MANAGEMENT OF *Sitophilus zeamais* MOTSCHULSKY (COLEOPTERA: CURCULIONIDAE) USING HOST RESISTANCE, RAWDIATOMACEOUS EARTH AND MALATHION IN STORED MAIZEGRAINS

BY

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Ph.D/CPT/15/1161

NOVEMBER, 2019

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A Ph.D THESIS SUBMITTED TO THE DEPARTMENT OF CROP PROTECTION, SCHOOL OF AGRICULTURE AND AGRICULTURAL TECHNOLOGY, MODIBBO ADAMA UNIVERSITY OF TECHNOLOGY YOLA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN CROP PROTECTION (ENTOMOLOGY)

NOVEMBER, 2019

DECLARATION

I hereby declare that this thesis was written by me and it is a record of my own research work. It has not been presented before in any previous application for a higher degree. All references cited have been duly acknowledged.

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MEDUGU, Marcel Alexander Date

DEDICATION

This work is dedicated to Almighty God and my late mother, Mrs. Juliana (Gugwai) Alexander Medugu, who passed away during the course of my study, may her soul rest in perfect peace, Amen.

APPROVAL PAGE

This thesis entitled **"Management of *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) using Host Resistance, Raw Diatomaceous Earth and Malathion in Stored Maize Grains"** meets the regulations governing the award of Doctor of Philosophy in Crop Protection (Entomology) of the Modibbo Adama University of Technology, Yola and is approved for its contribution to knowledge and literary presentation.

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ABSTRACT

The maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae)is a very serious primary pest of stored maize grains which causes severe losses in storage. Therefore, this study was carried out on the management of this weevil using host resistance, raw Diatomaceous Earth (RDE) and Malathion (MT) in stored maize grains. The study consists of three experiments which lasted for a period of sixteen (16) months in the Laboratory of the Department of Crop Protection, Modibbo Adama University of Technology, Yola. Two experimental designs were used; Completely Randomized Design (CRD) and Split Plot Design (SPD) for the second and third experiments, respectively which were all replicated three times. A total of twenty (20) improved and five (5) local maize genotypes were sourced from the Institute for Agricultural Research (IAR) Samaru, Zaria and Adamawa State Agricultural Development Programme (ADP), respectively .In the first experiment, morphological, morphometric and chemical characteristics of the maize genotypes were determined while in the second experiment, susceptibility index (SI) of the different maize varieties was determined. In the third experiment, the treatments include; Raw Diatomaceous Earth (RDE), Malathion powder (MT), Raw Diatomaceous Earth + Malathion powder (RDE + MT) and a control and data collected were mortality,F_1 progeny produced, grain weight loss and damage and were analyzed using ANOVA and means separated using Tukey Kramer HSD test at $P>0.05$. Results for the morphological characteristics: Two color types were differentiated: white and yellow while shapes were hexagonal, oval and rectangular. In respect to face-type, the varieties were dent, semi dent, flint or dent-flint and all the varieties were smooth in texture. However, all these characteristics did not confer resistance among the maize varieties. The results of morphometric characteristics, such as grain length, width, thickness, 100 grains weight and hardness, only grain hardness confers resistance to insect attack which ranged from 121.40 to 382.20 Newton in SAMMAZ 34 and SAMMAZ 16, respectively. Similarly, the results of the proximate composition of maize showed that maize contained appreciable level of crude protein, low levels of ether extract, crude fibre and ash but high levels of carbohydrate and starch. In this study, moisture content ranged from 8.98 to 12.00 % for SAMMAZ 25 and SAMMAZ 34which very well played an important role in susceptibility of maize varieties. In the second experiment, susceptibility index (SI) ranged from 3.4 to 6.5. Based on Dobie rating, SAMMAZ 17, SAMMAZ 21 and SAMMAZ 34 were moderately susceptible with higher F_1 progeny production of 53.3 to 56.0 and lower median developmental time of 26.7 to 28.3. So also, SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29 were resistant with lower F_1 progeny production of 26.0 to 35.0 and higher median developmental time of 38.0 to 42.0, while the rest were moderately resistant. In the third experiment, the control had the lowest percent weevil mortality rate among the four varieties throughout the periods of assessment. Highest weevil mortality was recorded with increase in dose rates of RDE and MT and progresses to 100% with increase in days (14^{th} DAI), though mixture of RDE with MT even in the lowest dosage of both, keeps the population of *S. zeamais* at low levels (>90%). Weight loss and grain damage after application of treatments showed that the control recorded the highest weight loss and grain damage of 16.5%and 38.1, respectively as compared to all the treatments. The study showed that RDE had a promising potential to substitute synthetic insecticides or can be incorporated in an integrated pest management strategy against the maize weevil. Therefore, it is recommended that further work be done to refine RDE so as to standardize the most effective dosage application rate for management of insect pests of stored maize and other cereals.

Keywords: Diatomaceous earth, Malathion, *Sitophilus zeamais*, Maize, Susceptible, Resistant.

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CHAPTER ONE
INTRODUCTION

Maize *Zea mays* (L.) belong to the grass tribe Andropogoneae of the family Gramineae (Poaceae) (Kellogg, 2001; Bolot *et al.*, 2009) and an important food, cash and industrial crop (FAO, 2003; Jones *et al.*, 2011). It is one of the world's most important and widely grown grain crop throughout the Americas (FAO, 2009; Strable and Scanlon, 2009) with 332 million metric 4.56tons grown annually in the United States alone (New York Times, 2011). Nigeria cultivates 2 million tons of the 4 million hectares cultivated in West Africa and it produces about 7.7 million tons of grains annually, representing 0.9% of the world production (Amudalat, 2015). Though, occupying less land area than either wheat or rice, maize gives a greater average yield per unit area (5.5 t/ha), thus fostering drive towards global food security (Sasson, 2012).

Maize is one of the staple foods in the southern, northern and middle zones of Nigeria and the most widely cultivated cereal crop in the country after guinea corn and millet. Maize provides families with much needed nutrients such as carbohydrates, proteins, fats, vitamin B and minerals (Tongjura *et al.*, 2010) and a primary source of energy in developing countries where it contributes up to 60% and 30% of the diet's energy and protein, respectively (Mlynekov *et al.*, 2013). As food, the whole grain, freshly green or dried, may be used or may be processed by wet or dry milling methods to give a variety of food products. Preparation and uses of maize alone or in combination with other food materials as staple food or snacks in Nigeria include the followings: Ogi (in hot and cold forms), tuwo, donkunnu, maasa, couscous, akple, gwate, nakia, egbo, abari, donkwa, ajepasi, aadun, kokoro, elekute etc. (Abdulrahaman and Kolawale, 2006). In West Africa and Central Africa in the last 20 years, wide spread adoption of early maturing maize varieties in the savannas means that maize is no longer a backyard crop but a major cereal grown for both cash and food (Eckebil, 1994, Fajemish, 1994; Smith *et al*., 1997). The development and promotion of quality protein maize (QPM), a high lysine type of maize can improve the nutrition, particularly for women and children, in places where maize comprises a major source of protein in human diets. Quality protein maize also boosts the productivity of monogastric farm animals (poultry and swine) when used in feeds, and is valuable where farmers cannot afford or obtain lysine supplements for feeds (CIMMTY, 2008). Maize therefore has a considerable potential to enhance food security and the productivity and sustainability of the crop-livestock system (Arege *et al*., 2006) and also significantly contributes towards the national food self-sufficiency strategy (FAO 2003; Rukuni, *et al*., 2006; Demissie *et al*., 2008).

Both in the field and storage, insects are the principal cause of maize grain losses (Tadesse, 1991, 1997; Kabir *et al*., 2009; Dubale *et al*., 2012; Simbarashe *et al*., 2013). Nevertheless, insects not only cause postharvest losses in terms of quantity, but also reduce grain quality through depletion of specific nutrients (Abebe *et al*., 2009), and contaminate grain with their cast skins, excrement, fragments of immature insects and other products, consequently affecting its economic value and germination potential (Jood *et al*., 1993, Sanchez-Marinez *et al.*, 1997; Olakojo and Akinlosutu, 2004; Ozkaya *et al*., 2009). In some countries, these losses can reach up to 50% of total harvest, which represents a serious and continuing problem for the grain merchant and milling industries (Adedire, 2001; Fornal *et al.*, 2007; Ozkaya *et al*., 2009; Mebarkia *et al.*, 2009; Keskin and Ozkaya, 2013). Worldwide an estimated annual loss of about 9.4% on maize grain due to insect pests was recorded (Shurtleff, 1980).

Although, many types of insects occur during storage of maize which causes significant losses, few of these are larger grain borer (*Prostephanus truncatus* Horn), Angoumois grain moth (*Sitotroga cerealella* Olivier), rice weevil (*Sitophilus oryzae* Linnaeus) and maize weevil (*Sitophilus zeamais* Motschulsky). It has been reported that the maize weevil, *Sitophilus zeamais* Motschulsky. is a very serious primary pest of stored maize grains which cause severe losses in stored maize grain in Africa (Ofuya and Lale 2001; Thanda and Kevin, 2003; Niewiada *et al*., 2005; Mebarkia *et al*., 2009; Tongjura *et al*., 2010). Maize damage by *Sitophilus zeamais* causes food loss, increased poverty and lower nutritional values of grain, increased malnutrition, reduced weight and market values (Keba and Sori, 2013). Damage is done by both the adult and larva as they feed on the endosperm of the grain and creates exit holes. Taylor (1981) estimated that one larva can consume about 7% of the weight of maize grains. This pest is so devastating and is capable of multiplying to large populations causing tremendous damage to the grain (Parwada*et al.,* 2012). Declining food production, worsened by huge losses resulting from *S. zeamais* attack during maize storage expose farmers to different magnitudes of food shocks (Nwosu and Nwosu, 2012).

As a primary pest of stored maize, *S. zeamais* is capable of penetrating and infesting intact kernels of grain, in which immature stages develop (Ofuya and Lale, 2001) leaving the maize emptied of its nutritional and seed value culminating in outright rejection of the product at the local and international markets. It is estimated that about 10 - 40% of the total damage to stored maize grains worldwide is caused by this insect pest (Matthews, 1993) of which they account for approximately 5 - 10% of maize grain loss in almost all African countries (AREX, 2004). Bergvinson (2004) observed that maize weevils can consume as much as 15% of a harvest in a few months and have the ability to reduce maize quality. Grain weight loss of 12 - 80% caused by the maize weevil is common in untreated maize grain stored in traditional structures in tropical countries (Boxall *et al*., 2002; Chaubey, 2008; Muzemu *et al*., 2013). In Nigeria, it was revealed that Scania beetle causes weight losses of maize stored for 3 to 6 months to about 10-30%. Under severe infestations, this maize weevil can cause up to 90% loss of stored grain (Giga *et al*., 1991; Tadele *et al*., 2011).

The economic importance and wide distribution of *Sitophilus* species have prompted many researchers to go into studies on various aspects of the weevils, especially *S. zeamais* (Udo, 2005; Asawalam and Emosairue, 2006; Abulude *et al*., 2007; Ngamo *et al*., 2007; Ousman, *et al*., 2007; Asawalam *et al*., 2007, 2008; Parugrug and Roxas, 2008; Efidi *et al*., 2009; Danjuma *et al*., 2009; Owolabi *et al*., 2009; Makate, 2010) with the aim of developing of an affordable alternatives which offer same control levels of weevils as synthetic insecticides (Parwada *et al.*, 2012). Synthetic insecticides have been widely used for the control of pests of stored grains, particularly *S. zeamais*. The wide spread use of insecticides for the control of stored-product insect pests is of global concern due to its associated environmental hazards, presence of chemical residues in food, adverse effects on non-target organisms and exorbitant prices of the insecticides (Cherry *et al*, 2005; Nwosu and Nwosu, 2012). Evidence from different African countries illustrates that improper use of chemicals is causing loss of life and negative repercussions on human health (FAO, 2003), also consumers generally prefer reduced pesticide residues on all agricultural products, including raw stored commodities (Arthur, 1996).

The current trend in stored-product pest control is to use reduced-risk or low-toxicity insecticides as a replacement for conventional grain protectants, chiefly organophosphates. This led to the development of several studies on inert dust formulations (Korunic, 1998) and the use of resistant maize varieties (Temesgen and Waktole, 2013). During the past two decades, inert dusts, including diatomaceous earth (DE), have received considerable attention (Golob, 1997, Korunic, 1998, Subramanyam and Roesli, 2000; Arthur and Throne, 2003; Athanassiou *et al*., 2006). Diatomaceous earths (DEs) are very promising alternatives to traditional residual grain protectants. They are particularly effective against stored product insects (Kabir *et al.,* 2011; Kabir *et al.,* 2013), which tend to have a large surface to volume area, have extremely low mammalian toxicity, and their use is compatible with other reduced-risk integrated pest management-based control methods in storage facilities (Subramanyam and Roesli, 2000; Athanassiou *et al*., 2006). DEs are 'Generally Regarded as Safe' by the USA Environmental Protection Agency (Anon, 1991). They are of natural origin and can be applied with similar technology to that needed for residual pesticides (Korunic, 1998; Subramanyam and Roesli, 2000). As a result, several DE formulations are now commercially available (Subramanyam and Roesli, 2000), and many studies document that they are very effective against a wide range of stored-product insect species (Subramanyam and Roesli, 2000; Mewis and Ulrichs, 2001; Stathers *et al*., 2002; Vayias and Athanassiou, 2004; Athanassiou *et al*., 2004, 2005a; Vayias *et al*., 2006; Athanasiou and Korunic, 2007).

The use of resistant varieties is effective, technically easy, environmentally benign, economically feasible and acceptable by the society.Some workers have already documented that resistance in stored maize to insect attack is related to some physical, chemical and biochemical characteristics of a maize variety (Dobie 1977; Adedire *et al*., 2011). Grain color, shape, size, hardness, protein, moisture, sugar and phenol have been reported as the bases of resistance (Dobie, 1974; Osipitan and Odebiyi, 2007; Tongjura *et al*, 2010). Thus, it is deemed possible to use varietal resistance, synthetic chemical and DE as anintegrated management option of *S. zeamais*.

Therefore, this research project is aimed at evaluating an integrated management of *S. zeamais* by studying the susceptibility of improved maize (*Zea mays*) varieties and local cultivars to maize weevil *Sitophilus zeamais* as well as the efficacy of raw diatomaceous earth and Malathion alone and in combination against *S. zeamais*. The objectives of the study are:

i. to determine the morphological, morphometric and chemical characteristics of different maize varieties and to screen maize varieties which confer resistance;

ii. to determine mortality of *S. zeamais* adult exposed to resistant maize varieties, different rates of raw Diatomaceous Earth and malathion alone and in combination;

iii. to determine the effect of resistant maize varieties, raw Diatomaceous Earth and malathion on progeny development of *S. zeamais*, and

iv. to determine the most effective combination dose rates of raw Diatomaceous Earth and malathion on maize varieties for the management of *S. zeamais.*

CHAPTER TWO
LITERATURE REVIEW

2.1 Origin of Maize

Maize originated in the Americas (Poehlman and Sleper, 1995; OECD, 2003). Maize (Poaceae) is a member of the world's most successful family of agricultural crops, including wheat, rice, oats, sorghum, barley, and sugarcane. Maize belongs to the genus *Zea*, a group of annual and perennial grasses native to Mexico and Central America, where many diverse types of maize are found. The genus *Zea* includes closest wild taxa known collectively as teosinte (*Zeamays* sub sp. *parviglumis*) (Aylor *et al*., 2005) and domesticated corn or maize (*Z. mays* sub sp. *mays*). There are two types of teosinte; the basal branching teosinte sub-species are called *Zea mays parviglumis* (L.),(Iltis and Doebley (OECD, 2003). The lateral branching sub-species is named *Zea mays mexicana* Schrader (Poehlman and Sleper, 1995; OECD, 2003). The name maize is derived from the South American Indian Arawak-Carib word maize. It is also known as Indian corn or corn in America (Kochhar, 1986; Purseglove, 1992).

Although, maize did not originate from Africa, it is introduced to the continent in the 16^{th} century and by the 19^{th}century; it had spread all over the continent. It is perhaps, the most important cereal crop of significant economic importance in African countries that has replaced sorghum and millet (Amudalat, 2015). Though, it introduction into Nigeria was probably in the 16^{th} century by the Portuguese (Osagie and Eka, 1998). In Nigeria, maize is known and called by different vernacular names depending on locality like 'agbado', 'igbado' or 'yangan' (Yoruba); 'masara' or 'dawar masara' (Hausa); 'ogbado' or 'oka' (Ibo); 'apaapa' (Ibira); 'oka' (Bini and Isha); 'ibokpot' or 'ibokpot union' (Efik) and 'igumapa' (Yala); 'masar' (Margi).

Maize is cultivated throughout the world from 58°N latitude to 40°S latitude, the crop spreads and cultivated over 139 million ha of area and around 600 million tons of maize is produced. This crop occupies the third position next to rice and wheat in area and production. It is staple human food, feed for livestock, for fermentation and many industrial uses. It is having abundant starch (65%). In the new millennium, it is an alternate crop to rice and wheat. About 35% production is consumed by human, 25% poultry and cattle feed, 15% food processing (OECD, 2003).

2.2 Maize Domestication

The evolution of maize and the development of Native American societies were intimately connected; indeed, maize has been credited as the grain that civilized the New World. These early farming communities used corn not only for food but also for art and religious inspiration. Maize probably was domesticated over a period of a few thousand years in south central Mexico, the principal habitat of its immediate ancestor, *Z. mays* ssp. *Parviglumis.* Archaeological remains of the earliest maize cob, found at Guila Naquitz Cave in the Oaxaca Valley of Mexico, date back roughly 6250 years (Piperno and Flannery, 2001). There is also much microfossil evidence suggesting dispersal to Central and South America by 7000–5000 bp (Piperno and Pearsall, 1998). Therefore maize probably was domesticated between 12,000 and 7500 years ago, as the first steps of domestication necessarily preceded this evidence, and its initiation cannot be older than the significant human migrations to the New World in roughly 15,000 bp (Dillehay, 1989).

Although the extraordinary morphological and genetic diversity among the maize landraces led some researchers to propose multiple, independent origins for maize (Kato, 1984), recent phylogenetic analyses based on comprehensive samples of maize and teosinte indicate a single domestication event. As noted earlier, a microsatellite-based phylogeny for a sample of 264 maize and teosinte plants showed all maize in a single monophyletic lineage that is derived from within ssp. *parviglumis* (Matsuoka *et al*., 2002). After this domestication, maize spread from Mexico over the Americas along two major paths (Matsuoka *et al.*, 2002). Domesticated maize was the result of repeated interaction with humans, with early farmers selecting and planting seed from plants with beneficial traits while eliminating seed from plants with less desirable features. As a result, alleles at genes controlling favored traits increased in frequency within the population, less favored alleles decreased. Thus with each succeeding generation these ancient agriculturists produced a plant more like modern maize and less like the wild grass of their ancestors. This human selection process probably was both conscious and unconscious (Rindos, 1984).

Native Americans may have combed the Mexican hillsides in search of teosinte plants with promising mutations, deliberately choosing the plants that provided more of an easier access to the sustenance they needed. For example, teosinte kernels are surrounded by a hard protective covering, or glume. Because this glume makes them very difficult to eat, plants with a softer glume were conceivably targeted during domestication. However, loss of shattering (a natural mechanism for seed dispersal) was more likely to be an inadvertent consequence of the harvesting process because early farmers could only plant the seeds that arrived home with them, still attached to the central rachis, or eventual maize cob. Over time, these ancient agriculturists were able to select, consciously or not, the combination of major and many minor gene mutations that now distinguish maize from its wild ancestor. As it turns out, any of the same genes involved in this transformation might also be involved in that of other grasses, including wheat, rice, and sorghum (Paterson *et al*., 1995). Despite the independent domestication of these cereal complexes, it now appears that the earliest plant selectors desired the same sets of traits, as evidenced by selection at a common set of loci. Quantitative Trait Loci (QTL) for seed size, seed dispersal (shattering), and photoperiod have been mapped in maize, rice, and sorghum. These QTLs correspond to homologous regions between taxa more often than would be expected by chance and provide further evidence that domestication of these grasses was the result of mutations in a small number of genes with large effects (Buckler *et al*., 2001).

2.3 Scientific Classification of Maize

Kingdom: Plantae

Order: Poales

Family: Poaceae

Subfamily: Panicoideae

Tribe: Andropogoneae

Genus: *Zea*

Species: *Z. mays*

Subspecies: *Z. mays* subsp. *mays*

Trinomial name: *Zea mays* subsp. *mays*

2.4 Maize Grain Types

Based on kernel characteristics, maize can be classified into six main groups: dent, flint, popcorn, sweet, floury and waxy (Boutard, 2012).

2.4.1 Flint corn (*Zea mays* Indurata) - Entire outer portion of kernel is hard starch. Flint comes in many colours such as white, yellow, red-blue or their variable. The hardness of the flint corn outer layer makes it less prone to damage by grain mold and insects, both in the fieldand in storage (Paliwal *et al*., 2000). It is a multicolored grain, ranging from pale orange to dark red (Suleiman *et al*., 2013). Flint corn is extensively grown in central and south America, Asia, some parts of Africa and Southern Europe for human consumption and industrial purposes (OGRT, 2008).

2.4.2 Dent corn (*Zea mays* indentata) - About 95% of production in USA is dent corn. Hard starch is confined to kernel only. The amylose of soft starch in the core contracts when the grain is dried producing characteristic dent in the top of the kernel. Dent corn may be yellow, white and red colour of kernel.

2.4.3 Sweet corn (*Zea mays* Saccharata) - Grown for food and harvested at 70% moisture content. It is good source of energy. About 20% of dry matter is sugar compared to 3% in dent corn. It is also a good source of vitamins C and A. Production and consumption of sweet corn have increased dramatically over the past 30 years in the US, Brazil, Canada, China, Australia, and Europe for both consumption as a fresh vegetable and for food processing (Williams, 2012). According to Hansen *et al*. (2013), in 2012 approximately 3.4 million million tons of sweet corn valued at over US $1.1 billion were produced, a 10% increase from the previous year. This is expected to increase in upcoming years (NASS, 2013). Suleiman *et al*. (2013) reported that sweet corn originated from a genetic mutation of field corn in the Peruvian race Chullpi. It differs from dent (field corn) by only one recessive gene (su1) or sugary that prevents some of the sugars from being converted to starch (Najeeb *et al*., 2011).

2.4.4 Flour corn(*Zea mays* Amylacea) - Kernel is largely composed of soft starch with little or no hard starch. Kernels are easy to grind. Primarily used by natives of Andean Highlands of South America.

2.4.5 Pop-corn(*Zea mays* Everta) - Its kernel is small and extreme form of flint corn. When heated to 170°C, the grain swells and burst and turning inside out. At this temperature, the water held in the starch turns to steam and the pressure causes the explosion. Popcorn (*Zeamays* everta Sturt) is the most popular snack in the United States (US) and around the world. The US is the largest producer and consumer of popcorn in the world; over 230 million tons of popcorn were produced in 2012 (Hansen *et al*., 2013). It is estimated that over 54 million tons of popcorn are consumed every year in the US. This enormous consumption of popcorn may be partially due to claims made by the Dietary Guidelines for Americans and as one among whole-grain food/snacks (Grandjean *et al*., 2008). Popcorn is described as a special type of flint corn with small ears and small pointed or rounded kernels and a structure characterized by hard starch, and very hard pericarp and outer layers of endosperm (Karababa, 2006; Yang *et al*., 2005).

2.4.6 Waxy corn (*Zeamays* Ceretina) - Due to waxy appearance of the kernel, it is called as waxycorn. The starch is entirely amylopectin whereas dent has 78% and 22% amylose. Hybrids of waxy are raw materials for wet milling starch industry for textile and paper sizing and corn oil.

2.5 Maize Production in Nigeria

Maize *(Zea mays* L.*)* is one of the main cereal crops of West Africa, and the most important cereal food crops in Nigeria. It comes after wheat and rice in terms of world importance (Onyibe *et al.,* 2006). Maize is becoming the miracle seed for Nigerian agricultural and economic development. It has established itself as a very significant component of the farming system and determines the cropping pattern of the predominantly peasant farmers, especially in the Northern States (Ahmed, 1996). Maize consists of 71% starch, 9% protein and 4% oil on a dry weight basis (Onuk *et al.*, 2010) and has been of great importance in providing food for man, feed for livestock and raw materials for some agro-based industries. In Nigeria, about 80% is consumed by man and animals while 20% is utilized in variety of industries processes and it constitutes a stable food in many regions of the world. It is a basic stable for large population groups particularly in developing countries (FAO and ILO, 1997).

Nigeria has an annual maize production in excess of 7 million metric tons. Until recent years, the bulk of maize grain produced in Nigeria was from the southwest zone with western Nigeria generally produced about 50% of Nigeria green maize, the remaining 50% being split between the North and the East (Ogunbodede, 1999). Although large proportion of the green maize is still produce in the south-western part, there has been a dramatic shift of dry grain production to the savanna, especially the Northern Guinea savanna. This can now be regarded as the maize belt of Nigeria. In this zone, farmers tend to prefer maize cultivation to sorghum. This trend may have been brought about for several reasons including availability of streak resistant varieties for all ecological zones in Nigeria, availability of high-yielding hybrid varieties, increase in maize demand coupled with the federal Government imposed ban on importation of rice, maize and wheat (Iken *et al.,* 2002).

In developed countries, maize is consumed mainly as second-cycle produce, in the form of meat, eggs and dairy products. In developing countries, maize is consumed directly and serves as staple diet for some 200 million people. Most people regard maize as a breakfast cereal. However, in a processed form it is also found as fuel (ethanol) and starch. Starch in turn involves enzymatic conversion into products such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint (Plessis, 2003).

Maize will continue to play a large and important role in Nigeria's food production due to the following advantages; it is a major source of energy, and of all cereals gives it gives the highest yield per man-hour invested; it is usually the first crop to be harvested for food during the hunger period; it is easy to grow as sole crop or intercropped with other crops; and it is easy to harvest, it does not shatter and is not liable to bird damage. Its industrial demand is also increasing particularly in the food, beverage, and livestock feed industries (USAID/Markets, 2010).

2.6 Properties of Maize

The composition of mature white maize grain per 100 g edible portion is: water 10.4 g, energy 1527 kJ (365 kcal), protein 9.4 g, fat 4.7 g, carbohydrate 74.3 g, dietary fibre 7.3 g, Ca 7 mg, Mg 127 mg, P 210 mg, Fe 2.7 mg, Zn 2.2 mg, thiamin 0.39 mg, riboflavin 0.20 mg, niacin 3.6 mg, vitamin B6 0.62 mg, folate 19 μg and ascorbic acid 0 mg. The essential amino-acid composition per 100 g edible portion is: tryptophan 67 mg, lysine 265 mg, methionine 197 mg, phenylalanine 463 mg, threonine 354 mg, valine 477 mg, leucine 1155 mg and isoleucine 337 mg. The principal fatty acids per 100 g edible portion are: linoleic acid 2097 mg, oleic acid 1247 mg and palmitic acid 569 mg (USDA, 2005). Maize is deficient in tryptophan and lysine, but cultivars with higher content of these amino acids have been bred using the recessive gene Opaque-2 with modifiers. These cultivars are referred to as Quality Protein Maize (QPM). In general 100 kg of whole maize, with 16% moisture content, yields about 64 kg starch and 3 kg oil. The endosperm, which accounts for 80% of the weight of the grain, is poor in phosphorus and calcium and contains most of the starch and two-thirds of the protein. More than 80% of the fat and most minerals are in the embryo or germ, which constitutes about 12% of the grain. The starch of the endosperm usually consists of a mixture of about 75% amylopectin and 25% amylose, but waxy maize contains only amylopectin.

The most common grain colours are yellow and white. Yellow maize predominates in the United States, China and Brazil, whereas white maize predominates in tropical Africa, Central America and the northern part of South America. White maize has harder grain and gives sweeter, more flavorful products; it is primarily grown for food, whereas yellow maize is mainly used as animal feed. Yellow maize contains the provitamin A cryptoxanthin. Most vitamins are found in the outer layers of the endosperm and in the aleurone layer. Maize is deficient in gluten and therefore unsuitable for making leavened bread; it is tolerated by patients with coeliac disease. Maize oil is considered premium oil for human consumption, due to its flavour, colour and stability and the presence of linoleic acid and vitamin E.

Maize grain in tropical Africa often contains mycotoxins such as aflatoxins and fumosinins, which are harmful to humans and livestock. Aflatoxins are produced by *Aspergillus* spp., especially *Aspergillus flavus*; they are powerful carcinogens, especially affecting the liver, and have immuno suppressive properties. Fumosinins are produced by *Fusarium* spp., especially *Fusarium verticillioides*; they have been implicated in various animal diseases. Human health risks due to fumosinins are possible, but so far there is no conclusive evidence, although correlation studies have suggested a link between consumption of maize with fumosinins and high incidence of human oesophageal carcinoma.

2.7 Nutritional Value and uses of Maize

The importance of maize in West Africa is well-studied and yet, receiving increased attention (Nwosu, 2014). 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 QPMs thus making it firmly establish its superiority to the rest of the cereals (FAO, 2007: IITA, 2009). It is also an important source of carbohydrate, oils, vitamin B and minerals (IITA, 2009). Maize is an important food in countries all over the world (CABI, 2012). In sub-Sahara Africa, it is a staple crop for an estimated 50% of the population (IITA, 2003). Almost every part of the maize plant is utilized (Romain, 2001), where the ears can be cooked and eaten from the cob as a vegetable or the kernels can be removed and either eaten as it is or used to produce a wide variety of foodstuffs including cereals and flour (CABI, 2012). While in developed countries, the starch can be processed into oils and high fructose corn syrup though, the bulk of maize produced is used as livestock feed and as a raw material for industrial processing while, in developing countries such as Nigeria, it is mainly used for human consumption (Aquino *et al*., 2001).

