Screening of Some Botanical Insecticides against Maize Weevil, Sitophilus zeamais Motschlsky (Coleoptera: Curculionidae) on Maize

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Abstract

Maize is one of the major cereal crops grown for food in Ethiopia and the maize weevil, Sitophilus zeamais is a major insect pest of stored maize. Controlling of the pest by use of synthetic insecticides is raising serious concern on the environmental safety, consumer health hazards and high costs for subsistence farmers and thus there is a need to develop alternative safe and cheap methods of insect control strategies such as the use of insecticidal botanicals against the storage pest. The aim of this study was to evaluate the efficacy of powders of seeds of Azadrichta indica, Millettia ferruginea and Jatropha curcas, leaves of Croton macrostachyus and Euphorbia schimperiana and to screen the minimum effective dose of each botanical for the management of maize weevil. The plant materials were collected air-dried under shade and ground separately into a fine powder using micro plant grinding machine. Three, four, and five grams of powder of each botanical were added to each 100 g of clean maize in each 250 cm^3 *glass jar and mixed uniformly by shaking. A standard insecticide, Pirimiphos-methyl 2 % dust (2 g) and untreated check were included for comparison. Twenty-six newly unsexed emerged adult weevils were placed in each jar and covered with muslin cloth. The treatments were arranged in completely randomized design (RCD) with three replications. Weevil mortality was recorded at 3, 7, 14, 21, and 28 days after initial infestation. During the last counting, both dead and alive weevils were counted and removed and the grains were kept under the same conditions for the emergence of* F_1 *generation. The numbers of F1 progeny weevils emerging were recorded every other day for 33 days. Seed germination was tested using 15 randomly picked seed from undamaged grains from each jar. A significant difference* ($P < 0.05$) *was observed between all the botanicals at all rates and the untreated control three to 28 days after treatment. The cumulative mortality 28 days after infestation was very high (97.43 –100%) and there was no significant difference between all the botanicals at all rates and the standard chemical. No significant difference was observed* ($P > 0.05$) *in the number of emerged* F_1 *among the botanical treatments and the chemical insecticide, but significant difference was recorded between these treatments and the control at 1 and 2 days and cumulative emerged progeny after 28 days. Seed germination test generally revealed over 77 % seed viability and no significant difference was found among all the treatments. The study revealed that the botanicals can be used as components of maize weevil management options as they caused high weevil mortality and very low fecundity and showed insignificant effect on seed viability.*

Keywords: *Adult emergence, botanical powders, cumulative mortality, exposure time, grain damage mortality, germination.*

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Table of contents

Contents **Pages**

List of Tables

List of Figures

List of Appendix

1. INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is a cereal grass related to wheat, rice, oat and barley; ranking second after wheat and is followed by third-ranking rice in order of world grain production. This plant is regarded as versatile with many uses and is cultivated in a wider range of environments than wheat and rice and any other crop because of its greater adaptability (Asiedue, 1989; Parugrug and Roxas, 2008; Onuh *et al*., 2008). Maize is high yielding, easy to process, readily digested, and cheaper than other cereal (Onuh *et al*., 2008).

Maize is a very important cereal grain in Africa where it is widely cultivated and consumed. It serves as a source of dietary carbohydrate for humans (Asawalam *et al*., 2007). It is cultivated in Ethiopia in diverse ecological conditions and constitutes about 17 % of the total cultivated area and 24 % of the grain produced in the country (CSA, 1996). In Ethiopia, maize is one of the major cereal crops grown for its food and feed values. It is one of the most important staple foods and cash crops providing calories for the consumers and income for the traders (Waktole Sori and Amsalu Ayana, 2012).

Although production of corn has increased to meet the global demand, several biotic and abiotic factors play an important role in limiting the productivity. Among biotic factors contributing for storage losses, insect pests play a major role inflicting 20–30 % damage of corn grain in tropical regions (Haque *et al*., 2000) due to favorable conditions for their development and poor storage conditions (Abraham Tadesse, 1997). Insects are most often considered as the principal cause of maize grain losses. The most important insect pests that cause damage to maize in the field and storage are lepidopterous stalk borers and coleopterous weevils, respectively. More than 37 species of arthropod pests are associated with maize grain in storage (Waktole Sori and Amsalu Ayana, 2012).

Initial infestations of maize grain occur in the field just before harvest and the insects are carried into the store where the population builds up rapidly. The huge post-harvest losses and quality deterioration caused by this insect pest is a major obstacle to achieving food security in developing countries (Asawalam *et al.,* 2007). Insect pests which commonly attack stored grains like maize weevil cause severe damage to the commodity resulting in losses in weight, seed viability, and nutritive quality of foodstuffs (Parugrug and Roxas, 2008). *S. zeamais* is one of the most destructive stored product pests of grains, cereals, and other processed and unprocessed stored products in sub-Saharan Africa. It causes qualitative and quantitative damage to stored products, with grain weight loss ranging between 20 to 90% for untreated stored maize, and the severity of damage depends on factors which include storage structures and physical and chemical properties of the produce. Heavy infestation of adults and larvae of maize weevil which cause postharvest losses have become increasingly important constraints to storage entomology and food security in the tropics (Ojo and Omoloye, 2016).

The maize weevil is a major insect pest of stored maize in Ethiopia. It causes substantial quantitative and qualitative loses manifested by seed perforation, and reduction in weight, market value and seed germination. Loses ranging from 20 to 30% are common in some localities in Ethiopia. Under farm-storage conditions in the Bako area, up to 100% damage to maize stored for 6-8 months have been reported (Girma Demisie *et al*., 2008).

In the assessment of insect store pests of maize in Jimma Zone of Oromia Regional State, among the different arthropods, Waktole and Amsalu (2012) recorded maize weevil (*Sitophilus zeamais)* as the dominant species in all area surveyed followed by Angoumois grain moth (*Sitotroga cereallela),* rice weevil (*Sitophilus oryzae)* and flour beetle (*Tribolium confusum)* and the pests are widespread, abundant and cause damage and loss to maize grain.

Besides storage insect pests, a number of microorganisms attack maize in the field as well as in the storage and of these fungi are among the principal causes of deterioration and loss of maize grain (Ominski *et al*., 1994). Insects play an important role in infection of maize by *Fusarium* spp. They can act as wounding agents or as vectors spreading the fungus from origin of inoculum to plants (Dowd, 1998). Borers and insects of the family Nitiduidae are most often cited as favoring maize infection by *Fusarium* species.

