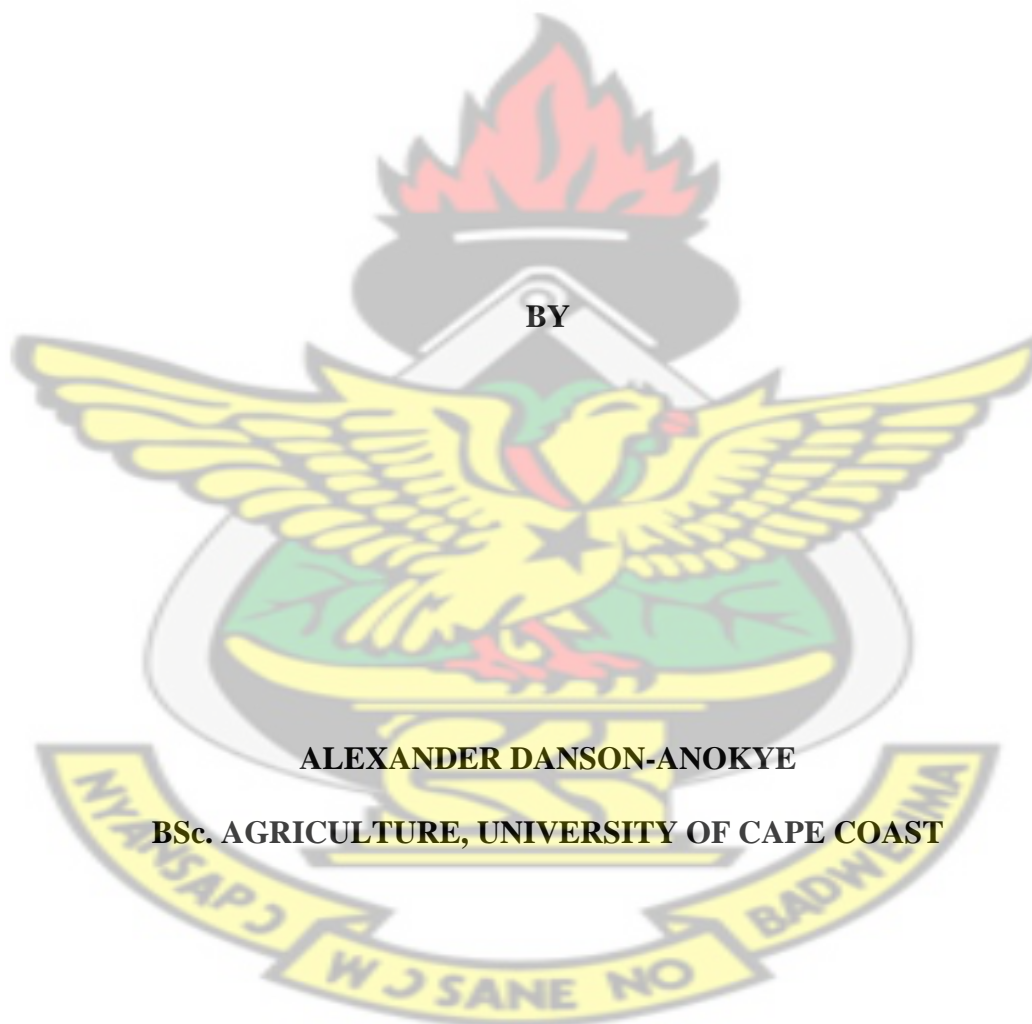


**SCREENING TEN VARIETIES OF MAIZE (*Zea mays* L.) FOR RESISTANCE TO
THE MAIZE WEEVIL (*Sitophilus zeamais* Motsch.)**

KNUST



BY

ALEXANDER DANSON-ANOKYE

BSc. AGRICULTURE, UNIVERSITY OF CAPE COAST

JANUARY, 2019

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

KUMASI, GHANA

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

KNUST
**SCREENING TEN VARIETIES OF MAIZE (*Zea mays* L.) FOR RESISTANCE
TO THE MAIZE WEEVIL (*Sitophilus zeamais* Motsch.)**

BY

ALEXANDER DANSON-ANOKYE

BSc. AGRICULTURE, UNIVERSITY OF CAPE COAST

A Thesis submitted to the Department of Crop and Soil Sciences,
Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

In Partial Fulfilment of the Requirements for the Degree of

MASTER OF PHILOSOPHY

IN

CROP PROTECTION (ENTOMOLOGY)

JANUARY, 2019

DECLARATION

I hereby declare that the research work presented in this thesis is my own work and that, to the best of my knowledge, it contains no material previously published by another person for the award of a degree in any other University, except where acknowledgement has been made in the text.

KNUST

.....

Signature

.....
Date

ALEXANDER DANSON-ANOKYE
(Student)

.....

Signature

.....
Date

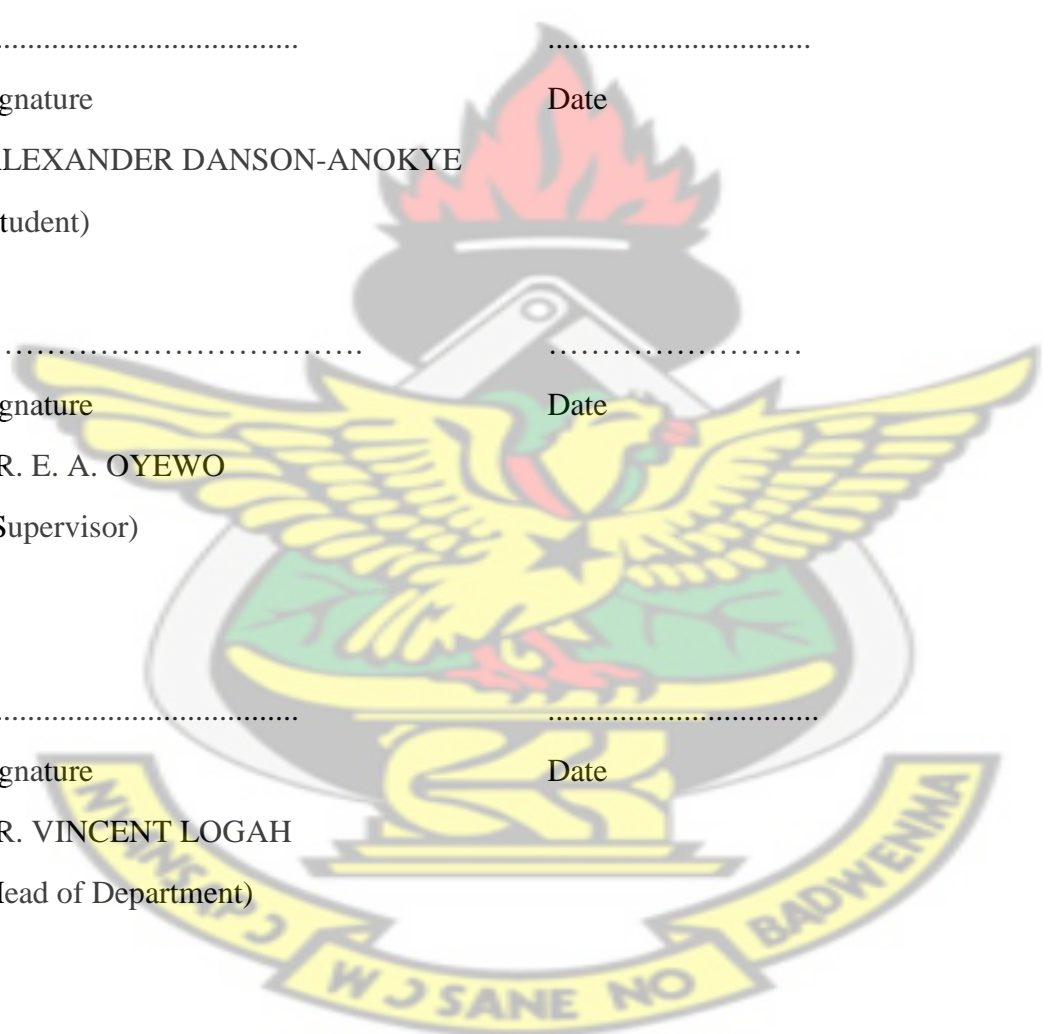
DR. E. A. OYEWO
(Supervisor)

.....

Signature

.....
Date

DR. VINCENT LOGAH
(Head of Department)



ABSTRACT

Post-harvest maize insect pests are a serious constraint to food security and income generation in sub-Saharan Africa. Ten varieties of maize cultivated in Ghana were screened to ascertain their resistance to the maize weevil, *Sitophilus zeamais* L. to assist farmers select a variety that can withstand the attack of the insect during storage. The study was conducted at the insect laboratory of the Department of Crop and Soil Sciences of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, KNUST, Kumasi. The Dodie Index of Susceptibility was used to group the varieties. Abeleehi, Omankwa, Abontem, and Adikanfo had indices less than 4 hence were classified as resistant. Weevils placed on Abeleehi produced the smallest number of progeny, had the highest median development period and lowest percentage seed damage and weight loss. Obatanpa, Aburohoma, Aburohemaa and Pan 12 were classified as moderately resistant whiles 10C8446 and 12C7636 were classified as moderately susceptible. Abeleehi had the best germination percentage with 12C7636 recording the lowest germination percentage after 90 days of storage. The resistant varieties, particularly Abeleehi can be recommended for *S. zeamais* management in maize especially for smallholder farmers in Ghana, whose seed can also be saved by farmers for planting in the subsequent season.

ACKNOWLEDGEMENT

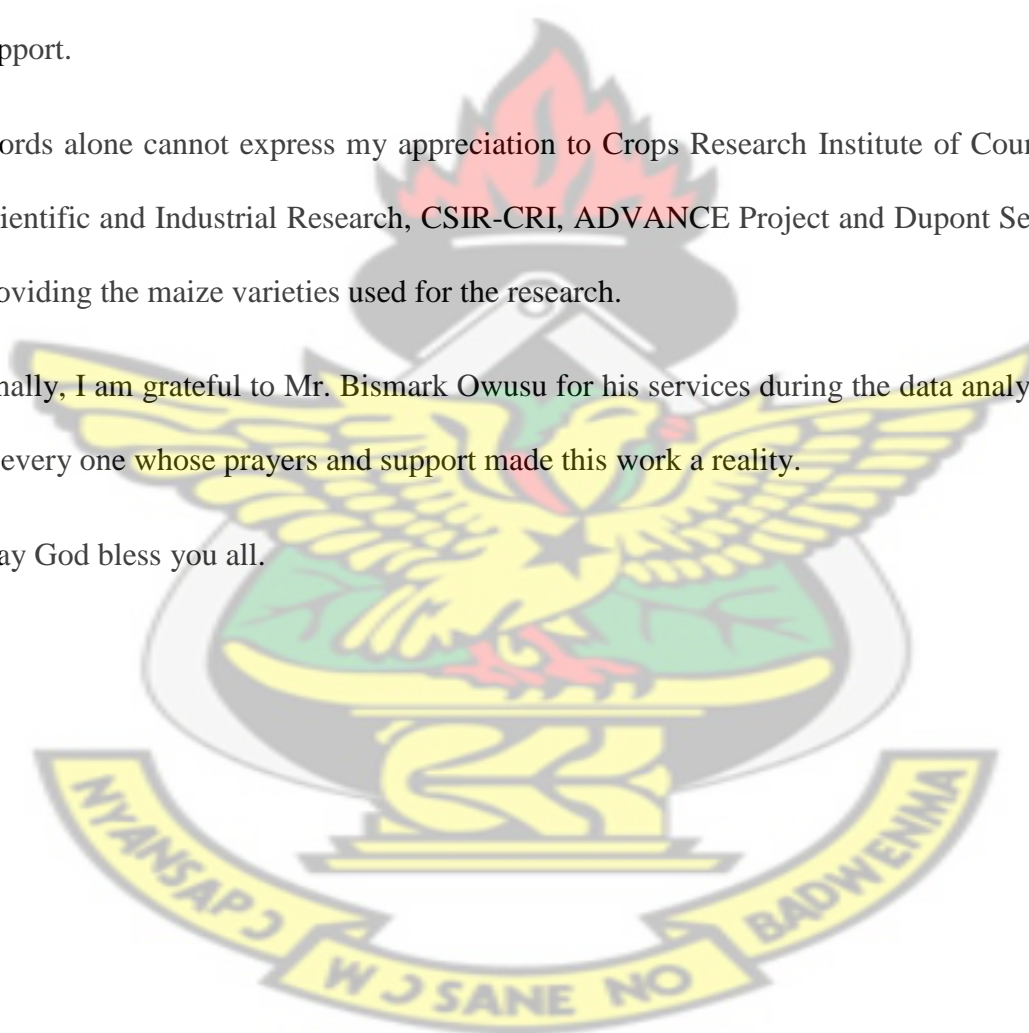
In the first place, I am ever grateful to the Almighty God for his guidance throughout this programme. I am grateful to my supervisor, Dr. Emmanuel Oyewo, as well as Prof. J.V.K. Afun and Dr. Enoch A. Osekre, all of the Department of Crop and Soil Sciences, Faculty of Agriculture, KNUST. I am ever grateful for their guidance, invaluable suggestions and support.

I extend my gratitude to the staff of the Department of Crop and Soil Sciences for their support.

Words alone cannot express my appreciation to Crops Research Institute of Council for Scientific and Industrial Research, CSIR-CRI, ADVANCE Project and Dupont Seeds for providing the maize varieties used for the research.

Finally, I am grateful to Mr. Bismark Owusu for his services during the data analysis and to every one whose prayers and support made this work a reality.

May God bless you all.



DEDICATION

This work is dedicated to the Lord Almighty for the gift of life and good health throughout my study period and to my sweetheart, Ophelia Kugblenu for her support.

KNUST



TABLE OF CONTENTS

DECLARATION	i
ABSTRACT.....	ii
ACKNOWLEDGEMENT	iii
DEDICATION	iv
TABLE OF CONTENTS.....	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
CHAPTER ONE	1
INTRODUCTION	1
CHAPTER TWO	6
2.0 LITERATURE REVIEW	6
2.1 Maize production in Ghana.....	6
2.2 Nutritional value of maize and uses of maize	6
2.3 Some cultivated maize varieties in Ghana	7
2.4 Post-harvest operations in maize production	8
2.4.1 Drying.....	8
2.4.2 Storage of maize in Ghana (duration/time)	9
2.4.3 Storage Structures	10
2.5 Losses along maize value chain	11
2.6 Magnitude of losses in the maize value chain.....	11
2.7 Post-harvest insects of stored maize and their damage	12
2.8 Economic impact of insect pests in maize value chain	13
2.9 Biology and behaviour of <i>Sitophilus zeamais</i>	13
2.9.1 Distribution and Economic Importance of <i>Sitophilus zeamais</i>	14
2.9.2 Management of <i>S. zeamais</i> in stored maize	15
2.9.2.1 Chemical control	15
2.9.2.2 Temperature control	16
2.9.2.3 Controlled atmospheres.....	16
2.9.2.4 Botanical insecticides	17
2.9.2.5 Host Plant Resistance	17
2.9.2.6 Resistant varieties.....	19
CHAPTER THREE	21

3.0 MATERIALS AND METHODS.....	21
3.1 Experimental Site	21
3.2 Maize Varieties used for the experiment.....	21
3.3 Multiplication of Seeds	21
3.3 <i>Sitophilus zeamais</i> culture preparation.....	22
3.4 Sexing of <i>Sitophilus zeamais</i>	22
3.5 Effect of maize varieties on development and emergence of <i>S. zeamais</i>	23
3.6 Cumulative damage on maize varieties and adult emergence.....	24
3.7 Data collected.....	24
3.7.1 Adult Mortality (%).....	25
3.7.2 Germination percentage	25
3.8 Statistical analysis	26
CHAPTER FOUR.....	27
4.0 RESULTS	27
4.1 Weevil emergence	27
4.2 Percentage Grain Damage.....	28
4.3 Weight of Dust Produced	29
4.4 Percentage Weight loss (%)	31
4.5 Percentage mortality of <i>S. zeamais</i> on the various maize varieties/lines	32
4.6 Median development period (MDP)	33
4.7 Index of susceptibility	34
4.8 Germination (%).....	34
CHAPTER FIVE	36
5.0 DISCUSSION.....	36
5.1 Weevil emergence and multiplication of <i>S. zeamais</i> on the maize varieties/lines..	36
5.2 Damaged grains, Percentage Weight loss and Percentage Dust produced	36
5.3 Percentage Mortality	37
5.4 Germination percentage	38
5.5 Median Development Period.....	38
5.6 Susceptibility Index.....	38
5.7 Indication of Resistance in the Maize Varieties.....	39
CHAPTER SIX.....	40
CONCLUSION AND RECOMMENDATION.....	40
6.1 CONCLUSION	40
6.2 RECOMMENDATION	40

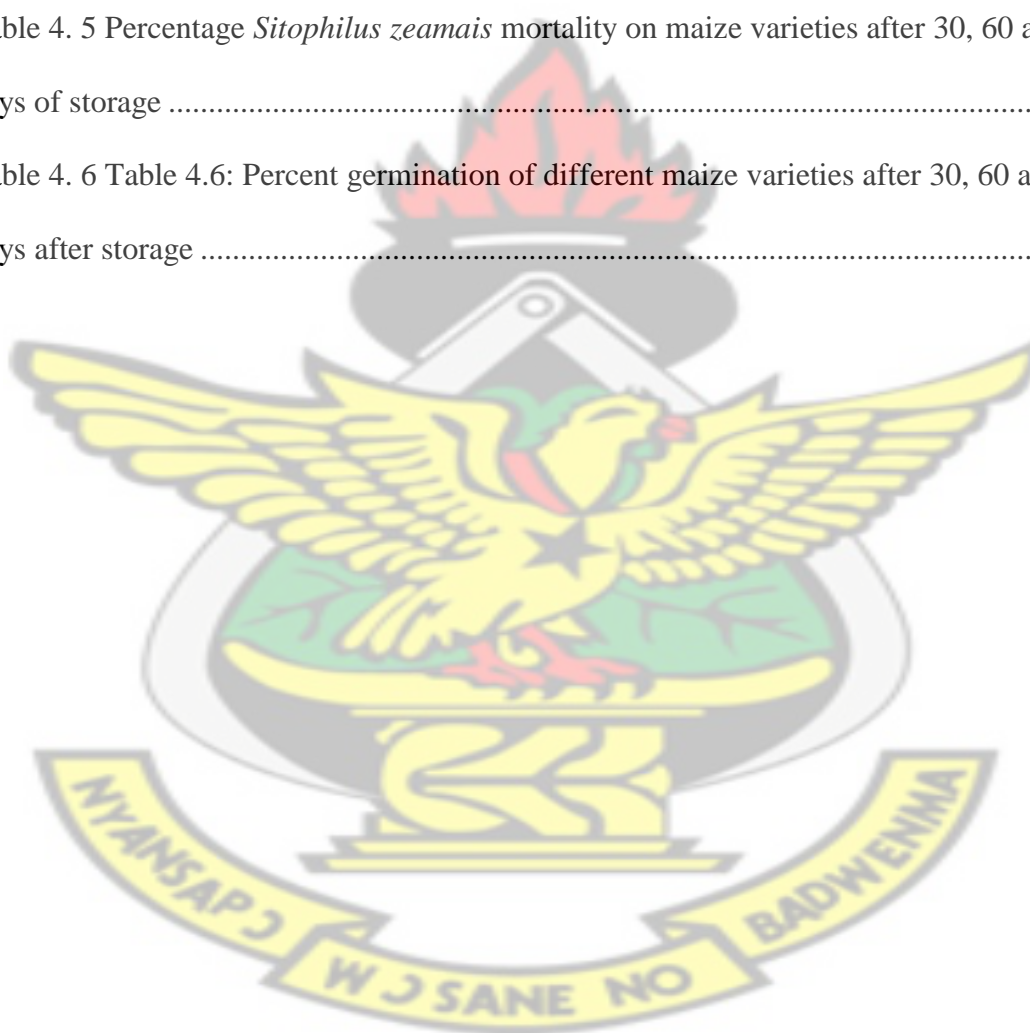
REFERENCES 41
APPENDICES 62

KNUST



LIST OF TABLES

Table 4. 1 Number of <i>Sitophilus zeamais</i> emerging after 30, 60, 90 days	27
Table 4. 2 Percentage damaged grains of different maize varieties after 30, 60, 90 days	29
Table 4. 3 Percent dust produced due to <i>Sitophilus zeamais</i> activities after 30, 60, 90 days of storage.....	30
Table 4. 4 Percent weight loss of different maize varieties after 30, 60, 90 days of storage	31
Table 4. 5 Percentage <i>Sitophilus zeamais</i> mortality on maize varieties after 30, 60 and 90 days of storage	32
Table 4. 6 Table 4.6: Percent germination of different maize varieties after 30, 60 and 90 days after storage	35



LIST OF FIGURES

Figure 4. 1: Median development period (MDP) of *Sitophilus zeamais* on different maize varieties 33

Figure 4. 2 Dobie's index of susceptibility. Susceptibility index of maize varieties: ≤ 4 = resistant, 4.1 – 6.0 = moderately resistant, 6.1 – 8 = moderately susceptible, 8.1- 10 = susceptible and > 10 = highly susceptible. 34

Figure 4. 3: Multiplication of *Sitophilus zeamais* on different maize varieties **Error!**

Bookmark not defined.



