, *Lantana camara* and *Chromolaena odorata* on the mortality of *Sitophilus zeamais* (Coleoptera: Curculionidae). *Journal of Stored Product Research* **37(2)**: 103-109.

Boxall, R. A. (1986). A critical review of the methodology for assessing farm- level grain losses after harvest. Report of the Tropical Products Institute (Tropical Development and Research Institute). London: Ministry of Overseas Development G 191, 139 pp.

Boxall, R.A., Brice, J.R., Taylor, S. J. and Bancroft, R.D. (2002). Technology and management of storage. *In*: Crop Post- Harvest: Science and Technology Volume 1 Principles and Practice. Blackwell Science Ltd, a Blackwell Publishing Company, 141 pp.

Bressani, R. (1990). Chemistry, technology and nutritive value of maize tortillas 6: 225-264.

Brice, J. R. (2002). Small –scale farm storage in the developing world. *In*: Crop Post- harvest Science and Technology, Volume 1 Principles and Practice. Blackwell Publishing Company, U.K., pp.192-199.

Brower, J.H., Smith, L., Vall, P.V. and Flinn, P.W. (1995). Biological Control *In:* Subramanyam, B. and Hagstrum, D.W. (eds.), Integrated Management of Insects in Stored Products, Marcels Dekker Inc, New York, pp. 223-286.

Brundu, G. and Camarda, I. (2004). The exotic flora of Chad: a first contribution. Weed Technology[Invasive plants in natural and managed systems (IPINAMS) conference, Fort Lauderdale, Florida, USA, November 2003.] 18 (Suppl.): 1226-1231.

Burkill, H.M. (1994). The useful plants of west tropical Africa. Volume 2. Kew, UK: Royal Botanic Gardens, 636 pp.

CABI. (2007). *Tribolium castaneum* (red flour beetle) datasheet. Crop Protection Compendium, 2007 Edition. CAB International Publishing. Wallingford, UK. (Accessed on 01/15/2013).

CABI. (2010). *Sitophilus zeamais* (maize weevil) datasheet. Crop Protection Compendium, 2010 Edition. CAB International Publishing. Wallingford, UK. www.cabi.org/cpc. (Accessed on 01/11/2013).

Caceres, A., Menendez, H., Mendez, E., Cohobon, E., Samayoa, B.E., Jauregui,E., Peralta,E. and Carrillo, G. (1995). Antigonorrheal activity of plants used in Guatemala for the treatment of sexually transmitted diseases. *Journal Ethnopharmacol* **48(2)**: 85-88.

Cantwell, M. C. and Kader, A.A. (2006). Produce quality rating scales and colour charts. Davis: University of California, Post-Harvest Technology Centre, Post-Harvest Horticulture Series 23A 19: 61-72.

Caswell, G.H. (1962). Agricultural entomology in the tropics. Edward Arnold, London, pp. 40-76.

Caswell, G.H. and Akibu, S. (1980). The use of pirimiphos-methyl to control bruchids attacking selected varieties of stored maize. Trop. Grain Legume Bull., 17-18: 9-11.

Chadhokar, P.A. (1978). Weed problems of grazing lands and control of some problem weeds in the Markham Valley of Papua New Guinea. *PANS* 24(1): 63-66.

Chatterjee, A., Das, B., Adityachaudhury, N. and Debkirtaniya, S. (1980). Note on the Insecticidal properties of the seeds of *Jatropha gossypifolia* Linn. *Indian Journal of Agricultural Sciences* **50(8)**: 637-638.

Chawla, R.P. and Bindra, O.S. (1976). Laboratory screening of some safe insecticides as grain protectants. Pesticides (India) 10: 29-31.

Chopra, R.N.and Badhwar,R.L.(1940). Poisonous plants of India. *Indian Journal of Agricultural Science* **10**: 1-44.

"*Chromolaena odorata*". Flora of North America.<http://www.efloras.org/florataxon.aspx?flora_id=1&taxon_id=242312602> (Accessed on 10 / 02/2013).

CIAT (Centro Internacional de Agricultura Tropical) (2001). Annual Report IPM Project, Cali, Colombia: Centro Internacional de Agricultura Tropical 211 pp.

Cobbinah, J. R., Moss, C., Golob, P. and Belmain S. R. (1999). Conducting ethnobotanical surveys: an example from Ghana on plants used for the protection of stored cereals and pulses. NRI Bulletin No. 77 Chatham, UK, 59 pp.

Compton, J.A.F. (1992). Reducing losses in small farm grain storage in the tropics. Chatham: NRI *In*: Ensuring food security in Ghana-The role of maize storage systems. Strategies analysis for growth and access,7 pp.

Compton, J.A.F., Floyd, S., Ofosu, A. and Agbo, B. (1998). The modified count and weigh method: an improved procedure for assessing weight loss in stored maize cobs. *Journal of Stored Products Research* **34**: 277-285.

Compton, J. A. F. and Sherrington, J. (1999). Rapid assessment methods for stored maize cobs: weight losses due to insect pest. *Journal of Stored Products Research* **35**: 77-87.

Cruttwell, R.E. (1988). History and Distribution of *Chromolaena odorata*. *In*: R. Muniappan (ed.), Proc. First Int. Workshop on Biol. Control of *Chromolaena odorata* pp. 7-12. Agr. Exp. Stn., Univ. of Guam.

Csurhes, S.M. (1999). Bellyache bush (*Jatropha gossypiifolia*) in Queensland. Pest status review series - land protection. Brisbane: Queensland Department of Natural Resources, unpaginated.

Dalziel, J. M. (1948). The useful plants of west tropical Africa (being an appendix to the flora of west tropical Africa by J. Hutchinson and J.M. Dalziel). The Crown agents for the colonies, London.

Das, B. and Das, R. (1994). Medicinal properties and chemical constituents of *Jatropha gossypiifolia* Linn. *Indian Drugs* **31**: 562-567.

Dawson, P.S. (1977). Life history, strategy and evolutionary history of *Tribolium* flour beetles. Evolution 31(1): 226-229.

Dehgan, B. (1982). Novel Jatrophas for Florida landscapes. *Proceedings Florida State Horticultural Society* 95: 277-280.

De Lima, C.P.F. (1979). The assessment of losses due to insects and rodents in maize stored for subsistence in Kenya. *Tropical Stored Products Information* **38**: 21-26.

Delobel, A. and Malonga, P. (1987). “Insecticidal properties of six plant materials against *Caryedon serratus* (Ol.) (Coleoptera: Bruchidae),” *Journal of Stored Products Research* **23(3)**: 173–176.

Denloye, A.A. and Makanjuola,W. A. (1997). Evaluation of the crude aqueous extracts of onion (*Allium cepa*) and garlic (*A. sativum*) for the control of cowpea weevils (*Callosobruchus maculatus*) and Maize weevils (*Sitophilus zeamais*). *Journal of Prospects Science* **1**: 58-62.

Dev, S. and Koul, O. (1997). Insecticides of natural origin. Taylor and Francis, New York. 352 pp.

Devereau, A.D., Myhara, R. and Anderson, C. (2002). Physical factors in Post –Harvest Quality *In*: Crop Post: Science and Technology Volume 1 Principles and Practice. Blackwell Publishing Company, pp. 69-73.

Dick, K. (1988). A review of insect infestation of maize in farm storage in Africa with special reference to ecology and control of *Prostephanus tuncatus* Horn. Overseas Development NRI Bulleting 18, Chatham, UK: National Resources Institute, 42 pp.

Dlamini, C. (2003). Analysis of appropriate technology utilization in food storage and preservation by rural women in selected communities in Swaziland. B.Sc. Project Report, University of Swaziland. *In*: Assessment of crop storage structures in Swaziland 8(22): 1-17.

Don-Pedro, K.N. (1989). Mode of action of fixed oils against eggs of *Callosobruchus maculatus* (F.). Pesticide Science 26: 107-115.

Egyir, S.I. (2003). Econometrics analysis of technology adoption for stored cereals and polices of crops pest management in Ghana. Ph.D. Thesis, University of Ghana, 240 pp.

Egyir, S.I., Sarpong, D.B. and Obeng- Ofori, D. (2008). Harvest and Post-harvest Baseline Study. *In*: Report submitted to the Ministry of Food and Agriculture, Accra- Ghana. Department of Agriculture Economics and Agribusiness, University of Ghana, pp. 69-71.

Farrell, G., Hodges, R.J., Wareing, P.W, Meyer, A.N. and Belmain, S.R. (2002). Biological factors in post- harvest quality. *In*: Crop Post–Harvest: Science and Technology Volume 1 Principles and Practice. Blackwell Publishing, pp. 93-140.

Fatope, M.O., Nuhu, A.M. and Takeda, Y. (1995). Cowpea weevil bioassay: A simple pre-screen for plants and grains protectant effect. *International Journal of Pest Management* **41**: 84-86.

Feng, P.C., Haynes, L.J., Magnues, K.E. and Plimmer, J.R. (1964). Further pharmacological screening of some West Indian medicinal plants. *J.Pharm. Pharmacology* **16**: 115-117.

Fields, P.G. and Muir, W.E. (1995). Physical control. *In*: Subramanyam, B. and Hangstrum, D.W. (eds.), integrated management of insects in stored products, Marcels Dekker Inc., New York. pp. 195-221.

Food Agriculture Organization (1969). Bigger crops and better storage : The role of storage in world food supplies Food and Agriculture Organization of the United Nations (FAO), Rome. *In*: Springerlink 1(4): 313-319.

Food Agriculture Organization (1985). Prevention of post-harvest food losses. Training Series No. 10 (122). Rome, Food and Agricultural Organization of the United Nations. 120 pp.