Synthetic pesticides have been used for many years to control agricultural pests including those that damage durable food crops in storage like *S. zeamais* (Girma Demissie *et al*., 2008; Tilahun Firomsa and Daniel Hagos, 2016). They are effective in controlling pests yet expensive, dangerous to human health and may create other problems in post-harvest industry (Parugrug and Roxas, 2008). Considerable problems may arise from the continued application of these insecticides which include high persistence, poor knowledge of application, pest resurgence, genetic resistance by the insect, lethal effects on non-target organisms in addition to direct toxicity to users, and increasing costs of application that subsistence farmers cannot afford (Asawalam *et al.,* 2007; Girma Demisie *et al*., 2008; Tilahun Firomsa and Daniel Hagos, 2016).

These problems associated with the use of synthetic insecticides have necessitated research on the use of alternative eco-friendly cheaper insect pest control methods amongst which are the use of powdered plant parts and their extracts (Asawalam *et al.*, 2007). The current concerns of synthetic insecticides and the desire for residue-free grains by consumers demand for searching and developing alternative management options to integrate with other control measures such as varietal resistance and botanicals.

The common control methods for this pest are the use of chemical insecticides, biological control, and botanical insecticides among others (Ojo and Omoloye, 2016). The use of botanical pesticides to protect plants from pests is very promising because of several distinct advantages. Pesticidal plants are generally much safer than conventionally used synthetic pesticides. Pesticidal plants have been in nature as its component for millions of years without any ill or adverse effect on the ecosystem. In addition, plant-based pesticides are renewable in nature and cheaper. Also, some plants have more than one chemical as an active principal responsible for their biological properties. These may be either for one particular biological effect or may have diverse ecological effects. The chances of developing quick resistance to different chemicals are highly unlikely (Parugrug and Roxas, 2008).

Plant-derived pesticides can be transferred into practical applications in natural crop protection, which can help the small-scale farmers (Parugrug and Roxas, 2008). The use of natural and easily biodegradable crop protection inputs like azadirachtin can be a useful component of an IPM strategy since the compound is known for its low toxicity against beneficial insects (Koona and Njoya, 2004).

Therefore, the current study was initiated to evaluate the insecticidal effect of powders of of seeds of *Azadrichta indica* and *Millettia ferruginea*, leaves of *Croton macrostachyus*, *Euphorbia schimperiana*, and *Jatropha curcas* as grain protectant against *S. zeamais* under laboratory condition.

1.2 Statement of the Problem

Maize is a major staple food for millions of Ethiopia and it is often stored for more than six months. Loss of maize ranging from 20 – 30 % is very common by insect pests of these maize weevil is the main pest during storage period. Once the grains are damaged, this will reduce the market value, the percentage of germination, the weight and the nutritional value.

Chemical control of stored product insect pests has been the most efficient and effective means of protection of stored produce. However, synthetic chemicals have associated drawbacks like environmental hazards, chemical residues in food and unaffordable increasing costs for subsistence farmers. Thus, alternative to chemical insecticides environmentally friendly and safe to human health, effective and cheap methods are needed to reduce the damage caused by *S. zeamais* to reduce food insecurity. Plant materials with insecticidal properties remain one of the most important locally available, biodegradable and inexpensive methods for the control of pests of stored products.

Therefore, as alternative methods, five plant powders were evaluated for their insecticidal activities for their potential management of maize weevils which could be easily utilized by subsistence farmers of Ethiopia.

1.3 Objectives

General objective

- To evaluate the efficacy of some selected botanicals on maize weevil

Specific objectives

- To determine the mortality effect of some selected botanicals on maize weevil
- To determine the impact of some selected botanicals on the fertility of maize weevil
- To compare the efficacy of some selected botanicals on maize weevil

1.4 Significance of the research

Resource poor farmers in developing countries like Ethiopia can grow their own botanical insecticides with minimum expense for grain weevil control. Thus, the results of the study may be helpful to the poor farmers as it is cost effective and improve the underlying ecological problems imposed by the use of persistent synthetic insecticides which cause acute and chronic toxicity to humans and other beneficial organisms. The results of this study can also be used by researchers for future investigation of alternative methods of insect pest control.

2. LITERATURE REVIEW

It is estimated that the food plants of the world are damaged by more than 10,000 species of insects, 30,000 species of weeds, 100,000 diseases (caused by fungi, viruses, bacteria and other microorganisms) (Dhaliwal *et al*., 2015). Crop protection has been developed for the prevention and control of crop losses due to pests in the field (pre-harvest losses) and during storage (post-harvest losses). Crop losses due to these harmful organisms can be substantial and may be prevented, or reduced, by crop protection measures (Oerke, 2006). Post-harvest losses of grains due to insect pests are high and their management requires integrated approach, based on understanding and knowledge of biology, behavior and ecology of pests, should be developed. An integrated approach utilizing varieties with insect resistance grain, and seed treatment using readily available botanicals can be implemented by resource poor farmers of developing countries.

2.1 Stored grain insect pests

There are thousands of species of insects associated directly or indirectly with stored grains and grain products. Of these, some cause enormous losses and are mainly responsible for most of the damage to grain in farm, transportation and storage. They are termed as major primary pests (Khare, 1994). Seeds already damaged by such primary insect pests are liable to infestation by secondary feeders such as *Tribolium castaneum* (Adhanom Negasi, 1989).

Most economically important post-harvest grain insect pests belong to two insect orders: Coleoptera (beetles) and Lepidoptera (moths). Of these, beetles are far more diversified and are highly destructive stored grain insects in comparison to moths (Tyler and Boxall, 1989; Upadhyay and Ahmad, 2011). Both grubs and adult insects attack the stored food material while among the moth, only the caterpillars are harmful life stage that causes the damage. Besides, there are certain insect pests which do not breed in stored grain but their presence in the stores is harmful because they generate filth and nuisance. They do not cause large damage to food grains but create noxious smell and debris. These include mainly insects like cockroaches, ants, crickets and silverfishes. All important stored grain pests are listed in Table 1 (Upadhyay and Ahmad, 2011).

