

ADDIS ABABA UNIVERSITY
COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
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**Studies on the management of maize weevil (*Sitophilus zeamais L.*) using
Botanicals on maize grain in storage**

BY

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A Thesis submitted to the Department of Zoological Science of Addis Ababa University in Partial fulfillment of the Requirements for the Degree of Master of Science in Entomology (Insect science).

JUNE, 2017

DECLARATION

I, the under signed, declare that this thesis is my original work. It has never been submitted to any institution and that all sources of materials used for the thesis have been acknowledged.

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LIST OF ABBREVIATIONS

AAU	Addis Ababa University
BARC	Bako Agricultural Research Center
CRD	Completely Randomized Design
CPSE	Crop Protection Society of Ethiopia
CSA	Central Statistical Authority
EARO	Ethiopian Agricultural Research Organization
EIAR	Ethiopian Institute of Agricultural Research
IITA	International Institute of Tropical Agriculture
IPM	Integrated pest management
K-PHC	Kombolch Plant Health Clinic
MARC	Melkassa Agricultural Research Center
NSIA	National Seed Industry Agency
PMJOE	Pest Management Journal of Ethiopia
HSD	High Significant difference
SAS	Statistical Analysis System
SNNP	Southern Nations, Nationalities Peoples regional state
w/w	weight by weight

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ABSTRACT

The production and storage of maize are threatened by a wide range of pre-and post harvest pests like stalk borer, Angoumois grain moth (*Sitotroga cerealella* Olivier), and *Sitophilus* spp among others. The current experiment was conducted to determine the efficacy of leaf and seed powder of four botanical plants (*Azadirachta indica* Juss, *Lantana camara* L., *Jatropha curcas* L., *Croton macrostachys* Hochst) at four concentrations against maize weevil (*Sitophilus zeamais* Motsch.) on stored maize grains under laboratory conditions. For comparison, malathion 5% dust as a standard check and untreated check were used. The experiment was designed in a completely randomized design in three replications. The experiment was conducted under room temperature of 25^{0c}–28^{0c} and relative humidity of 68.5%–74.5 % at Kombolcha Plant Health Clinic Laboratory. Powders of each plant component were then mixed thoroughly with 200 gram grains in plastic jars roofed with muslin cloth and tightened with rubber band. Thirty adult weevils were released in each plastic jar. Number of dead weevils, F1 progeny, percent protection from F1 progeny, weight loss, and damaged seed and number of germinated seed were recorded after treatment application. Data were transformed prior to analyses. Transformed data were subjected to ANOVA in SAS software. All botanical powder significantly resulted in weevil mortality, F1 progeny reduction, low seed damage and weight loss. The botanical powders did not affect the germination capacity of maize seed. *J. curcas* seed powder and *A. indica* seed powder were highly significant than the rest of the treatments which was comparable with malathion 5% dust (P <0.05) in all of the parameters, while *L. camara* and *C. macrostachyus* was the least effective compared to the botanicals and the standard check, but significantly (p<0.05) better than the untreated check (P <0.05). In general, *J. curcas* seed powder and *A. indica* seed powder found to be the most effective treatment against maize weevil on stored maize grain. However, further investigation of those plant powders under real storage conditions and their long term (chronic) toxicity on mammals and beneficial organisms are needed. Consequently, the current result should reach the stakeholders mainly farmers through extension agents.

Key words: *Botanicals, S.zeamais, Rates, Maize, untreated check.*

1. INTRODUCTION

Maize (*Zea mays L.*) is the third important cereal crop globally after wheat and rice (FAO, 2011).

Maize is a member of the grass family, Poaceae (Gramineae). Maize is one of the most important cereal crops cultivated in the world and it constitutes one of the major diets of millions of people.

In Africa, maize is mainly grown by small-scale farmers for utilization as both human food and animal feed. Maize is the staple food and one of the main sources of calories in the major producing regions (Kebede Mulatu *et al.*, 1993).

The recent volatile food market and rising prices for most food crops may increase the importance of maize production. In addition, because of its productivity and wide adaptation, maize remains an important source of food with great potential to improve the livelihoods of most poor farmers in developing countries (FAO, 2011). But, its productivity is low due to several constraints: biotic (inadequate improved varieties, pests and diseases), abiotic (low soil fertility, land and water degradation, and drought) and socio-economic (input unavailability, lack of storage facility, poor access to markets) (CSA, 2010).

Maize is also becoming one of the export crops of Ethiopia generating foreign currency for the nation (EARO, 2000). In addition, maize provides nutrients for humans and animals and serving as a basic raw material for the production of starch, oil and protein, alcoholic beverages, food sweeteners and more recently, fuel (FAO, 1992). The crop is mainly grown for its grain, which is utilized for human consumption and forms about 50 - 70% of the constituent of livestock feed (Longe, 2010).

Maize can be processed into various food and industrial products including starches, sweeteners, oil, beverages, industrial alcohol and fuel ethanol. Likewise, thousands of foods and other everyday items such as toothpaste, cosmetics, adhesives, shoe polish, ceramics, explosives,

construction materials, metal molds, paints, paper goods clothing, packaging, carpeting, recreational equipment and food utensils of renewable resource and textiles contain corn components. In addition, maize products are rapidly replacing petroleum in many industries in the world (Ogunsina *et al.*, 2011).

It is an important source of protein ranking 4th after meat, fish and legumes in term of annual protein production (Dasbak *et al.*, 2008). The green plant, made into silage, has been used with much success in the dairy and beef industries. Worldwide, about 66% of maize is used for feeding livestock, 25% for human consumption and 9% for industrial purposes. In the developing world, about 50% of all maize is consumed by humans as food, while 43% is fed to livestock and the remainder for industrial purposes (IITA, 2003).

Maize weevil (*Sitophilus zeamais* Motsch) is a major pest that attack stored maize grains in the tropics and sub-tropics of the world (Adedire, 2001; Sagheer *et al.*, 2013). The attack may start in the mature crop when the moisture content of the grain had fallen to 18-20% (Radha, 2014). Subsequent infestations in store result from the transfer of infested grain into store or from the pest flying into storage facilities, probably attracted by the odor of the stored grain.

Post-harvest losses of food grains due to insect pests pose significant nutritional and economic losses to subsistence farmers in developing countries'. Lack of improved storage structures for grains and absence of storage management technologies force maize growers to sell their produce immediately after harvest. Consequently, farmers receive lower market price for the surplus grain they produced (Firdisa Eticha and Abraham Tadesse, 1999). In view of the great value of maize, it is imperative, that greater attention should be given to the crops during storage in order to make them available for use throughout the year (Longe, 2010).

In order to reduce serious losses experienced during storage, various techniques and control methods have been developed and more are still being developed. The destructive activities of insects and other storage pests have been adequately subdued by synthetic chemical control methods comprising fumigation of stored commodity with carbon disulphide, phosphine or dusting with malathion, carbaryl, pirimiphosmethyl or permethrin (Ileke and Oni, 2011). However, there are problems associated with the use of these synthetic chemicals.

The problems of many synthetic insecticides include high persistence, poor knowledge of application, increasing costs of application, pest resurgence, genetic resistance by the insect and lethal effects on non-target organisms in addition to direct toxicity to users (Akinkurolele *et al.*, 2006; Oni and Ileke, 2008). Currently, attention is being given to the use of plant materials with medicinal properties as grain protectants (Longe, 2010). Most of them are non toxic to consumers and are readily available (Asawalan *et al.*, 2006).

Plant-derived insecticides are short-lived in the environment, thus posing less risk to non-target organisms and are accepted by organic certification programs and certain consumer groups because they are naturally occurring (Isman, 2000). These are less cost effective for storage of large quantities of grain. Many farmers are interested in learning about non-chemical pest control, either because they have had insufficient money for pesticides, or because they are interested in farming more organically, so farmers in Ethiopia use different botanical plants to protect their maize grain from insect infestation (Abraham Tadesse, 1997), while the type of botanical plants used varies from locality to locality.

However, the efficacy of these botanicals is not known except for few. In addition to this most farmers are ignorant of the correct rate and parts of the botanicals and amount of botanicals that

could be toxic to storage pests for effective pest control. This has led to investigate the insecticidal activities of various botanical plants at various rates using seed and leaf of the plants.

1.1 Objectives of the Study

1.1.1 General objective

To investigate environmentally safe and economically feasible management of *S. zeamais* through the use of appropriate rate of locally available plant powders.

1.1.2 Specific objectives

1. To determine the efficacy of different locally available botanicals on maize grain in storage.
2. To determine the rate of botanicals at which they could be applied to stored grains in order to effectively control *S. zeamais*.
3. To know which part of the plant (the seed or the leaf powder) is more effective against the maize weevil (*S. zeamais*).

2. LITERATURE REVIEW

2.1 Production and Productivity of Maize

Maize is the most important cereal and cash crop in sub-Saharan Africa and is part of the staple diet for over 1.2 billion people in developing countries. Under certain circumstance maize is used to generate cash for farmers (IITA, 2016). The center of origin is believed to be the Mesoamerica region, at least 7000 years ago when it was grown as a wild grass called *teosinte* in the Mexican highlands. Maize is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions. Maize together with wheat and rice are the three most cultivated cereal crops worldwide (Suleiman *et al.*, 2013).

Current world maize production is about 10.14 billion metric tons (De Groote *et al.*, 2013). The United States of America is the largest producer of maize which contributes nearly 35 % of the total production in the world. The word maize means “one that sustains life” and also an Indian legend says that maize was the food of the Gods that created the earth.

The area under maize cultivation is the highest in United States, China, Brazil, Mexico and India. These countries contribute about 4/5th of the world’s total maize production. The production of maize is constantly increasing because of the rising demand from the industries since maize is used as raw material. Globally, India ranks 5th in area and 4th in production (Pal *et al.*, 2009). It is notable that eight major maize producing countries in Asia, China, India, Indonesia, Nepal, Pakistan, Philippines, Thailand and Vietnam taken together, now produce 98 per cent of Asia’s maize and 26 per cent of global maize (Erenstein, 2010). In all these countries, maize is predominantly grown under rain fed conditions by the small holders, resource-poor farmers.

Hence, maize plays an important role in the livelihood of poor farmers, not only in Latin America and sub-Saharan Africa, but also in Asia (Prasanna, 2011). Because of its productivity and wide adaptation, maize remains an important source of food with great potential to improve the livelihoods of most poor famers in developing countries (FAO, 2011).

Current maize production in sub-Saharan Africa is about 7 million metric tons (FAO, 2014). Maize is known to Ethiopia since the last 500 years. It was introduced in between 1600s to 1700s. Ethiopia, one of the world's centers of genetic diversity in crop germplasm (McCann, 2001), produces more of maize than any other crop (CSA, 2010). Ethiopia is the fifth largest producer of maize in Africa and smallholder farmers make up 94 % of the crop production. It is the cheapest source of caloric intake in Ethiopia, providing 16.7 % of per capita calorie intake nationally followed by sorghum (14 percent) and teff (11 percent). Maize is an important crop for overall food security. Maize is grown primarily in the Amhara, Oromia and SNNP regions of Ethiopia.

Maize is widely grown in all parts of Ethiopia. An area of 1.4 million hectares of land is covered with maize and the annual maize production is not less than 2.52 million tons (NSIA, 2001). Maize productivity ($1.98 \text{ tons ha}^{-1}$) is leading all cereals in the country (CSA, 2000), but compared to the world's average production (3.7 tons ha^{-1}) and to that of developing countries (2.5 tons ha^{-1}) is still low.

The largest quantity (95%) of maize is produced by small-scale farmers in Ethiopia. Surplus production comes from the southern, south western, western and eastern parts of Ethiopia (Mulatu Kebede *et al.*, 1993). The major production zone of maize lays between 1000 m to 2000 m asl. Maize was also number one in yield per hectare and total production in the mid-altitude, sub-humid areas of Western Ethiopia (CSA, 2011).

2.2 Major post harvest insect pests of maize in storage

Among the major constraints of maize production and productivity in tropical countries including Ethiopia are the damage caused by insect pests both in the field and storage. Maize is attacked by many insect pests during all stages of growth from seedling to storage (Shiferaw *et al.*, 2011). Insects and other pests are a major threat to maize production and responsible for direct and indirect losses of maize on the farm and storage (Bankole and Mabekoje, 2004). According to Mihale *et al.* (2009) insects are responsible for 15-100 % and 10-60 % of the pre and post-harvest losses of grains in developing countries, respectively.

Two major groups of insects are economically important on stored maize grain: Coleoptera (beetles) and Lepidoptera (moths and butterflies). Crop damage by Lepidoptera is only done by the larvae. In the case of Coleoptera, both larvae and adults often feed on the crop and the two stages are responsible for the damage. Post-harvest insect pests may be primary, i.e. are those which damage previously undamaged seed such as the genus *Sitophilus*, while secondary pests are those which cannot damage sound seed but attack seeds which are already damaged either mechanically or by primary pests such as the genus *Sitophilus*. The most important insect pests that cause damage to maize are stalk borers (in the field) and weevils and moths (in the storage) (Emana Getu and Tsedeke Abate, 1999). Crop losses and deterioration of produce during storage are likely to occur unless adequate precautions are taken (Araya G/silassie, 2007)

The major insect pests of stored maize grains include maize weevil (*Sitophilus zeamais* Motsch.), the Angoumois grain moth (*Sitotroga cerealella* Olivier), the tropical warehouse moth (*Ephestia cautella* Hubner), the Indian meal moth (*Plodia interpunctella* Hubner), flour beetle (*Tribolium spp.*), *Cryptolestes spp* and *Carpophilus spp.* (Abraham Tadesse, 2003).

According to Obeng-Ofori and Amiteye (2005), *S. zeamais* is a serious cosmopolitan field-to-store pest of maize in tropical and subtropical regions. *S.cerealella* is also the most important primary pest of maize in the field and storage. The curculionids, *S. zeamais* and *S. oryzae* and the Gelechid, *S. cerealella* are the most destructive primary pests of stored grain in Ethiopia (Abraham Tadesse, 2003).