CHAPTER ONE

INTRODUCTION

Maize (*Zea mays* L.), is the most widely grown crop in Ghana and second largest after cocoa, representing 50-60% of total cereal production (Obeng-Antwi *et al.*, 2013). The levels of per capita consumption of maize in Ghana is estimated at 45 kg/head/year (SRID, 2009).

Maize, rice and wheat are the three most important cereal crops cultivated globally. Maize has invaluable benefits in the economy of developing countries by serving as staple food, cash crop, important source of calories as well as ensuring food security (Jones *et al.*, 2011; Smale *et al.*, 2011). According to Mlynekova and Ceresnakova (2013), the crop is a main source of nutrient in Africa and contributes up to 30% and 60% protein and energy of diets respectively.

Maize can be classified as sweet, popcorn, dent, flint and floury based on kernel characteristics (Boutard, 2012). The hard flint corn outer layer causes it to be less susceptible to destruction and loss by both field and storage insect pests as well as mould growth (Paliwal *et al.*, 2000). The grain has multi colours, varying from pale-orange to dark red (Suleiman *et al.*, 2013). Flint corn is widely cultivated in Central and South America, Asia, certain African and Southern European countries for human and animal consumption and industrial use (OGRT, 2008).

Maize is enjoyed by people in various forms, whole maize, gluten, flour, maize starch, syrup, cooking oil, popcorn and cornflakes, porridge among others. Maize meal is made into a thick porridge in many cultures and enjoyed by both adults and children. The corn meal mush in the Ghanaian dish is used for kenkey (Fanti or Ga), banku, tuo zaafi, abolo, kooko, and tom brown. It is an important source of protein and ranks only after meat, fish

and legumes with regard to annual protein production. Maize is also a good source of vitamins (B1, B5, B7, C, A and E) and minerals, magnesium, fibre and complex carbohydrate (Dasbak *et al.*, 2008).

According to Fening *et al.* (2011), maize is widely cultivated in all the agro-ecological zones of Ghana. It is cultivated on nearly 1,042,000 ha of land with an average yield of 1,835 Mt and an annual growth rate of 13.86% (SRID, 2009). Although maize production continues to increase every year, losses caused by biotic post-harvest factors including insects and fungi continue to be a major challenge globally (FAO, 2009). Estimated total losses of maize produced annually from insect damage in developing countries are higher (14 to 50%) compared to that of the developed nations with 1 to 2% (Ojo and Omoloye, 2012).

Grain storage increases food security, and also serves as an investment to farmers. In sub-Saharan Africa, premium price is paid for maize during the lean season which is usually six months after harvest than maize sold at the harvest season when it is in abundance (Meikle *et al.*, 2002). But farmers who store their maize risk losing their produce to post-harvest insect pests due to improper storage facilities and resources. Therefore, they begin to contemplate whether to store their maize or sell off their grain soon after harvest at a cheaper market price. “Sell for less or lose everything,” becomes a farmer’s dilemma (CIMMYT, 2011).

In sub-Saharan Africa, substantial produce and grain quality losses of maize due to insect pests’ attack occur which presents a critical food and income security challenge (Abebe *et al.*, 2009). *Sitophilus zeamais* Motschulsky, the maize weevil, is amongst the most damaging insect pests of stored grains, particularly maize in tropical developing countries (Paes *et al.*, 2012). *S. zeamais* is classified as a primary pest of grains. The adult female

causes damage by boring into the grain and ovipositing inside them. The larvae consume the endosperm, which results in a damaged grain and decreased grain weight (Ojo and Omoloye, 2012). Aside weight losses, weevils feeding activity results in serious decrease in nutritive and economic values, decrease seed viability, and also grains get contaminated by chemical excretions and exuviae (Ukeh *et al.*, 2012). The infestation also increases temperature and moisture content in the stored grain mass, which may result in mould development, especially by toxigenic species such as *Aspergillus flavus* (Chu *et al.*, 2013). *S. zeamais* causes substantial qualitative and quantitative losses of grain on-field and during storage (Sabbour, 2012).

In most tropical regions, *Sitophilus zeamais* is a key stored product insect pests of economic importance. Attack commences in the field, however, severe harm is done during storage of grains (Fikremariam *et al.*, 2009). Giga *et al.* (1991) and Muzemu *et al.* (2013) reported grain weight loss of 20-90% in sub Saharan Africa as a result of maize weevil attack on untreated maize. In advanced nations, maize storage is done in modern structures equipped with appropriate and effective temperature and moisture content monitoring devices to manage activities of insect pests. Contrastingly, in developing nations, maize storage is usually done in traditional structures with no control of the environment and often with no chemical protectants (Dhliwayo and Pixley, 2003). Maize damage by *S. zeamais* results in food loss, increases poverty and malnutrition, reduces weight, as well as decreases the nutritional and market values of grains (Keba and Sori, 2013). Additionally, *S. zeamais* infestation reduces seed viability and maize production because a lot of farmers in sub Saharan Africa store grain and seed together (Pingali and Pandey, 2001). A study by Renkow *et al.* (2004) found that in developing countries, a lot of small-scale farmers (83%) sell their maize grains within two months after harvest to evade damage and loss caused

by stored grain insect pests and therefore do not benefit from premium sales during the lean season. A lot of research have indicated that the use of resistant varieties like flint can reduce the activities of *S. zeamais* (Suleiman, 2015). The use of weevil resistant cultivars is effective, harmless, ecologically sound, appreciated by farmers, economically practicable and can be incorporated into already on-going programmes such as integrated pest management (IPM) approach (Keba and Sori, 2013).

Most stored-product pests including *S. zeamais* have been widely controlled by the use of synthetic chemical insecticides. The widespread application of pesticides for the management of stored grain insect pests is of serious concern with respect to pollution of the environment, development of resistance, pesticides residues in food, adverse consequence on beneficial organisms and also cost (Cherry *et al.*, 2005). Because of the health risks and environmental pollution associated with the use of conventional pesticides, current researches have been focusing on developing an alternative insect pest control strategies like the use of resistant maize varieties. Weevil-resistant maize varieties have the potential of providing a sustainable control option which would be inexpensive and suited to resource-poor farmers who produce at the subsistence level (Derera *et al.*, 2001).

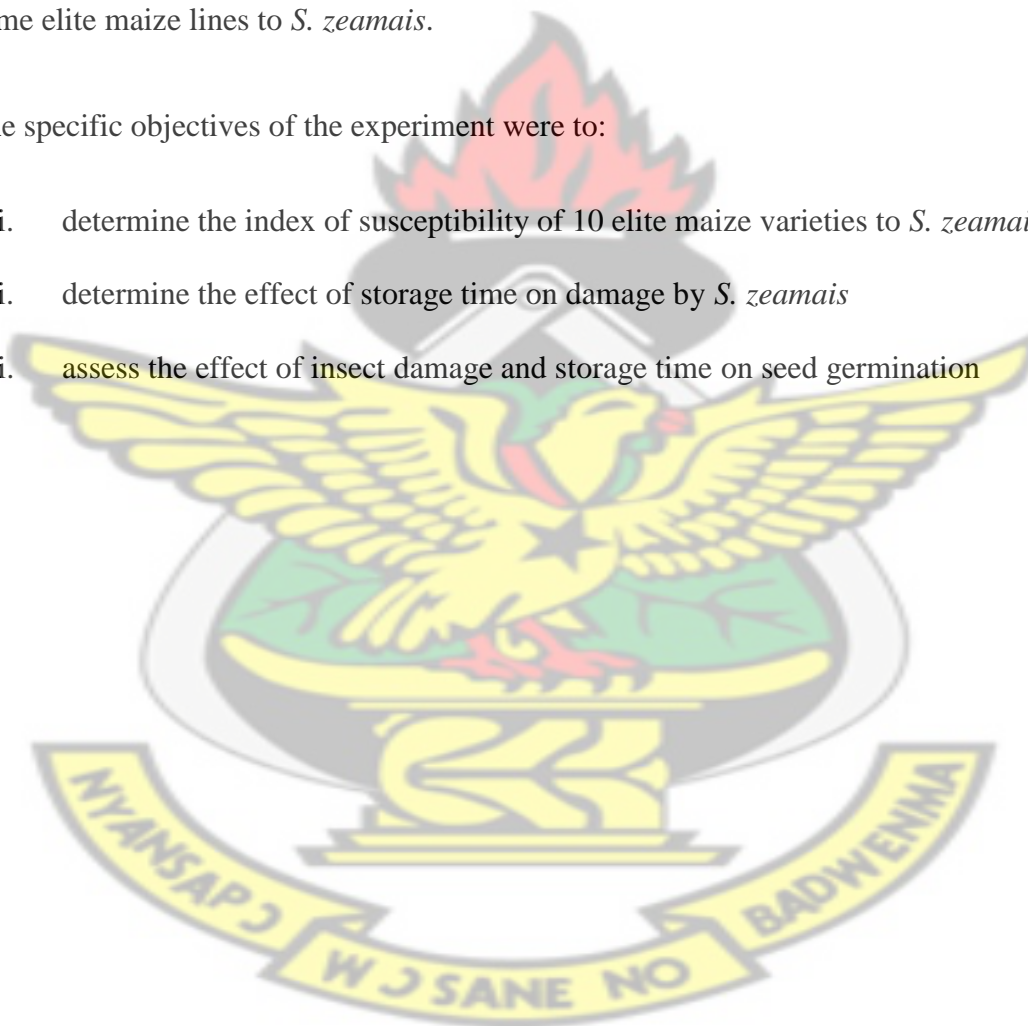
Genetic variability for resistance to the maize weevil has been found in maize varieties and inbred lines (Giga and Mazarura, 1991; Tadesse, 1995). In maize, various physical features such as kernel hardness and pericarp traits have been recognised as mechanisms of kernel resistance to *S. zeamais* (Gudrups *et al.*, 2001; García-Lara *et al.*, 2004). Kernel resistance as a result of physical barrier through mechanical protection of the pericarp cell wall and antibiosis through the toxic effects of phenolic acid amides and peroxidase activity localized in the aleurone layer (García-Lara *et al.*, 2007). The use of maize varieties that

will ensure a low reproductive and long lag-phase of *S. zeamais* in conjunction with other control strategies in an integrated pest management package, would keep the weevil populations in stored maize at sub-economic levels (Akob and Ewete, 2007). In order to reduce grain losses of smallholder farmers at the post-harvest level, it has become necessary to identify resistance sources that will facilitate the breeding of resistant varieties.

The main objective of the experiment was to identify the status or levels of resistance of some elite maize lines to *S. zeamais*.

The specific objectives of the experiment were to:

- i. determine the index of susceptibility of 10 elite maize varieties to *S. zeamais*
- ii. determine the effect of storage time on damage by *S. zeamais*
- iii. assess the effect of insect damage and storage time on seed germination



CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Maize production in Ghana

Maize (*Zea mays*) is an important staple food in most Ghanaian households and widely cultivated in greater parts of the country (USAID-EAT, 2012). The crop is ranked first in terms of area of cultivation and accounts for more than 50% of the total cereal production in the country (MiDA, 2012). According to a report by SRID-MoFA (2017), since 2007, annual maize production has been over 1 million MT and averaged over 1.7 million MT from 2014 to 2016 with an average yield of about 1.9 tons per hectare in 2016. In Ghana, production is commonly done by resource-disadvantaged farmers under natural rainfall conditions over a wide range of soils and ecological zones (SARI, 1996). However, production is concentrated in the Forest-Savanna transition zone. Major production centres are Ejura and Sekyedumasi in the Ashanti Region, Techiman and Wenchi in the Brong Ahafo Region and the Afram plains in the Eastern Region (GGDP, 1991; Onumah and Coulter, 2001). Marketing of maize is predominantly done by women. The principal participants in the maize commerce include producer, local aggregator, commission agent, long distance wholesaler and market-based wholesaler or retailer. Maize prices mostly depend on proximity to market centres and time of the year. Prices at farm gate decrease with increase in distance to major market centres and the accumulated increase in transportation cost (USAID-EAT, 2012).

2.2 Nutritional value of maize and uses of maize

Prior to the development of quality protein maize (QPM), the superiority of maize over the other cereals was limited by its low protein content. This difficulty has been largely corrected with the advent of QPM thus making it superior to the rest of the cereals in nutritional terms (FAO, 2007). Maize is an essential supplier of carbohydrate, oils, vitamin

B and minerals (IITA, 2007). It also contains potassium which is mostly deficient in most grains (Kumar and Jhariya, 2013). A study by Nuss and Tanumihardjo (2010) showed that maize gives an estimated 10% and 15% of the global calories and protein, respectively. In sub-Saharan Africa, it is a staple grain for about half of the population (IITA, 2003). However, in developed countries, the bulk of maize produced is utilized as feed for livestock and as a raw material for industrial processing whereas it is principally consumed by humans in developing countries such as Ghana (Aquino *et al.*, 2001). The per capita consumption of maize in Ghana has been estimated at 44 kg/person/year. The demand at the national level is anticipated to grow at about 1.83% per annum (FAO, 2007; IITA, 2007).

2.3 Some cultivated maize varieties in Ghana

Generally, maize can be grouped as early, intermediate or late maturing. The Crop Research Institute (CRI) and Savanna Agricultural Research Institute, (SARI) of the Council for Scientific and Industrial Research (CSIR) in collaboration with the International Institute of Tropical Agriculture, (IITA) and Maize and Wheat Improvement Centre (CIMMYT) have released 21 maize varieties that were registered in Ghana between 1983 and 1998 (Obeng-Antwi *et al.*, 2013). Between 2007 and 2012, 12 new varieties were also released of which, Ewul-Boyu, Sanzal-Sina, Abontem, Omankwa, Aburohemaa, Bihilifa, Wang dataa are open pollinated varieties while Etubi, Enii-Pibi (Enibi), Tintim, Opeaburoo and Aseda are hybrids. These varieties were screened against the key foliar diseases, including Maize Streak Virus, (MSV), leaf rust, ear rot, downy mildew and the maize stalk borer (*Eldana saccharina* Walker) and against *Striga*. Obatanpa continues to remain the leading OPV since its release in 1992. It represents 95% of all maize seeds planted in Ghana (Obeng-Antwi *et al.* (2013).

2.4 Post-harvest operations in maize production

Before maize grains get to the final consumer after harvest, variety of operations such as threshing, drying, winnowing, cleaning and grading are performed mostly on-farm which are known as primary post-harvest operations. Currently, mechanical threshing of maize cobs is commonly employed by small-scale and medium-scale farmers. This is fuelled by the drudgery associated with hand threshing, it also requires lengthy time which consequently promotes losses. Many small-scale farmers are unable to procure thresher and therefore contract the services of limited thresher owners. Mostly, threshers are limited in the farming communities, which hinders their accessibility to farmers, consequently promoting substantial grain loss at the piling stage when farmers wait for available service. Additionally, moving the one thresher across farms may also encourage cross infestation of insect pests, pathogenic fungi and viruses. One of the critical contributory factors to early loss of maize grains during storage is inability of farmers to remove infested and mouldy cobs prior to threshing. During the major season where moisture content of maize grain is usually high, damage of grains caused by mechanical threshing may be high which inadvertently promotes multiplication of insect pests and fungi infection consequently leading to production of mycotoxins (Opit *et al.*, 2014).

2.4.1 Drying

Maize grains are often harvested at high moisture content in tropical humid conditions to reduce shattering losses in the field (Kumar and Kalita, 2017). Nonetheless, for safe storage of maize, it is recommended that moisture content is below 13% (Baloch, 2010). A lot of small-scale farmers in most developing countries lack effective drying systems or equipment and this challenge is usually worsened by unfriendly rainy conditions during the major season (Weinberg *et al.*, 2008). Ineffective drying may cause proliferation of insects and importantly mould infection which results in substantially high storage losses.

Therefore, grains are dried after harvesting in order to maintain quality, reduce losses during storage and minimize cost of transportation (Kumar and Kalita, 2017). A report by Hodges (2012) indicated that natural sun drying is the most commonly used method of drying maize by smallholder farmers in Africa because they find it economical. However, mechanical dryers are also occasionally used. In Ghana, farmers usually spread their maize grains in an open area on crop fields, on plastic sheets or mats and on sides of paved road (Nsafoah, 2012). Mostly, natural sun drying depends on the weather, requires lengthy time, it is labour intensive, grains are exposed to attack by birds, fowls, rodents and insects, as well as contamination by dust and other foreign materials. Another inherent limitation of natural sun drying is that grains are not often dried uniformly and effectively to achieve appreciable levels of insect mortality (USDS, 2013).

2.4.2 Storage of maize in Ghana (duration/time)

Maize is stored after harvest, mainly to maintain quality of harvested produce to ensure sustainable supply of the commodity throughout the year and also to enable farmers earn better household incomes (Adejumo and Raji, 2007). Many studies have shown that traditional maize storage techniques are widespread in sub Saharan Africa including Ghana (Addo *et al.*, 2002; Brice, 2002). Different types of traditional storage containers such as cribs, woven baskets, jute sacks, rhombus etc. are used based on financial strength of the farmer and his or her locality. Most farmers find these traditional structures less expensive and environmentally friendly. Open storage is perhaps the most widespread traditional technique employed in sub-Saharan Africa. It may be constructed with wooden platforms on stakes on top where the cobs are arranged either in heaps or regular pattern or layers. An iron or straw roof is normally provided to offer protection to the stored grains from dump conditions. This type of storage enhances natural air circulation and allows for further drying of the cobs. Notwithstanding the benefits of traditional maize storage

methods, they are mostly not able to provide adequate protection to stored maize against destruction by insect pests and pathogens, resulting in estimated grain loss ranging between 20-30% (Tefera *et al.*, 2010). Traditional storage methods generate favourable microclimate for insects and fungi proliferation (Ngamo *et al.*, 2007). Because farmers lack access to effective storage methods to control insect pest infestation, they often forced to sell their produce at reduced market prices soon after harvest (CIMMYT, 2011). On the large-scale level, storage bins and large warehouses are used to store maize after shelling, drying and pre-storage treatment with prescribe pesticides.

2.4.3 Storage Structures

A report by Nsafoah (2012) indicated that three main grain storage methods can be found in Ghana. These include; traditional storage methods mostly at the households (examples are rhombus, elevated platforms, woven basket, cribs, cemented floors, cooking area etc.), Semi-modern storage methods such as enhanced rhombus, well-aerated cribs, and brick bins and contemporary storage systems for commercial purposes (for example; silos, metal or plastic storage bins and warehouses). The crib mostly serves two essential purposes as drying and storage structure for dehusk or undehusk maize (FAO, 2011). A report by Sallam (2010) indicated the successful utilization of crib in many regions of Africa with high humidity. When produce is not treated with protectants, cribs enable storage times of about 3-4 months (Sallam, 2010). On the other hand, silos are usually built using more lasting structures, for example metal silos or wooden granaries with aluminum roof. Permanent silos have been demonstrated to be effective in humid regions of sub-Saharan Africa particularly when grains are dried to recommended moisture content. Silos are mostly used in medium and large-scale farms because farmers at this level normally have the financial wherewithal to construct them (Peterson and Simila, 1990; Sallam, 2010).