Table 1: List of stored grain insects

Common name	*Scientific name*	Family	Order
Rice weevil	*Sitophilous oryzae (L)*	Curculionidae	Coleoptera
	Sitophilous granarius (L)	Curculionidae	Coleoptera
Khapra beelte	*Trogoderm granarium (L)*	Dermastidae	Coleoptera
	Trogoderma glabrum (Herbst)	Dermastidae	Coleoptera
Lesser grian borer	*Rhizopertha dominica (Fabr)*	Bostrichidae	Coleoptera
Rust red flour beetle	*Tribolium castaneum (Herbst)*	Tenebrionidae	Coleoptera
	Tribolium confusum	Tenebrionidae	Coleoptera
Pulse beetle	*Pachymerus chinensis (Lin.)*	Bruchidae	Coleoptera
	Bruchus analis (Fabr)	Bruchidae	Coleoptera
	Acanthoscelides obstectus	Bruchidae	Coleoptera
	Callosobruchus chinensis	Bruchidae	Coleoptera
	Callasobruchus maculatus	Bruchidae	Coleoptera
Angonmois grain moth	*Sitotroga cerealella (Oliv.)*	Gelechidae	Coleoptera
Rice moth	*Corcyra cephalonica (Staint.)*	Lariidae	
Almond moth	*Ephestia cautella (Walker)*	Pyralidae	Lepidoptera
Saw toothed	*Oryzaephilus surinamensis (Linn.)*	Grain beetle	Indian meal moth
	Plodia interpunctella (Hubner)	Pyralidae	Lepidoptera
Drug stone beetle	*Stegobium paniceum (L.)*		
Cigarette beetle	*Lasioderma sericorne (F)*		
	Anagasta kuehniella	Pyralidae	Lepidoptera
Psocids	*Liposcelis bostrychophila*	Liposcelididae	Psocoptera
	Liposcelis decotor (Pearman)	Liposcelididae	Psocoptera
	Cryptolestes ferrugineus	Cucujidae	Coleoptera
	Lasioderma serricorne (Fab)	Anobiidae	Coleoptera
	Zabrotes subfasciatus (Boh)	Chrysomalidae	Coleoptera
	Holotrichia serrata	Scarabaeidae	Coleoptera
	Eurygaster integriceps (Puton)	Scutelleridae	Hemiptera
Maize weevil	*Sitophilus zeamais (Motsch)*	Curculionidae	Coleoptera

Source: Upadhyay and Ahmad (2011).

Sitophilus zeamais Mosch. (maize weevil), *S. oryzae* (L.) (rice weevil) and *S. granarius* (L.) (granary weevil), species of beetle in the family Curculionidae, are the most destructive primary pests of stored grain in the world, and which can infest sound grain in the field before harvest (Tyler and Boxall, 1989). *Sitophilus zeamais* is the most destructive pest of stored maize under good conditions of tropic and sub-tropic temperatures and maize moisture content ranges of 10 to 14 % in many parts of the world (Hill, 1983; Khare, 1994). Adult maize weevil can readily fly from stocks of stored grain into growing maize and at harvest time all stages of development of this insect may be present in the grains.

Maize weevil is widely distributed throughout the tropics and subtropics as well as in Southern Europe. The hosts are primarily maize while sorghum, rice and other stored grains are secondary. The weevils also attack and breed in dried wheat, sweet potato, cassava, beans, and cowpeas (Singh, 1983).

The damage pattern by maize weevil is a small tunnel, which is bored in the center of the maize and typified by the round exit holes on the grain surface. The larvae usually bore circular holes on the surface of the grain, enter and eat the internal contents of the grain. Significant reduction in the viability of the grain is a common effect of infestation by *Sitophilus* spp. (Okiwelu *et al*., 1987). Infested grain is found to be heating at the surface and it may become dump resulting into sprouting grains (Singh, 1983).

Insect infestations causing losses are the most series problem in grain storage, particularly in developing countries. These are attributed to humid tropical conditions, poor sanitations and use of inappropriate storage facilities (Jilani and Ghiosuddin, 1988). African farmers suffer heavy losses because of grain deterioration of seed quality during storage and seed viability (loss of germination). Losses ranging from 2.2 to 30 % in Kenya (De Lima, 1979), over 20 % in Zimbabwe (Giga *et al.,* 1991) and 20 to 30 % in Ethiopia (Girma Demisie *et al*., 2008) have been reported. Often these high storage losses have created food insecurity.

2.2Biology and life cycle of maize weevil

The maize weevil is a small beetle about 3 mm in length with head protruded into a snout, a distinct beak or proboscis. At the end of this structure, there is a pair of mandibles or jaws. The insect is generally reddish brown, sometimes dark brown or almost black. A newly emerged weevil is light brown to reddish-brown. It has a long, narrow snout and clubbed eight-segmented antennae. It is easily identified by the presence of four light reddish or yellowish pale spots on the elytra (Khare, 1994).

Infestation (Egg-laying) of maize starts in the field on maize cobs, where the shucks do not encase the head properly or in which graminaceous borers have made holes. The adult female bites or chews into the maize grain and makes a cavity inside them. It deposits an egg in each of the holes made and later seals them with a hard secretion called 'egg plug' (Lale 2001). Eggs hatch into larvae (tiny grubs) in about six days at a temperature of 25°C which feed exclusively inside the grain, excavating a tunnel as it develops. The larvae are plump, cruciform (cross-shaped), creamy-white in appearance and apodous (legless); hence, they are immobile. A fully grown larva is white and is about 4 mm long (Hill, 1983). The larval stage is the most destructive stage of the weevil and accounts for most of the damage done to the grain (Hill, 1983). This impacts considerable loss in weight, deterioration of quality and promote rapid growth of micro-flora on the infested grains, moisture content and endosperm value while also producing significant grain dust (maize components in powder form). When not controlled, weevils will completely consume all components inside the maize kernel during storage (Denis, 2014).

There are four larval instars and pupation occurs at about 25 days after eggs are laid (Hill, 1983). The development of the larvae and pupae takes place inside the grain and after pupation, the newly developed adult chew its way out of infested grain through a fairly large characteristic circular emergence hole made on the outer coat of the grain. Emerged adults are good fliers (Adedire, 2001) and they re-enter holed maize seeds at will, either to feed or to lay eggs. When the adults emerge, the females move to a high surface and release sex pheromones. Males are then attracted to this pheromone

(Mason, 2003) for mating. Male to female ratio of the maize weevil is 1:1 and female weevils live longer than male weevils (Abraham Tadesse *et al.*, 1996). The longevity period of the adult weevil, is up to 5 months (Adedire, 2001) or even l year (Lale, 2002). The female may lay between 300 and 400 eggs in its life span. Eggs are laid throughout most of the adult life, although 50 % may be laid in the first 4-5 weeks (Hill, 1983).