2.3 Post harvest losses due to *S. zeamais*

Maize storage is constrained by a number of factors which include attack from pathogens and insect pests. Insect pests are the major threat destroying approximately 20% to 50% of stored maize grain in most African countries (CABI, 2012). In many developing countries, overall post harvest losses of grain of about 10% to 15% are fairly common. Insect pest damage in stored food grains may account for 10% to 40% in countries where modern storage technologies have not been introduced. One of the main problems in storage in developing countries is management of the store and a continuous source of infestation in the stored area. Farmers in most areas keep old and new harvest grain in the same vicinity, which causes an easy migration or infestation of new grains from the old grains which is known as cross infestation (Adugna Haile, 2006).

Among insect pests, the maize weevil, *S. zeamais* is reported to cause high grain loss in stored maize. The maize weevil is a major pest of stored maize grains and its infestation causes severe post harvest losses of staple food crops in Nigeria (Oni and Ileke, 2008). Weevil damage reduces the availability of maize and may also reduce future maize production for farmers who use stored grains. In developing countries, maize production and consumption often falls below demand as a result of post-harvest losses due to storage pests and other spoilage agents (Udo, 2005). In stored

maize, heavy infestation of this pest may cause weight losses of 30% to 40% (Ogunsina *et al.*, 2011; Radha, 2014). Like many other crops, insect pests are one of the limiting factors during storage of maize in Ethiopia. The problem is mostly severe in developing countries in the tropics due to unfavorable climatic conditions and poor storage structures (Bekele Jembere *et al.*, 1997). Insect infestation of maize grains leads to a reduction in both quality and quantity of harvested crops and in most cases pre-disposes the stored grains to secondary attack by disease causing pathogens. Post-harvest losses due to *S. zeamais* have been recognized as an important constraint to grain storage in Africa (Oduor *et al.*, 2000).

The maize weevil is one of the most destructive stored product pests of grains, cereals, and other processed and unprocessed stored products in sub-Saharan Africa (Ojo and Omoloye 2012). *S. zeamais* causes qualitative and quantitative damage to stored products, with grain weight loss ranging between 20% to 90% for untreated stored maize grain (Muzemu *et al.*, 2013). Damaged grain has reduced nutritional value, low percentage germination, reduced weight and lowered market value (Girma Demissie *et al.*, 2008).

2.4 Biology and description of *S. zeamais*

Knowledge of the biology of the insect pests is paramount importance in any control or pest management strategy. There cannot be a realistic success in management without a better understanding of the phenology and dynamics of insects' life cycle (Merville *et al.*, 2014). Adult maize weevils are 3–3.5 mm long, dark brown to black in color and shiny and pitted with numerous punctures. The punctures on the thorax are in an irregular pattern, while those on the elytra (wing cases) are in lines.

A newly emerged weevil is light brown to reddish-brown. It is easily identified by the presence of four light reddish or yellowish pale spots on the elytra (Khare, 1994). The maize weevil has the characteristic rostrum (snout or beak). At the end of this structure, there is a pair of mandibles or jaws and elbowed antennae of the family *Curculionidae*. The antennae have eight segments and are often carried in an extended position when the insect is walking.

The maize weevil, although similar to rice weevil is somewhat bigger in size than the rice weevil. Adult maize weevils are slightly larger than rice weevils. They have circular punctures on the thorax compared to oval punctures on the rice weevil and more distinct colored spots on the forewings. Maize weevils are strong fliers than rice weevils. Rice weevil is found more often on small grains and has a higher temperature tolerance than maize weevil. Both species fly and thus attack cereals in the field before harvest, but flight activity is more pronounced in maize weevil. Harney (1993) demonstrated that maize weevil differs from rice weevil mainly with respect to genital character.

The origin of maize weevil is not known, but now it is found in all warm and tropical parts of the world (Dicko *et al.*, 2006). Maize weevil is widely distributed throughout the warm humid areas of the world and can attack a wide range of cereals although it is particularly a pest of maize (Ranjan, 2005). It is well established in tropical countries including Ethiopia. Maize weevil and rice weevil are found in all warm and tropical parts of the world. These pests are carried all over the world in grain shipments and can establish themselves wherever there is food and where grain moisture and temperature are favorable. In various locations, one species may be more common than the other. The female weevil chews a minute hole in the grain in which the eggs are deposited.

Eggs are deposited singly in narrow cavities chewed in the kernels and the hole is sealed with a mucilaginous material secreted by the female (Hill, 2008). The eggs are white and oval in shape, measuring 0.7 mm by 0.3 mm, and each female may deposit as many as five eggs per day laying a total of 150 to 400 eggs during its life span (Bosque-Perez, 1992). The eggs hatch into tiny grubs in four to nine days. Larval development last about 25 days under favorable conditions of temperature of 30°C and 70% relative humidity, but under unfavorable environmental conditions, the larval stage may last for up to 98 days (Mattah, 2001). The grub is white in color with a brown head and strong jaws. Pupation occurs within the grain, and the pupal stage lasts for three to six days. The newly emerged adult remains in the grain for a few days before it leaves it (Chilio *et al.*, 2004)

Eggs, larval and pupal stages are all found within tunnels and chambers bored in the grain and are not seen. Because larval stages feed in the internal parts of the grain, it is difficult to detect infestations early. Damage caused by this insect becomes noticeable when the adult insect makes holes that reach approximately 1mm in size in the grain and deposits its eggs within the hole. The insect then closes up the developmental stage of the insect takes place within the grain after which the adult weevil bores its way out, leaving a characteristic emergence hole on the grain. Adults emerge from the grain and can be seen walking over the grain surfaces. The life span (from egg to adult) is about 30 days, which is slightly longer than that of rice weevil. Mating takes place within a few hours after the adult weevils emerge (Abraham Tadesse, 1991).

Abraham Tadesse (1991) and Abraham Tadesse *et al.* (1996) studied the biology of the maize weevil at room temperature and relative humidity conditions at Bako. He found that a female maize weevil remained fecund throughout its lifetime; however, the actual time of oviposition

was about 50% of the mean life span of the ovipositing female. The duration of the life cycle varies with temperature, relative humidity and diet (Abraham Tadesse, 1991). Abraham Tadesse (1991) reported that the mean time required for adult emergence around Bako areas ranged from 35.7_47.4 days, and females lived longer than males. The sex ratio is about 1:1 and up to four weevils can emerge from a single kernel. Adult maize weevil is an active flier resulting in many field infestations in areas adjacent to infested storage.

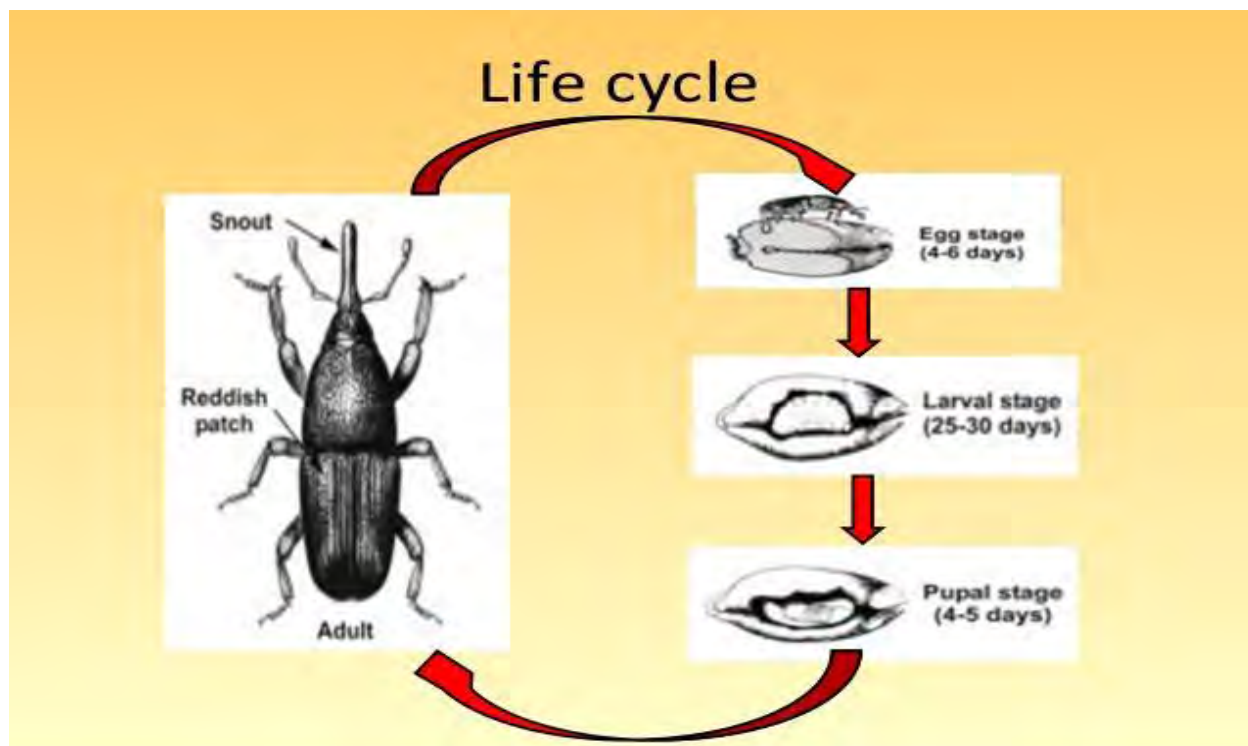


Figure 1: Life cycles of *S. zeamais*

2.5 Management Practices of *S. zeamais*

Most of the maize grain harvested was stored on the farm where postharvest pest management practices are inadequate (Dubale, 2011) leading to huge amounts of maize grain losses to pests of stored grain. Maize weevil populations build up when maize grain is kept longer in the store. So it is important to inspect the stock regularly. If the pest is found beyond certain population level some form of control is being required.

2.5.1 Cultural practices

Initial infestation by maize weevil occurs in the field. From the field, it is carried over to the store where the population can rapidly build up. Field infestations may result from insects migrating from infested seeds in adjacent granaries to the ripening crop. Thus, pre-harvest cultural methods and storage management can be effective in the control of pests affecting stored grain. Field isolation; prompt harvesting, selection of uninfected grain, proper drying before storage and storage hygiene among others are important cultural practices reported for the management of storage pests (Abraham Tadesse and Firdissa Eticha, 2000). Repairing and thorough cleaning of storage containers before filling with grain alone kept the grain for longer time in the traditional (well built and well managed) experimental stores at Melkassa (Abraham Tadesse, 2003).

The severity of maize weevil infestation can be reduced by good store hygiene: cleaning the store between harvests, removing and burning infested residues, fumigating the store to eliminate residual infestations and the selection of only uninfected material for storage. Harvesting maize as soon as possible after it has reached physiological maturity will reduce weevil damage, reduces the availability of maize and may also reduce future maize production for farmers who use stored grains as seeds.

In developing countries, maize production and consumption often falls below demand as a result of post-harvest losses due to storage pests and other spoilage agents (Udo, 2005).

2.5.2 Physical control

Physical methods are important means to prevent, detect and control stored product pest within the concept of Integrated Pest Management (IPM) and Integrated Stored Product Protection. Physical control refers to non-chemical, non-biological methods that destroy pests or make the environment unsuitable for the entry or survival of pests. The removal of adult insects from the grain by sieving can reduce populations but this is very labour-intensive. If one thinks of staple food such as grains or pulses, cleaning, drying, and cooling are physical processes essential to keep a durable product in good quality during prolonged storage periods (Vincent *et al.*, 2003).

Physical control methods can be simple, affordable, and safe methods of controlling stored insect pests in grain facilities. Physical control methods have been described as effective and alternative methods to pesticides to prevent and control pests during grain handling and storage. (Jayaprakash *et al.*, 2010).

Studies on physical methods of pest managements generally involved heat treatment and testing the effectiveness of solar radiation, although few studies also evaluated the role of oven heating. Another method that has gained importance in industrialized countries in recent years is the heat treatment of empty structures (Beckett *et al.*, 2007). The high temperatures needed for pest control can be achieved by burning oil or gas and fanning the heated air into a building from outside through air ducts. Another method is the recirculation of air within a building and heating with mobile electrical heaters (Hofmeir, 2000).

Insulation material such as corrugated cardboard or large amounts of grain, dust or flour need to be removed prior to a heat treatment because insects would find a safe refuge from where to re-infest a structure after the treatment (Adler, 2006). Mechanical techniques such as sieving may be used for pest control. Sieving has the advantage of separating the contaminant or insect from the flour while milling can be used to destroy living insects prior to packaging. In a number of mills rotary mills (e.g. Bühler Entoleter) are used for this purpose (Plarre and Reichmuth, 2000).

Among various methods tested at Bako Agricultural Research Center (BARC), slight roasting or warming maize on heated clay pan and exposure to the sun gave comparable results to the standard insecticide, pirimiphos-methyl at 10 ppm in protecting maize grain from maize weevil (Demissew Kitaw *et al.*, 2002). Abraham Tadesse (2003) reported that solar heating of maize grain placed on a black polyethylene sheet, and covered with a translucent plastic sheet for at least five sunny days caused significant mortality of maize weevil. Moreover, oven heating, a simulation of farmers' practice of warming batches of grain over the heat of fire was effective. In many rural areas of Ethiopia, farmers commonly hang heads of grain such as sorghum, barely, wheat and cobs of maize mainly selected for seed from the rafters of the dwelling huts where heat and smoke from the fire promote further drying and, possibly reduce insect infestation (Abraham Tadesse, 1997).

2.5.3. Varietal resistance

Resistant varieties are integral part of integrated pest management of storage pests. Substantial data has been accumulated from varietal screening researches in Ethiopia. Differences in resistance among maize genotypes to weevils have been reported (Demissew Kitaw *et al.* 2004). Insect resistant maize varieties generally complement integrated pest management (IPM) tactics

such as chemical in combination with biological control. For safety of the consumer the use of resistant varieties offers the most cost effective control measure against the pests. Since infestation starts in the field, use of maize cobs with tight and complete husk cover that extends beyond the tip protects the grain better than bare tipped ears.

