

**THE EFFECT OF FEVER TEA TREE (*LIPPIA JAVANICA*) IN THE CONTROL OF  
MAIZE WEEVIL (*SITOPHILUS ZEAMAI*) IN STORED MAIZE (*ZEA MAYS*)**

**BY**

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of Science Degree in Agronomy**

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## DECLARATION

### CERTIFICATION OF DISSERTATION

I certify that the ideas, experimental work, results analysis and conclusions reported in this dissertation are completely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted, except where otherwise acknowledged.

The undersigned certify that they have read and recommended to the Department of Agronomy for acceptance, a dissertation entitled:

THE EFFECT OF *LIPPIA JAVANICA* IN THE CONTROL OF MAIZE WEEVIL  
(*SITOPHILUS ZEAMAI*S) IN STORED MAIZE (*ZEA MAYS*)

A dissertation submitted by Majoro Mordester in partial completion of the requirements of Bachelor of Science Honours Degree in Agronomy

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## ABSTRACT

*Sitophilus zeamais* Motschulsky is the major insect pest seen damaging stored maize in Zimbabwe. The environmental hazards of synthetic insecticides, the unreliability supply and high costs of these chemicals resulted in the search for cheaper and safer use of the naturally available plant material to control this pest. This study evaluates effective rates for *L. javanica* leaf powder. Bioactivity of *Lippia javanica* leaf extracts was evaluated under average room temperature, at three dosage levels (0.5g, 10g and 15g), negative control of untreated grain were mixed with 1kg of disinfested Pannar 413 maize variety in plastic containers. A positive control of Actellic Gold Dust was also used at label rates and the effect on grain damage, weight loss, insect mortality; progeny production was assessed. The leaf extract showed significant difference between 0.5g and 10g on one hand and 15g and the positive control showed no statistical difference. The 15g that recorded the highest mortality inflicted 85.25%. The maize grain treated with 10g and 15g dosage levels of the leaf extract showed much promise by significantly reducing the number of damaged grains by the maize weevil, reproduction of the maize weevils well as reducing weight loss in stored maize compared with the negative control. Grain weight loss in leaf powder treated grains was dose dependent ranging from 4% in the highest dose to 44.6% with untreated grain at 59% in untreated maize grain showing significant differences in 21 days.

## **DEDICATION**

To my daughter Yemura, sons Omali and Chewire, my mother and my siblings.

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## LIST OF ACRONYMS

AGRITEX	: Agricultural Technical and Extension Services
ANOVA	: Analysis of variance
CIMMYT	: International maize and Wheat Improvement Centre
CRD	: Complete Randomised Design
FAO	: Food and Agricultural Organisation
FAO STAT	: Food and Agriculture Organisation Statistics
GMB	: Grain Marketing Board
g	: grams
kg	: kilograms
LGB	: Larger grain borer
MAMID	: Ministry of Agriculture Mechanisation Irrigation Development
P<0.05	: Probability less than 5%
WHO	: World Health Organisation
Zim ASAT	: Zimbabwe Agenda for Sustainable Socio-Economic Transformation

## CHAPTER ONE

### 1.1 INTRODUCTION AND JUSTIFICATION

Maize (*Zea mays*), is a staple food in Zimbabwe and is greatly relied on in the achievement of food security. Besides being used as food for human consumption, maize can be used for livestock feed and as raw material in the confectionary industry as it has basic ingredients for local drinks e. g maheu, food products like cereals, spaghetitis, cornflakes, meal rice, maize flour and maputi FAO (2007). The crop is dominantly grown in natural regions1, 11A, and11B where 50-70% is attained and 40-50% is grown in region III, IV and V. National Early Warning unit Agritex (1994). Globally in terms of importance, maize come worlds third after wheat and rice, Morris (2001).

Zimbabwe maize production trends vary on output, providing no significant yield improvement, yield declining, yield stagnation and or moderate yield improvement. In the 2014/2015 season, maize production went down to 35%, which was one third lower than the previous season, FAO, Agribusiness World Zimbabwe (2015). Currently average maize yield is at 0.8t/ha which is far below the expected average of 4t/ha MAMID (2016). The decline is attributed to late planting due to unavailability of seed on the market on time, unaffordable prices of inputs e.g. fertilizers by most farmers, shortage of draft power and erratic rainfall. According to FAO STAT, (2010) Zimbabwe needs 1; 7 million tonnes of maize for direct human consumption per year and according to WHO, maize consumption per day per person is 241g. There is therefore great need to guard against losses that may befall maize grain in storage. Between 20-40% losses in grain is caused by insect pest in the tropics ,Nuepane (1995). This is cause for concern on guarding against post harvest losses mainly caused by insect pests. In Zimbabwe, grain damage of 92% in stored maize was reported due to insect pests, Mutiro et al.. (1992). Quality of grain, weight and nutritional value are lost, threatening food security globally if insect pests are left unattended, Rouanet (1992). Major insect pests threatening food security include the maize weevil (*S. zeamais*) and the larger grain borer (*Prostaphanus truncutus*).