The lifecycle (from egg to adult) is on average 36 days at 27 ± 10^{o}C, and 69 ± 3% relative humidity (RH) (Sharifi and Mills, 1971) (Figure 1). Various factors like diet, varietal differences within cereals and low temperatures influence the number of generations and the life span of adult *Sitophilus* species (Darling, 1951).

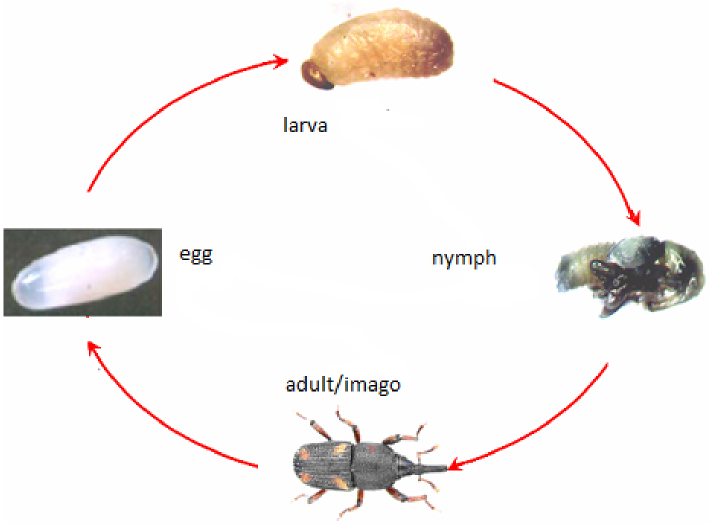

Figure 1: The life cycle of *S. zeamais*

Source:
https://www.researchgate.net/profile/Langsi_Jacob/publication/319289140/figure/fig6/AS:531381 022150661@1503702516969/Life-cycle-of-Sitophilus-zeamais-Meikle-et-al-1999_W640.jpg

2.3 Effects of storage insects on storage fungi

Many insect pests damage grain directly by feeding and indirectly by increasing susceptibility to secondary insect pests and fungi, and contaminate the produce with fragments, faeces, webbing, ill-smelling metabolic products and a variety of mycoflora that inflict major quantity and quality losses. Fungi associated with seed at planting are usually ear-rotting fungi. The most common fungi associated with the seed are *Aspergilus, Penicillium, Fusarium moniliforme*, and *Rhizoctonia spp.* (Fajemisin, 1985).

Maize grains are subject to infection by fungi causing seed rots and diseases of the seedlings. These fungi are soil and/or seed-borne and the symptom of seed rot is the complete decay of the seed before or at the time of germination. Storage fungi regularly follow infestation of grains by weevils and usually many insects, whose larvae develop within the kernels of grains, are accompanied by storage fungi (Christensen and Kaufmann, 1965).

Sitophilus zeamais does not only feed on maize, its infestations result in *Asperigillus flavus* (Link) infection. In addition to providing sites for fungal infection through their feeding damage, insects create environment in which fungi can grow by causing spontaneous heating of dry grains, releasing water through respiration and causing moisture migration. Besides, insects and mites carry fungal spores in their gut, on hairs, ovipositors or mouthparts (Dunkel, 1998).

Post-harvest grain losses could be very high in the tropics resulting from grain consumption by insects, in addition to losses to secondary fungal infection, and reduction in quality due to biochemical changes brought on by fungal and insect attack (Mbata, 1992). Degradation of products during storage is influenced by a combination of moisture, temperature and oxygen factors. Moisture and temperature are determining factors in accelerating or delaying the biochemical oxidation of grain and other living organism. Also, they influence the rate at which insects and microorganisms such as molds, fungi, yeasts and bacteria grow, and the premature germination of maize (Denis, 2014).

2.4 Management of stored maize insect pests

2.4.1 Chemical control

Insecticides are generally the most effective management tool and in many instances provide the only feasible method of reducing insect populations or reducing them to acceptable levels (Perez-Mendoza, 1998). Many conventional (synthetic) insecticides have been demonstrated to be effective against curculionids, particularly *S. zeamais*; either as dusts or fumigants. Insecticidal dusts of Malathion, chlorpyrifos methyl, femitrothion, methacrifos or pirimiphos methyl (Organo-phosphorus compounds), carbaryl (cabamate) or permethrin and deltamethrin (synthetic pyrethoids) can protect maize grains stored in bags or in air-tight containers from *S. zeamais* damage for several months (Adedire, 2001). Two major chemical methods used for managing insect pests of stored grains and these are fumigation and contact insecticides (Kostyukovsky, 2016).

2.4.1.1 Fumigation

Fumigants are chemicals available as gases, liquids and in solid formulations, but act on the insect pests of stored grains such as maize in gaseous state (Chakraverty *et al*., 2003). Fumigation is one of the most effective management method in which insect pests are exposed to a poisonous gaseous environment, by applying a grain fumigant. It is applied in buildings, ware houses; small bags, soil, seed and stored products, and fumes generated by fumigants enter the body of insect through the spiracles and spread to trachea and tracheoles and bind to the hemolymph components (Upadhyay and Ahmad, 2011). Accordingly, fumigation plays a key role in grain preservation as it controls insects developing inside and outside the grain, and crawling and hidden pests (Chakraverty *et al*., 2003).

Currently, phosphine and methyl bromide are the two common fumigants used for stored-product protection over the world (Boyer *et al.*, 2012). Among these fumigants, the usage of methyl bromide was phased out in developed countries due to its ozone depletion effects and instead, phosphine is widely used now a day (Daglish *et al*., 2014).

2.4.1.2 Contact insecticides

Contact insecticides are solid or liquid formulations which are toxic to insects and exert their effect when insect pests of stored grain such as maize come into direct contact with them. Most of these available for post-harvest use were originally developed to protect field crops and then found to be useful for stored products (Golob *et al*., 2002). They play a significant role in grains preservation along with other control measures, regular hygiene and sanitation measures. Insecticides kill insects previously exist, as well as hinder cross-infestation and re-infestation of non-infested grains (Chakraverty *et al*., 2003).

Synthetic organic chemicals that are currently approved for use in stored gain insect pest management fall into one of three groups: organophosphates, carbamates and synthetic pyrethroids (Golob *et al*., 2002). These insecticides have been used in management of stored grains as grain admixture treatments, residual surface and space treatments (Proctor, 1994).