2.8 Industrial uses of Maize

Products resulting from industrial processing of maize include starch, high fructose syrup, dextrose, corn oil, ethanol, cosmetic or skin care products, beverages, crayons, soaps, absorbent material for diapers, food additives, biodegradable plastics and food supplements. Other products are livestock feed and other components such as fuel (Halm *et al*., 1996; Cardona and Sanchez, 2007; Yong, 2003). Maize starch is used mainly as a thickener or as a stabilizer of other ingredients such as baking powder, candies, puddings and other prepared food mixes. Paper and textile industries also utilize corn starch. Maize oil is used for making salad, as cooking oil and in the production of margarine. It is also used as a carrier for some vitamins and medicines (Dupoint *et al*., 1990). On the other hand dextrose is utilized in the bakery industries where it serves as a yeast nutrient, and provides some sweetness and browning of the crust on baked products. Other major uses of dextrose are in food canning, frozen packaged foods, ketchup, jams and jellies, soft drinks, wines and malt liquors (Okoruwa and Ling, 1996). Maize can also be used to produce bio-ethanol and used as a gasoline additive, which when used as fuel can help reduce air pollution (Yong, 2003).

2.9 Maize Storage

The quantity of grain produced in a season influences the nature of storage method and the duration of the storage period (Owusu, 1981). Maize storage in Nigeria is predominantly in traditional cribs with cobs drying out gradually through natural ventilation. There is also the improved narrow crib which enhances faster drying and storage (Nicol *et al*., 1997). There are three main traditional storage systems based on type and location and these are; indoor, outdoor and underground systems (Osei-Akrasi, 1999). The indoor and outdoor structures are usually used to store both shelled and unshelled maize but the underground storage is for shelled maize and it is used in drier regions. Thus, maize storage structures tend to be specific to a climatic zone and are constructed to meet the requirements of that particular area (Nicol *et al*., 1997).

Small quantities of seed maize are usually stored indoors using calabashes, gourds and earthenware clay pots at the rural household level. On the large-scale maize is stored in jute sacks or bins in large warehouses after shelling, drying and treating with the recommended pesticides. Many farmers store their maize cobs with the husk on, which does not significantly affect the rate of grain drying in cribs (FAO, 2007). Un-dehusked maize and grains on the cob are less susceptible to *S. zeamais*, *Tribolium* sp. and *Rhyzopertha* sp. attack than the shelled, but shelled maize suffers less damage from pest such as *Prostephanus truncatus* Horn (Coleoptera: Bostrychidae) than maize stored on the cob (Hodges, 1995 and Meikle*et al.*, 1998). In Nigeria and particularly the northern savanna region, 40-85 % of food grains harvested are stored traditionally and averagely over 3 to 12 months (Ivbijaro, 1989; Mailafiya *et al.*, 2014). Longer grain storage periods of between 7-10 years have also been reported in this region, where annual food grain losses have been documented in the range of 40-60 % (Youdeowei and Service, 1986; Ivbijaro, 1989; Adejumo and Raji, 2007).

2.10 Maize storage structures

2.10.1 Storage in bags

Bags or sacks are generally the most common method of storing maize and in sub-saharan Africa.Bags have a capacity of 50 kg while in some countries bags have a capacity of 100 kg. (Noah and Gordon, 2008)Synthetic poly bags are currently the most popular while gunny bags are both rare and more expensive. The following is a summary of recommendations regarding the use of bags or sacks in order to reduce the amount of storage pests; Use new bags, and spray in and outside the used bags with Actellic Super EC, Store maize filled bags on a raised platform e.g. made of wood or poles and should be kept away from the wall, Boil used sacks in hot water and dry properly before re-use

2.10.2 Storage in stores

Brick constructed stores are also used for storing bags of maize and are ideal for fumigating maize since they are situated far from the household but stores are uncommon since they are costly and susceptible to break-ins and theft. Bricks can be removed from the stores giving thieves easy access to the stored maize.

2.10.3 Traditional granaries (rhumbu)

Granaries are normally made of sticks and are common storage structures in most African countries. Stores should be smeared with mud inside and out in order to prevent damage from insect pests, covered with a roof in order to keep rain water off and built well off the ground with rat guards attached to the poles supporting the platform (CABI, 2012). Granaries are normally built outside the house but due to security concerns, many are built inside the house

2.10.4 Improved granaries/cribs

Improved granaries or cribs are a major improvement over the traditional granaries. The platform is made of a brick structure, and cement is used for plastering inside and outside, instead of mud, giving the twig/stick woven structure (some improved granaries are made from brick) to increased durability (Noah and Gordon, 2008). The improved structure also has a door for removing maize grain and a better ventilation system due to the insertion of a plastic pipe and an improved granary can also support fumigation of grains under supervision of trained personnel.

2.10.5 Small Metal silos/drums

Small metal silos are ideal for storing maize at small holder farmer level. Small silos have different capacities, the lowest holding 5 bags, and can be sealed after loading thus suffocating any insect pests in the grain (Noah and Gordon, 2008). Silos can also be kept inside the house, which can mitigate theft. The following recommendations apply when using metal silos should be kept off the ground and away from the wall, maize should be dried and tested before storage, kept away from the Roof to avoid overheating of grains, maize should be stored for a minimum of two months, maize should be removed quickly, and the silo re-sealed to prevent excess air getting in when removing part of the maize and grains should be removed from the outlet section only not the top in order to create a vacuum.

2.10.6 Community metal silos

Large silos are ideal for community storage because of their capacity, ranging from 500kg to 1800kg, to store larger amounts of grains. Large silos work on the same principle as the small metal silos; both are made from flat metal sheets, and should be air tight and shaded in order to prevent overheating of the grain and sudden temperature fluctuation.

2.10.7 Community Grain Stores/ National scale silos

Community grain stores are large storage buildings with the capacity for fumigating and storing tonnes of maize such as those used by grain marketing organizations. Examples of these grain stores are brick and iron sheeted community grain stores.

2.11 Major Insect Pests of Stored Maize

One of the main causes of food insecurity in Africa is the high prevalence of storage pests and although maize is an excellent food source for humans, and an ideal breeding site for storage pests. These arthropod pests are also one of the major constraints to cereal production in Africa, it attack crops during all stages of growth from seedling to storage (Abate *et al.*, 2000). Generally, maize storage insect pests fall under two main categories: the primary and secondary pests of which are found in two orders: Coleoptera (beetles and weevils) and Lepidoptera (grain moths). There are about 20 different insect pests that attack stored maize, of these the maize weevil, *S. zeamais*Motschulsky, is the most important primary pest. However, the larger grain borer, *P. truncatus* is assuming primary pest status (Vowotor *et al.*, 2005). Some of the insect pests that attack maize grains in the store are; *Sitophilus* spp. (Coleoptera: Curculionidae), *Rhyzopertha dominica*(F.),(Coleoptera: Bostrychidae), *Sitotroga cerealella* (Olivier.) (Lepidoptera: Gelechiidae), *Trogoderma granarium* (Everts) (Coleoptera: Dermetidae), *Oryzaephilus surinamensis* (L.), (Coleoptera: Silvanidae), (Gilse, 1964; Utono, 2013; Mailafiya *et al.*, 2014).

2.11.1 Larger grain borer(*Prostephanus truncatus* Horn)

The Larger grain borer (LGB), which is sometimes referred to as the Greater Grain Borer (GGB) is the single most serious pest of stored maize and dried cassava roots (chips), and will attack maize in the field just before harvest (Dwivwdi and Kumar, 2009). The primary host is maize, most especially maize on the cob both before and after harvest. Larger grain borer also bores into non-food substances such as wood, bamboo, and even plastic, which poses a challenge to controlling the pest. Infestations in maize may start on the mature crop in the field, i.e. when moisture content is at or below 18%. Weight losses of up to 40% have been recorded from maize cobs stored for 6 months (Giles and Leon, 1975). In Tanzania, losses of up to 34% have been observed after 3 months storage of maize on the farm, with an average loss of 8.7% (Hodges, *et al.*, 1983).

2.11.2 Angoumois grain moth (Sitotroga cerealella **Olivier***)*

The grain moth is a pest of various stored products. Grains affected are maize, oats, barley, rice, pearl millet, rye, sorghum, and wheat. However, the grain moth is often found alongside other pests, with which it may act synergistically. The complex with other storage pests resulted in grain losses of up to 90% in Malawi in varieties of soft grains (Schulten, 1975). In Malawi infestation was found to be caused by a combination of Angoumois grain moth, Maize weevil, and Rice weevil. However, in Zimbabwe, losses in storage were mainly caused by Angoumois grain moth and Maize weevil with losses of 70% in untreated maize. Angoumois grain moth is found in all sub-Saharan regions of Africa.

The Angoumois grain moth adult *S. cerealella* are smaller than other stored product moths (Canadian Grain Commission (CGC), 2013). It is a small buff or yellowish-brown moth with a wing expense of 10 to 18 mm (Adedire, 2001). Females lay up to 250 eggs on or near the surface of stored grain. The eggs hatch into larvae which bore into grain kernels remaining inside until maturity (Rees, 2007). Before pupation, the larva prepares a hole making way out of the grain, but it does not go out, leaving characteristic exit pin holes on the grain surface (Johnson, 2014; DAF, 2016). It is through this hole that the fully developed adult moth eventually comes out of the grain leaving silken ‘door’ still attached to grain and does not feed (Adedire, 2001; Rees, 2007; USAID, 2011). The complete life cycle lasts for 25 to 28 days at 30°C and 80% RH (USAID, 2011). *S. cerealella* is a primary pest of stored whole cereal grains including sorghum which infests ripening grains in the field and also conveyed into the store where it continues its destructive activities (Adedire, 2001). The biting mouth parts of the larvae of Angoumois grain moth make them so much destructive that even out-compete that of *Sitophilus* especially in very dry grains or when the condition is less favourable to the latter (Haines, 1991). Adedire (2001) observed that apart from direct loss caused by the feeding and developmental activities of the larvae, infested grains could probably be rendered susceptible to colonization by secondary insect pests, fungi and changes in grains’ physical characteristics.

2. 11.3 Trogoderma granarium **(Everts)**

The Khapra beetle, *T. granarium*, is a dermestid beetle and a serious pest of stored grains. Adults of *T. granarium* are 1.8 to 3.8 mm long, have wings but do not fly nor eat (Robinson, 2005; Musa *et al*., 2007). Elytra are yellowish brown to reddish brown, and have a brown and yellow colour pattern. The pronotum is usually darker than the elytra, and the dorsal setae are pale yellow. Full grown larvae which are the grain destructive stage of the insects are about 6 mm long, brown to yellowish brown (Robinson, 2005). Eggs are laid singly on the surface or in crevices of the food and the life cycle lasts for 25 days at optimum conditions of 33 to 37°C and 40 to 75% RH (Rees, 2007). The beetle breeds most rapidly under hot, dry conditions and has a potential to spread internationally through international trade (Musa and Dike, 2009). It is also among the most serious and widest occurring insect pests in stored cereal grains including sorghum in tropical and subtropical regions of Asia and Africa (Dwivedi and Kumar, 1998; Adedire, 2001). Adults of *T. granarium* are short-lived and do not feed on commodity, while the larvae commence feeding on the germ and eat deep into the grain which results in hollowing the grains coupled with severe powdering (Adedire, 2001; Rees, 2007). These activities may possibly lead to serious damage to the stored grain and also the seed viability may be lost.

2.11.4 Rhyzopertha dominica **(F.)**

This is a member of the Family, Bostrychidae and commonly called the lesser grain borer. Adults are 2 to 3 mm in length, reddish-brown and cylindrical (Rees, 2007). The elytra are parallel-sided, the head is not visible from above, pronotum has rasp-like teeth at the front, and the thorax is large which gives the adult insect a hump-backed appearance (Robinson, 2005). The female lays an egg outside the kernel, and the newly hatched larva bores into the kernel where it completes development (Kavallieratos *et al*., 2012). The young larvae are mobile in grain bulks but become immobile and gradually C-shaped as they pupate within grain and adults can emerge without leaving an emergence hole (van Emden, 2013). Life cycle takes about 4 weeks at 34°C and 70% RH (Rees, 2007; USAID, 2011; van Emden, 2013). Adults and larvae of *R. dominica*feed primarily on entire grain of stored cereals including sorghum, leaving behind empty husks and grain dust (Adedire, 2001; Rees, 2007; USAID, 2011). They are also found on a wide variety of foodstuffs including beans, dried chilies, turmeric, coriander, ginger, cassava chips, biscuits and wheat flour (Wakil *et al*., 2011). Adedire (2001) observed that adults of *R. dominica*feed on the grain germ, while the larvae devour the endosperm. This infers that the grain would perhaps lose its viability, quantitative and qualitative values and hence leading to serious damage that could affect food security and general income to the farmers.

2.11.5 Oryzaephilus surinamensis (L.)

Adult saw-toothed grain beetle, *O. surinamensis* is an active, dark brown, slender beetle 2.5 to 3.5 mm long which can be easily recognized by the six distinctive saw-like projections on each side of the thorax (Odeyemi, 2001; Rees, 2007). Its flattened body is well adapted for crawling into cracks and crevices (Odeyemi, 2001). The elytra are longitudinally grooved, while three longitudinal ridges are found along the top surface of the thorax (Rees, 2007). There are well developed wings in both sexes (Mason, 2003). *O. surinamensis* is one of the key stored grain pest which occurs worldwide (Hashem *et al*., 2012). It is considered to be a secondary pest in stored cereals including sorghum, and other cereal products, infesting bulks already damaged by primary feeders (Rees, 2007).

They can also establish on whole grains with minor cracks or mechanical lesions (Pricket *et al*., 1990). After pre-oviposition period of 5 to 6 days, each female is capable of laying about 350 to 400 eggs and depositing them either loosely in flour or other milled grain products or tucked in a crevice of a grain kernel at 30°C in 6 to 8 months (Odeyemi, 2001; Mason, 2003). Eggs hatch in 3 to 8 days and the larvae begin to feed within a few hours of hatching (Mason, 2003). Larvae are typically free-living, mobile, external feeders and not concealed (Rees, 2007). Under favourable conditions, larvae complete their development in 12 to 15 days. Pupae develop in about 4 to 7 days and total development time from egg to adult varies from 21 to 51 days, depending on temperature (Calvin, 1990). The life cycle was also reported to complete in 20 to 22 days at 30 to 33°C and 70 to 90% RH, while the optimum conditions for development of the insect are 30 to 35°C and 70 to 90% RH (Halstead, 1980; Odeyemi, 2001; Rees, 2007). *O. surinamensis* is very cold tolerant and infestations could develop at 17 to 37°C and 10 to 90 RH (Rees, 2007). Adults normally live for 6 to 10 months, or even up to 3 years but quickly die on dust-free, undamaged grains (Surtees, 1965; Calvin, 1990). Considering feeding habits of adults and larvae of *O. surinamensis* and their low humidity tolerance, severe damage to infested sorghum may possibly occur.

2.11.6 Cryptolestes ferrugineus (Stephens)

The rusty grain beetle, *C. ferrugineus* is a worldwide cosmopolitan pest of stored products, particularly grains. Adults are flat, small, shiny light brown beetles, about 1.5 to 2 mm in length (Odeyemi, 2001; Rees, 2007; CGC, 2013). Adults are good fliers and are readily identified by their very long antennae (Weaver and Petroff, 2004). This is a secondary pest attacking cereal grains and their products, and other dried materials of plant origin, packaged and processed goods (Rees, 2007). An adult female of *C. ferrugineus* lays up to 40 eggs on or amongst the commodity which hatch into mobile larvae (Odeyemi, 2001; Rees, 2007). Upon hatching, the larvae seek out food preferring to feed on the germ of the kernel. Larvae and pupae develop singly under the seed coat covering the germ of cereal seeds (Suresh *et al*. 2001). Adults are long-lived, walk with characteristic sway, feed on commodity and fly actively at temperatures above 21°C (Rees, 2007). Development is completed in 21 days at 35°C and 100 days at 20°C (Odeyemi, 2001). Robinson (2005) further observed that development of *C. ferrugineus* from egg to adult takes 69 to 103 days at 27°C. The rate of development of *C. ferrugineus* was reported to be retarded and its mortality increased at low humidities (below 40%) and grain moisture content was low (12%), (Odeyemi, 2001; CGC, 2013).

2.11.7 Rice weevil **(*Sitophilus oryzae* Linnaeus)**

The *Sitophilus oryzae* Linnaeus,rice weevil, which is also called the Rice weevil, is an important pest of stored maize, rice, cassava, sorghum, and wheat. It also infests pearl millet, barley, lentil, millets, peas, rye, broad bean, and cowpea (van Emden, 2013). The Lesser grain weevil is regarded as one of the most destructive primary pests of stored cereals, its voracious feeding on whole grains results in weight loss, fungal growth, and quality loss through an increase in free fatty acids. Its invasion may cause grain heating and may facilitate the establishment of fungal colonies, secondary insect pests and mites. In maize or sorghum, attack by the lesser grain weevil may start in the mature crop when the moisture content of the grain has fallen to 18-20% (Adedire, 2001). Subsequent infestations in storage result from the transfer of infested grain into the stores or from the pest flying into storage facilities. In stored maize heavy infestations by the lesser grain weevil may cause weight losses of up to 30-40%. The Lesser grain weevil, like the maize weevil, is found in all warm and tropical parts of the world, and may also be found in temperate climates.

Sitophilus oryzae is winged and very similar with large round punctures on the thorax and elytra and four large lighter patches on the elytra. However, *S. oryzae* is smaller with 2 to 3 mm body length (van Emden, 2013). The snout is long (1 mm), almost one-third of the total length. The head with snout is as long as the prothorax or the elytra (Rees, 2007; van Emden, 2013). Females generally lay eggs within a kernel but they may lay multiple eggs per kernel and more than one larva can develop within a single kernel (Rees, 2007; USAID, 2011). Life cycle of *S. oryzae* may take only 26 to 32 days during hot summer months, but requires a much longer period during cooler weather. The eggs incubate for about 3 days and hatch into apodous larvae which eat their way into the germ of the grain (Adedire, 2001). The pupa is naked and lasts for an average of 6 days and the new adult remains in the seed for 3 to 4 days to harden and mature (Koehler, 2015). Adults make a small, circular emergence hole, as compared to large, and oblong emergence hole made by the wheat/grain/granary weevil (*S. granarius*) which is also 2 to 3 mm long, but has no light patches on the elytra and the punctures are elongated rather than round (van Emden, 2013).

2.11.8 Maize weevil (*Sitophilus zeamais* Motschulsky. 1865)

2.11.8.1 Description of maize weevil

Maize weevil, also called greater grain weevil is the most common pest of stored maize in most African countries. The adult *S. zeamais* is a small weevil measuring 2.5 to 4 mm long. It has a protruded rostrum or snout, uniformly coloured dark brown or reddish brown, used in chewing and boring into the grain. The prothorax and elytra are densely pitted with rows of microscopic circular holes. The legs are prominent, and the wings are well developed making them good fliers (Figure 1). The larva which feeds in the grain is a white, legless, thick-bodied grub (Kiritani, 1965).

Maize weevil prefers maize, but has also been reported as a pest of cassava, rice, sorghum, and wheat. Minor hosts include taro, soybean, common beans, wheat, adzuki bean and cowpea. Maize weevil causes substantial losses in maize or sorghum. Attack may start in the mature crop when the moisture content of the grain has fallen to 18-20%. Subsequent infestations in store result from the transfer of infested grain into store or from the pest flying into storage facilities, probably attracted by the odour of the stored grain. Re-use of sacks borrowed from neighbours or traders is a source of maize weevil infestation. In stored maize heavy infestations may cause weight losses of as much as 30-40%, although losses are commonly 4-5%. The Maize weevil is found in all warm and tropical parts of the world. In Africa it occurs in all sub-regions.

Sitophilus zeamais is described by van Emden (2013) as a 3.5 to 4.0 mm long beetle with large round punctures on the thorax. The head is protruded into rostrum, with a biting-chewing mouthpart type. According to Robinson (2005), the antennae of *S. zeamais* are elbowed and slightly clubbed. Chapman (2009) further describes the elytra as highly sclerotized that cover the hind wings. Female *S. zeamais* deposit their eggs in grain kernel which hatch into white grub-like and apodous larvae that feed inside the grain and excavate tunnels as they develop. This feeding habit causes most of the damage to the grains (Robinson, 2005; Anankware *et al*., 2012; Rugumamu, 2012). Golob *et al*. (2002) reported that the larva of *S. zeamais* pupates inside the kernel and the life cycle completes in about 35 days under favourable conditions of 27°C and 70% relative humidity (RH). The developmental and feeding activities of the weevils often lead to severe powdering and tainting of the grain with their excrements (Adedire, 2001). The infested grains are also rendered susceptible to cracking and mould infection as a result of respiration of the weevils that heats the grain and drives water vapour to other areas where it condenses to wet the grain, thereby reducing their market value (van Emden, 2013).

2.11.8.2 Scientific classification of Maize weevil

Kingdom:	Animalia
Phylum:	Arthropoda
Class:	Insecta
Order:	Coleoptera
Family:	Curculionidae
Sub-family:	Dryopthorinae
Genus:	*Sitophilus*
Specie:	*zeamais*

Binominal name: *Sitophilus zeamais* Motchulsky.

Plate I. Adult maize weevil (*Sitophilus zeamais* Motschulsky)

2.11.8.3 Distribution of maize weevil

The maize weevil *Sitophilus zeamais* Motschulsky, 1865 (Coleoptera: Curculionidae) can be found in the entire world's warm and tropical areas. It is the primary pest for maize, wheat, rice and sorghum. It can also grow in processed cereals, such as pasta, cassava, etc. (Pacheco and De Paula, 1995). It is also a pest of some solid cereal product thus forcing many farmers to sell their stored produce prematurely in fear of deterioration. In Nigeria, precisely Northern Nigeria it is the most notorious and common pest that causes uncertainty in food security since "tuwo masara" from maize is the staple food of this part of the country.

2.11.8.4 Biology of maize weevil

The adult weevils appear on maize in the field as soon as it reaches the roasting ear stage. Oviposition, however, does not begin until the ear becomes firm. At this stage, the female weevil chews a minute hole in the grain in which the eggs are deposited. The hole is sealed with a mucilaginous material secreted by the female (Hill, 2008). The eggs are white and oval in shape, measuring 0.7 mm by 0.3 mm, and each female may deposit as many as 5 eggs per day laying a total of 150 to 400 eggs during its life span (Bosque-Perez, 1992). The eggs hatch into tiny grubs in 4 to 9 days. Larval development last about 25 days under favourable conditions of temperature of 30^{o}C and 70% relative humidity but under unfavourable environmental conditions, the larval stage may last for up to 98 days (Mattah, 2001). Hatchability is about 90%, and first instar larval mortality can be as high as 30% at 50% RH (Arbogast 1991). The grub is white in colour with a brown head and strong jaws. Larvae are creamy white with a brown head and legless. They go through four instars before pupating within the kernel. During the four to five months of cold winter weather, the larva remains within the kernels. Pupation occurs within the grain, and the pupal stage lasts for 3 to 6 days. The newly emerged adult remains in the grain for a few days before it leaves it (Hugh, 1988; Chilio *et al*., 2004).

Maier*et al*. (1996), reported that under optimum laboratory conditions of 31^{o}C and 74% temperature and relative humidity, respectively.Maize weevil takes from 30 to 40 days to develop from egg to adult whereas unfavorable conditions such as temperatures above 32^{o}C with less than 14% maize moisture content it may extend to 110 days (Kiritani, 1965). Chilio *et al.* (2004) demonstrated that the weevil is unable to survive at temperatures above 32^{o}C. There are generally four to five generations per year in most grain storage facilities. Heated storage buildings may house twice that many generations. Adults live about four to eight months.

2.11.8.5Host range of maize weevil

The maize weevil has a host range similar to the rice and granary weevil, and although it is commonly found on maize, it can feed on most cereal grains, including wheat, barley, sorghum, rye, and rice. Maize weevils prefer whole grains but have been reported to feed on many processed grain products including pet food and pastas. They have a wider tolerance for host moisture content, even feeding on stored apples. Typically one egg is laid per kernel (Gomez *et al*. 1982), but on occasion more than one adult may emerge. If multiple eggs are laid, larvae compete with active aggression among the seed occupants (Guedes *et al*. 2010). Immature survivorship is only 18% (Throne, 1994).

2.12 *Sitophilus zeamais* Infestation and Damage on Maize Grains

Grain storage is important especially for period of scarcity (FAO, 1996). However grains inappropriately stored, suffer considerable losses in quality, quantity and viability from insect pests (Ayertey and Ohiagu, 1982). Weight loss, deterioration in quality, biochemical changes and contamination of grains due to infestation by insect pests has been reported (Lale and Ofuya, 2001). *S. zeamais* infests maize in the field before harvest which is mainly determined by the completeness of the husk covering the cob and continues in storage or through transportation (Bosque-Perez, 1992; Mejia, 2007). In the store, number of *Sitophilus zeamais* present at any time depends upon the initial population of the insect at harvest, the number of insects subsequently infesting the crop from elsewhere, and the rate of multiplication of the insects within the crop (Dobie, 1974). Though, the rate of multiplication of the insect depends upon the temperature and moisture content of the maize. It bores holes in the grain, consumes a large portion of the endosperm, destroys the germ and thus reduces the nutritive value and viability of the grain. In the process moisture is produce and this aid in caking and fungal growth of the grain, which constitutes quality loss. The grain is left with foul odour, the excrement of insects and micro-organisms leading to the production of mycotoxins thereby lowering the quality and also rendering it undesirable for consumption (Mejia, 2007).

2.13 Control of Insect Pests of Stored-Product

Several control measures are effective in the control of insect pests associated with stored cereals and cereal products (Panaglotakopulu and Buckland, 1991). Araya (2007) reported that the control of storage pests will vary with the type of facility, the pest species and the type of food supporting the infestation and the legal and economic methods of control available at a given time. Most often, however, an effective management effort always begins with a thorough inspection of the site to determine the source, type and importance of the infestation (Gwinner *et al.*, 1990; Araya, 2007). Therefore curative rather than preventive measures are more frequently employed in both large and small-scales grains storages to contain insect pests damage below severe economic injury level (Labeyrie, 1981) and control of stored-product pests is crucial to the sustainable production of cereal grains and cereal legumes in all the areas where it occurs.

2.13.1 Chemical control

Control of insect populations in stored food, feed stuffs and other agricultural primarily dependent upon continued applications of organophosphorus and pyrethroids insecticides and the fumigants methyl bromide and phosphine (Araya, 2007). Commercially available chemicals most commonly applied to control insects infestation in stored grains include organophosphates, carbamates and synthetics pyrethroids. These groups of insecticides have been used for over five decades to control insect pests both at the field and storage conditions. Many researchers have reported that the effective utilization of synthetic insecticides including fumigants, dusts or admixture of seeds and sprays for control of insects in general (Gwinner *et al.*, 1990; Golob, 1997; Araya, 2007).

Dusts formations of insecticides, which are sold ready for use usually contains 0.1-5% active ingredient (Gwinner *et al*., 1990*)*. These formations often contain addition, which increases the adhesive power of the active ingredients to the stored grains. Dust formations can be applied mixed with grains by shovel, on floors, flat surfaces and around the bottom of storage containers. Dusts should be mixed thoroughly and distributed all over the produce in order to achieve effective control of insects (Araya, 2007). Atleast 16 chemicals have been registered as fumigants, but because of concern for human safety, methyl-bromide, phosphine, methyl iodide, carbon disulfide and aluminium phosphate are the primary fumigants currently being used commercially for stored products (Lee *et al.*, 2003; Araya, 2007).

However, the main disadvantages of fumigants are that the treatments confers no residual protection against re-infestation, once the commodity is again exposed , and the fact that their repeated use for decades has disrupted biological control by natural enemies and lead to outbreaks of their insect species and sometimes resulted in the development of resistance to pesticides. It also has an undesirable effects on non-target organism, and fostered environmental and health concern (Subramanyan and Hagstram, 1995; White and Lessch, 1995). Moreover, use and production of methyl bromide are scheduled to end worldwide by 2020 under terms of the Montreal Protocol (TEAP, 2000). In addition, the uses of other insecticides in stored product protection are facing restrictions as a result of adverse eco-toxicity (Lorini *et al.*, 2007; Umoetok *et al.*, 2009; Mbata *et al*., 2009).

2.13.2 Cultural control

The principals involved in the cultural control of insect pests is purposeful manipulation of the environment to make it less favourable , thereby exerting economic control of the pest or at least reducing their rates of increase and damage (Araya, 2007). The development of cultural method requires a thorough knowledge of the life history and habits of the insect and the plant host, vulnerable stages of the insect pests' life cycle must be determined and storage practices must be altered to prevent attack, kill the pest, or slow down its rates of reproduction (Araya, 2007). Proper modification of storage practices has controlled many species of insect pests in the storage structures (Araya, 2007). Sanitation or store hygiene is the leading preventive tasks in insect pests control in stored grain stores, silos and cribs (Araya, 2007). Sanitation imparts its crucial role in preventing or reducing insect infestation in stored grains or foodstuffs. This method can be applied through removal of old grains, mechanically damaged grains, which attract secondary pests and residue of organic matter present in storage structure including sub-floor spaces, bins and old bags.

Manson and Obermeyer (2004) stated that a newly harvested product should never be stored with remainders of previous harvest as well as in used bags without cleaning. Thus, perfect storage hygiene is the basic prerequisites for successful storage and for the effectiveness of all on-going measures, like the use of insecticides or fumigants (Gwinner *et al*., 1990). Other cultural control methods most predominantly employed by small-scale farmers include storing unthreshed pods where the dry pod provides a physical barrier against oviposition (Abate and Ampofo, 1996).

Moreover, sun drying at regular intervals to protect the threshed seeds. For instance, Lale and Vidal (2003) reported on effects of simulated solar heat on oviposition , development and survival of *C. maculatus* and *C. subinnotatus* in stored ,at three high temperatures (40^{o}c, 45^{o}c and 50^{o}c) at a constant , low humidity (30% relatively). The uses of different storage methods like wooden bin are some of the feasible cultural practices (Abate and Ampofo, 1996, Kiruba *et al*., 2006). Research on tumbling containers and repeated sieving as control methods has produced encouraging results, but the applicability of these techniques to large-scale production remains to be proven (Myers *et al*., 2001).

2.13.3 Use of plant materials

With the increasing concern about the use of synthetic insecticides, the need to find alternatives that are readily available, affordable, less poisonous and less detrimental to the environment was apparent (Niber, 1994). Plant products and their secondary metabolites are receiving increasing attention in stored product management (Arthur, 1996; Zettler and Arthur, 2000; Haque *et al*., 2000). The use of plants, plant materials or crude plant extracts and oils for the protection of crops and stored products from insect pests is probably as old as crop protection itself (Thacker, 2002). Infact, before the successful emergence of commercial synthetic insecticides from the 1940s, botanical insecticides were the major global technology for insect pests control (Isman, 2008). In Africa the technology still has a major place in the arsenal of farmer's despites its decline elsewhere in the world (Cork *et al*., 2009). Several workers have evaluated the insecticidal, repellent or antifeedant and development inhibiting effects of various plant parts and plant products on *S. zeamais* with varying degrees of success (Obeng-Ofori *et. al*., 1998; Belmain *et al*., 2001; Udo, 2005; Asawalam *et al*., 2006; Arannilewa *et al*., 2006).