Food Agriculture Organization (1992). Moths of economic importance infesting stored products. FAO Corporate Document Repository. *In:* Semple, R.L., Hicks, P.A., Lozare, J.V. and Castermans A. (eds.), *Towards Integrated Commodity and Pest Management in Grain Storage. A Training Manual for application in humid tropical storage systems*. 526 pp.

Food Agriculture Organization (1992). Maize in human nutrition. Post-Harvest Technology. Pre- Processing. Food and Agriculture Organization of the United Nations (FAO), Rome, 112 pp.

Food Agriculture Organization (1994 a). Grain storage techniques-Evolution and trend in developing countries. D. L. Proctor, (ed.) Food and Agriculture Organization of the United Nations, Rome.FAO. Agricultural Services Bulletin No. 109, pp. 135-145.

Food Agriculture Organization (1994 b). Report of the FAO/WHO global survey of pesticide susceptibility of stored grain pests. FAO Plant Production and Protection Service 5 and Joint Codex Committee. FAO Rome, 297 pp.

Food Agriculture Organization, Corporate Document Repository (2004). Grain storage techniques-Evolution and trend in developing countries. Food and Agriculture Organization of the United Nations, Rome. INPHO *In*: Determinates of the use of maize storage techniques by farmers in Kwara State, Nigeria 10(1): 31-40.

Forni-Martins, E.R. and Cruz, N.D. (1985). Research in progress with physic nut at the Instituto Agronômico. (*Pesquisas em desenvolvimento com pinhão-paraguaio no Instituto Agronômico*.) Agronômico **37(2)**: 109-113.

Forsyth, J. (1962). Major food storage problems. *In*: J.B. Wills (ed.) *Agriculture and Land Use in Ghana.* Oxford University Press, Oxford, pp. 394-401.

Frimpong, E.A. (2004). Studies of storage insect pests of maize in Southern Ghana. M.Phil. Thesis, University of Cape Coast, Ghana, 150 pp.

Gardner, C. and Bennetts, H. (1956). The Toxic Plants of Western Australia. Perth, Australia: Periodicals Division, West Australian Newspaper.

Gbeassor, M., Kossou, Y., Amegbo, K., Souza, C.de. and Koumaglo, K. (1989). Antimalarial effects of eight African medicinal plants. *Journal of Ethnopharmacology* **25(1)**: 115-118.

Ghana Living Standard Survey (2000). Report of fourth round (GLSS 4), Ghana Statistical Service, Accra, 86 pp.

Ghana Living Standard Survey (2008). Report of the fifth round (GLSS 5), Ghana Statistical Service, Accra, 131 pp.

Ghana Living Standard Survey 5 (2008-2009), pp. 74-83.

Ghana Living Standard Survey (2011). Report of the fifth round (GLSS 5), Ghana Statistical Service, Accra, 128 pp.

Ghani, A. (2003). Medicinal plants of Bangladesh with chemical constituents and uses. 2nd edition, Asiatic Society of Bangladesh, 5 Old Secretariate Road, Nimtali, Dhaka, Bangladesh.

Giga, D. P. and Canhao, J. (1992). Persistence of insecticide spray deposits on different surface against *Prostephanus truncatus* (Horn) and *Sitophilus zeamais* (Motsch). *Insect Science and its Application* **13**: 755-762.

Gilman, G. A. and Boxall, R.A. (1974). The storage of food grains in traditional underground pits. *Tropical Stored Products Information* **22**: 19-38.

GISD (2006). Global Invasive Species Database online data sheet. *Chromolaena odorata* (herb). www.issg.org/database. (Accessed on 20/02/ 2013).

Golob, P. (1981). A practical appraisal of on- farm storage losses and storage loss assessment methods in the Shire Valley of Malawi. *Tropical Storage Products Information* **40**: 5-13.

Golob, P. (1997). Destruction of stored products by insects in Africa. *In*: Hamish G. Robertson (ed.) Insects in African Economy and Environment. *Proceedings of the Joint Congress of the Entomological Society of Southern African (11th Congress) and the African Association of Insect Scientists (12th Congress)*, Stevenbosch, 30th June-4th July 1997. pp. 89-91.

Golob, P, Farrell, G. and John E. Orchard, J.E. (2002). (eds.). Crop Post-Harvest: Science and Technology. Volume 1 Principles and Practice. Blackwell Publishing Company, UK, 578 pp.

Golob, P., Kutukwa, N., Devereau, A., Bartosik, R.E. and Rodriguez, J.C. (2004). Maize. *In*: R. Hodges and G. Farrell (eds.) Crop Post- Harvest: Science and Technology, Volume 2, Durables. Blackwell Publishing Company, pp. 26-59.

Golob, P., Moss, C., Dales, M., Fidgen, A., Evans, J. and Gudrup. (1999). The use of spices and medicinal as bioactive protectants for grains. FAO Agricultural Service Bulletin No. 137, 239 pp.

Golob, P. and Tyler, P.S. (1994). Extension and training in post- harvest practices for farmers, with particular reference to Africa. *FAO Plant Protection Bulletin* **42(3)**: 117-128.

Golob, P. and Webley, D.J. (1980). The use of plants and minerals as traditional protectants of stored products. Report, Tropical Product Institute, G 138.

Goosens, H. J. (1949). A method for staining insect egg plugs in wheat. *Cereal Chemical Journal* **26**: 419 – 420.

Grain and Feed Annual Grain Report (2011). Global Agricultural Information Network, 68 pp.

Haines, C.P. (1991). Insects and Arachnids of tropical stored products: their biology and identification (A training manual) 2nd Edition. Natural Resources Institute, U.K, 246 pp.

Hall, J.B., Kumar, R. and Enti, A.A. (1972). The obnoxious weed *Eupatorium odoratum* (Compositae) in Ghana. *Ghana J. Agric. Sciences* **5**: 75-78.

Hassanali, A., Lwande, W., Ole- Sitayo, N., Noreka, L.,Nokoe, S. and Chapya, A.(1990). Weevil repellent constituents of *Ocimum suave* leaves and *Eugenia caryophyllata* cloves used as grain protectant in parts of Eastern Africa. Discovery and Innovations 2: 91-95.

Hill, A.F. (1952). Economic Botany. A textbook of useful plants and plant products. 2nd ed. McGraw-Hill Book Company Inc, New York.

Hill, D.S. (1983). Agricultural insect pest of the tropics and their control (2nd ed.) Cambridge University Press, Cambridge, 746 pp.

Hill, D.S. (1990). Pests of stored products and their control. Belhaven Press. London, UK, 274 pp.

Hodges, R. J. (1986). The biology and control of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) - A destructive storage storage pest with an increasing range. *Journal of Stored Product Research* **22**: 1-14.

Hodges, R. and Farrell, G. (2004). Crop Post-Harvest: Science and Technology Volume 2. Durables: Case studies in handling and storage of durable commodities. Blackwell Publishing Company, U.K, 295 pp.

Holm, L.G., Pancho, J.V., Herberger, J.P. and Plucknett, D.L. (1979). A Geographical Atlas of World Weeds. New York, USA: Wiley.

Home – Grown Cereals Authority (1999). The Grain Storage Guide. Home-Grown Cereals Authority, London, UK. Topic Sheet 13(34): 39-212.

Home- Grown Cereals Authority (2000). Moisture meter guidelines. Home- Grown Cereals Authority, London, UK. Topic Sheet 14(30): 24-200.

Horsten, S.F.A.J., Berg, A.J.J., van den, Kettenes-van den Bosch, J.J., Leeflang, B.R. and Labadie, R.P. (1996). Cyclogossine A: a novel cyclic heptapeptide isolated from the latex of *Jatropha gossypifolia*. *Planta Medica* **62(1)**: 46-50.

Hoseney, R.C and Faubion, J, .M. (1992). Physical Properties of Cereal Grains. *In*: D.B. Sauer (ed.) Storage of Cereal Grains and their Products. America Association of Cereal Chemist, Minnesota, U.S.A, pp. 1-38.

Howard, R.A. (1989). Flora of the Lesser Antilles, Leeward and Windward Islands. Vol. 6. Arnold Arboretum, Harvard University, Jamaica Plain, MA. 658 pp.

Howe, R. W. (1952). The biology of the rice weevil, *Calandra oryzae* (L). *Annals of Applied Biology* **39**: 168-180.

Howe, R.W. and Oxley, T.A. (1944). The use of carbon dioxide as a measure of infestation of grain by insects. Bull. Ent. Res. **35**: 11-22.

Huang, F. and Subramanyam, B. (2005). Management of five stored-product insects in wheat with pirimiphos-methyl and pirimiphos-methyl plus synergized pyrethrins. *Pest Management Science* **61**: 356-362.

Igbeka, J.C. and Olumeko, D. O. (1996). An appraisal of village- level grain storage practices in Nigeria. Agricultural Mechanization in Asia, Africa and Latin America 27(1): 29-33.

IITA (1995). Plant Health Management Division. *Annual Report*, 43 pp.

IPCS INCHEM (2004). *Jatropha gossypiifolia*.unpaginated.<http://www.inchem.org/documents /pims/plant/jgossyp.htm> (Accessed on 12/02/13).

IPCS INCHEM (2006). Pirimiphos-methyl. ICI Plant Protection Ltd. Report, JMPR, pp. 511.

Irvine, F.R. (1961). Woody plants of Ghana with special reference to their uses. London, UK: Oxford University Press.

ISSER (2011). The State of the Ghanaian Economy, 2010. Institute of Statistical Social and Economic Research, University Of Ghana, 123 pp.

ISSER (2012). The State of the Ghanaian Economy in 2011. Institute of Statistical Social and Economic Research, University of Ghana, Legon, pp.118-138.