Maize cobs which are completely covered by the husk are less infested than those whose tips are slightly exposed (IvbiJaró, 2009). Thus resistant varieties in combination with botanicals in their minimum effective dosages have a potential in keeping the damage caused by weevil below economic injury levels. 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). Since infestation starts in the field, use of maize cobs with tight and complete husk cover that extends beyond the tip protects the grain better than bare tipped ears. The existence of crop genotypes resistant to storage pests has been confirmed. Hence, breeders should consider storability in their breeding programs. Resistant varieties are integral part of integrated pest management of storage pests substantial data has been accumulated from varietal screening researches in Ethiopia. Differences in resistance among maize genotypes to weevils (Firdisa Eticha *et al.*, 2001; Demissew Kitaw *et al.* 2004) have been reported. Maize genotypes 27/2, Birkata, UCA and UCB were resistant to weevils while SC22 (the male parent of Gutto, BH-140 and BH-540), Jimma- Bako, Alemaya Composite, Gutto, KCB, Alemaya-28 (Pop corn), KCC, Ambo- Bako, BH-140, NSCM-41, H-625, Bukuri, A-511 and Bako Composite were susceptible (Abraham Tadesse *et al.*, 1995).

2.5.4 Biological control

Biological control is a method of controlling pests that relies on predation, parasitism, herbivore and other natural mechanisms and can be an important component of integrated pest management (IPM) programs. Biological control involves using biological means, as opposed to chemical and physical means, to control pest species (PCE, 2000). Traditionally, biological controls have involved the introduction of an exotic species such as predators, parasites and diseases (Cowen, 2000; PCE, 2000). However, the efficacy of biological control using natural enemies depends on a complex but delicate relationship between natural enemies and their insect pest hosts whose balance can be offset by a changing climate. It is well known that temperature fluctuations are the major factors affecting insect biology, activity and distribution of natural enemies in agro-ecosystems (Sorribas *et al.*, 2012).

Natural enemies undoubtedly play a part in reducing pest numbers in many traditional storage systems, but they may not give economically acceptable level of control. Abraham Tadesse (2003) recorded six species of wasps from farm-stored maize in Ethiopia. *Anisopteromalus calandrae* (Abraham Tadesse 1997; Emanu Getu and Assefa Gebra-Amlake, 1998) and *Choetospila elegans* (Abraham Tadesse, 1997) were the most common natural enemies of farm-stored maize.

There have been various studies on biological control agents for maize weevil. Various parasitoids (*Anisopteromalus calandrae*, *Cephalonomia tarsalis*, *Lariophagus distinguendus* and *Theocolax elegans*) could be effective if introduced early in the storage period. The effect of different isolates and formulations of the fungus *Beauveria bassiana* on maize weevil in stored maize are reported by Adane Kassa *et al.* (1996).

2.5.5 Botanical control

The choice of pesticides for storage pest control is very limited because of the strict requirements imposed for the safe use of synthetic insecticides on or near food. Furthermore, the continuous use of chemical pesticides for control of stored-grain pests has resulted in serious problems such as insecticide resistance (Mohan *et al.*, 2010). Current research and the increasing knowledge about the harm derived from the indiscriminate use of synthetic insecticides have encouraged studies related to novel tactics of pest control like the use of botanical insecticides. Plant materials with insecticidal properties, are one of the most important locally available, biodegradable, and inexpensive methods for control of stored-grain pests (Mishra *et al.*, 2012). The main advantage of botanicals is that they are easily produced by farmers, small-scale industries and are potentially less expensive (Nikkon *et al.*, 2009). The utilization of botanical insecticides to protect stored products is promising, mainly due to the possibility of controlling environmental conditions inside the storage units, maximizing the insecticidal effect; in these places the natural product can be used as powder, extract and oil (Guzzo *et al.*, 2006). Nevertheless, many plants commonly regarded as safe contain noxious compounds, which may render them unsafe for both animals and humans to consume (Suthisut *et al.*, 2011).

Plant extracts have shown ovicidal, repellent, antifeedent and toxic effects in insects (Devi and Devi 2011). There has been a steady increase however in recent times, in the use of plant products as a cheaper and ecological safer means of controlling insect pests of stored grains, especially in the tropics. While currently, attention is being given to the use of edible plant materials with medicinal properties as grain protectants (Longe, 2010).

Several workers have evaluated the insecticidal, repellent or antifeedant and development inhibiting effects of various plant parts and plant products on *S. zeamais* with varying degrees of success (Arannilewa *et al.*, 2006; Asawalam *et al.*, 2006; Udo, 2005). Plant products are widely used by small-scale farmers in countries like India to control pests. In Ethiopia, farmers use different botanical plants to protect their maize grain from insect infestation (Abraham Tadesse, 1997) while the type of botanical plants used varies from locality to locality. However, the efficacy of these botanicals is not known except for few. Therefore, alternative methods like plant products and use of resistant varieties, which could be easily utilized by farmers, need to be considered as tools for stored grain pest management.

2.5.5.1 Neem (*Azadirachta indica* Juss)

Neem (*Azadirachta indica* Juss) is a fast growing tree that is native to the Indian subcontinent and which is now distributed throughout Southeast Asia, East and Sub-Saharan Africa, and parts of Central America. The neem tree, *A. indica* is the most researched tree in the world and is said to be the most promising tree of 21st century. The neem tree contains a potential ingredient for soap-making in cottage industry. It is often planted as a shade tree and wood source in Africa. Neem is well known for its insecticidal properties and it is very effective against a wide range of insect pests (Radha, 2014).

Azadirachtin, the active insecticidal ingredient of *Azadirachta indica* A. Juss, (Meliaceae), the most active insecticidal ingredients present mostly in the seeds, leaves and other parts of the neem (Sonalkar *et al.*, 2014). Its various plant parts have been traditionally used to control domestic insect pests in stored grains, crop, in human and livestock medicine. *Azadirachtin*, the active insecticidal ingredient of *Azadirachta indica*, is found to be an environment-friendly pesticide and

has many desirable properties. It is also selective with short persistence, toxic to target pests, has minimal toxicity to non-target and beneficial organisms and caused less damage to the ecosystem (Barrek *et al.*, 2004). For these reasons, it has generated enormous worldwide interest due to its potential as a new insect pest control agent. It disrupts molting by inhibiting biosynthesis or metabolism of Ecdysone, the juvenile molting hormones (White, 2008).

Neem is effective against numerous pests and it has been shown that it can control over 100 species of insects, mites and nematodes. It has been used for thousands of years as a homeopathic cosmetic and health aid (Sharma *et al.*, 2007). It has scientifically proven to possess antibacterial, antiviral, anticancer, ant malarial, contraceptive, etc properties. The complex triterpenoids azadirachtin, obtained from the seeds of the neem tree is a potent insect growth regulator and feeding deterrent, with minimal mammalian toxicity and environmental persistence (Isman, 2006).

2.5.5.2 Lantana (*Lantana camara* L.)

Lantana camara L.(Verbenaceae), a fast-growing woody shrub, is native to tropical and subtropical South and Central America and currently widely distributed in many countries including Ethiopia (Zalucki *et al.*, 2007). It is among the top ten invasive weeds on earth (Sharma *et al.*, 2005). Lantana (*Lantana camara* L.) also commonly known as lantana, red-flowered sage, wild sage, white sage, is a small shrub with variously colored flowers that seem even more attractive to birds. It has been cultivated for over 300 years and now has hundreds of cultivars and hybrids. Earlier work has shown that leaves of *L. camara* are a source of insecticidal activity (Dua *et al.*, 2010).

The different parts of lantana contain allelochemicals mainly aromatic alkaloids and phenolic compounds (Ambika *et al.*, 2003) which can interfere with early growth of many plant species (Sharma *et al.*, 2005). Species of *L. camara* with their repellent behavior reduce or control bruchids on grain legumes and potato tuber moth (*Phthorimaea operculella* Zuller) in vegetables. *Lantana camara* is known to be toxic to livestock such as cattle, sheep, horses, dogs and goats (Burns, 2001). The active substances causing toxicity in grazing animals is pentacyclic triterpenoids called lantadenes which result in liver damage and photosensitive (Barceloux, 2008).

2.5.5.3 Wild oil nut (*Jatropha curcas* L.)

Jatropha curcas L. is a shrub of the Euphorbiaceae family which originated from Central America. It is a multi-purpose tree. Its origin was found in Central America over 70 million years ago. Wild oil nut is a drought resistant shrub that grows up to 20 m tall under favorable condition with spreading branches. Normally, it grows between three and five meters in height. Wild oil nut can be grown on waste and other lands such as along the canals, roads railways tracks, on borders of farmers' fields as boundary fence or live hedge in the arid and/or semi-arid areas and even on alkaline soils ([http:// www.maxpages.com/jatropha-cur.html](http://www.maxpages.com/jatropha-cur.html)).

In northern part of Ethiopia it is known by local name Aiderke. The black thin-shelled seeds are considered toxic; they contain the toxalbumin curcin and this makes them fatally toxic. Roasting the seeds seems to remove the toxicity. Nash (2005) reported the use of its seed oil as biofuel and its potential as a biopesticide. They also contain a high percentage of clean oil used for candles, soap and bio-diesel production. It has yellow-green flowers and large pale green leaves. The fruit contains 2 or 3 large black, oily seeds.

The seeds contain 37% of this non- edible oil. Wild oil nut has insecticidal and fungicidal properties. The leaves are used for fumigating houses against bed-bug. In addition to this, they are used against stomachache, diagnosed in children: boiled leaves for conditions of the gums and throat; tea of the leaves for stoppage of urine, constipation, backache and inflammation of ovaries ([http:// www.maxpages.com/jatropha-cur.html](http://www.maxpages.com/jatropha-cur.html)).

2.5.5.4 *Croton macrostachyus Hochst*

Croton macrostachyus Hochst, belonging to the family Euphorbiaceae, is commonly found on forest edges along rivers, around lakes, woodlands, wooded grasslands, and along roadsides. It is native to Ethiopia, Eritrea, Kenya, Nigeria, Tanzania, and Uganda. In Ethiopia, it is used for the treatment of malaria in several endemic areas (Gidey *et al.*, 2009; Orwa *et al.*, 2009) Ethno botanical and pharmacological studies revealed that various parts (stem barks, leaves, and fruits) of *C. macrostachyus* possess a wide range of activities (Asmare *et al.*, in press; Gidey *et al.*, 2009). It is used for Traditional medicine to treat rabies, epilepsy, cough, skin disease, dysentery, lung complaints, plain full eyes, toothache etc (Monica, 2005).

Moreover, the methanol leaf extract also exhibited larvicidal activity against late third instar larvae of *An. arabiensis*, a predominant malaria vector in Ethiopia (Karunamoorthi and Ilango, 2010). The ethanol and water extracts from the leaves of *C. macrostachyus* were found to contain phytochemical constituents such as saponnins, flavonoids, carbohydrates, free amino acids, and vitamin C (Asmare *et al.*, in press). Phytochemical screening of the hydro alcoholic crude extract of the leaves of *C. macrostachyus* also revealed alkaloids, saponins, phenolic compounds, cardiac glycosides, tannins, terpenoids, and flavonoids (Bantie *et al.*, 2014).

2.5.6 Chemical control

Pesticides are agricultural technologies that enable farmers to control pests and weeds and constitute an important input when producing a crop (Jansen and Dubois 2014). Control of *S. zeamais* populations around the world is primarily dependent upon continued applications of synthetic insecticides, which are often the most effective treatments for the disinfestations of stored food, feedstuffs and other agricultural commodities from insect infestation. As farmers have little tolerance for pest infestation, they rely heavily on the use of pesticides. Also, government extension programs encourage the use of pesticides arguing that farmers have no alternative (Damte and Tabor, 2015; Mengistie *et al.* 2014). due to high exposure and unsafe application techniques, smallholders experience more pesticides health risks than larger-scale farmers (Williamson *et al.* 2008). Although effective, their repeated use for decades has disrupted biological control by natural enemies and led to outbreaks of other insect species and sometimes resulted in the development of resistance (Park *et al.*, 2003).

They are also prone to user abuse, expensive, highly toxic, have low shelf life and farmers generally lack the technical expertise in handling and applying them. some other researchers have also opined that though synthetic chemicals continue to play an important role in reducing storage losses due to insect pest activities, insecticides resistance, toxic residues in food, environmental pollution, adverse effects on beneficial and non target insects, increased risk to workers safety and high cost of the chemicals make them less attractive (Asawalam *et al.*; 2006). Pesticides are poisons so it is essential to follow all safety precautions on labels. In some parts of Ethiopia (Abraham Tadesse and Firdissa Eticha, 2000), 70% of farmers treated their grains with synthetic chemicals.

Insecticides have played an important role in reducing losses due to weevils widespread and continuous use of chemicals has been blamed for the evolution of resistance strains of insect pests. During the survey of storage pests in the Bako area, it was found that several farmers had treated their grain with inappropriate chemicals or insecticides meant for the control of field pests (Abraham Tadesse, 1997). Deltamethrin, Malathion, permethrin, a cocktail of Malathion with permethrin, methacrifos, fenitrothion and pirimiphos-methyl effectively protected maize and sorghum (Adane Kassa and Abraham Tadesse, 1996) from the maize weevil.

Fumigants are low molecular weight chemicals, highly toxic and volatile and are, therefore self-dispersing and non-persistent. Fumigation is a widely used method all over the world particularly for large scale storage. Fumigants have an ability to kill all insect stages residing in the grains, but do not protect grain from new attacks. Fumigants must be used in air tight containers. The most widely spread fumigants in use are Phosphine and Methyl bromide (Manson and Obermeyer, 2004).

2.5.7 Integrated pest management (IPM)

The IPM concept emphasizes the integration of disciplines and control measures such as varietal resistance, cultural methods, physical control, insecticidal plants, natural enemies, and pesticides into a total management system to prevent pests from reaching damaging levels. These should be combined into an integrated pest management strategy, taking into account costs and feasibility of the control methods, toxicity, environmental safety, and sustainability. This is because none of the various methods alone can ensure safe storage. However, no report on integrated management of post-harvest pests in Ethiopia has been so far available.

3. MATERIALS AND METHODS

3.1 Description of the study site

The study was carried out in Kombolch Plant Health Clinic (K-PHC) Laboratory between October 2016 and March 2017. Kombolch Plant Health Clinic Laboratory is located about 367 km away from Addis Ababa, South Wollo Zone of the Amhara Region. Its location is 11° 06'N latitude and 39° 45'E longitude. The altitude of the area is 1800 m asl. The site is located at woina dega (mid altitude) agro-ecological zone with an average rain fall of 1029.4mm. Its mean monthly temperature range between 25 °C and 28°C and relative humidity of 68.5 to 74.5. The area is warm and humid that makes it a favorable environment for the development of storage insect pests like the maize weevil.