2.5 Losses along maize value chain

Harvested maize passes through a chains of processes where certain unique value is added before it reaches the final consumer. Grain value addition aims at ensuring that the preferences of the consumer such as quality, taste, purity and volume are adequately satisfied (Kibe, 2015). A study by Abass *et al.* (2014) showed that about 26-40% of maize is lost due to the processes that occur from production to final consumption. According to AGRA (2013) losses of maize can occur before harvest, during harvest and after harvest. Loss during harvest and post-harvest loss may occasionally be put together as they share certain unique features. These losses lead to reduction in physical weight, nutritional quality and edibility as well as monetary value of maize grains (Zorya *et al.*, 2011; Tefera, 2012). Therefore, to maintain the quantity and quality of maize grain after harvest, it is essential to understand the various operations in the supply chain which contribute to the losses.

2.6 Magnitude of losses in the maize value chain

Currently, losses of maize are estimated to range between 5–40% in sub-Saharan African which is estimated to worth about \$ 4 billion (Zorya *et al.*, 2011). The losses of maize in various storage facilities in developing nations have been reported to range from 15-25% (Merouck, 1987). In Zambia and Zimbabwe, losses of maize dried on raised platforms were estimated to be 3.5% and 4.5%, respectively. Large amount of maize estimated to be about 4% is lost through spillage during threshing and winnowing (Sarkar *et al.*, 2013). Maize post-harvest loss of over 17.44% was recorded in Kenya in 2008. In Ghana, losses are estimated to be between 5-70% (WABS Consult Limited, 2008; Amankwah, 2009), which is about 488,791 Mt (FAOSTAT, 2012). A study by Dzisi *et al.* (2007) indicated that field and post-harvest could range from 5-10% and 15-20%, respectively. Another important operation in the maize value chain is transportation. Lack of proper

transportation system and poor road network lead to losses through spillage. Losses of 2-10% during transportation of rice in Southeast Asia was reported by Alavi *et al.* (2012).

2.7 Post-harvest insects of stored maize and their damage

Globally, it has been reported that insect infestations cause the greatest loss during storage of grains which threatens food and income security of farmers. The microclimate created by the grain storage environment is mostly conducive for stored grain insects to thrive, feed, reproduce and contaminate grains with exuviae and faecal matters (Boxall, 1991; Paliwal, 2000). It is estimated that 20-50% of stored grains are lost as a result of insect infestation in developing countries (Nukenine, 2010). According to Montross *et al.* (1999) insects that attack stored grains can be categorized into two major groups; Internal feeders such as *Sitophilus zeamais*, *Prostephanus truncatus*, *Rhyzopertha dominica* which have the ability to bore into undamaged grain and develop inside kernels, while external feeders including *Tribolium castaneum*, *Plodia interpunctella*, *Cryptolestes ferrugineus* cannot attack whole grains and develop outside kernels. Grain damage caused by insect leads to reduction in nutritional value, reduced seed viability, as well as decrease weight and market values (Abebe *et al.*, 2009). Post-harvest losses of grain caused by stored product insect pests such as *S. zeamais* have been reported as critically important food security challenges in Africa (Markham *et al.*, 1994; Abebe *et al.*, 2009). Even though post-harvest losses of maize caused by stored product insect pests are generally reported to be between 20-30%, infestation by *Prostephanus truncatus* and *Sitophilus zeamais* caused weight loss of about 34-40% and 10-20% respectively, when maize grains were stored on-farm for three months (Boxall, 2002). Nonetheless, in Sub-Saharan Africa, losses are high, and maize weight losses of more than 30% usually occurs after few months of storage (Lale and Ofuya, 2001; Adedire, 2003). The storage losses could be weight loss, nutritional loss and economic loss (Magrath *et al.*, 1996). Losses as a result of post-harvest stored product insect pests attack

may also be influenced by the period of storage, insect species and the populations' density during attack.

2.8 Economic impact of insect pests in maize value chain

Amongst other biological agents which cause losses to grains, insect pests are the most destructive because of the substantial losses they cause to grain mostly during storage (Shiferaw *et al.*, 2011). Research has shown that approximately weight losses of about 5-45% as a result of insect pests' destruction are caused in sub-Saharan Africa and the losses are often influenced by the insect species involved, harvesting operations and post-harvest activities, time of storage, geographical location, cropping season and type and variety of crop (Rees, 2004; Tefera *et al.*, 2011; Anankware *et al.*, 2013). Post-harvest damage due to storage insect pests results in loss of nutrients and market value due to early sale of produce (Magrath *et al.*, 1996). Stain and contamination of grain or grain products by insects, their frass, faeces, exuviae, offensive odour and webbing in products and storage materials can also result in financial loss (Scott, 1991; Sallam, 2010; Shadia, 2011).

2.9 Biology and behaviour of *Sitophilus zeamais*

S. zeamais is about 2.5 to 4 mm long and is uniformly coloured dark brown or reddish brown. It has a projected rostrum or snout for chewing and boring into the grain. The prothorax and elytra are densely pitted with rows of microscopic circular holes. The legs are prominent, and they have well-developed functional wings. The adult female *S. zeamais* lays between 300 to 400 eggs within 4 to 5 weeks. The female inserts the eggs into small cavities in the grain. The cavities are afterwards closed with a waxy secretion, sealing the eggs inside the grain. These eggs hatch into tiny larvae after six days at temperature of 25°C. The larva which feeds inside the grain is a white, thick-bodied grub with no legs

(Kiritani, 1965). The grub goes through four moults and afterwards pupates. Because the growth and development of the larva and pupa occur within the grain, destruction caused is hence usually concealed from visual examination. Pupation takes place at the end of the tunnel in a cell made from frass borings and excreta from the larvae (Abraham, 1991). Pupation occurs within the grain after fourth larval instar. The cycle is accomplished in approximately 35 days at a temperature of about 27 °C and 70% relative humidity (Loeck, 2002; Lorini *et al.*, 2007). It has been reported that the nature of diet and differences in variety of crop could influence the fecundity, fertility and time of development and of *S. zeamais* whereas some factors may affect adults' longevity as well as the number of generations of the insect (Dobie and Kilminster, 1977; Gomez, 1983). For instance, in colder climates, the maize weevil has a longer life cycle compared to that in the warmer climates (Cash, 2011).

2.9.1 Distribution and Economic Importance of *Sitophilus zeamais*

S. zeamais is a devastating pest of enormous economic importance in stored grain globally (Rees, 2004). The pest is very destructive and capable of proliferating to large populations causing a lot of havoc to the grain particularly during storage. The weevil commences its infestation in the field prior to harvesting (Demissie *et al.*, 2008), but most of the destruction is accomplished during grain storage. The activities of *S. zeamais* cause reduction in nutritional value, low percent germination and reduced weight and market values of the maize. The flour produced in the course of insect feeding include also the insect eggs, excreta and exuviae which become a substrate of fungal growth and with time grows mouldy, and therefore becomes unfit for human and animal consumption. According to a study by Bergvinson (2001), maize losses due to *S. zeamais* infestation could range from 15–30% in most developing countries. Moreover, Youdeowei and Service (1986) reported about 15% loss of harvested maize grains annually in Ghana as a result of *S.*

zeamais attack. Some researchers have also estimated that seed losses caused by *S. zeamais* range from 20–90% worldwide when maize is not treated and under heavy infestations (Delima, 1987; Giga *et al.*, 1991). This is most common in tropical humid regions when maize is not treated and stored in traditional structures (Boxall, 2002; Chaubey, 2008). Aside loss of quantity due to direct feeding and proliferation of insects, increased population also increases grain moisture content and temperature which consequently increase respiration leading to further quantitative and qualitative loss of the stored commodity (Odogola, 1994). Additionally, activities of *S. zeamais* pre-dispose the stored maize to opportunistic attack by pathogens including fungi which produce certain mycotoxins such as aflatoxin and fumonisin. *Aspergillus flavus*, which is part of the fungal complex in the stored maize produces the mycotoxin, aflatoxin, a potent health hazard to man and animal. Maize weevil damage may decrease the prospects of maize production of significant number of smallholder farmers in sub Saharan Africa who mostly cultivate grains they have saved from previous harvest. (Boxall, 2002).

2.9.2 Management of *S. zeamais* in stored maize

Environmental manipulations have proven effective in managing stored product insect pests. These environmental manipulations may be accomplished by using varying control mechanisms, such as cultural methods, application of chemicals, physical and biological control mechanisms (Pereira *et al.*, 2009).

2.9.2.1 Chemical control

Traditionally, control of stored product insect pests has been accomplished mainly through the use of persistent pesticides and fumigation. In Ghana, Betallic and Actellic (active ingredient; Pirimiphos-methyl) are the most common synthetic insecticides for the storage of maize. Although synthetic pesticides can control it, majority of communal farmers are resource-poor and have no means and proper skills to acquire and handle them. Moreover,

pesticides are costly, not readily accessible and pose health risks to consumers because they are highly toxic and also since most have some residual effect. Studies in some African countries have shown that inappropriate application of chemicals is claiming a lot of human life and untold adverse impact on environment (FAO, 2003); and other problems associated with their use are loss of efficacy, regulatory restrictions as a result of adverse effect on non-target organisms and eco-toxicity (Lorini *et al.*, 2007; Umoetok *et al.*, 2009). The problems are exacerbated by the development of resistance to these insecticides by the pests, resulting in their resurgence, hence the need to search for effective and safer alternatives. Moreover, the use of conventional chemicals used to control insect activities in stored grain cannot be sustained due to the widespread poverty in the farming communities in Africa (Gadzirayi *et al.*, 2006).

2.9.2.2 Temperature control

Heat treatment to control stored grain insect pests is an ecologically friendly and may serve as better alternative to pesticide application. In the process of heat treatment, temperature is elevated to 50-60⁰C and maintained at these temperatures for 24-36 hours to destroy all forms of insects in the stored grains (Mahroof *et al.*, 2003). In a research by Nakakita *et al.* (1997), when *S. zeamais* were exposed to low temperatures at 10⁰C, eggs were unable to hatch and metamorphosis ceased, whereas at 15⁰C few adults emerged. All the developmental stages of *S. zeamais* can be effectively controlled by the use of dry heat treatment (Mohammed-Dawd and Morallo-Rejesus, 2000). Eggs, developmental forms and adult of *S. zeamais* were destroyed when they were exposed to 60⁰C for 2 h, and 70-80⁰C for 1 h.

2.9.2.3 Controlled atmospheres

Modified atmospheres can offer an efficient and effective, pesticide-free means of controlling insect pests during grain storage. Hermetic storage materials with modified

microclimate suppresses the development of insect population through oxygen deprivation (Murdock *et al.*, 2012). Oxygen is required by insects for energy production and also for supply of water needed for metabolic activities. When it is limiting or insects are deprived of it, feeding, growth and development is suppressed. It can also impair the reproductive behaviour of females. When Guedes *et al.* (1995) exposed *S. zeamais* to 20% carbon dioxide, they were killed in 120 h. In a related research to control *S. zeamais* on corn and wheat in Brazil, Santos *et al.* (1997) reported that, 50% carbon dioxide concentration killed all life stages after been exposed for 10 days. A study by Casella *et al.* (1998) reported an effective control of *S. zeamais* using modified atmosphere and 0.5 or 0.75 g/m³ of phosphine during five days of exposure.

2.9.2.4 Botanical insecticides

Various plant-based compounds produce different physiological and behavioural changes in stored product insect pests. Commonly among these plants are several spices and medicinal plants used conventionally for protecting foodstuffs against insects' attack (Echendu 1991; Ho *et al.*, 1995; Okosun and Adedire 2010). They include: *Dennettia tripetala*, *Piper guineense*, *Monodora myristica* and *Xylopi aethiopica* (Okonkwo and Okoye, 1996); *Ocimum suave* (Bekele *et al.*, 1996); cinnamon, garlic, coriander, *Capsicum annum* and *Murraya paniculata* (Ho *et al.*, 1997); *Tagetes minuta* (Weaver *et al.*, 1997); *Ocimum kenyense* (Bekele *et al.*, 1997); Eucalyptus (Obeng-Ofori *et al.*, 1997); *Allium sativum* (Chiam *et al.*, 1999); *Ocimum kilimandscharicum* (Obeng-Ofori *et al.*, 1998); *Calotropis gigantea* and *Operculina turpethum* (Haque *et al.*, 1999). All of these were reported as having potent control action against *S. zeamais*.

2.9.2.5 Host Plant Resistance

Host-plant resistance, through genetic advancement, continues to play integral role in integrated pest-management approach to reduce damage and loss of quality during storage

of grain. Breeding for resistance to post-harvest insect pests was formerly disregarded, perhaps as a result of the lengthy period from crop establishment to post-harvest screening for resistance and the consequent prohibitive cost of operations. Genetic variability and inheritance of resistance to *S. zeamais* and some stored product insect pests have been documented (Derera *et al.*, 2001; Mwololo *et al.*, 2010). Therefore, introduction of *S. zeamais*-resistant traits into elite maize germplasm is a hopeful proposition. Although development of maize varieties which are resistant to attacks by stored product insect pests have been advanced, the current resistance programme is mostly centered on a narrow source of an unimproved gene bank accession. Furthermore, the current insect-resistant germplasm is not sufficient since the cultivars bred developed normally some desirable traits preferred by farmers. A successful breeding strategy to combat post-harvest insect pests would be hinged on the amount of genetic variations amongst the maize germplasm. Where more variations exist in a given trait, it increases the genetic gain from the selection process. Therefore it is essential to explore a lot of sources of resistance among adapted genotypes within the tropics. A successful integration of resistant cultivars in the control of stored product insect pests, would have a lot of added advantage over other control strategies, especially the use of chemical control with many reported limitations (Gemechu *et al.*, 2011).

Genetic variability for resistance to *S. zeamais* has been well-known in maize cultivars and inbred lines (Giga and Mazarura, 1991; Tadesse *et al.*, 1995). Resistance to maize weevil was reported for the Tanzanian open-pollinated variety Kilima (Derera *et al.*, 1999), for Mexican landraces, notably Sinaloa 35 and Yucatan-7 (Arnason *et al.*, 1993), for temperate inbred lines B37, B68, R805, and T220 (Tipping *et al.*, 1988) and the tropical inbred lines Hi41, Hi34, ICA L29, KU1409, Hi39, and ICA L221 (Kim *et al.*, 1988). Because many breeding programmes anticipate that weevil destruction will be reduced by application of

chemicals, global efforts to breed for weevil-resistant varieties have not been intensified (Dhliwayo and Pixley, 2003).

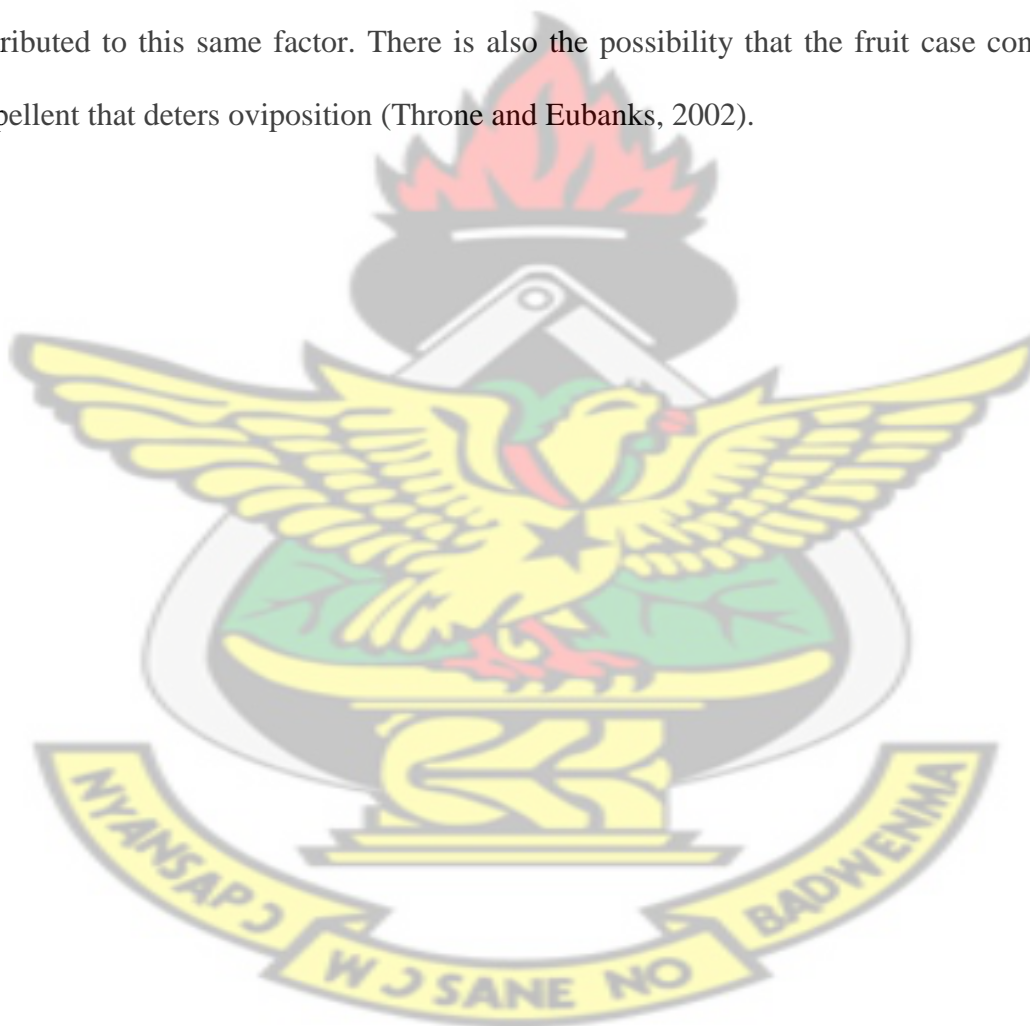
2.9.2.6 Resistant varieties

For stored grains to be resistant to insect pests' infestation, physical and nutritional properties including grain hardness, pericarp surface texture, amylose, lipid and protein contents play key to its accomplishment (Dobie, 1974; Tipping *et al.*, 1988). Also, non-nutritional factors such as phenolic compounds help in grain resistance to stored grain insect attacks (Serratos *et al.*, 1987). A study by Bergvinson (2001) showed strong correlations between insect resistance, kernel hardness and elevated levels of diphenolic acids found in the pericarp of the kernel. It has been documented that the key resistance factor to *S. oryzae* is grain hardness (Bamaiyi *et al.*, 2007). According to Leuschner *et al.* (2000), a larger number of *S. oryzae* progenies were found on pearl millet genotypes with a higher proportion of soft endosperm. A study by Garcia-Lara *et al.* (2004) showed correlation between pericarp roughness and susceptibility.

The role of phenolics to induce resistance in these surface tissues may be both related to structural components and antibiosis factors (Arnason *et al.*, 1993). Some researchers also suggested that variability in maize hybrids was due to antibiosis. Reduced grain damage may be due to antixenosis mechanisms such as smooth pericarp which may discourage weevils from egg laying and feeding as well as stops mandibles from gripping maize kernels. Maize genotypes with increased levels of cell wall cross-linking components in the pericarp are known to be more resistant to the maize weevil. The key cell wall components associated with this resistance are phenolic acids, diferulates and structural proteins, which have been reported to have strong negative correlations with susceptibility indicators and a positively correlate with grains hardness (Garcia-Lara *et al.*, 2004). Siwale *et al.* (2009) found the best five performing maize genotypes with resistance to *S. zeamais*

to have higher protein content compared to the susceptible genotypes. This was also reported by Derera *et al.* (2001); Dhliwayo and Pixley (2003) and Garcia-Lara *et al.* (2004).