A wide range of plant materials as well as oils derived from plants have been used with some success in bruchid control (Cork *et al*., 2009). The efficacy of plant materials is highly variable even within plant species depending on variety, season, soil types and the way that the plant material used (whole dried products, powders extracts etc (Cork *et al*., 2009). The non-volatile cooking oils (e.g. maize, sunflower, cotton seed, groundnut, etc) and essential oils (West African Black pepper, ginger) can be used to coat pulses. All oils may create a surface on pulses that deters eggs lying and oil itself may coat eggs and kill them by preventing respiration (Cork *et al*., 2009). In the case of cooking oils, in the short term they do not affect the viability, palatability, cooking quality or physical appearance of pulses however, after lengthy storage periods all oils that are persistent are likely to become rancid. Although cooking oils are relatively expensive usually the cost for treating small quantities of pulses is well justified (Kitch and Giga, 2000).

Oparaeke and Bunmi (2006) reported that in Nigeria, cashew nut shell was highly toxic to insect pests like *C. subinnotatus* and *C. maculatus* and achieved 100% mortality within 72 hours at 2.5 and 5.0% concentration oviposition and progeny development of the insect were severely suppressed while seeds were protected from damage by the bruchid. Seed germination was, however, impaired at all concentration, suggesting that seed treated with cashew products may be sustainable for consumption but not be sustainable in planting stock. Despite the efficacy of wide range of botanical products against stored product insects, there are draw-back to their widespread usage. The main barriers being commercialization of botanical insecticides, sustainability of the botanical resources and standardization of chemically complex extracts (Murray, 2006).

The hazardous nature of synthetic insecticides leads to search for less hazardous and environment-friendly methods such as the use of botanicals in the control of insect pests. The practice of using natural sources against pests for storage of various household items dates back to the very earliest periods of known history (Karthikeyan *et al*., 2009). Rugumamu (2015) considers botanical method as an indigenous pest management for reducing damage caused by pests. Recently, the effects of different plant materials on repellency, adult mortality, oviposition, adult emergence, total development period, grain damage and seed germination were assessed bymany researchers (Rotimi and Evboumwam, 2012; Muzemu *et al*., 2013; Rugumamu, 2014, 2015). But most of the researchers concentrated on maize and cowpea grains, while a few worked on sorghum. Among the five plant powders tested by Suleiman *et al*. (2012), *Jatropha curcas* L., *Euphorbia balsamifera* L. and *Lawsonia inermis* L. were found to be more effective in protecting sorghum grains against *S. zeamais* infestation by resulting in total (100%) adult mortality within 28 days after treatment. They also reported absence of adult emergence when 20 g of sorghum grain was treated with 2 g of *J. curcas* leaf powder, which showed similar effect with that of the conventional insecticide (permethrin powder). Further, it was found that leaf powder of *J. curcas* applied at 10% (w/w) gave sorghum grain a complete protection against *S. zeamais* attack by resulting in zero weevil perforation index which was not significantly different

(P > 0.05) from permethrin powder (Suleiman *et al*., 2012). In a field investigation, it was found that extracts from *Cymbopogon nardus* and *Ocimum basilicum* had repellent activity against *T. castaneum* in threshed sorghum stored in store rooms in Kebbi State, northern Nigeria (Utono, 2013). Powders of *Allium sativum* L., *Capsicum frutescens* L. and *Zingiber officinale* Rosc were reported to have caused total (100%) adult mortality of *S. zeamais* in sorghum grains 14 days after introduction under laboratory condition (Suleiman, 2014). The spices were also found effective in reducing grain damage of sorghum from 53.30% in the control to 3.30 to 33.30% in the botanical treatments, depending on the concentration applied.

The little information gathered has revealed that morelaboratory investigations are required on those botanicals with insecticidal properties that have been tested and found effective against insect pests of other stored grains by some researchers (Musa *et al*., 2007; Ileke and Oni, 2011; Khaliq *et al*., 2014; Rugumamu, 2014, 2015; Tilahun and Daniel, 2016; Oni *et al*., 2016). This would likely contribute to integrated pests management (IPM) strategies in controlling insect pests of stored sorghum by using botanicals incorporated with other alternatives such as improvement of local storage structures which may conceivably minimize the use of synthetic insecticides and at the same time reduce damage to stored grains (Suleiman and Rugumamu, 2017).

2.13.4 Use of resistant varieties

In the absence of sustainable remedy to insect pests' attack in stored maize grains, evidenced from increased reports on susceptibility of maize varieties to storage pests (Arnason *et al*., 1994; Adedire *et al*., 2011), urgent efforts are required to investigate the maize characters that have relationships with resistance to *S. zeamais*. Resistance in stored maize to *S. zeamais* attack has been attributed to a number of factors (Arnason *et al.*, 1994; Ivbiljaro, 2009; Siwale *et al.*,2009). Some workers have already hinted that resistance in stored maize to insect attack is related to some physical, chemical and biochemical characteristics of a maize variety (Sing and Mc Cain, 1963; Dobie 1977; Adedire *et al*., 2011). Grain color, shape, size, hardness, protein, moisture, sugar and phenol have been reported as the bases of resistance (Dobie, 1974; Osipitan and Odebiyi, 2007; Tongjura *et al*, 2010). Garcia-Lara*et al.*, 2004 found that increased phenolic acid, structural protein and diferulates of grain hull increased resistance to *S. zeamais*. Ivbiljaro (2009); Siwale *et al*. (2009) and Arnason *et al*. (1994) reported that some Mexican landraces of maize were resistant to *S. zeamais* and attributed the resistance to the phenolic acid content of the maize. Similarly, Bergvinson (2001) reported that there were strong correlations between the insect resistance, kernel hardness and elevated levels of diphenolic acids located within the pericarp of the kernel. Kernel hardness as a resistance mechanism was only limited by moisture content. Moisture content above 16% renders resistant maize genotypes susceptible. This highlights the importance of grain conditioning before storage. Incidentally, the bases and locus of maize grain resistance to stored products insects is still debatable (Dobie, 1974; Shafique and Chaudry, 2007; Astuti *et al*., 2013; Chinaru, *et al*., 2015) and vary from insect to insect.

2.13.4.1 Maize cell wall resistant properties

Maize genotypes with elevated levels of cell wall cross-linking components in the pericarp are known to be more resistant to the maize weevil. The principal cell wall components associated with this resistance are phenolic acids, diferulates and structural proteins, which have strong negative correlations with susceptibility parameters and a positive correlation with grains hardness (Garcia-Lara *et al*., 2004). Tripsacorn, hybrid maize developed from a perennial teosinte, *Zea diploperennis* L. and eastern gamagrass, *Tripsacum dactyloides* L., may have resistance to storage insect pests that could be incorporated into commercial maize hybrids (Throne and Eubanks, 2002). Whole Tripsacorn grains are not attacked by *S. zeamais*. The grains are difficult to grind because of 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). Chicken avidin has been known to possess insecticidal property causing mortality in many species of stored-product insects by preventing the absorption of dietary biotin (Flinn *et al*., 2006). The avidin gene has been incorporated into maize plants and avidin maize grains are resistant to insects, especially when the grains are ground into a meal or powder. When avidin content in transgenic maize grains reached about 100 ppm or higher, it inhibited the development of almost all insect pests that damage grains during storage, including the maize weevil, *S. zeamais* (Flinn *et al.*, 2006).

According to Ivbiljaro (2009), resistant maize cultivars can reduce losses due to weevil infestation but no maize grain was immune to attack by the weevil. The use of resistant varieties alone may not provide a permanent solution to the problems of maize storage but rather may contribute to integrated pest management (Gudrups *et al*., 2001; Credland *et al*., 2003).

2.13.5 Use of inert materials

Inert dusts are non-toxic materials that can be mixed with the produce to control stored-product insect pests. Inert dusts can also be used to disinfect storage facilities before new produce is brought for storage. These dusts do not deteriorate or break-down and, therefore, provide long-term control of insect pests and are non-toxic, and therefore completely harmless to humans and mammals. In India during the 1960, about 70% of the grain was treated with activated Kaolin clay. Egypt also used rock phosphate as a grain protectant. Some local farmers in West Africa use ashes, lime and sand dust to protect grains against pest infestation (Obeng-Ofori and Boating, 2008).

Soil and clay dust is often used by birds that take "dust baths" to free themselves of mites and other parasites. This observation may have led the Chinese to use diatomaceous earth (diatomite) for the pest control 4000 years ago (Allen, 1972). Inert dust commonly used in storage structure against storage insect pests include: non silica dust as rock phosphate, lime and lime stone , sand , wood ash ,tobacco ash and saw dust, and clays; diatomaceous earth, and silica aerogels (Golob *et al*., 2002). Insects exposed to inert dusts are subjected to desiccating and other physiological stresses (Fields, 2000). Farmers have practice admixing inert materials and organic materials with stored grains for many decades to prevent insect infestation (Gwinner *et al*., 1990, Golob, 1997). The protection success depends upon the effect of the preservation on the grain, the rapidity of its action, the period of storage and proper mixing (Golob, 1997). The admixture of finely ground silica-based dusts for stored –products insect control is not a new concept. During 1930s and 40s, commercials products such as "Naaki" in Germany and "Neosyl" in England were marketed for stored-products protection (Parkin, 1994). The recommended rate was 10 grams per kilogram of grains (Jenkins, 1940). In these dusts, quqartz was the active ingredient (Subramanyam and Roesli, 2000). Quartz is made up of crystalline silica (Goldsmith *et al*., 1997).

Among all the inert dusts, diatomaceous earth appears to be the most promising for the control of stored-product insects (Kabir, 2013). Diatomaceous earth is obtained from deposits of diatomite, fossilized sedimentary layers of microscopic planktons called diatoms (Quarles, 1992). They are either of marine or fresh water origin. According to Korunic (1997), the tapped density (grams per litre) among DEs ranged from 195-679, pH from 4.4-9.2, and the amorphous silica (Sio2) content was 70% or greater. The mean particle sizes range from 7-16.4 micro meters (Korunic and Ormesher, 2000). Diatomaceous earths are excellent absorbents (Calvert, 1930). Ebeling and Wagner (1961) reported that the lipid absorption ability is related to effectiveness of the DE. The commercial diatomaceous earth (DE) formulations marketed now predominantly are made up of amorphous silica and contain little (<40%) or no crystalline silica (Subramanyam and Roesli, 2000). Furthermore, it has been reported that the efficacy of DEs could be enhanced when combined with low doses of insecticides (Korunic, 2001;Stathers *et al.*, 2003; Athanassiou *et al*., 2004, Vayias and Stephon, 2009). It has been reported that the use of DEs in combination with pyrethroids seems to offer good potential in stored product protection. Moreover, the addition of small doses of low mammalian toxicity may reduce the required application rate of a given DE (Athanassiou, 2006). An insecticide dissolves in an organic solvent and can be formulated on silica gels (Subramanyam and Roseli, 2000). For instance, the addition of solvent alone (hexane) changed the bulk density of gasil from 50g/1-10g/l, but this change in bulk density did not increases the potency of the pyrogenic silica gel,cab-o-sil M5 against *T. casteneum* (Le Patourel and Singh, 1984).

Stored-product insects are perhaps the most commonly tested species with a variety of DE dust (Ebeling, 1971; Golob, 1997; Korunic, 1998; Subramanyam and Rorsli, 2000; Stathers *et al*., 2004; Demissie *et al*., 2008; Kabir, 2013). Species listed as being susceptible to DE include; cigarette beetle (*Lasioderma serricorne*), drug store beetle (*Stegobium paniceum*), Lesser grain borer (*Rhyzopertha dominica*), flat grain beetle (*Cryptolestes ferrugineus*), saw toothed grain beetle (*Oryzaephilus surinamensis*), merchant grain beetle (*Oryzaephilus mercator*), grain weevils (*Sitophilus granarius*), rice weevil (*Sitophilus oryzae*), Dermestid beetles, warehouse beetle (*Anthrenus verbasci*), yellow and dark mealworm beetle (*Tenebrio molitor*), red flour beetle (*Tribolium casteneum*), confused flour beetle (*Tribolium confusum*), cadelle (*Tenebroides mauritanicus*), Angoumois grain moth (*Sitotroga cerealella*), Mediterranean flour moth (*Ephestia kuehniella*), Indian meal moth (*Plodia interpunctella*), larger grain borer (*Prostephanus truncatus*), cowpea bruchids (*Callosobruchus maculatus*) and bean weevils (*Acanthoscelides obtectus*)(Subramanyam and Rorsli, 2000).

2.13.5.1 Current Status of the use of inert dusts for stored-product pest control

The use of inert dusts is one of several innovative, reduced-risk or biorational and physical methods for stored-product insect pest management (Subramanyam and Roesli, 2000). Inert dusts are non-toxic dry powders of different origins that are chemically un-reactive in nature and, which can be mixed with the produce to control stored-product insect pests. Inert dusts can also be used to disinfect storage facilities before new produce is brought for storage. Inert dusts do not deteriorate or break-down and, therefore, provide long-term control of insect pests and are completely harmless to humans and mammals. Clays were used as grain protectant in North America and Africa over thousands of years ago (Ebeling, 1971; Golob and Webley, 1980). The research on inert dusts against storage pests started in the 1920s (Headlee, 1924) and there have been several reviews and research papers on the subject since then (Ebeling, 1971; Fields and Muir, 1995; Golob, 1997; Korunic, 1998; Subramanyam and Roesli, 2000). The main advantages of inert dusts are that they are non-toxic and provide continued protection of produce. They do not affect baking quality when applied to grains and are compatible with other control techniques such as heat treatment, fumigants and aeration (Bridgeman, 2000) and host-plant resistance (Chanbang *et al*., 2008). Inert dusts are suitable for disinfesting empty storage facilities and for grain treatment.

2.13.5.2 Mode of action of inert dusts

Inert dusts cause desiccation in insects by destroying the wax layer in the cuticle. Insects die of desiccation when they lose 60% of their water i.e. 30% total body weight (Ebeling, 1971). Inert dusts such as silica aerogels can absorb as much as three times their own weight in oils. As insects move through the grains the inert dusts absorb waxes from the insect cuticle. Because storage insects live in very dry environments with limited access to free water, water retention is crucial to their survival. Also by their small size insects have a large surface area in relation to their body weight and therefore have greater problems retaining water than large animals. The wax layer in the insect cuticle consists of an ordered monolayer of lipid, and determines the permeability characteristics of the cuticle. Indeed, the wax layer that inert dusts destroy is one of the main mechanisms insects use to maintain water balance. The presence of powdered dusts between grains also interferes with the movement and respiration of insects. Dusts may also affect the oviposition behavior and sensory perception in insects. In summary, the modes of action of inert dusts include the following: (inert dusts block insect spiracles and insects die from asphyxiation, inert dusts lodging between cuticular segments increase water loss through abrasion of the cuticle, inert dusts absorb water from the insect's cuticle, insects may die from ingesting the dust particles, and inert dusts absorb the epicuticular lipids of insects leading to excessive loss from the cuticle (Subramanyam and Roesli, 2000).

2.13.5.3 Susceptibility of storage pests to inert dusts

Insects differ in their susceptibility to inert dusts (Kabir *et al*., 2009). In general, *Tribolium* species are the most resistant and *Cryptolestes* species are the least resistant. The capacity of insects to survive dry conditions is correlated with resistance to inert dusts. The effectiveness of inert dusts may be determined by such factors as greater capacity of insects to gain water from their food, greater water re-absorption during excretion, less water loss through the cuticle, type of cuticular wax or amount of movement through grain. The effectiveness of inert dusts may also depend on the size of the particles, the finer the particle size, the more active they are. Generally, DEs are more effective against insects at higher temperatures and lower grain moisture contents (Fields and Korunic, 2000). The condition of the grains may affect efficacy of inert dusts. Most DE dusts are more effective on clean grains than in cracked grains (McGaughey, 1972).

2.13.6 Types of inert dusts

There are four main types of inert dusts available for use against stored products insect pests. These are earth, diatomaceous earth, silica aerogels, and non-silica dusts (Antonides, 1977).

2.13.6.1 Earth

Earth includes clays, sand, paddy husk ash, wood ash and volcanic ash (Subramanyam and Roesli, 2000). These materials have been applied traditionally in some developing countries as stored-product protectants and are usually used as a layer on top of stored seeds (Golob and Webley, 1980). These materials are effective at high rates >10 g per kilogram of grains (Subramanyam and Roesli, 2000). Local farmers in West Africa including Ghana, Benin, Senegal, Niger and Mauritania still use varying levels of fine sand and ashes from different plants to protect stored grain against insect pest infestation (Obeng- Ofori, 2007). Research is being carried out in many parts of Africa to replace these traditional dusts with more effective synthetic silica dusts that work at lower rates (Golob, 1997; Obeng-Ofori, 2007).

2.13.6.2 Diatomaceous earth (silica dusts)

Diatomaceous earth is used in a number of countries for stored-product protection. The admixture of finely ground silica-based dusts with quartz as the active ingredient isused as an industrial absorbent and as non-toxic insecticide to control stored-product and household pests is an ancient practice during the 1930s and 40s, because, commercial products such as 'Naaki' and 'Neosyl' were marketed in Germany and England, respectively as grain protectants (Jenkins, 1940; Parkin, 1994). The commercial DE formulations currently available are predominantly made up of amorphous silica and contain little or no crystalline silica (Subramanyam and Roesli, 2000). Diatomaceous earth is the fossilized siliceous remains of diatoms that were deposited during the Cenozoic era. Diatoms are microscopic unicellular aquatic plants closely related to brown algae that have a fine shell made of silica ($SO_2 + H_2O$). The main constituent of these deposits is therefore silica (SO_2), although there are small amount of oxides of other minerals such as aluminum, iron, lime, magnesium and sodium.

2.13.6.3 Mineral (non-silica) dusts

Mineral (non-silica) dusts have been tested for their efficacy as grain protectants. Several workers have reported the use of different types of mineral dusts for the control stored-product insect beetle and moth pests (Davis *et al.*, 1984; Davis and Boczek, 1987). Typical mineral dusts include calcium carbonate (lime), rock phosphate, zinc oxide, magnesium oxide and dolomite.

2.13.6.4 Silica gels

Silica gels are made up of 99.5% silicon dioxide. Silica gels are dusts that contain extremely small particles of less than 3 micrometers with a bulk density in the range of 72-450 g/L and specific surface in the range of 200-850 m^2/g (Quarles, 1992). Silica gels are capable of absorbing about 1.9-3 g of linseed oil per gram gel and this makes them more effective than DE dusts (Subramanyam and Roesli, 2000). There are three main types of silica gels namely, precipitated silica gel, silica aerogel and fumed silica. In general silica gels could become suitable alternatives for grain protection in most developing countries where access to quality insecticides is limited or where local expertise on the use of synthetic insecticides is lacking. Currently, some commercial DE products such as Dryacide and Protect-It contain silica gels to improve their effectiveness (Fields and Korunic, 2000).

2.13.7 Commercially available inert dusts

Commercially, a number of inert dusts especially diatomaceous earth products are registered as residual grain protectants and for use in crack and crevice treatment and disinfestations of storage structures before new grain is stored in a few countries, especially in the USA. Several products have been registered by the US Environmental Protection Agency. Australia has made considerable progress in integrating DE with aeration and fumigation (Bridgeman, 2000). In Germany, SilicoSec has been a registered diatomaceous earth since 1997. It is a natural silica powder based on fossilized diatom algae and contains 96% inert amorphous SO_2 with particle size between 13-15 microns. SilicoSec controls all stored grain insect pests including weevils, beetles, borers and moths. Even species resistant to chemical insecticides are controlled. The sharp-edged silica particles destroy the wax layers of the insect cuticle and quickly absorb lipids and body fluids leading to desiccation and death. In the UK, two products of diatomaceous earth are commercially available for use in stored-product protection. These are Protect-It and Dryacide. These products have been found to be effective in protecting grain against insect pest damage for small-scale on-farm storage systems in Zimbabwe. The two products have been evaluated in a community-wide basis in Tanzania and the treated products include maize, sorghum and beans. However, field tests in Malawi using different rates of Dryacide, Protect-It and a precipitated silica gel (Gasil 23D) failed to provide long term protection of shelled or cob maize against infestation by *Tribolium castaneum* (Herbst) and *Sitotroga cerealella* (Olivier) (Gudrups *et al*., 2000). Other examples of commercial inert dust products include Perma-guard (DE), Dri-Die (DE and silica aerogel), Sipernat (silica aerogel) and SG-67 (silica aerogel). In India during the 1960, about 70% of grain was treated with activated Kaolin clay. Egypt also used rock phosphate as grain protectant. Some local farmers in West Africa use ashes, lime and fine sand dusts as grain protectants.

2.13.8 Diatomaceous earth as insect pests' control

Diatomaceous Earth, also known as DE or diatomite has been used as insecticide since antiquity with China indicating its use for over 4,000 years ago (Quarles, 2007). Diatomaceous earth is a naturally occurring, soft, siliceoussedimentary rock that is easily crumbled into a fine white to off-white powder. It has a particle size ranging from less than 3 micrometers to more than 1 millimeter, but typically 10 to 200 micrometers. Depending on the granularity, this powder can have an abrasive feel, similar to pumice powder, and has a low density as a result of its high porosity. The typical chemical composition of oven-dried diatomaceous earth is 80 to 90% silica, with 2 to 4% alumina (attributed mostly to clay minerals) and 0.5 to 2% iron oxide (Antonides, 1997). Diatomaceous earth consists of fossilized remains of diatoms, a type of hard-shelled algae. Diatomite forms by the accumulation of the amorphous silica (opal, $SiO_2 \cdot nH_2O$) remains of dead diatoms (microscopic single-celled algae) in lacustrine or marinesediments. The fossil remains consist of a pair of symmetrical shells or frustules (Antonides, 1997). It is also used as a filtration aid, mild abrasive in products including toothpaste, mechanical insecticide, absorbent for liquids, matting agent for coatings, reinforcing filler in plastics and rubber, anti-block in plastic films, porous support for chemical catalysts, cat litter, activator in blood clotting studies, a stabilizing component of dynamite, and a thermal insulator.

2.13.8.1 Mode of action of diatomaceous earth

Inert dusts generally, including diatomaceous earth kill arthropods by removing or absorbing the epicuticular lipid layers causing excessive water loss through the cuticle (Zacher and Kunike, 1931; Ebeling, 1971), loss of body water causes death within hours or days (Subramanyam and Roesli, 2000). DEs are chemically un-reactive and kill by physical rather than chemical means (Allen, 2000). Due to desiccation and water loss insects become knocked down and they are more vulnerable to death (Korunic, 1997). It is unclear whether desiccation causes death or leads to some physiological changes that result in death (Vrba *et al*., 1983). In principle insects died losing about 30% of their body weight (Ebeling, 1971) or nearly 60% of the body water (Arlian, 1979). Mbata (1994) pointed out that insects' movement through DE treated seeds and egg laying on treated surfaces caused accumulation of considerable amounts of DE on the ovipositors. Such accumulation caused the ovipositor to dry off and ultimately leading to blockage and interruption of the process of egg-laying.

Diatomaceous earth has long been known as a potentially useful grain protectant. Because it is safe to use, does not affect the end-use quality of grain, provides long term protection, and is comparable in cost to other methods of grain protection (Korunic *et al*., 1996). DE is also non-toxic and does not leave residues or contaminants in the environment (Ebeling, 1971; Fabiane *et al*., 2005).

Despite the numerous advantages of DEs, their use to control stored-product insects remains limited(Fields and Korunic, 2000). The problem with its use is that it affects physical properties of grains such as grain bulk density and grain flow ability (flow speed) (Korunic *et al*., 1996; Golob, 1997). Generally the efficacy of DE decreases with increase in humidity and grain moisture content (Subramanyam and Roesli, 2000).Another factor that restricts the wider use of Diatomaceous earth is its varying efficacy on different target species (Fields and Korunic, 2000; Athanassiou *et al*., 2005a), or even among different life stages of the same species (Vayias and Athanassiou, 2004) or different strains (Arnaud *et al*., 2005).

2.13.8.2 Diatomaceous earth current status and usage in storage product pests control

The commercial exploitation of DE for pest control did not occur until the 1950's (Quarles, 1992). Arthur and Brown, (1994) evaluated the effectiveness of commercial formulation of DE Insecto as a surface application to stored peanuts. Adults of *T. castaneum* were not found in peanuts 2 and 4 months after treatment. DE is effective against several beetle species in several grain commodities such as *Sitophilus oryzae* (Athanassiou, 2005a), *Tribolium confusum* (vayias and Athanassiou, 2004; Athanassiou *et al*., 2005a and b; Athanassiou, 2006; Kabir *et al*., 2011; Kabir, 2013); and *Rhyzopertha dominica* (Kavallieratos *et al*., 2005; Kabir *et al*., 2013). Ling *et al*. (1998) also compared several doses of commercial formulations of DE to control *R. dominica* in store rice. They concluded that 500g/ton presented a satisfactory control, but only at rate of 700 g/ton that suppression of progeny production was achieved. Pinto Jr. (1994), tested four dosages of DE in the laboratory, he obtained 78% mortality for *Sitophilus* spp and 100% for *Cryptolestes* spp respectively, by 9^{th} and 19^{th} days after treatment. Diatomaceous earth is particularly effective against stored product insects which tend to have a large surface to volume ratio and feed on dry grain. Research into optimal methods of DE use for grain storage pest management has been undertaken and DEs are registered for use as grain protectant in Australia, Brazil, Canada, China, Germany, Japan, Saudi Arabia, and the US (Stathers *et al*., 2004).

Diatomaceous earth is used as an insecticide, due to its abrasive and physico-sorptive properties (Fields *et al*., 2002.). The fine powder absorbs lipids from the waxy outer layer of insects' exoskeletons, causing them to dehydrate. Arthropods die as a result of the water pressure deficiency, based on Fick's law of diffusion. This also works against gastropods and is commonly employed in gardening to defeat slugs. However, since slugs inhabit humid environments, efficacy is very low. It is sometimes mixed with an attractant or other additives (Lartigue and Rossanigo. 2004; Fernandez *et al*., 1998). It is commonly used in lieu of boric acid, and can be used to help control and possibly eliminate bed bug, house dust mite, cockroach, ant and flea infestations (Faulde *et al*., 2006). In order to be effective as an insecticide, diatomaceous earth must be uncalcinated (i.e., it must not be heat-treated prior to application) (Capinera, 2008) and have a mean particle size below about 12 µm (i.e., food-grade). Although considered to be relatively low-risk, pesticides containing diatomaceous earth are not exempt from regulation in the United States under the Federal Insecticide, Fungicide, and Rodenticide Act and must be registered with the Environmental Protection Agency (EPA, 2013).

Rojht *et al.* (2010) evaluated the effect of diatomaceous earth of different origin, and at different temperature and relative humidity against adults of *Sitophilus oryzae* in stored wheat. They found out that the mortality of adults increased with increasing dose rates and days of exposure. In all the samples the mortality of *Sitophilus oryzae* adults at the dose level of 900ppm at 21 days of exposure was above 90%. In another study, standardized testing for diatomaceous earth was evaluated by four laboratories against laboratory reared cultures of 7 to 21-day old unsexed adult *Sitophilus oryzae* and *Tribolium castaneum* and the results from the four laboratories were generally in concurrence (Fields *et al.*, 2002).

Shayesteh and Ziaee (2007) investigated the insecticidal efficacy of diatomaceous earth against 7-14 day adults of *Tribolium castaneum* in wheat. They found that mortality increased with increase in days of exposure with further observation that adults in treated wheat had their reproductive potential suppressed when compared with those in untreated wheat. Similar findings were reported by Wakil *et al.* (2005) when they evaluated the insecticidal efficacy of the diatomaceous earth formulation SilicoSec® against the adults of *Tribolium castaneum* at laboratory scale. The experiment was conducted on wheat grains, by treating them at dose rates of 75, 100 and 125ppm at 30oC and 60% R.H. The insect mortality was recorded after 14 and 21 days exposure interval, and emergence of 10 progeny examined after 56 days. Biological and environmental parameters also impact on product efficacy (Arthur, 2002; Kljajic *et al.* 2006). Contrary to this, Vardeman *et al.* (2007) found that exposure interval and temperature had no effect on adult survival or progeny production, although the study was based on surface applications of diatomaceous earth and not homogenized to the entire grain.

Diatomaceous earth at high dosages were found effective against *Tribolium castaneum* based on findings by Marsaro Junior*et al.* (2006) when they evaluated the effectiveness of different dosages of diatomaceous earth to control this insect pest in stored corn in the state of Roraima. Likewise Chanbang *et al.* (2007) reported increased mortality with increase in exposure period and that the two diatomaceous earth commercial products did not completely suppress *Rhyzopertha dominica*on rough rice. They recommended combination treatments with another insecticide to give complete control.

In a study by Baldassari *et al.* (2008) where they evaluated the insecticidal efficacy of a diatomaceous earth formulation against a mixed age population of adults of *Rhyzopertha dominica* and *Tribolium castaneum* as function of different temperature and exposure time, they found that although the insecticide Protector® based on diatomaceous earth was effective it did not attain complete mortality against the age admixture of the populations of the two species of grain pests. Mvumi *et al.* (2004) carried out field assessments of the efficacy and persistence of diatomaceous earth dust admixed with sorghum, maize and cowpeas to protect the grain against insect pests in three agro-ecological zones of Zimbabwe for two consecutive storage seasons. Their findings indicated that diatomaceous earth formulations were effective and persistent grain protectants against major storage pests attacking sorghum, maize and cowpeas for storage periods of 40 weeks in the climatic conditions found in Zimbabwe, although this was also closely linked to the application concentration and commodities under protection.

Under the most ideal situations where best practices are followed, the least tolerant species (saw-toothed grain beetle) can be killed within 2 weeks and the most tolerant (grain weevil) within 5 weeks when using diatomaceous earth making it an ideal insecticide for treating empty stores when used as part of an integrated strategy as revealed by an efficacy study of diatomaceous earth, applied as structural treatments, against stored product insects and mites (Cook *et al.* 2004; Cao *et al.* 2006). Suppression of progeny emergence and infestation by rice and maize weevils can be achieved using diatomaceous earth (Arthur and Throne, 2003; Arnaud *et al.* 2005; Wakil *et al.* 2006; Lorini and Beckel, 2006).