Itto, A. and Wongo, L. (2002). Postharvest grain losses in on-farm and cooperative stores: A case study of Miridi and Yambio Counties, 45 pp.

Iwu, M.M. (1993). Handbook of African Medicinal Plants, CRC Press Inc., Beca Raton. pp. 181-182.

Jacobson, M. (1985). Control of stored product insects with phytochemicals. *Lloydia* **38**:183 -195.

Jayas, D.S. (1995). Mathematical modeling of heat, moisture and gas transfer in stored-grain ecosystems. *In*: D.S. Jayas, N.D.G.White and W.E. Muir (eds.) Stored-grain ecosystems. Marcel Dekker, New York, USA, pp. 527-567.

Joubert, P.H., Brown, J.M.M., Hay, I.T. and Sebata, P.D.B. (1984). Acute poisoning with *Jatropha curcas* purging nut tree in children. *South African Medical Journal* **65**: 729-730.

Karma, C. (2000). Post-harvest maize storage losses. RNR-RC Jakar, Bumthang, Bhutan, 3 pp.

Katz, R., Lee, M.R. and Milner, M. (1950). X-ray inspection of wheat. Non-destruction testing 9(2): 16-18.

Khanam, L.M., Khan, A.R. and Rahman, S.M. (2008). Effect of *Sapium indicum*, *Thevetia neriifolia* and *Jatropha gossypiifolia* leaf extract on the fecundity and fertility of *Tribolium castaneum* and *Tribolium confusum*. *Bangladesh Journal Sci Ind Res*. **43**: 55-66.

Kingsbury, J.M. (1964). Poisonous plants of the United States and Canada. Eagle-wood Cliffs, N.J., Prentice Hall, Inc., xiii+626 pp.

Kirkpatrick, R.L. and Tilton, E.W. (1972). Infrared radiation to control adult stored product Coleoptera, *Journal of Georgia Entomology* Society **7**: 73-75.

Koomson, C.K. (2003). On- farm evaluation of Candlewood *Zanthoxylum xanthoxyloides* (Lam) on two stored product pests. M. Phil Thesis, University of Ghana, Legon, 110 pp.

Kossou, D.K., Mareck, J.H. and Bosque-Perez,N.A. (1993). Comparison of improved and local maize varieties in the Republic of Benin with emphasis on susceptibility to *Sitophilus zeamais* (Motschulsky). *Journal of Stored Product Research* **29**: 333-343.

Kupchan, S.M., Wanger,C.R. and Bryan, R.F. (1970). Jatrophone, a novel macrocyclic diterpenoid tumor inhibitor from *Jatropha gossypiifolia*. *Journal of American Chemical Society* **92**: 4476-4477.

Kupchan, S.M., Sigel, C.W., Matz, M.J., Gilmore, C.J. and Bryan, R.F. (1976). Structure and stereochemistry of jatrophone a novel macrocyclic diterpenoid tumour inhibitor. *Journal of the American Chemical Society* **98**: 2295-2300.

Lamptey, D.I. (2000). Adequacy of grain storage structure in Ghana. *University of Science and Technology, Kumasi Journal*, Ghana, pp.191-203.

Leconti, J.D. and Roth, L.M. (1953). Composition of the odorous secretion of *Tribolium castaneum*. *Annals of the Entomological Society of America* **4**: 281-289.

Liogier, H.A. (1990). Descriptive flora of Puerto Rico and adjacent islands. Spermatophyta, 2: 481.

Liogier, H.A. (1997). Descriptive flora of Puerto Rico and adjacent islands. Vol. 5. Editorial de la Universidad de Puerto Rico, San Juan, PR.436 p.

Lloyd, C.J. (1969). Studies on the cross tolerance to DDT related compounds of a pyrethrum resistant strain of Sitophilus granarius L. (Coleoptera: Curculionidae). *J. Stored Prod. Research* **5(4)**: 337-377.

Longstaff, B. C. (1981). Biology of grain pest species of the genus *Sitophilus* (Coleoptera; Curculionidae). *A Critical Review Protection Ecology* **2**: 83-130.

Longstaff, B. C. (1986). The rice weevil-A serious pest under control. *In*: R. L Kitching (ed.) The ecology of exotic animals and plants. Brisbane: John Wiley and Sons, pp.109-127.

Makanjuola, W. A. (1989). Evaluation of extracts of neem (*Azadirachta indica* A. Juss) for the control of some stored product pests. *Journal of Stored Product Research* **25**: 231-237.

Marcano-Fondeur, E. (1992). [English title not available]. (Las plantas venenosas en la medicina popular.) *Naturaleza Dominicana*.6 p.

Markham, R.H., Bosque-perez, N.A., Borgemeister, C. and Meikle, W.G. (1994). Maize weevil, *Sitophilus zeamais* and the larger grain borer, *Prostephanus truncatus*, in the humid and sub-humid tropics. *FAO Plant Protection Bulletin* 42: 165 pp.

Marsland, N. and Golob, P. (1999). Participatory and rapid rural appraisal for addressing post-harvest problems: a case study in Malawi. *In*: Crop Post-Harvest: Science and Technology. Volume 2, Durables, 288 pp.

M'Boob, S.S. (1991). Preliminary results of a survey and assessment of *Chromolaena odorata* (Siam weed) in Africa. *Biotropica Special Publication* **44**: 51-55.

McDonald, L. L., Guy, R. H. and Speirs, R. D. (1970). Preliminary evaluation of new candidate materials as toxicants, repellants and attractants against stored product insects. Marketing Reseach Report 882 (Washington: Agricultural Research Service, US Dept. of Agriculture), 8 pp.

Mejia, D.J. (2003). An overview of Rice Post-harvest Technology: Use of small metallic silos for minimizing losses. Agricultural Industries, Agricultural and food engineering Technologies Service. *In*: Sustainable rice production for food security. *Proceedings of the 20th session of the International Rice Commission*, FAO, Rome Italy, 306 pp.

Metwally, A.M. and Ekejuba, E.C. (1981). Methoxylated flavonols and flavones from *Eupatorium odoratum* I. *Planta Medica* **42**: 403.

Mijinyawa, Y. (2002). Farm structures. Aluelemhegbe Publishers, Ibadan, Nigeria, 129 pp.

Mijinyawa, Y., Mwinjilo, M. and Dlamini, P. (2006). Assessment of crop storage structures in Swaziland. *The CIGR Journal*, Invited Overview **22(8)**: 1-18.

Milner, M., Barney, D.L. and Shellenberger, J.A. (1950). Use of selective flourescent stains to detect insect egg plugs in grain kernels. *Science* **112**: 933-935.

Milner, M., Lee, M.R. and Katz, R. (1952). Radiography applied to grain and seed. Food Tech. 6: 44-45.

Ministry of Food and Agriculture (2010). Production of major crops in Ghana, PPMED, Accra, humid and sub-humid tropics. *FAO* Plant Protection Bulletin 42,165 pp.

Ministry of Food and Agriculture (2012). Annual Progress Report 2011 Volume 3. www.ndpc.gov.gh/.../sector% APR.20/2011/Food and Agriculture – 2011 Annual Progress Report. pdf. (Accessed on 10/21/12), 122 pp.

Morris, M. L., Tripp, R. and Dankyi, A.A. (1999). Adoption and impacts of improved maize production technology: A Case Study of the Ghana Grains Development Project. Economics Program Paper 99-101. Mexico, D.F.: CIMMYT.

Morton, J.F. (1981). Atlas of medicinal plants of Middle America: Bahamas to Yucatan. Springfield, USA: Charles C. Thomas, 1448 pp.

Morton, J.F. (1982). Plants poisonous to people in Florida and other warm areas. Stuart, Florida, USA: Southeastern Printing Co., Inc., unpaginated.

Mould, H.A. (1973). Grain Storage in Ghana. Grain Storage Seminar, Ibadan, 1971, *Tropical Stored Product Information* **25**: 44.

Multon, J. L. (1988). Spoilage mechanisms of grains and seeds in post- harvest ecosystem: the resulting losses and strategies for the defense of stocks *In*: Crop Post- Harvest: Science and Technology, Volume 2. Durables:Case studies in the handling and storage of durable commodities. Blackwell Publishing Company, U K. pp.74.

Muniappan, R. (1988). Proc. First Int. Workshop on Biol. Control of *Chromolaena odorata*. Agr.Exp. Stn., Univ. of Guam.

Nang'ayo, F.L.O., Hill, M. G., Chandi, E. A., Chiro, C.T., Nzeve, D.N. and Obiero, J.W. (1993). The natural environment as a reservoir for *Prostephanus truncatus* (Horn) in Kenya. *African Crop Science Journal* **1**: 39-47.

Niber, T.B. (1994). The ability of powers and slurries from ten plant species to protect stored grain from attack by *Prostephanus truncatus* Horn Coleoptera: Bostrichidae and

Sitophilus oryzae L. (Coleoptera: Curculionidae). *Journal of Stored Product Research* **30 (4)**: 297-301.

Nyanteng, V.K. (1972). The storage of food- stuffs in Ghana. Technical publication series, No. 18. Institute of Statistical, Social and Economics Research, Legon, pp. 2-3.

Nyanteng, V.K. and Asuming-Bempong, S. (2003). The Role of Agriculture in the Food Security of Ghana 2003. Paper presented at “Roles of Agriculture Project” International Conference, pp. 20-23.

Oakes, A.J. and Butcher, J.O. (1962). Poisonous and injurious plants of the US Virgin Islands. Washington DC: United States Department of Agriculture, Agricultural Research Service, unpaginated. [Miscellaneous Publication 882.]

Obeng-Ofori, D. and Coaker, T.H. (1990). Some factors affecting responses of four stored product beetles (Coleoptera: Tenebrionidae and Bostrichidae) to pheromones. *Bulletin of Entomological Research* **80**: 433-441.

