EVALUATION OF MAIZE VARIETIES FOR RESISTANCE TO MAIZE WEEVIL *(Sitophilus zeamais* Motschulsky*)* *(*Coleoptera: Curculionidae) UNDER LABORATORY CONDITION

M.Sc. Thesis

By

Temesgen Keba Warke

July, 2012

Jimma University

Ethiopia

EVALUATION OF MAIZE VARIETIES FOR RESISTANCE TO MAIZE WEEVIL *(Sitophilus zeamais* Motschulsky) *(*Coleoptera: curculionidae) UNDER LABORATORY CONDITION

Submitted to the School of Graduate Studies Jimma University College of Agriculture and Veterinary Medicine

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agricultural Entomology

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APPROVAL SHEET

School of Graduate Studies

As thesis research advisor, I hereby certify that I have read and evaluated this thesis prepared, under my guidance, by Temesgen Keba, entitled "**EVALUATION OF MAIZE VARIETIES FOR RESISTANCE TO MAIZE WEEVIL [*(Sitophilus zeamais (*Motschulky)] Coleoptera: Curculionidae*)* UNDER LABORATORY CONDITION.** I recommend that it be submitted as fulfilling thesis requirement.

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As member of the *board of Examiners* of the *M.Sc. Thesis Open Defense Examination*, we certify that we have read, evaluated the thesis prepared by **Temesgen Keba** and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Agricultural Entomology.

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DEDICATION

This thesis is dedicated to all my beloved families, especially to my mother Rude Duressa.

STATEMENT OF THE AUTHOR

I hereby affirm that the contents of this thesis "**EVALUATION OF MAIZE VARIETIES FOR RESISTANCE TO MAIZE WEEVIL [*(Sitophilus zeamais (***Motschulsky)] **Coleoptera: Curculionidae*)* UNDER LABORATORY CONDITION** is the product of my own research and no part has been copied from any published source; except the references, standard mathematical or models/equations/protocols etc and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for M.Sc. degree at the Jimma University and is deposited at the University Library to be available to borrowers under rules of the library. The University may take action if the information provided is found inaccurate at any stage. I seriously declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate. Brief quotations from this thesis are allowable without special permission provided that accurate acknowledgement of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the College and head of School of Graduate Studies when in his or her judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

Temesgen Keba was born on July 6,1985 at Kiremu, in East wollega, Ethiopia. He attended and completed grade 1 to 8 at Kiremu Elementary School (1991-1998) and grade 9 to 12 at Gidda Ayana Senior Secondary School (1999-2003), in Wollega, Ethiopia. He was joined Haramaya University fuculity of Agriculture in September 2004 and graduated with a B.Sc.degree in Plant Science in July 2006. He was employed by Ehiopian minstry of Agriculture in September 2007 and served as Crop Production Expert for four years at Limu woreda. In March 2010, He again joined the School of Graduate Studies at Jimma University to pursue his graduate study in Agricultural Entomology.

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LIST OF ABBREVIATION

CRD	Complete Randomized Design
JUCAVM	Jimma University College of Agriculture and Veterinary Medicine,
IPM	Integrated Pest Management
CV	Coefficient of Variation
HPR	Host Plant Resistant
UNDP	United Nation Development Program
CSA	Central Statistical Agency
IS	Index of Susceptibility
MDP	Median Development Period
IGR	Insect Growth Regulation
ANOVA	Analysis of variance
HSD	Honestly significant difference
SAS	Software Statistical Analysis System
MSD	Minimum significant difference
FAO	Food and Agricultural Organization
DML	Dry matter lost
CIMMYT,	International maize and wheat improvement center
BH	Bako hybrid
BHQP	Bako hybrid Quality protein maize
BHQPY	Bako hybrid Quality protein yellow maize

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ABSTRACT

Maize is an important crop ranking second in world grain production only preceded by wheat and it is an important component of agriculture and food systems all over the world. A study was conducted with the objective to determine the resistance of maize varieties to maize weevil, *Sitophilus zeamais*. It was conducted at Jimma University College of Agriculture and Veterinary Medicine in entomology laboratory at room temperature of 25 to 27°c and 40 - 60 % R.H in 2011/2012. The maize varieties were collected from Bako and Holeta Agricultural Research Centers, Ethiopia and the local variety was collected from Jimma area. The varieties are currently under production in different parts of Ethiopia. About 300g seeds from each of the maize varieties were placed in a one liter glass jar with brass screen lids allowing ventilation and preventing escape of the weevils. No choice test method in which the weevils were introduced to each jar was used for the study. The treatments were arranged in a completely randomized design (CRD) with three replications. A total of 13 maize varieties were screened for their relative resistance to *S. zeamais*. The index of susceptibility was used to classify the varieties in to different reaction categories. Varieties were significantly different in terms of susceptibility index (at 5% probability level). Only the standard checks variety, 'BHQP-542', had 3.5 index of susceptibility and was regarded as resistant variety to maize weevil attack. However; most of the varieties, namely BH660, BH670, BH543, BHQPY545, Gibe-1, Gibe-2, Wanchi, Argane, Hora and Local variety-Orome had index of susceptibility 4.6, 5.3, 4.7, 4.8, 4.9, 4.8, 5.2, 5.7, 5.2, 6.0 respectively and are regarded as moderately resistant to maize weevil attack. Two varieties (BH661 and Kuleni) had index of susceptibility 7.11 and 7.09 respectively and are regarded as moderately susceptible varieties to maize weevil attack. The standard check variety produced low numbers of F_1 progenies (51.33), had a high median developmental time (48.33 days), a low percentage of seed damage (15.85%), less production of grain dust (powder (0.03%)), low percentage of seed weight loss (4.11%) and high percent weevils mortality (14.24%) and seed germination (93.66 (undamaged) & 86.60% (damaged)).Weevils progeny emergency is significantly and positively associated with seed damage and weight loss but inversely with median development time. The use of resistant varieties in insect pest management is an eco-friendly and cost effective means that should be promoted for *S. zeamais* management in maize especially for small-scale farmers in the tropics.

Key words: Maize varieties, resistance, seed infestation, *Sitophilus zeamais*, susceptibility index.

1. INTRODUCTION

Maize (*Zea mays* L.) is an important crop ranking second in world grain production only preceded by wheat. Maize production and distribution is a cosmopolitan (Makate, 2010) and it is an important component of agriculture and food systems all over the world. The crop is versatile in its uses and environmental adaptation. It is consumed all over the world both by human being and animals. Maize grains find themselves in many industries to be processed in to various food and industrial products of multi-purpose functions. In Ethiopia, maize is predominantly used for human consumption; and the crop is a strategic crop selected as one of the national commodity crops to satisfy the food self-sufficiency program of the country. It is the staple food and one of the main sources of calories in the major producing areas (Abebe *et al.,* 2009).

The production and productivity of maize has increased since the development of high yielding hybrid maize varieties by the Ethiopian Institute of Agricultural Research (Bako Agricultural Research Center) in collaboration with other centers. These hybrid varieties are reported to be highly susceptible to insect pest attacks both in the field and storage (Demissie, 2008). Hence, farmers are not as such the beneficiaries of the increased production and productivity potential of the varieties. Traditionally, maize grain is stored by Ethiopian farmers, both in and outdoors for consumption and sell in the later months of the year depending on the quantity produced per household. The stored maize is attacked and damaged by several pests that lead to quality deterioration forcing farmers to sell at throwaway price even below the production cost. In the world total production of maize is 822 million tone in over 160 million hectares, United Nation Development Program (UNDP, 2008). In Ethiopia, maize ranks first in total production and it is estimated that the crop covers for about 1.8 million hectares with average yield of 2.2 ton ha^{-1} Central Statistical Agency (CSA, 2009).

Worldwide maize production is decreasing due to various biological, physical and environmental factors. These include the problems of insect attack, storage structures, weeds and pathogen infestation, soil fertility and climate (Adugna and Melaku, 2001). The great majority of crop harvest in Ethiopia, as in any developing country, is stored on the farm in small quantities. The protection of farm-stored produce largely depends on the virtue of the traditional storage systems which has two major aspects namely, the storage structures and management practices. The nature of the structures mainly varies with respect to the materials they are made from, the type and amount of produce they can accommodate and their location. The management practices, although influenced by the nature of the storage structures, are largely dependent on various environmental factors and the tradition of the society (Eshetu *et al*., 2006).

It has been estimated that between 60 and 80 % of all grain produced in the tropics is stored at the farm level (Boxall, 1998). Delima (1987) demonstrated that between 25% and 40% of stored agricultural produce is lost annually in the tropics because of the activity of storage pests. However, most of the grain including maize suffers major economic loss caused by grain infesting insects because of cumulative effects of feeding, breeding, transmission of toxic and saprophytic fungi and associated changes in the micro-ecological conditions in the grain bulk, which hasten the deterioration process in the grain (Kiruba, 2008).

The sources of pests attacking stored products include cross infestation (the infestation of one commodity by movement of insects and mites from another commodity), residual infestation (results from attack by insects which have remained in the structure of the store, vessel or vehicle after the removal of a previously infested commodity), infestation by flight and crawling insects (All moths and many beetles move to stored products by flight and some species like *Tribolium castaneum* and *Tribolium confusum* also crawl into new uninfected stored products) and natural source of infestation (arise from natural sources including nests of birds, rodents, spiders and insects (Berhanu, 2010).

The important constraints of having every day sufficient food is the post harvest preservation of its quality and quantity. Post-harvest insect pests could be categorized broadly as primary and secondary insect pests. Primary insect pests are those insects which can able to attack intact grains (*Sitophilus spp. S. cerelealla* and others) where as secondary pests are insects that can only attack the already damaged grains or grain products (*Tribolium* spp*., Plodia interpunctella, Ephestia* spp. and others) (Emana, 1993, Addis, 2008). In other word, primary insect pests are those that are capable of penetrating and infesting intact kernels of grain, and have immature stages that can readily develop within a kernel of grain whereas, secondary insect pests cannot infest sound grains, but feed on broken kernels, debris, higher moisture weed seeds, and grain damaged by primary insect pests and immature stages of these species are found external to the grain (Berhanu, 2010). It is often thought that secondary invaders cannot initiate an infestation, which is not true as in almost any storage situation there will be adequate amounts of broken grains and debris to support an infestation by secondary invaders and secondary invaders also contribute directly to grain spoilage after establishment, just as primary insect pests do (Weaver and Petroff, 2005).

A wide range of insect pests the commonest among them being beetles and moths in the orders of Coleoptera and Lepidoptera (Allotey, 1991; Bekele *et al*. 1997; Emana and Assefa, 1998; Ferdu *et al*. 2001) attack all stored products. Crop damage by Lepidoptera is only done by the larvae and several Lepidoptera larvae feeding through silky secretion which turns products into entwined lumps but, in the case of Coleoptera, both larvae and adults often feed on the crop and the two stages are responsible for the damage (Kiruba, 2008).