Tripsa corn, hybrid maize developed from a perennial teosinte, *Zea diploperennis* L. and eastern gama grass, *Tripsacum dactyloides* L., could have resistance to storage insect pests that can be incorporated into commercial maize hybrids (Throne and Eubanks, 2002). Whole Tripsa corn grains are not attacked by *S. zeamais*. The grains are difficult to grind due to the hardness of the fruit case, and the inability of the weevil to lay eggs is also attributed to this same factor. There is also the possibility that the fruit case contains a repellent that deters oviposition (Throne and Eubanks, 2002).



CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted from August 2015 to July 2016 at the insect laboratory (6°40'33.7"N 1°34'00.9"W) of the Department of Crop and Soil Sciences of the Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, KNUST, Kumasi. The experiments were conducted at ambient temperature of 27°C - 34°C and 66%-85% RH.

3.2 Maize Varieties used for the experiment

Ten maize varieties/ lines were tested for their resistance to *S. zeamais*. The tested materials were: 10C8449, 12C7636, Abelehi, Abontem, Aburohema, Aburohoma, Adikanfo (30Y87), Obaatanpa, Omankwa and Pan 12. Aburohoma was the local cultivar included. (See Appendix 1 for the characteristics of the varieties).

3.3 Multiplication of Seeds

Certified seeds of Obataanpa, Aburohoma, Omankwa, Abeleehi, 10C8449, Abontem, 12C7636, and Aburohoma were obtained from CSIR-Crops Research Institute (CSIR-CRI). Pan 12 was obtained from Wienco Ghana Limited and certified 30Y87 (Adikanfo) seeds were obtained from Pioneer (Dupont). Each variety was planted separately in rows at a planting distance of 75 cm x 40 cm, each separated by at least four rows of mango trees in Ohumpong Mango plantation in Kintampo in the Brong Ahafo Region. Controlled (hand) pollination was done to avoid cross pollination. Each variety was pollinated with pollen from the same variety. The maize was harvested and placed in separate sacks and

labelled. They were dehusked and dried for two weeks before shelling. The grains were put in a deep freeze (-4°C) for two weeks to remove any possible hidden infestation. After two weeks, they were cleaned and sorted out and used for the experiment.

3.3 *Sitophilus zeamais* culture preparation

Mamaba maize grain was first sifted to remove dirt and broken seeds. The grains were put into paper envelopes and placed in a deep freeze (-4°C) for two weeks to kill any hidden infestation present in the grain. The grain was then allowed to thaw in the laboratory for 24 hours to achieve uniform grain temperature and moisture content. Three 1.5l Kilner jars with perforated lids to allow for air circulation, were filled with the grain to about a quarter full level and stored on shelves. Each Kilner jar containing the grains was infested with about 100 unsexed adult weevils. After fourteen days the grains were sifted to remove adult weevils. Newly emerged adults after thirty-six days of infestation were used for the experiment.

3.4 Sexing of *Sitophilus zeamais*

The weevils were sexed by examining the rostrum and abdominal shape of the insects. The rostrum of the male *Sitophilus* is rough, distinctly shorter and wider than that of the female, while the rostrum of the female is smooth, shiny, distinctly longer and narrower than that of the male (Markham *et al.*, 1994).



Male Maize weevil



Female Maize weevil

3.5 Effect of maize varieties on development and emergence of *S. zeamais*

An average of 100 g of maize grain was taken from each variety and put into 500 ml plastic containers and replicated five times. Each container with maize was infested with 10 males and 10 females of 0-3-day old *S. zeamais* adults. Three days after infestation, the *S. zeamais* were sieved out of the maize. Twenty-eight days after infestation the maize samples were sieved after every five days for weevil count. The weevils were removed after the count and this activity was continued until forty-eight days after infestation.

The following data were collected:

- Number of weevils that emerged every day on each variety and the total number of emerged weevils.
- The Median development period.

The median development time was calculated as the time (days) from the middle of the oviposition time to the 50% emergence of F₁ adults (Dobie, 1977).

The index of susceptibility was calculated from the formula below:

$$IS = \frac{\text{LogeX}}{\text{MDP}} \times 100$$

IS = Dobie's index of susceptibility, LogeX = the natural logarithm of the total number of F₁ progeny emerged and MDP = median development period. Dobie's Index of susceptibility was used to categorise the maize lines/varieties. Dobie Index scale: ≤ 4 is classified as resistant; 4.1-6.0 is moderately resistant; 6.1-8.0 is moderately susceptible; 8.1-10 is susceptible and >10 is highly susceptible.

3.6 Cumulative damage on maize varieties and adult emergence

Ten pairs of *S. zeamais* adults, 0-3 days old were introduced into each 500 ml container containing 100 g of each variety of maize grain. The plastic containers were then covered with a lid made of wire mesh to allow enough aeration and stop insects from escaping. The plastic containers were arranged in a completely randomized design with five replications for each treatment on wooden shelves in the insectary. Three set-ups of 30, 60 and 90 day duration were maintained for this experiment. Ninety days was used as the maximum duration of the trials.

3.7 Data collected

On each assessment date (30, 60 and 90 days after infestation), the plastic containers were opened and the content separated into grains, insect and frass using 4.7 and 1.0 mm mesh size. The number of live and dead insects, number of damaged kernels, weight of undamaged and damaged grains and weight of the dust produced were recorded.

Grain weight loss was calculated using the count and weigh method of Gwinner *et al.* (1996).

$$\text{Weight loss (\%)} = \frac{(W_u \times N_d) - (W_d \times N_u)}{(W_u \times (N_d + N_u))} \times 100$$

Where, W_u = Weight of undamaged grain, N_u = Number of undamaged grain, W_d = Weight of damaged grain and N_d = Number of damaged grain.

3.7.1 Adult Mortality (%)

Weevil mortality was assessed at 30, 60 and 90 days after the introduction of the insects. The grain was sifted out and the number of live and dead insects was counted from each jar to determine weevil mortality. The formula below was used to calculate the percentage weevil mortality;

$$\text{Parent weevil mortality} = \frac{\text{Number of dead insects}}{\text{Total number of insects}} \times 100$$

3.7.2 Germination percentage

The viability of the maize varieties were tested at the end of each storage period. One hundred seeds were randomly selected from the lot and planted in steam sterilised soil in germination trays at the plant-house. The number of emerged seedlings were counted and recorded after seven days (standard germination period for maize seeds). The seedlings were evaluated after seven days where they were put into two categories: Germinated seeds and non-germinated seeds. Percentage germination was calculated according to Zibokere (1994) using the formula:

$$\text{Germination (\%)} = \frac{NG}{TG} \times 100$$

Where NG =number of seeds germinated and TG =total number of seeds sown

3.8 Statistical analysis

The number of insects were $\log(x+1)$ transformed, whilst per cent grain damage, dust production and weight loss, was angular transformed (arcsine proportion) in order to stabilize the variance. The transformed data was analysed using one-way analysis of variance (ANOVA). Significant differences between means were separated using Tukey test at $p < 0.05$.



CHAPTER FOUR

4.0 RESULTS

4.1 Weevil emergence

Table 4.1 shows the number of weevils that emerged from the different maize varieties at specific intervals, namely 30 days, 60 days and 90 days. After 30 days more insects emerged on 10C8449 than the rest of the varieties except 12C7636 and Obaatanpa. Variety 10C8449 had the highest number of weevils emerging from it after 60 days of infestation but was significantly similar to 12C7636. The most resistant variety after 60 days of infestation was Abelehi which recorded significantly lowest number of weevil emergence. It was however similar to Adikanfo, Aburohema, Omankwa, Abontem and Aburohoma. After 90 days of weevil infestation, 12C7636 was the variety with the highest number of weevil emergence. It was similar to that of 10C8449. The least number of insect emergence was recorded on Abelehi after 90 days but was it was significantly similar to all varieties except 10C7636, 12C7636, and Obaatanpa.

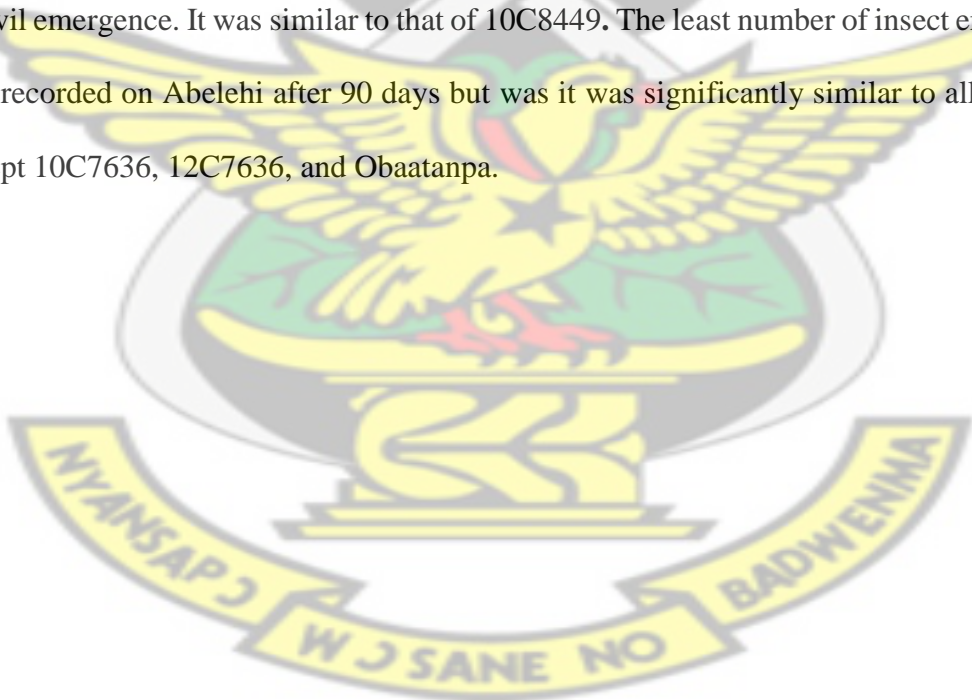


Table 4. 1 Mean Number of *Sitophilus zeamais* emerging at 30, 60, 90 days

Maize Variety/Line	Mean Number of Insects (\pm SE)		
	30 Days	60 Days	90 Days
10C8449	39.2 \pm 0.6a	136.2 \pm 21.2a	241.0 \pm 31.2a
12C7636	35.4 \pm 3.2a	124.2 \pm 7.6a	245.8 \pm 35.5a
Abelehi	20.0 \pm 0.0b	41.2 \pm 4.6cd	82.2 \pm 9.7c
Abontem	20.0 \pm 0.6b	49.2 \pm 5.0cd	124.4 \pm 8.5bc
Aburohema	20.2 \pm 0.8b	61.0 \pm 5.3bcd	103.2 \pm 28.1bc
Aburohoma	20.8 \pm 0.6b	50.6 \pm 2.4cd	98.2 \pm 29.8bc
Adikanfo	20.0 \pm 0.0b	77.4 \pm 11.0bc	165.6 \pm 24.5abc
Obaatanpa	21.4 \pm 0.2a	77.8 \pm 3.9bc	185.4 \pm 20.3ab
Omankwa	20.4 \pm 0.4b	55.6 \pm 4.5bcd	170.8 \pm 29.8abc
Pan 12	20.0 \pm 0.0b	84.8 \pm 8.7b	141.4 \pm 32.6bc
p-values	0.7	0.0	0.0

Means followed by the same letter(s) in columns are not significantly different at $p < 0.05$ of Turkey's test

4.2 Percentage Grain Damage

Table 4.2 shows the percentage of grains damaged for each variety by the maize weevils after 30 days, 60 days and 90 days.

The mean percentage grain damage at 30 days of infestation has 10C8449 as the worst damaged but was significantly similar to 12C7636 and Pan 12. The rest of the varieties suffered similar level of damage at 30 days of storage. After 60 days, the mean percentage grain damage has 12C7636 as the most damaged variety, but was similar to 10C8449 and Obaatanpa. The least damaged variety after 60 days was Abelehi, but was only significantly different from 12C7636, 10C8449, Obaatanpa and Pan 12. The mean performance of the

varieties after 90 days has 12C7636 as the highest variety (% grain damage) but was similar to 10C8449. Abontem recorded the lowest grain damage after 90 days.

Table 4. 2 Mean percentage damaged grains of different maize varieties/lines after 30, 60, 90 days of storage

Maize Variety/Line	Per cent Insect Damaged Grain (\pm SE)		
	30 Days	60 Days	90 Days
10C8449	2.7 \pm 0.2a	40.5 \pm 7.5a	53.1 \pm 4.3ab
12C7636	2.4 \pm 0.0a	42.1 \pm 4.4a	62.2 \pm 4.0a
Abelehi	0.0 \pm 0.0b	5.6 \pm 1.6d	22.8 \pm 9.8de
Abontem	0.0 \pm 0.0b	5.7 \pm 1.8d	19.3 \pm 5.7e
Aburohema	0.4 \pm 0.0b	15.7 \pm 3.8cd	41.5 \pm 3.3abcd
Aburohoma	0.3 \pm 0.0b	12.2 \pm 3.8cd	30.7 \pm 3.3cde
Adikanfo	0.1 \pm 0.0b	19.2 \pm 6.0bcd	40.1 \pm 4.2bcde
Obaatanpa	0.5 \pm 0.1b	31.5 \pm 3.7ab	41.9 \pm 4.4abcd
Omankwa	0.2 \pm 0.1b	10.2 \pm 2.4d	24.8 \pm 3.3cde
Pan 12	1.7 \pm 0.0ab	24.8 \pm 7.1bc	44.6 \pm 2.5abc
p-values	0.0	0.0	0.0

Means followed by the same letter(s) in columns are not significantly different at $p < 0.05$ of Turkey's test

4.3 Weight of Dust Produced

Table 4.3 shows the data on weight of dust produced from the feeding of *S. zeamais* at 30 days, 60 days and 90 days of infestation. With respect to mean weight of dust produced, 10C8449 had the highest dust weight but was significantly similar to 12C7636 at 30 days.

At 60 days, Abelehi produced the least dust weight but was significantly similar to the other varieties except 12C7636 which produced the highest weight of dust. However, at 90 days, Abontem had the least dust produced, similar all other varieties except 12C7636 and 10C8449.

Table 4. 3 Mean weight of dust produced due to *Sitophilus zeamais* activities at 30, 60, 90 days of storage

Maize Variety/Line	Mean weight (g) ±SEM		
	30 Days	60 Days	90 Days
10C8449	0.2±0.0a	0.6±0.1b	2.8±0.4a
12C7636	0.2±0.0a	1.1±0.0a	2.4±0.8ab
Abelehi	0.0±0.0b	0.1±0.0b	0.7±0.5c
Abontem	0.0±0.0b	0.4±0.0b	0.5±0.4c
Aburohema	0.0±0.0b	0.2±0.0b	0.7±0.4c
Aburohoma	0.0±0.0b	0.4±0.1b	1.0±0.3c
Adikanfo	0.0±0.0b	0.3±0.1b	0.9±0.7c
Obaatanpa	0.0±0.0b	0.4±0.2b	1.4±0.5bc
Omankwa	0.0±0.0b	0.2±0.0b	0.9±0.4c
Pan 12	0.0±0.0b	0.2±0.0b	0.8±1.7c
p-values	0.0	0.0	0.0

Means followed by the same letter(s) in columns are not significantly different at $p < 0.05$

of Turkey's test

4.4 Percentage Weight loss (%)

The mean percentage weight losses of the different maize varieties caused by the feeding of the maize weevil are shown in Table 4.4. The mean percentage weight loss after 30 days showed that Obatanpa suffered the highest weight loss and was significantly lower than that of Aburohoma, Aboruhemaa, Abontem and Abelehi but significantly similar to the other varieties. At 60 days, Abelehi had the least percentage weight loss. 12C7636 was the worst variety but was similar to 10C8449. After 90 days of weevil infestation, the varieties tested were not significantly different from each other with respect to grain weight loss.

Table 4. 4 Mean percent weight loss of different maize varieties/lines at 30, 60, 90 days of storage

Maize Variety	Mean weight loss (%) \pm SEM		
	30 Days	60 Days	90 Days
10C8449	0.1 \pm 0.0ab	6.7 \pm 2.4a	12.0 \pm 0.0a
12C7636	0.1 \pm 0.0ab	7.1 \pm 2.6a	10.5 \pm 3.5a
Abelehi	0.0 \pm 0.0b	0.6 \pm 0.1c	5.6 \pm 1.5a
Abontem	0.0 \pm 0.0b	1.6 \pm 0.4bc	5.1 \pm 2.1a
Aburohema	0.0 \pm 0.0b	3.5 \pm 1.6abc	9.5 \pm 6.6a
Aburohoma	0.0 \pm 0.0b	1.5 \pm 0.2bc	4.5 \pm 0.8a
Adikanfo	0.0 \pm 0.0ab	1.7 \pm 0.3bc	5.7 \pm 1.3a
Obaatanpa	0.2 \pm 0.1a	2.2 \pm 0.9bc	8.1 \pm 2.4a
Omankwa	0.0 \pm 0.0ab	2.1 \pm 0.6bc	8.8 \pm 2.7a
Pan 12	0.0 \pm 0.0ab	4.9 \pm 1.4ab	8.1 \pm 1.8a
p-values	0.4	0.0	0.1

Means followed by the same letter(s) in columns are not significantly different at $p < 0.05$

of Turkey's test

4.5 Percentage mortality of *S. zeamais* on the various maize varieties/lines

Table 4.5 provides information on the mean percentage mortality of maize weevils at 30, 60 and 90 days of weevil infestation.

Table 4. 5 Mean percentage *Sitophilus zeamais* mortality on maize varieties/lines after 30, 60 and 90 days of storage

Maize Variety	Mortality (%)		
	30 Days	60 Days	90 Days
10C8449	7.6±3.8a	12.7±1.4b	39.7±6.2a
12C7636	7.6±2.6a	8.3±2.0b	33.1±4.8a
Abelehi	13.6±3.4a	35.3±6.8a	38.0±4.3a
Abontem	14.7±1.9a	13.0±4.6b	57.7±9.3a
Aburohema	9.4±0.8a	18.1±1.5ab	38.7±2.4a
Aburohoma	9.9±0.4a	24.8±2.7ab	43.2±5.5a
Adikanfo	11.4±4.5a	6.3±3.1b	53.0±16.5a
Obaatanpa	11.4±0.6a	12.3±0.9b	36.6±2.9a
Omankwa	14.7±3.1a	21.6±5.8ab	54.6±9.3a
Pan 12	11.6±1.8a	5.2±1.6b	49.0±11.6a
p-values	0.4	0.0	0.3

Means followed by the same letter(s) in columns are not significantly different at $p < 0.05$ of Turkey's test.

The results of the mean percentage mortality at 30 days of infestation show that none of the varieties performed significantly better than the other. At 60 days of infestation, however, Pan 12 recorded the lowest weevil mortality, but only significantly different from Abelehi which recorded the highest weevil mortality. There were no significant differences among the varieties tested at 90 days.

KNUST

4.6 Median development period (MDP)

Figure 4.1 shows the median developmental period of the maize weevils. There were significant differences ($P < 0.05$) among the varieties/lines tested with respect to median development period. The median development period ranged from 27.90 days on 12C7636 to 40.10 days on Abelehi.