The abrasive action of diatomaceous earth enhances entomopathogenesis as exhibited by *Beauveria bassiana* and *Metarhizium anisopliae against Tribolium spp. Rhyzopertha dominica* and *Sitophilus oryzae* after the insect cuticle had been damaged and further increasing conidial attachment (Akbar *et al*. 2004; Athanassiou, 2005 a and b; Kavallieratos *et al.,* 2006). Athanassiouet *et al.* (2006) investigated diatomaceous earth formulations enhanced with soil bacteria metabolite Abamectin and plant extract Bitterbarkomycin against *Prostephanus truncatus, Rhyzopertha dominica, Sitophilus oryzae* and *Tribolium castaneum* on maize and wheat and found that complete adult mortality and progeny suppression was achieved with low concentrations of these formulations and therefore could be used with success against stored-grain beetle species, at very low application rates ranging from 75ppm to 125ppm.

Similar results of potential combination treatments were also reported by Chintzoglou *et al.* (2008) when they studied the insecticidal effect of spinosad dust, in combination with diatomaceous earth, against two stored-grain beetle species – *Sitophilus oryzae* and *Tribolium confusum* in maize and wheat. The mix of two or three diatomaceous earth formulations is generally more effective at low dose rates than the application of one diatomaceous earth formulation against major stored-grain beetle species - *Rhyzopertha dominica*, *Sitophilus oryzae*, and *Tribolium confusum* as found out by Athanassiou *et al*. (2007) when they investigated insecticidal effect of three diatomaceous earth formulations - Insecto®, PyriSec®, and Protect-It® when applied alone or in combination, against three stored-product beetle species on wheat and maize. Korunic *et al*. (1996) investigated the long term effectiveness of DE and deltamethrin admixture against *Sitophilus oryzae*, *Rhyzopertha dominica*and *Tribolium castaneum* and found that the admixture provided 100% population reduction of all the three species for up to 12 months with little or no progeny produced.

The foregoing studies indicate that the efficacy of diatomaceous earth against insect pests when used alone is hinged on large quantity applied and longer time of exposure. The limitation associated with high dose is reduced grain flowability and bulk density leading to lower grain grading. The prolonged exposure period required for appreciable efficacy of diatomaceous earth against *S. zeamais* provides sufficient time to the rapidly multiplying insect pest to inflict more damage to the grain as the larval stage occurs inside the grain which is not easily accessible to diatomaceous earth dust. Application of diatomaceous earth in combination with other grain protectants reduce the limitations noted above in addition to increased efficacy against the target insect pests.

2.13.9 Overview of Effects of Chemical Insecticides in Grain Protection

The use of chemical insecticides in grain protection spans over many years. Residual chemical grain protectants, chiefly organophosphate, pyrethroid and carbamate insecticides have been used on a world-wide scale in management programs of insect pests in stored raw agricultural commodities (Arthur, 1996). Halliday (1989) indicated that potential hazards to consumers from contamination of food with pesticide residues are currently a major public concern in many countries. This has led to pressure on governments to tighten legislation covering use of chemical insecticides and increase the requirements for research data before uses for individual compounds can be allowed. Most pesticide residues detected in food grains arise from contact chemical insecticides or fumigants, deliberately applied to protect the grain from postharvest insect attack. The ranges of compounds used for this purpose are mostly organophosphates such as Malathion, pirimiphos-methyl, fenitrothion and chlorpyrifos methyl, or pyrethroids such as permethrin, deltamethrin and bioresmethrin.

Although assessments of potential hazards to consumers have previously centred on single insecticide, concern has also been expressed about possible additive or interactive effects of pesticide combinations and of particular importance that relate to grain protectants, where combinations of pyrethroids and organophosphates are being used increasingly to provide protection for food grains (GIFAP, 1988). There is need for environmental protection and remediation to reduce possible impact of pesticide pollution by minimizing their use among other measures (Kennedy and Devereau, 1994). Avino *et al.* (2011) noted that although pesticides are widely used in agriculture, they and in particular the relative residues in foodstuffs, water and atmosphere, may cause remarkable sanitary problems due to the harmful effects and their spread in waters and atmosphere can produce undesired effects on various organisms and/or water contamination.

2.13.10 Use of Malathion powder in the control of Sitophilus zeamais

Malathion with chemical name of diethyl (dimethoxy phosphinothioyl) thiobutanedioate is a non-systemic, wide spectrum insecticide. It was one of the earliest organophosphate insecticides developed (introduced in 1950). Malathion is a general use pesticide widely used in agriculture, residential landscaping, public recreation areas, and in public health pest control programs such as mosquito eradication(Bonner *et al*.,2007*)*.It control broad spectrum of insects including: ants, aphids, fleas, fruit flies, hornets, mites, mosquitoes, moths, spiders, thrips, ticks, wasps, and weevil (EPA, 2006). Malathion is also known as carbophos, maldison and mercaptothion. Trade names for products containing Malathion include Celthion, Cythion, Dielathion, Karbofos, Maltox, El 4049, Emmaton, Fyfanon and Exathion among many others. Malathion may also be found in formulations with many other pesticides (Howard and Blomquist, 2005; Cannon and Ruha, 2013). It protects grains in storage against damage from confused flour beetle, granary weevil, saw-toothed grain beetle, flat grain beetle, rusty grain beetle, lesser grain borer and Indian meal moth (Floyd, 2014). The use of inert dust, with conventional insecticides has been explored to determine antagonistic, additive, or synergistic effects (Subramanyam and Roesli, 2000).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Site

Three experiments were conducted for a period of sixteen (16) months, where the first and second experiments were conducted from September, 2016 to August, 2017, while the third experiment was conducted from September, 2017 to December, 2017 in the Laboratory of the Department of Crop Protection, Modibbo Adama University of Technology, Yola. Yola is located in the Northern Guinea Savannah Agro-Ecological Zone of Nigeria at latitude 90^o 14`N, longitude 12$^o$ 28`E and altitude 190.5m and has the minimum and maximum rainfall,temperatures and relative humidity of 0.80 and 4.92ml; 27^{o}C and 42^{o}C and 35% and 75%, respectively (DMSY, 2017).

3.2 Sources of Experimental Materials

3.2.1 *Sources of maize genotype, malathion and raw diatomaceous earth*

A total of twenty five (25) maize genotypes, comprising twenty (20) improved ones acquired from the Institute for Agricultural Research (IAR) Samaru, Zaria, Kaduna State, viz; SAMMAZ 11, SAMMAZ 13, SAMMAZ 14, SAMMAZ 15, SAMMAZ 16, SAMMAZ 17, SAMMAZ 18, SAMMAZ 19, SAMMAZ 20, SAMMAZ 21, SAMMAZ 22, SAMMAZ 25, SAMMAZ 26, SAMMAZ 27, SAMMAZ 29, SAMMAZ 30, SAMMAZ 33, SAMMAZ 34, SAMMAZ 37 and SAMMAZ 38. Five (5) local cultivars sourced from Adamawa State Agricultural Development Programme (ADP) viz; Baleji, Bataji, Bodeji, Daneji, and Saksi were sourced from the open market in Jimeta, Adamawa State, Nigeria.Malathion powder was purchased from an agrochemical dealer in Jimeta town, Adamawa State while Raw Diatomaceous Earth (RDE) was obtained locally from Diatomaceous Earth mines in Bularafa village, Gujba Local Government Area, Yobe State, Nigeria.

The diatomaceous earth was supplied in a form of crude soft chalky rock (Plate III). The rock was milled finely in the laboratory using mortar and pestle and was then sieved through a mesh of 0.20 mm (Laboratory Test Sieve; BS410/86) to obtain a powdery consistency. The fine powder was analyzed for pH and tapped density in accordance with methods described by Korunic (1997). Mineral composition was analyzed in the Mineralogy Laboratory of the

Department of Geology, University of Maiduguri by X-ray florescence method on Minimate (Panalytical Company, UK).

3.2.1.1 Characteristics of different maize varieties

SAMMAZ 11 - Old name: TZL Comp.1-w; Origin/source of variety: IITA, Ibadan; Type of variety: composite, Pedigree: TZB-SR×7STR inbreds (1188,5012,9091,9432 and 9849; Morphological characteristics: Tall with high ear position, white grains; Adaptation: Lowland tropics and savanna zones; Days to maturity: intermediate- Late maturity (100-120days); Potential yield: 5t/ha; Pests/Diseases tolerance: Moderate levels of resistance to Striga hermonthica, resistance to maize streak virus; Outstanding characteristics: Striga resistance, high yield potential, suitable for inter- copping; Year of release: 2001.

SAMMAZ 13 - Old name: 95 TZEE-Y; Origin/source of variety: IITA-WECAMAN; Type of variety: Composite; Pedigree: TZEE-YPOP$_x$POP 146 EE-Y; Morphological characteristics: Tall 155cm, yellow grains; Adaptation: Lowland tropics and savanna zones; Days to maturity: Extra early (80-85days); Potential yield: 4t/ha; Pests/Diseases tolerance: resistance to maize streak virus, susceptible to Striga hermonthica; Outstanding characteristics: Extra-earliness, high yield potential, suitable in areas with≥600mm rainfall distributed within 80days cropping season, drought tolerant; Year of release: 2001.

SAMMAZ 14 - Old name: Obatanpa; Origin/source of variety: Crops Research Institute, Kumasi, Ghana; Type of variety: Open Pollinated; Pedigree: GH8362-SRC1; Morphological characteristics: Non-tillering, erect and medium maturity; Adaptation: Across Nigeria agro-ecological zones but adapted specifically for savanna zones; Days to maturity: 106-110 days; Potential yield: 5.8 t/ha; Pests/Diseases tolerance: Resistance to maize streak virus and stem borers; Outstanding characteristics: High lysine and tryptophan content, medium maturing, good seed quality, high yield, tolerant to Striga; Year of release: 2002.

SAMMAZ 16 - Old name: TZL Compl1SynW-1; Origin/source of variety: IIT Ibadan; Type of variety: Synthesis; Pedigree: 10 STR inbred lines; Morphological characteristics: Non-tillering, erect and medium maturity, 180-185cm tall; Adaptation: Nigerian savanna

Striga hermonthica prone zones; Days to maturity: 120 days; Potential yield: 6.4 t/ha; Pests/Diseases tolerance: tolerant to maize streak virus Late maturity, good seed quality; Outstanding characteristics: high yield potential, tolerant to Striga hermonthica; Year of release: 2004.

SAMMAZ 17 - Old name: Acr Sakatitu CA; origin/source of variety: IAR Samaru; Type of variety: Open pollinate; Pedigree: S1 selection from QPM Germplasm; Morphological characteristics: Medium Maturing at 58 days to mid – silking with 220cm in height, white seeded kernels; Adaptation: Lowland tropics; Days to maturity: 90-95days, Potential yield: 5.0 t/ha; Pests/Diseases tolerance: Tolerant to streak and striga; Outstanding characteristics: medium maturing, good seed quality, high yield potential, tolerant to Striga; Year of release: 2009.

SAMMAZ 18 - Old name: Tillering maize; Origin/source of variety: IAR Samaru; Type of variety: open pollinated; Pedigree: S1 Selection; Morphological characteristics: Early maturing at 53 days to mid-silking with 220cm in height, white seeded kernels; Adaptation: Lowland tropics; Days to maturity: 85-90days, Potential yield: 4.5 t/ha, post/Disease Tolerance: Tolerant to streak virus and striga; Outstanding characteristics: Early maturing to streak high yield potential, tolerant to Striga; Year of release: 2009.

SAMMAZ 19 - Old name: S.14 DKD DT; Origin/source of variety: IAR Samaru; Type of variety: Open pollinated; Pedigree: S1 selection from QPM Germplasm; Morphological characteristics: Medium maturing at 58days to mid-silking with 220cm in height, white seeded kernels; Adaptation: Lowland tropics, Days to maturity: 90-95days; Potential yield: 5.0 t/ha; Pests/Diseases tolerance: Tolerant to streak virus and striga; Outstanding characteristics: High yield, drought and Striga tolerance; Year of release: 2009.

SAMMAZ 20 - Old name: TZE Comp3; origin/source of variety: IITA, Type of variety: Open pollinated; Pedigree: TZE Composite 3; Morphological characteristics: Medium maturing with 52 days to mid-silking, tall 185-195cm, white seeded, grain is flint/dent; Adaptation: Widely adapted but better adapted to drought prone areas and second planting in southern Nigeria; Days to maturity: 95-100 days; Potential yield: 3-4 t/ha in drought prone area; Pests/Diseases tolerance: Tolerance to drought prone area; Outstanding characteristics:

Highly tolerant with resistant to streak and tolerance to low soil nitrogen; Year of release: 2009.

SAMMAZ 21 - Old name: TZE Comp 5-W; Origin/source of variety: IITA; Type of variety: Open pollinated; Pedigree: TZE Composite 5; Morphological characteristics: Medium tall 150-170cm, white seeded, grain is flint/dent With 52 days to mid-silking under non-infested Striga condition; Adaptation: adapted to drought prone areas with Striga hermonthica infestation; Days to maturity: 90-105 days; Potential yield: 1.5-20 t/ha under Striga infestation and 5.0 t/ha under non-infested condition; Pests/Diseases tolerance: Tolerant to Striga infestation; Outstanding characteristics: Highly tolerant to Striga hermonthica infestation; Year of release: 2009.

SAMMAZ 22 - Old name: M0826-1; Origin/source of variety: IITA; Type of variety: three way cross hybrid; Pedigree: 9071/1368$_x$HI$_x$4269-1$_x$1368-7-2-B-B-B-B/P43SRC9FS100-1-1-8-B1-13-B1-B-B-B-B; Morphological characteristics: Medium tall 200-220cm white seeded, grain is semi-flint with 62 days to mid-silking; Adaptation: Adapted to drought prone areas of the Northern Guinea Savanna; Days to maturity: 100-120 days; Potential yield: 2-4 t/ha in drought stress highly tolerant to drought; Pests/Diseases tolerance: Tolerant to drought stress Highly tolerant to draught; Outstanding characteristics: with resistant to streak and tolerant to low soil nitrogen; Year of release: 2009.

SAMMAZ 25 - Old name: M0826-11; Origin/source of variety: IITA; Type of variety: Top-cross hybrid; Pedigree: DT-SR-WCO/TZL –COMP3 –C-S2-34-4-1-2-B-B; Morphological characteristics: Medium tall 190-210cm, white seeded, grain is flint/dent with 60 days to mid-silking; Adaptation: Adapted to drought prone areas of the Northern Guinea Savanna; Days to maturity: 100-110 days; Potential yield: 3-4 t/ha in draught prone areas and >7t/ha under normal under normal condition; Pests/Diseases tolerance: Tolerant to draught stress; Outstanding characteristics: Highly tolerant to draught with resistant to streak and tolerance to low soil nitrogen; Year of release: 2009.

SAMMAZ 26 - Old name: DSTR –wc1; Origin/source of variety: IITA; Type of variety: Open pollinated; Pedigree: DSTR; Morphological characteristics: Medium tall 185 -195cm, white seeded, grain is flint/dent with 56 days to mid-silking; Adaptation: Widely adapted;

Days to maturity: 95-110 days; Potential yield: 3-4 t/ha in draught prone areas; Pests/Diseases tolerance: Tolerant to drought stress; Outstanding characteristics: highly to drought with resistant to streak and tolerance to low soil nitrogen; Year of release: 2009.

SAMMAZ 28 - Old name: 99TZEE –Y-STR; Origin/source of variety: IITA; Type of variety: Open pollinated; Pedigree: TZE- Y Pop DT STR C3; Morphological characteristics: Early maturity at about 50 days to mid silking with 170cm in height, yellow seeded kernels; Adaptation: Lowland, tropics; Days to maturity: 80-85 days; Potential yield: 4.0 t/ha; Pests/Diseases tolerance: Tolerant to Striga hermonthica and resistant to Maize Streak Virus; Outstanding characteristics: Drought tolerant and Striga resistant; Year of release: 2009.

SAMMAZ 29 - Old name: 2000SynEE -W-STR; Origin/source of variety: IITA; Type of variety: Open pollinated; Pedigree: TZE –W Pop DT STRC3; Morphological characteristics: Very early maturity, white grains, 170cm tall, 57 days to mid –silking under uninfected conditions with Striga hermonthica; Adaptation: Lowland tropics; Days to maturity: 80-85days; Potential yield: 4.0 t/ha; Pests/Diseases tolerance: Tolerant to Striga hermonthica and resistant to Maize Streak Virus; Outstanding characteristics: Extra early maturing drought escaping and Striga tolerant; Year of release: 2009.

SAMMAZ 30 - Old name: LNTP×LNTP -WC3; Origin/source of variety: IITA; Type of variety: Open pollinated; Pedigree: LNTP -LNTP -W; Morphological characteristics: Medium tall 200- 210cm, grain is flint/dent with 60 days to mid-silking; Adaptation: widely adapted to the middle –belt zone of Nigeria; Days to maturity: 100-110 days; Potential yield: 3.5-4.0 t/ha under low soil nitrogen application; Pests/Diseases tolerance: tolerant to low soil nitrogen; Outstanding characteristics: highly tolerant to low soil nitrogen with resistant to streak; Year of release: 2009.

SAMMAZ 33 - Old name: 2000 Syn EE -W STR QPM CO; Origin/source of variety: IITA, Ibadan; Type of variety: Synthetics; Pedigree: TZEE -W Pop STR S4 F2, Morphological characteristics: Non-tillering, erect and medium maturity; Adaptation: Sudan Savanna and transition zones between Sudan and Northern Guinea Savanna; Days to maturity: 85

days; Potential yield: 3.9t/ha; Pests/Diseases tolerance: Tolerant to maize streak virus and striga infestation; Outstanding characteristics: improvement over SAMMAZ 28; Year of release: 2009.

SAMMAZ 33 - Old name: IAR MULTI-COB EARLY DT, Multi cob; Origin/source of variety: IAR ABU, Zaria; Type of variety: Composite; Pedigree: S1 family selection of prolific early maize population introduced from CIMMYT and IITA with imposed drought; Morphological characteristics: Often non-tillering, erect and early maturing; Adaptation: Sudan Savanna and Transition zones between Sudan and Northern Guinea Savanna; Days to maturity: 95-days; Potential yield: 4.7t/ha; Pests/Diseases Tolerance: Tolerant to maize streak virus; Outstanding characteristics: Early maturing, prolific cob bearing, good stay green, good quality fodder; Year of release: 2011.

SAMMAZ 37 - Old name: Pop66 SR/Acr 91 SUWAN -1-SR; Origin/source of variety: IITA, Ibadan; Type of variety: Synthetics; Pedigree: S1 family selection of TZL COMP4 C3 F2. TZL COMP3C3F2 and TZUTSR-WSGY) and elite maize varieties with resistance to Striga (ACR97 STR SYN –Y, TZL COMP1SYNW-1, IWDC2SYNF2, and ZEADIPLOSYNW-1) AND MILDEW (ACR91SUWAN1 –SRC1 and DMR –LSRY) crossed to PO66SR QPM donor; Morphological characteristics: Non-tillering, erect and Medium Maturing; Adaptation: Nigerian Savanna; Days to maturity: 115 days; Potential yield: 5.9t/ha; Pests/Diseases tolerance: Tolerant to maize streak virus and striga infestation; Outstanding characteristics: Medium maturing, good quality grains, tolerant to streak virus disease and striga infestation; Year of release: 2011.

Plate II: Sample of Crude Soft Chalky Rockof Nigeria Raw Diatomaceous Earth

3.3 Insect Culture

Sitophilus zeamais population was obtained from naturally infested maize grains obtained from a local grain merchant in Yola, Adamawa state, Nigeria. The insects were reared on a susceptible local maize variety "Saksi" (Agesa *et al.*, 2017) in two 1-litre transparent plastic bucket and routinely maintained to provide weevils of similar age for the study (Plate V). Each bucket contained 100 adults of *S. zeamais* per 500 g grains. The buckets were then covered with muslin cloth to allow aeration and to prevent escape of the weevils. All parents *S. zeamais* in each bucketwas removed after seven days by sieving and then placed on another fresh set of grain medium repeatedly until sufficient numbers of weevils of the same age are obtained for the experiments. The set up was then kept at laboratory conditions on an open air shelf (Plate V). Emerged F_1 progeny 7 - 14 days old was then used for the experiments.

3.4 Sample Preparation

The most resistant and susceptible maize varieties against *S. zeamais* were screened under ambient laboratory conditions. The experimental jars and maize varieties were examined, cleaned and sterilized thermally in a hot-air oven (Hot Air Circulated Oven; OV95c) at 60^{o}C for 1 hour to kill any pest and pathogen that might be present, and afterwards allowed to equilibrate for 24 hours in the laboratory (Atijegbe, 2004; Zakka, 2005; Medugu, 2012). The above preparation was carried out prior to morphological, morphometric and chemical characterization and standardization for bioassays.

Plate III. Cultures of *S. zeamais* on a Laboratory table

3.5 Experimental Design and Layout

Experiment II was laid in completely randomized design (CRD) with three replications.Each experiment consists of twenty five (25) varieties giving a total of seventy five (75) experimental units as shown in Figure 1. While experiment III was laid ina split-plot design. It consistted of fifteen (15) treatments (Diatomaceous Earth, Malathion and Diatomaceous Earth + Malathion) which were assigned to the main plot and four (4) maize varieties were assigned to the sub plots replicated three times, giving a total of (15x4x3) one hundred and eighty (180) experimental units including the control (Figure 2).

3.6 Experiment I: Determination of Morphological, Physical and Chemical Characteristics of Maize Genotypes

3.6.1 Morphological characteristics of maize genotypes

Ten randomly selected maize grains from each variety were carefully examined for morphological characteristics (Chinaru *et al.*, 2015). The description for each variety was based on visual observation of color, shape and texture of seed coat (Dobie, 1974; Adedire *et al.*, 2011). The colour of each maize grain variety were then determined using primary colour chart. The texture was felt with hand to supplement visual observation (Chinaru *et al.*, 2015).

3.6.2 Physical characteristics of maize genotypes

The physical properties pertinent to the study are grain size (length, width and thickness), grain weight and grain hardness. To measure the grain size, a sample of Ten (10) grain kernels of each variety was selected randomly and their length, width and thickness measured using micrometer screw gauge (Chinaru *et al.*, 2015). For each variety the procedure was replicated 3 times.

For the weight of grains of each variety, 100 grains was randomly selected and weighed on digital electronic balance (Electronic Compact Weighing Scale, BL20001). As above it was replicated 3 times.

To determine the grain hardness, 10 grain kernels from each variety was randomly selected and their hardness determined with a compression machine (model: 200063 Milano, Italy). A grain was placed at a time on the beam of the machine and the lever rolled down gradually until the grain cracks. The bearing ratio/strength value was then recorded and multiplied by a factor of

23.8 N to convert the strength value to Newton (N). The amount of force (N) needed to break the grain was then taken as a measure of grain hardness (Nwosu *et al.*, 2015).

3.6.3 Chemical characteristic of maize genotypes

The chemical characteristics of each maize variety were determined by subjecting grains to proximate analysis. This was done by producing fifty (50) grams grain hull of each variety using a locally fabricated small sized mortar and pestle. The produced mixture was then sieved to assemble the hulls in a stainless basin. The hulls for each variety was then milled and sieved through a 0.4 mm sieve. The milled samples were then subjected to chemical analysis at the Laboratory of Department of Food Science and Technology, Modibbo Adama University of Technology, Yola. The amount of ash, carbohydrate, crude fiber, crude protein, ether extract, starch, and lysine were determined using the standard method of AOAC (1990).

3.7 Moisture Content of Maize *genotypes*

Moisture content of each maize variety was determined. Five (5) gram maize grains from each variety was initially weighed and then dried in an air circulated oven (Hot Air Circulated Oven; OV95c) at 120°C for one hour, allowed to cool down at room temperature for 2 hours and re-weighed. This procedure was replicated five times for each maize variety. The percent moisture content was then expressed mathematically as described by Lale and Ofuya (2001):

$$\mathrm{Mc} = \frac{\mathrm{m1} - \mathrm{m2}}{\mathrm{m1}} \times 100$$

where:

Mc = % moisture content on wet basis.

m_1 = initial weight;

m_2 = Final weight.

REP 1

V_{12}	V_{22}	V_{10}	V_{17}	V_7
V_{18}	V_8	V_{13}	V_3	V_{23}
V_{24}	V_{19}	V_{25}	V_9	V_4
V_5	V_2	V_{15}	V_{11}	V_{20}
V_1	V_{16}	V_{21}	V_6	V_{16}

REP 2

V_{13}	V_{16}	V_{23}	V_7	V_{18}
V_3	V_8	V_2	V_{21}	V_{12}
V_{22}	V_4	V_{14}	V_9	V_{25}
V_{10}	V_1	V_{20}	V_{17}	V_{15}
V_6	V_{21}	V_{16}	V_{14}	V_1

REP 3

V_{18}	V_6	V_{21}	V_{15}	V_{11}
V_{20}	V_{24}	V_8	V_{19}	V_3
V_9	V_{12}	V_{17}	V_2	V_{23}
V_{22}	V_{16}	V_5	V_{14}	V_{10}
V_{21}	V_6	V_1	V_{16}	V_{21}

Figure 1: Experimental lay out for Assessment of Susceptibility of different MaizeVarieties

Key:

V_1 = SAMMAZ 11	V_6 = SAMMAZ 17	V_{11} = SAMMAZ 22	V_{16} = SAMMAZ 30
V_2 = SAMMAZ 13	V_7 = SAMMAZ 18	V_{12} = SAMMAZ 25	V_{17} = SAMMAZ 33
V_3 = SAMMAZ 14	V_8 = SAMMAZ 19	V_{13} = SAMMAZ 26	V_{18} = SAMMAZ 34
V_4 = SAMMAZ 15	V_9 = SAMMAZ 20	V_{14} = SAMMAZ 27	V_{19} = SAMMAZ 37
V_5 = SAMMAZ 16	V_{10} = SAMMAZ 21	V_{15} = SAMMAZ 29	V_{20} = SAMMAZ 38
V_{21} = Baleji	V_{22} = Bataji	V_{23} = Bodeji	V_{24} = Deneji
V_{25} = Saksi			

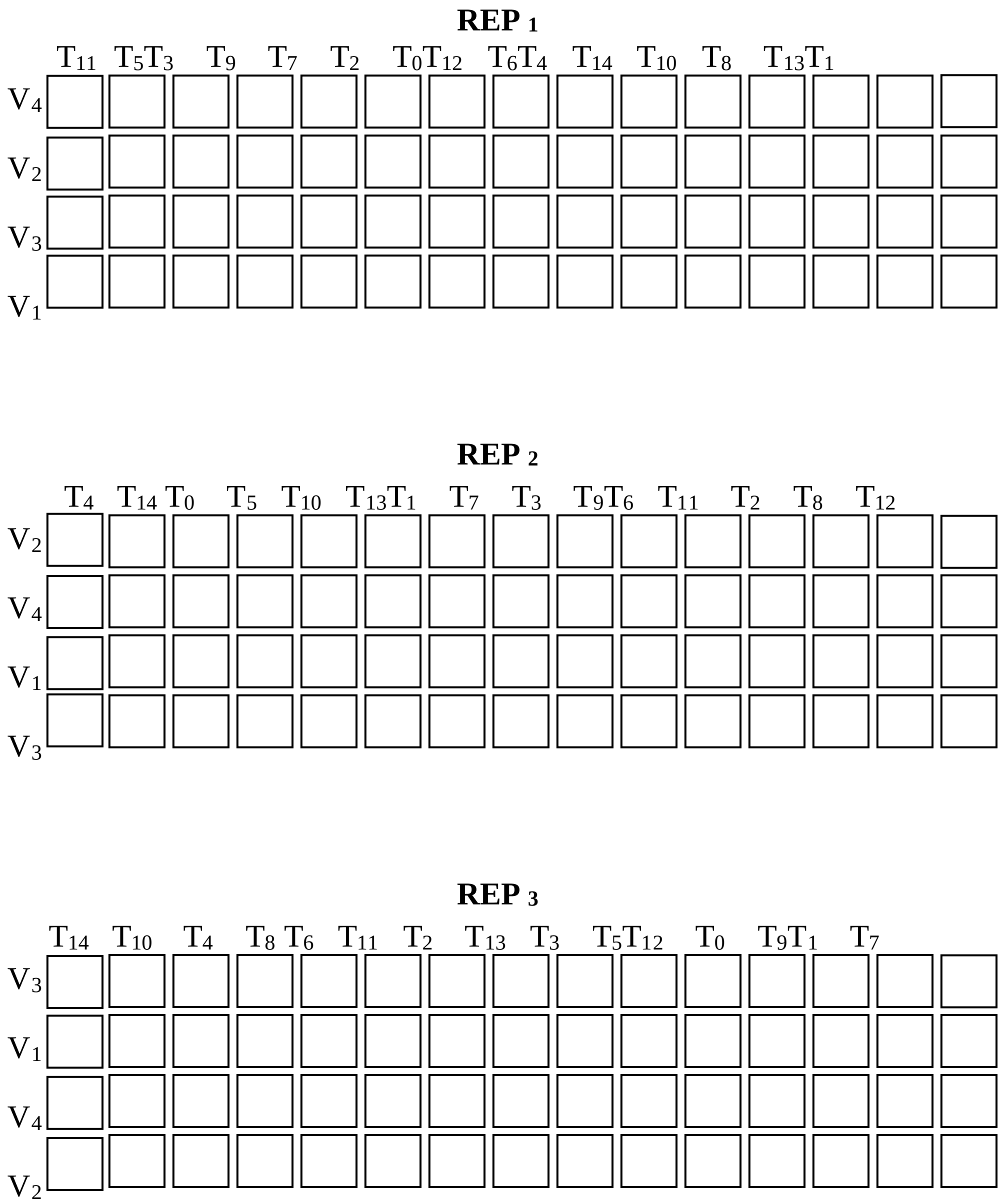

Figure 2: Experimental lay out for Assessment of Efficacy of Diatomaceous Earth, Malathion and Diatomaceous Earth+ Malathion

Key:

<u>**Main plot (**Treatments - T)</u>

Control	- T_0 = 0.00 mg	
Raw Diatomaceous earth (RDE)	- T_1 = 250 mg	
	T_2 = 500 mg	
	T_3 = 750 mg	
	T_4 = 1000 mg	
Malathion (MT)	- T_5 = 6 mg	
	T_6 = 10 mg	
	T_7 = 14 mg	
	T_8 = 16 mg	
Raw Diatomaceous Earth + Malathion (RDE + MT)	- T_9 = 250 + 6	
	T_{10} = 500 + 6	
	T_{11} = 750 + 6	
	T_{12} = 250 + 10	
	T_{13} = 500 + 10	
	T_{14} = 750 + 10	

<u>**Sub plot (**Varieties - V)</u>

V_1 = SAMMAZ 16
V_2 = SAMMAZ 20
V_3 = SAMMAZ 25
V_4 = SAMMAZ 29

3.8 Experiment II: Screening Maize Varieties for Relative Resistance to*S. zeamais*

Five pairs of (7 - 14 days old) adult *S. zeamais* were introduced into separate bottles containing 20 g of each maize variety (Plate VI) weighed on a sensitive electronic balance (Electronic Compact Weighing Scale BL20001). The adult insects were then allowed to oviposit for seven days and then removed by sieving. The content of each jar were carefully returned, kept on the shelf and left undisturbed for additional 21 days. There on, the jars was then examined daily to record the emergence of F_1 adults. Adult count was continuing until no adult(s) emerged in each jar for three consecutive days (modified after Throne and EubanksS, 2002). Each treatment was replicated three times in a completely randomized design (CRD) (Plate VI).