The beetles comprise the largest order in the animal Kingdom with a total of no less than 300,000 described species, of which more than 600 have been associated with stored food products throughout the world (Berhanu, 2010). Some, through the agency and dispersal by man in international trade have attained cosmopolitan distribution and constitute the major cereal insect pests that attack stored cereals and grain legumes. Lepidoptera associated with stored products are all moths and one species the Angoumois grain moth, (*Sitotroga cerealella)* is capable of destroying sound, unbroken grain kernels, but most infest broken or damaged kernels or milled products (Berhanu, 2010).

Every year, large quantities of stored grains are destroyed or contaminated because of the presence of insect pests especially beetles, which are the most important group of arthropods attacking these products. Among the beetles the predominant damaging insect pests of stored maize is maize weevil (*S.zeamais).* This insect pest has been recognized as an increasingly important problem in Africa. Infestation by this weevil commences in the field (Demissie, 2008), but most damage is done during storage. Worldwide seed losses ranging from 20 to 90% have been reported for untreated maize due to the maize weevil *S. zemais***.** Damaged grains have reduced nutritional values, low percent germination and reduced weight and market values. This insect is cosmopolitan insect pest of stored cereal and the most important pest of stored maize. Infestation of cobs may start before harvest. The female lay their eggs under the pericarp, and the larvae complete their development entirely within a single grain. Adult continue to feed on the grain. They live for several months and lay an average of 350eggs during their life time (Golob, 1984)

Some produces are susceptible to attack along the entire processing and marketing chain, thus insect pests must be controlled in diverse storage environments, including on-farm product storage, warehouses, food processing facilities, packinghouses, and retail outlets (Johnson, 2002). Overall, biotechnical, biological, cultural and chemical methods are crucial approaches for successful control of the most dominant stored product pests in general (Gwinner *et al*., 1990).

The use of insecticides for the control of stored grain insect pests has created many problems such as environmental hazards, resistance in target species and is a heavy burden on the economy of a country, when imported as formulated chemicals. This is an additional expenditure with extremely limited budget in many countries. Furthermore, imprecise uses of pesticides leave residues on food and increase the resistance in insect pest populations (Abdul and Sohail, 2007).

However, cheap and effective methods for reducing *S. zeamais* damage are needed (Danho, 2002). To this effect, the increased public awareness and concern for environmental safety has directed research to the development of alternative control strategies such as the use of resistant maize varieties against *S. zeamais*. The resistant varieties provide practical and economical ways to minimize losses to insect pests (Martha, 2010). It is perhaps the easiest, most economical and effective means of controlling insect pests on stored grains as there is no special technology which has to be adopted by farmers. Screening of many seed varieties had led to the successful isolation of strains that are resistant to insect pests in some African countries (Ahmed and Yusuf, 2007).

In spite of the effectiveness of host grain resistance in combating pests in storage, research works conducted on screening resistant maize varieties were meager and not sufficiently done in Ethiopia. Hence, the current investigation was initiated with the following objectives:

Objectives

General objective

To reduce the product losses by storage insect pests and contribute to the improvement of food self-sufficiency programe of the Ethiopia.

Specific Objective

To determine potential resistant maize variety (ies) against maize weevil (*S. zeamais*)

2. LITERATURE REVIEW

2.1. Post harvest insect pests of maize

The main agents causing deterioration of stored products are microorganisms, rodents, birds, insects and mites. Among these, insects are the principal pests responsible for losses of food grains. During storage foods are currently destroyed by insects and other pests (Negamo *et al.*, 2007). The pests of stored products are the most dangerous of all insects, because they feed up on products that have been grown, harvested, sometimes manufactured and stored. Two major groups of insects harbor the most economically important post-harvest products include Coleopterans (beetles) and Lepidopterons (moths and butterflies). Several species under Coleopteran and Lepidopteran attack crops both in the field and in store. Stored product insect pests are a problem throughout the world, because they reduce the quantity and quality of grain (Negamo *et al.,* 2007). The reasons for their widespread presence range from evolutionary adaptations (morphological, physiological and behavioral) to the actions of humans who transport them throughout the world and offer a protected habitat.

The pests of sound stored grains include rice, maize and granary weevils (*Sitophilus oryzea, Sitophilus zeamais and Sitophilus granary,* respectively*),* angoumois grain moth, *(Sitotroga cerealella),* the lesser grain borer (*Rythoperta dominica*), several species of pulse beetles (C*allosobruchus chinensis, Callosobruchus maculates, Acanthoscelides obtectus)* and others. *S. zeamais*, *S. oryzea, A. obtectus, C. chinensis, Z. subfasciatus, Tribolium* and *Crytolestes* species from the Coeleptera and *S. cereallela,* almond moth (*Ephestia cautella),* Indian Meal Moth *(Plodia interpunctella*), Potato tuber moth (*Phthorimaea operculella*) from Lepidoptera were recorded as major insect pests of stored grains (Abraham, 1991; 1996; 1997).

Post harvest insect pests can be primary or secondary pests. Primary insect are pests are those which posses strong mouth part and able to attack intact grains, while secondary insect pests have weak mouth part and attack damaged grains or grain products (Addis, 2008).

2.1.1. Maize Weevil (*Sitophilus zeamais*)

Sitophilus zeamais belongs to the order Coleoptera and Family Curculionidea. This insect is cosmopolitan pest of stored cereal and the most important pest of stored maize. Infestation of cobs may start before harvest. The female lay their eggs under the pericarp, and the larvae complete their development entirely within a single grain. Adult continue to feed on the grain. They live for several months and lay an average of 350eggs during their life time (Golob, 1984).

2.1.1.1. Economic importance

Sitophilus zeamais, or the maize weevil, is a species of weevil that is commonly found in maize crops causing serious losses to resource-poor farmers in the tropics. Donald (2010) reported total post-harvest crop losses of 40% in hot, humid regions and more than 10% in dry regions of the world and 10%-20% world-wide and 25%-40% in tropical regions. The maize weevil is one of the most serious pests of farm-stored grain and basket or bag-stored grain in stores under tropical and sub-tropical conditions. The weevil causes damage to stored maize grain by boring the grains and eating the inner part which reduces maize weight and quality in terms of consumption and germination. Damage caused by *S. zeamais* on stored cereals can be extremely high. It is reported that up to 18.3% weight loss occurred due to *S. zeamais* infestation when single maize kernels were exposed to ovipositing adults and kept at 27 ºC and 70% relative humidity for only 37 days (Demissie *et al* 2008). *Sitophilus zeamais* infestation has also resulted in significant reduction in the viability of the grains. Post-harvest crop losses due to storage pests such as *S. zeamias* have continued to persist and pose major problems to food security in Africa. These problems have increased as traditional crop varieties have been replaced by improved, high-yielding varieties with shorter growth cycles but which are generally more susceptible to insect damage. In Western Africa, losses caused by storage pests like *S. zeamais* constitute a major constraint to increasing maize production through the introduction of improved varieties. In Ethiopia in general, post-harvest losses caused by *S. zeamais* ranging from 20-30% are common, and studies in conducted around Bako areas have shown grain damage levels up to 100% in some samples from farm stores after 6-8 months. Insect contaminants such as excreta (uric acid), exuviate (cast skins) and dead bodies, webbing, and secretions in food commodities pose a quality-control problem for food industries. Processing and end-use qualities of food commodities are also affected by insect infestation, as are cash value and marketability of products (Demissie *et al.,* 2008).

2.1.1.2. Description and systematic position

The maize weevil, *S. zeamais*, is a small snout beetle with adults reaching lengths of between 3 to 3.5 mm, dark reddish-brown in color and it is capable of flight. The maize weevil is larger than rice weevil but so closely resembles it in appearance that the two are not easily separated. *Sitophilus zeamais* is one of the most serious cosmopolitan pest of stored cereal grain, especially of maize (Zea mays, L.), in tropical and sub-tropical regions (Throne, 1994). Scientific classifications are kingdom: Animalia, Phylum: Arthropoda, Class: Insecta, Order: Coleoptera, Family: Curculionidea, Genus: *Sitophilus, Species*: *zeamias* (Sallam, 1994). This is a large group of beetles that contains some of the most serious crop and stored grain pests. Morphologically, members of this family are characterized by the form of the snout (rostrum) which is elongated in most species. This family contains the most destructive stored grains insect pests in the world (Ashenafi, 2010).

2.1.1.3. Biology and Behavior

Adult female weevils excavate shallow pits in the seed coat and lay a single egg inside, sealing it with a waxy plug. Upon hatching, the single fleshy grub develops, growing and feeding within a single grain. The larva changes to a naked white pupa and later the adult eventually emerges via an emergence hole, which may subsequently be enlarged by feeding of the adult inside or by other storage insects. Jacobs and Calvin (1988) reported the adult female Maize weevil lays her eggs within the actual grain kernels of the maize at a rate of 25 per day spread over 100 days. The maize weevil bores into the grain with her long snout, deposits her ovipositor and lays a single egg. The eggs hatch in approximately 3 days, depending on the humidity and moisture content of the grain. The larvae, which are approximately 4 mm, white and legless, begin to eat the internal contents of the maize while developing, which takes approximately 18 to 23 days. At this point, the larvae become pupae, and transformed/developed they into the adult weevil form, much like a butterfly. This process takes approximately 6 days. During these 6 days, the pupae do not eat or move. The weevil then emerges, by cutting a small circular hole in the grain, as an adult and begins the process over again. The entire process takes about 30 to 45 days to complete. The adult maize weevil will also feed on the maize during its lifespan, which is approximately 5 to 8 months long, before dying (Ashenafi, 2010).

2. 1.1.4. Host range

Sitophilus zeamais is commonly associated with corn and rice in tropical storage and to a lesser extent in other raw or processed cereals, including wheat, oats, barley, sorghum, rye and buckwheat. The range of moisture contents within which it will breed has been found to be much wider than that of *S. oryzae* and it has been found to attack fruit, such as apples, in storage. *S. zeamais* commonly infests standing crops prior to harvest, particularly maize, where the moisture contents can exceed 20% (Anon, 2009).

2.1.1.5. Distribution

The maize weevil is slightly larger than the rice weevil and is more prominently marked. It is also a considerably more proficient flier, allowing it to distribute itself more easily. Its main endemic areas are tropical and temperate regions. *Sitophilus zeamais* occurs throughout the warmer, more humid regions of the world, especially where maize is grown. *Sitophilus zeamais* is widely distributed throughout growing areas of northern Australia (Zimmerman, 1994).

2.1.2. Larger grain borer (*Prostephanus truncatus* (Horn)

2.1.2.1. Economic importance

Prostephanus truncatus was incidentally introduced to Africa from Mesoamerica in early 1980s (Boxall, 2002). *Prostephanus truncatus* is currently established in almost most parts of Africa threatening maize production due to its aggressive nature and the extensive damage it causes within a short period of time. Although postharvest losses in maize due to *P. truncatus* are generally estimated to range between 34 to 40% within 3 months after storage on the farm (Boxall, 2002).

The extensive tunneling in maize grain by *P. truncatus* adults characteristics allows it to convert grain into flour within a very short time. The flour produced during the insects feeding consists of the insect eggs, excreta and exuvia; hence, neither fit for animal nor human consumption due to its unattractive taste. This implies that in the absence of control measures, post-harvest losses due to the *P. truncatus* during storage can be severe (Tefera *et al*., 2011).