Obeng – Ofori, D. (1991). Analysis of orientation behaviour of *Tribolium castaneum* and *T. confusum* to synthetic aggregation phenomones. *Entomologia Experimentalis et Applicata* **60**: 125-133.

Obeng- Ofori, D. (1995). Plant oils as grain protectant against the infection of *Cryptolestes pusillus* (Schorr) and *Rhyzopertha dominica* (Fab) in stored grain. *Entomologia Experimentalis et Applicata* **77**: 133- 139.

Obeng-Ofori, D. and Reichmuth, C. (1997). Bioactivity of eugenol, a major component of essential oil of *Ocimum suave* (Wild.) against four species of stored-product Coleoptera. *International Journal of Pest Management* **43(1)**: 89-94.

Obeng- Ofori, D., Reichmuth, C.H., Bekele, J. and Hassanali, A. (1997). Biological activity of 1,8 cineole, a major component of essential oil of *Ocimum kenyense* (Ayobangira) against stored product pest. *Journal of Applied Entomology* **122**: 237-243.

Obeng- Ofori, D. and Akuamoah, R.K. (2000). Biological effects of plant extracts against the rice weevil *Sitophilus oryzae* in stored maize. *Journal of Ghana Science Association* **2 (2)**: 62-69.

Obeng- Ofori, D. and Amiteye, S. (2005). Efficacy of mixing vegetables oils with Pirimiphos-methyl against the maize weevil, *Sitophilus zeamais* Motschulsky, in stored maize. *Journal of Stored Product Research* **41**: 57-66.

Obeng- Ofori, D. (2007). The use of botanicals by resource poor farmers in Africa and Asia for the protection of stored agricultural products. *Stewart Post-harvest Review* **6**: 1-8.

Obeng-Ofori, D. (2008a). Major Stored Product Arthropod Pest *In*: Cornelius, E. W. and Obeng-Ofori, D. (eds.). Post-Harvest Science and Technology, Smartline Publishing Limited, Accra, pp. 67-91.

Obeng- Ofori, D. (2008b). Sustainable management of pests of vegetable crops in Ghana with neem bio-pesticides for food and environmental protection. *Workshop on Agriculture and Economic Enterprise (IIAS),* Accra, Ghana.

Obeng- Ofori, D. (2010). Residual insecticides, inert dusts and botanicals for the protection of durable stored products against pest infestation in developing countries. *Proceedings of the 10th International Working Conference on Stored Product Protection*, Portugal, pp. 773-787.

Ofuya, T. I. and Okuku, I. E. (1994). Insecticidal effect of some plant extracts on the cowpea aphid *Aphis craccivora* Koch. (Homoptera: Aphididae). *Anzeiger für Schädlingske,* *Pflanzenschutz, Umweltschutz* **67**: 127-129.

Ogbobe, O. and Akano, V. (1993). The physico-chemical properties of the seed and seed oil of *Jatropha gossypiifolia*. *Plant Foods for Human Nutrition* 43(3): 197-200.

Ogendo, J.O., Deng, A.L., Belmain, S.R., Walker, D.J. and Musandu, A.A.O. (2004). Effects of insecticidal plant materials, *Lantana camara* L. and *Tephrosia vogelii* Hook, on the quality parameters of stored maize. *J. Food Technol*. **9**: 29-35.

Ohtsuka, T. (1999). Early stages of secondary succession on abandoned cropland in north-east Borneo Island. *Ecological Research* **14(3)**: 281-290.

Okonkwo, E.U. and Okoye, W.I. (2006). The efficacy of four seed and leaf extracts as protectants of cowpea and maize grains infestation by *Callosobruchus maculatus* and *Sitophilus zeamais* in Nigeria. *International Journal of Pest Management* **42(3)**: 143-146.

Okunade, S.O., Williams, J.O. and Ibrahim, M.H. (2002). Comparative efficacy of twelve botanicals and two synthetic insecticides against the Lesser Grain Borer, *Rhyzopertha dominica* Fabricius (Coleoptera: Bostrichidae) on stored sorghum. *Nig. J. Entomol*. **191**: 22-30.

Oloruntoba, A. and Adegbite, D.A. (2006). Improving agricultural extension services through university outreach initiative: A case study of farmers in model village in Ogun State, Nigeria. *The Journal of Agricultural Education and Extension* **12(4)**: 273-283.

Osafo, W. F. (1998). Extracts of three plant materials as post-harvest grain protectants against *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). BSc. Dissertaion, Zoology Department, University of Ghana, Legon, 32pp.

Owusu- Akyaw, M. (1991). Evaluation of plant products for the control of cowpea and maize storage insects. Paper presented at the Joint SAFGRAD Research Networks Workshop, Niamey, Niger.pp. 8-14.

Owusu, E.O. (2001). Effect of some Ghanaian plant components on the control of two stored-product insect pest of cereals. *Journal of Stored Products Research* **37(1)**: 85-91.

Owusu, E.O., Akutse, K.S. and Afreh-Nuamah, K. (2008). Effect of some traditional plant components on the control of termites, *Macrotermes spp*. (Isoptera: Termitidae). *African Journal of Science and Technology* **9(2)**: 82-89.

Pacific Island Ecosystems at Risk (2001). Invasive plant species: *Chromolaena odorata* (L.) King & Robinson, Asteraceae. http://www.hear.org/pier/chodo.htm. 3 p.

Padua, L.S.de, Bunyapraphatsara, N. and Lemmens, R.H.M.J. (1999). Plant resources of South-East Asia no 12 (1). Medicinal and poisonous plants 1. Leiden, The Netherlands: Backhuys, 711 pp.

Parsons, W. T. and Cuthbertson, E. G. (1992). 'Noxious Weeds of Australia'. Inkata Press, Melbourne.

Parsons, W.T. and Cuthbertson, E.G. (2001). Noxious weeds of Australia. Melbourne, Australia: Inkata Press, 698 pp.

Pederson, J. R. (1992)."Insect: identification, damage and detection." *In*: D.B. Sauer (ed.) Storage of cereal grains and their products. American Associate of Cereal Chemists Inc. St.Paul, Minnesota, U.S.A, pp. 435-489.

Pedigo, L. P. (1999). Entomology and pest management. Prentice Hall, New Jersey. *Journal of Applied Entomology* **120**: 257-264.

Pieterse, A.H., Schulten, G.G.H. and Kuyken, W. (1972). A study of insecticide resistance in *Tribolium castaneum* in Malawi. *Journal of Stored Product Research* **8(3)**: 183.

Pinedo, M., Rengifo, E. and Cerruti, T. (1997). Plantas medicinalis de la Amazonia Peruana. Iquitos: Instituto de Investigaciones de la Amazonia Peruana.

Pitt, J. L., Smith, R. A. and Crothers, M. (1990). *Jatropha gossypiifolia* in the Northern Territory.*Proceedings of the 9th Australian Weeds Conference*, Adelaide, South Australia, August 6-10, 1990, p. 414.

Pitt, J.L. and Miller, I.L. (1991). The pest status and chemical control of *Jatropha gossypiifolia* L. in the Northern Territory, Australia. *In*: *Proceedings of the 13th Asian-Pacific Weed Science Society*, Jakarta. unpaginated.

Pomeranz, Y., Martin, C.R., Traylor, D.D. and Lai, F.S. (1984). Corn harness determination. Cereal Chemistry 61: 147-150.

Pomeranz, Y., Czuchajowska, Z., Martin, C.R. and Lai, F.S. (1985). Determination of corn hardness by the Stenvert hardness tester. Cereal Chemistry 62: 108-112.

Pomeranz, Y., Czuchajowska, Z. and Lai, F.S. (1986). Comparison of methods for determination of hardness and breakage susceptibility of commercially dried corn. Cereal Chemistry 63: 39-43.

Poswal, M. A. T. and Akpa, A. D. (1991). Current trends in the use of traditional and organic methods for the control of crop pests and diseases in Nigeria. *Tropical Pest Management* 37: 329-333.

Prasad, Y.R., Alankararao. G.S. and Baby, P. (1993). Constituents of the seeds of *Jatropha gossypiifolia*. Fitoterapia 64: 376.

Prempeh, H. R. B. A. (1971). Maize crop harvesting, processing and storage in Ghana. Maize- the wonder crop, Symposium University of Science and Technology, Kumasi, pp.18-87.

Purseglove, J.W. (1992). Tropical Crops: Monocotyledons. Longman Scientific and Technical, New York. pp. 300-305.

Rastogi, R.P. and Mehrotra, B.N. (1993). Compendium of Indian Medicinal Plants. Vol. 1, CDRI, Lucknow --and ID, New Delhi, India.

Ratnadass, A. and Fleurat- Lessard, F. (1991). Improvement in the practical methods of assessment of losses caused by insect in grain stored at the village level in tropical Africa. *In*: F. Fleurat- Lessard and P. Ducom (eds.). *Proceedings of the 5th International Working Conference on stored Product Protection.* Bordeaux, France 3: 20-65.

Ratnadass, A., Berte, S., Diarra, D. and Cise, B. (1994). Insect losses in sorghum stored in Selected Malian villages, with particular emphasis on varietal difference in grain resistance. *In*: E Highley, E.J.Wright, H.J.Banks and B. R.Champ (eds.) *Proceedings of the 6th International Conference on Stored Product Protection*, Canberra. CAB International, Wallingford, U.K 2: 953-959.

Rawnsley, J. (1969). Crop Storage: Food research and development unit, Ministry of Agriculture, Accra, Ghana. *Technical Report* 1.Rome: Food and Agriculture Organization of the United Nations. 89 pp.