The use of synthetic insecticides in pest management is becoming less attractive, due to high cost, increased incidence of pests resistance, high mammalian toxicity, high level of persistence in the environment, workers' safety, adulteration, leaving of poisonous residues in food after use and other health hazards (Longe, 2016). These situations hence, inspired the search for safe, effective, pest specific and economical alternative methods including inert dusts, botanicals, varietal resistance, biological control and others (Smith et al., 2006). Hence, these chemicals do not have very promising future for food grains such as maize and they may be used with hazard restrictions (Mohapatra *et al*., 2015).

2.4.2 Varietal resistance

Maize varieties differ greatly in their intrinsic susceptibility to insect attack (Schoonhoven *et al*., 1976) permitting resistant lines to be selected (Dobie, 1977). Maize hybrids had a significant effect on progeny emergence, indicating that it may play an important role in suppressing maize weevil populations. 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 contents (Tipping *et al*., 1988).

Insect resistant maize varieties generally complement integrated pest management (IPM) tactics such as chemical in combination with biological control. The use of resistant varieties integrated with other sustainable pest control methods will provide a long lasting solution to losses in storage (Dobie, 1977). Development of weevil-resistant maize varieties, and which forms the core of an integrated approach to the control of weevils, should be seriously considered by breeders to improve food security (Giga and Mazarura, 1991). Resistance of host plants to insect pests was used as a primary method of pest control long before the advent of synthetic organic insecticides. For crops grown in developing countries, perhaps the most attractive feature of using pest resistant plants is that virtually no skill in pest control or cash investment is required from the grower. In this setting they provide practical and economical ways to minimize losses to insect pests (Adkinsson and Dyck, 1980).

Resistant maize varieties that can be grown by resource poor farmers without being vulnerable to effects by insects and without needing the application of usually scarce, expensive and often, dangerous insecticides help these farmers increase their production while protecting the environment (Chamo and Dyte, 1976).

But, breeding for the resistance to stored grain insect pests was ignored initially (in the past), probably due to the long duration from crop establishment to postharvest screening for resistance and the high cost involved. Because of the widespread use of insecticides and its associated risks, breeding for screening maize resistant to maize weevils has been recommended recently as alternative methods of control. Use of resistant maize variety is important as it is the cheapest, effective and ecologically safe method of protecting grains (Tefera et al., 2011) avoids health risks and requires little or no scientific knowledge by the farmers (Ahmed and Yusuf, 2007) and maintains high levels of resistance for a long time despite upsurge of biotypes (Mwololo *et al*., 2012).

2.4.3 Botanical control

Botanicals refer to the chemicals that are produced by plants, and repel approaching of insects, deter feeding and oviposition on the plant or disrupt the behavior and physiology of insects in various ways (Said and Pashte, 2015) and these include spices, medicinal and other plants. The use of plant extracts in the protection of stored products is an old practice in Africa, because of the high rate of post-harvest losses in this continent. However, this practice was progressively abandoned with advent of synthetic insecticides during this century (Huang, 1998). Insecticidal properties of plant products that are traditionally used and produced by the farmers in the developing countries appear to be quite safe and promising against weevils (Jilani and Ghiosuddin, 1988).

Current research efforts on stored-products development are being focused more on ecologically tolerable, readily available and cheaper control measures, with particular reference to the use of plant derived insecticides, such as plant powders, oils and extracts (Adedire, 2001). There is also an increasing awareness that plants possess chemicals which naturally protect them from pests and pathogens. The tropical region is well endowed with a wide array of these floristic species with defensive chemicals and quite a number of them have been used traditionally in protecting cowpea against beetles attack (Adedire, 2001; Longe and Ofuya, 2010). Many of these plants have known medicinal and pharmacological properties (Sofowora, 1982) and some have been subjected to empirical verification for effectiveness against *S. zeamais* (Longe and Ofuya, 2010).

Plant products used as protectants for stored agricultural commodities are normally obtained from leaves, roots, flowers, fruits, seeds, bark and stems of plants (Dupriez and De Leener, 1989); which can be made into various forms such as plant material formulations and admixtures, dusts, wettable powders, emulsifiable concentrate formulations, plant material fumigants, repellants and anti-feedants, as well as plant oils and extracts as attractants and synergists (Longe, 2016).

The use of such locally available plant materials for stored-product protection is a common practice, and has been believed to have more potential in subsistence and traditional farm storage conditions in developing countries like Ethiopia. The use of botanicals has several advantages over synthetic pesticides often having such as several modes of action, and their toxicity against insect pests may be expressed by: (1) directly killing particular life stages of the insect, (2) interfering with mating or suppressing reproduction, (3) acting as a repellent or affecting host finding and selection in a way that prevents infestation or (4) reducing or preventing feeding (Berhanu Hiruy and Emana Getu, 2018).

Currently only few botanicals only few plants have led to major commercial pesticidal products similar to those produced by the synthetic pesticides industry. Neem products from *Azadirachta indica,* Pyrethrum from *Tanacetum cinerariifolium* and rotenone from *Derris* and *Lonchocarpus* spp. are commercial examples of botanical pesticides that have been developed and are being traded globally. But, subsistence farmers throughout sub-Saharan Africa often lack the financial resources to buy good quality commercial insecticides to protect their stored grain and their inappropriate use of conventional pesticides can result in the risks to human and environment. As a result, traditional storage methods using indigenous plant materials with insecticidal properties could, if improved, offer a low-cost, safer and more dependable method of storage protection, while reducing the increasing reliance upon conventional pesticides. Thus, botanicals could offer a solution for the problems of availability, health risks, costs and resistance in the case of synthetic pesticides, and for the lack of equipment for hermetic storage, gamma irradiation and controlled atmospheres (Berhanu Hiruy and Emana Getu, 2018).

2.4.4 Inert dusts, sands and silica aerogel

Chemically these are unreactive and kill insects by physical contact. Insects coated with inert dusts show massive dehydration and die very soon. They kill insects by dessication and their effectiveness is increased with the decrease in relative humidity. Sands and soil components were also used as traditional insecticides. Sands provide protective layer on top of stored seed. Besides this, fossilizized remains of diatoms known as diatomaceous earth (DE) were also used to protect food grains. It is mainly composed of opaline silica which shows very toxicity to mammals. Besides natural DE arttficially modified CaDE are also being made which have shown insecticidal repellent and ovicidal activity against *Callasobruchus maculates*. Similaly silica aerogel that contain sodium silicate is used as a non-hygroscopic powder to control field and store grain insects (Upadhyay and Ahmad, 2011). The use of chemically inert materials such as sand, wood ashes or minerals in large amounts fill up the interstitial space in grain bulks and offer an obstacle to insect movement (Berhanu Hiruy and Emana Getu, 2018).