3.2. Experimental design

The design of the experiment was Completely Randomized Design (CRD) in three replications in factorial arrangement. Treatments consist of four botanicals with two parts (seed and leaf) powder with standard check (Malathion 5% Dust) and the untreated check, and 4 rates or dose (1%, 3%, 5%, and 10% w/w).

3.3. Collection and preparation of Plant materials

The plant materials used as powders for the experiment were obtained from the following plants and plant parts: Neem (*A. indica*) seed and leaf powder, Lantana (*L. camara*) Seed and leaf powder, Wild oil nut (*J. curcas*) seed and leaf powder, *C. macrostachys* leaf and seed were used (Table 1). Neem seeds were obtained from Kobo Agricultural Office compound and other botanicals were obtained from the field around Kombolcha town. The seeds and leaves of the collected plants were dried under shade for 20 days. The dried leaves and seeds of the plants

were finely ground using mortar and pestle and the powder from each plant part was used for the experiment. Powders were kept in polythene bags at room temperature and properly sealed to prevent quality loss (Chayengia *et al.*, 2010).

3.4 Establishment of maize weevil culture

Maize weevil was reared in the laboratory at the temperature of 25⁰C to 28⁰C and relative humidity of 68.5 to 74.5%. The food media used were maize grain. The grain was cleaned and disinfested by keeping it in a deep freezer at -20 to 0 ⁰C for two weeks to eliminate possible internal infestation. It was then kept for two more weeks at the experimental conditions for acclimatization (Abraham Tadesse, 2003). Culture of maize weevil was established to supply similar aged weevils for the experiments. About 15kg of weevil-infested maize grains were purchased from local market. Unsexed adult maize weevils were collected from infested maize grain and cultured on a clean and disinfested maize grain in 8 jars. Each jar, with 1.5 lt capacity, containing 1kg of grain was infested with 300 adult weevils. The jars were covered with muslin cloth and fixed with rubber band to allow aeration and to prevent escape of weevils.

Then they were kept at room temperature. After two weeks, all parent weevils were counted (dead and alive) and removed. Newly emerged, 0-3 days old adult weevils were used for the experiment. The sexes of *S. zeamais* were determined by examining the snout using a hand lens. The snouts of females are longer and thinner, while that of males are shorter and fatter. Also, the females have smooth textured bodies, while that of the males are rough (Kranz *et al.*, 1978). The daily temperature and relative humidity of the laboratory were recorded using digital thermo Hygro meter.

Table 1: List of botanical powders and insecticide tested against *S.zeamais*

Treatments	Scientific name	Common name	Parts used
T1	<i>A. indica</i>	Neem	Seed powder
T2	<i>A. indica</i>	Neem	Leaf powder
T3	<i>L. camara</i>	Lantana	Seed powder
T4	<i>L. camara</i>	Lantana	Leaf powder
T5	<i>J. curcas</i>	Wild oil nut	Seed powder
T6	<i>J. curcas</i>	Wild oil nut	Leaf powder
T7	<i>C. macrostachyus</i>	Bisana	Leaf powder
T8	<i>C. macrostachyus</i>	Bisana	Seed powder
T9	Malathion 5% Dust	-	-
T10	Untreated check	-	-

3.5. Application of Botanicals for the Control of *S. zeamais*

About 50 kg maize seed of MH-130 maize-variety were collected from Melkassa Agricultural Research Center (MARC) from the harvest of 2009 crop season. About 200g of disinfested MH-130 maize seeds were put into plastic jar of 1 lt capacity and four different rates of each botanical (1%w/w (2g), 3%w/w (6g), 5%w/w (10g), 10%w/w (20g)) were weighed and added onto the grain in each glass jar and shaken well to ensure even distribution. Thirty unsexed, laboratory reared adult maize weevils of the same age group were introduced into each treatment, including the untreated control and standard insecticide and maintained under laboratory conditions. The glass jars were covered with muslin cloth and fixed by rubber band to allow sufficient ventilation and to prevent escape of the weevils.

3.6 Data Collection

3.6.1. Effect of botanicals on parent adult mortality

This was assessed 1, 5, 10, 15, 21 and 28 days after infestation with the weevils. Dead adult weevils were counted and discarded during each assessment, while the alive ones were returned to their respective treatments. On the 28th day, the remaining weevils (dead and alive) were counted and discarded. Cumulative insect mortality rate (%) was calculated using the Equation developed by Omotoso and Oso (2005) as follows:

$$\text{Cumulative mortality (\%)} = \frac{\text{Cumulative number of dead insects}}{\text{Total number of insects}} \times 100$$

Mortality data were corrected for control mortality using Abbott's (1925) correction formula as follows:

$$\% \text{ CM} = \frac{(\% \text{ T} - \% \text{ C})}{(100 - \% \text{ C})} \times 100$$

Where CM is corrected mortality, T is mortality in treated grain and C is mortality in untreated grain (Abbott, 1925).

3.6.2 Effect of botanicals on F1 progeny

After 28 days of introduction of the parent adult weevils to the treated seeds, all the dead and alive weevils were sieved, counted and discarded. The grains were placed back in to the jars and covered with nylon mesh and kept under the same conditions to assess the F1 progeny. Emergence of F1 progeny weevils were monitored, counted and removed until 58 days. The counting of F₁ adults was done once a week for 4 weeks to avoid overlapping of generations. Emerging adults were counted and removed from the jar on each assessment day. Evans (1985) found that this period of time allows the emergence of the majority of F1 progeny.

3.6.3 Protection of grain from F1 progeny

The effectiveness of different treatments in protecting the seed from F1 progeny was calculated. Percentage reduction in adult emergence or inhibition rate (% IR) was calculated using the following formula (Araya G/selase and Emanu Getu, 2009).

$$(\% \text{ IR}) = \frac{\text{Total F1 progeny in control} - \text{Total F1 progeny in treatment}}{\text{Total F1 progeny in control}} \times 100$$

Total F1 progeny in control

3.6.4. Seed weight loss assessment

Weight loss assessment was done on treated and untreated grains. To determine percent weight loss, samples of 100 grains were taken randomly from each jar. The number of damaged (grains with characteristic hole) and undamaged grains were counted and weighted and percentage weight loss was determined using the method described by Gwinner *et al.* (1996) which is known as count and weight method.

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

Where: W_u = Weight of undamaged grain

N_u = Number of undamaged grain

W_d = Weight of damaged grain

N_d = Number of damaged grain

3.6.5. Seed damaged assessment

Insect damage was assessed by the count method. One hundred seeds were randomly taken from each maize sample and the number of insect damaged and un-damaged grains was observed using a hand lens for the presence of hole or burrow. The percentage of insect damaged seed was then calculated (Fekadu *et al.*, 2000; Wambugu *et al.*, 2009) as follows.

$$\text{Insect damaged grain (\%)} = \frac{\text{Number of insect damaged grain}}{\text{Total number of grains}} \times 100$$

3.6.6 Percent maize grain germination

Germination test was carried out at the end of the experiment after the data were collected for other parameters. For germination test, 100 seeds were taken randomly from each treatment jar. Then, 20 seeds from each treated and control group were placed separately in sterilize petri dishes containing moistened filter paper (What man No. 1) and kept at room temperature. Each treatment was replicated three times. Untreated seeds were used as a control. The number of emerged seedlings from each Petri dish was counted and recorded after 7 days. Percent germination was computed as follows:

$$\text{Viability index (\%)} = \frac{\text{NG}}{\text{TG}} * 100$$

Where NG = number of seeds germinated and TG = total number of seeds tested in each Petri dish (Uke *et al.*, 2011).

3.7. Data Analysis

The data were analyzed using the general linear model procedure of the statistical analysis system (SAS JMP statistical discovery v10). For botanicals and rates Significant means ($P < 0.05$) were separated using Tukey's Studentized range test (HSD) at 5% significant level. To normalize the distribution data transformations were used for the analyses though reporting of results was done with back transformed data.

4. RESULTS

4.1. Effect of botanicals on parent adult weevil mortality

Results of percent adult parent *S. zeamais* mortality one day after treatment application is given in Figure 2. One day after treatment application about 91.11% of the adult parent of *S. zeamais* died in malathion 5% dust treatment. From the botanicals *J. curcus* seed and *A. indica* seed showed 5.55 and 3.33% adult mortality, respectively. In general, in the case of *J. curcas* the seed part gave the highest mortality than the leaf part, but in the other botanicals there was no significant difference between the seed and leaf parts on adult mortality one day after treatment application. The highest concentration (10%w/w) of the botanical powders gave the highest mortality of the adult parent *S. zeamais* one day after treatment application.

Five days after treatment application, Malathion dust 5% gave 100% mortality of adult *S. zeamais* five days after treatment application. From the botanicals the highest concentration of *J. curcas* (95.51%) and *A. indica* (87.66%) significantly ($p < 0.05$) gave the highest percent adult mortality of *S. zeamais*. During this period also the seed powder for *J. curcas* and *A. indica* and the leaf powder for *C. macrostachys* gave the highest adult mortality. The highest concentration (10w/w) of the botanicals significantly ($p < 0.05$) gave the highest mortality (Figure 3).

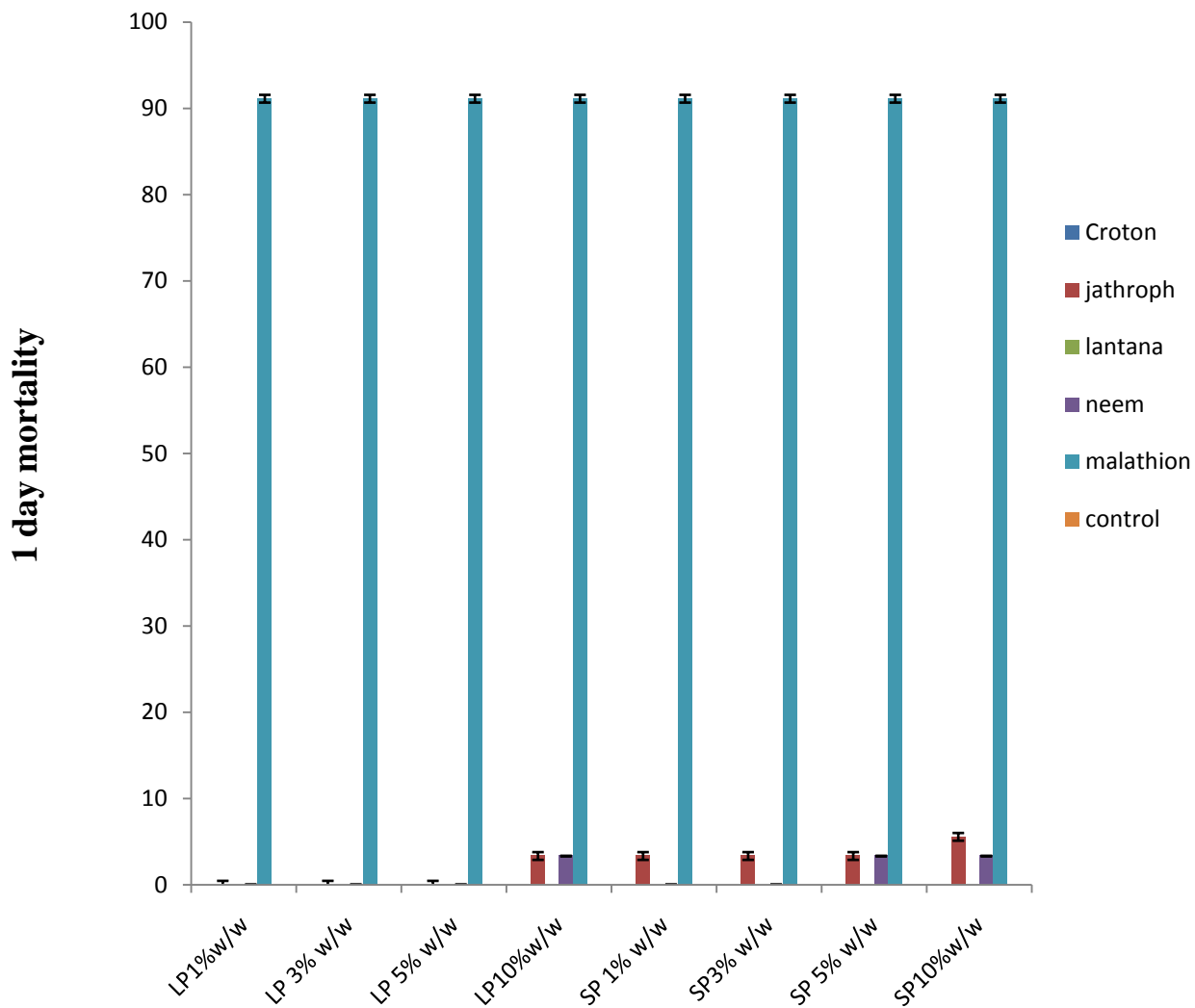


Figure 2: Mean percent adult mortality of *S.zeamais* on maize grains treated with different botanical powders one day after treatment application.