Rembold, H. (1994). Advances in invertebrate reproduction. *Elsevier Science* **3**: 481-491.

Reusse, E. (1968). *Report on maize farm storage and marketing survey*, Accra, Ghana. Regional office for Africa. Council for Scientific and Industrial Research, Food Research Institute, 25 pp.

Roentgen, W.C. (1895). On a new kind of rays. Vet. Rachol and Ultrasound, 36:371.

Rogers, E.M. (1995). Diffusion of Innovations. 4th edition, New York, The Free Press, 519 pp.

Sackey, S.I. (2006). Waste management in cassava processing to gari. BSc. Dissertation, University of Ghana, 40 pp.

Sajisee, P.E., Palis, R.K., Norcio, N.V. and Lales, J.S. (1974). The biology of *C.odorata* L. King and Robinson. 1. Flowering behaviour, pattern of growth and nitrate metabolism. *Phil. Weed Sci. Bull*.**1**: 17-24.

Salunkhe, D.K., Chavan, J.K. and Kadam, S.S. (1985). Post-Harvest Biotechnology of Cereals. Loss assessment methodology. CRC Press, Boca Raton, Florida, 208 pp.

Santhoy, G. and Rejesus, B. M. (1975). The development rate, body weight and reproduction capacity of *Sitophilus zeamais* (Motsch.) reared on three natural hosts. *Physiological Entomology* **2**: 311-321.

Saucer, D. B. (1992). Storage of cereal grains and their products. 4th Edition, 135 pp.

Saxena, R.C., Jillian, G. and Kareem, A.A. (1988). Effect of neem on stored grain insects. *In*: M. Jacobson (ed.), Focus on phytochemical pesticide (Vol.1). The neem tree, C.R.C. Press, Florida. pp.79-111.

Schmutterer, H. (1985). Which insects can be controlled by application of neem kernel extracts under field conditions? *Journal of Applied Entomology* **100**: 468-475.

Schmutterer, H. (1995). The Neem Tree.Source of unique natural products for integrated pest management, medicine, industry and other purposes. VCH Publisher, Weinheim, New York, Bassel, Cambridge, Tokyo. 696 pp.

Schuler, R. T., Radokowski, N.N. and Kucera, H.L. (1978). Small grain harvesting and loss evaluation in North Dakota. *In*: Grain and forage harvesting. *Proceedings of the first international Grain and forage conference*, Iowa State University, Ames, Iowa, USA. American Society Of Agricultural Engineers, pp.130-132.

Setamou, M., Cardwell, K.F., Sculthess, F. and Hell, K. (1998). Effect of insect damage on maize ears in Republic of Benin. *Journal of Economic Entomology* **91**: 433-438.

Shay, E. and Ikan, R. (1980). Insect control using natural products. *Review of Applied Entomology* **68(1)**: 88.

Simonsen, J.L. (1945). List of indigenous plants of the colonial empire of possible scientific and technical interest. London: Imperial Institute, unpaginated.

Sinha, R. N. (1995). The stored – grain ecosystem. *In*: Jayas, D.S.,White, N.D., Muir, W.E. (eds.) Stored Grain Ecosystems. Marcel Dekker, New York, pp.1-32.

Siriacha, P., Kawashima, K., Kawasugi, S., Saito, M. and Tomboon, I.K. P. (1998). Post-harvest contamination of Thai corn with *Aspergillus flavus*, Cereal Chemistry 66: 445-448.

Smith, B.L. (ed.) (1990). Codex Alimentarius: abridged version. Food and Agriculture Organization of the United Nations/World Health Organization, Rome, Italy.

Smith, N.M. (1995). Weeds of natural ecosystems: a field guide to environmental weeds of the Northern Territory. Darwin: Environment Centre, Darwin.

Soon-II, K., Young-Joon, A., Do-Hyoung, K. and Han-Seung, L. (2003). Insecticidal activities of aromatic plant extracts and essential oils against *Sitophilus zeamais* and *Callosobruchus chinensis*. *Journal of Stored Product Research* **39(3)**: 293-303.

Souder, P. (1963). Poisonous plants on Guam. *In*: Venomous and poisonous animals and noxious plants of the Pacific region, Keegan, L.,Macfarlane, H. W. V(eds.) New York, USA: Pergamon Press, pp. 15-29.

Statistics, Research and Information Directorate (SRID) and Ministry of Food and Agriculture (2002-2011). Production of some major crops in Ghana, pp.70.

Stoll, G. (2000). Natural crop protection in the tropics: Letting information come to life. Margraf Verlag, Weikersheim, p. 376.

Subramanian, S. S., Nagarajan, S. and Sulochana, N. (1971). Flavonoids of the leaves of *Jatropha gossypiifolia*. Phytochemistry 10: 1690.

Subramanyam, B. and Hagstrum, D.W. (1995). Resistance measurement and management. *Integrated Management of Insects in Stored-Products.* B. Subramanyam and D.W. Hagstrum (eds.), Marcel Dekker, New York, USA, pp. 331-399.

Swarbrick, J. T. (1997). Weeds of the Pacific Islands. Technical paper no. 209. South Pacific Commission, Noumea, New Caledonia.124 pp.

Swennen, R. and Wilson, G.F. (1984). In-situ mulch production for plantain. *Banana Newsletter* **7**: 20-22.

Talukder, F.A. (1995). Isolation and characterization of the active secondary Pithraj (*Aphanamixis polystachya*) compounds in controlling stored product insect pests. PhD Thesis, University of Southampton, U.K, pp. 234.

Talukder, F.A. (2006). Plant product as potential stored product pest management agent-A mini review. *Emir. Journal of Agric Science* **18(1)**: 17-32.

Talukder, F. A. and Howse, P. E. (1994). Laboratory evaluation of toxic and repellent properties of the pithraj, *Aphanamixis polystachya* Wall and Parker, against *Sitophilus oryzae* (L.) *International Journal of Pest Management* **40(3)**: 274-279.

Talukder, F.A. and Howse, P.E. (1995). Evaluation of *Aphanamixis polystachya* as a source of antifeedants, toxicants and protectants in storage against *Tribolium castaneum* (Herbst). *Journal of Stored Product Research* **31**: 55-61.

Taponjou, L.A., Adler, C., Bouda, H. and Fontem, D.A. (2002). Efficacy of powder and essential oil from *Chenopodium ambrosioides* leaves as post-harvest grain protectants against six stored product beetles. *Journal of Stored Products Research* **38**: 395-402.

Taura, D. W., Mukhtar, M.D. and Adoum, O.A. (2004). Lethality of the aqueous extracts of *Acacia nilotica*,*Guiera senegalensis*, *Kigelia africana* and *Securidaca longepedunculata* on *Culex* mosquito larva. *Ife Journal of Science* **6**: 115-118.

Taylor, M.D., Smith, A.B., Furst, G.T., Gunasekara, S.P., Bevelle, C.A., Cordell, G.A., Farnsworth, N.R., Kupchan, S.M., Uchida, H., Branfman, A.R., Dailey,R.G. and Sneden, A.T. (1983). New anti-leukemic derivatives from *Jatropha gossypiifolia*: structural and stereochemical assignment through nuclear magnetic resonance spectroscopy. *Journal of the American Chemical Society* **105**: 3177-3183.

Thamaga-Chitja, J.M., Hendricks, S.L., Ortmann, G.F. and Green, M. (2004). Impact of maize
` storage on rural household food security in northern Kwazulu-Natal. *Journal of Family Ecology and Consumer Science* **32**: 8-15.

Thompson, A.K. (1996). Post –harvest Technology of Fruit and Vegetables. Publisher: Blackwell Science, London, UK, 410 pp.

Timbilla, J.A. (1996). Status of *Chromolaena odorata* biological control using *Pareuchaetes pseudoinsulata*, in Ghana .V. C. Moran and J. H. Hoffmann (eds.). *Proceedings of the IX International Symposium on Biological Control of Weeds*. pp. 327-331.

Torres, D.D. and Paller, E.C. Jr. (1989). The Devil Weed (*Chromolaena odorata* L., R.M. King and H. Robinson) and its management. SEAWIC Weed Leaflet, p. 4.

Triratana, T., Suwannuraks, R. and Naengchomnong, W. (1991). Effect of *Eupatorium odoratum* on blood coagulation. *Journal of Medical Association of Thailand* **74(5)**: 283-

287.

Udo, I. O. (2000). Efficacy of Candlewood *Zanthoxylum xanthoxyloides* (Lam) for the control of three stored product pests. M.Phil. Thesis, University of Ghana, Legon, 79 pp.

Udo, I.O. (2011). Potential of *Zanthoxylum xanthoxyloides* (Lam) for the control of stored product insect pests. *Journal of Stored Product and Postharvest Research* **2(3)**: 40-44.

Udo, I.O., Epidi, T.T. and Osakwe, J.A. (2009). Susceptibility of *Sitophilus zeamais* Motsch and *Callosobruchus maculatus* F. to plant parts of *Ricinodendron heudelottii. Journal of Plant Protection Research* **49(4)**: 411-415.

Udoh, J.M., Cardwell, K.F. and Ikotun, T. (2000). Storage structures and aflatoxin content of maize in five agroecological zones of Nigeria. *Journal of Stored Products Research* **36**: 187-201.

U.S. Department of Agriculture Research Service (2011). National Genetic Resources Program. Germplasm Resources Information Network (GRIN). Online searchable database. http://www.ars-grin.gov/cgi-bin/npgs/html/taxgenform.pl (Assessed 19/02/2013).

U.S. EPA (2003). Pirimiphos-methyl IRED facts. U.S. Environmental Protection Agency. WashingtonDC.*http://www.epa.gov/oppsrrd1/REDs/factsheets/pirimiphosmethyl_ired_fs.htm* (Accessed 14/05/13).