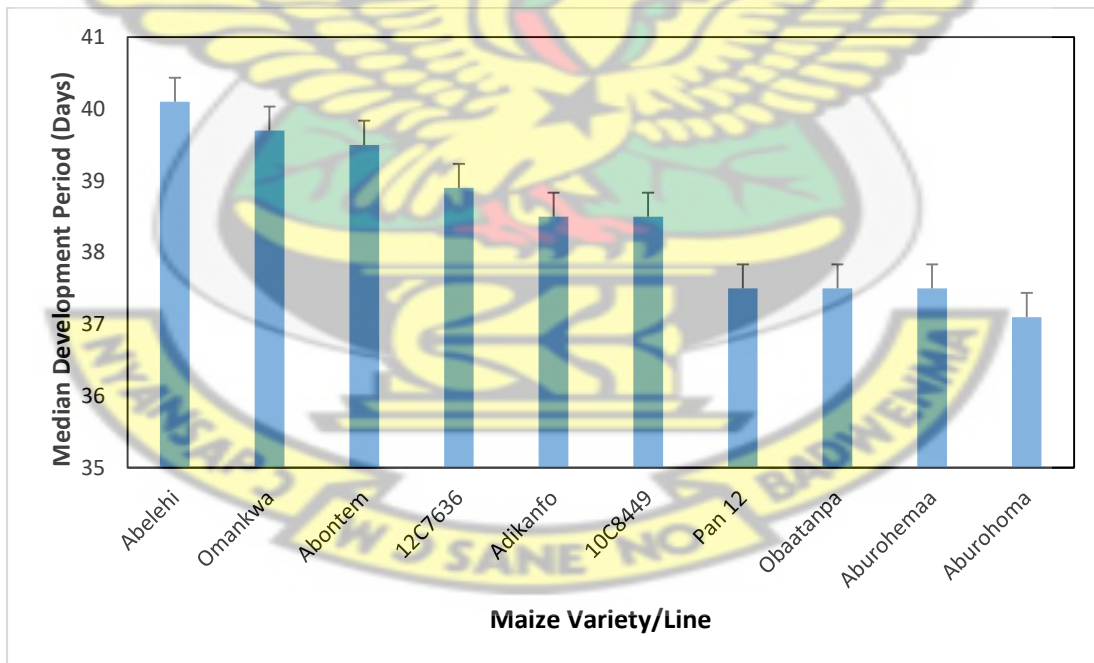


Figure 4. 1: Median development period (MDP) of *Sitophilus zeamais* on different maize varieties/lines

4.7 Index of susceptibility

According to Dobie's index of susceptibility, Abelehi, Abontem, Adikanfo and Omankwa could be classified as resistant, while Obataanpa, Aburohema, Aburohoma and Pan 12 could be classified as moderately resistant. 10C8449 and 12C7636 could also be classified as moderately susceptible (Figure 4.2).

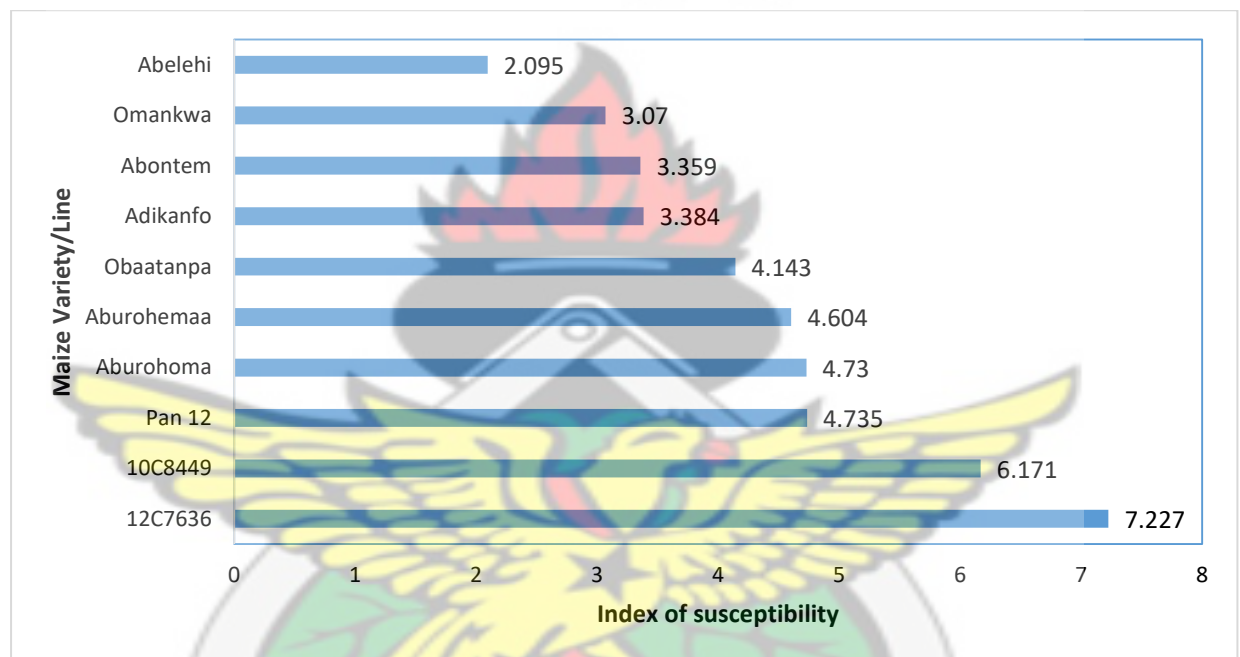


Figure 4. 2 Dobie's index of susceptibility. Susceptibility index of maize varieties: ≤ 4 = resistant, 4.1 – 6.0 = moderately resistant, 6.1 – 8 = moderately susceptible, 8.1-10 = susceptible and > 10 = highly susceptible.

4.8 Germination (%)

Table 4.6 provides information on the germination percentage of the different varieties/lines tested at 30 days, 60 days and 90 days after infestation. At 30 days of infestation, Obataanpa had significantly, the highest percentage germination but was similar to Abelehi, Omankwa, Aburohema, Abontem, Aburohoma. 10C8449 was the variety with the lowest germination but was similar to 12C7636 and Pan12. After 60 days

of storage, Abelehi had the highest germination value which was significantly better than almost all the other varieties tested but was similar to Obataanpa, Omankwa, Aburohoma and Aburohema. 12C7636 had the lowest germination percentage at 60 days but was similar to 10C8449. Abelehi was the variety with the best germination at 90 days, performing significantly better than all the other varieties except Obataanpa, Abontem, Aburohoma and Aburohema. 12C7636 recorded the lowest germination percentage after 90 days but was similar to 10C8449 and Adikanfo.

Table 4.6: Mean percent germination of different maize varieties after 30, 60 and 90 days after storage

Maize Variety	Mean Germination (%) ± SEM		
	30 Days	60 Days	90 Days
10C8449	44.2±4.3c	29.8±3.2c	7.8±1.4d
12C7636	51.0±2.4c	29.2±4.7c	6.8±0.7d
Abelehi	94.6±1.6a	91.6±1.9a	81.8±2.8a
Abontem	94.4±0.4a	81.6±5.2a	72.6±2.3ab
Aburohema	93.0±3.5a	86.6±2.4a	72.8±4.0ab
Aburohoma	90.4±3.7a	80.6±1.8a	73.6±3.2ab
Adikanfo	67.0±4.9b	49.6±2.1b	28.2±6.8cd
Obataanpa	95.4±1.5a	85.6±4.0a	74.4±0.4ab
Omankwa	94.4±0.4a	81.6±5.2a	72.6±2.3ab
Pan 12	52.0±5.6bc	63.0±4.0b	51.2±2.8bc
p-values	0.0	0.0	0.0

Means followed by the same letter(s) in columns are not significantly different at 5% of Tukey's test.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Weevil emergence and multiplication of *S. zeamais* on the maize varieties/lines

After 60 and 90 days of storage, significant differences were recorded among the varieties. Abelehi variety recorded the least weevil emergence and the differences in the number of weevils that emerged showed that variation existed in the maize varieties. The varieties with higher number of weevil emergence showed greater susceptibility to maize weevil destruction hence less resistance. This could have been as a result of lack of resistance mechanisms in or on the grain (Keba and Sori, 2013). The less weevil emergence in these varieties could be due to lack of essential nutrients and unbalanced proportion of nutrients resulting in the death of the larvae (Metcalf and Luckman, 1975). The significant differences in the number of weevils that emerged among the varieties could be as a result of antibiosis effects in resistant varieties resulting in stunted development of weevil progeny and occasionally death of weevils before laying eggs (Derera *et al.*, 2001).

The development of an insect is stimulated by nature of food on which the insect is cultured. Generally, on favourable host, oviposition is high and development is rapid than unfavourable host (Painter, 1951). Therefore, 10C8449 and 12C7636 could be classified as suitable for feeding and development of the weevils.

5.2 Damaged grains, Percentage Weight loss and Percentage Dust produced

After 60 and 90 days of infestation Abontem variety was the least damaged grains and was significantly similar to Abelehi whiles 12C7636 and 10C8449 were the highest damaged. Weight loss and grain damage were considered as indicators of a variety's susceptibility to weevil attack. Low weight loss in Abelehi and Abontem could be as a result of resistance mechanisms in or on the grain which stopped weevil attack. 12C7636 and 10C8449 with the greatest weight loss thus could be said to be more susceptible to weevil attack than

other varieties. Resistance mechanisms may be in the form of restraints which could be morphological or biochemical or a combination of both (Dent, 1991). Biochemical compounds in the form of phenolic amides including dicoumaroyl and defeuoyl could be antibiosis factors to *S. zeamais* (Mihm, 1997). These phenolic compounds have been identified by fluorescence imaging techniques which visibly display the phenolic barrier to insects in the outer tissue (Mihm, 1997). Additionally, research has indicated that antibiotic effects intensify restlessness of insects which decrease feeding and could contribute to less grain destruction and weight loss among resistant varieties (Dent, 1991). Minimal grain destruction could be as a result of antixenosis mechanisms like a smooth pericarp which is capable of preventing weevils from laying eggs and feeding and also prevents mandibles from gripping maize kernels.

Virtually there was no dust produced after 30 days. 12C7636 produced the highest amount of dust after 60 and 90 days followed by 10C8446. The dust produced by weevil activity on Abontem was however the least among all the varieties after 90 days suggesting it was not a preferred variety by the *S. zeamais*. 10C8449 and 12C7636 are the preferred varieties of *S. zeamais*, hence consumed more and led to the most produced dust on those varieties.

5.3 Percentage Mortality

There were significant differences among the varieties for weevil mortality after 60 days but there were no significant difference among the varies after 30 and 90 days of infestation with Abelehi registering the highest parent weevil mortality followed by Aboruhoma, Omankwa and Aburohema while Pan 12 had the least weevil mortality. The highest mortality which was observed in Abelehi may be as a result of physical factors including antibiosis or hardiness due to biochemical compounds which are toxic to the insects which led to subsequent death of the weevils (Siwale *et al.*, 2009). This indicates that this variety has resistant factors in or on its grain which helped to prevent weevil attack. High parent

weevil mortality may also be due to antixenosis, that is, resistance mechanisms which deter colonization by the insect (Dent, 1991). High parent weevil mortality might also be attributed to absence of nutritional factors in the grain which might be important for insect development (Derera *et al.*, 1999). Pan 12 had the lowest parent weevil mortality indicating high susceptibility to weevil attack.

5.4 Germination percentage

Obaatanpa and Abelehi had the highest germination recording a germination value of over 93.2%. 10C8449 and 12C7636 recorded less than 5.2% germination at 90 days of storage. The endosperm of these varieties might have been consumed. The observed differences in germination percentages showed that the varieties differed in susceptibility to maize weevils. 10C8449 and 12C7636 had low germination percentages indicating their susceptibility to *S. zeamais*. This could be attributed to lack of resistance mechanisms within or in the grain to protect it from weevil attack.

5.5 Median Development Period

Abelehi having the longest developmental period followed by Omankwa means that it is the most resistant variety and does not support the fast development of the weevils. With 12C7636 having the shortest developmental period means that it supports faster development of *S. zeamais* than the rest of the varieties/lines.

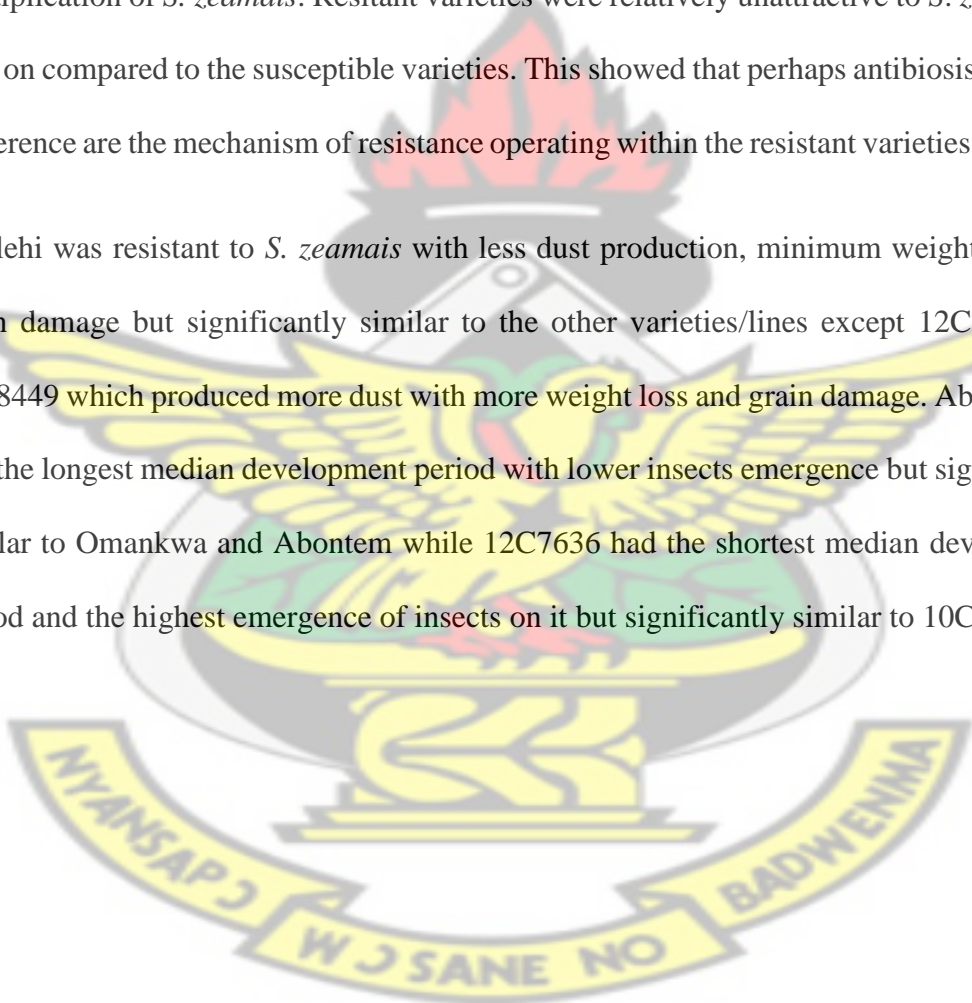
5.6 Susceptibility Index

Results of susceptibility indices of the ten varieties tested in the study showed that Abelehi, Omankwa, Abontem and Adikanfo were all resistant. Obataanpa, Aburohema, Aburohoma and Pan 12, were classified as moderately resistant whiles 10C8449 and 12C7636 were classified as moderately susceptible.

5.7 Indication of Resistance in the Maize Varieties

Considerable differences were recorded amongst the maize varieties tested with reference to the variables investigated. This showed the differences in impact *S. zeamais* has on the different maize varieties. These differences in susceptibility of the maize varieties may be as a result of different varietal capabilities to resist *S. zeamais* attack. The resistant varieties produced small quantity of dust; increased adult mortality, less grain damage, reduced weight loss, high germination percentage, high median development period and reduced multiplication of *S. zeamais*. Resistant varieties were relatively unattractive to *S. zeamais* to feed on compared to the susceptible varieties. This showed that perhaps antibiosis and non-preference are the mechanism of resistance operating within the resistant varieties of maize.

Abelehi was resistant to *S. zeamais* with less dust production, minimum weight loss and grain damage but significantly similar to the other varieties/lines except 12C7636 and 10C8449 which produced more dust with more weight loss and grain damage. Abelehi also had the longest median development period with lower insects emergence but significantly similar to Omankwa and Abontem while 12C7636 had the shortest median development period and the highest emergence of insects on it but significantly similar to 10C8449.



CHAPTER SIX

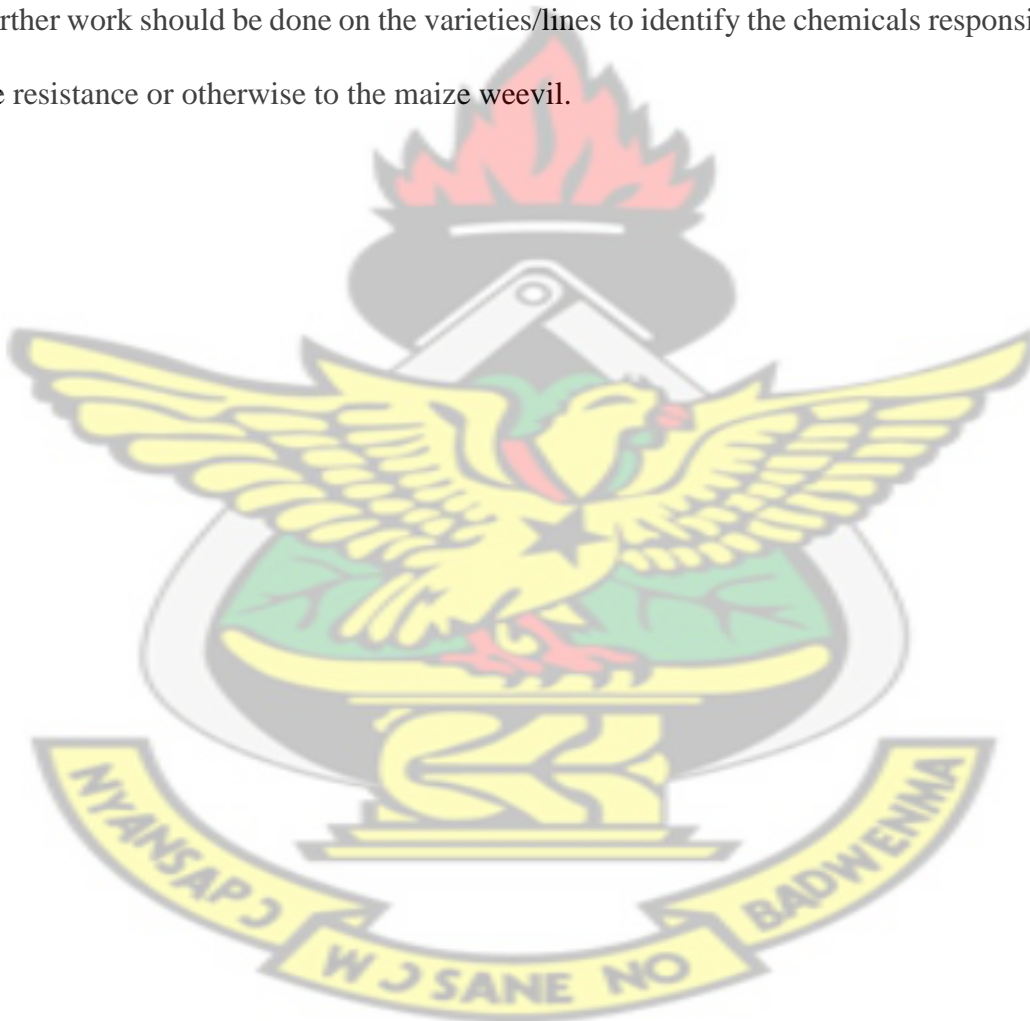
CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

At the end of the research, Abelehi, Omankwa, Abontem and Adikanfo were identified as promising varieties with some level of resistance to the activities of the maize weevil while 10C8449 and 12C7636 were classified as moderately susceptible.

6.2 RECOMMENDATION

Further work should be done on the varieties/lines to identify the chemicals responsible for the resistance or otherwise to the maize weevil.



REFERENCES

- Abass, A. B., Ndunguru, G., Mamiro, P., Alenkhe, B., Mlingi, N. and Bekunda, M. (2014). Post-harvest food losses in a maize-based farming system of semi-arid Savannah area of Tanzania. *Journal of Stored Products Research*, 57: 49 – 57.
- Abebe, F., Tefera, T., Mugo, S., Beyene, Y. and Vidal, S. (2009). Resistance of maize varieties to the maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). *African Journal of Biotechnology*. 8: 5937 - 5943.
- Abraham T. (1991). The biology, significance and control of the maize weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on stored maize. MSc Thesis presented to the School of Graduate Studies of Alemaya University of Agriculture, Ethiopia. 250 pp.
- Addo, S., Birkinshaw, L. and Hodges, R. J. (2002). Ten years after the arrival in Ghana of the large grain borer: Farmers responses and adaptation of IPM strategies. *International Journal of Pest Management* 48(4): 315-325.
- Adedire C. O. (2003). Use of nutmeg *Myristica fragrans* (Houtt.) powder oil for the control of cowpea storage bruchid, *Callosobruchus maculatus* Fabricius. *Journal of Plant Disease Protection*, 109 (2):193 – 199.
- Adejumo, B. A. and Raji, A. O. (2007). Technical appraisal of grain storage systems in the Nigerian Sudan Savanna. *Agricultural Engineering International: CIGR Journal*. Invited Overview No. 11. Vol. IX. September 2007.
- AGRA (2013). African Agriculture Status Report. Pp 23 – 41.
- Akob, C. A. and Ewete, F. K. (2007). The development and field infestation of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) on maize in the western

highlands of Cameroon. *Journal of the Cameroon Academy of Sciences*, 7(2): 77–84.