SP = Seed powder

LP = Leaf powder

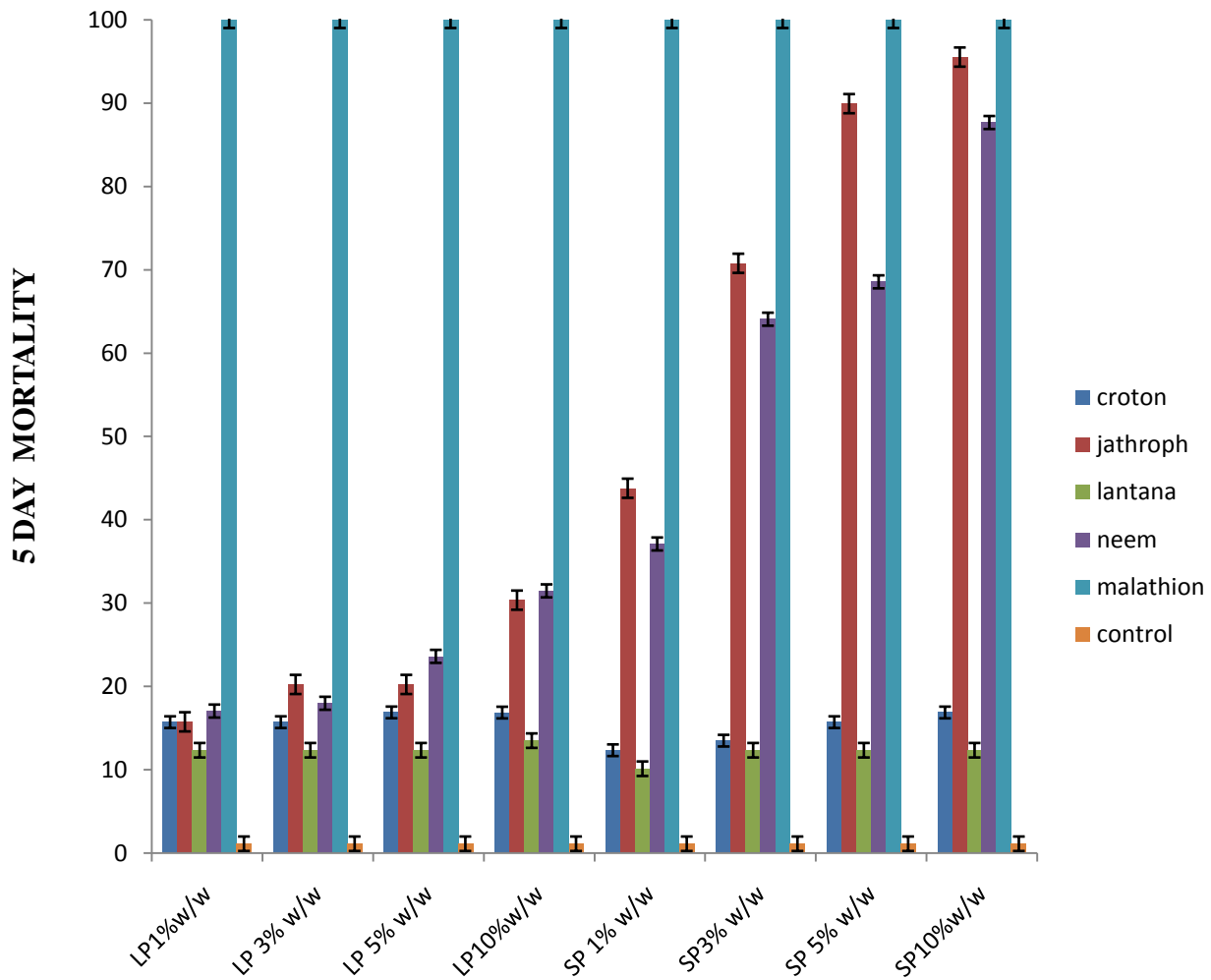


Figure 3: Mean cumulative percent adult mortality of *S. zeamais* on maize grains treated with different botanical powders five days after treatment application.

SP = Seed powder

LP = Leaf powder

Ten days after treatment application, Malathion 5% dust gave 100% mortality of adult *S. zeamais* ten days after treatment application. From the botanicals 5 and 10% of *J. curcas* (100%) and 10% of *A. indica* (100%) significantly ($p < 0.05$) gave the highest percent adult mortality of *S. zeamais* (Figure 4) which was similar effect with Malathion 5% dust. During this period also the seed powder for *J. curcas* and *A. indica* and the leaf powder for *L. camara* and *C. macrostachys* gave the highest adult mortality (Figure 4). The effective botanicals (*J. curcas* and *A. indica*) were effective in controlling adult *S. zeamais* in the highest rate. The less effective botanicals (*L. camara* and *C. macrostachys*) also gave better control at the highest rate (Figure 4)

Fifteenth days after treatment application, Malathion 5% dust gave 100% mortality of adult *S. zeamais* fifteenth days after treatment application. From the botanicals the seed powder of *J. curcas* (100%) and *A. indica* (100%) significantly ($p < 0.05$) gave the highest percent adult mortality of *S. zeamais* (Figure 5). During this period also the seed powder for *J. curcas* and *A. indica* and the leaf powder for *L. camara* and *C. macrostachys* gave the highest adult mortality (Figure 5). *J. curcas* and *A. indica* were effective in controlling adult *S. zeamais* regardless of the rates, while the less effective botanicals (*L. camara* and *C. macrostachys*) gave better control at the highest rate (Figure 5).

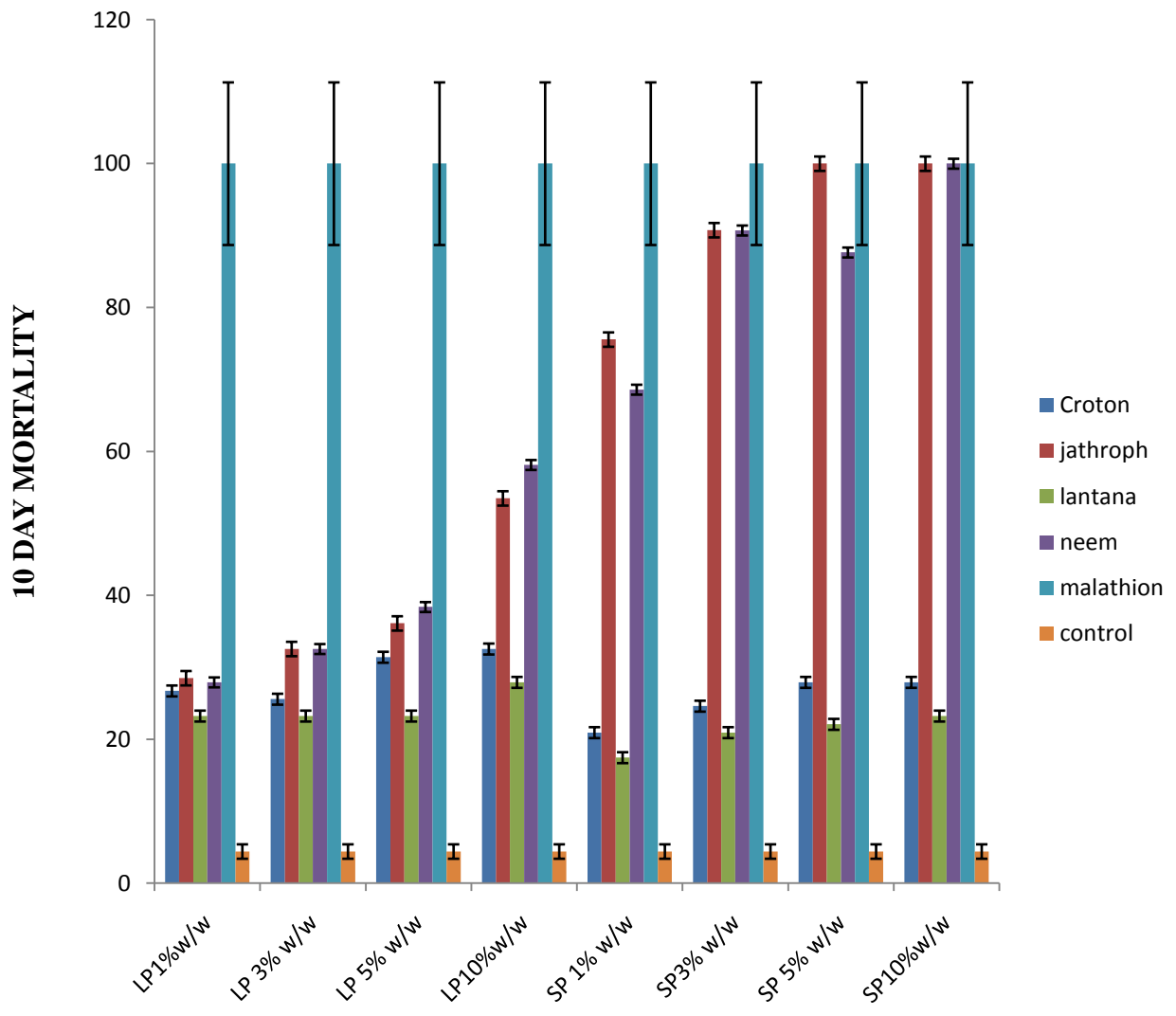


Figure 4: Mean cumulative percent adult mortality of *S. zeamais* on maize grains treated with different botanical powders ten days after treatment application.

SP= Seed powder

LP= Leaf powder

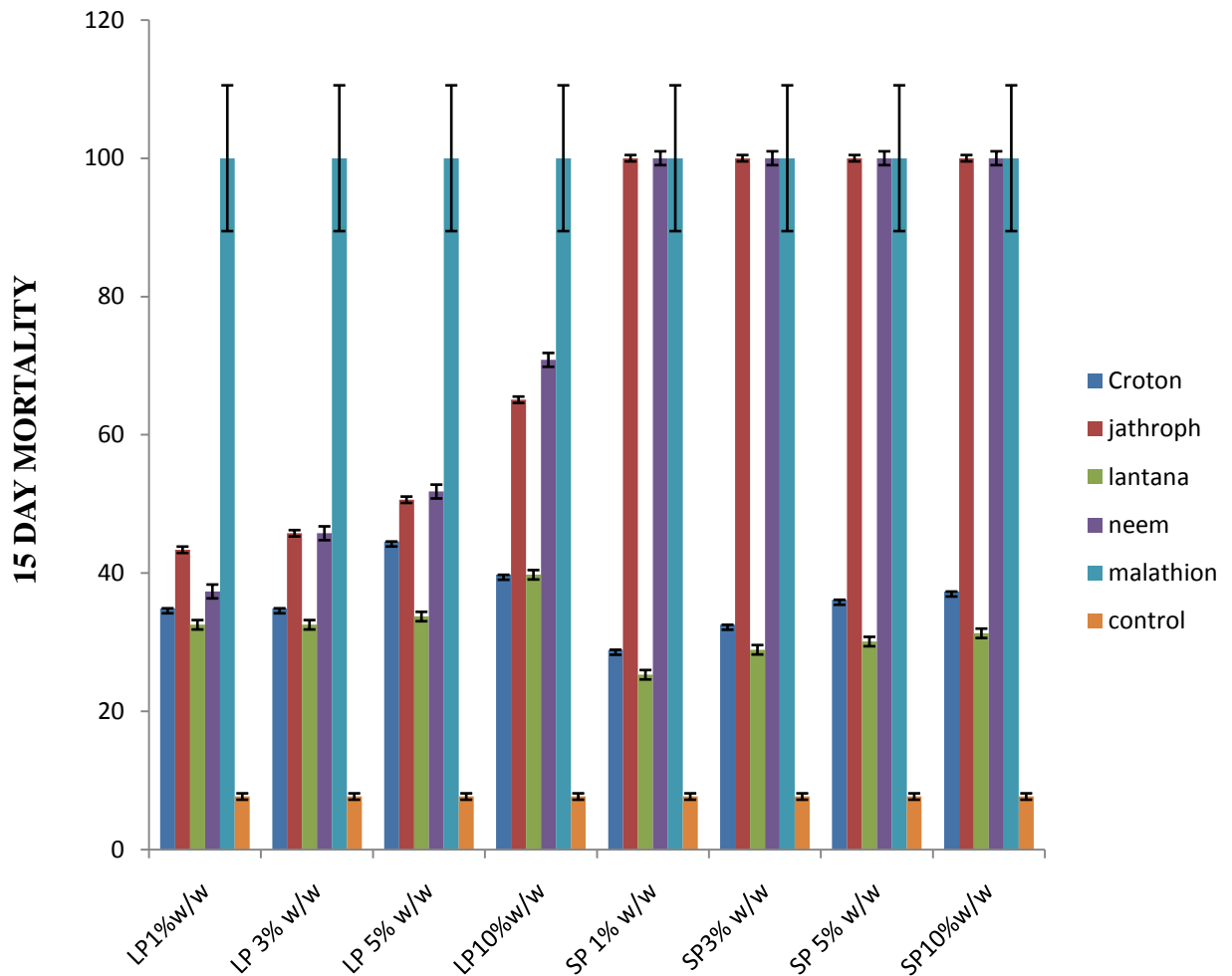


Figure 5: Mean cumulative percent adult mortality of *S. zeamais* on maize grains treated with different botanical powders fifteenth days after treatment application.

SP = Seed powder

LP = Leaf powder

Results of percent adult parent *S. zeamais* mortality are given in Figure. Malathion 5% dust gave 100% mortality of adult *S. zeamais* twenty one days after treatment application. From the botanicals the seed powder of *J. curcas* (100%) and *A. indica* (100%) significantly ($p < 0.05$) gave the highest percent adult mortality of *S. zeamais* (Figure 6). During this period also the seed powder for *J. curcas* and *A. indica* and the leaf powder for *L. camara* and *C. macrostachys* gave the highest adult mortality (Figure 6). The effective botanicals (*J. curcas* and *A. indica*) were effective in controlling adult *S. zeamais* regardless of the rates, while the less effective botanicals (*L. camara* and *C. macrostachys*) gave better control at the highest rate (Figure 6).

Results of percent adult parent *S. zeamais* mortality are given in Figure. Malathion 5% dust gave 100% mortality of adult *S. zeamais* twenty eight days after treatment application. From the botanicals the seed powder of *J. curcas* (100%) and *A. indica* (100%) significantly ($p < 0.05$) gave the highest percent adult mortality of *S. zeamais* (Figure 7). During this period also the seed powder for *J. curcas* and *A. indica* and the leaf powder for *L. camara* and *C. macrostachys* gave the highest adult mortality (Figure 7). The effective botanicals (*J. curcas* and *A. indica*) were effective in controlling adult *S. zeamais* regardless of the rates, while the less effective botanicals (*L. camara* and *C. macrostachys*) gave better control at the highest rate (Figure 7).