The Dobie index of susceptibility was then used as a criterion to separate maize varieties into different resistance and susceptible groups (Dobie, 1974; 1977). The susceptibility Index is given by the formula:

$$\mathrm{SI} = \frac{\log \mathrm{F1}}{\mathrm{D}} \text{ x } 100,$$

where:

SI = Susceptibility Index;

Log F_1 = Log number of F_1 emerged adults;

D = Mean length of developmental period (days).

3.8.1 Median developmental periodof S. zeamais

The median developmental period (MDP) is the time (in days) from the middle day of oviposition period to 50% emergence of F_1 adults (Dobie, 1977), which is used to calculate the susceptibility index of maize grains to *S. zeamais* infestation.The Dobie Index was then used to classify the maize varieties into susceptibility groups using the scales as shown in Table 1.

Table 1: Rating of Pest Densities and Infestation Level

Dobie index	Susceptibility status
≤4	Resistant
4.1 - 6.0	Moderately resistant
6.1 - 8.0	Moderately susceptible
8.1 - 10	Susceptible
>10	Highlysusceptible

Source: Dobie, 1974.

Plate IV. Experimental set up for screening maize varieties for relative resistance to *S. zeamais*

3.9 Experiment III: Assessment of Efficacy of Diatomaceous Earth (DE) and Malathion (MT) aloneand in Combination against *Sitophilus zeamais*

The treatments consist of DE, MT and DE + MT in combination. Diatomaceous earth and malathion consists of four dose rates each while, combination of DE + MT have six dose rates, with an untreated control, each replicated three times (Plate VII).

DE alone: 250, 500, 750 and 1000 mg/kg

Malathion alone: 6, 10, 14 and 16 mg/kg

DE + Malathion: 250 DE + 6 MT mg/kg
500 DE + 6 MT mg/kg
750 DE + 6 MT mg/kg

250 DE + 10 MT mg/kg
500 DE + 10 MT mg/kg
750 DE + 10 MT mg/kg

Control: 0.00 mg

Two Lots of 200 g of each maize variety were treated with four dose rates each of 250, 500, 750 and 1000 mg/kg of DE and 6, 10, 14, and 16 mg/kg a.i MT, respectively. For the combine treatment, lots of 300 g of each maize variety were treated with six dose rates each of 250+6, 500+6, 750+6, 250+10,500+10 and 750 mg+10 mg/kg DE + MT. Each lot was placed in 500 ml capacity bottles, and then capped and shaken manually for approximately 5 minutes to achieve uniform distribution of raw DE, MT and DE + MT in the entire grain mass, while control (0 mg/kg) has no treatment.

Subsequently, four samples of 50 g of treated or control maize was then taken from each lot, and placed in 250 ml capacity glass jars. In each jar, twenty (20) *S. zeamais* adults was then introduced, then the jars was covered with muslin cloth fitted with rubber band to allow gaseous exchange (Plate VII). The jars were then kept under ambient laboratory conditions at 26 - 38°C and 48 - 65% relative humidity.

Plate V: Experimental set up forassessment of efficacy of Diatomaceous Earth and Malathion alone and in combination against *Sitophilus zeamais*

3.10 Data Collection

3.10.1Adult mortality of S. zeamais

Adult mortality in both treated and untreated (control) bottles were assessed 3, 7 and 14 days after infestation (DAI) of weevils. All adult insects were removed from each bottle and the dead and alive insects counted and recorded. After 3 and 7 DAI count, live insects were returned to their respective bottles. On the 14 DAI counts, all dead and live insects were removed and grains kept under same condition for observation on progeny development and grain damage. An insect is assumed dead when probed with a pin and there was no movement.

3.10.2 Progeny production of S. zeamais

After removing all the introduced adult insects as described above, each bottle was then kept under the same experimental conditions to further assess the emergence of F_1 progeny. The number of F_1 progeny in each bottle was counted after additional 40 days. To do this, the content of each bottle was poured onto a tray and every emerging progeny was removed, counted and recorded on each assessment day.

3.10.3 Maize grain damage

After F_1 progeny count, 100 grains was randomly taken from each jar to assess the percentage of grain damage (grains with weevil emergence hole(s)) and grain weight loss due to weevil feeding.

Grain damage was then expressed as a proportion of the total number of seeds sampled (Abebe *et al*., 2009):

$$\%\ \text{Grain damage} = \frac{\text{Total number of grains} - \text{Number of damaged grains}}{\text{Total number of grains}} \text{X}\ 100$$

3.10.4 Maize grain weight loss

The percentage weight loss was determined by count and weigh method as describe by Lale (2002) thus:

$$\%\ \text{Weight loss} = \frac{[\text{UaN} - (\text{U} + \text{D})]}{\text{UaN}}\ \text{X}\ 100,$$

where:

Ua = average weight of one undamaged grain;

N = total number of grains in the sample;

U = weight of undamaged fraction in the sample;

D = weight of damaged fraction in the sample.

3.11 Data Analysis

Where necessary mortality data were corrected using Abbott's formula (Abbott, 1925).Before analysis, data on mortality, seed damage and weight loss were arc-sine transformed while, data on progeny production was square root $\sqrt{(x + 0.5)}$ transformed. The transformed data were then subjected to analysis of variance (ANOVA) using the GLM procedure of Statistix 8.0 to determine differences among treatment means. Treatment means were then separated using Tukey-Kramer "Honestly Significant Difference" (HSD) test at 5% level of probability.

CHAPTER FOUR

RESULTS

4.1 Physico-Chemical Characteristics ofRaw Diatomaceous Earth

The physico-chemical characteristics of the raw DE are as follows: Tapped density - 313.5 g/L, pH - 9.1; mineral composition: SiO_2 - 29.4%, Al_2O_3 - 12.8%, CaO - 26.6%, Na_2O - 11.6%, K_2O - 9.4%, FeO - 0.8%, ZnO - 0.35%, CuO - 0.18%, MnO - 0.56% and LOI (loss on ignition) - 1.86%.

4.2 Determination of MorphologicalPhysical and Chemical Characteristics of Maize Varieties

4.2.1 Morphological characteristics of maize varieties

The varieties differed in terms of color and shape but not in appearance, face-type and texture. Two color types were differentiated (Plate VI): yellow in SAMMAZ 36, SAMMAZ 37, SAMMAZ 38, Bataji and Bodeji, while white in the other varieties (Table 2). All sampled varieties were opaque in appearance, had dent or flint face and are smooth in texture, and the shapes varied from hexagonal as in SAMMAZ 13, SAMMAZ 21, SAMMAZ 22, SAMMAZ 27, SAMMAZ 30, SAMMAZ 37, SAMMAZ 38, Baleji, Bataji and Saksi; oval in SAMMAZ 15, SAMMAZ 16, SAMMAZ 20, SAMMAZ 33, SAMMAZ 34 and bodeji while they are rectangular as in SAMMAZ 11, SAMMAZ 14, SAMMAZ 17, SAMMAZ 18, SAMMAZ 19, SAMMAZ 25, SAMMAZ 26, SAMMAZ 29 and Deneji Varieties (Table 2). However, in this study, morphological characteristics did not play any role in conferring resistance. Though, the most resistant varieties (SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29) are white in colour (Table 2).


(a) White maize


(b) Yellow maize

Plate VI: Pristine white (a) and yellow (b) varieties of maize grains

Table 2 Morphological characteristic of maize varieties

Variety	Colour	Shape	Face-type	Texture
SAMMAZ 11	white	rectangular	semi dent	smooth
SAMMAZ 13	yellow	hexagonal	dent/flint	smooth
SAMMAZ 14	white	rectangular	dent/flint	smooth
SAMMAZ 15	white	oval	dent/flint	smooth
SAMMAZ 16	white	oval	flint	smooth
SAMMAZ 17	white	rectangular	flint	smooth
SAMMAZ 18	white	rectangular	dent/flint	smooth
SAMMAZ 19	white	rectangular	dent/flint	smooth
SAMMAZ 20	white	oval	flint	smooth
SAMMAZ 21	yellow	hexagonal	dent	smooth
SAMMAZ 22	white	hexagonal	dent	smooth
SAMMAZ 25	white	rectangular	flint	smooth
SAMMAZ 26	white	rectangular	dent	smooth
SAMMAZ 27	white	hexagonal	flint	smooth
SAMMAZ 29	white	rectangular	dent	smooth
SAMMAZ 30	yellow	hexagonal	dent	smooth
SAMMAZ 33	white	oval	dent/flint	smooth
SAMMAZ 34	yellow	oval	flint	smooth
SAMMAZ 37	yellow	hexagonal	flint	smooth
SAMMAZ 38	yellow	hexagonal	dent/flint	smooth
BALEJI	white	hexagonal	dent	smooth
BATAJI	yellow	hexagonal	dent/flint	smooth
BODEJI	yellow	oval	dent	smooth
DENEJI	white	rectangular	dent/flint	smooth
SAKSI	white	hexagonal	flint	smooth

4.2.2 Morphometric characteristics of maize varieties

The physical characteristics of maize grain varieties are presented in Table 3. Significant differences ($p<0.05$) among grain lengths of maize varieties measured were observed. The result indicates that SAMMAZ 13 had the longest grain length (1.71 mm) while SAMMAZ 27 had the shortest length (0.86 mm). The maize varieties grain width sizes do not differ significantly ($P<0.05$) from each other. However, the biggest grain widths of 0.92 mm were observed in SAMMAZ 26 and Deneji while smaller widths (0.78) were recorded in SAMMAZ 25, SAMMAZ 27, SAMMAZ 34 and Bataji. The thickest and thinnest maize grain of 0.50 and 0.40 were recorded in Sammaz 18 and SAMMAZ 15, SAMMAZ 17, SAMMAZ 55 and Bataji, respectively, though they do not differ significantly ($P<0.05$) from each other.

Table 3 also shows the mean grain weight of the maize varieties. The heaviest grain weight of 30.3 g was recorded in SAMMAZ 16 which did not significantly differ ($p<0.05$) from that of SAMMAZ 22, SAMMAZ 20 AND SAMMAZ 37 of 29.0, 27.7 and 28.3 g, respectively, the lightest grain weight of 16.3 g was recorded in variety Saksi which did not differ significantly ($p<0.05$) to all the other varieties except varieties SAMMAZ 11, SAMMAZ 14, SAMMAZ 16, SAMMAZ 20, SAMMAZ 21, SAMMAZ 22, SAMMAZ 27, SAMMAZ 37 AND SAMMAZ 38.

The hardest (382.20 N) maize grain variety was obtained from SAMMAZ 16 variety, while the softest (121.40 N) was from SAMMAZ 34 variety (Table 3). The results reveal that the strength of the hardest variety was not significantly ($p<0.05$) different to all the other varieties except SAMMAZ13, SAMMAZ 17, SAMMAZ 21, SAMMAZ 22, SAMMAZ 25, SAMMAZ 26, SAMMAZ 34, SAMMAZ 37, SAMMAZ 38, Bodeji and Saksi. However, the strength of the softest variety did not significantly differ ($p<0.05$) to the above mentioned varieties (Table 3).

Table 3 Morphometric characteristics of different maize varieties

Variety	Size (mm) Length	Width	Thickness	Weight (g/100 grains)	Hardness (N)
SAMMAZ 11	1.07^{d-i}	0.81^{a}	0.45^{a}	24.0^{d-g}	293.5^{a-f}
SAMMAZ 13	1.04^{g-j}	0.83^{a}	0.45^{a}	19.0^{hij}	245.9^{c-i}
SAMMAZ 14	0.98^{jk}	0.86^{a}	0.44^{a}	25.3^{b-e}	285.6^{a-g}
SAMMAZ 15	0.96^{k}	0.84^{a}	0.41^{a}	17.7^{ij}	285.1^{a-h}
SAMMAZ 16	1.71^{a}	0.92^{a}	0.42^{a}	30.3^{a}	382.2^{a}
SAMMAZ 17	1.05^{f-j}	0.83^{a}	0.40^{a}	19.0^{hij}	161.5^{ij}
SAMMAZ 18	1.13^{cd}	0.78^{a}	0.50^{a}	19.7^{hij}	296.6^{a-f}
SAMMAZ 19	1.12^{cde}	0.87^{a}	0.48^{a}	18.0^{ij}	296.6^{a-f}
SAMMAZ 20	1.20^{b}	0.92^{a}	0.48^{a}	29.0^{ab}	356.9^{abc}
SAMMAZ 21	0.85^{l}	0.78^{a}	0.42^{a}	21.0^{c-f}	176.9^{hij}
SAMMAZ 22	1.06^{e-i}	0.77^{a}	0.43^{a}	18.0^{ij}	245.6^{c-i}
SAMMAZ 25	1.16^{bc}	0.90^{a}	0.40^{a}	28.3^{abc}	369.9^{ab}
SAMMAZ 26	1.12^{cg}	0.87^{a}	0.45^{a}	19.0^{hij}	221.3^{e-j}
SAMMAZ 27	1.09^{d-h}	0.87^{a}	0.47^{a}	24.7^{f-i}	292.1^{a-g}
SAMMAZ 29	1.16^{bc}	0.88^{a}	0.40^{a}	27.7^{a-d}	359.9^{ab}
SAMMAZ 30	1.11^{c-f}	0.83^{a}	0.46^{a}	17.7^{ij}	340.4^{a-d}
SAMMAZ 33	0.96^{k}	0.82^{a}	0.45^{a}	19.0^{hij}	303.6^{a-e}
SAMMAZ 34	1.05^{f-j}	0.78^{a}	0.43^{a}	17.3^{ij}	121.4^{j}
SAMMAZ 37	0.99^{jk}	0.84^{a}	0.45^{a}	17.3^{ij}	195.5^{f-j}
SAMMAZ 38	1.02^{ijk}	0.84^{a}	0.43^{a}	26.7^{e-h}	187.1^{g-j}
BALEJI	1.04^{f-j}	0.80^{a}	0.44^{a}	20.7^{ghi}	191.7^{f-j}
BATAJI	1.02^{ijk}	0.78^{a}	0.40^{a}	17.3^{ij}	301.5^{a-e}
BODEJI	1.04^{hij}	0.84^{a}	0.41^{a}	16.7^{j}	267.9^{b-i}
DENERI	1.02^{ijk}	0.87^{a}	0.41^{a}	18.3^{ij}	297.4^{a-f}
SAKSI	1.06^{e-i}	0.84^{a}	0.42^{a}	16.3^{j}	245.9^{c-i}
SE±	0.01	3.30	1.78	2.91	0.80
CV	2.59	4.91	5.01	5.84	12.52
HSD $_{(0.05)}$	0.0001	0.0001	0.0001	0.0001	0.0001

Means followed by the same superscript along the column are not significantly different ($P<0.05$) from each other using Tukey-Kramer HSD test.

4.2.3 Chemical composition of the grains of the maize varieties

Table 4 shows the results of proximate analysis of the nutrient composition of the grains of the different maize varieties. It shows that maize contained appreciable level of crude protein and moisture content, low levels of ash, crude fibre, ether extract and lysine but high levels of carbohydrate and starch. Statistically, significant ($p<0.05$) differences exist between the mean values of nutrients content of the grains of the maize varieties.

Results indicated that, ash content were low (1.28 – 2.20 %). However, the highest ash content was found in SAMMAZ 17 (2.20) which significantly differ ($p<0.05$) to SAMMAZ 18, SAMMAZ 19, SAMMAZ 20, SAMMAZ 37, SAMMAZ 38, Baleji, Bataji and Deneji, while, the lowest value was found in Sammaz 19 (1.28 %) which differ significantly to all the other varieties.

Carbohydrate content of the maize grains was found to vary in the range of 67.85 % (SAMMAZ 17) to 76.34 % (Saksi) (Table 4). The highest carbohydrate content was found in variety Saksi which differed significantly ($p<0.05$) to the rest of the varieties except SAMMAZ 38 (76.13 %), while the lowest content was found in SAMMAZ 17 (67.85 %) which significantly differed ($p<0.05$) to the rest of the varieties except SAMMAZ 14, SAMMAZ 21, SAMMAZ 22, SAMMAZ 26 AND SAMMAZ 34.

The result of the Percentage crude fiber is presented in Table 4. The Table indicates that the percentage crude fiber was found in the range of 1.71 - 2.11% in SAMMAZ 30 AND SAMMAZ 17, respectively. The variation of the crude fibre content has been found in SAMMAZ 13, SAMMAZ 17, AND SAMMAZ 34 which differ significantly ($p<0.05$) to the rest of the varieties. The lowest fibre content (1.71 %) in SAMMAZ 30 did not significantly differs ($p<0.05$) to that of SAMMAZ 18, SAMMAZ 19, SAMMAZ 20, SAMMAZ 27, SAMMAZ 29 and Deneji of 1.81, 1.81, 1.76, 1.78 and 1.83 %, respectively (Table 4).

Table 4 shows percentage crude protein content in the range of 9.61 - 11.99 in SAMMAZ 26 and SAMMAZ 34, respectively. The study shows that SAMMAZ 34 did not differ significantly ($p<0.05$) to SAMMAZ 17, SAMMAZ 21, SAMMAZ 22 AND SAMMAZ 38 but there is significant difference ($p<0.05$) among the other varieties. However, the variety with the lowest protein content 9.61 % (SAMMAZ 26) differs significantly ($p<0.05$) to all the varieties but did not significantly differ to SAMMAZ 13 (9.68 %).

Percentage ether extract was found in the range of fiber of 3.41 - 4.13 % in SAMMAZ 20 and SAMMAZ 17, respectively. The Table shows that the highest ether extract (4.13 %) was found in variety SAMMAZ 17 followed by SAMMAZ 34 (4.04 %) which differ significantly ($p<0.05$) to the rest of the varieties. While the lowest content (3.41 %) was found in SAMMAZ 20.which did not significantly differ to SAMMAZ 19 (3.48 %) and SAMMAZ 33 (3.63 %) but significantly different ($p<0.05$) to the rest of the varieties,

The mean percentage starch yield of the grains of maize varieties ranged from 62.64 % (SAMMAZ 17) to 72.44 % (SAMMAZ 15) (Table 4). The starch obtained from SAMMAZ 15 (72.44 %) was significantly ($P<0.05$) higher followed by SAMMAZ 21 (71.18 %). While SAMMAZ 17 with values 62.64 % had the lowest and differ significantly ($p<0.05$) to SAMMAZ 11, SAMMAZ 15, SAMMAZ 19, SAMMAZ 21, SAMMAZ 22, Baleji, Bataji and Saksi.

The Lysine content was found in the range of 2.44 - 2.91 % in SAMMAZ 16 AND SAMMAZ 17, respectively. The study shows that the highest lysine content of 2.91 % (SAMMAZ 17) differ significantly ($p<0.05$) to all the other varieties except SAMMAZ 34 (2.8 %) (Table 4), While, variety with the lowest lysine content (2.44 %) SAMMAZ 16 is not significantly different ($p<0.05$) to all the varieties except SAMMAZ 17 AND SAMMAZ 34.

4.3 Moisture content of different Maize Varieties

The grain moisture content is presented in Table 4. The moisture contents of maize grains were at appreciable level (8.98 - 12.00 %). The highest value of moisture content was found for SAMMAZ 34 (12.00 %) which is significantly different ($p<0.05$) to all the other varieties except SAMMAZ 15, SAMMAZ 16, SAMMAZ 17, SAMMAZ 21, and Bodeji. The lowest moisture content value was found in SAMMAZ 26 (8.98) which did not significantly differ ($p<0.05$) to values obtained in SAMMAZ 13, SAMMAZ 18, SAMMAZ 22, SAMMAZ 27, SAMMAZ 33, and Saksi.

Table 4Chemical composition of maize grain varieties

	%							
Variety	**Ash**	**CHO**	**CF**	**CP**	**EE**	**Starch**	**Lysine**	**Mc**
SAMMAZ 11	2.13^{ab}	69.23^{hij}	1.86^{e-i}	10.43^{h}	3.62^{hij}	67.80^{a-d}	2.49^{a}	10.74^{b-e}
SAMMAZ 13	2.18^{ab}	71.52^{ef}	2.04^{a-d}	9.68^{jk}	3.80^{c-g}	67.52^{a-e}	2.50^{a}	11.16^{a-d}
SAMMAZ 14	2.19^{a}	68.86^{ijk}	1.97^{b-e}	11.45^{b-e}	4.02^{b}	64.79^{cde}	2.50^{a}	11.08^{bcd}
SAMMAZ 15	2.14^{ab}	70.52^{fg}	1.92^{c-g}	11.53^{bc}	3.82^{cde}	64.35^{de}	2.53^{a}	11.27^{abc}
SAMMAZ 16	2.16^{ab}	76.34^{a}	1.88^{e-i}	10.46^{gh}	3.88^{c}	72.44^{a}	2.44^{a}	9.93^{e-h}
SAMMAZ 17	2.20^{a}	67.85^{k}	2.11^{a}	11.85^{a}	4.13^{a}	62.64^{e}	2.91^{b}	11.36^{ab}
SAMMAZ 18	1.73^{cde}	69.11^{ij}	1.81^{g-j}	10.62^{g}	3.59^{ij}	64.20^{de}	2.51^{a}	9.56^{ghi}
SAMMAZ 19	1.28^{f}	70.77^{fg}	1.81^{g-j}	11.34^{cde}	3.48^{kl}	68.17^{a-d}	2.48^{a}	10.49^{b-f}
SAMMAZ 20	1.70^{de}	73.08^{cd}	1.81^{g-j}	9.92^{i}	3.41^{lm}	71.18^{ab}	2.49^{a}	9.85^{e-i}
SAMMAZ 21	2.14^{ab}	68.57^{jk}	1.9^{c-g}	11.80^{a}	4.0^{b}	65.11^{cde}	2.56^{a}	11.3^{abc}
SAMMAZ 22	2.14^{ab}	68.83^{jk}	1.95^{b-f}	11.80^{a}	3.58^{jk}	64.85^{cde}	2.50^{a}	9.86^{e-i}
SAMMAZ 25	2.10^{ab}	76.13^{a}	1.92^{c-g}	10.99^{f}	3.80^{c-f}	69.54^{abc}	2.61^{a}	8.98^{i}
SAMMAZ 26	2.17^{ab}	68.95^{ijk}	1.90^{e-h}	9.61^{k}	3.76^{d-g}	65.82^{cde}	2.51^{a}	10.54^{b-f}
SAMMAZ 27	2.14^{ab}	70.42^{fgh}	1.76^{ij}	11.28^{e}	3.86^{cd}	65.45^{cde}	2.52^{a}	11.02^{bcd}
SAMMAZ 29	2.13^{ab}	74.5^{b}	1.78^{hij}	9.84^{ij}	3.69^{ghi}	69.50^{abc}	2.50^{a}	9.50^{hi}
SAMMAZ 30	2.07^{ab}	71.02^{fg}	1.71^{j}	11.03^{f}	3.99^{b}	65.16^{cde}	2.50 ^{a}	10.41^{c-h}
SAMMAZ 33	1.93^{a-d}	70.43^{fgh}	1.91^{d-h}	10.63^{g}	3.63^{m}	64.21^{de}	2.51^{a}	9.66^{f-i}
SAMMAZ 34	2.13^{ab}	68.23^{jk}	2.07^{ab}	11.99^{a}	4.04^{ab}	64.42^{de}	2.8^{b}	12.00^{a}
SAMMAZ 37	1.75^{cde}	74.14^{bc}	1.91^{c-g}	11.33^{ed}	3.72^{e-h}	65.81^{cde}	2.50 ^{a}	10.39^{c-h}
SAMMAZ 38	1.58^{e}	70.10^{hij}	1.97^{b-e}	11.81^{a}	3.71^{fgh}	65.56^{cde}	2.51 ^{a}	9.92^{e-h}
BALEJI	1.73^{cde}	73.13^{cd}	1.93^{c-g}	11.51^{bcd}	3.69^{ghi}	68.53^{a-d}	2.46 ^{a}	10.46^{b-g}
BATAJI	1.73^{cde}	72.16^{de}	1.95^{b-f}	11.46^{b-e}	3.72^{e-h}	66.51^{b-e}	2.49 ^{a}	10.36^{d-h}
BODEJI	1.93^{acd}	70.42^{fgh}	1.87^{e-i}	11.41^{b-e}	3.85^{cd}	66.86^{b-e}	2.50 ^{a}	11.20^{a-d}
DENERI	1.90^{b-d}	71.51^{ef}	1.83^{f-j}	11.57^{b}	3.97^{c}	65.46^{cde}	2.50^{a}	11.01^{bcd}
SAKSI	2.01^{abc}	69.13^{ij}	1.96^{b-e}	10.97^{f}	4.00^{b}	67.80^{a-d}	2.59^{a}	9.76^{f-i}
SE±	0.05	0.23	0.02	0.03	0.02	0.92	0.04	0.17
CV	4.71	0.56	2.16	0.54	0.90	2.39	3.00	2.77
HSD $_{(0.05)}$	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0004	0.0001

Means followed by the same superscript along the column are not significantly different ($P<0.05$) from each other using Tukey-Kramer HSD test. CHO = Carbohydrate; CF = Crude Fibre; CP = Crude Protein; EE = Ether Extract; Mc = Moisture Content

4.4 Screening Maize Varieties for Relative Resistance to*S. zeamais*

4.4.1 Progeny emergence

The number of progeny produced by *S. zeamais*is presented in Table 5. There were significant differences (*P*<0.05) among the maize varieties in the number of progeny produced as indicated in Table 5. The highest number of progeny was counted in bottles of the varieties SAMMAZ 29 followed by SAMMAZ 20 and SAMMAZ 16 of 56.0, 54.0 and 53.3, respectively. An appreciably higher number of progeny were also recorded in varieties Baleji, Bataji and Deneji of 44.7, 42.3 and 40.7, respectively. The result also shows significantly (P<0.05) lower number of progeny was produced in most of varieties. Though, the least number of F_1 progeny in SAMMAZ 25 (26.0) differed significantly (P<0.05) to most of the varieties. However, SAMMAZ 20, SAMMAZ 29, SAMMAZ 25 AND SAMMAZ 16 had the lowest progeny of 36.0, 30.3, 30.0 and 26.0 g, respectively.

4.4.2 Mean developmental time (MDT)

Significant differences (P<0.05) among the varieties were recorded with regard to the median developmental time (MDT) (Table 5). The MDT ranged from 26.7 to 42.0 days. *Sitophilus zeamais* reared on the varieties SAMMAZ 34, SAMMAZ 21 AND SAMMAZ 17 had relatively lower MDT of 26.7, 28.0 and 28.3, respectively which was significantly different (P<0.05) to the other varieties (Table 5). However, SAMMAZ 25, SAMMAZ 20, SAMMAZ 29, SAMMAZ 11 and SAMMAZ 16 had the highest MDT of 42.0, 40.0, 39.0, 38.3 and 38.0, respectively. The general trend in MDT appeared to be inversed to that of F_1 progeny emergence. Generally, as the MDT increases, the F_1 progeny emergence decreases. It was observed that, a shorter MDT gives rise to more F_1 progeny.

4.4.3 Index of susceptibility (SI)

Table 5 shows the index of susceptibility which indicates that there are significant differences (P<0.05) among the grains of maize varieties. The SI ranged from 3.4 in SAMMAZ 25 to 6.5 in SAMMAZ 34. Out of the twenty five maize varieties tested against *S. zeamais* for resistance, only four varieties; SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 AND SAMMAZ 29 had index of susceptibility of 3.9, 3.9, 3.4 and 3.8, respectively and are regarded as resistant to weevil attack. However, most of the varieties do not differ significantly to each other in regard to SI as in SAMMAZ 11, SAMMAZ 13, SAMMAZ 14, SAMMAZ 15, SAMMAZ 18, SAMMAZ 19,

SAMMAZ 22, SAMMAZ 26, SAMMAZ 27, SAMMAZ 30, SAMMAZ 33, SAMMAZ 37 and SAMMAZ 38. Baleji, Bataji, Bodeji, Deneji and Saksi had SI which ranges from 4.1 to 5.4 and are regarded as moderately resistant to weevil attack. Three varieties SAMMAZ 17, SAMMAZ 21 and SAMMAZ 34 had SI of 6.1, 6.2 and 6.5, respectively and are regarded as moderately susceptible to weevil attack (Table 5). The result shows that the SI is inversely related to MDT. However, the number of F_1 progeny showed a positive relationship with the SI (Table 5).