Prostephanus truncatus, caused high grain damage and weight loss, indicating that control measures should be designed at the onset of grain storage if the grain is planned to be stored for more than 30 days. Traditional grain storage facilities may not offer protection against *P. truncatus*. However, the current promotion of the use of resistant varieties for grain storage is an alternative approach to reduce losses by *P. truncates* (Tefera *et al*., 2011).

2.1.2.2. Biology and behaviour

The larger grain borer, *Prostephanus truncatus* is an important pest of maize *Zea mays*, and can infest the standing crop as well as maize in storage. The ability of the beetle to establish itself as a serious pest in both the hot, dry conditions and the hot, humid conditions (Boxall, 2002).

Prostephanus truncatus is a long-lived species with an extended oviposition period and a relatively rapid larval development stage. Its development pattern is similar to the closely related *Rhyzopertha dominica*, lesser grain borer, which is from the same insect family. The species has a potential life span of several months, during which adults continue to feed and infest the host (Boxall, 2002).

Infestations often begin in the field prior to harvest, when the moisture content of maturing maize may still exceed 40%. Insects cause seed damage by feeding elevate moisture content through accelerated respiration associated with reproductive activity and growth, and produce frass. These changes are likely to create a favorable substrate and environment for the growth of postharvest fungi (Tefera *et al.,* 2011)

Prostephanus truncatus larvae usually burrow into the nutrient and energy-rich germ or corn kernels. Adult chewing of the host material may also be a mechanical pre-conditioning treatment, to facilitate food uptake by the larvae. Chewing may also facilitate the establishment of microorganisms required for cellulose digestion and possibly provide the inoculums (Nansen & Meikle, 2002).

The life cycle can be completed in 24-25 days and the adults bore into maize grains making neat round holes, generating large quantities of dust as they tunnel from grain to grain. After mating, adult females lay most eggs within the grain and Eggs are laid in batches of 20 and covered with finely chewed maize dust. Oviposition begins 5-10 days after adult emergence, reaching a peak at 15-20 days. The mean development period under optimum conditions for eggs is 3.0 days, for larvae (3 instars) 13 days, pre pupae 4 days, and pupae 2 days (Demianyk & Sinha, 1988).

2.1.2.3. Description and systematic position

The larger grain borer does almost as much damage as the rice weevil. It feeds in both larval and adult stage in the interior of nearly all types of grain. It can also ingest flour and the insect is dark brown black in color and Body length of *P. truncatus* adults ranges from 2 to 3.5 mm, and width from 1 to 1.5 mm (Nansen & Meikle, 2002). The tip of the abdomen is square when viewed from above or below. There is a ridge marking the junction of the side and tip of the elytra classified into kingdom:Animalia, Phylum: Arthropod; Class: Insecta: Order: Coleoptera; Family: Bostrichidea, Genus: *Prostephanus: spcies: truncatus*.

2.1.2 .4. Host range

Prostephanus truncatus is capable of damaging a wide range of foods (hard winter wheat, short grain rice, butter beans, and cocoa beans) but appears only able to breed successfully on maize. Bostrichids in general live on failed timber or dead wood, and *P. truncatus* was considered a wood-boring species that has become adapted to stored commodities. Tubers and roots probably serve as the natural host. *P. truncatus* bred successfully on 27 species of woody plant from eight families under laboratory conditions, particularly Burseraceae and Mimosaceae. *Prostephanus truncatus* adults and larvae have also been found in branches of trees in the family's Anacardiaceae and Burseraceae that have been girdled by cerambycids (Nansen & Meikle 2002, Hill *et al*. 2002 ,Nansen *et al*. 2004).

2.1.2.5. Ditribution

Prostephanus truncatus originated in Central America but has been found in many other countries including Africa. Spread can occur as a result of commodity movement in trade and natural dispersion by flight. *Prostephanus truncatus* is capable of sustained flight, and a tagged individual under laboratory conditions flew the equivalent of 25 km in 45 h (Nansen & Meikle 2002). Flight activity peaks between 8-12 days post-elusion. Temperature is an important factor in determining flight initiation, with adults being most likely to move at 25-30^{o}C. Food quality and population densities also have a bearing on flight initiation. Field studies have shown that most females have mated prior to dispersing, but they are still attracted to the male aggregation pheromone. This behaviour may assist in locating suitable breeding sites (Hill *et al*. 2002).

2.1.3. Flour Beetle (*Tribolium confusum*)

2.1.3.1. Economic importance

These insect are the most common pest of cereals and cereal products in the world. They feed on all kinds of grain, beans, peas, dried fruits, nuts, chocolate and even cymene pepper. Adult and larvae feed on the food and cause contamination and impart a disagreeable taste and odor when the insects are present in large numbers the flour may turn grayish and mold more quickly. Both insect may infest stored foods in grocery stores, which may serve as sources of infestation around home (Berhanu, 2010).

2.1.3.2. Description and Systematic position

The red flour beetle is reddish-brown in color and its antennae end in a three-segmented club. Whereas the confused flour beetle is the same color but its antennae end is gradually club-like, the "club" consisting of four segments. The head of the red flour beetle is visible from above, does not have a beak and the thorax has slightly curved sides. The confused flour beetle is similar, but the sides of the thorax are more parallel. The red and confused flour beetles live in the same environment and compete for resources. The red flour beetle may fly, especially before a storm, but the confused flour beetle does not fly. Eggs, larvae, and pupae from both species are very similar and are found in similar environments. The eggs are white, microscopic and often have bits of flour stuck to their surface. The slender larvae are creamy yellow to light brown in color. They have two dark pointed projections on the last body segment. The pupae are lighter in color, being white to yellowish. These beetles can breed throughout the year in warm areas (Pugazhvendan *et al*, 2009). Scientific classifications are kingdom: Animalia, Phylum: Arthropoda, Class:Insecta, Order: Coleoptera, Family: Tenebrionidea, *Genus: Tribolium, Species: confusum.*

2.1.3.3. Biology and Behavior

The red and confused flour beetles may be present in large numbers in infested grain, but are unable to attack sound or undamaged grain. The adults are attracted to light, but will go towards cover when disturbed. Typically, these beetles can be found not only inside infested grain products, but in cracks and crevices where grain may have spilled. They are attracted to grain with high moisture content and can cause a grey tint to the grain they are infesting. The beetles give off a displeasing odor, and their presence encourages mold growth in grain (Baldwin and Fasulo, 2009). All forms of the life cycles are holometabolous insects, may be found in infested grain products at the same time (Rees, 2004). The beetles breed in damaged grain, grain dust, high-moisture wheat kernels, flour etc. The female lays 300 to 400 eggs in flour or other foods during a period of five to eight months (two to three eggs per day). The length of the larval period varies from 22 to more than 100 days. The pupal period is about eight days. Fully grown larvae transform to naked pupae, and in a week adults emerge. The life cycle requires seven to 12 weeks, with the adults living for three years or more (Alabi *et al*., 2008). Ideally the flour beetle prefers temperatures of around 30 °C and will not develop or breed at temperatures lower that 18 °C (Fedina and Lewis, 2007).

2.1.3.4. Host range

Red and confused flour beetles attack stored grain products such as flour, cereals, meal, crackers, beans, spices, pasta, cake mix, dried pet food, dried flowers, chocolate, nuts, seeds, and even dried museum specimens. These beetles have chewing mouthparts, but do not bite or sting. The red flour beetle may elicit an allergic response (Alanko *et al.*, 2000), but is not known to spread disease and does not feed on or damage the structure of a home or furniture. These beetles are two of the most important pests of stored products in the home and grocery stores. The confused flour beetle apparently received this name due to confusion over about its identity as it is so similar to the red flour beetle at first glance (Mahroof *et al*., 2003).

2.1.3.5. Distribution

The red flour beetle is of Indo-Australian origin and found in temperate areas, but will survive the winter in protected places, especially where there is central heat. The confused flour beetle, originally of African origin, has a different distribution in that it occurs worldwide in cooler climates (Tripathi *et al.,* 2001).

2.2. Post harvest losses of maize

The term loss is often expressed in various ways and it is confusing whether it refers to the total amount of grain lost or damage. Similarly, the term loss has been synonymsly used with the term damage. Nevertheless, in the context of stored food, it is usually expressed as loss of commodity weight in the period between harvest and consumption, loss of nutrients in stored grain, qualitative deteriorations caused by contaminants or biochemical changes rendering grain unfit for human consumption, loss of seed viability and loss as a result of physical damage. While damage refers to the superficial evidence of deterioration for example, holed or broken grains or bruised fruits or physical spoilage which may later result in loss (Martha, 2010).

Crop losses and deteriorations of produce during storage are likely to occur unless adequate precautions are taken. It is frequently, reported that worldwide a minimum of 10 percent of cereals and legumes are lost after harvest (Boxall *et al.,* 2002). Likewise, in Ethiopia loss of stored produce ranges from 20 to 30 percent. However, it is widely agreed that food losses after harvest can be substantial and are important in terms of quantity, quality, nutritional and economic value (Golob *et al.,* 2002).

The degree of loss due to weevil damage is quite variable and depends on the storage period, storage conditions, storage containers and varieties (Nchimbi-Msolla and Misangu, 2002). In Ethiopia, the structural condition of the traditional granaries used for storage of grains varies from one farm to another. The main problem associated with these storage structures are lack of repair or replacement of the old structures, poor hygiene store, and the distance at which they are located. Granaries that are not repaired permit easy access to rodents, insects and flooding. Moreover, poor store hygiene and storage structures located near the farm land may cause the development, carry over and cross-infestation of insect pest from previous season harvest. As a result, they attribute to different amount of stored grain loss and damage by weevil (Berhanu Hiruy, 2010).

In addition to direct weight loss, maize weevil also renders qualitative loss, which is more frequently based up on subjective judgment and it perhaps identified via comparison with locally accepted quality standard. It may include the presence of contaminants, such as uric acid and other nitrogenous wastes, the presence of adult weevil inside the seed, exit holes, glued eggs to the seeds, coastal larval skin, and changes in appearance, texture and taste, making it unfit for human consumption, Commercial grain buyers usually reject or refuse to accept delivery of insect contaminated grain or may pay very low price for it (Hill, 1990, Espinal, 1993, Nchimbi-Mosolla and Miswangu, 2002).

Damage can also cause nutrition loss which is represented by the reduction in the food value of the grain because of decrease in its starch, carbohydrate and oil content and it is also the product of both qualitative and quantitative losses (Sing, 1997).

2.3. Management practices of maize weevil

There is a continuous need to protect the stored products against deteriorations, especially loss of quality and weight during storage (Mohale, 2004; Negamo *et al*., 2007). In general, biotechnical, biological, cultural, and chemical methods are crucial approaches for successful control of the most dominant stored product insect pests of maize (Gwinner *et al*., 1990). Some of the management tools used in storage insect pest management for maize crop is mentioned below.