The maize weevil (*S. zeamais*) is one of the most important insect pests to attack pre and post harvested maize Warui et al (1990). It is an invader pest contributing post harvest losses of 20 to 90% if grain is left untreated, Dhiwayo and Pixley (2003). Zimbabwe farmers currently rely on synthetic chemicals in controlling this pest. Some of these chemicals due to continuous use are being resisted by the insect pest. Most Zimbabwean farmers are also poor resource farmers who cannot afford buying the chemicals which are expensive and not readily available in most rural markets, besides they are a health hazard to applicators, consumers and the environment, Mabbet (2007). The destruction of non target species as well as pesticide resistance is cause for concern in using these synthetic chemicals. It is at this juncture that locally available botanicals are under research to replace or supplement the chemical control method.

Research technologies seeking protection of stored products include development of non-target chemicals to abrogate the use of synthetic insecticides and have economic and health benefits for applicators, consumers and the environment, Murdock et al (1997), Elhag, (2000); Talukdf and Howse, (2000). The use of natural methods of protecting harvested crops from insect damage is not only gaining prominence, Golob et al (1999) but are also generating positive results. Some botanical

control methods researched include the use of eucalyptus leaves, *Tagetes minute* leaves and according to Musundire et al (2014), plant powder of *E. gaudis* and *T. mimuta* can be used as natural pesticides in maize storage and can successfully limit grain damage.

*Lippia javanica*, fever tea tree/lemon bush of Verbenaceae family known as zumbani in Shona and um suswane in Ndebele is an aromatic woody shrub. It grows up to a height of 5m and is widely spread in many parts of Zimbabwe. It is used in various ways including repelling and controlling insects e.g. bark beetle, used in pre and post harvest management, used against rape aphids and tomato red spider mites Van Wyk et al (2000). According to Souza et al (2005), *L. javanica* contain essential oils that inhibit insect growth.

## **1.2 Overall objective**

- To determine the effects of *Lippia javanica* leaf powder in controlling *Sitophilus zeamais* in stored maize.
- **1.2.1 Specific objectives**
- To evaluate the effect of *L. javanica* leaf powder on mortality of *S. zeamais* in stored maize.
- To determine the effects of *L. javanica* leaf powder on grain damage by *S. Zeamais* in stored grain.
- To determine the effects of *L. javanica* leaf powder on reproduction of *S. zeamais* in stored maize
- To determine the effects of *L. javanica* on weight loss of stored maize.

### **1.2.1Hypotheses**

- There is no significant effect of *L. Javanica* leaf powder in mortality of *S. zeamais* in stored maize.
- There is no significant effect of *L. javanica* leaf powder on grain damage by *S. zeamais* in stored maize
- There is no significant effect of *L. javanica* leaf powder on reproduction of *S. zeamais* in stored maize

- There is no significant effect of *L. javanica* leaf powder on weight loss on stored maize.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Maize production and economic importance

According to Ashworth, (1990); Roth, (1990); and Masters, (1991), maize is a dominant crop across all agricultural ecological zones in Zimbabwe occupying 50-70% of the cropped area in natural region 1, 11A, and 11B, and 40-50% of the cropped area in natural regions 111, 1V and V. Maize area is uniform across the communal areas in natural regions 11A and 11B with an average of 1.7 ha, National Early Warning Unit, Agritex (1994). Maize production is largest in relation to other crops in natural regions 11A, 11B and 111. Maize can be grown successfully in soils whose pH ranges from 5.5 to 7.5. Maize requires considerable moisture and warmth from germination to flowering. It is a warm weather plant. Minimum soil temperature requirement of 10 to 13°C is needed for maize germination and seedling growth. The ideal temperature for germination is 16°C to 32°C (Rouanet 1987). There is significant decline in yield of maize in all regions of Zimbabwe and this is triggered by temperature and precipitation as physical variables (BEAP, 2007), unavailability of labour, seed, fertilizer as well as irrigation on time leading to late planting. Irregular rainfall distribution has made maize production a very risky endeavour for many small holder farmers who rely on rainfall. Drought reduces maize yields by an average of 15% each year in Sub-Saharan Africa. This is equivalent to US\$200 million in lost grain (<http://www.iita.org>).