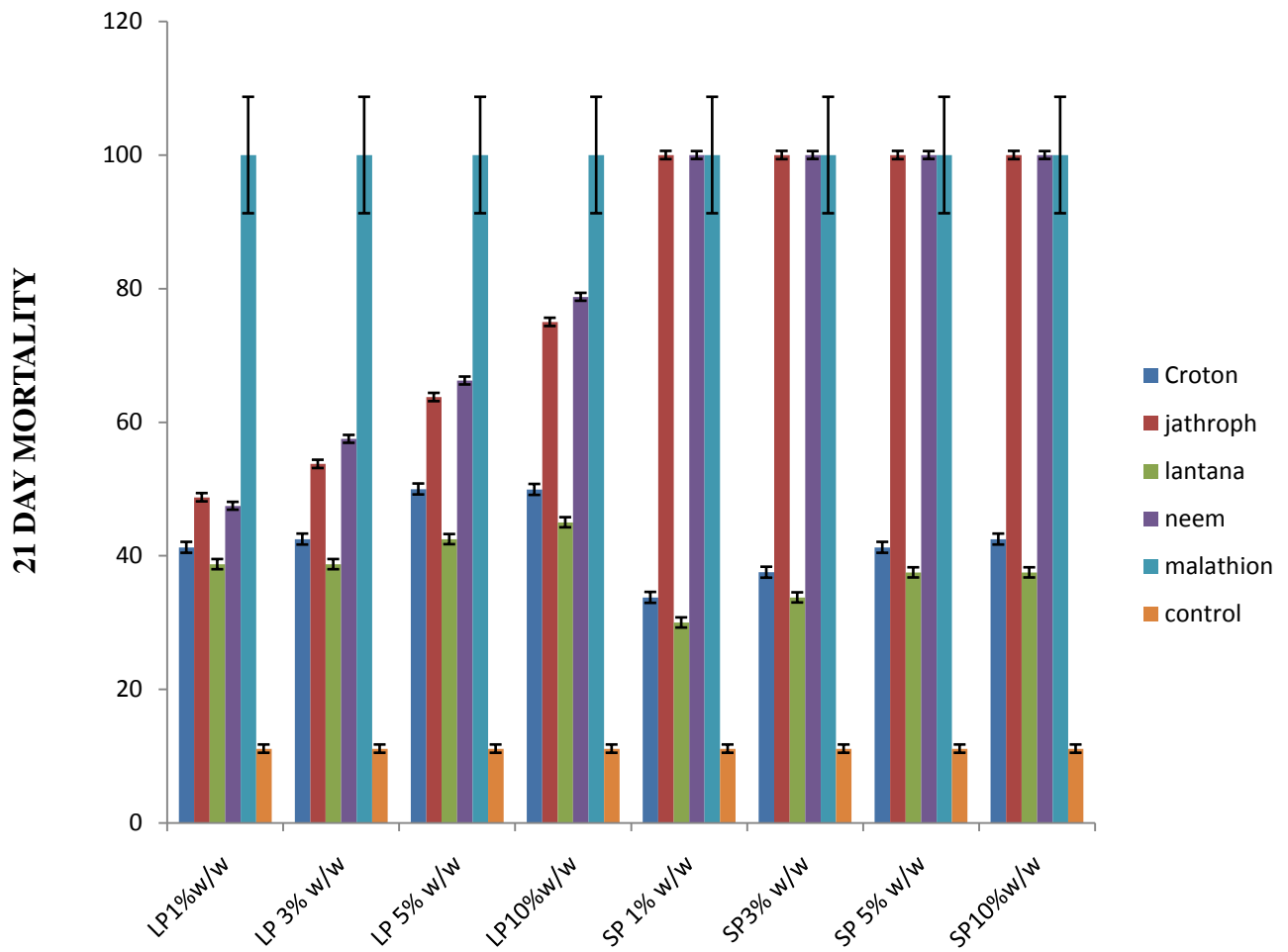


Figure 6: Mean cumulative percent adult mortality of *S.zeamais* on maize grains treated with different botanical powders twenty one days after treatment application.

SP= Seed powder

LP= Leaf powder

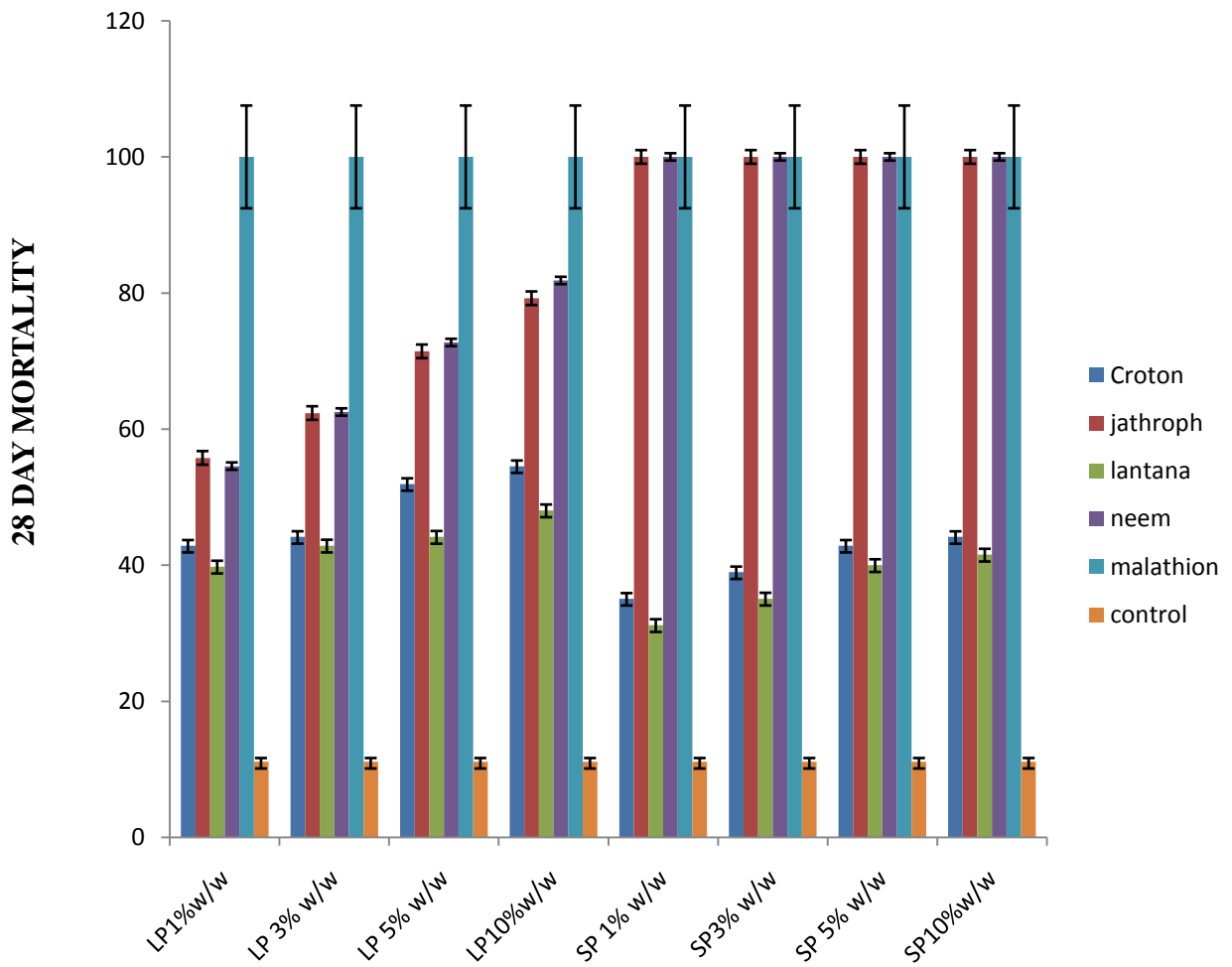


Figure 7: Mean cumulative percent adult mortality of *S. zeamais* on maize grains treated with different botanical powders twenty eight days after treatment application.

SP = Seed powder

LP = leaf powder

4.2. Effect of botanicals on emergence of F1 progeny

F1 progeny of *S. zeamais* emergence status on maize grains treated with different botanicals are shown in Figures 8. F1 progeny emerged in maize grains treated with seed powder of *J. curcas* (0.00) and *A. indica* (0.00) were significantly ($p < 0.05$) low. There was no F1 progeny emerged from maize grains treated with malathion 5% dust. The highest number of F1 progeny was emerged from the untreated check (61.00). During this period also the seed powder of *J. curcas* and *A. indica* decreased the number of F1 progeny emergency than the leaf powders that had similar effect with Malathion 5% dust treatments (0.00). High number of F1 progeny emerged from maize grains treated with seed powders of *L. camara* and *C. macrostachys*. The leaf powder of *L. camara* and *C. macrostachys* gave the lowest number of F1 progeny emergence than the seed powder (Figure 8). The highest concentration of the botanicals yielded the lowest F1 progeny emergence (Figure 8).

4.3. Effect of botanicals on protection of grain from F1 progeny

Results of mean percent protection of maize grains from F1 progeny of *S. zeamais* are given in Figure 8. Maize grains treated with malathion 5% dust, *J. curcas* seed powder and *A. indica* seed powder were almost totally protected the grain from F1 progeny (Figure 9). During this period also the seed powder of *J. curcas* and *A. indica* better protected the grain from F1 progeny than the leaf powders that had similar effect with Malathion 5% dust treatments (Figure 9). As compared to the above botanicals *L. camara* and *C. macrostachys* were the least effective in protection of maize grains from F1 progeny but by far better than the control. The highest concentration of the botanicals yielded the highest protection of grain from F1 progeny (Figure 9).

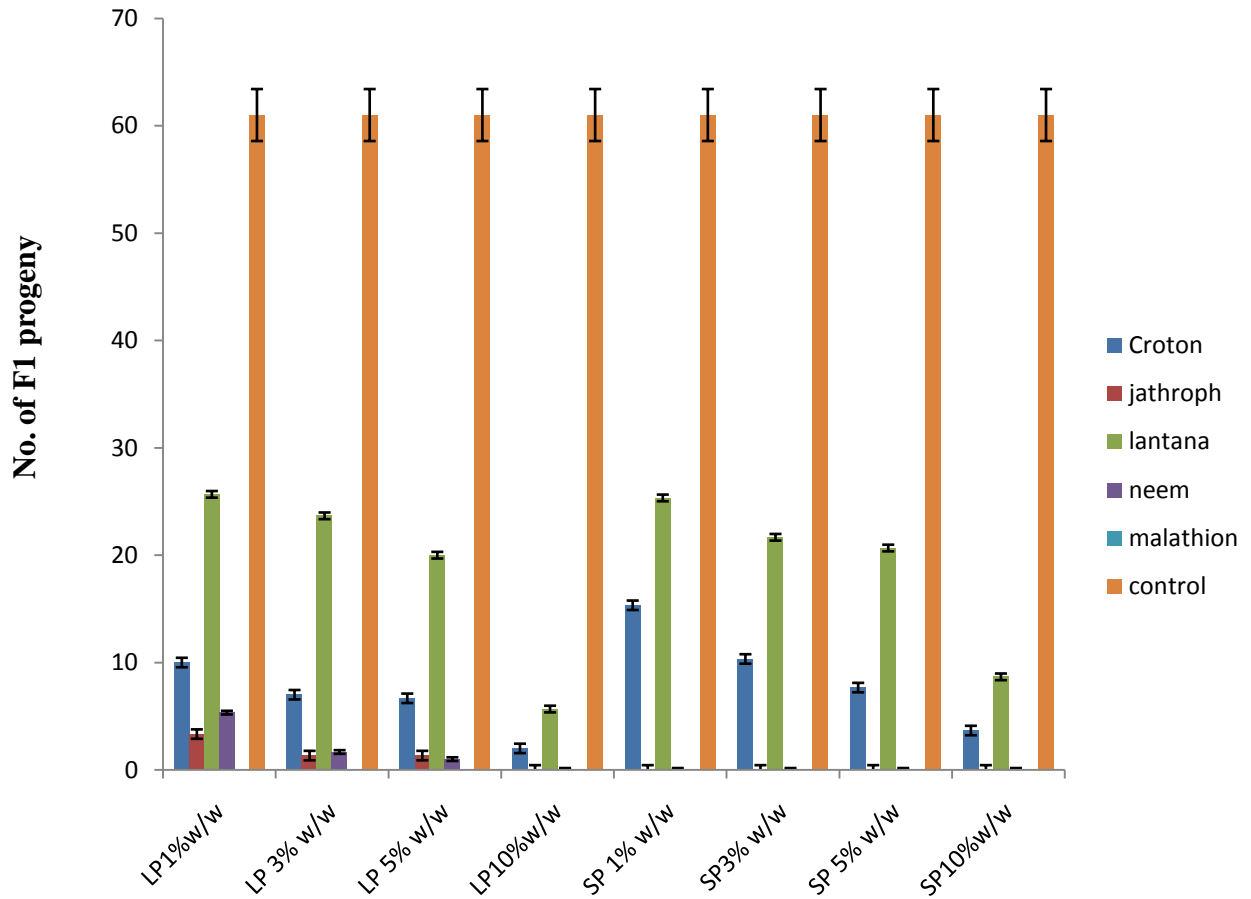


Figure 8: F1 progeny emergency of *S.zeamais* from maize grain treated with different botanical powders.