2.3.1. Cultural management

The principle involved in the cultural control of insect pests is purposeful manipulation of the environment to make it less favorable, there by exerting economic control of the pests or at least reducing their rates of increase and damage. The development of cultural method requires a thorough knowledge of the life history and habits of the insect, and the plant host (Songa and Rono, 1998). The most vulnerable stage or 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 rate of reproduction. Proper modification of storage practices has controlled many species of insect pests in the storage structures (Songa and Rono, 1998).

Sanitation or store hygiene is the leading preventive task in insect pest control in stored grain. Stores, silos, cribs and others and their nearby surroundings must be kept as clean as possible. Sanitation imparts its crucial role in preventing or reducing insect infestation in stored grains or foodstuffs (Emana *et al*., 2003). 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. Emana *et al*. (2003) also suggested that maize stores must be free from weevil and only adequately dried clean seeds be stored. 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. Sanitation practices can bring satisfactory output if it is coupled with appropriate and adequate drying technologies. Thus, perfect storage hygiene is the basic prerequisite for successful storage and for the effectiveness of all on- going measures, like the use of insecticides or fumigants (Gwinner *et al*., 1990).

Farmers have practiced different types of traditional methods of control for many decades to prevent insect infestation. These methods will certainly keep on playing a role in small farm storage in the future (Gwinner *et al*., 1990; Golob, 1997). The most common treatments to limit insect activity are mixing inert materials and organic materials with stored grain. According to Golob (1997), the protection success depends up on the effect of the preservation on the grain, the rapidity of its action, the period of storage and proper mixing.

Inert dusts (diatomaceous earths) are finding increasing use as storage protectants in the grain industry. These dust particles primarily exert their effects on insects as a result of desiccation: water loss is a consequence of the destruction of the cuticle (Gwinner *et al*., 1990; Salunkhe *et al*., 1985; Golob, 1997; Golob *et al*., 2002). They also fill in the spaces between the grains, usually causing restricted locomotion towards partners whereby they cause reduced progeny emergence (Gwinner *et al*., 1990). Inert dusts commonly used in storage structure against storage insect pests include: nonsilica dusts as rock phosphate, lime and lime stone; sand, wood ash, tobacco and saw dust, and clays; diatomaceous earths; and silica aerogels (Emana and Assefa, 1998).

2.3.2. Physical Control

In physical control methods, the physical environment of the pest is modified in such a way that the insects no longer pose a threat to the agricultural crop, and this can be achieved by generating stress levels ranging from agitation to death or by using devices such as physical barriers that protect produce or plants from infestation. Many Physical control methods target an ensemble of physiological and behavioral processes, whereas chemical methods have well-defined and limited modes of action (Vincent *et al*., 2003).

The use of physical control measures include temperature, mechanical, moisture, relative humidity, structural (e.g. grain silos, packaging), irradiation, and sanitation, for example lower temperatures reduce the rate of development, feeding, reproduction, and survival (Herrman, 1998). The use of heat and cold, irradiation microwaves and mechanical shock are promising alternatives in certain areas of species. Besides, inert dusts based on diatomaceous earths were proposed in the late 1930s and are now available for use in species (Scholler *et al.*, 1997). Inert dusts have been used traditionally as stored-grain protestants'and a number of publications has reviewed their efficacy against stored-product insects (Collins, 2006).

2.3.3. Biological Control

Nontoxic means of control are of particular significance for on-farm storage in developing countries. Biological control can be a viable tool, as beneficial insects may occur naturally or can be released where needed by farmers. Additionally, this method is of interest as a safe alternative to fumigation and traditional chemical insecticides since it is nontoxic and does not damage human health or the environment. Though many species of natural enemies that attack stored-product insects have been reported, literature on the natural enemies and their impact as biological control agent against weevil is scanty (Adane *et al*., 1998; Flinn *et al.*, 2006).

The hymenopteran parasitoids have been shown to be effective in suppressing a limited number of pest species both in bulk grain storages and in food processing facilities and warehouses, promising that they can be used as potential biological control agents. Additionally, other polyphagous parasitoids of internally developing Coleopteran and Lepidopteran stored product pests include *Anisopteromalus calandrae* and *Pteromalus calandrae* has been associated with storage insect pest species infesting various stored grains. *Xylocoris flavipes* (Reuter) is a generalist predator of stored product insects; the population suppression by the predator was likely being because of either predation or indirectly by disruption of mating and oviposition. Moreover, entomopathogenic fungi have been shown to be effective biological control agents against several insect pests of both field and stored grain. For instance, fungi such as *Beauveria bassiana* (Vuill.), *B. brongniartii* (Sacc.), *Metarhizium anisopliae* (Mots.) and *Paecilomyces fumosoroseus* have been found to control a number of stored product insect pests including *S. zeamais* and other bruchids as *C. maculates* (Imamura *et al*., 2004; Flinn *et al*., 2006).

2.3.4. Botanicals

Botanical pesticides are an alternative to chemical pesticides i.e. insecticidal plants or plant compound and the use of natural compounds, such as essential oils that result from secondary metabolism in plants. Essential oil and their constituents have been shown to be a potent source of botanical pesticides. The toxicity of a large number of essential oils and their constituents has been evaluated against a number of weevils. In the context of agricultural pest management, botanical insecticides are best suited for use in organic food production in industrialized countries, but can play a much greater role in the production and post harvest protection of food in developing countries (Isman, 2005).

The use of botanical insecticides and plant-derived pesticides for the control of insect damage to stored foodstuffs is a very common and an age- old practice of farmers in small- scale stores in tropics (Mekuria, 1995; Rajapakse and Emden, 1997; Bekele *et al*., 1997; Bekele, 2002; Tapondjou *et al*., 2002; Shaaya and Kostyukovysky, 2006).

The insecticidal activity of extracts derived from different plants and parts of the plant against stored product insects have been reported by many authors. Example Bekele (1995) evaluated the bioactivity of plant materials from the leaves of *Ocimum kilimandscharicum* against *S. zeamais* and *Sitotroga cerealella* (Oliver). They have reported 100% mortality after 48 hrs. Bekele (2002) also evaluated toxicity of different plant extracts and seed powder of *Milletia ferruginea* (Hochest.) against *S. zeamais* in maize seeds. Moreover, Mebeasilassie (2004) reported the efficacy of *M. ferruginea* seed powder against *Zabrotes subfasciatus* and found that 100percent mortality at the dose of 15g/250g of grain within 24 hr exposure.

2.3.5. Pheromones

Insects use pheromones to communicate in many insect orders, females produce sex pheromone and release into the air to attract con specific males. Sex pheromones have been identified from most economically important insects and pheromones are used to monitor and control insects (Carde and Minks, 1997).

The use of pheromones is one of the most promising techniques aimed at the control of stored-product insects. The use of these substances may lead to a drastic reduction of chemical treatments, thus determining remarkable economic advantages and improvement of product quality. In recent years, considerable progress has been made in monitoring and control of stored-product insects by using mass trapping, mating disruption and attracticide (lure and kill) methods (Trematerra, 1997).

Mass trapping of insects pest is an alternative to mass killing by using insecticides. The intention is to catch a pest species selectively and thereby suppressing the population to a level below the threshold of damage. This method is especially appreciable: where control by conventional insecticide is inapplicable and resistance has developed to conventional insecticides. For instance, successful control of Mediterranean flour moth *E. kuehniella* in stored-product was achieved using mass trapping method (Trematerra, 1997).

2.3.6. Host plant resistance

Insect resistance in crop varieties refers to their inherent ability to combat specific insect pests and to achieve better performance over other varieties of the same crop at the same levels of insect populations. Crop varieties differ in their susceptibility to storage insect pests (Siwale *et al*., 2009).

The use of varietal resistance is a prominent component of integrated pest management, particularly for small holding farmers where economic status does not permit them to apply synthetic insecticides. Plant resistance is an indirect pest control method, which involves the manipulation of the genetic make-up of the host so that it is resistant to pest attack. It is now well established that various staple cereals, such as rice, maize, wheat, sorghum, oats and barley, and legumes such as cowpeas, vary quite significantly in their inherent resistance or susceptibility to both field infestations, and to postharvest insect attack in storage by the more recognized grain storage insects (Siwale *et al.,* 2009).

The full yield potential of the growing crop is seldom realized due to the interaction of many factors (climatic, ecological and edaphic) of which pre-harvest insect infestation and consequent damage is one of the most important. Crop losses estimated due to pests to be around 35% worldwide, while post-harvest losses may range from (a maximum value of) 9% in the United States, to 20% or more in some developing countries, especially in the tropics (Siwale *et al.*, 2009).

Plants and insects have long time coexistence relationship. Thus harmful insects were suppressed by either other insects or toxic or by plant defense mechanisms, to create a balance between the insect pest population and host, and to avoid serious crop losses. One of the modern ways of reducing insect damage is to apply the concept of integrated pest management (IPM). This approach uses a combination of host plant resistance, cultural, biological and chemical control methods. Among all, host plant resistance is one of the most effective tools for reducing insect damage. Each plant species has a unique set or collection of defense traits ranging from morphological to photochemical parameters that have behavioral and physiological ramification for a potential herbivore consumer. Insects that feed on plant known as phytophagous insects should be capable to locate the most suitable nutritional substrates in plant (Martha, 2010).

2.3.6.1. Mechanism of the resistance

Stored product insect pests are capable of inflicting serious damage to stored commodities, due to their very rapid capacity to increase in numbers, and to migrate and infest separate lots thus spreading and expanding the infestation. The use of resistant varieties, particularly in farmers and village cooperative stores, will more than likely extend the period that produce can be stored safely without the use of pesticides. When susceptible high yielding varieties (HYV's) have been planted, rural storages may be forced to utilize expensive pesticides that are often unavailable, or if so, in packaging and formulations that are not suitable for small-scale use. The principle behind the use of varietal resistance is mostly based on one of the mechanisms of resistance Antixenosis (non-preference), antibiosis, and tolerance, where biophysical or biochemical factors are involved (Savidan, 2002).

Antixenosis (Non preference): Oviposition may be affected by small differences in seed coat smoothness and convexity, by plumpness or wrinkling and perhaps by size and hardness of the seed as well as its odor. Moreover, doesn't oviposit on seed chillum, which is spongy in texture deep pit like and rich fibrils (Nwanze *et al.,* 1975).

Non preference the selection or avoidance of potential host plants by phytophagous insects is guided by a complex combination of physical and chemical stimuli. Color, shape and olfactory cues may play a role in the initial orientation; whereas acceptance or rejection of a plant depends on texture as well as chemical stimulants or deterrents. Initiation of feeding is stimulated or deterrents. Initiation of feeding is stimulated or deterred by the presence or absence of specific chemicals or groups of chemicals, many of which have been identified. The selection of suitable plant for oviposition is also crucial for survival of the progeny of most herbivorous insects, but the chemical factors involved are known in relatively few cases. Oviposition stimulants and deterrents often appear to be quite different from the chemical that elicit or inhibit feeding responses of larvae (Savidan, 2002).