Pests and diseases add problems in the production of maize. They include rust, maize streak virus, leaf blights, stalk and ear rots, leaf spot, downy mildew and weeds such as the problematic witch weed (*striga*). However maize production has been at the helm of employment creation in farms, GMB, industry and the current Zimbabwe Agenda for Socio-Economic Transformation (Zim Asset) has seen people making brisk business in the brewing and selling of maheu, maputi and maize meal. In farms people are hired for land preparation,



planting, weeding, harvesting and even storage. At the GMB maize is the main crop and people get different forms of employment from stacking, to record keeping. Globally maize is ranked third after wheat and rice in terms of importance. To minimize losses in storage, farmers need to observe sanitation, possibly cropping of natural resistant varieties, practice hermetic storage and use botanical methods to repel or kill insect pests to reduce use of synthetic chemicals

## **2.2 Storage and Postharvest Pests**

Farming is all in vain if farmers fail to store the harvested produce. Storage of maize is a constant priority so as to bridge seasons. It is done to ensure household food and nutritional security. Impelling maize grain storage is more critical at this time of climate change where associated weather vagaries adversely affect crop yields. Whatever has been produced must be well managed as research has proved grain storage loss due to moisture, insect pests, moulds and mildew costing farmers 25 to 30% of their yield each season. (Manica Post 2014 July 25).

Most rural farmers store their maize in the traditional granaries which have no guarantee of grain safety against major storage insects. Polythene sacks are also not insect and fungus proof. Improvised galvanized metal silos and the use of airtight hermetic bags have been put in place to reduce weevil and fungus damage. However new types of hybrids have shorter and looser husks and need to be stored shelled and in closed store with the use of pesticide and 30% moisture content. Insect pests in the fields include stem and ear borers, army worm, cutworm, grain moth weevils, grain borers, rootworms, and white grubs.

### **2.2.1 Post harvest pests in maize**

Among the insect pest which attack stored maize are the rust –red flour beetle (*Tribolium castaneum* Herbst), angoumois grain moth (*Sititroga cerealla* Oliv.), larger grain borer (*Prostephenus truncates*), and the maize weevil (*Sitophilus zeamais*) (Warui et al 1990).

### **2.2.1.1 Rust-red flour beetle ( *Tribolium castaneum*)**

Very common in Zimbabwe, it is very small 3-4mm long and reddish in colour. Lays eggs outside kernels which are sticky causing them to become covered with flour and stick to containers. Adult and larva feeds mainly on the germ of the cereal. It is a major pest of maize, groundnuts, oats, rice, beans wheat and sorghum at post harvest and in storage. It damages seed and grains through internal feeding, contaminates grain with faeces and it promotes moulds making grain unfit for human use.

### **2.2. 1.2 Angoumois grain moth**

Infestation by moth starts in the field. Maize infested in the field may harbour larvae feeding within the kernels, the adult continue to develop, pupate and emerge as adults which in turn deposit eggs on un-infested kernels. By feeding, moth causes reduction on weight and quality. Heavily infested grain produce bad odour. Cribs infested by this pest will contain ears with small holes on individual kernels

### **2.2.1.3 The larger grain borer**

This pest is foreign in Zimbabwe and is suspected to have been introduced through maize aid from Tanzania but it originated from Mexico. The pest is a wood boring pest and is a serious pest of stored maize, dried cassava and other domestic products. This serious pest has devastating effects and demands adequate preparation on its management. It is a notify able pest in Zimbabwe. The LGB can eat all the grain and induce loss of up to 100%. The notorious pest resists most synthetic chemicals.

### **2.2.1.4 Maize weevil (*Sitophilus zeamais*)**

It is described as a primary storage pest of maize. It is a very serious pest on stored maize that enhances food insecurity among farmers (Longstaff, 1981). Though it attacks standing maize before harvest, it is also commonly associated with rice. It can also infest raw and precede wheat oats sorghum and barley. The pest can also infest apple fruits during storage. It

has ability to fly. Female bore holes to lay eggs in the grain. A development stage happen within the grain, feeding from the germ and later bores its way out as an adult. More damage is caused by heat produced by the pest activity which may lead to sprouting of grain (Jacob and Calvin, 1988). Accumulation of frass, insect cadavers and the spread of post harvest fungal pathogens adds to damage causing grain to be unfit for human consumption (Ashworth, 1993).