Van Gastel, A.G.J., Gregg, B.R. and Asiedu, E.A. (1999). Dehumified seed drying, a cost effective option for storage and marketing in hot and humid climate.Workable Approach. No. 4, Accra, Ghana. West Africa Seed Development Unit. *In*: M.O. Adetunji (ed.) *Economics of Maize Storage Techniques by farmers in Kwara State, Nigeria* 4(3): 442-450.

Vander Velde, N. (2003). The vascular plants of Majuro Atoll, Republic of the Marshall Islands. Smithsonian Institution, Atoll Research Bulletin No. 503:1-141.(Assessed 19/02/2013).

Voices Newsletter (2006). Increasing Post- Harvest Success for Smallholder farmers. *In: IFDC Report* 30(92): 12.

Walker, D. J. (1994). Food storage manual. *World Food Programme / Natural Resources Institute*.180 pp.

Waller, J.M. (2001). Post-harvest disease. *In*: J.M Waller, J.M Lenn and S. J. Waller (eds.) Plant Pathologist's Pocketbook. Third Edition. CABI Publishing, Wallingford, UK, 528 pp.

Wande, W.L., Hassanali, A., McDowell, P.G., Moreka, L., Nokoe, S. K. and Waterman, P.G. (1992). Constituents of *Commphora rostrata* and some of their analogues as maize weevil, *Sitophilus zeamais* repellents. *Insect Science and its Application* **13**: 679-683.

Waterhouse, D. (1973). Background paper presented at the Ninth Session of the FAO Working Party of Experts on Pest Resistance to Pesticides. Rome, 73 pp.

Watt, J.M. and Breyer-brandwijik, M.G. (1962). Medicinal and Poisonous Plants of Southern and Eastern Africa. E and S Livingstone (eds.), Edinburgh.

Weaver, D.K., Phillips, T.W., Dunkel, F.V., Weaver, T., Grubb, R.T. and Nance, E.L. (1995). Dried leaves from rocky mountain plants decrease infestation by stored-product beetles. *Journal of Chemical Ecology* **21**: 127–142.

Weaver, D. K., Dunkel, F.V., Ntezurubanza, L., Jackson, L.L. and Stock, D. T. (1998). The efficacy of linalool, a major component of freshly-milled *Ocimum canum* Sims (Lamiaceae), for protection against post-harvest damage by certain stored products Coleoptera. *Journal of Stored Product* **27(4)**: 213-220.

Weniger, B. and Robinean, L. (1988). Elements for Carribean Pharmacopoiea. *Proceedings of TRAMIL workshop*, Cuba.

Wheeler, B. E. J. (1969). An Introduction To Plant Diseases. John Wiley, London, UK 9: 374.

Wheeler, R., Rye, J.L., Koch, B.L. and Wilson, B.A.J.G. (1992). Flora of the Kimberley Region. Western Australia: Western Australian Herbarium, Department of Conservation and Land Management.

Wills, R., Mc Glasson, B., Graham, D. and Joyce, D. (1998). Post-harvest: An introduction to the physiology and handling of fruit, vegetables and ornamentals. Wallingford: CAB International, Fourth Edition. Wallingford UK, 262 pp.

Wink, M. (1988). Plant breeding: Importance of plant secondary metabolites for protection against pathogens and herbivores. *Theoretical and Applied Genetics* 75: 225-233.

Wink, M. (1993). Production and application of phytochemicals from an agricultural perspective. *In*: *Phytochemistry and Agriculture Proceedings*. Phytochemical Society of Europe 34: 171-213.

World Bank Group Report (2011).

World Resources (1998). Disappearing food: How big are post-harvest losses? Available online <http: // population. Wri.org/pubs> (Accessed on 14 / 01/2013).

www.ghananation.com

Yadava, T. D. (1973). Studies of the insecticidal treatment against bruchids: *Callosobruchus maculatus* (Fab.) and *C. chinensis* (Linn.). Practical applications of neem against pests of stored product. *Proceedings of MBAO* 2006. pp.110-114.

Yusuf, M., Begum, J., Hoque, M.N. and Chowdhury, J.U. (2009). Medicinal plants of Bangladesh. BCSIR Chittagong. 794 pp.

Zehrer, W. (1980). Traditional methods of insect pest control in stored grain. *In*: Post-harvest problems. Documentation of an OAU /GTZ Seminar, Lome. 45 pp.

Zehrer, W. (1994). The effect of traditional preservatives used in Northern Togo and of neem oil for the control of storage pest, *In*: Schmutterer, H. and Ascher, K.R.S. (eds.), Natural Pesticides from the Neem Tree (*Azadirachta indica* A.Juss) and other tropical plants. *Proceedings of the 2nd International Neem Conference,* Ralliescholzhausen, Germany, 1983. Eschborn: GTZ, pp. 453-460.

APPENDICES

APPENDIX 1:

Questionaire

TOPIC: POSTHARVEST LOSSES AND EVALUATION OF THE BIOEFFICACY OF *CHROMOLAENA ODORATA* AND *JATROPHA GOSSYPIIFOLIA* AGAINST *SITOPHILUS ZEAMAIS* MOTSCH AND *TRIBOLIUM CASTANEUM* HERBST IN THE AWUTU-SENYA DISTRICT OF THE CENTRAL REGION OF GHANA

This research is an academic exercise and all information given shall be used solely for the purpose stated. All information given would be treated strictly confidential.

Section A - General information on farmer

1. Name of Interviewer: ……………………………………………………………..
2. Date of Interview: ……………..
3. Place of Interview: ………………………………………………………………..
4. Type of storage structure: ………………………………………………………
5. Village status and tribe: ……………………………………………………………
6. Age: 20 and under …………. 21 – 40 ………. 41 – 60 ………. Over 60 ………
7. Sex of head of household M F
8. Number of wives / husbands ………………...
9. Number of children / dependents ………..
10. Age of children permanently resident:
    0 – 7 ……… 8 – 14 ………. 15 – 18 ……….
11. How many people were you feeding regularly? …………………
12. Amount of cash spent on food per month? ……………………...
13. How long have you been farming on your farm? ………………..
14. Where were you living before? District ……. Village …….
15. What type of storage is commonly used there? ………………………
16. Have you received any education?
    Yes ………….. No …………..
17. If yes, indicate level.
    Primary/Form …….. Secondary/Grade ……. Diploma …… Others ……
18. Farming experience (years)
    10 and below ……………. 11-15 ……. 16-20 ……. 21 and above ……………
19. Do you do any other work other than farming?
    Yes ……. No …….

20. If yes, please specify? …………………..
21. Indication of monthly income per household.
    a. Cash in wages …………………
    b. Cash in salary …………………
    c. Pension allowance ……………..
22. Type of farm animals in the house.
a) Poultry ………..
b) Goat ………….
c) Sheep ………..
d) Pig …………..

Section B – Crops and Storage

1. What crops did you grow?
   Maize …………
   Cassava ………..
   Beans ………….
   Others ……….
2. Which of the food crops did you grow in most quantity?
   Maize ………. Cassava ………… Beans …………… Others …………
3. A. Were any of your crops mainly grown for the purpose of sale?
   a. Yes …. b. No …..
   B. If yes, specify …………………..
   Maize………. Cassava ………. Beans ………. Others ……….
4. Which crops did you store most?
   Maize ………. Cassava ………… Beans …………. Others …………..

5 Reason(s) for storage?
………………………………………………………………………………………………

6. How did you decide what quantity of maize to grow?
……………………………………………………………………………………………………
……………………………………………………………………………………………………

7. Are there any conditions in which you would grow?
   More maize ……………….. Less maize …………………….
8. What variety (ies) of maize did you grow?
   Local ………….. Obaatanpa.………….. Hybrid (once grown) ……………..
9. Has the quantity of maize you have grown changed in recent seasons?

	No	More	Less
Local	……………	………………..	………………
Obaatanpa	………..	………………...	……………….
Hybrid	……………	…………………	………………

10. Do you intend to change the quantity of maize you are growing?

	No	More	Less
Local	……………….	………….	………………..
Obaatanpa	……………	……........	………………..
Hybrid	……………..	…………….	………………..

11. A. Have you received any training on when to harvest, how to dry and store maize?
a. Yes …………….. b. No ……………….
B. If yes, how often do you receive these visits? …………………….
12. A. By what method did you plant your maize?
Broadcasting …………….. Rows without spacing……………
Rows with spacing ………. Others ……………..
B. What tools did you use?
Hoe ………. Plough ……….. Planter ………… Other ………………
13. Did you use fertilizer or insecticide on your crops last season?

	No	Fertilizer	Insecticide
Local	……………….	……………..	………………….
Obaatanpa	…………...	………………	………………….
Hybrid	……………….	……………..	………………….

14. What was the approximate date of harvest? …………………….
15. What was the approximate date of storage? ……………………
16. Which variety of maize did you store? Local ……… Obaatanpa……. Hybrid ……
17. How did you dry your maize? Natural drying ……………..
Mechanical drying…………….
18. a. Did you store your maize in the form of cobs or as shelled grains?

Cobs (with husks)	Cobs (without husks)	Shelled grains
…………………..	……………………..	……………………..

b. If shelled, how did you shell it?
By hand ……………. Simple sheller ………………… Other ………………
19. What quantity of maize did you put in store last season? ………………..
20. a. Did you keep any maize for seed? A. Yes ……………. B. No …………..
b. If yes, i) What variety did you store? ………………….
ii) How did you store it? ……………………..
iii) How much did you store? ………….………..
21. Is there any condition that will let you store?
More maize ………………………………..
Less maize ……………………………………………………………………………………
22. A. Did you buy any maize for seed? a. Yes …………………. b. No ……………….
B. If yes, i) What variety did you buy? ………………………
ii) From where did you obtain it? ……………….…
iii) What price did you buy it? ………………………

Section C – Storage Facilities

1. How many warehouses/stores did you have last season? ……………………………….
2. Of what were these made (materials)?

………………………………………………………………………………………………
…………………………………………………………………………………

3. From where were these materials obtained?

…………………………………………………………………………………………

4. What price did you buy it? ……………………………………………………………
5. How old are your stores/warehouses? ....
6. For how many seasons have you used them? ……………………………………………...
7. A. Did you spend any time repairing your stores? a. Yes …… b. No ……….