Antibiosis : The mechanism where the pests feed but factors in the plant have an adverse effect on them usually expressed as reduced growth and thus rate of multiplication, or on survival. Level of resistance to pests varies among plant varieties (Hill, 1990). Screening of many seed varieties had led to the successful isolation of strains that are resistant to insect pests in some African countries. Four varieties of groundnut (*Arachis hypogea* (L.) were found to be resistant to both Indian meal moth *(Plodia interpunctella* (Hubner) and rust red flour beetle (*Tribolium castaneum* (Herbest) (Ahmed and Yusuf, 2007).

Tolerance: The term used when host plants suffer little actual damage in spite of supporting a sizeable insect pest population. This is characteristic of healthy vigorous plants, growing under optimum conditions that heal quickly and show compensatory growth. Tolerance is frequently a result of the greater vigor of a plant and this may result from the more suitable growing conditions rather than from the particular genetic constitution of the plant.

Over the years, there have been numerous successes in breeding for resistance to a variety of pests and currently many crops are being selected for this purpose. Some of the mechanisms that attribute resistance to storage pests include morphological characters as seed size, seed coat, texture and color (Lara, 1997; Goossens *et al*., 2000; Mazzoneto and Vendramim, 2002).

2.3.6.2. Causes of Resistance

Physical barriers: The extreme value of a complete, well-fitting set of sheathing leaves in maize to reduce pre-shelling infestation by *Sitophilus spp*. has been well recognized for many years. Tight husks are an important resistance mechanism for maize, wherever climatic conditions encourage field infestations. In unhusked rice or paddy, the tightness of the glumes that cover each grain is of primary importance in reducing damage done by *Rhizopertha dominica*, *Sitophilus oryzae,* and *Sitotroga cerealella*, the success of these species, particularly *Sitophilus spp.*, being dependent on the presence of hull defects (Tongjura *et al*., 2010).

The seed coat of food grains may also be sufficiently thick and tough so as to inhibit penetration to a degree, even though primary feeders are well adapted to chew into whole undamaged kernels. The efficiency of penetration in whole grains is also strongly influenced by the presence of defects in the outer layers of the grain, so that varieties that possess strong, intact outer layers do exhibit a certain level of resistance to storage pests (Tongjura *et al*., 2010).

Seed hardness: Hardness is one quality of maize seeds, which may affect their resistance to maize weevils, specifically the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). Hardness varies from seed to seed, from plant to plant, and from variety to variety. The harder a seed is, the more resistant it is to storage pests, such as the larger grain borer and *Sitophilus spp***.** Grain hardness was found to be negatively correlated with grain damage and grain weight loss. The harder seed the lower the seed damages and the lower the grain weight loss. The hardness of seeds has been demonstrated, especially in cereals, as affecting the successful and rapid multiplication of insect pests. Hard, flinty maize varieties are often more resistant than soft, and floury varieties and reflects their high degree of susceptibility to attack by *S. zeamais and S. cerealella*. The good nutritional characteristics of these particular varieties must be combined and selected for hard kernels to enhance their storability (Siwale *et al*., 2009).

Resistance in stored maize to insect attack has been attributed to physical factors such as grain hardness, pericap surface texture, and nutritional factors such as amylose, lipid and protein content or non-nutritional factors, especially phenolic compounds (Abebe *et al.,* 2009).

Biochemical Factors: Several chemical constituents of plants serve as olfactory and gustatory stimuli for insect. These chemicals may be nutrients (i.e. sugars, amino acids, phospholipid etc) or non-nutritive constituents (i.e. glycosides, alkaloids, terpenoids etc). The insect may be repelled by plant volatile compounds without coming in contact with plant or having made contact, feeding may be suppressed, or having bitten the leaf, the insect may deterred from further feeding (Siwale *et al.,* 2009).

Moisture content: Smaller seeds that were hard and compact had less moisture and were therefore more resistant to the maize weevil attack. On the other hand bigger grains were loose, soft and contain higher moisture and hence more easily attacked by the weevils. The harder a seed is, the more resistant it is to storage pests, such as the maize weevils (Tongjura *et al.,* 2010).

2.3.7. Chemical control

Commercially available chemicals most commonly applied to control infestation in stored grain include organophosphates, carbamates and synthetic 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 the control of storage pests (Gwinner *et al*., 1990; Golob, 1997; Harberd, 2004).

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Dust formulations of insecticides, which are sold ready for use usually contain 0.1- 5 % active ingredient (Gwinner *et al*., 1990). These formulations often contain additives, which increase the adhesive power of the active ingredients to the stored grain. Dust formulations 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 weevil. Most of synthetic pesticides in use for liable emergency action against weevil when their population approaches or exceeds economic threshold level include: malathion, lindane, pirimiphos-methyl, permethrin, deltamethrin, metacrifos, fenitrothin, iodofenphos, chloropicrin, and cocktail of malathion and permethrin, primophos-methyl and permethrin (Actellic super), fenitrothion, iodofenphos, chloropicrin, deltamethrin and permethrin (Hill, 1990).

Chemical fumigation of stored grains is another approach to insecticidal control. Fumigants are low molecular weight chemicals, highly toxic and volatile and are hence self- dispersing and non- persistent. It is noted that fumigation is one of the technique that most widely practiced all over the world in the control of weevils, especially in large scale storage. Correctly applied, the tiny gas molecules of fumigants easily penetrate large stacks of grain right in to the individual grains, reaching and killing all stages of development of the pests. At least 16 chemicals have been registered as fumigants, but because of concern for human safety, methyl bromide, phoshine, methyl iodide, Carbon disulfide and aluminium phosphide are the primary fumigants currently being used commercially for stored products (Lee *et al*., 2003).

However, the choice of insecticides for storage pest control is very limited because of the strict requirements imposed for the safe use of synthetic insecticides on or near food and also the continuous use of chemical insecticides for control of storage insect pests has led to problems such as disturbance of the environment, pest resurgence, pest resistance and lethal effect on none target organisms in addition to toxicity to the users (Khan and Selman, 1987).

2.3.8. Insect growth regulation

IGRs are compounds that disrupt the normal development of insects by mimicking the action of insect hormones and/or by interfering with hormone regulated processes and they have been used in a variety of practical applications and are effective against a range of stored-product insects (Collins, 2006).

Insect growth regulators (IGRs) used in stored product systems in the United States and elsewhere include the insect juvenile hormone analogs methoprene, hydroprene, and pyriproxyfen and all these three compounds mimic the effects of sustained increased titer of insect juvenile hormone by disrupting normal development between larval instars and in metamorphosis from larvae to pupae and then from pupae to normal adults, however, these IGRs are not directly toxic to adults, although their potential effects on reproductive sterility have not been fully investigated, and they have another key attribute such as their low levels of toxicity to mammals and inherent high level of food safety (Phillips and Throne, 2010).

Besides, among the effects of these IGRs are interference with embryogenesis, followed by death, at IGR doses about 1/1000th the value of conventional ovicides; abnormal development of the integument in postembryonic stages, leading to inability to molt properly and impaired sensory function (hence inability to locate food, mates, oviposition sites, etc.); improper metamorphosis of internal organs or external genitalia, causing sterility and/or inability to mate; interference with diapauses, so that an insect becomes seasonally maladjusted; and abnormal polymorphism in aphids. Because these effects by which they take some time to manifest themselves, IGRs are less valuable against rapidly growing larval pests, however, a number of commercial preparations are now available for insects that are long-lived pests and/or pests in the adult stage, for example, fenoxycarb (livestock flies), methoprene (fleas, mosquitoes, stored product pests), hydroprene (cockroaches), and kinoprene (homopteran pests of greenhouses and ornamentals) (Gillott, 2005).

2.3.9. Integrated Pest Management

Integrated pest management (IPM) provides feed manufacturers an effective alternative strategy to sole reliance on chemical control of stored product pests. IPM relies on managing insect populations through physical and biological control techniques and, as necessary, chemical insecticides. The adoption of an IPM strategy requires an understanding of stored product insects including their identification; biology and ecology, sampling to monitor insect populations, physical, biological and chemical control (Rees, 1995).

Current interest in IPM results from food safety concerns related to the use of residual insecticides and the development of resistance in populations of insects to insecticides (Herrman, 1998). In addition, IPM is an approach to pest control that uses cost benefit analysis in decision-making. Thus, in some cases, IPM offers a more economical means of controlling stored product insects than traditional chemical control techniques that relied on pre-determined (calendar based) application intervals.

3. MATERIAL AND METHODS

3.1. Description of study area

This study was conducted at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM). JUCAVM is located in Jimma town, Jimma Zone of Oromiya Regional State in the south western part of Ethiopia. JUCAVM is found distance of 354 km south west of Addis Ababa. JUCAVM is located at an approximate geographical coordinates of latitude 06°36' N and longitude of 37°12' East at an altitude of 1710 meters above sea level. Minimum temperature 11.4^{o}c, Maximum temperature 26.8% and minimum relative humidity 39.92% and maximum relative humidity 91.4% (Amsalu *et al* 2011).

3.2. Rearing/ Culturing of test insect (*S.zeamais)*

S. zeamais was multiplied on susceptible maize variety seed to obtain similar aged weevils for the experiments. Twenty kilo gram seed of BH-660 maize variety was bought from the market in Jimma town and cleaned to remove seeds with visible damage symptoms. The cleaned seeds were disinfested in an oven at 40°c for 4hrs and kept in the air cooled condenser before use (Bekele, 1995). Seeds were then transferred to plastic bags and kept at room conditions for three weeks. Unsexed *S. zeamais* were collected from infested maize seeds and multiplied on clean and disinfested maize seeds (BH-660) in 6 jars (2.0 lit. capacities). To each jar containing 600g of seeds, 75 adult weevils were introduced. Then, the jars were covered with muslin cloth and fixed with rubber band to prevent escape of weevils and allow aeration. Ten days after oviposition, all parent weevils were removed from each jar and the seeds were kept under the same experimental conditions (incubator at temperature of 27^{o}c). The weevils were multiplied in jars of maize grain for two to three generation to obtain uniform population for the experiment (Abebe *et al.,* 2009).

3.3. Treatments

A total of thirteen maize varieties, namely BH-660, BH-670, BH-661, BH-543, BHQP-542, BHQPY-545, Wanchi, Argane, Gibe-1, Gibe-2, Kulani, Hora, and a local variety-Orome were collected from different sources and used for the experiment. The varieties were collected from Bako and Holeta Agricultural Research Centers and the local variety-Orome was bought from Jimma-Merkato market. Most of the varieties are hybrids developed by National maize research coordination center-Bako Agricultural Research Center and are currently under production in different maize belts of Ethiopia. Freshly harvested seeds of each variety were procured, cleaned and disinfested by keeping them in a deep freezer at -20°C for one week prior to starting the experiments. The seeds were then kept for one week at the experimental conditions (room temperature) for acclimatization (Abebe *et al*., 2009). Resistance variety BHQP-542 was used as standard check.