SP = Seed powder

LP = leaf powder

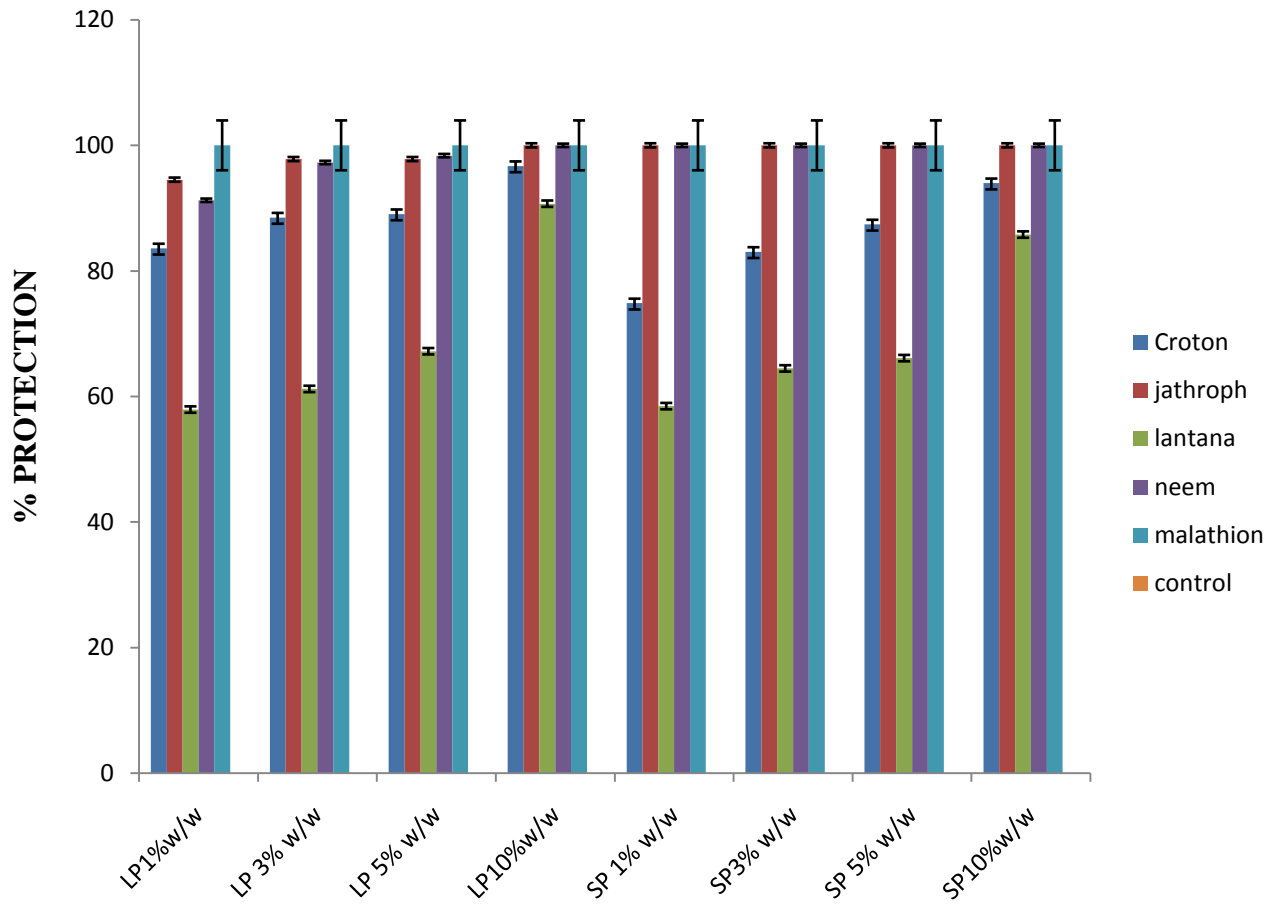


Figure 9: Effect of botanicals on mean percent protection of maize grain from F1 progeny

SP = Seed powder

LP = leaf powder

4.4. Evaluation of Percent Weight loss

Results of mean percent weight loss of *S. zeamais* on maize grains are given in Figure 9. Maize grains treated with malathion 5% dust, the seed powder of *J. curcas* and *A. indica* were almost totally protected the grains from weight loss (Figure 10). During this period also the seed powder of *J. curcas* and *A. indica* and the leaf powder of *L. camara* and *C. macrostachys* gave the lowest percent weight loss (Figure 10). The effective botanicals (*J. curcas* and *A. indica*) were effective in controlling adult *S. zeamais* regardless of the rates, while the less effective botanicals (*L. camara* and *C. macrostachys*) gave better control at the highest rate (Figure 10).

4.5. Evaluation of Percent seed damage

Results of mean percent seed damaged of *S. zeamais* on maize grains are given in Figure 10. Maize grains treated with malathion 5% dust, the seed powder of *J. curcas* and *A. indica* were 100% protected the grains from seed damage (Table 11). During this period the seed powder of *J. curcas* and *A. indica* and the leaf powder of *L. camara* and *C. macrostachys* gave the lowest percent seed damage (Figure 11). The effective botanicals (*J. curcas* and *A. indica*) were effective in controlling adult *S. zeamais* regardless of the rates, while the less effective botanicals (*L. camara* and *C. macrostachys*) gave better control at the highest rate (Figure 11).

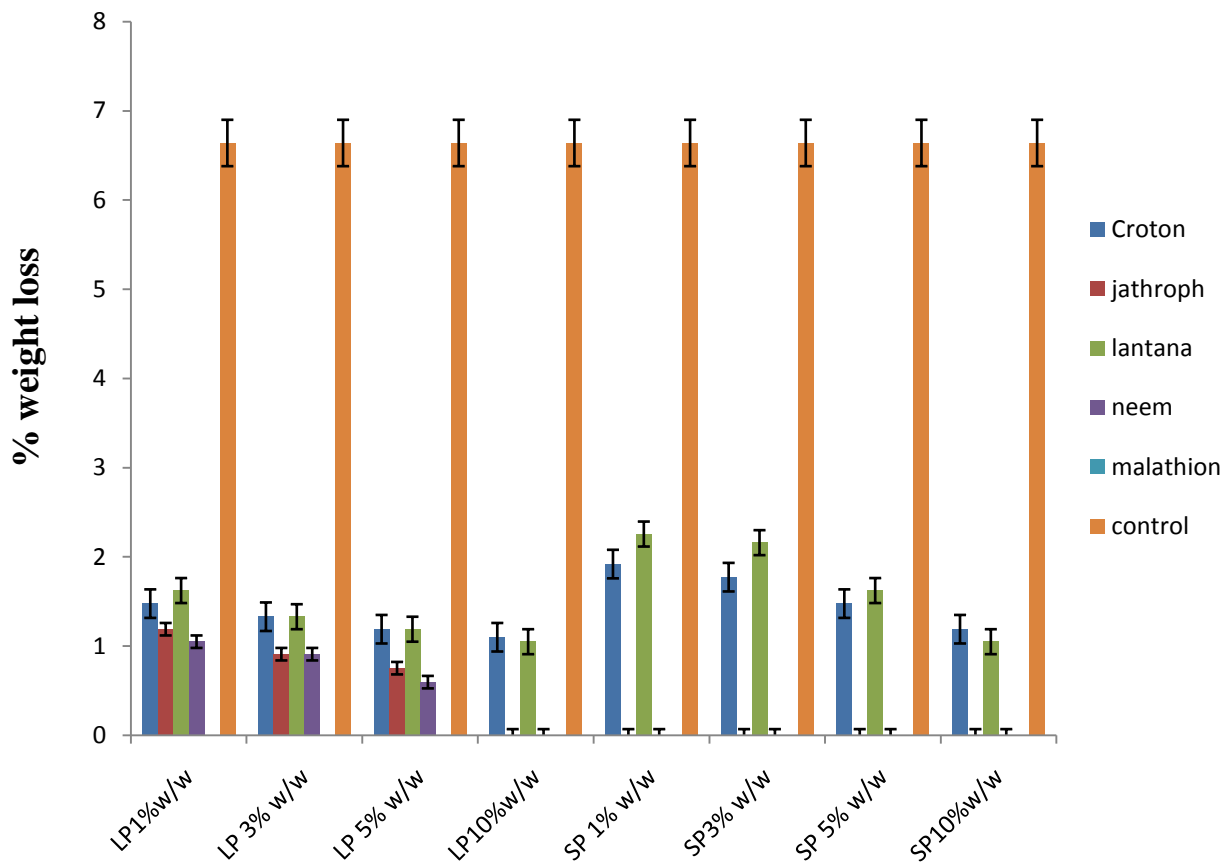


Figure 10: Effect of botanicals on mean percent weight loss of maize grains treated with different botanical powders

SP = Seed powder

LP = leaf powder

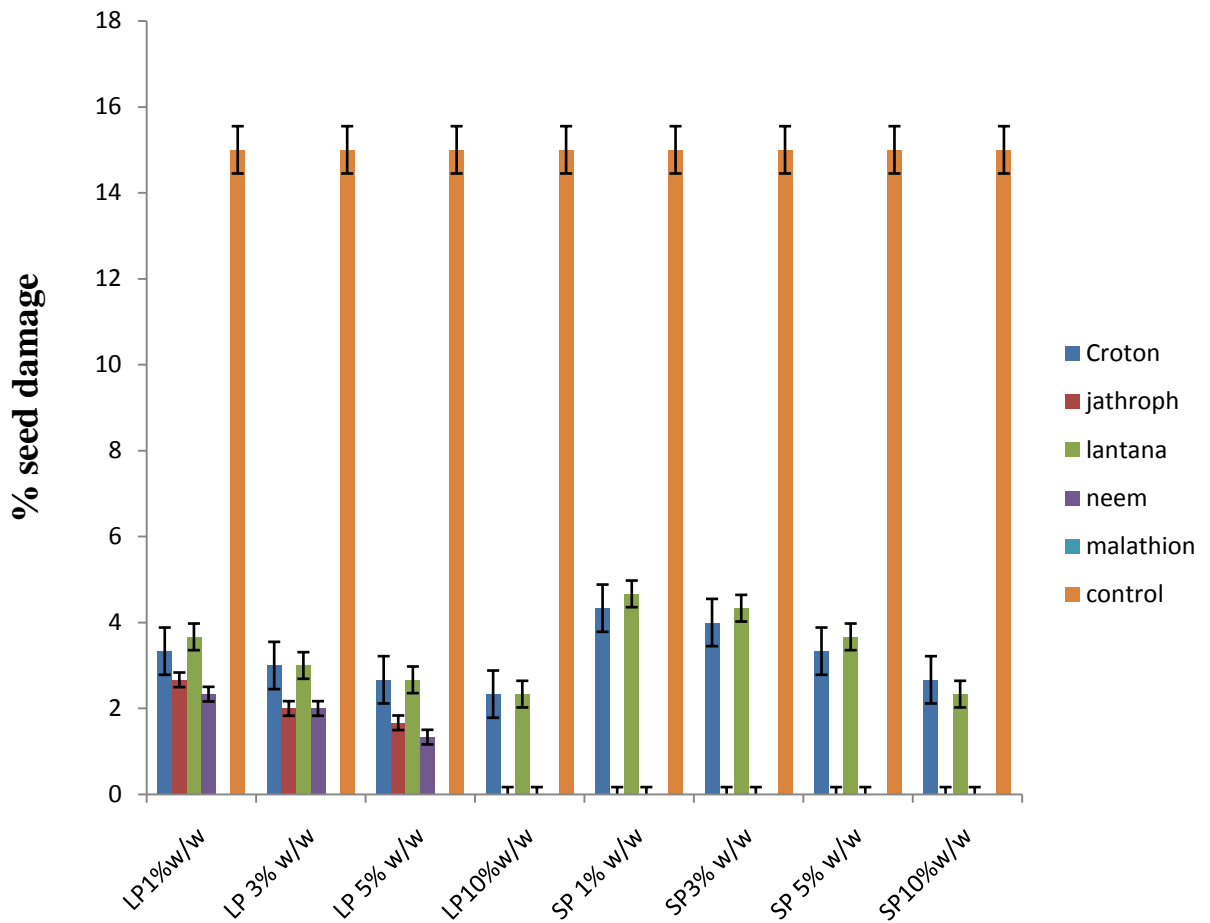


Figure 11: Effect of botanicals on mean percent seed damaged of maize grains treated with different botanical powders

SP = Seed powder

LP = leaf powder

4.6. Effect of botanicals on germination of seeds

Results of mean percent germination of maize grains are given in Figure 11. Maize grains treated with all botanicals were almost totally germinated (Table 12). There was no variation in terms of plant parts used (Figure 12). Almost there was no variation in terms of rates used (Figure 12).

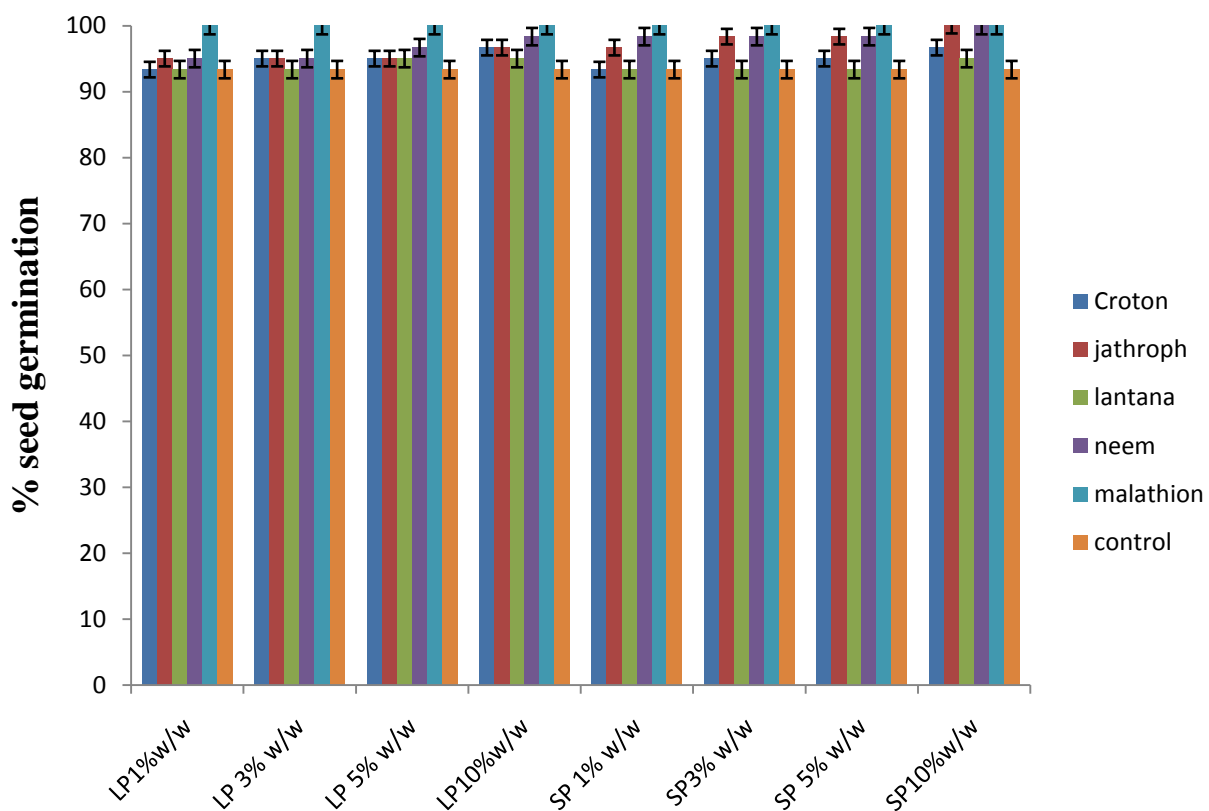


Figure 12: Mean percent germination of maize grains treated with different botanical powders

SP = Seed powder

LP = Leaf powder

5. DISCUSSION

The result of the present laboratory study showed that *Jatropha curcas* and *Azadirachta indica* were the most effective botanicals in all of the parameters measured even in the lowest rate. The seed parts of *J. curcas* and *A. indica* gave 100.00% cumulative adult weevil mortality in all of the doses used (1.0, 3.0, 5.0 and 10%w/w) which was similar effect with malathion 5% dust. Those botanicals decrease emergency of F1 progeny, weight loss, and seed damaged and fully protected the grain from emergency of F1 progeny but did not affect germination of seeds. So the present study showed that we can use even the lowest amount of *J. curcas* and *A. indica* seed to protect the maize grain from maize weevil infestation

The result of the present laboratory study also showed that as compared to the above botanicals *L. camara* and *C. macrostachys* were the least effective botanicals in all of the parameters except germination test but, by far better than the untreated check. The leaf parts of those botanicals were effective than the seed parts in all of the parameters measured except germination test. The result also showed that those botanicals gave better control at the highest rate, in general when the amount of botanicals increased from 1%w/w to 10%w/w the effectiveness also increased. So we can use the highest rate (10%) incorporated with other IPM methods for effective control in areas where the best botanicals are not available.