   B. If yes, how frequent? …………………………………………………
8. Did you do anything else to your stores before filling it? a. Yes …. No……
9. A. Did you treat the maize before storage? a. Yes ……….b. No ……………

   B. If yes, i) with what? ……………………………………………………………

   ii) At what rate? …………………………………………………………….
10. A. Do you give the maize any further treatment whilst in store? a. Yes …. .b. No…..

    B. If yes, what treatment did you give it? ....
11. Have you ever considered changing your method(s) of storage? a. Yes …... b. No……..
12. If yes, what changes have you considered? ……..……………………………………

Section D – Usage of Stored Maize

1. How often did you take maize out of your store? ………………………………………..
2. Did you take out a similar quantity each time? a. Yes ………… b. No …………….
3. From which part of the stack did you pick the maize?

   Top ………….. Side door …………….. Others ………………
4. For what purpose did you use your maize?

   Food ……………..

   Feeding animals …………

   Seed ……………..

   To sell …………….

   Gifts …………….

   Replace of loans ………….

   Other purpose ……………

Section E – Losses

1. A. Did the maize you stored show any signs of damage? a. Yes ………. b. No ……….

   B. If yes, were some varieties of maize affected more than others? a. Yes …. b. No……..
2. What do you think caused this damage?

   Insects ……… Moulds …………. Rats ……………… Others …………..
3. What did you do to prevent these organisms from causing damage to your stored products?

…………………………………………………………………………………………

4. At what time of the year did most of the damage occur? …………………………………

5. What did you do with the damaged maize?

………………………………………………………………………………………

6. What proportion of your crop was affected?

   i) In total ……………….. ii) By variety of maize ……………………………..

7. How much maize did you throw away?

   i) In total ……………….. ii) By variety of maize …………………………….

8. How much of your maize stored for seed did you throw away?

……………………………………………………………………………………..

9. If your maize suffered less damage, would this alter the quantity that you

		No	More	Less
a) Grow:	Local	…………….	…………	…………
	Opaatanpa	…………….	…………	…………
	Hybrid	…………….	…………	…………
b) Store:	Local	…………….	…………	…………
	Opaatanpa	……………..	…………	…………
	Hybrid	…………….	…………	…………

Section F – Marketing

1. What variety of maize did you sell? …………………………………..
2. In what form did you sell it? Cob ……………… Shelled …………..
3. In what month did you sell your maize? …………………………………..
4. What was the reason that made you sell it at that time? ....
5. A) What grades of maize did you sell?

   Good …………… Slightly damaged ……………… Damaged.................

   B) What proportion of the maize did you sell before storage? ……………………………
6. What price did you receive? ………………………………………
7. A) Did these remain so for the rest of the season? a. Yes …………… b. No...........

   B) If no, give details

………………………………………………………………………………………

8. A. Whom did you sell the maize to?

   MoFA ……………….. Local traders …………….. Others ……………………………

   B. What quantity did you sell to each people?

   MoFA ……………….. Local traders ……………. Others ……………………...
9. By what method did you transport your maize to the market?

   Manually ………… Road ………………. Rail …………………..
10. A. Did you buy any maize last season? a. Yes ………… b. No ………………….

    B. If yes, for what purpose? ……………………………………………………………..
11. What variety? Local …… Opaatanpa……….. Hybrid …………………
12. What quantity? ……………………………………………………………………….
13. From where did you obtain it? ……………………………………………………..

14. When did you buy it? ……………………………………………………………………..
15. What price did you buy it? …………………………………………………………….

APPENDIX 2:
Analysis of variance for contact toxicity of methanol and diethyl-ether extracts of plants against *S. zeamais* and *T. castaneum* by topical application

Analysis of variance for contact toxicity of 20% plant extracts on *S. zeamais* after 48 hours

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	15594.30	1732.70	72.95	<.001
Residual	20	475.04	23.75		
Total	29	16069.33			

Analysis of variance for contact toxicity of 20% plant extracts on *T. castaneum* after 48 hours

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	13669.33	1518.81	54.50	<.001
Residual	20	557.40	27.87		
Total	29	14226.72			

APPENDIX 3:
Analysis of variance for repellent effect of extracts on *S. zeamais* and *T. castaneum*

Analysis of variance for repellent effect of *C. odorata* and *J. gossypiifolia* leaves and bark extracts on *S. zeamais*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	1474.1	184.3	0.89	0.545
Residual	18	3733.3	207.4		
Total	26	5207.4			

Analysis of variance for repellent effect of *C. odorata* and *J. gossypiifolia* leaves and bark extracts on *T. castaneum*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	8	5466.7	683.3	1.81	0.141
Residual	18	6800.0	377.8		
Total	26	12266.7			

APPENDIX 4:
Analysis of variance of the effect of extracts on adult insect in treated grains

Analysis of variance of the effect of extracts on *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	10870.37	1207.82	49.92	<.001
Residual	20	483.92	24.20		
Total	29	11354.29			

Analysis of variance of the effect of extracts on *S. zeamais* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	13777.91	1530.88	106.93	<.001
Residual	20	286.33	14.32		
Total	29	14064.23			

Analysis of variance of the effect of extracts on *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	11810.34	1312.26	71.20	<.001
Residual	20	368.61	18.43		
Total	29	12178.94			

Analysis of variance of the effect of extracts on *S. zeamais* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	12343.56	1371.51	52.71	<.001
Residual	20	520.38	26.02		
Total	29	12863.93			

Analysis of variance of the effect of extracts on *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	12964.17	1440.46	56.79	<.001
Residual	20	507.28	25.36		
Total	29	13471.45			

Analysis of variance of the effect of extracts on *S. zeamais* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	14141.63	1571.29	131.26	<.001
Residual	20	239.42	11.97		
Total	29	14381.05			

Analysis of variance of the effect of diethyl-ether extract of *C. odorata* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	125.51	125.51	4.04	0.115
Residual	4	124.35	31.09		
Total	5	249.87			

Analysis of variance of the effect of methanol extract of *C. odorata* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.00	0.00	0.00	1.000
Residual	4	58.89	14.72		
Total	5	58.89			

Analysis of variance of the effect of diethyl-ether extract of *C. odorata* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	5.55	5.55	0.50	0.519
Residual	4	44.37	11.09		
Total	5	49.91			

Analysis of variance of the effect of methanol extract of *C. odorata* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	6.04	6.04	0.26	0.635
Residual	4	91.69	22.92		
Total	5	97.73			

Analysis of variance of the effect of diethyl-ether extract of *J. gossypiifolia* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	29.445	29.445	4.00	0.116
Residual	4	29.445	7.361		
Total	5	58.890			

Analysis of variance of the effect of methanol extract of *J. gossypiifolia* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	7.36	7.36	0.50	0.519
Residual	4	58.89	14.72		
Total	5	66.25			

Analysis of variance of the effect of diethyl-ether extract of *J. gossypiifolia* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.00	0.00	0.00	1.000
Residual	4	44.37	11.09		
Total	5	44.37			

Analysis of variance of the effect of methanol extract of *J. gossypiifolia* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	6.04	6.04	0.26	0.635
Residual	4	91.69	22.92		
Total	5	97.73			

Analysis of variance of the effect of acetone control on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.	0.		
Residual	4	0.	0.		
Total	5	0.			

Analysis of variance of the effect of actellic on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 20% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	226.56	226.56	4.00	0.116
Residual	4	226.56	56.64		
Total	5	453.13			

Analysis of variance of the effect of diethyl-ether extract of *C. odorata* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	36.39	36.39	1.98	0.232
Residual	4	73.51	18.38		
Total	5	109.90			

Analysis of variance of the effect of methanol extract of *C. odorata* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	62.16	62.16	3.10	0.153
Residual	4	80.28	20.07		
Total	5	142.45			

Analysis of variance of the effect of diethyl-ether extract of *C. odorata* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	6.04	6.04	0.26	0.635
Residual	4	91.69	22.92		
Total	5	97.73			

Analysis of variance of the effect of methanol extract of *C. odorata* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.00	0.00	0.00	1.000
Residual	4	48.33	12.08		
Total	5	48.33			

Analysis of variance of the effect of diethyl-ether extract of *J. gossypiifolia* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	11.02	11.02	1.00	0.374
Residual	4	44.07	11.02		
Total	5	55.08			

Analysis of variance of the effect of methanol extract of *J. gossypiifolia* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	29.445	29.445	4.00	0.116
Residual	4	29.445	7.361		
Total	5	58.890			

Analysis of variance of the effect of diethyl-ether extract of *J. gossypiifolia* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	5.55	5.55	0.50	0.519
Residual	4	44.37	11.09		
Total	5	49.91			

Analysis of variance of the effect of methanol extract of *J. gossypiifolia* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	6.041	6.041	1.00	0.374
Residual	4	24.165	6.041		
Total	5	30.206			

Analysis of variance of the effect of acetone control on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.	0.		
Residual	4	0.	0.		
Total	5	0.			