3.4. Procedures and Experimental Designs

Three hundred gram of each collected maize variety seeds were placed in a one liter glass jar with brass screw lids at the top allowing ventilation and preventing escape of the weevils. No choice test method in which pre-determined weevils were introduced to each jar was used for the study (Abebe *et al.,* 2009). Fifty emerged unsexed adult weevils were introduced to each jar to infest 300g seeds of each variety and were kept for ten days for oviposition (Siwale *et al.,* 2009). A control was maintained for each variety without *S. zeamais* for comparison. The treatments were arranged in a completely randomized design (CRD) with three replications each. The experiment was maintained in a laboratory at room temperature (25 -27^{O} C) and 40-60% RH.

3.5. Data collected

3.5.1. Protein and Moisture contents of Maize Varieties

Protein and moisture contents of the thirteen varieties of maize were determined before weevils were introduced into each maize variety. The moisture content of the variety was measured by moisture tester and protein contents were determined by grounding of twenty gram sample of whole maize kernel in laboratory mill for each variety and were determined by using the Biuret procedure.

3.5.2. Adult mortality

Mortality was assessed ten days after introduction of weevils by counting. All insects were removed; dead and alive insects were counted.

3.5.3. F_1 progeny

In adult mortality data assessment all the dead and alive adult insects were removed from each jar and the seeds of each test variety were kept under the same experimental conditions to further assess F_1 progeny emergency for the subsequent two months period (56 days). Inspection of the progenies was made every day were every emerging progeny were removed and counted per jar on each assessment day. This interval of counts did not pose a risk of the F_1 progeny laying eggs in the maize samples to produce the F_2 generation (Siwale *et al.,* 2009).

3.5.4. Seed damage and weight loss

Sixty-six days after introduction of the weevils, 200 seeds were randomly taken from each jar to assess each maize variety seed damage (seeds with hole (s)) and grain weight loss. Seed damage was expressed as a proportion of the total number of seeds sampled (Abebe *et al.,* 2009). The count and weight method of Gwinner *et al.* (1996) was used to determine seed weight loss using the formula:

$$W(\%) = \frac{(Wu\ x\ Nd) - (Wd\ x\ Nu)}{Wu\ x\ (Nd + Nu)}\, x\, 100$$

Where; W= weight loss, Wu = Weight of undamaged seed, Nu = Number of undamaged seed, Wd =Weight of damaged seed and Nd = Number of damaged seed.

3.5.5. Median development time (day) (MDP)

The median development period were calculated as the time (in days) from the middle of the oviposition period to the 50% emergency of F_1 adults (Dobie, 1977).

3.5.6. Index of susceptibility

The Dobie index of susceptibility was used as the criterion to separate varieties into different resistance groups (Dobie, 1977). The index of susceptibility is given by the formula:

$$IS = \frac{LogeX}{MDP} x100$$

Where; IS= Dobie's Index of susceptibility, Log_e^X= the natural logarithm of the total number of F_1 progeny emerged, and MDP=Median development period (the period in days from the middle of the oviposition period to the middle of the 50% emergency of the F_1 progeny).

The Dobie Index was used to classify the maize varieties into susceptibility groups following the scales as follows: scale index of ≤ 4 was classified as resistant; scale index of 4.1 to 6.0 as moderately resistant; scale index of 6.1 to 8.0 as moderately susceptible; scale index of 8.1 to 10 as susceptible; and scale index of >10 was classified as highly susceptible.

3.5.7. Germination test

The viability of the varieties was tested by randomly drawing 100-seeds from each variety before and after the grains was damaged by weevils. The randomly selected seeds were placed in Petri dishes containing moistened filter paper and arranged in a CRD with three replications for each variety. The number of emerged seedlings from each Petri dish were counted and recorded after seven days (standard germination period needed for maize seeds). The percent germination (viability index) was computed according to Ogendo *et al*. (2004) as follows:

$$VI = \frac{NG}{TG} x100$$

Where; VI stands for Viability index (germination percentage), NG stands for number of seeds germinated from each Petri-dish and TG is the total number of seeds tested in each Petri - dish.

3.6. Data Analysis

All data collected were subjected to analysis of variance (ANOVA) procedures (SAS, 2008) soft ware package 9.2. Tukey test were used to detect mean differences between treatments. Data dult mortality, seed damage and weight loss were subjected to angular-transformation while numbers of F_1 progenies were log transformed in order to ensure assumptions of ANOVA before analysis. Then, the transformed data were analyzed using one-way ANOVA. Tukey standardized “honestly significant difference” (HSD) test were used to differentiate statistical mean differences at 5% level of significance whenever the means were found significant for pair wise comparison of the treatments.

4. RESULT AND DISCUSSION

The experiments showed considerable variation among the maize varieties with respect to F_1 progeny emergency, percent adult mortality, median developmental time, seed damage (perforated seeds), seed weight loss, percent dust produced, protein content, moisture content, susceptibility index and germination percentage. These differences in the susceptibility of the maize varieties indicate the inherent ability of a particular variety to resist (with stand) *S. zeamais* attack. The overall result of the study is presented and discussed under this chapter in detail.

4.1. Protein and Moisture contents of Maize Varieties

Crude protein and moisture contents of the thirteen varieties of maize were determined before weevils were introduced into the jars containing maize varieties. The varieties were highly significantly different ($P<0.05$) for crude protein and moisture contents (Table 1). BHQPY-545 contained relatively high and significant crude protein content (8.59%). On the other hand, varieties such as BH-660 (7.10%), Kuleni (7.15%), Orome (7.21%), Hora (7.24%), Argane (7.24%) and BH-670 (7.25%) were found to contain statistically similar and significantly less amount of crude protein content. Varieties such as Kuleni (11.53%) and BH-661 (11.50%) contain relatively higher and significant moisture content were standard check resistance variety BHQP-542 (9.30%), BH-670 (9.63%), BH-660 (9.70%), BHQPY-545 (9.70%), Hora (9.70%) and Gibe-2 (9.73%) were found to contain significantly lower moisture content as compared to other varieties.

Table 1. Mean percent of moisture and crude protein contents of maize varieties.

Variety	Crude protein content (%)*	Moisture content (%)*
BH660	7.10e	9.70d
BH543	7.51d	9.86d
BH670	7.25e	9.63d
BH661	7.68cd	11.50a
BHQP542	8.24b	9.30d
BHQPY545	8.59a	9.70d
Gibe-1	8.21b	9.80cd
Gibe-2	8.20b	9.73cd
Kuleni	7.15e	11.53a
Wanchi	7.77c	9.83cd
Argane	7.24e	10.38cb
Hora	7.24e	9.70d
Orome	7.21e	10.53b
P value	<.0001**	<.0001**
CV	1.58	2.05
MSD	0.22	0.62

*** Highly significant, CV-coefficient of variation, MSD-minimum significance difference*

*Means with the same letter with in the column are not significantly difference at P<0.05.

4.2. Adult Mortality, F_1 Progeny and Median Development period (days)

Percentage adult mortality, F_1 progeny emergency and median development period among the varieties was significantly different (P<0.05) (Table 2). Maximum and significantly higher weevil's adult mortality was recorded from standard check resistance variety BHQP-542 (14.24%) followed by Gibe-2 (10.41%) and Gibe-1 (10.09%). There was no mortality recorded from BH-660 (1.81%) and BH-661(1.81%). Among all the maize varieties tested, maximum and significant numbers of F_1 progenies were emerged from BH-661(326) and Kuleni (322.33) while significantly lower number of F_1 progenies was emerged from standard check resistance variety BHQP-542 (51.33). The median development period ranged from 35.33 days (BH-661) to 48.33 days standard check resistance variety BHQP-542 maize variety. Generally, the median development period appeared to be negatively and significantly associated with F_1 progeny emergence (r=-0.95) and positively associated with percentage adult weevil mortality (r=0.75)

(Table 6). Varieties with high F_1 progeny emergency tended to have shorter median development period and very minimum percentage adult mortality.

Table 2. Adult mortality, F_1 progeny and median development time of S. zeamais on different maize varieties

Varieties	Adult mortality (%)*	F_1 Progenies emerged *	MDP (days)*
BH660	0.00 (1.81h)	106.16g	44.00b
BH543	2.33 (8.78c)	130.33f	44.66b
BH670	2.03 (8.19d)	163.00d	42.00c
BH661	0.00 (1.81h)	326.00a	35.33f
BHQP542	6.06 (14.24a)	51.33h	48.33a
BHQPY545	2.00 (8.13d)	155.33de	41.30cd
Gibe-1	3.06 (10.09b)	152.33de	41.40c
Gibe-2	3.26 (10.41b)	143.66ef	41.60c
Kuleni	0.21 (2.66g)	322.33a	35.36f
Wanchi	2.03 (8.19d)	151.33de	41.83c
Argane	0.40 (3.63e)	205.00c	40.16d
Hora	2.00 (8.13d)	152.00de	42.33c
Orome	0.30 (3.15f)	253.00b	38.16e
P value	<.0001**	<.0001**	<.0001**
CV	1.86	3.57	0.95
MSD	0.43	18.86	1.17

***Highly significant, CV-coefficient of variation, MSD-minimum significance difference*

*Means with the same letter with in the column are not significantly difference at P<0.05.

*Figure in the parenthesis is transformed data

In this particular study the maize varieties were significantly different with respect to weevils' mortality. However, weevil's adult mortality percentage was generally low with a maximum of 14.24 per cent (from the resistant variety) and minimum of 1.81 percent (from the moderately resistant and susceptible varieties) and is not a good indicator of susceptibility and or resistance of the varieties. Similarly, Dobie (1974) stated that overall rate of mortality of maize weevils on different maize varieties as low and concluded that there was no evidence for a variation among the varieties in their effects upon the mortality of *S. zeamais*. Also, Abebe *et al*., (2009) found non-significant differences among thirteen maize varieties tested against *S. zeamais* with respect to adult weevil mortality. According to Abraham (1991) adult weevils can survive without food for more than ten days in a laboratory test. These indicate weevil's mortality is not a good indicator of resistance in maize varieties. Never the less, less adult weevils mortality in storage is an indication of more number of egg laying from the survived adult weevils leading to more number of F_1 progenies emergency.

Mean number of F_1 progenies produced from the different maize varieties were highly variable ranging from 51.33 (in standard check resistance variety BHQP-542) to 326.00 (in the most susceptible variety- BH-661). More number of progeny productions is strongly associated with more susceptibility of the variety indicating the attractiveness/conduciveness of the varieties for maize weevils to flourish. On such susceptible varieties maize weevils required less developmental time (35.33 days) were as they required longer time on the standard check resistance variety BHQP-542 (48.33 days) displaying minimum index of susceptibility. Thus, less mortality and more number of progenies production is associated with more infestation to the maize seeds resulting to greater grain loss. Less number of days to complete the life cycle causes more number generations in a year compounding the damage they cause to maize grains. Differential reaction of maize varieties to maize weevil have been reported by several authors (Horber, 1988; Abraham, 1991; Giga et al, 1991; Arnason *et al*., 2004; Tefera *et al.*, 2011). Garcia-Lara *et al*., (2004) indicated that progeny emergence tended to be higher in susceptible genotypes than in resistant ones. According to Abraham (1991) the extent of damage caused to maize grains during storage depends on the number of emerging adults during each generation and the duration of each life cycle and varieties/genotypes/landraces permitting more generations per year and more number of adult weevil's emergence are subject to more serious damage by maize weevils.