2.4.5 Cultural Control

Food grains store houses must be clean all around, dirt; egg shells and dead larvae should be removed. Broken infested grains are removed and burnt before new grains are stored before storage these should be properly fumigated and closed till the new harvest comes. All cracks and crevices made in the flour walls and ceiling of the store should fill up with cement and labeled. Stores should be white washed or painted by repellent paint. For painting purpose coal-tar is used. For better disinfestation, godowns should be superheated with burning charcoal at the rate of 8 kg per cubic feet space so as to raise the temperature of the room to about 150°F. During temperature treatment the doors should be tightly closed for 48 h after which godowns should be allowed to cool and cleaned before storage (Upadhyay and Ahmad, 2011).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

This experiment was conducted at Melkassa Agricultural Research Center, entomology laboratory from February to May, 2018. The Center is located at the Central Rift Valley of Ethiopia at $8^{o}24'$N latitude and 39^{o} $21'$E longitude and at an elevation of 1550 meter above sea level and the mean relative humidity was 80 %, and it receives annually 763mm rain falls. The maximum and minimum annual mean temperatures are 28.4^{o}C and

14^{o}C respectively (MARC, 1996). According to the recent agro-ecological zones classification of Ethiopia (MoA, 2000), the Melkassa Hypo Calcic Regosol ecotope falls in the zone termed hot to warm semi-arid lowlands. Loam and clay loam soil textures are the dominant textural classes (MARC, 1995; Tsion et al., 2009).

3.2 Plant material collection and preparation

Five locally available plants including seed of *Azadrichta indica* A. Juss (collected from Dire Dawa city), seed of *Millettia ferruginea* (Hochst.) Baker (collected from Addis Ababa city), leaf of *Croton macrostachyus* Hochst (from Adama district), leaf of *Euphorbia schimperiana* Scheele (from Adama district), and leaf of *Jatropha curcas* L. (collected from compound of Melkassa Agricultural Research Center) were evaluated to determine insecticidal effect as grain protectant against *Sitophilus zeamais*. These plant materials were air-dried under shade, pulverized separately into a fine powder using micro plant grinding machine and sieved through a 0.25 mm (250 μm) pore size mesh sieve to obtain uniform fine dust particles. Each plant material was kept in a plastic bag in a cool place until treatment.

3.3 Insect rearing

Parent adult maize weevils were obtained from Melkassa Agricultural Research Center. Following the methods used by Girma Demisie et al. (2008) and Bekele Jembere et al. (1995) maize weevils were cultured under laboratory conditions at 27 ± 2^{0}C, 60-65% R.H. and 12:12 h light: dark regimes on whole clean, undamaged and uninfested maize grain variety Melkassa 2 provided by the Research Center. The grains were washed from impurities using distilled water, dried and disinfested by keeping in a deep freezer at -20 ± 2^{0}C for 96 h. After disinfestations, the seeds were cleaned and kept for two weeks at the experimental conditions for acclimatization and adjusted to moisture contents of 12 to 13 % before use. Two kilograms of the disinfected seeds were placed in four-liter capacity plastic containers covered with perforated lids and replicated 10 times. About 800 unsexed adult maize weevils were introduced onto the grain in each plastic container and kept to oviposit for two weeks, after which they were removed and discarded. The grains were kept for progeny emergence to be used for the experiment.

3.4 Treatment application

Three different rates 3, 4 and 5 g, equivalent to 3, 4 and 5 %, respectively of each of the five botanicals were weighed separately and added to each 100 g of clean maize put in each 250 cm^3 glass jar and shook well manually for uniform mixing. A standard insecticide, Pirimiphos-methyl 2 % dust (2 g) and untreated check were included for comparison. The experiment was laid out in a complete randomized design (CRD) with three replications. Twenty-six newly unsexed emerged adult weevils (one day old) were placed in each jar and covered with muslin cloth held in place with rubber bands. The jars were kept in the laboratory at room temperature (25 ± 2 °C and 60-65% R.H. and 12:12 h light: dark regimes.

3.5 Data collection

3.5.1 Weevil mortality

Weevil mortality was recorded 3, 7, 14, 21, and 28 days after initial infestation (DAI) based on Girma Demisie et al. (2008) and dead weevils were counted and discarded each time. During the last counting, both dead and alive weevils were counted and removed and the grains were kept under the same conditions for the emergence of F_1 generation.

3.5.2 F_1 progeny emergence

After removing dead and alive weevils, the seeds were kept under the same conditions for the F_1 progenies to emerge. The numbers of F_1 progeny weevils emerged were recorded every other day and were stopped after 33 days (60 days, DAI) to avoid overlapping of generations.

3.5.3 Seed germination test

Seed germination test was performed at the end of the F_1 progeny for all the treatments to check the effect of the botanicals on germinating power (seed viability) of the seeds. Accordingly, 15 undamaged grains (seeds without visible holes) were randomly picked from each treatment and placed on a moistened filter paper in Petri dishes replicated three times and the numbers of germinated seeds were recorded after seven days and the percentage germination was computed.

3.6 Data analysis

Adult weevil mortality data in each replication was expressed as a percentage of the total number of adult weevils introduced, F1 progeny emergence of each replication was counted and computed as means and seed germination was computed as percentage. Prior to statistical analysis, data on percentage mortality were arcsine-transformed, while percentage of seed germination and the number of F_1 progeny emergence were square root-transformed to reduce variance heterogeneity (Gomez and Gomez, 1984). All data were analyzed using one-way Analysis of Variance (ANOVA) model by SAS software, version 9.2 package (SAS, 2008). Treatment mean separations were conducted using Student-Newman-Keuls Test (SNK) at 5 % level of significance.

4. RESULTS AND DISCUSSION

4.1 Effect of botanicals on parent adult weevil mortality

The results of the effects of the botanical treatments on weevil mortality at different days after treatment application are depicted in Table 2. *Azadirachta indica, M. ferruginea* and *J. curcas* relatively inflicted higher weevil mortality than *C. macrostachyus, E. schimperiana,* and the untreated control three days after infestation. Only the chemical insecticide, Pirimiphos-methyl 2 % dust, caused 100 % weevil mortality within three days of treatment application, whereas, the efficacy of the botanical powders increased with exposure time and the cumulative mortality was found to be very high and no significant difference ($P < 0.05$) was found among the botanicals and the chemical insecticide 28 days after treatment application. Seven days after treatment application, all the treatments showed significant difference ($P < 0.05$) from the untreated control at all rates (3, 4, and 5 g w/w, i.e., 3, 4 and 5 %, respectively).