Analysis of variance of the effect of actellic on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 50% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	56.6	56.6	0.50	0.519
Residual	4	453.1	113.3		
Total	5	509.8			

Analysis of variance of the effect of diethyl-ether extract of *C. odorata* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.00	0.00	0.00	1.000
Residual	4	88.13	22.03		
Total	5	88.13			

Analysis of variance of the effect of methanol extract of *C. odorata* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.00	0.00	0.00	1.000
Residual	4	88.13	22.03		
Total	5	88.13			

Analysis of variance of the effect of diethyl-ether extract of *C. odorata* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	6.04	6.04	0.22	0.663
Residual	4	109.73	27.43		
Total	5	115.77			

Analysis of variance of the effect of methanol extract of *C. odorata* bark on adult *S. zeamais* and *T.castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	24.165	24.165	4.00	0.116
Residual	4	24.165	6.041		
Total	5	48.330			

Analysis of variance of the effect of diethyl-ether extract of *J. gossypiifolia* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	11.02	11.02	0.50	0.519
Residual	4	88.13	22.03		
Total	5	99.15			

Analysis of variance of the effect of methanol extract of *J. gossypiifolia* leaves on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	145.55	145.55	7.92	0.048
Residual	4	73.51	18.38		
Total	5	219.06			

Analysis of variance of the effect of diethyl-ether extract of *J. gossypiifolia* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	6.041	6.041	1.00	0.374
Residual	4	24.165	6.041		
Total	5	30.206			

Analysis of variance of the effect of methanol extract of *J. gossypiifolia* bark on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	24.165	24.165	4.00	0.116
Residual	4	24.165	6.041		
Total	5	48.330			

Analysis of variance of the effect of acetone control on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	0.	0.		
Residual	4	0.	0.		
Total	5	0.			

Analysis of variance of the effect of actellic on adult *S. zeamais* and *T. castaneum* in treated grains on Day 4 at 100% concentration

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Days	1	226.56	226.56	4.00	0.116
Residual	4	226.56	56.64		
Total	5	453.13			

APPENDIX 5:
Analysis of variance for effect of extracts of *C. odorata* and *J.gossypiifolia* on immature stages of *T. castaneum* and *S. zeamais*

Analysis of variance for effect of extracts of *C.odorata* and *J.gossypiifolia* on eggs of *T.castaneum*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	580.7000	64.5222	71.69	<.001
Residual	20	18.0000	0.9000		
Total	29	598.7000			

Analysis of variance for effect of extracts of *C. odorata* and *J. gossypiifolia* on eggs of *S. zeamais*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	609.4667	67.7185	96.74	<.001
Residual	20	14.0000	0.7000		
Total	29	623.4667			

Analysis of variance for effect of extracts of *C. odorata* and *J. gossypiifolia* on larvae of *T. castaneum*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	512.0000	56.8889	106.67	<.001
Residual	20	10.6667	0.5333		
Total	29	522.6667			

Analysis of variance for effect of extracts of *C. odorata* and *J. gossypiifolia* on larvae of *S. zeamais*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	641.4667	71.2741	118.79	<.001
Residual	20	12.0000	0.6000		
Total	29	653.4667			

Analysis of variance for effect of extracts of *C. odorata* and *J. gossypiifolia* on pupae of *T. castaneum*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	654.6667	72.7407	90.93	<.001
Residual	20	16.0000	0.8000		
Total	29	670.6667			

Analysis of variance for effect of extracts of *C. odorata* and *J. gossypiifolia* on pupae of *S. zeamais*

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	575.4667	63.9407	91.34	<.001
Residual	20	14.0000	0.7000		
Total	29	589.4667			

APPENDIX 6:
Analysis of variance for the effect of extracts of *C.odorata* and *J.gossypiifolia* on grain damage by *S. zeamais* and *T. castaneum*

Analysis of variance for the effect of extracts of *C. odorata* and *J.gossypiifolia* on grain damage on *S. zeamais* egg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	95.3603	10.5956	31.50	<.001
Residual	20	6.7267	0.3363		
Total	29	102.0869			

Analysis of variance for the effect of extracts of *C. odorata* and *J. gossypiifolia* on grain damage on *S. zeamais* larva

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	88.0805	9.7867	67.06	<.001
Residual	20	2.9189	0.1459		
Total	29	90.9993			

Analysis of variance for the effect of extracts of *C. odorata* and *J. gossypiifolia* on grain damage on *T. castaneum* egg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	39.0468	4.3385	13.61	<.001
Residual	20	6.3762	0.3188		
Total	29	45.4230			

Analysis of variance for the effect of extracts of *C. odorata* and *J. gossypiifolia* on grain damage on *T. castaneum* larva

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	14.1503	1.5723	15.06	<.001
Residual	20	2.0876	0.1044		
Total	29	16.2379			

APPENDIX 7:
Analysis of variance for the effect of oviposition on damage caused by *S. zeamais* and *T. castaneum* on stored grains using the acid fuschin solution egg staining technique

Analysis of variance for the effect of oviposition on damage caused by *S. zeamais* on stored grains using the acid fuschin solution egg staining technique

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	2299.2	255.5	1.39	0.256
Residual	20	3668.9	183.4		
Total	29	5968.1			

Analysis of variance for the effect of oviposition on damage caused by *T. castaneum* on stored grains using the acid fuschin solution egg staining technique

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	2237.9	248.7	2.16	0.073
Residual	20	2302.5	115.1		
Total	29	4540.4			

APPENDIX 8:
Analysis of variance for the effect of infestation level on damage caused by *S. zeamais* and *T. castaneum* on stored grains using grain dissection

Analysis of variance for the effect of infestation level on damage caused by *S. zeamais* larva on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	2628.51	292.06	14.03	<.001
Residual	20	416.36	20.82		
Total	29	3044.88			

Analysis of variance for the effect of infestation level on damage caused by *S. zeamais* pupa on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	1932.90	214.77	16.26	<.001
Residual	20	264.13	13.21		
Total	29	2197.03			

Analysis of variance for the effect of infestation level on damage caused by *T. castaneum* larva on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	930.01	103.33	4.95	0.001
Residual	20	417.75	20.89		
Total	29	1347.76			

Analysis of variance for the effect of infestation level on damage caused by *T. castaneum* pupa on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	9	2401.23	266.80	13.57	<.001
Residual	20	393.15	19.66		
Total	29	2794.38			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *C. odorata* leaves on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	50.85	50.85	1.09	0.356
Residual	4	187.20	46.80		
Total	5	238.05			

Analysis of variance for the effect of infestation level of methanol extracts of *C. odorata* leaves on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	177.33	177.33	12.15	0.025
Residual	4	58.38	14.59		
Total	5	235.71			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *C. odorata* bark on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	13.260	13.260	1.50	0.287
Residual	4	35.291	8.823		
Total	5	48.551			

Analysis of variance for the effect of infestation level of methanol extracts of *C. odorata* bark on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	6.04	6.04	0.21	0.669
Residual	4	114.26	28.56		
Total	5	120.30			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *J. gossypiifolia* bark on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	0.00	0.00	0.00	1.000
Residual	4	87.85	21.96		
Total	5	87.85			

Analysis of variance for the effect of infestation level of methanol extracts of *J. gossypiifolia* bark on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	91.16	91.16	6.42	0.064
Residual	4	56.83	14.21		
Total	5	148.00			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *J. gossypiifolia* leaves on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	95.36	95.36	6.30	0.066
Residual	4	60.56	15.14		
Total	5	155.92			

Analysis of variance for the effect of infestation level of methanol extracts of *J. gossypiifolia* leaves on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	6.55	6.55	0.42	0.551
Residual	4	62.05	15.51		
Total	5	68.61			

Analysis of variance for the effect of infestation level of actellic on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	76.54	76.54	3.46	0.136
Residual	4	88.51	22.13		
Total	5	165.05			

Analysis of variance for the effect of infestation level of acetone control on damage caused by *T. castaneum* and *S. zeamais* larvae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	39.24	39.24	1.89	0.241
Residual	4	83.17	20.79		
Total	5	122.41			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *C. odorata* leaves on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	51.910	51.910	5.97	0.071
Residual	4	34.763	8.691		
Total	5	86.674			

Analysis of variance for the effect of infestation level of methanol extracts of *C. odorata* leaves on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	50.268	50.268	5.98	0.071
Residual	4	33.635	8.409		
Total	5	83.903			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *C. odorata* bark on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	0.00	0.00	0.00	1.000
Residual	4	144.08	36.02		
Total	5	144.08			

Analysis of variance for the effect of infestation level of methanol extracts of *C. odorata* bark on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	0.00	0.00	0.00	0.986
Residual	4	46.93	11.73		
Total	5	46.93			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *J. gossypiifolia* bark on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	68.45	68.45	3.78	0.124
Residual	4	72.39	18.10		
Total	5	140.84			

Analysis of variance for the effect of infestation level of methanol extracts of *J. gossypiifolia* bark on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	1.401	1.401	0.24	0.648
Residual	4	23.008	5.752		
Total	5	24.409			

Analysis of variance for the effect of infestation level of diethyl-ether extracts of *J. gossypiifolia* leaves on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	0.000	0.000	0.00	1.000
Residual	4	11.685	2.921		
Total	5	11.685			

Analysis of variance for the effect of infestation level of methanol extracts of *J.gossypiifolia* leaves on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	5.842	5.842	4.00	0.116
Residual	4	5.842	1.461		
Total	5	11.685			

Analysis of variance for the effect of infestation level of acetone control on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	155.71	155.71	6.08	0.069
Residual	4	102.46	25.61		
Total	5	258.16			

Analysis of variance for the effect of infestation level of actellic on damage caused by *T. castaneum* and *S. zeamais* pupae on stored grains using grain dissection

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Stage	1	0.41	0.41	0.01	0.929
Residual	4	182.49	45.62		
Total	5	182.90			