4.3. Percentage grain damage and weight loss

Significance difference ($P<0.05$) was recorded among the varieties with respect to maize seed damage, weight loss and percentage dust produced from the different varieties (Table 3). The highest and significantly different percentage seed damage was observed from BH-661(46.80%) and Kulani (45.02%) maize varieties. The trend was similar with respect to weight loss and percent dust produced. On the contrary, significantly lower percentage seed damage (15.85%), weight loss (4.11%) and dust production (0.03%) was observed in standard check resistance variety BHQP-542 maize variety. Percentage seed damage, weight loss and dust production were positively related with the number of F_1 progenies emerged from the varieties tested. With increasing number of F_1 progeny, there were increasing and highly significant percentage seed damage (r=0.91), weight loss (r=0.94) and dust produced (r=0.95) from the varieties (Table 7).

Table 3. Extent of infestation (seed damage, weight loss and dust produced) of maize varieties due to maize weevil, *S. zeamais*

Varieties	**Mean seed damage (%)***	**Mean weight loss (%)***	**Mean dust (powder) produced (%)***
BH660	26.16 (30.76e)	1.03(5.83g)	0.24f
BH543	27.23 (31.46de)	1.33 (6.55fg)	0.28e
BH670	31.23 (33.95bcd)	1.91 (7.92de)	0.28e
BH661	56.46 (46.80a)	5.63(13.77a)	0.83a
BHQP542	7.46 (15.85fg)	0.51 (4.11i)	0.03g
BHQPY545	30.13 (33.29cde)	2.30 (8.72d)	0.28e
Gibe-1	30.23 (33.36cde)	1.30 (5.76gh)	0.28e
Gibe-2	19.46 (26.18f)	0.67 (4.80hi)	0.28e
kuleni	50.03 (45.02a)	4.90 (12.83a)	0.80b
Wanchi	27.53 (31.65de)	2.26 (8.72d)	0.28e
Argane	33.36 (35.28bc)	3.06 (10.08c)	0.71d
Hora	30.20 (33.33cde)	1.46 (6.96ef)	0.28e
Orome	34.90 (36.21b)	3.77 (11.24b)	0.74c
P value	<.0001**	<.0001**	<.0001**
CV	2.79	3.99	0.81
MSD	2.75	0.97	0.01

*** Highly significant, CV-coefficient of variation, MSD-minimum significant difference*

*Means with the same letter with in the column are not significantly difference at P<0.05.

* Figure in the parenthesis is transformed data

Considerable variation was observed among the maize varieties tested with respect to seed damage, weight loss and dust production. This indicates that the impact of *S. zeamais* on different maize varieties under production in Ethiopia differs with these variables. This difference in the susceptibility of the maize varieties is due to the differences in the ability of a particular variety to resist *S. zeamais* attack. The resistant maize varieties produced small quantity of powder/dust; are with minimum weight loss and grain damage, high germination of seeds, less moisture contents, more adult mortality, long median development period and less multiplication of the *S. zeamias*. Resistant variety seeds were less attractive to maize weevil to feed on when compared to the susceptible varieties; this indicates that probably antibiosis cum non-preference are the mechanism of resistance operating within the resistant varieties of maize seeds. Tefera *et al* (2011) and Abraham (1991) indicated that the extent of damage during storage depends on the number of emerging adults during each generation and the duration of each life cycle, and varieties permitting more rapid and higher levels of adult emergence are more seriously damaged.

4.4. Index of Susceptibility

Significant differences (P<0.05) were observed in the index of susceptibility (IS) among the varieties tested (Table 4). The IS ranged between 3.50 to 7.10 for standard check resistance variety BHQP-542 and BH-661 in that order. Out of the thirteen maize varieties tested against *S. zeamais* for resistance, only standard check resistance variety 'BHQP-542', had 3.5 index of susceptibility and was regarded as resistant to weevil attack. However; most of the varieties, namely BH-660, BH-670, BH-543, BHQPY-545, Gibe-1, Gibe-2, Wanchi, Argane, Hora and Local variety-Orome had index of susceptibility 4.6, 5.3, 4.7, 4.8, 4.9, 4.8, 5.2, 5.7, 5.2, and 6.0 respectively and are regarded as moderately resistance to weevil attack. Two varieties (BH-661 and Kuleni) had index of susceptibility 7.10 and 7.09 respectively and are regarded as moderately susceptible varieties to weevil attack.

Table 4. Susceptibility index of maize varieties to maize weevil, S. zeamais

Varieties	Dobie's IS *	Classification
BH660	4.60g	Moderately resistance
BH543	4.70fg	Moderately resistance
BH670	5.30d	Moderately resistance
BH661	7.10a	Moderately Susceptible
BHQP542	3.50h	Resistance
BHQPY545	4.80ef	Moderately resistance
Gibe-1	4.90e	Moderately resistance
Gibe-2	4.80ef	Moderately resistance
kulani	7.09a	Moderately Susceptible
Wanchi	5.20d	Moderately resistance
Argane	5.70c	Moderately resistance
Hora	5.20d	Moderately resistance
Orome	6.00b	Moderately resistance

P value <.0001**, CV=1.19, MSD=0.18

**Highly significant, CV=Coefficient of variation, MSD=minimum significant difference

*Means with the same letter with in the column are not significantly difference at P<0.05.

In this experiment, among thirteen maize varieties tested for their resistance to maize weevils, *S. zeamais*, only standard check resistance variety BHQP-542, was found resistant to maize weevils based on susceptibility indices. Further, two varieties, BH-661 and Kuleni were moderately susceptible and the remaining ten varieties were moderately resistant. Standard check resistance variety BHQP-542 is a Bako hybrid quality protein maize and resistant to *S. zeamais.* This variety is of compact small sized seeds and contained less moisture which might have contributed for its resistance. Abebe *et al* (2009) identified the same variety as resistant variety of maize against *S. zeamais*. According to them, the resistance of this variety is attributed due to high tryptophan and lysine content of the variety relative to the other varieties tested. Further, Arnason *et al.,* (2004) also indicated protein content was negatively correlated with the susceptibility of maize varieties to *S. zeamais*. On the contrary, this study revealed that there is no consistent relationship between protein content of the maize varieties and resistance to weevil's infestation suggesting the existence of other factors for resistance which need to be further investigated. Arnason *et al*., (1997) reported ferulic acid in the kernels as contributing factor to confer resistance to maize seeds against maize weevil's attack.

4.5. Impact of Moisture and Crude Protein Contents of Maize Varieties on Maize Weevil Emergence and Infestation

Moisture content and crude protein content of the maize varieties tested were significantly different ($P<0.05$) (Table 1). More maize weevils were found in maize varieties with higher moisture content, suggesting that moisture plays an important role in maize susceptibility to insects' pests. The seed size of the grains varied considerably among the varieties and there exist a relationship between size and moisture content of the varieties tested. Smaller seeds that were hard and compact had less moisture and were therefore more resistant to the maize weevil attack. On the other hand bigger grains were loose, soft and contain higher moisture and hence more weevils emerged and are easily attacked by the weevils. However, the differences in the protein contents of the varieties didn't showed strong relationship with the maize infestation by maize weevil. The number of weevils recorded in each maize variety did not vary according to the variation in the protein content of the maize varieties studied.

Table 5. Impact of crude protein and moisture contents of maize varieties on maize weevil

varieties	**Crude protein content (%)***	**Moisture content (%)***	Classification
BH660	7.10e	9.70d	Moderately resistance
BH543	7.51d	9.86d	Moderately resistance
BH670	7.25e	9.63d	Moderately resistance
BH661	7.68cd	11.50a	Moderately susceptible
BHQP542	8.24b	9.30d	Resistance
BHQPY545	8.59a	9.70d	Moderately resistance
Gibe-1	8.21b	9.80cd	Moderately resistance
Gibe-2	8.20b	9.73cd	Moderately resistance
Kuleni	7.15e	11.53a	Moderately susceptible
Wanchi	7.77c	9.83cd	Moderately resistance
Argane	7.24e	10.38bc	Moderately resistance
Hora	7.24e	9.70d	Moderately resistance
Orome	7.21e	10.53b	Moderately resistance

*Means with the same letter with in the column are not significantly difference at $P<0.05$.

The number of insect pest recorded in each maize variety did not vary according to the variation of protein content of the maize varieties. Thus, the authors suggest further study in order to establish the protein content and susceptibility indices of more maize varieties/genotypes/landraces. Moreover, study conducted at CIMMYT (CIMMYT, 2001) revealed the positive association of grain moisture content and maize varieties susceptible to weevil's damage. Grain seeds with higher moisture contents are more susceptible to maize weevil's attack. Similarly, in this study, the moderately susceptible maize varieties (Kuleni and BH-661) are with more moisture contents and bigger seed size. Tongjura *et al.* (2010) indicated the existence of no correlation between nutrient content of maize varieties and their susceptibility to *S. zeamais*. However, they stated variability in the size of the grains among maize varieties does influence the level of damage caused by maize weevils. Smaller seeds that were hard and compact had less moisture and were therefore more resistant to the maize weevil attack. On the other hand bigger grains were loose, soft and contain higher moisture and hence more easily attacked by the weevils. The harder a seed is, the more resistant it is to storage pests, such as the maize weevils. Kevin (2002) reported seed hardness and thickness, both in the pericarp and the whole kernel confer resistance because such seeds are very hard to penetrate by the weevils. Siwale *et al.,* (2009) reported undamaged pericarp serves as barrier against weevils and so reduced the number of insects' progeny emergency. Bergvinson (2004) mentioned maize with tighter husks or a harder kernel are insect resistant variety.

Siwale *et al.,* (2009) reported sugar content as the responsible factor contributing to grain resistance to weevils attack in maize seed. Many workers reported a tendency of increased nutrients in maize varieties association with resistance to weevils attack (Derera *et al*., 2001; Dhliwayo and Pixley, 2003; Garcia-Lara *et al.,* 2004).

4.6. Percentage Germination of Maize Varieties

Viability index (germination percentage) among the varieties (undamaged and damaged seeds) was significantly different at P<0.05 (Table 6). Generally, high percent of germination were recorded on the treatments of undamaged grain when compare to damaged grain. In damaged grain significantly higher percent of germination were recorded from standard check resistance variety BHQP-542 (86.6%) and significantly lower percent germination was recorded from BH-661 (29.50%) and Kulani (31.83%). The resistant variety registered better germination even after weevils attack and the more susceptible variety registered very poor germinability.