Table 5 Total number of F_1 progeny emergence, median developmental time (MDT) and Susceptibility index (SI) of different maize varieties to *Sitophilus zeamais*

Variety	F_1 progeny Emerged	MDT (days)	Susceptibility index (SI)	Susceptibility status
SAMMAZ 11	36.0^{d-h}	38.3^{a-d}	4.1^{efg}	moderately resistant
SAMMAZ 13	36.3^{d-h}	36.3^{b-f}	4.3^{c-f}	moderately resistant
SAMMAZ 14	37.0^{d-h}	37.0^{i}	4.2^{efg}	moderately resistant
SAMMAZ 15	37.0^{d-h}	34.7^{b-g}	4.5^{c-f}	moderately resistant
SAMMAZ 16	30.0^{h-i}	38.0^{a-d}	3.9^{fg}	resistant
SAMMAZ 17	53.3^{b}	28.3^{d-h}	6.1^{a}	moderately susceptible
SAMMAZ 18	33.3^{e-i}	28.0^{hi}	5.4^{ab}	moderately resistant
SAMMAZ 19	35.0^{d-h}	35.0^{b-g}	4.4^{c-f}	moderately resistant
SAMMAZ 20	36.0^{d-h}	40.0^{ab}	3.9^{fg}	resistant
SAMMAZ 21	54.0^{bc}	28.0^{ghi}	6.2^{a}	moderately susceptible
SAMMAZ 22	34.3^{e-h}	37.7^{a-e}	4.1^{efg}	moderately resistant
SAMMAZ 25	26.0^{i}	42.0^{a}	3.4^{g}	resistant
SAMMAZ 26	30.7^{ghi}	35.3^{b-g}	4.2^{def}	moderately resistant
SAMMAZ 27	39.0^{c-f}	36.3^{b-f}	4.4^{c-f}	moderately resistant
SAMMAZ 29	30.3^{ghi}	39.0^{abc}	3.8^{fg}	resistant
SAMMAZ 30	33.0^{f-i}	36.3^{b-f}	4.2^{efg}	moderately resistant
SAMMAZ 33	34.7^{e-h}	31.3^{f-i}	4.9^{bcd}	moderately resistant
SAMMAZ 34	56.0^{a}	26.7^{c-g}	6.5^{a}	moderately susceptible
SAMMAZ 37	35.9^{d-h}	33.7^{c-g}	4.6^{c-f}	moderately resistant
SAMMAZ 38	35.7^{d-h}	32.3^{e-h}	4.8^{b-e}	moderately resistant
BALEJI	44.7^{bc}	34.0^{e-h}	4.9^{bcd}	moderately resistant
BATAJI	42.3^{bcd}	35.7^{c-g}	4.6^{c-f}	moderately resistant
BODEJI	37.7^{c-g}	34.7^{b-g}	4.5^{c-f}	moderately resistant
DENERI	40.7^{cde}	34.7^{b-g}	4.6^{c-f}	moderately resistant
SAKSI	34.3^{e-h}	34.0^{c-g}	4.5^{c-f}	moderately resistant
SE±	0.12	0.98	0.15	
CV	3.32	4.88	5.66	
$HSD_{(0.05)}$	0.0001	0.0001	0.0001	

Means followed by the same superscript along the column are not significantly different ($P<0.05$) from each other using Tukey-Kramer HSD Test.

MDT = Median developmental time; SI = Susceptibility index.

4.5 Assessment of Efficacy of RDE and MT alone and RDE + MT in Combination against *Sitophilus zeamais*

4.5.1 Effects of treatments on adult mortality of S. zeamais on different maize varieties

Adult *S. zeamais* mortality was significantly affected by the doses of DE, of MT, DE + MT and by the exposure time (Table 6). In the treatments using only DE, the mortality of *S. zeamais* started in the 3rd day after treatment (Table 6) and by the 14th day there was significant difference between the dosage of 250 mg/kg and the two highest dosages. The accumulated mortality in the 14th day was of >75% at 250 mg/kg, >90% at 500 mg/kg and 100% at 750 mg/kg and 1000 mg/kg of DE. The mortality was <10% in the 14th day in the control bottles. In the treatments mixing DE with MT, the mortality of *S. zeamais* was affected by the dosages and by the exposure time. Dead insects were registered to be higher in the 3rd day after the application (Table 6). The accumulated mortality in the 3rd day was: >20% with the lowest dosage of DE and MT being >90% with 750 mg/kg + 10 mg/kg.

The result on the effects of RDE, MT and RDE + MT in combination at different dose rates on mortality of weevils after 3, 7, and 14 days on four stored maize varieties tested is presented in Table 6, whilemortality of *S. zeamais* on different maize grain varieties and the effects of treatments on mortality of *S. zeamais*is presented in Figures 3 and 4. Percentage adult mortality of *S. zeamais* in maize treated with different dose rates of RDE, MT and DE +MT were significantly different ($P < 0.05$) to the untreated grains, leading to 100% mortality compared to the untreated control (0.00g) which ranges from 1.7 to 8.6 % for the period of exposure (3, 7 and 14 days) on all the maize varieties (Table 6). However, SAMMAZ 25 had the highest weevil mortalityamong the other varieties testedwhich as well recorded higher mortality with increase in dose rates and days after treatment.

Treatments of RDE, MT and RDE + MTat the rate of 1000 g/kg, 16 g/kg and 750 + 10g/kg, respectively of grains were capable of inducing mortality of upto100% within 14 days after treatment (DAT). Similar result was recorded on grains treated with MT and RDE + MTat the doses 14g at 14 days and 750 + 6g; 750 + 10g at 7 days, respectively after treatment. Significantly ($P<0.05$) lower mortality was recorded with grains treated with dose rates of 250g, 6g, and 250 + 6g/kg grains of RDE, MT and RDE + MT 3 days after treatment application. At different dose rates of RDE at 3, 7 and 14 days; MT at 6 and 10g (3, 7 and 14 days) and RDE +

MT at 250 + 6g (3 and 14 days) and 750 + 6g (3 days) had no significant effect on adult mortality compared to control as seen in SAMMAZ 16 variety.

Similarly, the same trend was observed in SAMMAZ 29, SAMMAZ 25 and SAMMAZ 29 varieties were it was observed that the higher the dose and the longer the days after treatment, the more *S. zeamais* adult mortality recorded on all the varieties tested. Among the four varieties, the treatment, dose rates and number of adult *S. zeamais* mortality do not differ significantly (P<0.05) from each other (Table 6). Therefore, mortality effect of these treatments was dose and time dependent.

The effects of maize varieties on mortality of *S. zeamais* indicated that there was no significant difference (P<0.05) among the varieties on mortality of *S. zeamais* (Fig. 3).But, SAMMAZ 25 had the highest number of weevil mortality in all the assessment days (Fig. 3) Among the treatments (RDE, MT and RDE +MT) effects on mortality of*S. zeamais*,there was significant differences (P<0.05) (Fig. 4). However, in all the different treatments (RDE, MT and RDE +MT), day-3 recorded the highest weevil mortality while, day-14 recorded the lowest. Similarly, the combined treatment of RDE + MT had the highest mortality at all different dose rates followed by treatment with MT, while treatment with RDE had the lowest which is significantly different (P<0.05) to the control which had the lowest mortality throughout the assessment days (Fig. 4).

Table 6 Percentage mean mortality of *Sitophilus zeamais* on maize varieties days after treatments with RDE, MT and RDE + MT in combination

		Varieties											
		SAMMAZ 16			SAMMAZ 20			SAMMAZ 25			SAMMAZ 29		
Treatments	Dose (mg/kg)	3 d	7 d	14 d	3 d	7 d	14 d	3 d	7 d	14 d	3 d	7 d	14 d
Untreated	0.0	1.7^{h}	1.7^{l}	6.7^{f}	1.7^{k}	5.0^{j}	5.0^{e}	2.2^{j}	7.9^{i}	8.6^{e}	1.7^{j}	5.0^{i}	8.3^{e}
RDE	250	13.3^{j}	13.7^{k}	75.0^{e}	6.7^{j}	45.0^{i}	81.7^{d}	26.2^{i}	51.6^{h}	77.4^{d}	21.7^{i}	45.0^{h}	85.0^{d}
	500	23.3^{h}	56.7^{h}	85.0^{d}	15.7^{ib}	65.0^{f}	93.3^{c}	23.6^{h}	69.9^{g}	96.7^{bc}	23.3^{ab}	65.0^{ef}	95.0^{c}
	750	23.2^{h}	53.3^{hi}	86.7^{d}	21.7^{ab}	61.7^{g}	95.0^{b}	40.3^{g}	69.3^{g}	98.8^{b}	26.7^{h}	61.7^{f}	95.0^{c}
	1000	33.3^{fg}	68.3^{g}	100.0^{a}	31.7^{h}	76.7^{de}	100.0^{ab}	69.2^{d}	79.0^{e}	100.0^{a}	36.7^{ef}	76.7^{cd}	100.0^{a}
MT	6	18.3^{j}	48.3^{j}	95.0^{c}	16.7^{a}	56.7^{h}	95.0^{b}	27.3^{e}	89.7^{d}	96.3^{bc}	21.7^{i}	56.7^{g}	95.0^{c}
	10 `	28.3^{gh}	85.0^{e}	98.3^{b}	40.0^{f}	78.0^{d}	98.3^{ab}	47.2^{f}	88.5^{d}	99.0^{b}	31.7^{fg}	78.3^{c}	100.0^{a}
	14	53.3^{e}	96.7^{c}	100.0^{a}	46.7^{e}	95.0^{c}	100.0^{a}	46.9^{e}	97.6^{b}	100.0^{a}	38.3^{e}	95.0^{bc}	98.3^{b}
	16	85.0^{b}	96.7^{c}	100.0^{a}	90.0^{b}	100.0^{a}	100.0^{a}	96.8^{b}	99.4^{def}	100.0^{a}	83.3^{b}	100.0^{a}	100.0^{a}
RDE + MT	250 + 6	21.7^{i}	71.7^{f}	98.3^{b}	20.0^{ab}	71.7^{e}	95.0^{b}	24.8^{h}	73.3^{f}	96.4^{c}	25.0^{hi}	71.7^{d}	95.0^{c}
	500 + 6	36.7^{fg}	90.0^{d}	100.0^{a}	35.0^{g}	95.0^{c}	100.0^{a}	44.7^{f}	96.2^{bc}	100.0^{a}	33.3^{f}	95.0^{bc}	100.0^{a}
	750 + 6	40.0^{f}	100.0^{a}	100.0^{a}	35.0^{g}	96.3^{bc}	100.0^{a}	48.2^{f}	97.8^{b}	100.0^{a}	31.7^{fg}	98.3^{b}	100.0^{a}
	250 + 10	55.0^{d}	95.0^{c}	100.0^{a}	50.0^{d}	98.7^{b}	100.0^{a}	53.8^{e}	98.7^{b}	100.0^{a}	48.3^{d}	96.7^{bc}	100.0^{a}
	500 + 10	71.7^{c}	98.3^{b}	100.0^{a}	63.3^{c}	98.3^{b}	100.0^{a}	72.6^{c}	100.0^{a}	100.0^{a}	65.0^{c}	98.3^{b}	100.0^{a}
	750 + 10	93.3^{a}	100.0^{a}	100.0^{a}	96.7^{a}	100.0^{a}	100.0^{a}	98.2^{a}	100.0^{a}	100.0^{a}	91.7^{a}	100.0^{a}	100.0^{a}
SE±		1.07	0.83	1.22	1.34	0.93	0.58	0.17	1.32	1.47	1.14	0.45	0.78
CV (%)		9.28	3.86	9.35	4.82	5.06	1.86	17.02	20.52	36.13	5.20	2.44	7.12
$HSD_{(0.05)}$		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.004	0.0147	0.0381	0.0001	0.0001	0.001

Means followed by the same superscript along the column are not significantly different (P<0.05) from each other using Tukey-Kramer HSD Test.

RDE = raw Diatomaceous earth; MT = Malathion; RDE +MT = raw Diatomaceous earth + Malathion, d= day

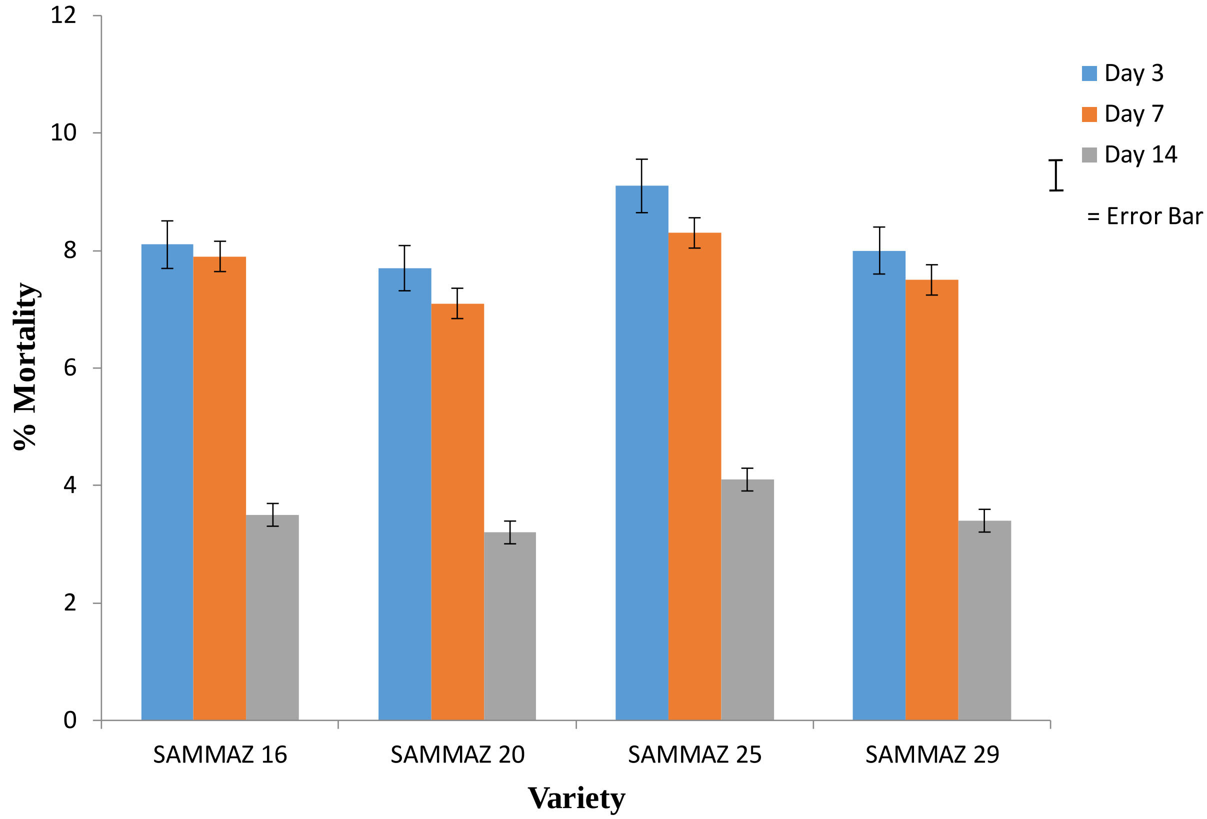

Figure 3: Mortality of *S. zeamais*on different maize varieties

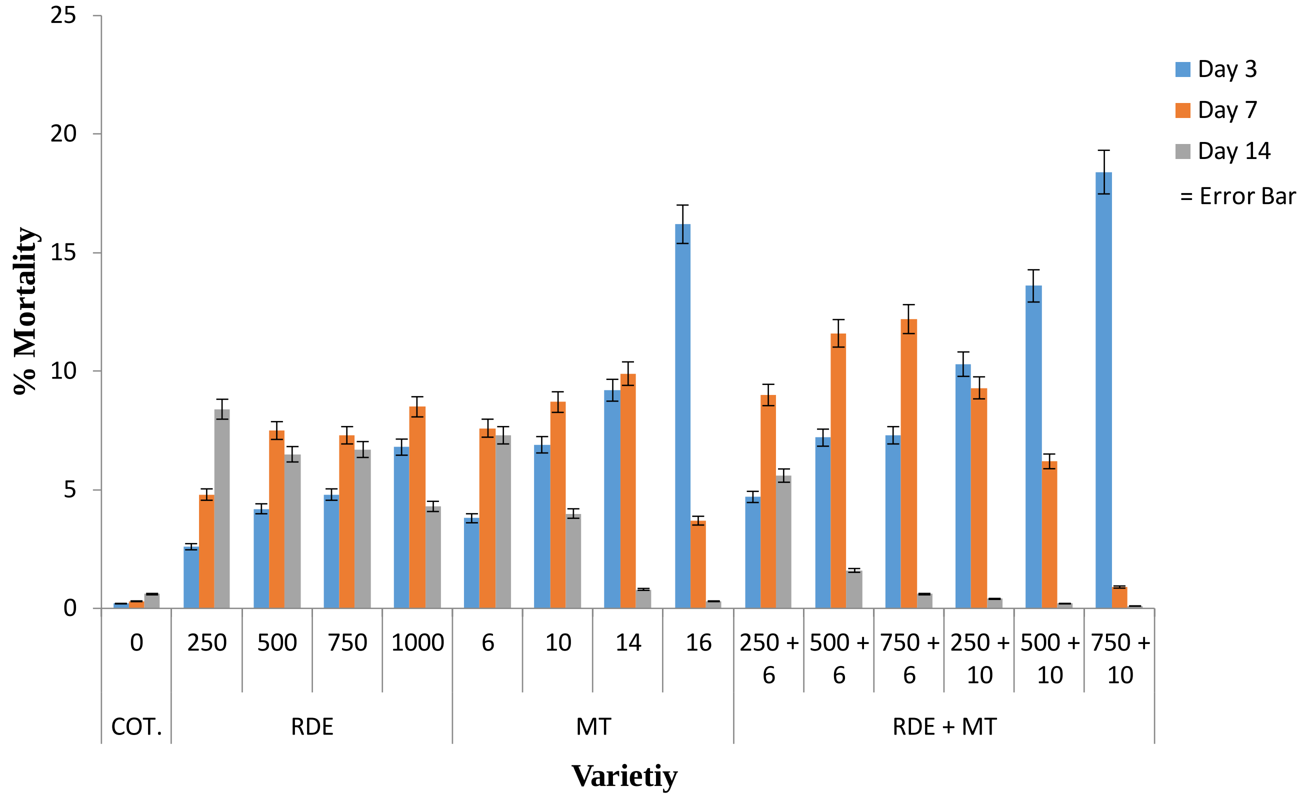

Figure 4: Mortality of *S. zeamais*on different treatments and dose rates

COT: Control; **RDE**: Raw Diatomaceous earth; **MT**: Malathion; **RDE + MT:** Raw Diatomaceous earth + Malathion.

4.5.2 Progeny production of S. zeamais on different selected maize varieties

The F_1 progeny emergence of *S. zeamais* on the maize varieties tested are presented in Figure 5. The result shows that there was no significant difference (P<0.05) among the mean number of progeny produced by *S. zeamais* in all the varieties. Though, SAMMAZ 29produced higher progeny compared to SAMMAZ 16, SAMMAZ 25 and SAMMAZ 21 varieties with respect to mean number of emerged adult progeny (Figure 5).

The dynamics of emergence of adult *S. zeamais* F_1 progeny on the maize varieties were presented on Fig. 5. Analysis of the figure indicated that adults emerged earlier, 21 days after treatment (DAT) on SAMMAZ 16 variety and SAMMAZ 29 variety. First adult emergence on SAMMAZ 25 variety was recorded three days later. Complete adult emergence on SAMMAZ 16 variety and SAMMAZ 20 variety were noted after 54 DAT. Period of emergence on SAMMAZ 29 variety was shorter than the two other varieties and lasted 51 days. The number of daily emergence was also lower in the case of SAMMAZ 25 variety as compared to SAMMAZ 16 and SAMMAZ 29 varieties. However, higher number of progeny was recorded on days 33, 36 and 39 on all the three varieties. Though, SAMMAZ 16 and SAMMAZ 29 varieties differ significantly (P<0.05) higher on number of progeny produced on each assessment day to SAMMAZ 20 (Figure 5). However, progeny emergence started on day 27 on SAMMAZ 25, cumulative adult emergence of 152.9 (Fig. 6).

The cumulative daily emergence curve of the weevilis shown in Figure 6. Throughout the period of adult emergence, higher number of adults emerged on SAMMAZ 29 of 230.0 followed by SAMMAZ 16of 221.4 and SAMMAZ 20 of 190.7. The lowest adult emergence was on SAMMAZ 25 of 152.9 which significantly differedto the total number of progeny produced by the other three varieties (Figure 6).

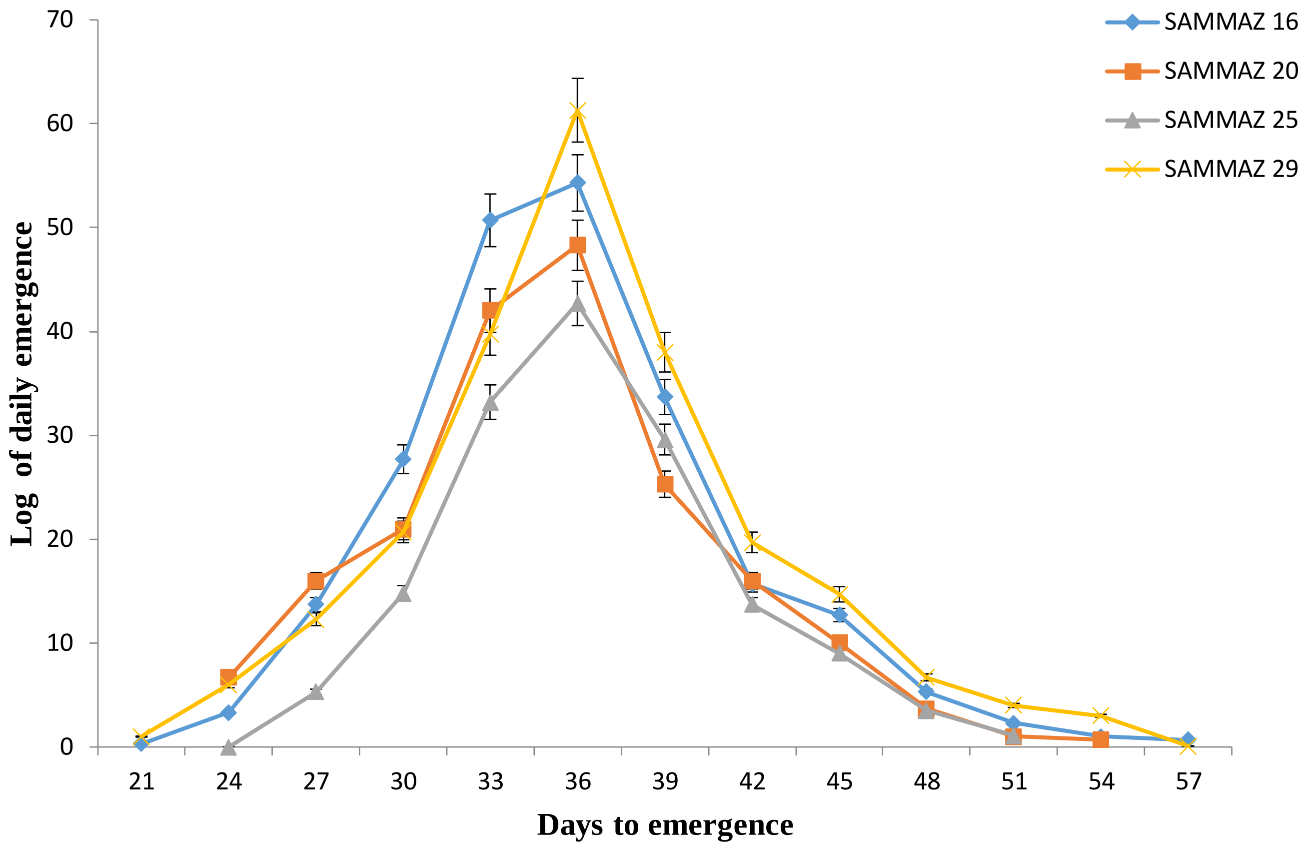

Figure 5: The trend of progeny emergence of *S. zeamais* from selected maize varieties

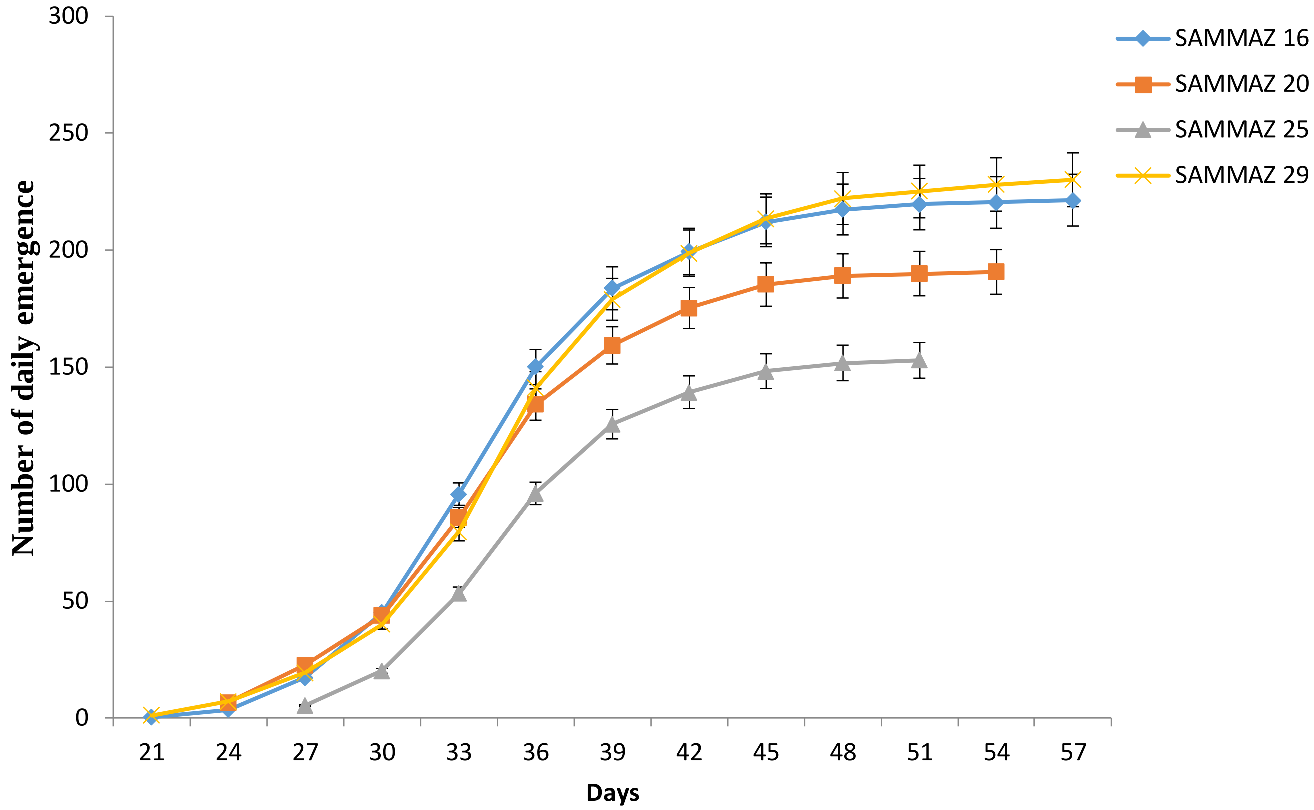

Figure 6: The Cumulative emergence curves of *S. zeamais* fromselected maize varieties

4.5.3 Grain weight loss of different selected maize varieties

Results on the assessment of the effects of treatments and varietieson the percentage weight loss due tothe infestation of *S. zeamais*in treated and untreated grains are shown in Table 7, and the effects on varieties and treatments on grain weight loss is presented in Figures 7 and 8. Most of the treatments, significantly (P<0.05) reducedweight loss when compared to the untreated check days after treatment (DAT). However, RDE at the lower rates (250 g and 500 g) was markedly lesseffective in reducing the weight loss caused by *S. zeamais* in SAMMAZ 16. There was less weight loss recorded on grainstreated with higher dose rates of RDE (750 and 1000 g). Significant difference (P<0.05) was recorded among the different treatments with respect to SAMMAZ 16 weight loss (Table 7). The highest and lowest percentage weight loss of 39.4, 25.5 and 12.4% was observed among the treatment with lower dose rates of 250 g RDE; 6 g MT and 250 + 6 g RDE, MT, respectively and the difference was statistically significant (P<0.05). On the contrary, significantly lower percentage weight loss was recorded on SAMMAZ 16 variety which ranges from 4.7 - 27.7% was observed in treatments with higher dose rates of 1000 g RDE; 16 g MT and 750 + 10 g RDE + MT, respectively, though, differed significantly to the untreated control which have higher weight loss (Table 7).

Figures 7 and 8 indicated that there weresignificant difference (P<0.05) among the varieties and among the treatments on grain weight loss. However, there were highly significant differences (P<0.01) among the varieties on grain weight loss which indicated that SAMMAZ 29 had the highest weight loss followed by SAMMAZ 16, while SAMMAZ 20 and SAMMAZ 25 had the least weight loss (Fig. 7).Similar trend was observed among the treatments on grain weight loss, which indicated significant difference (P<0.05)among the treatments (Fig. 8). However, it indicated that, the highest and lowest weight losses were recorded with increase and decreasein dose rate, respectively. All treatments (RDE, MT and RDE + MT) significantly differ (P<0.05) from the untreated control (Fig.8).

4.5.4 Grain damage of different selected maize varieties

Plate VII shows both white and yellow maize varieties damaged by the activities of *S. zeamais* during storage. The mean percentage grain damage of the maize varieties caused by *S. zeamais* is presented in Table 7, and the effects on varieties and treatments on grain damage is presented in Figures 9 and 10. Though, the trend was similar with that of weight loss. The table shows that maize grain damage caused by *S. zeamais* at different dose rates was significantly ($P<0.05$) different from each other. A significant ($P<0.05$) reduction in grain damage on all the varieties was obtained in the treated grains. There was significantly ($P < 0.05$) higher percentage grain damage in the untreated grains (Table 7).

Significance difference ($P<0.05$) was recorded among the maize varieties with respect to maize grain damage from the different dose rates which differ from that of untreated control (0.0 g) (Table 7). The highest and significantly different ($P<0.05$) percentage grain damage among the maize varieties was observed from lowest dose rates in all the varieties SAMMAZ 16 (54.3%), SAMMAZ 20 (51.8%) and SAMMAZ 29 (55.1%) while at the same dose rate SAMMAZ 25 had low grain damage of 34.8%. On the contrary, significantly ($P<0.05$) lower percentage grain damage was observed at higher doses of combined RDE + MT (750 + 10) of 4.3, 11.7, 17.0 and 18.3% on SAMMAZ 25, SAMMAZ 20, SAMMAZ 16 and SAMMAZ 34, respectively (Table 7).