Alavi, H. R., Htenas, A., Kopicki, R., Shepherd, A. W. and Clarete, R. (2012). Trusting Trade and the Private Sector for Food Security in Southeast Asia; *World Bank Publications*: Washington, DC, USA.

Amankwah, M. A. (2009). Assessment of post-harvest handling practices of maize at Odumase in the Sunyani west district of the Brong Ahafo Region. Doctoral dissertation presented to the Graduate School of Kwame Nkrumah University of Science and Technology, Kumasi. Pp. 1 – 94.

Anankware, J. P. A., Obeng-Ofori, D., Afreh-Nuamah, K., Oluwole, F. A. and Ansah, F.A. (2013). Use of the Triple-Layer Hermetic Bag against the Maize Weevil, *Sitophilus zeamais* (Mots) in Three Varieties of Maize. *Journal of Biology, Agriculture and Healthcare*, 3(12): 133 – 142 www.iiste.org ISSN 2224-3208 (Paper) ISSN 2225-093X (Online).

Aquino, P., Carrión, F., Calvo, R. and Dagoberto, F. (2001). Selected Maize Statistics. In: CIMMYT 1999-2000 World Maize Facts and Trends, Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector (ed. Pingali P.L.), 45-57, CIMMYT. Mexico.

Arnason J. T., Gale, J., Conilh de Beyssac, B., Sen A., Miller, S. S., Philogene, B. J. R., Lambert, J. D. H., Fulcher, R. G., Serratos A. and Mihm, J. (1993). Role of phenolics in resistance of maize grain to the stored grain insects, *Prostephanus truncates* (Horn) and *Sitophilus zeamais* Motsch. *Journal of Stored Products Research*, 28: 119 – 126.

- Arnason, J.T., Baum, B., Gale, J., Lambert, J.D.H., Bergvinson, D.J., Philogene, B.J.R., Serratos, J.A., Mihm, J.A. and Jewell, D.C. (1994). Variation in resistance of Mexican landraces of maize to maize weevil in relation to taxonomic and biochemical parameters. *EU-PHYTICA*, 74: 227-236
- Baloch, U. K. (2010). Wheat: Post-Harvest Operations; Lewis, B., Mejia, D., Eds.; Pakistan Agricultural Research Council: Islamabad, Pakistan, pp. 1–21.
- Bamaiyi L. J., Dike M. C. and Onu I. (2007) Relative susceptibility of some sorghum varieties to the rice weevil *Sitophilus oryzae* L. (Coleoptera: Curculionidae). *Journal of Entomology*, 4: 387 – 392.
- 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(3):169 – 173.
- Bergvinson, D. J. (2001). Storage pest resistance in maize. Pp. 32 – 39. In maize program. Maize Research Highlights 1999 – 2000. CIMMYT. Mexico D.F. Mexico.
- Boutard, A. (2012). Beautiful Corn: America's Original Grain from Seed to Plate. New Society Publishers, Gabriola Island, Canada.
- Boxall, R. A. (2002). “Post- harvest losses to insects: A World Overview.” International Biodeterioration and Biodegradation. *Tropical Product Institute*, 48(1): 137-152, Elsevier Science Limited, London.
- Boxall, R. A. (2002). Damage and loss caused by the larger grain borer, *Prostephanus truncatus*. *Integrated Pest Management Reviews*, 7(2): 105-121

- Brice, J. R. (2002). Small-scale farm storage in the developing world. In: Crop Postharvest Science and Technology, Volume 1 Principles and Practice. Blackwell Publishing Company, U. K., pp 192-199.
- Casella TL-de, C., Faroni, L. R. D., Berbert, P. A., Cecon, P. R. (1998). Carbon dioxide associated with phosphine on the control of maize (*Sitophilus zeamais*). *Revista Brasileira de Engenharia Agricola e Ambiental*, 2(2):179-185.
- Chaubey, M. K. (2008). Fumigant toxicity of essential oils from some common species against pulse beetle *Callosobruchus chinensis* (Coleoptera: Bruchidae). *Journal of Oleo Science*, 57: 171-179.
- Cherry, A. J., Bantino, A., Djegui, D., Lomers, C. (2005). Suppression of the stem borer *Sesamia calamistis* (Lepidoptera: Noctuidae) in maize following seed dressing, topical application and stem injection with African isolates of *Beauveria bassiana*. *International Journal of Pest Management*, 50: 67-73.
- Chiam, W.Y., Huang, Y., Chen, X.S. and Ho, S.H. (1999). Toxic and antifeedant effects of allyl disulfide on *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae). *Journal of Economic Entomology*, 92: 239–245.
- Chu, S. S., Du, S. S. and Liu, Z. L. (2013). Fumigant compounds from the essential oil of Chinese *Blumea balsamifera* leaves against the maize weevils (*Sitophilus zeamais*). *Journal of Chemistry*, 2013: 1-7.
- CIMMYT (2011). Effective Grain Storage for Better Livelihoods of African Farmers Project. Completion Report June 2008 to February 2011. International Maize and Wheat Improvement Center (CIMMYT), Mexico. Pp 65.

- Dasbak, M. A., Echezona, B. C. and Asiegbu, J. E. (2008). Post-harvest bruchid richness and residual activity of pirimaphos methyl on *Callosobruchus maculatus* F. infested pigeon pea (*cajanus cajan* L. Mill sp.) in storage. *African Journal of Biotechnology*, 8(2): 311-315.
- Delima, C. P. F. (1987). Insect pests and post harvest problems in the tropics. *Insect Science Application*, 8:673-676.
- Demissie, G., Swaminathan, R., Ameta O.P., Jain H.K., and Saharan V., (2015). Biochemical basis of resistance in different varieties of maize for their relative susceptibility to *Sito-troga cerealella*(Olivier) (Lepidoptera: Gelechiidae). *Journal of Stored Products and Postharvest Research*, 6: 1-12.
- Dent, D. (1991). Insect pest management. Wallingford (UK): CAB International. Pp 604
- Derera J, Pixley, K.V. and Giga, P.D, (1999). Inheritance of maize weevil resistance in maize hybrids among lines in Southern Africa, Mexico and CIMMIT – Zimbabwe. Pp. 19-23. In: *Maize production technology for the future: Challenges and opportunities. Proceedings of the South Eastern and Southern African Regional maize conference, 21-25 September 1998. Addis Ababa, Ethiopia: EARO (Ethiopia Agricultural Research Organisation) and CIMMYT, Addisa Ababa.*
- Derera J, Pixley, K.V. and Giga, D.P. 2001. Resistance of maize to maize weevil, Antibiosis, *African Crop Science*, 9: 431-440.
- Dhliwayo, T., and Pixley, K. (2003). Divergent selection for resistance to maize weevil to maize weevil in six maize populations. *Crop science*, 43: 2043-2049.

- Dobie P (1974). The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by *Sitophilus zeamais* (MOTSCH). *Journal of Stored Products Research*, 10: 183-197.
- Dobie, P. and Kilminster, A. M. (1978). The susceptibility of triticale to post-harvest infestation by *Sitophilus zeamais* Motschulsky, *Sitophilus oryzae* (L.) and *Sitophilus granarius* (L.). *Journal of Stored Products Research*, 14(2): 87–93.
- Dobie, P., and Kilminster, A. M. (1977). The susceptibility of triticale to post-harvest infestation by *Sitophilus zeamais* Motschulsky, *Sitophilus oryzae* (L.) and *Sitophilus granarius* (L.). *Journal of Stored Product Research*, 14, 87-93.
- Dzisi, K. A., Addo, A. and Bart-Plange, A. (2007). Strategies for the Development of Good Maize Processing, Handling and storage Systems in Ghana. In: Nsiah- Gyabaah, K., Agyepong M., Amoako, C., Nyamaah-Koffour, K., Adu, V., Okyere-Boateng, S., Nsiah, M. K., and Aning, S. K. (eds.). Proceedings of Sunyani Polytechnic Lecture Series II.
- Echendu, T. N. C. (1991). Ginger, cashew and neem as surface protectants of cowpeas against infestation and damage by *Callosobruchus maculatus* (F.). *Tropical Science*, 31: 209 – 211.
- Fening, J. O., Ewusi-Mensah, N. and Safo, E. Y. (2011) Short-Term Effects of Cattle Manure Compost and NPK Application on Maize Grain Yield and Soil Chemical and Physical Properties. *Agricultural Science Research Journal*, 1: 69 - 83.
- Fikremariam, A., Tadele, T., Stephen, M., Yoseph, B. and Stefan, V. (2009). Resistance of maize varieties to the maize weevil *Sitophilus zeamais* (Motsch.) (Coleoptera: Curculionidae). *African Journal of Biotechnology*, 8: 5937-5943.

Food and Agricultural Organization (FAO) (2011). Missing food: The Case of Post-harvest Grain Losses in sub-Saharan Africa. Available at http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10_web.pdf. Accessed in November, 2015

Food and Agricultural Organization Statistical Division (FAOSTAT) (2012). Available at: <http://faostat.fao.org> Accessed in March, 2015.

Food and Agriculture Organisation (FAO) (2007). <http://www.fao.org/inpho/maize> (Internet Information Accessed on 12 July, 2009).

Food and Agriculture Organisation (FAO). (2003). The Status of Food Production in Zimbabwe, Global Early Warning Unit, Ministry of Lands and Agriculture, Harare.

Food and Agriculture Organization (FAO). (2009). Post-Harvest Losses Aggravate Hunger: Media Center-FAO, Rome, Italy. www.fao.org. (Accessed 15 March 2013).

Gadzirayi, C. T., Mutandwa, E. and Chikuvire, T. J. (2006). Effectiveness of maize cob powder in controlling weevils in stored maize grain. *African Studies Quarterly* 8, No.4: (2006).

García-Lara, S., Arnason, J. T., Díaz-Pontones, D., Gonzalez, E. and Bergvinson D.J. (2007). Soluble peroxidase activity in maize endosperm associated with maize weevil resistance. *Crop Science*, 47: 1125 – 1130. doi:10.2135/cropsci2006.10.0687

García-Lara, S., Bergvinson, D. J., Burt, A. J., Ramputh, A. I., Díaz-Pontones, D. M. and Arnason, J. T. (2004). The role of pericarp cell wall components in maize weevil resistance. *Crop Science* 44 (5): 1546 - 1552.

- Gemechu, K., Endashaw, B., Emanu, G., Muhammad, I., Tebkew, D., Bayeh, M., & Kifle, D. (2011). Breeding Food Legumes for Resistance to Storage Insect Pests: Potential and Limitations. *Sustainability*, 3: 1399 – 1415
- GGDP (Ghana Grains Development Project) (1991). Maize Improvement, 1992 Annual Report. Ghana Grains Development Project, Crops Research Institute, Kumasi Ghana. Pg. 146.
- Giga, D. P. and Mazarura, U. W. (1991). Levels of resistance to the weevil, *Sitophilus zeamais* (Motschulski). in exotic local open pollinated and hybrid maize germplasm, *Insect Science and its Applications* 12: 159-169. CAB Extracts, Harare. Zimbabwe.
- Giga, D. P., Mutemererwa S., Moya, G. and Neeley, D. (1991). Assessment and control of losses caused by insect pests in small farmers' stores in Zimbabwe. *Crop Protection*, 10: 287 - 292.
- Giga, D. P., Mutemerewa, S., Moyo, G. and Neeley, D. (1991). Assessment and control of losses caused by insect pests in small farmers' store in Zimbabwe. *Crop Protection*, 10(4):287-292
- Gomez, L. A. (1983). Influence of Nutritional Characteristics of Selected Corn Genotypes on Food Utilization by the Rice Weevil (Coleoptera: Curculionidae). *Journal of Economic Entomology*, 76: 728 - 732
- Gudrups, I., Floyd, S., Kling, J. G., Bosque-Perez, N. A. and Orchard, J. E. (2001). A Comparison of Two Methods of Assessment of Maize Varietal Resistance to the Maize Weevil, *Sitophilus zeamais* (Motschulsky) and the Influence of Kernel Hardness and Size on Susceptibility. *Journal of Stored Products Research* 37(3):

287 - 302. Natural Centre for Biotechnology Information, National Library of Medicine. USA.

Guedes, R. N. C., Lima, J. O. G., Santos, J. P. and Cruz, C. D. (1995). Resistance to DDT and pyrethroids in Brazilian populations of *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae). *Journal of Stored Products Research*, 31: 145 – 150.

Gwinner, J., Harnisch, R. and Muck, O. (1996). Manual on the Prevention of Post-Harvest Grain Losses. Post-harvest Project. *Eschborn Publishers*: 81: 97 – 270.

Ho, S. H., Ma, Y., Goh, P. M., and Sim, K. Y. (1995). Star anise, *Illicium verum* Hook F., as a potential grain protectant against *Tribolium castaneum* (Herbst) and *Sitophilus zeamais* (Motsch.). *Postharvest Biology and Technology*, 6:341–347.

Ho, S. H., Ma, Y. and Huang, Y. (1997). Anethole, a potential insecticide from *Illicium verum* Hook F. against two stored product insects. *Internal Pest Control*. 39 (2): 50–51.

Hodges, R. J. (2012). Post-harvest Weight losses of Cereal Grains in Sub-Saharan Africa. African Post-harvest Losses Information System (APHLIS). <http://www.aphlis.net>. Accessed in June 2016.

IITA (2003). Research Guide 30, *IITA Training Program* PMB 5320, Ibadan, Nigeria 43.

IITA (International Institute of Tropical Agriculture) (2007). <http://www.iita.org/maize> (Internet information accessed on 10th September, 2015)

Jones, M. W., Boyd, E. C., and Redinbaugh, M. G. (2011). Responses of maize (*Zea mays* L.) near isogenic lines carrying Wsm1, Wsm2, and Wsm3 to three viruses in the Potyviridae. *Theoretical and Applied Genetics*, 123:729-740.

- Keba, T. and Sori, W. (2013). Differential resistance of maize varieties to maize weevil (*Sitophilus zeamais* Motschulsky) (Coleoptera: Curculionidae) under laboratory conditions. *Journal of Entomology*, 10(1): 1-12.
- Kibe, N. E. (2015). Occurrence of Mycotoxigenic Fungi in Maize from Food commodity Markets in Kenya. Master's dissertation submitted for the degree of Master of Science in Nutrition and Rural Development, Faculty of Bioscience Engineering, Gent University. Pp. 1 – 52.
- Kim, S. K., Brewbaker, J. L. and Hallauer, A. R. (1988) Insect and disease resistance from tropical maize for use in temperate zone hybrids, pp. 194–226. In Proceedings of the 43rd Annual Corn/Sorghum Research Conference, American Seed Trade Association, Washington DC, USA
- Kiritani, K. (1965). Biological Studies on *Sitophilus* complex (Coleoptera: Curculionidae) in Japan. *Journal of Stored Products Research*, 1(2): 169-176
- Kumar, D. and Jhariya, N. A. (2013). Nutritional, medicinal and economical importance of corn: A mini review. *Research Journal of Pharmaceutical Sciences*, 2: 7–8.
- Kumar, D. and Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. *Foods*, 6 (1): 1-8
- Lale, N. E. S. and Ofuya, T. I. (2001). Overview of pest problems and control in the tropical storage environment. In: Ofuya, T.I. and Lale, N.E.S. editors. *Pest of Stored Cereals and Pulses in Nigeria — Biology, Ecology and Control*. Dave Collins Publications. pp. 1–23.

- Leuschner, K. Monyo, E. S., Chinhema, E., Tembo, E. and Martin, D. (2000). Pearl Millet Grain Size and Hardness in relation to resistance to *Sitophilus Oryzae* (L) (Coleoptera: Curculionidae). *African Crop Science Journal*, 8: Page
- Loeck, A. (2002). Principais pragas que atacam produtos armazenados. In: Pragas de produtos armazenados. *Pelotas: EGUFPEL*, 4: 35-59.
- Lorini, I. Collins, P. J., Daghli, G.J., Nayak, M.K. and Pavic, H. (2007). Detection and characterisation of strong resistance to phosphine in Brazilian *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae). *Pest Management Science*, 63: 358-364.
- Magrath, P. A., Compton, J. A. F., Motte, F. F. and Awuku, M. (1996). Coping with a new storage insect pest: The impact of the larger grain borer in eastern Ghana. Chatham: Natural Resources Institute, UK.
- Mahroof, R., Subramanyam, B. and Eustace, D. (2003). Temperature and relative humidity profiles during heat treatment of mills and its efficacy against *Tribolium castaneum* (Herbst) life stages. *Journal of Stored Products Research*, 39: 555-569.
- Markham, R. H., Borgemeister, C., and Meikle, W. G. (1994). Can biological control resolve the larger grain borer crisis? In Proceedings of the 6th International Conference on Stored-product Protection (Vol. 17, p. 6-23).
- Meikle, W. G., Markham, R.H., Nansen, C., Holst, N., Degbey, P., Azoma, K. and Korie, S. (2002). Pest Management in Traditional Maize Stores in West Africa: A Farmer's Perspective. *Journal of Economic Entomology*, 95(5):1079-1088.
- Meronuck, R. A. (1987). "The significance of fungi in cereal grains." *Plant disease* 71(3): 287- 288.

Metcalf, R. L. and Luckman, W. H. (1975). Introduction to Insect pest management. John Wiley and Sons, Canada (3rd edition, pp. 56 – 61)

Mihm, J. A. (1997). Insect Resistant maize, Recent Advances and Utilization: Proceedings of an International Symposium held at the International Maize and Wheat Improvement Centre (Commit) 27 November – 3 December 1994, DF: CIMMYT, Mexico

Millennium Development Authority, MiDA (2012). Available at <http://www.mcc.gov/documents/investmentopps/bomghana-englishgrain.pdf>.

Mlynekova, Z. and Ceresnakova, Z. (2013). Degradation of starch and crude protein indent and dent × flint maize hybrids in different stages of maturity. *Slovakia Journal of Animal Science*, 46: 61-67

Mohammed-Dawd, E. and Morallo-Rejesus, B. (2000). Heat treatment for the control of corn weevil, *Sitophilus zeamais* Motsch. in stored corn. *Shashpa*, 7(1):57-62.

Montross, J. E., Montross, M. D. and Bakker-Arkema, F. W. (1999). Grain storage: In Bakker-Arkema, F. W., Amirante, D. P., Ruiz-Altisent, M., Studman, C. J. eds. CIGR Hand Book of Agricultural Engineering. Volume IV. Agro-Processing Engineering. St. Joseph, Michigan, USA. pp 46-59.

Montross, J. E., Montross, M. D. and Bakker-Arkema, F. W. (1999). Part 1.4 Grain storage 46-59. F. W. Bakker-Arkema, D. P. Amirante, M. Ruiz-Altisent, and C. J. Studman, eds. CIGR Hand Book of Agricultural Engineering. Volume IV. Agro-Processing Engineering. St. Joseph, Michigan, USA.