Table 6. Mean percent of Viability test of maize varieties to maize weevil

Varieties	Germination of undamaged grain (%)*	Germination of damaged grain by *S.zeamais* (%)*
edBH660	85.16def	75.06b
BH543	87.83cde	74.10b
BH670	89.83bcd	75.10b
BH661	79.06g	29.50f
BHQP542	93.66ba	86.60a
BHQPY545	94.83a	70.70cb
Gibe-1	81.16fg	66.91c
Gibe-2	91.00abc	70.06cb
Kuleni	83.33efg	31.83ef
Wanchi	82.46fg	60.40d
Argane	83.46efg	54.16d
Hora	82.76fg	68.66bc
Orome	84.90ef	38.06e
P value	<.0001**	<.0001**
CV	1.86	3.53
MSD	4.76	6.44

***Highly significant, CV-Coefficient of variation, MSD- minimum significant difference*

*Means with the same letter with in the column are not significantly difference at P<0.05.

Percent germination of maize varieties was higher in undamaged grains when compared with damaged kernel. In damaged grain high percent germination was recorded from standard check resistance variety BHQP-542 (86.60%) when compared to the other varieties. This may be because of less number of F_1 progenies emergency from this variety. Viability percentage is low, on the other hand, from BH-661, Kulani, Orome and Argane (29.50%, 31.80%, 38.06% and 54.16% respectively), because of higher number of F_1 progeny emergency from these varieties. This is in conformity with the work of Martha (2010), who reported that when the number of progeny emerged were high; the endosperms were totally lost therefore germination was inhibited. Kassa (1993) associated poor viability of haricot bean seeds (reduced germination) with more number of Mexican bean weevil emergence per grain seed.

4.7. Simple Correlation Coefficient of the Variables

The simple linear association between variables like weight loss, grain damage, germination percentage, dust or powder produced, moisture content, protein content, adult mortality, median development period and F_1 progenies emergency and susceptibility index were determined and summarized in (Table 6).

It is evident from Pearson Correlation Coefficients (r) that an inverse relationship exists between the susceptibility index (IS) and percent adult mortality (mor), median developmental time (mdp), percent germination (germ) and crude protein content (pro). However, the numbers of F_1 progeny emergency (F_1P), percent damaged grain (dam), percent dust produced (dust), moisture content (moi) and seed weight loss (wl) were positively related with the susceptibility index (Table 7). Adult mortality and germination test were moderately negatively correlated with susceptibility index where as median development period and crude protein content were highly and weakly negatively correlated with susceptibility index respectively. F_1 Progeny emergency, moisture content, weight loss, seed damage and dust (powder produced) were highly positively related with susceptibility index. This study was in agreement with Abebe *et al.,* (2009) an increasing number of F_1 progeny resulted in an increasing seed damage and seed weight loss and an inverse relationship between the susceptibility index and percent mortality and median developmental time; however, the numbers of F_1 progeny, percent seed damage and seed weight loss were positively related with the susceptibility index.

Table 7. Pearson Correlation Coefficients of seed weight loss (wl), damaged seeds (dam), seed germination (germ), dust or powder produced (dust), moisture (moi) and protein (pro) contents, adult mortality (mor), median development period (mdp), number of weevils produced (F_1P) and index susceptibility (IS).

	IS	mor	F1P	moi	pro	mdp	wl	dam	dust	germ
IS	1									
mor	-0.74**	1								
F1p	0.98**	-0.71**	1							
moi	0.89**	-0.69**	0.93**	1						
pro	-0.44*	0.59**	-0.35	-0.29	1					
mdp	-0.98**	0.75**	-0.95**	-0.87**	0.52**	1				
loss	0.92**	-0.72**	0.94**	0.89**	-0.43*	-0.91**	1			
dam	0.93**	-0.78**	0.91**	0.84**	-0.45*	-0.91**	0.87**	1		
dust	0.92**	-0.71**	0.95**	0.89**	-0.44*	-0.91**	0.91**	0.83**	1	
germ	-0.75**	0.76**	-0.74**	-0.73**	0.48*	0.76**	-0.73**	-0.71**	-0.75**	1

*,**= Significant at 0.05 and 0.01 Probability level respectively

5. SUMMARY AND CONCLUSION

The study was initiated with the objectives to understand the reaction of different maize varieties to maize weevil attack by establishing the susceptibility indices of the different maize varieties to maize weevil. The results of evaluations of some biological variables of maize weevil on different maize varieties indicated that preference of maize varieties by maize weevil for oviposition varied. The varieties also differed in their suitability to the development of the pest since there were significant differences in the number of adult emergence and developmental period.

The varieties varied in resistance and the variation was due to both non preference for oviposition and larval antibiosis may be because of biochemical constituents. The standard check resistance variety BHQP-542 were more resistant to the attack of maize weevil and this was manifested in terms of a lowered fecundity of the females and number of adult emergence together with prolonged developmental period and lower number of adult emergence. The moderate susceptibility of BH-661 and Kuleni could be attributed to the fact that there were high fecundity of the females and the number of adult emergence and short developmental time. Higher grain weight loss was recorded on BH-661, Kuleni, Orome and Argane while the least grain weight loss was recorded on standard check resistance variety BHQP-542 since this treatment was least preferred for oviposition and lower number of adult emergence due to antibiosis or antixenosis. Low germinations were recorded in treatments with higher number of adult emergence BH-661, kuleni, Orome and Argane. The low oviposition of maize weevil on standard check resistance variety BHQP-542 which resulted in low emergence of progeny, low grain damage, low grain weight loss, low moisture content, low powder (dust) and high germination than moderately resistance and susceptible varieties, indicated that the variety is resistant to maize weevil. Therefore, this variety has a type of resistance modality often said as non-preference or antibiosis. In addition, using insect-resistant crops allows natural and biological control to function more effectively and dependably and improves the efficacy of cultural management tactics and insecticide applications.

An important benefit to the use of insect-resistant varieties as a component in integrated pest management is that resistant varieties are compatible with other direct control tactics. Insect-resistant varieties have a distinct advantage over biological control, meaning the use of natural enemies to suppress the abundance of an insect pest, because plant resistance to insects is compatible with insecticide use whereas biological control is often not. However, insect· resistant varieties must be used like other non-chemical control tactics, especially cultural controls. Insect-resistant varieties can prevent development of damaging insect infestations, but susceptible varieties cannot cure or prevent insect damage when insect abundance is close to the damaging level.

The susceptibility index was inversely related with percent mortality, median developmental time, percent protein content and percent germination. However, the number of F1 progeny, percent seed damage, percent dust produced, percent moisture content and seed weight loss showed a positive relationship with the susceptibility index.

6. RECOMMENDATION

The present laboratory evaluation of different maize varieties for resistance to maize weevil illustrated the potential of resistant variety for the management of weevil. The resistant variety is a very good method of combating weevil in storage. It is perhaps the easiest, most economical and effective means of controlling this pest on stored maize as there is no special technology which has to be adopted by farmers. Hence, the current examination was mentioned with the following recommendation.

- Resistance and moderately Resistant varieties, therefore, can be utilized as an environmental friendly way to reduce damage by *S. zeamais* under traditional storage conditions when compared with moderately susceptible variety.

- The use of resistance and moderately resistant varieties in insect pest management is an eco-friendly and cost effective means that should be promoted for S. zeamais management in maize especially for small-scale farmers in the tropics.

- Crop proctection specialists and growers should be educated as to the benefit, both economic and environmental, that can be gained from the use of insect resistant varieties.

- Because of Ethiopia is a center of diversity for maize, it is necessary to carry out an extensive selection and screening work on more commissioner samples of germplasm for resistance to maize weevil.

7. FUTURE LINE OF WORK

- The standard check resistance variety BHQP-542 can be used as a source of resistance in breeding programmes to diversify the basis of resistance to maize weevil.

- More work need to be done to recognize the genetic basis for resistance to maize weevil found in maize varieties.

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8. APENDICES

Annex 1. Summary ANOVA table for mean percent moisture content of different maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	17.90923077	1.49243590	34.59	<.0001
Error	26	1.12166667	0.04314103		
Corrected Total	38	19.03089744			

Cv	2.05
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.043141
Critical Value of Studentized Range	5.13
Minimum Significant Difference	0.61

Annex 2. Summary of ANOVA table for mean percent crude protein content of different maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	12.35335897	1.02944658	69.63	<.0001
Error	26	0.38440000	0.01478462		
Corrected Total	38	12.73775897			

Cv	1.58
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.014785
Critical Value of Studentized Range	5.13
Minimum Significant Difference	0.22

Annex 3. Summary of ANOVA table for mean percent of adult mortality on different maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	542.3745641	45.1978803	2761.58	<.0001
Error	26	0.4255333	0.0163667		
Corrected Total	38	542.8000974			

Cv	1.86
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.01
Critical Value of Studentized Range	5.13
Minimum Significant Difference	0.37

Annex 4. Summary of ANOVA table for mean number of F1 progeny emergence of *maize weevil* on different maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	229589.3333	19132.4444	473.38	<.0001
Error	26	1050.8333	40.4167		
Corrected Total	38	230640.1667			

Cv	3.57
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	40.41
Critical Value of Studentized Range	5.13
Minimum Significant Difference	18.86

Annex 5. Summary of ANOVA table for mean developmental period of maize weevil on maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	430.9692308	35.9141026	228.49	<.0001
Error	26	4.0866667	0.1571795		
Corrected Total	38	448.05589			

Cv	0.95
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.15
Critical Value of Studentized Range	5.13
Minimum Significant Difference	1.17

Annex 6. Summary of ANOVA table for percent grain damage due to maize weevil

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	2099.597477	174.966456	202.93	<.0001
Error	26	22.416800	0.862185		
Corrected Total	38	2122.014277			

Cv	2.79
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.86
Critical Value of Studentized Range	5.13
Minimum significant differerence	2.75

Annex 7. Summary of ANOVA table for percent weight loss due to maize weevil

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	329.7679026	27.4806585	252.63	<.0001
Error	26	2.8282667	0.1087795		
Corrected Total	38	332.5961692			

Cv	3.99
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.10
Critical Value of Studentized Range	5.13
Minimum Significant Difference	0.97

Annex 8. Summary of ANOVA table for mean percent dust produced of due to maize weevil on different maize varieties

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	2.46409559	0.20534130	17955.9	<.0001
Error	26	0.00029733	0.00001144		
Corrected Total	38	2.46439292			

Cv	0.81
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.00001
Critical Value of Studentized Range	5.13
Minimum Significant Difference	0.01

Annex 9. Summary of ANOVA table for mean percent of susceptibility index of different maize varieties to maize weevil

Source	DF	Sum of Squares	Mean Square	F Value	Pr >F
Model	12	34.72269292	2.89355774	712.75	<.0001
Error	26	0.10555200	0.00405969		
Corrected Total	38	34.82824492			

Cv	1.19
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	0.00406
Critical Value of Studentized Range	5.13
Minimum Significant Difference	0.18

Annex 10. Summary ANOVA table for percent germination of different maize varieties to the effect of maize weevil

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	12	12007.37769	1000.61481	211.85	<.0001
Error	26	122.80167	4.72314		
Corrected Total	38	12130.17936			

Cv	3.53
Alpha	0.05
Error Degrees of Freedom	26
Error Mean Square	4.72
Critical Value of Studentized Range	5.13
Minimum Significant Difference	6.44