The killing effect of almost all botanicals at different concentration rates was high 28 days after treatment application than 1 and 5 days after treatment application. The effective botanicals have many medicinal properties. Gutierrez . *et al.*, (2014) reported that phytochemical screening

revealed the presence of alkaloids, flavonoids and steroids in the extracts of *J. curcas* while *Citrus grandis* and *Tinospora rumphi* are rich in alkaloids, saponins, tannins, flavonoids and steroids. These compounds possess insecticidal and larvacidal properties that cause mortality of insects and other pests (Nweze, *et al.*, 2004, Akinyemi *et al.*, 2005, Gutierrez Jr. *et al.*, 2014). Alkaloids, saponins and tannins are known to possess medicinal and pesticidal properties. Saponins are harmful to insects (Chaieb, 2010). Rahman *et al.* (2011) reported that the extracts from the seeds and leaves of *J. curcas* inhibit the growth of mycelium of *Colletotrichum gloeosporioides*, which causes anthracnose disease in bananas.

The extracts obtained from the leaves are used as nematocides (Sharma and Trivedi, 2002, Kumar and Sharma, 2008). It has been used as molluscicide, Rodenticides and fungicide (Goel *et al.*, 2007, Rahman *et al.*, 2011). The leaf extracts of *J. curcas* also has antimicrobial, larvacidal and insecticidal properties (Igbiosa, *et al.*, 2009, Kalimuthu, *et al.*, 2010, Kalimuthu, *et al.*, 2011). Makker, *et al.*, (1997) reported that the toxicity of *J. curcas* oil have been due to the presence of phorbol esters. The insecticidal activity of *J. curcas* has been reported by Habou *et al.* (2011). They reported further that the oil extracts of the plant has biocidal effects on cowpea pests such as *Aphis craccivora* K., *Megalurothrips sjostedti* T and *Anoplocnemis curvipes* F. Bashir and Shafie (2013) reported that the seed oil extracts of *J. curcas* caused significant mortality in the desert locust, *Scistocerca gregaria* Forskal, within 7 days of application. Singh (2008) reported that *J. curcas* caused antifeedant activity in termite, *Macrotermes besoni*.

In addition, the inhibition of *S. zeamais* progeny emergence and maize grain damage as a result of treatment with neem was probably due to the huge array of azadirachtin activities on the insect's hormone system. It has been proved that azadirachtin disrupts or inhibits development of insect eggs, larvae or pupae, preventing the molting of larvae or nymphs, disrupting mating and sexual communication, deterring females from laying eggs, sterilizing adults, poisoning larvae, thus preventing adult maturation by inhibiting the formation of chitin, the essential substance for the insect to form an exoskeleton (Murugan *et al.*, 1999). Bashir and Shafie (2014) reported that both oil extracts of neem and *J. curcas* resulted in 99.71% egg unhatchability in the desert locust.

Tigist Shiferaw (2004) suggested that natural pesticides could have direct or delayed insecticidal effects. The delayed effect operates indirectly by inhibiting reproduction and development (oviposition, larval penetration into the seed and adult emergence) that can be evaluated after a complete cycle of development of the pest. The synergistic effect of treatments in suppressing in F1 progeny could be due to combined factors such as, increased adult mortality, ovicidal and larvicidal properties of botanical formulations and/or presence of chemicals that interfere with insect feeding. Previous Several studies revealed the potential of botanicals in reducing F1 progeny production on different storage insect pests (Asmare Dejene, 2002; Shaheen, 2006).

Comparing the findings of the present study with other findings, the present study is in line with the findings of Ileke and Oni (2011) and Khaliq *et al.*,(2014). From their study on the toxicity of some plant powders to maize weevil, *Sitophilus zeamais* (motschulsky) (Coleoptera: Curculionidae) and on stored wheat grains (*Triticum aestivum*), Ileke and Oni (2011) found mortality of adult *Sitophilus zeamais* that increase with concentration from 2.5-25% w/w.

In addition to causing adult mortality, the insecticide powders either completely hindered or significantly reduced progeny emergence, indicating their potential for use in the management of the maize weevil. This also agrees with the findings of Araya G/selase and Emanu Getu (2009) which reported significant reduction in cowpea grain weight loss by *J. curcas* and some other plants when applied against *Z. subfasciatus*. This action might be as a result of its effectiveness in killing all the adult weevils introduced within a short period of time, and its larvicidal effects. Previous investigation on wheat treated with *A. indica* and *A. boonei* powder attributed suppression of F1 generation of *S. zeamais* to high mortality of adult insects which disrupts mating and sexual communication as well as deterring females from laying eggs and affecting developmental stages of insects (Ileke, and Oni, 2011).

Asmanizar *et al.* (2008) also reported 100.00% adult mortality of *S. zeamais* when treated with seed crude extract of *J. curcas*. Similarly, Suleiman *et al.* (2011) reported 100% adult mortality of *S. zeamais* when 0.5–2.0g of *J. curcas* was applied to 20g of sorghum grains. Boateng and Kusi (2008) recorded 100.00% adult mortality of *Dinarmus basalis* grown on cowpea grains when treated with seed oil extract of *J. curcas* at the rate of 0.5, 1.0, 1.5 and 2.0ml/150g grains.

The present study is in line with the findings of Asmare Dejene (2002). Among 20 species of botanicals for their efficacy to control the maize weevil on sorghum in the laboratory at Sirinka, *Chenopodium ambrosioides*, *Cissus rotundifolia*, *Jatropha curcas* and *Phytolacca dodecandra* caused 100% mortality of the pest within 28 days of infestation.

The control treatments with two synthetic insecticides, pirimiphos-methyl (8 ppm) and Malathion caused 100% mortality (Asmare Dejene, 2002). Muluemebet (2003) is evaluating the efficacy of neem leaf and seed powders, Mexican tea powder and other treatments including plant oils and inert dusts. Mexican tea seed and leaf powders at higher doses (3 and 6% w/w) significantly reduced oviposition, egg hatchability and adult emergence of *C. maculatus* on cowpea. Neem seed at 3% w/w was better than all other botanicals and had longer persistence as it was effective even after three months of application. It also delayed progeny emergence.

Abraham Tadesse (2003) also compared neem leaf and seed powders and other plant products at the rate of 1 and 2% w/w against weevils in stored maize and found that neem oil and seed powder provided complete protection to maize grains for six months, whereas substantial insect infestations were noticed after three months in other treatments. Application of neem seed powder at 1% w/w on shelled maize grain in the laboratory caused significantly higher mortality and lower emergence of maize weevil progeny than the untreated check at Bako (Abraham Tadesse, 1991).

Omotoso (2004) has earlier reported that the leaves and seeds of *Azadirachta indica* and *Ricinus communis* as well as the leaves of *Eucalyptus camaldulensis*, *Lonchocarpus seriseus* and *Erythrophleum guineense* are good toxicants and antifeedant against *S. zeamais*. Adane Kassa and Abraham Tadesse (1995) reported the gradual action of botanical plants such as leaf powder of neem and Persian lilac against *S. zeamais* and they recorded the maximum mortality due to the application of the botanicals at 28 days after the treatment application.

Tigist Shiferaw (2004) Evaluated Neem, Mexican tea, *Lantana*, and *Tagetes*, each at the rate of 4%, against *Zabrotes subfasciatus* on haricot bean. It was found that botanical treatments increased adult mortality, reduced F1 progeny number, percentage seed damage and seed weight loss. Mexican tea seed and leaf, *Tagetes* seed and leaf and neem seed powders gave better protection than the other botanicals. *Lantana* was the least in protecting haricot beans from damage by the bruchids.

Adane Kassa and Abraham Tadesse (1995) reported that *lantana* showed insecticidal activity against maize weevil by causing fairly high adult mortality and lower F1 progeny emergence compared to the untreated control. Ferede Negasi (1994) reported that *Lantana* seed powder at the rate of 10 per cent w/w caused adult mortality, suppressed oviposition and reduced F1 progeny emergence of *Zabrotes subfasciatus* on haricot bean compared to the untreated check. *L.camara* was found to be the least effective in affecting the emergence of adults, in reducing grain damage and weight loss compared to the other test powders. The effect on adult emergency was significantly different among all the plant powders tested and between the plant powders and malathion 5% dust, as well as the control. There was no progeny emergence from seeds treated with malathion 5% dust.

Adane Kassa and Abraham Tadesse (1995) also reported that there were significant differences in the number of F1 progeny emerged from grains treated with 17 plant species that were tested for their efficacy against maize weevil. Ferede Negasi (1994) reported the leaf powders of neem, pepper tree, Persian lilac, Mexican marigold and *lantana* showed significant differences in terms of the number of F1 progeny of bean bruchids, *Zabrotes subfasciatus*. Abraham Tadesse (2003) reported that neem seed powder treatments differed significantly from the untreated check in the percentages of damaged grain and grain weight losses at different dates after infestations.

Results from germination test showed that all botanical powders used to treat maize seeds against *S. zeamais* don't have negative effect in percent germination of the seeds at both dosage rates.

All the treated and untreated seeds gave 93.33 - 100% germination. The percentage germination (93.33%) observed on untreated seeds shows that the damage level due to maize weevil was not serious to affect germination. This indicates that weevil damage to maize seeds did not affect germination as far as the damage is not serious. During the experiment it was observed that most of the weevil emergence holes were found to be relatively more common on the crown of the kernel and endosperm than on the germ or tip of maize kernels. This has resulted in the highest percentage of germination, of all the grains. Earlier studies also showed that significant differences in germination might not be found between damaged and undamaged seeds if the damage is low. (Tigist Shiferaw, 2004) indicated that seeds with one hole could germinate like the healthy seeds.

An investigation carried out previously on effect of botanical on germination ability of treated seeds showed no significant difference between the treatments and untreated control (Araya G/selase and Emanu Getu, 2009). In related study, Asmare Dejene (2002) showed sorghum seed treatment with powders of *D. stramonium*, *J. curcas*, *P. dodecandra* and *A. indica* against *S. zeamais* did not have any adverse effect on the germination capacity of seeds. Nukenine *et al.* (2011) reported similar findings where Neem did not have negative effects on maize seed germination (germination rates of 92.23 % at 3 g/kg to 97.77 % at 12 g/kg were recorded). Enyew Abiyu and Raja (2015) and Tadele Desalegn (2014) stated that the effects of lantana leaf extracts on root and shoot growth was species specific (stimulatory effect on maize and finger millet and suppressive effect on tef.) and concentration dependent and they were generally more pronounced on the roots than shoots of the agricultural crops.

Adane Kassa and Abraham Tadesse (1995) who reported that the use of crude powders of 17 botanical plant species for the control of *S. zeamais* on sorghum had no effect on seed germination. The protection of stored products by the use of plant materials is a common practice among smallholder farms in Africa. In recent years, research efforts have focused on the use of natural products derivable from plants as viable alternatives to the conventional synthetic insecticides for protection of stored products (Abebe, 2006; Taddese, 2003). Solomon Gebeyehu (1996) indicated that plants with medicinal and biocide effects are found in Ethiopia and many of these plants may prove to have insecticidal value if properly evaluated on storage and field insect pests but little is known about their pesticidal effect so far.

6. CONCLUSION

Result from the current study indicated that there is great potential in using botanical plant powders as seed protectants against *S. zeamais*. The powder from *J. curcas* seed and *A. indica* seed was exhibited total (100%) control of *S. zeamais* within a short period of time. When we compare the effectiveness of the seed and the leaf parts of the botanicals, in the case of *J. curcas* and *A. indica* the seed parts were more effective than the leaf parts, but in the case of *L. camara* and *C. macrostachys* the leaf parts were more effective than the seed parts. The most effective botanicals (*J. curcas* and *A. indica*) were effective in controlling adult *S. zeamais* regardless of the rates, while the less effective botanicals (*L. camara* and *C. macrostachys*) gave better control at the highest rate. Economic, environmental and health implications indicate that it would be better to use botanical pesticides like *J. curcas* and *A. indica* that is cheaper, safer and more environmentally friendly, than to use the costly, poisonous and environmentally hazardous chemical pesticides in *S. zeamais* control. In general, the result showed that seeds of *J. curcas* and *A. indica* be utilized as options or components of *S. zeamais* integrated management.

7. RECOMMENDATION

- The botanicals effective in the current experiment (*J.curcas* and *A. indica*) should be utilized for the control of *S.zeamais* with other cultural methods.
- Array of chemicals having pesticidal properties in the botanicals should be identified.
- Further investigation of those plant powders under real storage conditions and its long term (chronic) toxicity on mammals and beneficial organisms need to be studied.
- Much work need to be done on plant based botanicals to develop effective rates and formulations, which can be commercialized for the purpose of insect pest control
- In the absence of the most effective botanicals (*J.curcas* and *A. indica*) the less effective botanicals (*C. macrostachys* and *L. camara*) can be used as components of IPM of *S.zeamais*.

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ANNEXES

ANNEX 1: Sample pictures taken during the experiment



ANNEX 2: Six-months mean monthly temperature and relative humidity of the laboratory at K-PHC (2009)

Month	Temperature (0C)	Relative humidity (%)
October	25.6	76.5
November	25.9	74.0
December	27.5	69.0
January	28.0	71.4
February	26.5	67.7
March	27.9	68.5
Mean	26.9	71.18