- Murdock, L. L., Margam, V., Baoua, I., Balfe, S. and Shade, R. E. (2012). Death by desiccation: Effects of hermetic storage on cowpea bruchids. *Journal of Stored Products Research*, 49, 166–170.
- Muzemu, S., Chitamba, J. and Goto, S. (2013). Screening of stored maize (*Zea mays* L.) Varieties grain for tolerance against maize weevil, *Sitophilus zeamais* (Motsch.). *International Journal of Plant Research*, 3: 17-22.
- Mwololo, J. K., Mugo, S., Okori, P., Tefera, T. and Munyiri, S. W. (2010). Genetic diversity for resistance to larger grain borer in maize hybrids and open pollinated varieties in Kenya. In Second RUFORUM Biennial Meeting (pp. 535-539). Kampala, Uganda.
- Nakakita, H., Ikenaga, H., Shaaya, E. and Bell, C. (1997). Action of low temperature on physiology of *Sitophilus zeamais* Motschulsky and *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) in rice storage. Ecologically safe alternatives for the control of stored-product insects. Papers from the XIII International Plant Protection Congress, July 1995, The Hague, *The Netherlands Journal of Stored Products Research*, 33(1):31-38.
- Ngamo, L. S. T., Ngassoum, M. B., Mapongmetsem, P. M., Maliasse, F., Hauburg, E., Lognay, G. and Hance, T. (2007). Current postharvest practices to avoid insect attacks on stored grains in northern Cameroon. *Agricultural Journal*, 2(2): 242-247
- Nsafoah, A. (2012). Centralized Grain Storage in Ghana: A Feasibility Analysis. Master's Thesis submitted to Oklahoma State University for the Degree of Master of Science. Oklahoma State University, 201: 1– 70.
- Nukenine, E. N. (2010). Stored product protection in Africa: Past, present and future. *Julius-Kühn-Archive*, 425: 26-4.

- Nuss, E. T., and Tanumihardjo, S. A. (2010). Maize: a paramount staple crop in the context of global nutrition. *Comprehensives Review in Food Science and Food Safety*, 5(4): 415-436.
- Obeng-Antwi, K., Allen, O., Manfred, B. E. and Priscilla, R. (2013). Maize improvement in Ghana - the contribution of CSIR. *International Journal of AgriScience*, 35: 49-57.
- Obeng-Ofori, D., Reichmuth, C. H. Bekele, J and Hassanali, A. (1998). Toxicity and protectant potential of camphor, a major component of essential oil of *Ocimum kilimandscharicum*, against four stored product beetles. *International Journal of Pest Management*, 44(4):203-209.
- Obeng-Ofori, D., Reichmuth, C. H., Bekele, J. and Hassanali, A. (1997). Biological activity of cineole, a major component of essential oil of *Ocimum kenyense* (Ayobangira) against stored product beetles. *Journal of Applied Entomology*, 121(4):237-243.
- Odogola, W. R. (1994). Postharvest management and storage of food legumes. Technical Systems for Agriculture. AGROTEC UNDP/OPS, Harare, Zimbabwe.
- OGRT (Office of Gene Technology Regulator). (2008), the biology of *Zea may* L. ssp mays (Maize or Corn). Version 1 September 2008. Australian government, department of health and ageing. Office of Gene Technology Regulator. [<http://www.ogtr.gov.au>], (Accessed September 2012).
- Ojo, J. A., and Omoloye, A. A. (2012). Rearing the maize weevil, *Sitophilus zeamais*, on an artificial maize–cassava diet. *Journal of Insect Science* 12, 1-9.

Okonkwo, E. U. and Okoye, W. I. (1996). The efficacy of four seed powders and the essential oils as protectants of cowpea and maize grains against infestation by *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) and *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae) in Nigeria. *International Journal of Pest Management*, 42(3):143-146.

Okosun O. O. and Adedire, C. O. (2010). Potency to cowpea seed, *Callosobruchus macula* (Fabricius) (Coleoptera: Bruchidae), of African nutmeg seed (*Monodora myristica*) extracted with different solvents. *Nigeria Journal of Entomology*, 27: 89-95

Onumah, G. and Coulter, J. (2001). "The maize commodity systems in Ghana: A Review", discussion Paper, 22. Natural Resource Institute, Chatham Maritime, Kent, United Kingdom.

Opit, G. P., Campbell, J., Arthur, F., Armstrong, P., Osekre, E., Wahburn, S., Baban, O., McNeill, S., Mbata, G., Ayobami, I. and Reddy, P. V. (2014). Assessment of maize post-harvest losses in the Middle Belt of Ghana. F. H. Arthur, R. Kengkanpanich, W. Chayaprasert, and D. Suthisut. (Eds.). *In: Proceedings of the 11th International Working Conference on Stored Product Protection*. Nov 24–28, Chiang Mai, Thailand.

Paes, J. L., Faroni, L. R. D.'A., Dhingra, O. D., Cecon, P. R. and Silva, T. A. (2012). Insecticidal fumigant action of mustard essential oil against *Sitophilus zeamais* in maize grains. *Crop Protection*, 34: 56–58.

Painter, R. H. (1951). *Insect resistance in crop plants*. MacMillan, New York, 520 pp.

Paliwal, R. L. G., Granados, H. R., Lafitte, A. D. and Marathee, J. P. (2000). *Tropical maize: improvement and production*. FAO Plant Production and Protection Series, 28. FAO, Rome, Italy.

Paliwal, R. L., Granados, G., Lafitte, H. R., Violic, A. D. and Marathée, J. P. (2000). Tropical maize: improvement and production. FAO Plant Production and Protection Series. Volume 28. FAO, Rome, Italy.

Pereira, C. J., Pereira, E. J. G., Cordeiro, E. M. G., Della Lucia, T. M. C., Tótola, M. R. and Guedes, R. N. C. (2009). Organophosphate resistance in the maize weevil *Sitophilus zeamais*: magnitude, costs and behavior. *Crop Protection*, 28: 168-173.

Peterson, M. and Simila, K. (1990). Research proposals for a grain storage project. International Rural Development Centre. Swedish University of Agricultural Sciences. 157: pp. 33.

Pingali L., and L. Pandey (2001). World Maize Facts and Trends. Meeting World Maize Needs: Technological Opportunities and Priorities for the Public Sector. Mexico, D.F: CIMMYT. Pp. 25.

Prince Maxwell Etwire, Tahirou Abdoulaye, Kwadwo Obeng-Antwi, Samuel S. J Buah, Roger A.L. Kanton, Henry Asumadu, Mashark S. Abdulai, Alidu Haruna and John C. Etwire. (2013). On-farm evaluation of maize varieties in the transitional and savannah zones of Ghana: *Journal of Development and Agricultural Economics*, 5 (6): 255-262.

Rees, D. P. (2004). Insects of Stored Products. CSIRO Publishing, Collingwood, Australia. Pp.192

Rees, D. P., 2004. Insects of Stored Products. CSIRO Publishing, Collingwood, Australia.

Renkow, M., Hallstrom, D. G. and Karanja, D. D., 2004. Rural infrastructure, transactions costs and market participation in Kenya. *Journal of Development Economics*, 73 (3): 349–367.

- Sabbour, M. M. (2012). Entomotoxicity assay of two nanoparticle materials 1-(Al₂O₃ and TiO₂) Against *Sitophilus oryzae* under laboratory and store conditions in Egypt. *Journal of Novel Applied Sciences*, 1: 103-108.
- Sallam, M. N. (2010). INSECT DAMAGE: Damage on Post-harvest. Food and Agriculture Organization of the United Nations. Post-harvest Compendium. www.icipe.org. Accessed in June, 2015.
- Santos, J. P., Santos, D. S., Goncalves, R. A. and Tom, T. P. H. F. (1997). CO₂-controlled atmosphere on the control of stored grain pests. Centro Nacional de Pesquisa de Milho e Sorgo (CNPMS), Sete Lagoas, Brazil. 6 pp.
- SARI. (1996). Savanna Agricultural Research Institute. Annual Report, 1996. *Journal of Environmental Protection*, 6 (10) page
- Sarkar, D., Datta, V. and Chattopadhyay, K. S. (2013). Assessment of pre and post-harvest losses in rice and wheat in West Bengal; Agro-Economic Research Centre, Visva-Bharati, Santiniketan; Santiniketan, India.
- Sarkar, D., Datta, V. and Chattopadhyay, K. S. (2013). Assessment of Pre and Postharvest Losses in Rice and Wheat in West Bengal. Agro-Economic Research Centre, Visva-Bharati, Santiniketan; Santiniketan, India.
- Scott, H. G. (1991). Nutrition Changes Caused by Pests in Food. *In: Ecology and Management of Food-industry Pests*, Gorham, J. R. (Ed.), AOAC, Virginia, USA, pp. 463 – 467.
- Serratos A., Arnason J. T., Nozzolillo C., Lambert J. D. H., Philogene B. J. R., Fulcher G., Davidson K., Peacock L., Atkinson J. and Morand P. (1987) Factors contributing

- to resistance of exotic maize populations to the maize weevil, *Sitophilus zeamais*. *Journal of Chemical Ecology*, 13: 751 – 761
- Shadia, E. A. E. (2011). Control strategies of stored product pest. *Journal of Entomology*, 8 (2): 101 – 122.
- Shiferaw, B., Prasanna B., Hellin J. and Banziger M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*, 3: 307 – 327.
- Siwale, J., Mbata, K., Mrobert, J. and Lungu, D. (2009). Comparative resistance of improved maize Genotypes and landraces to maize weevil *Sitophilus zeamais* (Motchulski). *African Crop Science Journal*, 17 (1): 1-116. African Crop Science Society, Uganda.
- Smale, M., Byerlee, D. and Jayne, T. (2011). Maize Revolutions in Sub-Saharan Africa Policy Research Working Paper WPS5659. pp; 3-9
- SRID-MoFA (2009). Agriculture in Ghana: Facts and figures, 2010.
- SRID-MoFA (2017). Agriculture in Ghana: Facts and figures, 2016.
- Suleiman, R., Williams, D., Nissen, A., Bern, C. J., & Rosentrater, K. A. (2015). Is flint corn naturally resistant to *Sitophilus zeamais* infestation? *Journal of Stored Products Research*, 60: 19-24
- Suleiman, R., Rosentrater, K. and Bern, C. (2013). Effects of Deterioration Parameters on Storage of Maize: A Review. *Journal of Natural Sciences Research*, 3(9): 147 – 165.
- Tadesse, A., (1995). Insects and other arthropods recorded from stored maize in Western Ethiopia. *African Crop Science Journal*, 4: 339-343.

- Tefera, T., Kanampiu, F., De Groote, H., Hellin, J., Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, P.M., Shiferaw, B. and Banziger, M. (2010). The metal silo: An effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. *Crop Protection*, 30: 240–245.
- Tefera, T., Mugo, S., and Likhayo, P. (2011). Effects of insect population density and storage time on grain damage and weight loss in maize due to the maize weevil *Sitophilus zeamais* and the larger grain borer *Prostephanus truncatus*. *African Journal of Agricultural Research*, 6:2247–2254.
- Tefera, T. (2012). Post-harvest losses in African maize in the face of increasing food shortage. *Food Security*, 4: 267-277.
- Throne, J. E. and Eubanks, M. W. (2002). Resistance of *Tripsacorn* to *Sitophilus zeamais* and *Oryzaephilus surinamensis*. *Journal of Stored Products Research*, 38(3): 239-245.
- Tipping, P. W., Rodriguez, J. G., Poneleit, C. G. and Legg, D. E. (1988) Resistance of dent corn inbreds to oviposition by the maize weevil. *Journal of the Kansas Entomological Society*, 61: 131 – 134.
- Ukeh, D. A., Woodcock, C. M., Pickett, J. A. and Birkett, M. A. (2012). Identification of host kairomones from maize, *Zea mays*, for the maize weevil, *Sitophilus zeamais*. *Journal of Chemical Ecology* 38(11): 1402-1409.
- Umoetok, S. B. A., Osuagwu, A. N., Udo, I. A., Idiongette, M. I. and Ukeh, D. A. (2009). Effects of *Azadirachta indica* products on the management of *Oothecha mutabilis* on *Telfairia occidentalis* in Calabar, Southeast Nigeria. *Crop Protection*, 28: 583-587. <http://dx.doi.org/10.1016/j.cropro.2009.03.002>.

USAID-EAT project (2012). The market of maize, rice, soy and warehousing in Northern Ghana. Pp 10.

USDS (United States Department of State) (2013). Post-harvest Loss Challenges. Discussion paper. Office of Agriculture, Biotechnology, and Textile Trade Affairs; Bureau of Economic of Economic and Business Affairs. Technical Paper No. 40. Paper 1– 42.

WABS Consulting Limited (2008). Maize Value Chain Study in Ghana: Enhancing Efficiency and Competitiveness, December 2008.

Weaver, D. K., Zettler, J. L., Wells, C. D., Baker, J. E., Bertsch, W. and Throne, J. E. (1997). Toxicity of fractionated and degraded Mexican marigold floral extract to adult *Sitophilus zeamais* (Coleoptera: Curculionidae). *Journal of Economic Entomology*, 90(6):1678-1683.

Weinberg, Z. G., Yan, Y., Chen, Y., Finkelman, S., Ashbell, G. and Navarro, S. (2008). The effect of moisture levels on high-moisture maize (*Zea mays* L.) under hermetic storage conditions-in vitro studies. *Journal of Stored Products Research*, 44: 136 – 144.

Youdeowei, A. and Service, M. W. (1986). Pest and Vector Management in the Tropics. ELBS and Longman Group Ltd. pp39

Zibokere, D. S. (1994). Insecticidal potency of red pepper (*Capsicum annum*) on pulse beetle (*Callosobruchus maculatus*) infesting cowpea (*Vigna unguiculata*) seeds during storage. *Indian J. Agric. Sci.* 64:727-728.

Zorya, S., Morgan, N. and Rios, L. D. (2011). Missing food: The Case of Postharvest Grain Losses in Sub-Saharan Africa. The International Bank for Reconstruction and

Development / The World Bank. Report No. 60371-AFR. The World Bank,
Washington, DC.

KNUST



APPENDICES

KNUST

APPENDIX 1: Characteristics of the maize varieties screened.

VARIETY	DAYS TO MATURITY	POTENTIAL YIELD (tons/ha)	TYPE OF MAIZE	GRAIN COLOUR	SELECTED CHARACTERISTICS
10C8449	85-90	6.0	OPV	White	Early maturing, High yielding
12C7636	80-95	6.0	OPV	White	Early maturing, High yielding
Abelehi	105-110	4.6	OPV	White	Streak resistant; White grain colour, Early maturing, Yield
Abontem	75-80	5.0	OPV	Yellow	Drought tolerant, <i>Striga</i> tolerant, QPM
Aburohema	90	5.0	OPV	White	Drought tolerant, <i>Striga</i> tolerant, QPM
Aburohoma	120-150	3.0	Land race	White	Local cultivar
Adikanfo (30Y87)	95-100	10.0	Hybrid	Yellow	Early maturing; Drought tolerant, Tolerant to several diseases including rust, maize streak virus, downy mildew and late blight.
Obaatanpa	105-110	4.6	OPV	White	High yielding, QPM, Lodging resistant, tolerance to pest and diseases (stem borer, blight, rust, streak)
Omankwa	90	4.7	OPV	White	Drought tolerant, <i>Striga</i> tolerant, QPM
Pan 12	115-120	8.0	Hybrid	Yellow	High yielding, Lodging resistant.

APPENDIX 2a: Completely Randomized Analysis of Variance for insect numbers at 30 DAI.

Source	DF	SS	MS	F	P
Trt.	9	0.37316	0.04146	0.61	0.7777
Error	40	2.70066	0.06752		
Total	49	3.07381			

Grand Mean 4.6625 CV 5.57

2b: Completely Randomized Analysis of Variance for insect numbers at 60 DAI.

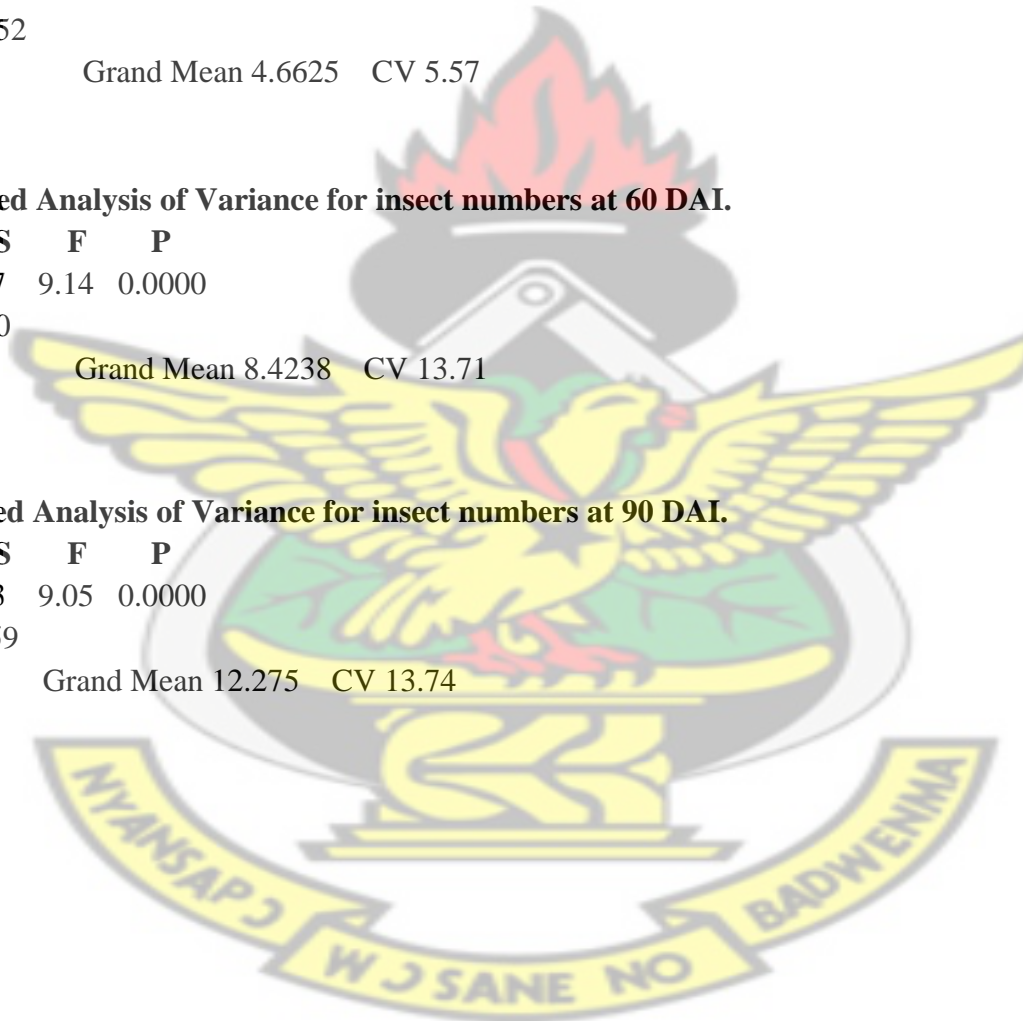
Source	DF	SS	MS	F	P
Trt.	9	109.698	12.1887	9.14	0.0000
Error	40	53.321	1.3330		
Total	49	163.019			

Grand Mean 8.4238 CV 13.71

2c: Completely Randomized Analysis of Variance for insect numbers at 90 DAI.

Source	DF	SS	MS	F	P
Trt	9	231.761	25.7513	9.05	0.0000
Error	40	113.837	2.8459		
Total	49	345.598			

Grand Mean 12.275 CV 13.74



APPENDIX 3a: Completely Randomized Analysis of Variance for Percentage Insect Damaged Grains at 30 DAI.