At all rates of application, there was no significant difference ($P > 0.05$) among *C. macrostachyus, E. schimperiana* and *M. ferruginea*, and the untreated control three days after application. However, significant different ($P < 0.05$) mortality was observed between these botanicals and the control with exposure of time.

Except *C. macrostachyus, E. schimperiana* and *M. ferruginea*, the rest of the botanical treatments and the chemical caused 100 % weevil mortality 14 days after treatment. However, 28 days after treatment application, high percentage of mean cumulative mortality (97.43 – 100 %) was recorded by all the botanical treatments at all rates and there was no significant difference ($P > 0.05$) among all the botanical treatments and the standard chemical, whereas a significant difference ($P < 0.05$) was recorded between all these treatments and the untreated control (11.53%). There was almost no significant difference ($P > 0.05$) among the different rates of each of the same botanical treatment in their mortality effect and this indicated that the lowest rate was as effect as the highest rate.

The results showed that the mean cumulative percentage mortality inflicted by all the botanical powders at all rates was almost as effective as the synthetic chemical insecticide, Pirimiphos-methyl 2 % dust at 2 g, differed only in their speed of action and this revealed that the botanicals had profound effect comparable with the standard insecticide. Thus, the results of this showed that the botanicals can be used by resource poor farmers for the management of maize weevil.

In a similar study, Asmare Dejen (2002) recorded a percentage mean cumulative mortality of 84.40% with seed powder of *A. indica*, 48.90% of *C. macrostachyus*, 100 % with leaf powder of *Jatropha curcas* and 34.5% with leaf powder of *M. ferruginea* 28 days after infestation at 50g/100kg (5 %) of each botanical product on sorghum. Except leaf powder of *J. curcas*, the mortality effect of rest of the products is lower than that of the current study. In the current study the seed powder of *J. curcas* (at 3, 4, and 5 %) inflicted 100 % weevil mortality 14 days after infestation which may show that the seed powder is more toxic than the leaf powder. In a different similar work, Kifle Gebreziher et al. (2016) reported that neem seed powder both at 5 and 10 % rate caused 100 % maize weevil mortality on sorghum seven days after treatment and the effect of 2.5 % increased with exposure time and achieved 100 % mortality after 21 days after treatment application.

Botanical extracts kill and repel pests, affect insect growth and development, have antifeedant and arrestant effects, and have antifungal, antiviral, and antibacterial properties against pathogens. Botanical insecticides have long been touted as attractive alternatives to synthetic chemical insecticides for pest management because botanicals pose little threat to the environment or to human health (Said and Pashte, 2015). The use of plant products as protectants could offer a solution for the problems of availability, health risks, costs and resistance over synthetic pesticides (Said and Pashte, 2015).

Tloba and Ekrakene (2006) reported that the mortality caused by different plants could be attributed to several mechanisms. The use of plant powders could have resulted to death as a result of physical barriers effect of the plant materials. This is because the powder has the tendency of blocking the spiracles of insects, thus impairing respiration leading to the death of insects. While feeding on whole grains by the weevil (*S. zeamais*) or the larvae might pick up a lethal dose of the treatment thus resulting in stomach poisoning. Schmutterer (1990) stated that *azadirachtin* has deterrent, antifeedant, growth disrupting, anti-ovipositional and fecundity reducing properties on a range of insects.

Bekele Jembere (2002) evaluated the toxicity of Millettia seed against *S. zeamais* and reported higher mortality of the weevil within 48 hours after treatment. Rotenones is one of the dominant compounds found in the seed and stem bark of Millettia, and is a well-known botanical insecticide through contact and stomach poisoning (Saxena 1983; Bekele Jembere, 2002). It is also highly toxic to fish and soluble in polar solvents (Bekele Jembere, 2002). Tebkew Damte and Mekasha Chichaybelu (2002) also tested the toxicity of Millettia seed against Adzuki bean beetle (*Callsobruchus chinunesis*) and found that it gave complete protection of stored chickpea for six months in the laboratory, even though it was not effective in controlling this storage pest when used by farmers. It deterred egg-laying. Bayeh Mulatu and Tadesse Gebremedhin (2000) reported from their laboratory study that the oils of *M. ferruginea* and *A. indica* were able to effectively control Adzuki bean beetle infestation of faba bean by partially or completely preventing egg-laying, and no bruchids emerged from the few eggs laid.

In a laboratory test of *J. curcas* seed powder at 1.00, 2.00 and 3.00 g/100 g (1, 2, and 3 %) against maize weevil, Ojiako et al. (2014) reported that the seed powder at the highest rate (3.00 g) inflicted adult mortality 6.67, 40.00, 70.0 and 100 % after two, three and seven days of infestation, respectively, with lowest adult emergence (0.67 - 2.67). The mortality effect of the other lower rates of the seed powders (1 and 2 g) increased with exposure time, i.e., the 1 g seed powder caused 0.00, 16.67, 53.33 and 83.33 after 1, 23, and 7 days, respectively, while the 2 g caused 3.33, 23.33, 66.67 and 90.00 % after one, two, three and seven days, respectively.

Table 2 Percentage mean mortality of maize weevil on maize grains treated by powders of different botanicals at different rates after different days of initial treatment application

		Percent mean weevil mortality days after treatment application			
Treatments	Rate/g	3	7	14	28 (Cumulative)
Azadirachta indica	3	57.69b	42.30b	100.00a	100.00a
	4	30.77cd	69.23ab	100.00a	100.00a
	5	44.87bc	53.84b	67.95ab	97.43a
Croton macrostachyus	3	2.57d	35.90b	32.07b	100.00a
	4	0.00d	78.20ab	16.67b	94.86a
	5	3.84d	74.36ab	16.67b	94.86a
Millettia ferruginea	3	28.20cd	44.87b	21.07b	97.43a
	4	28.20cd	52.56b	28.85b	100.00a
	5	21.79cd	58.97b	52.56ab	100.00a
Euphorbia schimperiana	3	3.84d	57.69b	23.07b	97.43a
	4	0.00d	53.84b	21.79b	100.00a
	5	0.00d	55.13b	30.77b	100.00a
Jatropha curcas	3	38.46bc	61.34b	100.00a	100.00a
	4	38.46bc	61.34b	100.00a	100.00a
	5	34.61bc	65.38ab	100.00a	100.00a
Pirimiphos-methyl 2 % dust	2	100.00a	100.00a	100.00a	100.00a
Untreated control		0.00d	1.28c	8.97b	**11.53b**
CV		41.68	26.33	37.88	2.76

Means with the same letter in the same column are not significantly different at α = 0.05.