Figures 9 and 10 indicated that there were significant difference ($P<0.05$) among the varieties and among the treatments on grain damage. However, there were highly significant differences ($P<0.01$) among the varieties on grain damage which indicated that SAMMAZ 16 had the highest grain damage followed by SAMMAZ 29, while SAMMAZ 25 and SAMMAZ 20 had the least grain damage (Fig. 9). Similar trend was observed among the treatments on grain damage, which indicated significant difference ($P<0.05$) among the treatments (Fig. 10). However, it indicated that, the highest and lowest grain damage was recorded with decrease and increase in dose rate, respectively. All treatments (RDE, MT and RDE + MT) significantly differ ($P<0.05$) from the untreated control (Fig. 8). However, the control had the highest grain damage when compared with the other treatments, though grain damage decreases with increase in dose rates (Fig. 10).

Table 7Mean percentage weight loss and grain damage by activities of *Sitophilus zeamais* on different maize varieties treated with different dose rates of RDE, MT and RDE + MT

		Varieties							
	Dose rate	**SAMMAZ 16**		**SAMMAZ 20**		**SAMMAZ 25**		**SAMMAZ 29**	
Treatments	**(mg/kg)**	WL	GD	WL	GD	WL	GD	WL	GD
Untreated	0.00	41.4^{a}	58.1^{a}	32.2^{a}	55.6^{a}	16.5^{a}	38.1^{a}	44.0^{a}	58.9^{a}
DE	250	39.4^{a}	54.3^{ab}	29.9^{a}	51.8^{ab}	15.0^{b}	34.8^{b}	42.0^{a}	55.1^{ab}
	500	33.8^{b}	51.0^{bc}	23.2^{b}	48.5^{bc}	11.1^{c}	31.8^{c}	36.7^{b}	51.8^{b}
	750	30.9^{bc}	48.9^{cd}	19.2^{bc}	46.4^{cd}	9.1^{d}	29.8^{d}	33.8^{bc}	49.6^{c}
	100	27.7^{cd}	44.6^{de}	16.1^{cd}	42.2^{de}	7.3^{e}	25.8^{e}	30.9^{cd}	45.3^{e}
MT	6	25.5^{cd}	41.4^{ef}	15.2^{cde}	38.9^{ef}	6.1^{f}	22.8^{f}	27.7^{de}	42.2^{cd}
	10	22.5^{de}	39.3^{fg}	14.3^{def}	36.8^{fg}	5.0^{g}	20.8^{g}	24.4^{e}	39.9^{de}
	14	19.9^{ef}	36.0^{gh}	$12.9^{d\text{-}g}$	33.3^{gh}	3.6^{h}	18.3^{h}	19.9^{f}	36.8^{e}
	16	15.3^{fg}	33.8^{hi}	$12.4^{d\text{-}g}$	31.8^{hi}	2.6^{i}	15.9^{i}	16.1^{g}	34.5^{ef}
DE + MT	250 + 6	12.4^{gh}	31.4^{i}	$12.2^{d\text{-}g}$	28.5^{hi}	1.9^{ij}	13.8^{j}	13.4^{gh}	32.2^{f}
	500 + 6	8.5^{hi}	30.2^{ij}	11.3^{efg}	27.2^{ij}	1.7^{j}	11.7^{h}	12.6^{hi}	31.0^{g}
	750 + 6	7.2^{hi}	26.4^{jk}	11.2^{efg}	23.1^{jk}	1.3^{k}	9.8^{l}	10.2^{hij}	27.2^{h}
	250 + 10	6.3^{i}	23.6^{kl}	10.5^{fg}	19.9^{kl}	1.2^{jk}	7.7^{m}	10.1^{hij}	24.6^{i}
	500 + 10	4.9^{i}	20.5^{lm}	9.8^{g}	16.3^{lm}	1.0^{k}	5.8^{n}	9.4^{ij}	1.6^{k}
	750 + 10	4.7^{i}	17.0^{m}	8.5^{g}	11.7^{m}	0.8^{k}	4.3^{n}	8.1^{j}	18.3^{j}
SE$\pm$		1.07	0.83	1.22	1.34	0.65	1.42	0.93	0.58
CV%		9.28	3.86	9.35	4.82	11.56	7.33	5.06	1.86
HSD $_{(0.05)}$		0.0001	0.0001	0.0001	0.0001	0.0001	0.5815	0.0001	0001

Means followed by the same superscript along the column are not significantly different from each other using Tukey- Kramer (HSD) at ($P \leq 0.05$).

RDE = Raw Diatomaceous earth; **MT** = Malathion; **RDE +MT** = raw Diatomaceous earth + Malathion; **WL**= Weight loss; **GD-** Grain damage

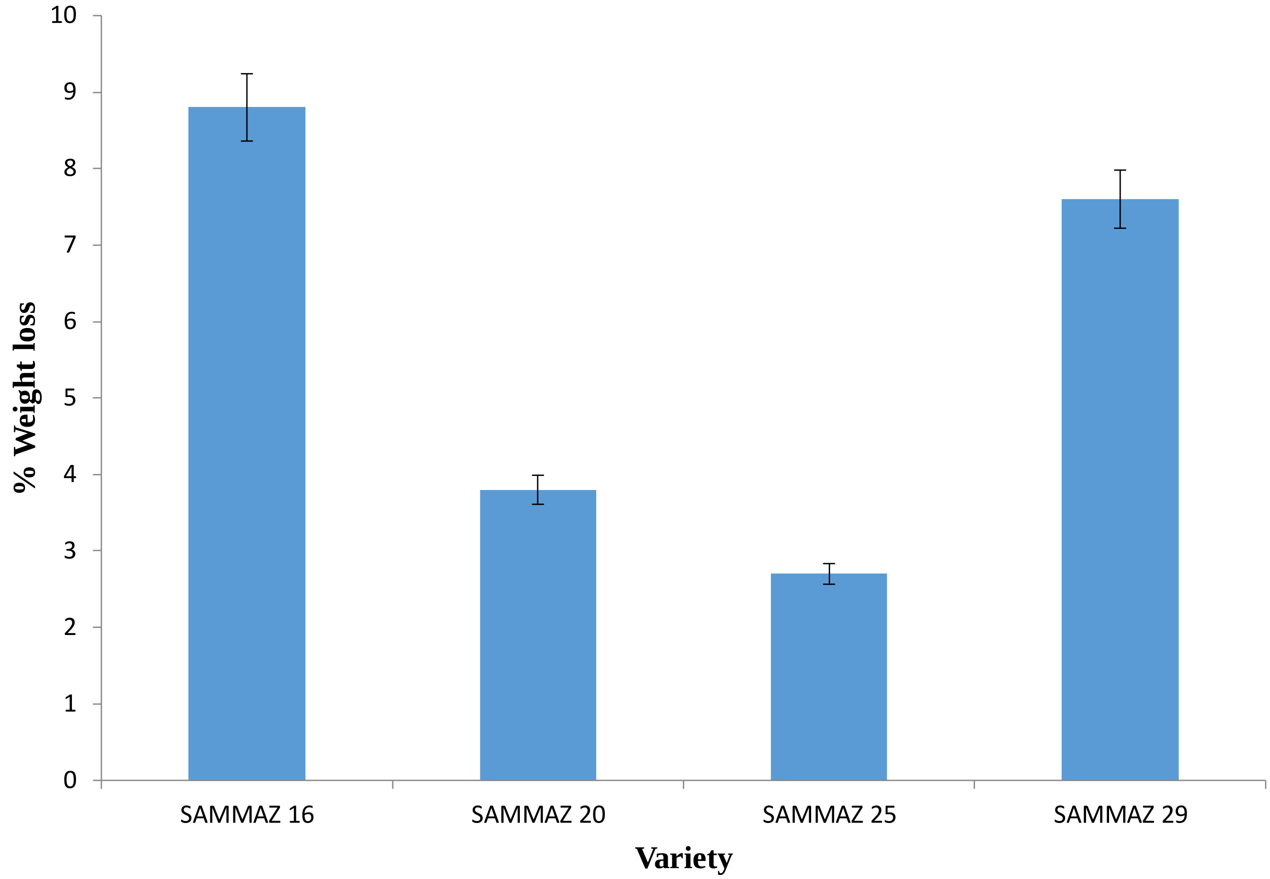

Figure 7: Percentage weight loss on differentselectedmaize varieties

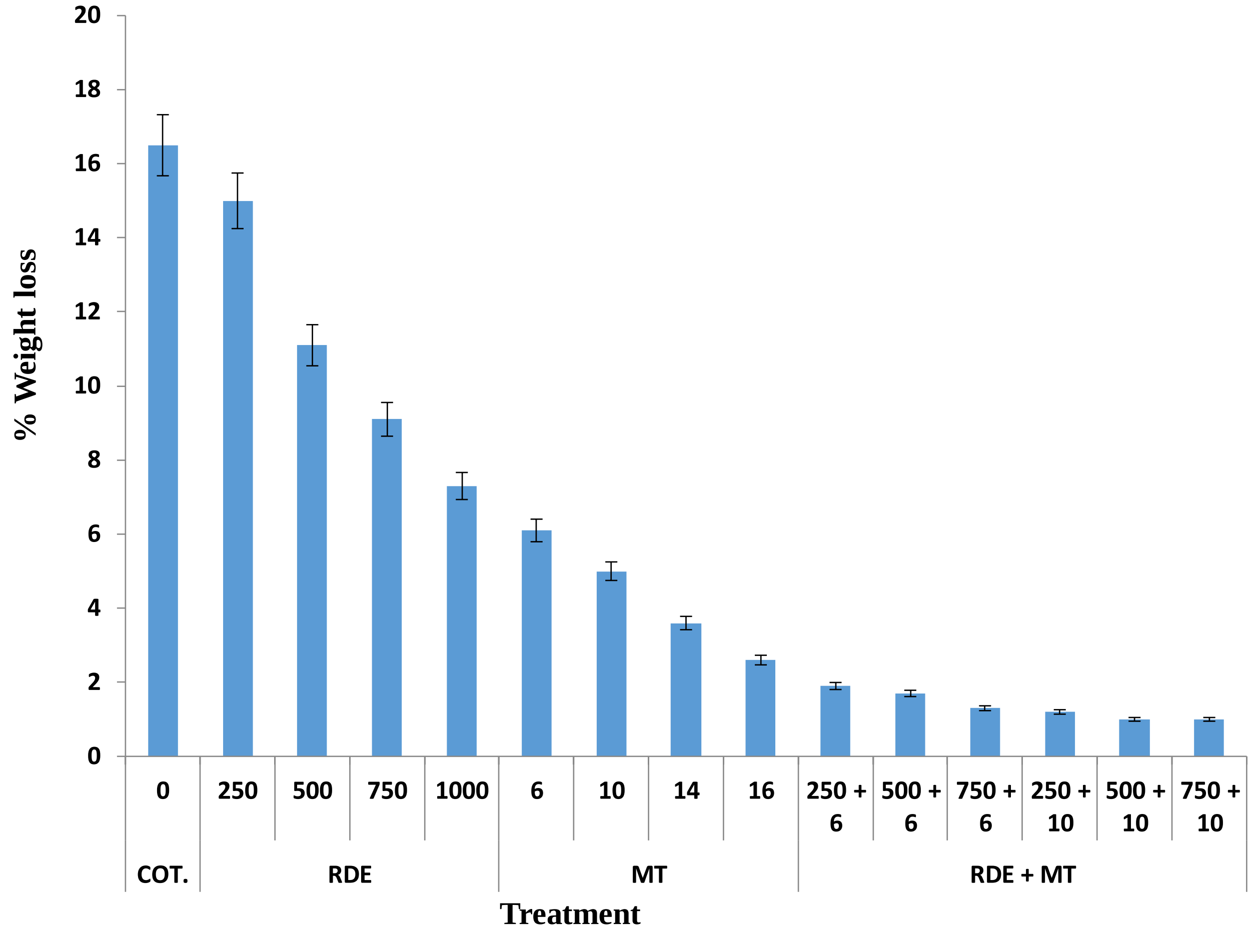

Figure 8: Effects of different treatments on percentage weight loss

COT: Control; **RDE**: Raw Diatomaceous earth; **MT**: Malathion; **RDE + MT:** Raw Diatomaceous earth + Malathion.

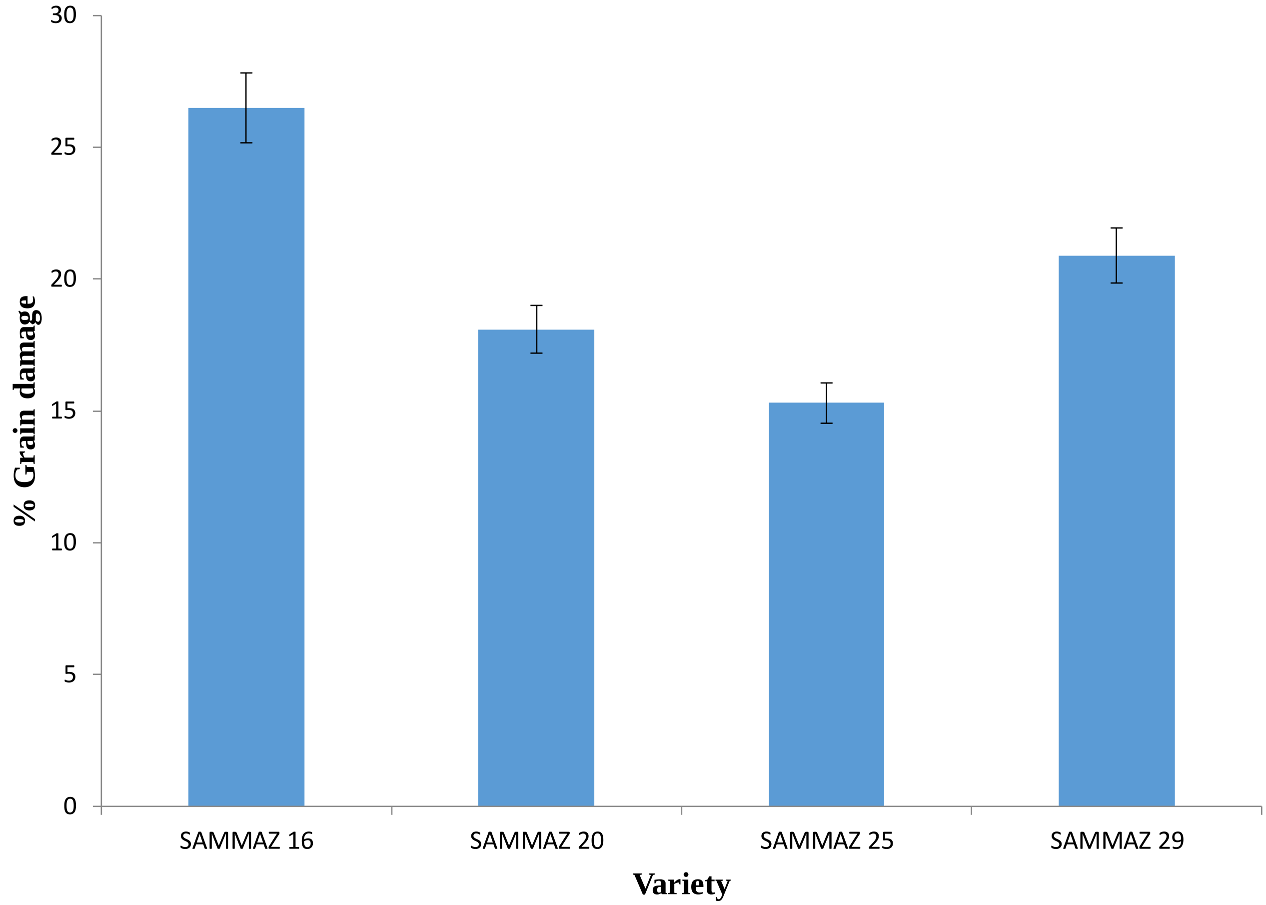

Figure 9: Percentage grain damage on different selectedmaize varieties

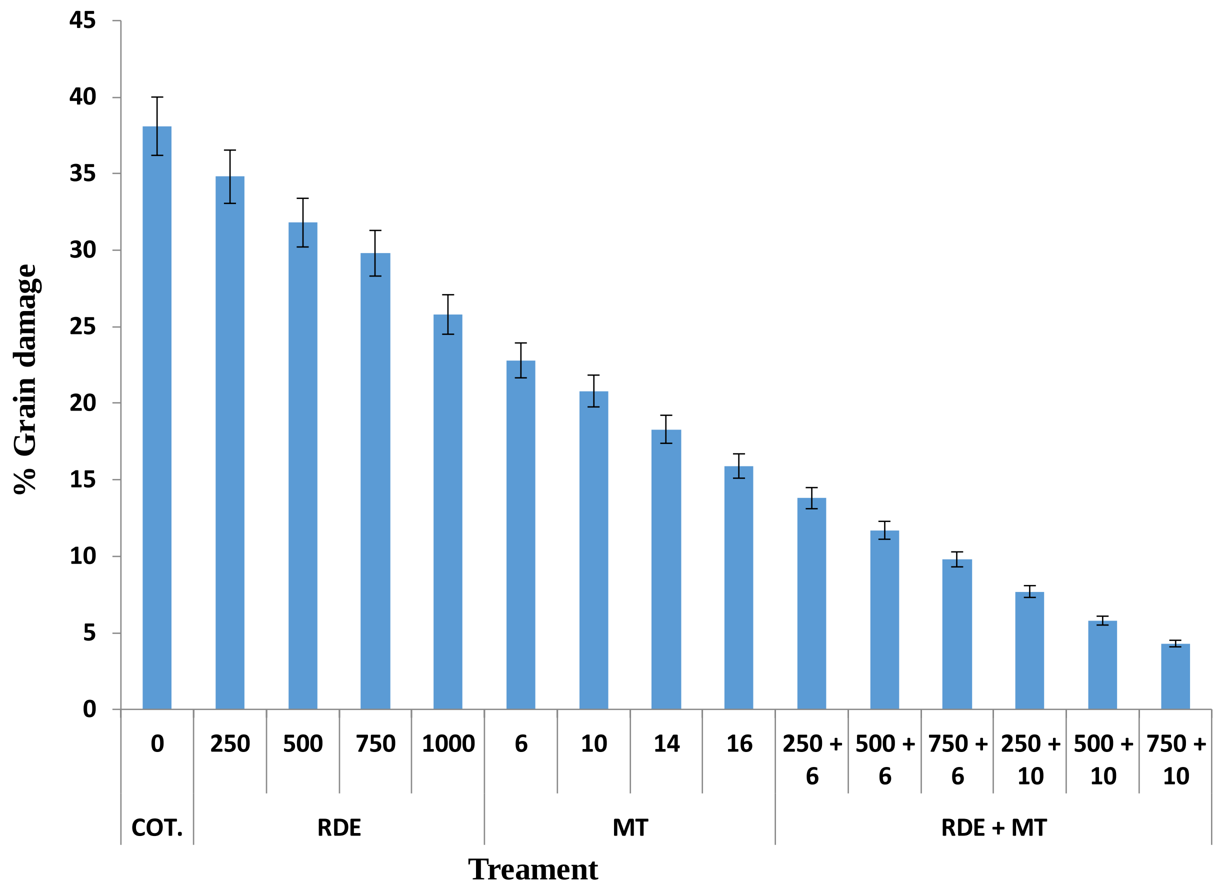

Figure 10: Effects of different treatments on percentage grain damage

COT: Control; **RDE**: Raw Diatomaceous earth; **MT**: Malathion; **RDE + MT:** Raw Diatomaceous earth + Malathion.

(a) White maize

(b) Yellow maize

Plate VII: White (a) and yellow (b) maize varieties damaged by the activities of *Sitophilus zeamais* in an untreated maize grains

CHAPTER FIVE

DISCUSSION

5.1 Morphological, Morphometric and Chemical Characteristics of Maize Varieties

In the absence of sustainable remedy to insect pests' attack in stored maize grains, evidenced from increased reports on susceptibility of maize varieties to storage pests (Arnason *et al*., 2004; Adedire *et al*., 2011), urgent efforts are required to investigate the maize characters that have relationships with resistance to *S. zeamais*. Resistance in stored maize to *S. zeamais* attack has been attributed to a number of factors. Some researchers have already hinted that resistance in stored maize to insect attack is related to some Morphological, physical, chemical and biochemical characteristics of a maize variety (Singh and Mc Cain, 1963; Dobie 1977; Adedire *et al*., 2011). Therefore, the results of this study collaborates the findings of these researchers.

5.1.1 *Effects of grain morphology on susceptibility of different maize varieties*

Variations recorded in the color of sampled maize genotypes are in agreement with observations of previous studies (Adegbola, 1992; Adedire *et al*., 2011, Nwosu *et al.*, 2015). These authors indicated that the color of maize grains differ among varieties, ranging from white, yellow, red, purple to black. None of the tested genotypes was purple or black in color; rather color observed on the maizevarieties did not play part inrendering resistance to the maize genotypes since the three susceptiblevarieties are either white (SAMMAZ 17) or yellow (SAMMAZ 21 and SAMMAZ 33), this is in contrast to the findings of Dobie (1977) who had identified color as one of the factor contributing to resistance to weevil infestation.

However, since most of the white colored varieties were resistant to the weevil, it may implythat, brightness of the color white repelled the insects from infesting the grains (Dobie, 1977). The observation that all sampled maize varieties appeared opaque corroborates the findings of Adedire *et al.* (2011) and Nwosu *et al.* (2015),that all varieties were smooth in texture was a matter of chance, since a variety can also have rough surface. The contributions of shape and face-type to grain resistance were not clear.

5.1.2 *Effect of grain morphometric characteristics on susceptibility of different maize varieties*

The occurrence of significant differences in the physical factors of the tested varieties in this study agree with the findings of other workers (Osipitan and Odebiyi, 2007; Makanjuola *et al*., 2009; Tonjura *et al*., 2010; Nwosu *et al.*, 2015). In this study, comparatively larger grain length, width, thickness, weight and hardness conferred good resistance to weevil infestation. However, it is well established that larger grain sizes are indicators of resistance against infestation and damage by *Sitophilus zeamais* (Gudrups *et al*., 2001; Makanjuola *et al.*, 2009) which is same to the result of the present study. The present result also corroborates the findings of Omoloye and Amodu (2006) that smaller-sized sorghum was comparatively more susceptible to infestation by *S. zeamais* than larger-grained type. On the contrary, Tongjura *et al*. (2010) documented that smaller seeds which must be hard and compact, with less moisture were more resistant to the maize weevil attack. Though with few exceptions (Olusanya, 1981; Osiptan and Odebiyi, 2007)various authorities have reported that grain hardness in particular, is one of the most important physical properties conferring certain degree of resistance to weevil attack on a maize variety (Tongjura *et al*., 2010; Adedire *et al*., 2011). Incidentally, the maize varieties which are resistance in the study had the greatest hardness ranging from 356.9 to 382.2 N, agreeing with the reports of these authorities. It is now obvious why 95% of all tested maize varieties were resistant to the weevil, since their hardness exceeded tremendously the "standard" (7 x 23.8 N = 166.60 N) as reported by Osipitan and Odebiyi (2007) and Nwosu *et al*. (2015).Bergvinson (2001) reported that there were strong correlations between insect resistance and kernel hardness which is only limited by moisture content. Conclusively, SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29 which are resistant to *S. zeamais* in this study had the longest, widiest, thckest, heaviest and hardest grains which indicate that these physical characteristics played and important role in confereing resistant to the maize varitiesb tested in the study.

5.1.3 Effects of chemical compositions on susceptibility of different maize varieties

Significant variations in the chemical constituents of the varieties are fairly well-documented (Singh and Mc Cain, 1963; Dobie, 1974; Arnason *et al*., 2004; Osipitan and Odebiyi, 2007; Adedire *et al*., 2011). The findings of other researchers suggest that the list of grain chemical characters that confer resistance to stored products insects is still debatable (Dobie, 1974; Shafique and Chaudry, 2007; Astuti *et al*., 2013; Chinaru, *et al*., 2015; Nwosu *et al*., 2015) and can vary from insect to insect.

The determination of proximate compositions of maize varieties will go a long way in providing substantive biochemical information of maize (Adedire *et al*., 2011). The results of the proximate composition of maize grains showed that maize contained appreciable level of crude protein, low levels of fat, crude fibre and ash but high levels of carbohydrate and starch which have been similarly observed by previous workers (El-Hkier and Hamid, 2008; Gernah *et al.,* 2011). Statistical analysis, shows significant differences exists ($P<0.05$) between the mean percentage values of the nutrient content of the grains of the maize varieties. Furthermore, the result of the proximate analysis indicates that carbohydrate, starch and moisture content played a significant role in conferring the resistance to *S. zeamais*, where all the resistant varieties have higher carbohydrate and starch content but low moisture content. This is in agreement with the findings of other authors (Garcia-Lara *et al.,* 2004; Tonjura *et al.,* 2010). However, the role of other chemical composition of maize grains in conferring resistance to *S. zeamais* is still poorly understood.

Percentage ash content of different maize varieties were found to be in the range of 1.28 (SAMMAZ 19) to 2.20% (SAMMAZ 17). Similar results 0.70 - 2.50% in different maize hybrids were reported by Saleem *et al.* (2008), keshun (2009), Egesel and Kalriman (2012) and Nutli *et al.* (2013). Maziya-Dixon *et al*. (2000) found results in the range of 1.4 to3.3%, which are in close consistency with the values determined in the present study, though with a little higher values which could be attributed to difference in varietal, environmental, analythical methods.

Maize is generally known to be high in carbohydrate and as such a good source of calories (Nuss and Tanumihardjo, 2011). Percentage Carbohydrate was found in the range of 67.85 (SAMMAZ 17) to 76.34% (Saksi) is in line with the above. Ijabadeniyi and Adebolu (2005) reported slightly lower values (65.63to70.23%) of the carbohydrate content for the maize varieties grown in Nigeria. Ullah *et al*. (2010) reported percent carbohydrate was found in the range of 69.65 to 74.55% which is close to the values found in this study.

Percentage crude fiber was found in the range of 1.71 to2.11%. Ijabadeniyi and Adebolu (2005) reported higher values 2.07 to 2.77% of the fiber content for the maize varieties grown in Nigeria which is also not in agreement with the present study. The variation of the crude fibre content has been well demonstrated by numerous studies. Ullah *et al*. (2010) reported that percentagecrude fiber in maize was in the range of 0.80 to 2.32 which is in close agreement with the values obtained in thestudy.

Percentage protein content was found in the range of (9.61 to 11.99%). This result is also in agreement with the findings of (Saleem *et al* 2008; Idikut *et al*., 2009; Berarddo *et al*., 2009). Also, Ijabadeniyi and Adebolu, (2005) who found the percentage protein content of three maize varieties grown in Nigeria to be in the range of 7.71 to 14.60% for the maize grains which differ from that of the present study. In the literature, some authors reported protein contents in maize hybrids from 7.77 to 13.84 % (Jiang *et al*., 2007). In this study, all the protein values recorded were lower than the range reported by Aisha and El-Tinay (2004) and this is probably attributed to varietal differences and perhaps environmental conditions under which the crops were grown.

Percentage ether extract were determined in the range of 3.41 (SAMMAZ 20) to 4.13% (SAMMAZ 17). The percentage ether extract obtained for maize varieties in this study was consistent and in agreement with that of Ikenie *et al*, (2002) but slightly differs from the findings of Ijabadenyi and Adebolu (2005) that found higher either extract content in the range 4.17 to 5.0%. Ullah *et al*. (2010) reported percentage ether extracts in Pakistan grown maize varieties in the range of 3.21% to 7.71% which is also in close to values obtained in the present study.

Starch is the main carbohydrate reserve in plants and an important part of our nutrition. The mean starch yield of the maize varieties ranged from 62.64% (SAMMAZ 17) to 72.44% (SAMMAZ 15) which is in agreement to the findings of Ndukwe *et al.* (2015). However, the starch yield is less than the values obtained by Nadiha *et al.* (2010) for potato and corn starch, which were 93.4% and 96.5% respectively. Also, protein, sugar and phenol have been reported as the bases of resistance (Dobie, 1974; Osipitan and Odebiyi, 2007; Tongjura *et al*, 2010). Garcia-Lara *et al.*,2004 found that increased phenolic acid, structural protein and diferulates of grain hull increased resistance to *S. zeamais*. We also believe in the present study that all the resistant maize varieties have higher percentage starch values.

5.1.4 *Grain moisture content of different maize varieties*

The grain moisture contents of maize varieties used for this study were low. The highest value of moisture content was found to be 12.00 % and the lowest was to be 8.98 %. Aisha and El-Tinay (2004) found the moisture value in 12 corn genotypes in the range of 4.3 to 6.7% which is below the values obtained in this study. Ullah *et al.* (2010) reported the value of moisture content in ten varieties of corn seeds in the range of 9.20 to 10.91 % which is close with the result of this study. Moisture contents seems to play an important role in susceptibility of these maize varieties because all the susceptible varieties have the highest moisture content as opposed to the low moisture content in all resistant varieties.

5.2 Screening Maize for Relative Resistance against *Sitophilus zeamais*

5.2.1 Progeny emergence, Mead developmental time (MDT) and Index of susceptibility

Considerable variation was found among the maize varieties with respect to F_1 progeny, median developmental time, and the susceptibility index. The differences in the resistance of the maize varieties indicate the inherent ability of a particular variety to resist *S. zeamais* attack. Resistance in stored maize to insect attack has been attributed to the presence of some morphological, physical and chemical factors (Dobie, 1974; Tepping *et al*., 1988) or non-nutritional factors, especially phenolic compounds (Serratos *et al.*, 1987). These factors acting alone or in combination are responsible for the varying levels of resistance to certain species of storage insect pests (Baker, 1976; Wongo and Perderson, 1990; Ramputh *et al.*, 1999; Chandrashekar and Satyanarayana, 2006). Bamaiyi *et al*. (2007) also reported grain hardness as the main resistance parameter against*S. oryzae* in stored sorghum. Goftishu and Belete (2014) noted that Progeny emergence was highly correlated with the susceptibility of varieties to weevil infestation. Consequently, varieties which are susceptible to maize weevils produce more number of progeny as compared to the resistant varieties. The large difference in the number of F_1 progenies produced among the resistant and susceptible varieties is an important variablethat underscores the effect of resistant varieties for the management of *S. zeamais* in stored maize.