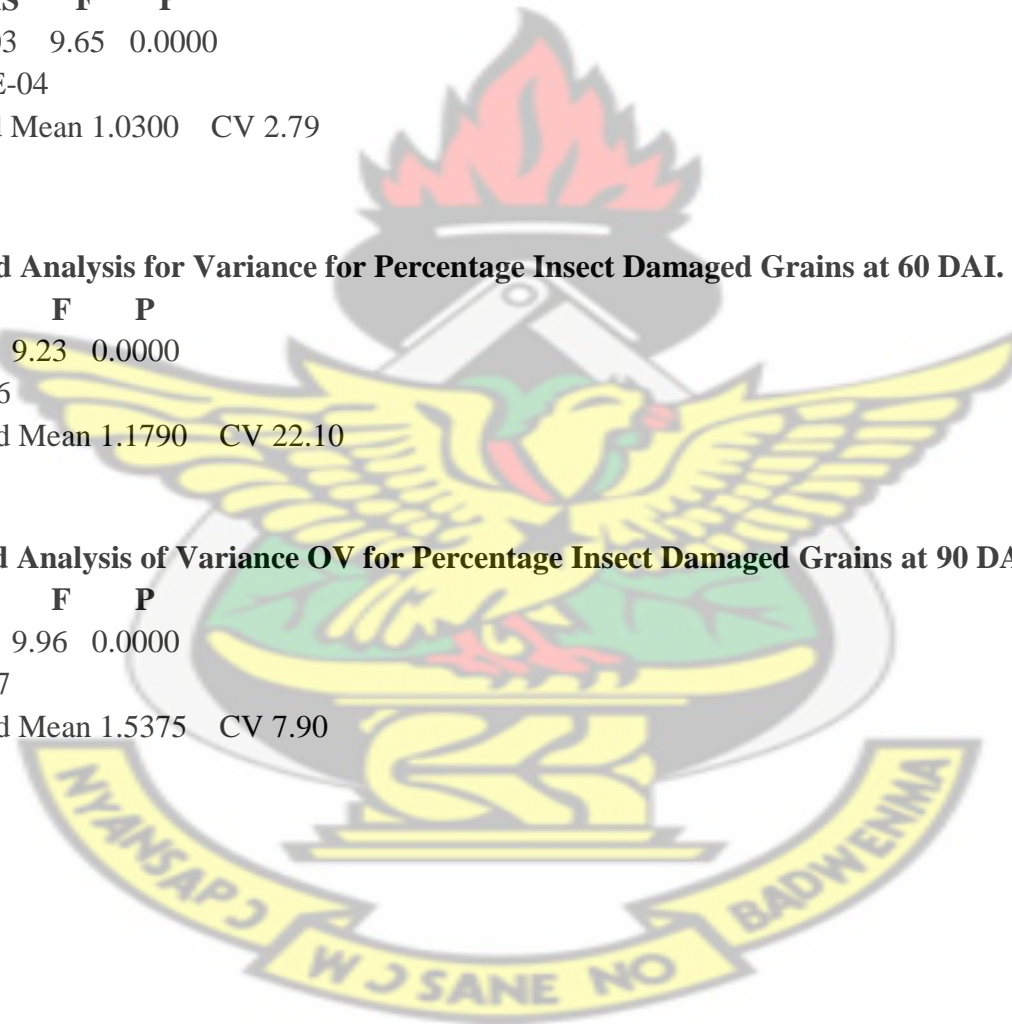
Source	DF	SS	MS	F	P
trt	9	0.07176	7.974E-03	9.65	0.0000
Error	40	0.03304	8.259E-04		
Total	49	0.10480		Grand Mean 1.0300	CV 2.79

3b: Completely Randomized Analysis for Variance for Percentage Insect Damaged Grains at 60 DAI.

Source	DF	SS	MS	F	P
trt	9	5.63603	0.62623	9.23	0.0000
Error	40	2.71438	0.06786		
Total	49	8.35042		Grand Mean 1.1790	CV 22.10

3c: Completely Randomized Analysis of Variance OV for Percentage Insect Damaged Grains at 90 DAI.

Source	DF	SS	MS	F	P
trt	9	1.32425	0.14714	9.96	0.0000
Error	40	0.59075	0.01477		
Total	49	1.91501		Grand Mean 1.5375	CV 7.90



KNUST

APPENDIX 4a: Completely Randomized Analysis of Variance for weight of grain dust produced at 30 DAI.

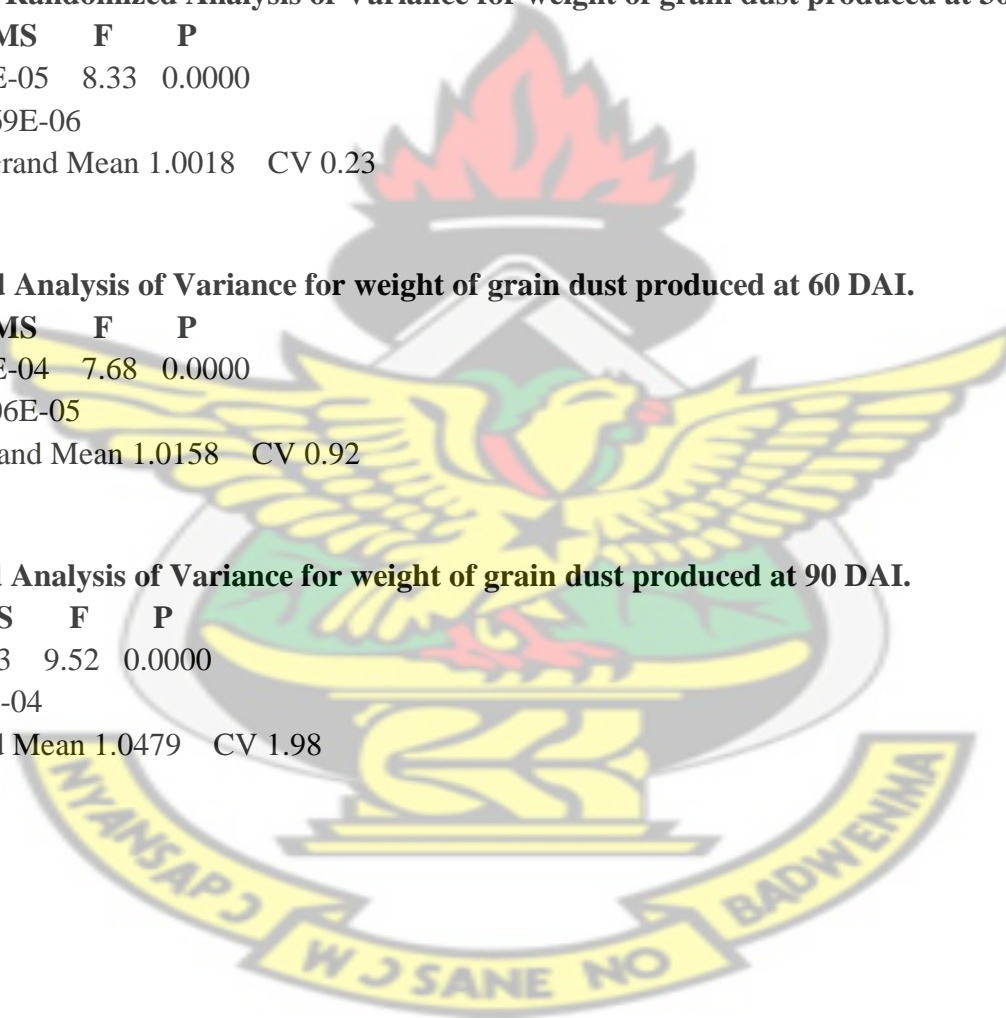
Source	DF	SS	MS	F	P
trt	9	3.876E-04	4.307E-05	8.33	0.0000
Error	40	2.067E-04	5.169E-06		
Total	49	5.943E-04		Grand Mean 1.0018	CV 0.23

4b: Completely Randomized Analysis of Variance for weight of grain dust produced at 60 DAI.

Source	DF	SS	MS	F	P
trt	9	6.086E-03	6.762E-04	7.68	0.0000
Error	40	3.522E-03	8.806E-05		
Total	49	9.608E-03		Grand Mean 1.0158	CV 0.92

4c: Completely Randomized Analysis of Variance for weight of grain dust produced at 90 DAI.

Source	DF	SS	MS	F	P
trt	9	0.03682	4.091E-03	9.52	0.0000
Error	40	0.01718	4.296E-04		
Total	49	0.05401		Grand Mean 1.0479	CV 1.98



APPENDIX 5a: Completely Randomized Analysis of Variance for percentage weight loss at 30 DAI.

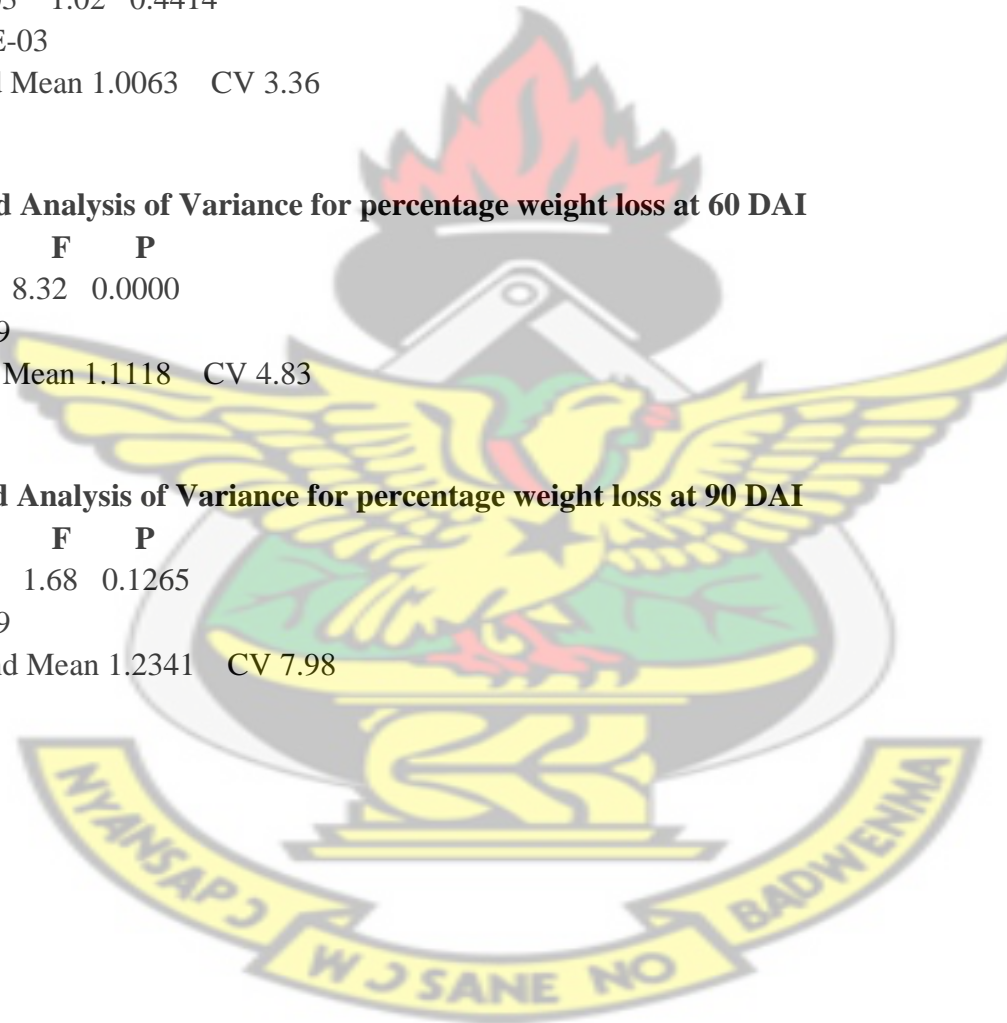
Source	DF	SS	MS	F	P
trt	9	0.01051	1.167E-03	1.02	0.4414
Error	40	0.04580	1.145E-03		
Total	49	0.05631		Grand Mean 1.0063	CV 3.36

5b: Completely Randomized Analysis of Variance for percentage weight loss at 60 DAI

Source	DF	SS	MS	F	P
trt	9	0.21607	0.02401	8.32	0.0000
Error	40	0.11543	0.00289		
Total	49	0.33149		Grand Mean 1.1118	CV 4.83

5c: Completely Randomized Analysis of Variance for percentage weight loss at 90 DAI

Source	DF	SS	MS	F	P
Trt	9	0.14641	0.01627	1.68	0.1265
Error	40	0.38765	0.00969		
Total	49	0.53406		Grand Mean 1.2341	CV 7.98



APPENDIX 6a: Completely Randomized Analysis of Variance for percentage germination after 30 DAI.

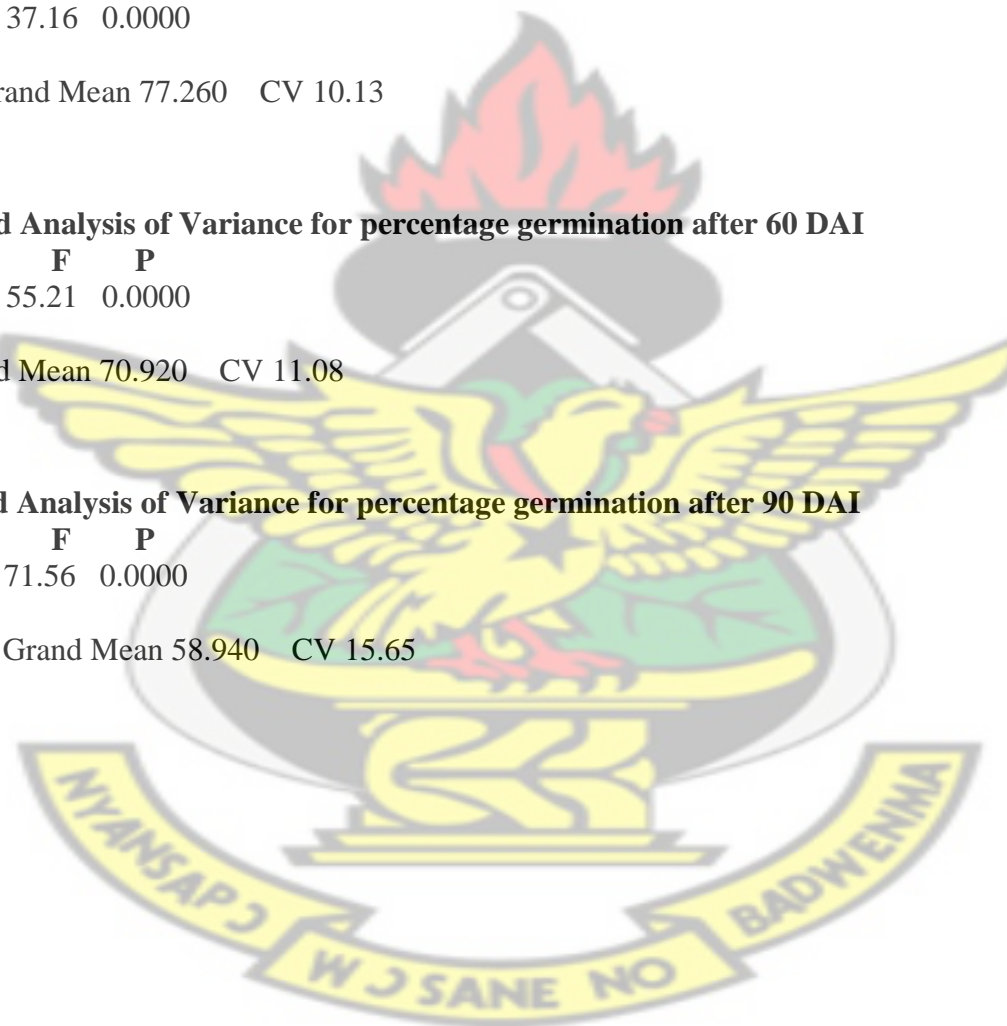
Source	DF	SS	MS	F	P
Trt	9	20485.6	2276.18	37.16	0.0000
Error	40	2450.0	61.25		
Total	49	22935.6		Grand Mean 77.260	CV 10.13

6b: Completely Randomized Analysis of Variance for percentage germination after 60 DAI

Source	DF	SS	MS	F	P
Trt	9	30670.5	3407.83	55.21	0.0000
Error	40	2469.2	61.73		
Total	49	33139.7		Grand Mean 70.920	CV 11.08

6c: Completely Randomized Analysis of Variance for percentage germination after 90 DAI

Source	DF	SS	MS	F	P
trt	9	54780.4	6086.71	71.56	0.0000
Error	40	3402.4	85.06		
Total	49	58182.8		Grand Mean 58.940	CV 15.65



APPENDIX 7a: Completely Randomized Analysis of Variance for percentage mortality at 30 DAI.

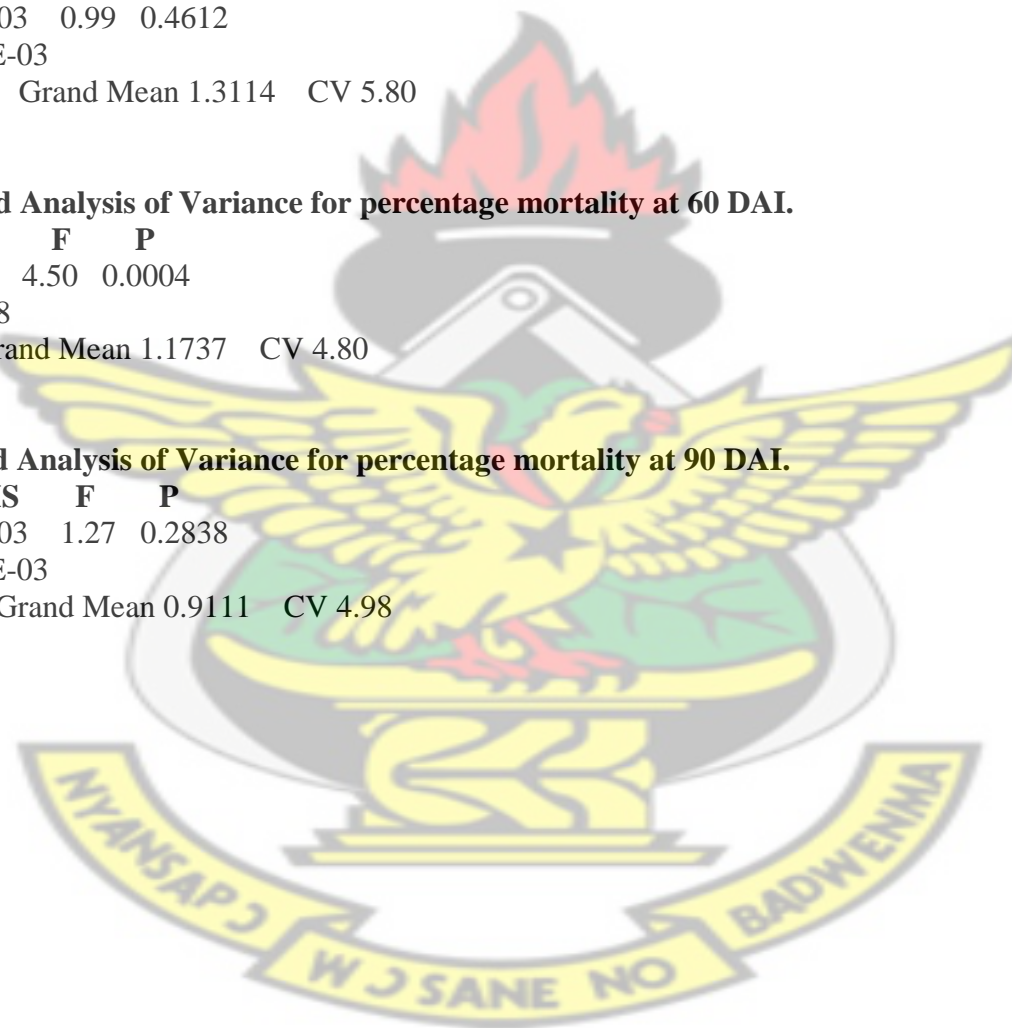
Source	DF	SS	MS	F	P
Trt	9	0.05166	5.740E-03	0.99	0.4612
Error	40	0.23125	5.781E-03		
Total	49	0.28291		Grand Mean 1.3114	CV 5.80

7b: Completely Randomized Analysis of Variance for percentage mortality at 60 DAI.

Source	DF	SS	MS	F	P
Trt	9	0.12885	0.01432	4.50	0.0004
Error	40	0.12721	0.00318		
Total	49	0.25606		Grand Mean 1.1737	CV 4.80

7c: Completely Randomized Analysis of Variance for percentage mortality at 90 DAI.

Source	DF	SS	MS	F	P
Trt	9	0.02350	2.612E-03	1.27	0.2838
Error	40	0.08237	2.059E-03		
Total	49	0.10587		Grand Mean 0.9111	CV 4.98



KNUST