4.2 Effect of botanicals on emergence of F_1 progeny

The mean number of F_1 progeny (emerged adults) from the maize grains treated with three rates of different plant powders and a standard insecticide is presented in Table 3. On the first day of observation, no progeny was emerged from all the treatments except in the untreated control. In *A. indica***,** *J. curcas* and chemical treated grains, no progeny were emerged after 28 days. The mean number of F_1 progeny throughout the observation period from all the botanical treatments at different rates was very low and there was a significant difference between all the other treatments and the untreated control.

The very low/and absence of F_1 progeny emergence from the botanically treated grains may be associated to the very high mortality of the treated weevils. The mortality effect of all the treatments was very high (97.43 - 100%) as compared to the untreated control (11.53) (Table 2). Adult weevils did not emerge from treated maize with *A. indica* and *J. curcas* at all rates unlike the other botanical treatments (Table 3) and this may indicate that besides causing high weevil mortality, the botanicals have significant effect on insect fertility. In line with the present findings, Dekeba Moges et al. (2016) reported a reduction in F_1 progeny emergence in botanically treated grains which might be due to increased adult mortality, ovicidal, and larvicidal properties of the tested botanical powders. The absence of adult weevil or F_1 emergence indicated the efficacy of the botanicals for the control of maize weevil. The botanicals caused high mortality of *S. zeamais* on one hand and completely hindered or significantly reduced progeny emergence on the other hand, indicating its potential use in the management of maize weevil. These findings coincide with the work of Dagna et al. (2015) who reported that botanicals such as neem seed powder completely hinders progeny emergence, percentage seed damage and seed weight losses caused to maize grains by maize weevil, probably due to the huge array of *azandirachtin* activities on the insect's hormone system. In a similar work by Kifle et al. (2016), no progeny was also emerged from sorghum treated by 5 and 10 % neem seed powder.

Table 3 Mean number of F1 progeny of maize weevil emerged from treated maize by different botanicals at different rates and percentage mean germination of treated seeds

		F1 progeny emergence			Germinated seeds (%)
Treatments	Rate/g	1 day	2 days	28 days (Cumulative)	
Azadirachta indica	3	0.00b	0.00c	0.00c	97.78a
	4	0.00b	0.00c	0.00c	88.89a
	5	0.00b	0.00c	0.00c	91.11a
Croton macrostachyus	3	0.00b	1.33c	1.33c	95.55a
	4	0.00b	1.00c	1.00c	82.22a
	5	0.00b	0.33c	0.33c	75.55a
Millettia ferruginea	3	0.00b	0.00c	0.00bc	84.44a
	4	0.00b	1.00c	1.00bc	100.00a
	5	0.00b	1.33bc	1.33bc	97.78a
Euphorbia schimperiana	3	0.00b	0.67b	0.67b	95.56a
	4	0.00b	1.67bc	1.67bc	93.33a
	5	0.00b	1.00c	1.00c	91.11a
Jatropha curcas	3	0.00b	0.00c	0.00c	88.89a
	4	0.00b	0.00c	0.00c	77.78a
	5	0.00b	0.00c	0.00c	82.22a
Pirimiphos-methyl 2 % dust	2	0.00b	0.00c	0.00c	97.78a
Untreated control		1.33**a**	**4.67a**	**6.00a**	91.11a
CV		178.69	**77.69**	**74.27**	13.67

Means with the same letter in the same column are not significantly different at α = 0.05.

4.3 Effect of botanicals on germination of seeds

There was no significant difference (P > 0.05) percentage mean seed germination among all the treatments. However, relatively lower rate of germination was recorded in *Croton macrostachyus* (75.55 % at 5 % rate) followed by *J. curcas* (77.78 % at 4 % rate) treated seeds (Table 3). The higher percentage mean mortality of the botanically treated maize grains and higher seed germination in all the treatments indicated that the botanicals can control the maize weevils and none of the botanicals affected the germination (seed viability) of the maize grains. This indicated that resource-poor farmers can use the botanicals for the control of maize weevil and also use the treated grains for planting the grains. In a similar work, Asmare Dejen (2002) also reported that powders of *Datura stramonium*, *J. curcas, Phytoloca dodecondra* and *A. indica* did not show any visible adverse effect germination on capacity of the grains. This is also in agreement with the findings of Ojiako et al. (2014) who reported that *J. curcas* seed powder does not have negative effects on the viability of treated seeds and found that percentage mean germination of treated seeds was 93.00, 90.00 and 96.67 % treated with 1.00, 2.00 and 3.00 ml of seed powder, respectively.

5. CONCLUSION AND RECOMMENDATIONS

The current study revealed that all the botanical powders tested against maize weevil caused very high adult weevil mortality and also highly affected their progeny production (fertility) which revealed their insecticidal activity. Besides, the botanicals did not affect significantly the germination capacity of the treated seeds. Therefore, all these qualities of the botanicals can be considered for potential use of their powders in the management of *S. zeamais* under subsistence farmer's storage conditions. However, evaluation of the botanical powders against naturally infesting maize weevils under farmers' storage conditions should be conducted.

The results of the current study showed that generally there was no significant difference among the different rates (3, 4, and 5%) of each botanical powder on the weevil mortality and progeny emergence. Therefore, further study is necessary to identify the minimum effective concentration of the botanical insecticides which can cause maximum weevil mortality.

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Approval of Investigators

We hereby declare that the research report entitled ‘**Screening of Some Botanical Insecticides against Maize Weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on Maize**’ is our original work; all sources are duly acknowledged and the report is compiled by incorporating the necessary comments and suggestions given by the reviewers.

	Name	**Signature**	**Date**
Principal Investigator :	Daniel Getahun		
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Approval of Reviewers

I hereby confirm that (PI) Dr. Daniel Getahun has accomplished his/her work as per the approved proposal and incorporated all the comments given by the reviewers in his/her terminal report of the project entitled **Screening of Some Botanical Insecticides against Maize Weevil, *Sitophilus zeamais* Motsch. (Coleoptera: Curculionidae) on Maize** and hence the report qualifies for submission as standard research output.

	Name	**Signature**	**Date**
Reviewer 1.			
Reviewer 2.			

Approval: **School Ethical Review Board (School Scientific Committee)**

	Name	**Signature**	**Date**
1.			
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