Out of the twenty five maize varieties tested against *S. zeamais*in this study, only three varieties (SAMMAZ 17, SAMMAZ 21 and SAMMAZ 34) were susceptible. The remaining twenty two varieties were resistant. Relatively longer developmental time was required on the resistant varieties, than on the susceptible varieties. Similarly, weevils on varieties having a high index of susceptibility displayed reduced periods for the completion of developments. Reduced survival and establishment will reduce the insect populations and the resultant crop damage. Prolongation of development periods will also result in reduction of number of generations in a season. According to Horber (1988) and Abebe *et al.* (2009) the index of susceptibility is based on the assumption that the more F_1 progeny and the shorter the duration of the development, the more susceptible the grains would be.

Several maize varieties, including local land races, have been characterized as sources of resistance to *S. zeamais* (Giga and Mazarura, 1991; Arnason *et al*., 1994) similarly, the present study found some local cultivars, such as Baleji, Bataji, Bodeji, Daneji and Saksi toshow resistance to *S. zeamais.* The difference in maize varieties in this study was mainly due to the variation in F_1 progeny emergence, median developmental time (MDT) and susceptibility index. These variations in the differential susceptibility of the varieties show the innate capacity of particular varieties to resist *S. zeamais* attack. Resistant varieties exhibited reduced multiplication of F_1 progeny, longer median developmental period and lower score of susceptibility index. A number of factors contribute to the differences in genetic resistance of varieties to stored grains insects attack through their influence on fecundity and development (Shazali, 1987, Adetunji, 1998). This indicates that presumably antibiosis and/or antixenosis (Non-preference) mechanism of resistance play a role in the varietal resistance. Similarly, several authors reported that antibiosis and non-preference act together as mechanisms of resistance to *S. zeamais* in maize grains (Santos and Foster, 1983; Torres *et al.*, 1996; Chuch-Hernandez *et al*., 2013;Temesgen and Waketole, 2013).

Sitophilus zeamais require less developmental time on the susceptible varieties, while longer developmental time was elapsed on the resistant varieties.This indicates that one effect of increased resistance is prolongation of the developmental period which has negative effect on population growth and consequent damage. Similarly, *S. zeamais* emerged from varieties having a high index of susceptibility exhibited reduced periods for the completion of developments. Horber (1988) observed that, the higher the number of F_1 progeny produced and the shorter the duration of the development, the more susceptible the varieties would be. According to Abraham (1991), the extent of damage during storage depends on the number of emerging adults during each generation and the duration of each developmental time. Thus, varieties allowing rapid and high levels of adult emergence will be more seriously damaged.

5.3 Efficacy of RDE, MT and RDE + MT in Combination against *S. zeamais*

5.3.1 Adult mortality of S. zeamais days after treatment

The observed adult mortality after 7 days exposure at 1000 ppm of raw DE product was not a complete kill but an acceptable level of control. This rate was more than the labeled rates for commercial DE products. For instance, the labeled rates for Protect-It and Insecto are 400 and 500 ppm, respectively (Vardeman *et al*., 2007). It is well established that DEs differ in efficacy against stored products insect pests including *S. zeamais*. Fields and Korunic (2000) investigated the efficacy of six commercial DEs from different geographical locations against five stored-products insect species including *S. zeamais* and found up to 70% differences in mortality between DE sources depending on experimental conditions.

Hence the results of this study suggest that relatively higher dose of this product is required to kill *S. zeamais* completely within 14 days. The most important finding of this study is that the RDE product used affects *S. zeamais* in ways similar to commercial DE formulations. Our results are in agreement with the findings of La Hue (1972), Wakil *et al*. (2006) and Athanassiou *et al*. (2005b) who also reported that adult mortality increased with increase in dose rate and exposure period, and efficacy varied between grain types. Variations in efficacy of DEs among different grain types has been noted in a series of recent studies, involving tests with different DE products on different grain types (Athanassiou *et al*., 2003; Athanassiou *et al*., 2004; Vayias and Athanassiou, 2004; Kavallieratos *et al*., 2005). The significant interaction effect ($P<0.05$) between dose rate and grain type on mortality of *S. zeamais* noted in this study, confirms the aforementioned statements that DE efficacy is influenced by grain type and dosages.

The study showed that the diatomaceous earth (DE) and Malathion (MT)were toxic to adult *S. zeamais*, causing significant mortality to the weevil. However, the toxic action of the DE was far slower than that of the MT. Malathion at the rate of 14 mg/kg caused >95% *S. zeamais* mortality within 7 days, while, for the same time, the DE caused <80% mortality to the weevil at the rate 1000 mg/kg. The potency of the MT was superior to that of DEsince within 7 days there is complete mortality of *S. zeamais* at 14 mg/kg.

The toxic action increased with ascending exposure period for all the treatments. This observation was well elucidated by the increasing mortality values from the 3rd to the 14th day after treatment (DAT). The increase of adult mortality according to ascending exposure period and contents was due to the increase of the quantity of active ingredients contained in the insecticidal materials. The exposure time is crucial for the effectiveness of DE, because insects' movement increases the contact of the cuticle with dust particles (Athanassiou *et al.,* 2005b). Diatomaceous earth induced more than 50% mortality from the 7th day post-treatment, but when in combination with MT total mortality is observed. The same tendency was recorded by Demissie *et al*. (2008) and Jean *et al*. (2015) using another commercial DE formulation (Silicosec) against *S. zeamais*. These authors reported that SilicoSec caused 100% mortality of *S. zeamais* within 7 days exposure period, at the rates of 1% and 2%.

The death of insects due to admixture with diatomaceous earth could be attributed to the dehydration provoked by the abrasiveness of the small particles of this inert dust and by adsorption of oils in the body of the insect (Fields and Korunic, 2000; Kavallieratos *et al.,* 2005; Korunic, 1998), which breaks the layer of wax on the epicuticle, exacerbating the fatal loss of water as reported by Subramanyam and Roesli (2000). Ibrahim *et al*. (2012) observed that DE reduced the production of progeny by increasing adult mortality, reducing oviposition, ovicidal and larvicidal activities. Arthur and Throne (2003) and Jean *et al*. (2015), showed that adult weevils are killed by exposure to DE, some oviposition could still occur and progeny suppression may not be effective. That may explain the emergence of progeny at lowest content of DE. The efficacy of insecticide is related to time of exposure, it decreases when the storage period goes on. Khakame *et al.* (2012) reported that Dryacide dust, a formulation of diatomaceous earth provided effective protection to stored maize grain against *S. zeamais* for 9 months. Thus, this inert powder remained effective for long time compared to the wood ashes. Kavallieratos *et al*. (2005) reported that DE was effective against *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) in: maize, wheat, barley, oats and rice. Stathers *et al.* (2002) also reported that diatomaceous earth did not have any negative effects on seed germination. However, DE, and MT showed their potency to protect stored maize grains against maize weevil infestation that can greatly contribute to fight food insecurity by reducing postharvest losses.

In this study, the mortality of *S. zeamais* caused individually by RDE and MT on the maize varieties was significantly high compared to the untreated control. This mortality increased with concentrations and days of exposure. Similar results were obtained by a number of previous studies on different beetles exposed to different DE formulations (Ceruti *et al*., 2008; Matti and Awaknavar, 2009; Nukenine *et al*., 2010; Athanassiou *et al*., 2011; Shams *et al*., 2011; Khakame *et al*., 2012; Chiriloaie *et al*., 2014; Shafighi *et al*., 2014; Gabriel *et al*., 2016). The work done by these authors showed the increased mortality of beetles with increased days of exposure. For each DE formulation used in the present study, mortality of *S. zeamais* did not exceed 40% with the four maize varieties within 3 day of exposure. But with increased concentration and exposure periods, this mortality was higher.

The insecticidal efficacy of DE is determined by its degree of adherence to the kernel and the physical characteristic of each type of grain (Korunic, 1997, 1998). Athanassiou *et al*. (2005b) and Nukenine *et al*. (2010) reported similar results with SilicoSec® on stored wheat against of *S. oryzae* (L.) and on maize against *S. zeamais* respectively. Since DE acts as a desiccant; when DE particles are picked up by the insect cuticle, the epicuticular layer is destroyed, resulting in death through water loss (Korunic, 1998; Subramanyam and Roesli, 2000). This might explain the highest mortality of weevil at the highest concentration of DE in this study because active compound increase with the increased concentration, so the insect picks up more DE particles in the highest concentration. The study showed that the diatomaceous earth (DE) and Malathion (MT)were toxic to adult *S. zeamais*, causing significant mortality to the weevil. However, the toxic action of the DE was far slower than that of the MT. Malathion at the rate of 6mg/kg caused >95% mortality of *S. zeamais* within 14 days, while, for the same time, the DE caused <85% mortality to the weevil at the rate of 250 mg/kg.

5.3.2 Progeny production of S. zeamais after treatment with **DE, MT and RDE + MT**

In this study, differences on the percentage reduction in F_1 emergence observed on all maize varieties treated with DE, MT and RDE + MT. Percentage of progeny reduction in both RDE and MT and their combination treated grains was higher compared to control for the four maize varieties treated with each DE in all exposure periods (3, 7 and 14 days). MT and RDE + MT were more effective on SAMMAZ 25. This could be due to the total mortality of parents in the mortality test at these concentrations. Suppression of progeny emergence and infestation by maize weevils can be achieved using diatomaceous earth (Arthur and Throne, 2003; Arnaud *et al.* 2005; Wakil*et al.*,2006; Lorini and Beckel, 2006). Effective control of protectants is qualified as mortality of adult and/or immature, confirmed by lack of progeny generation (Hertlein *et al*., 2011). On the other hand, on SAMMAZ 29 treated with each dose of DE, MT and RDE + MT, the percentage number of adult emerged was high. While, in SAMMAZ 25 the F_1 progeny emergence period was shorter (52 days) and the number of adult weevils produced were few (152.9).

5.3.3 Grain damage and weight loss of four maize varieties

Percentage of grain damage reflected the effects of raw DE on number of progeny. All the main and interaction effects were significant ($P<0.05$). Similarly, significant differences in levels of grain damage were noted between dose rates on all grains. Damage was relatively lower on all the varietiestreated with MT and RDE + MT, while the same varieties sustained heavy damage with >50% grain damaged when treated at 250 mg/kg RDE alone. However, none of the dose rates completely stopped grain damage, but grain damage did not exceed >50% on any variety treated with MT alone and RDE + MT. The emergence of some progenies in all the treated grains explains the presence of grain damaged despite the efficacy of the treatments. Wakil *et al*., (2006) and Vardeman *et al*., (2007)reported that commercial DE formulations provided complete control of *S. zeamais* at dose rate range of 500 to 1000 ppm. Similar effect was achieved with the RDE + MT (750 + 10 mg/kg) combination in this study. According to Fields and Korunic (2002), effective DE should have >80% SiO_2, a pH below 8.5, and a tapped density < 300 g/L. The raw DE used in this study has a lower level of SiO_2 (29.4%) content, the component responsible for insecticidal effect, higher pH value 9.5 and tapped density of 312.5. On the other hand, most commercial DE products contain other substances such as silica aerogel or baits, which either improve physical properties or enhance efficacy (Subramanyam and Roesli, 2000; Quarles and Winn, 1996). The aforementioned could be the reasons for reduced efficacy of this raw DE at high dose rates. Nevertheless, the efficacy observed can be considered satisfactory given that >50% mortality level and considerable (below the EIL) prevention of progeny production, grain damage and weight losses were noted.

Seed damaged was significantly reduced on the maize varieties treated with each dose of Diatomaceous earth after 3, 7, and 14 days of storage. Matti and Awaknavar (2009) observed no percentage of seed damage in the sorghum treated with Protect-It at the dosage of 0.1 g. The studies of the previous authors agree with the result of the present study which shows that SAMMAZ 25 variety treated with combined RDE + MT recorded Low (4.4 %) percentage of seed damage. In all the varieties treated with RDE, damage observed on grains may be attributed to the increase in population of weevils. Furthermore, the grains moisture content is one of the most important factors affecting efficacy of DE in pest control products (Khakame *et al*., 2012). The moisture content of the four susceptible maize varieties used here were 11.36,11.3 and 12.00% for SAMMAZ 16, SAMMAZ 20 and SAMMAZ 29, respectively under the ambient laboratory conditions (26 - 38°C and 48 - 65% relative humidity). For that reason, higher moisture content may have decreased the efficacy of DE and permitted the development of *S. zeamais*. This is in conformity to the study made by Snelson, (1987) and Afridi *et al*.(2001). In addition to reduce seed damage, since the mode of action of DE dusts is the desiccation, lower grain moisture content also increased their efficacy (Fields and Korunic, 2000), which were observed in the four resistant varieties with lower moisture content that ranged from 8.9 to 9.5 %. Khakame *et al.* (2012) observed in their study that when moisture content increased from 10 to 16%, the progeny emergence in grain treated with Actellic Super dust increased from 0 to 0.5% compared to the untreated grain. Generally,this result suggests that the grain weight loss of the maize varieties was not only affected by the dose rate of RDE but due to inherent variation of the maize varieties.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The varieties differed in terms of color and shape but not in appearance, face-type and texture. Two color types were differentiated: yellow in SAMMAZ 36, SAMMAZ 37, SAMMAZ 38, Bataji and Bodeji, while white in the other varieties. All sampled varieties were opaque in appearance, had dent or flint face and are smooth in texture, and the shapes varied from hexagonal, oval and rectangular. However, in this study, morphological characteristics did not play any role in conferring resistance. Though, the most resistant varieties are white in colour.

The physical characteristics of maize grain varieties were observed that SAMMAZ 13 had the longest grain length while SAMMAZ 27 had the shortest grain length. However, the biggest grain widths in SAMMAZ 26 and Deneji while smaller widths were recorded in SAMMAZ 25, SAMMAZ 27, SAMMAZ 34 and Bataji. The thickest and thinnest maize grain were recorded in Sammaz 18 and SAMMAZ 15, SAMMAZ 17, SAMMAZ 55 and Bataji,The heaviest grain weight was recorded in SAMMAZ 16 the lightest grain weight was recorded in variety Saksi which did not differ. The hardest maize grain variety was obtained from SAMMAZ 16 variety, while the softest was from SAMMAZ 34 variety. The results reveal that the strength of the hardest variety was not significantly ($p<0.05$) different to all the other varieties except SAMMAZ13, SAMMAZ 17, SAMMAZ 21, SAMMAZ 22, SAMMAZ 25, SAMMAZ 26, SAMMAZ 34, SAMMAZ 37, SAMMAZ 38, Bodeji and Saksi.

The results of the proximate analysis of the nutrient composition of maize grains of thedifferent maize varieties, it shows that maize contained appreciable level of crude protein and moisture content, low levels of ash, crude fibre, ether extract and lysine but high levels of carbohydrate and starch. Statistically, significant ($p<0.05$) differences exist between the mean values of nutrients content of the grains of the maize varieties. The moisture contents of maize grains were at appreciable level (8.98 - 12.00 %). The highest value of moisture content was found for SAMMAZ 34 while, the lowest moisture content value was found in SAMMAZ 26 (8.98). The highest number of progeny was counted in bottles of the varieties SAMMAZ 29 followed by SAMMAZ 20 and SAMMAZ 16 of 56.0, 54.0 and 53.3, respectively. An appreciably higher number of progeny were also recorded in varieties Baleji, Bataji and Deneji of 44.7, 42.3 and 40.7, respectively. The MDT ranged from 26.7 to 42.0 days. *Sitophilus zeamais* reared on the varieties SAMMAZ 34, SAMMAZ 21 AND SAMMAZ 17 had relatively lower MDT. However, SAMMAZ 25, SAMMAZ 20, SAMMAZ 29, SAMMAZ 11 and SAMMAZ 16 had the highest MDT. The general trend in MDT appeared to be inversed to that of F_1 progeny emergence. Generally, as the MDT increases, the F_1 progeny emergence decreases. It was observed that, a shorter MDT gives rise to more F_1 progeny.The SI ranged from 3.4 in SAMMAZ 25 to 6.5 in SAMMAZ 34. Out of the twenty five maize varieties tested against *S. zeamais* for resistance, only four varieties; SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 AND SAMMAZ 29 had index of susceptibility of 3.9, 3.9, 3.4 and 3.8, respectively and are regarded as resistant to weevil attack. However, most of the varieties do not differ significantly to each other in regard to SI as in SAMMAZ 11, SAMMAZ 13, SAMMAZ 14, SAMMAZ 15, SAMMAZ 18, SAMMAZ 19, SAMMAZ 22, SAMMAZ 26, SAMMAZ 27, SAMMAZ 30, SAMMAZ 33, SAMMAZ 37 and SAMMAZ 38. Baleji, Bataji, Bodeji, Deneji and Saksi had SI which ranges from 4.1 to 5.4 and are regarded as moderately resistant to weevil attack. Three varieties SAMMAZ 17, SAMMAZ 21 and SAMMAZ 34 had SI of 6.1, 6.2 and 6.5, respectively and are regarded as moderately susceptible to weevil attack. The result shows that the SI is inversely related to MDT. However, the number of F_1 progeny showed a positive relationship with the SI.

Adult *S. zeamais* mortality was significantly affected by the doses of DE, of MT, DE + MT and by the exposure time. In the treatments using only DE, the mortality of *S. zeamais* started in the 3rd day after treatment and by the 14th day there was significant difference between the dosage of 250 mg/kg and the two highest dosages. The accumulated mortality in the 14th day was of >75% at 250 mg/kg, >90% at 500 mg/kg and 100% at 750 mg/kg and 1000 mg/kg of DE. The mortality was <10% in the 14th day in the control bottles. In the treatments mixing DE with MT, the mortality of *S. zeamais* was affected by the dosages and by the exposure time. Dead insects were registered to be higher in the 3rd day after the application. The accumulated mortality in the 3rd day was: >20% with the lowest dosage of DE and MT being >90% with 750 mg/kg + 10 mg/kg. It was observed that the higher the dose and the longer the days after treatment, the more *S. zeamais* adult mortality recorded on all the varieties tested. Therefore, mortality effect of these treatments was dose and time dependent. However, in all the different treatments (RDE, MT and RDE +MT), day-3 recorded the highest weevil mortality while, day-14 recorded the lowest.

Similarly, the combined treatment of RDE + MT had the highest mortality at all different dose rates followed by treatment with MT, while treatment with RDE had the lowest which is significantly different ($P<0.05$) to the control which had the lowest mortality throughout the assessment days.

The treatments, significantly reduced weight loss when compared to the untreated check days after treatment (DAT). However, RDE at the lower rates (250 g and 500 g) was markedly less effective in reducing the weight loss caused by *S. zeamais*. The highest percentage grain damage among the maize varieties was observed from lowest dose rates in all the varieties, while at the same dose rate SAMMAZ 25 had low grain damage of. On the contrary, lower percentage grain damage was observed at higher doses of combined RDE + MT (750 + 10) on SAMMAZ 25, SAMMAZ 20, SAMMAZ 16 and SAMMAZ 34. However, it indicated that, the highest and lowest grain weight loss and grain damage was recorded with decrease and increase in dose rate, respectively. Though, the control had the highest grain weight loss and grain damage when compared with the other treatments, though grain weight loss and grain damage decreases with increase in dose rates.

It can be summarized that there exists differential reaction of different maize varieties with respect to most of the parameters tested/studied. From the present study, the most resistant varieties among the varieties tested are SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29. This may be due to the differences of these varieties from the other varieties in its morphological, morphometric and chemical compositions that confer resistance and reduced the successful utilization of itself by this weevil, *S. zeamais*. The varieties (SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29) that exibits resistance in this study, had less moisture content, F_1 progenies emergency, grain weight loss, grain damage and low indices of susceptibility; and more adult mortality and median development time as compared to the other varieties. These indicate that the overall loss incurred to these varieties during storage will be minimal as compared to the other varieties. Therefore, these varieties can be stored for longer periods of time with reduced cost of weevil's management and no adverse effect on the environment.

The results of this study indicated that, the RDE at higher dose rates was effective against *S. zeamais*and can provide substantial level of control of *S. zeamais*despite low SiO_2 content. Efficacy varied with dose, exposure period and grain type. To achieve 100% adult mortality or prevention of grain damage, dose rates higher than 1000 ppm should be used for DE alone while lower Malathion combined with lower dose rate of RDE will also achieve 100% mortality.

6.2 Conclusion

The information obtained from the present study will assist to devise the management strategies against this legendary pest of maize as well as other cereals. Resistant varieties can reduce the cost of weevil management and can also be utilized as an environmental friendly way to reduce damage by *S. zeamais.* In the past, a reasonable number of maize varieties have been evaluated for their resistance to maize weevil, but still more explorations are needed to achieve long-term and sustainable pest management strategies and to diversify the basis of resistance to this pest.

However, when deciding between a chemical insecticide and DE for insect control, the advantage and disadvantage of both should be considered. The action of chemical insecticides is faster reducing the chances of reproduction and consequently the production of a second generation. High dosages of insecticides also leave residues in the grain and processed end products and cause environmental contamination. The DE is non-toxic and do not leave residues neither contaminants in the environment. However, its action is slower than that of chemical insecticides and the insects may reproduce and leave progeny, but since it stays adsorbed on the grain the residual action will continue to keep the population in low numbers below economic injury level (EIL).

The efficacy of insecticide (RDE and MT) is related to time of exposure, it decreases when the storage period goes on. This revealed importance to determine the “action duration” of each insecticidal material used for grain storage and also the persistence of the insecticide. Diatomaceous earth remains effective for long time compared to other inert materials (wood ashes etc). Diatomaceous earths and MT showed their potency to protect stored maize grains against maize weevil infestation.

Finally, the foregoing study indicates that the efficacy of Diatomaceous earth against *S. zeamais* when used alone is hinged on large quantity applied and longer time of exposure. The limitation associated with high dose is reduced grain flowability and bulk density leading to lower grain grading. The prolonged exposure period required for appreciable efficacy of diatomaceous earth against *S. zeamais* provides sufficient time to the rapidly multiplying insect pest to inflict more damage to the grain as the larval stage occurs inside the grain which is not easily accessible to Diatomaceous earth dust. Application of Diatomaceous earth in combination with other grain protectants especially Malathion can reducethe limitations stated above in addition it increases the efficacy against the target insect pests.

6.3 Recommendations

Effort must be intensified to control the damage caused by *S. zeamais* to stored maize, this could be achieved by the use of raw Diatomaceous earth which is cheap, low risk control techniques and is readily available to the farmers which prompted this study. Therefore, the following recommendations were put forward;

i. The contributions of shape and face-type to grain resistance were not clear and therefore merit further investigation.

ii. Moisture content above 16% renders resistant maize variety susceptible to *S. zeamais* infestation. This highlights the importance of grain conditioning before storage. I therefore recommend that maize grain should be dried to the lowest moisture content (<16 %) before storage.

iii. It is necessary that factors which influence susceptibility such as grain hardness and grain moisture content to be elucidated so as to provide more information to maize breeders. Therefore only the resistant varieties should be stored for longer period.

iv. The refinement of RDE to arcertain the silicon (SiO_2)content and to reduce impurities so as to standardize the most effective dosage application rates for different pests should be further investigated.

v. Further work would be required to estimate the duration of efficacy and consumer safety, before promoting their use in stored product protection.

vi. The resistance varieties SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29 should be recommended to farmers in order to avoid economic damage due to *S. zeamais* infestation.

vii. More research on the use of efficacy of RDE's for the management of other insect pests of stored maize and other cereals should be carried out.

6.4 Contribution to knowledge

This research work has provided reliable information on importance of using maize resistant varieties SAMMAZ 16, SAMMAZ 20, SAMMAZ 25 and SAMMAZ 29to avoid economic damage by *S. zeamais.* It has ascertained the efficacy of Raw Diatomaceous Earth(750 mg/kg) alone and/or in combination with Malathio (6 mg/kg) against *S. zeamais*. Besides, it hasrevealed the optimum rate of combining Raw Diatomaceous Earth and Malathion (500 + 6 mg/kg) for the management of *S. zeamais*. Furthermore, the result of this work will serve as a promising integrated management strategy for*S. zeamais* in stored maize grains.

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APPENDICES

Appendix I: Analysis of Variance (ANOVA) Model for Completely Randomized Design (CRD)

Source of Variance	Df	Ss	Ms	*F*cal.	Tabulated *F*	
					5%	1%
Treatment (t-1)	24					
Error (a) t(r-1)	50					
Total (r)(t)-1	74					

Appendix II: Analysis of Variance Model for Split Plot Design (SPD)

Source of Variance		Df	Ss	Ms	*F*cal.	Tabulated *F*	
						5%	1%
Replication	(r-1)	2					
Main plot factor (A)	(a-1)	14					
Error (a)	(r-1)(a-1)	28					
Sub-plot factor (B)	(b-1)	3					
AXB interraction	(a-1)(b-1)	42					
Error (b)	a(r-1)(b-1)	90					
Total	rab-1	179					

Appendix III: ANOVA table of Morphometric characteristics of maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	P > F
Length					
Variety	24	2.75325	0.11472	146	0.0000
Error	100	0.07852	0.00079		
Total	124	2.83177			
Width					
Variety	24	1292.88	53.8700	1.00	0.4776
Error	100	5403.87	54.0387		
Total	124	6696.75			
Thickness					
Variety	24	382.57	15.9404	1.00	0.4686
Error	100	1587.42	15.8742		
Total	124	1969.98			
Weight/100 g					
Variety	24	13.18213333	0.54925556	36.78	<.0001
Error	50	0.74666667	0.01493333		
Corrected Total	74	13.92880000			
Hardness					
Variety	24	594.6133333	24.7755556	12.99	<.0001
Error	50	95.3333333	1.9066667		
Corrected Total	74	689.9466667			

Appendix IV: ANOVA table of Chemical Characteristics of Maize Varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Ash					
Variety	24	4.13833867	0.17243078	20.04	<.0001
Error	50	0.43020000	0.00860400		
Corrected Total	74	4.56853867			
Carbohydrate					
Variety	24	410.6274000	17.1094750	109.21	<.0001
Error	50	7.8334667	0.1566693		
Corrected Total	74	418.4608667			
Crude Fibre					
Variety	24	0.70403200	0.02933467	17.36	<.0001
Error	50	0.08446667	0.00168933		
Corrected Total	74	0.78849867			
Crude Protein					
Variety	24	35.69556533	1.48731522	414.68	<.0001
Error	50	0.17933333	0.00358667		
Corrected Total	74	35.87489867			
Ether Extract					
Variety	24	2.85900000	0.11912500	102.58	<.0001
Error	50	0.05806667	0.00116133		
Corrected Total	74	2.91706667			
Lysine					
Variety	24	0.41123200	0.01713467	3.05	0.0004
Error	50	0.28086667	0.00561733		
Corrected Total	74	0.69209867			
Starch					
Variety	24	403.6495013	16.8187292	6.64	<.0001
Error	50	126.5738667	2.5314773		
Corrected Total	74	530.2233680			
Moisture Content					
Variety	24	38.26684533	1.59445189	19.22	<.0001
Error	50	4.14693333	0.08293867		
Corrected Total	74	42.41377867			

Appendix V: ANOVA table of Screening Maize Varieties for Relative Resistance to *S. zeamais*

Source	DF	Sum of Squares	Mean Square	F -Value	Pr > F
F_1 Progeny Emerged					
Variety	24	2922.000000	121.750000	20.80	<.0001
Error	50	292.666667	5.853333		
Corrected Total	74	3214.666667			
Median Developmental Time					
Variety	24	928.186667	38.674444	13.43	<.0001
Error	50	144.000000	2.880000		
Corrected Total	74	1072.186667			
Susceptibility Index					
Variety	24	34.76784259	1.44866011	21.60	<.0001
Error	50	3.35341793	0.06706836		
Corrected Total	74	38.12126052			

Appendix VI: Interaction ANOVA table of mortality of *Sitophilus zeamais* at 3, 7 and 14 DAI

Source	DF	SS	MS	F	P
3 DAI					
Insect	3	170754	56918.1	142.17	0.0000
Dose	5	7400	1479.9	3.70	0.0035
Exposure	2	8	3.8	0.01	0.9905
Insect*Dose	15	3329	221.9	0.55	0.9048
Insect*Exposure	6	251	41.8	0.10	0.9958
Dose*Exposure	10	339	33.9	0.08	0.9999
Insect*Dose*Exposure	30	921	30.7	0.08	1.0000
Error	144	57652	400.4		
Total	215	240653			
7 DAI					
Insect	3	163573	54524.4	119.55	0.0000
Dose	5	12428	2485.7	5.45	0.0001
Exposure	2	193	96.7	0.21	0.8091
Insect*Dose	15	5402	360.1	0.79	0.6875
Insect*Exposure	6	413	68.9	0.15	0.9886
Dose*Exposure	10	224	22.4	0.05	1.0000
Insect*Dose*Exposure	30	583	19.4	0.04	1.0000
Error	144	65678	456.1		
Total	215	248495			
14 DAI					
Insect	3	165629	55209.8	123.09	0.0000
Dose	5	8359	1671.8	3.73	0.0033
Exposure	2	214	107.0	0.24	0.7880
Insect*Dose	15	3952	263.5	0.59	0.8810
Insect*Exposure	6	423	70.5	0.16	0.9873
Dose*Exposure	10	328	32.8	0.07	1.0000
Insect*Dose*Exposure	30	906	30.2	0.07	1.0000
Error	144	64588	448.5		
Total	215	244400			

Appendix VII: ANOVA table of weight loss of different maize varieties caused by *S. zeamais*

Source	DF	SS	MS	F	P
SAMMAZ 16					
TRT	14	6801.36	485.811	141	0.0000
Error	30	103.72	3.457		
Total	44	6905.08			
SAMMAZ 20					
TRT	14	2185.69	156.120	70.3	0.0000
Error	30	66.59	2.220		
Total	44	2252.27			
SAMMAZ 25					
TRT	14	6562.47	468.748	358	0.0000
Error	30	39.25	1.308		
Total	44	6601.71			
SAMMAZ 29					
TRT	14	6562.47	468.748	358	0.0000
Error	30	39.25	1.308		
Total	44	6601.71			

Appendix VIII: ANOVA table of damage of different maize varieties caused by *S. zeamais*

Source	DF	SS	MS	F	P
SAMMAZ 16					
TRT	14	6652.99	475.214	232	0.0000
Error	30	61.57	2.052		
Total	44	6714.56			
SAMMAZ 20					
TRT	14	7351.38	525.098	194	0.0000
Error	30	81.11	2.704		
Total	44	7432.48			
SAMMAZ 25					
TRT	14	6524.28	466.020	938	0.0000
Error	30	14.91	0.497		
Total	44	6539.19			
SAMMAZ 29					
TRT	14	6524.28	466.020	938	0.0000
Error	30	14.91	0.497		
Total	44	6539.19			