### **2.3.0 Biology of *Sitophilus zeamais* and infestation**

The maize weevil is of 2.5mm to 4mm in length, is brown in colour with reddish brown spots on the wing cover larger than those of rice weevil. It is able to fly.



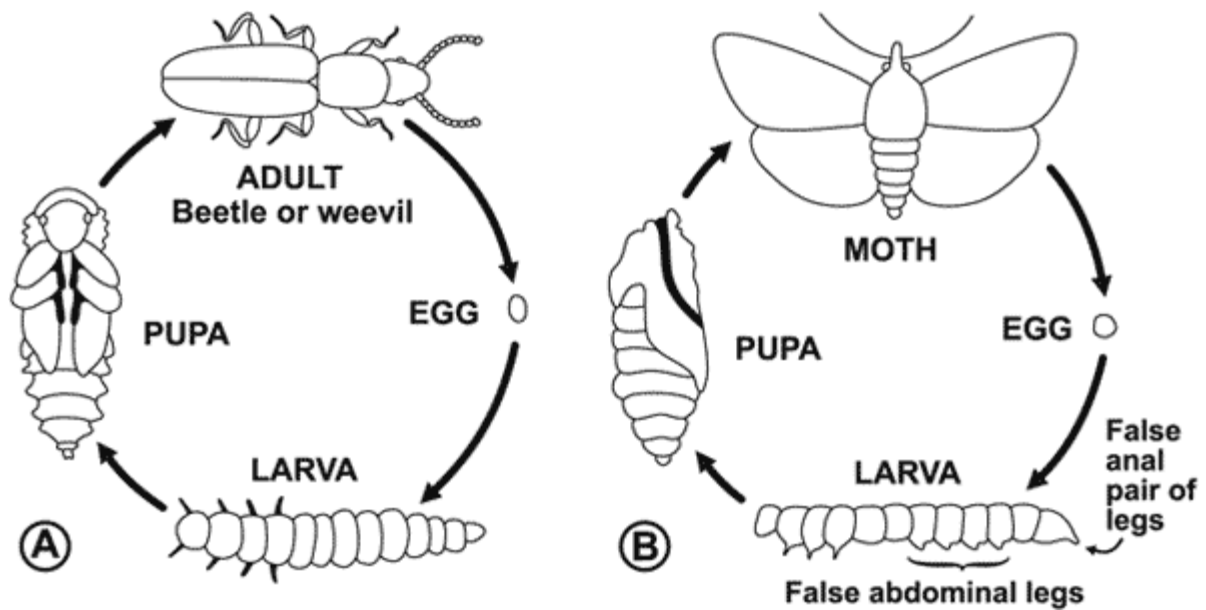
**Figure 2.1 The maize weevil (*S. zeamais*)**

Kingdom:       Animalia

Phylum:       Arthropoda

Class:           Insecta

Order: Coleoptera  
 Family: Curculionidae  
 Subfamily: Dryophthorinae  
 Genus: Sitophilus  
 Species: S.zeamais



**Figure 2.2 Life cycle of the maize weevil**

The complete development time for the maize weevil averages 36 days. The female chews through the surface of the grain creating a hole to lay an egg. Not all excavated holes are used for oviposition, some maybe deserted while others are expanded into feeding holes (Campell, 2002). On a hole meant for laying, a white oval egg is laid. As the ovipositor is removed, a waxy secretion covers the hole with a plug which quickly hardens and is not easily visible. One egg is laid in each grain. The egg hatches into a legless grub and feeds within the grain and develop to a larvae which also feeds from within the grain and normally, weevil larvae allow their frass to accumulate inside the grain in which they are feeding. This makes grain

unpalatable and when carbon dioxide level exceeds 5%, the larva makes a small hole in the grain to eject much of the frass. Only one larva lives within a normal sized kernel as the existence of more than one will result in cannibalism (Hall, 1970). Subsequently the larvae puppets within the grain and chew its exit hole outside the grain to an adult beetle. One female may lay 300 to 400 eggs in its lifetime. In temperatures of 15 to 34°C and relative humidity of 40% adults can live for 5 to 8 months. When they emerge, females move on high surface and release sex pheromones to attract males. Invasion by this primary coloniser may facilitate the establishment of secondary coloniser and mite pests and stored products pathogens (Trematerra et al, 2007).

Damage may be further confounded by heat produced by pest activity, so much so that sprouting of grain occurs (Jacobs and Calvin, 1988). Indeed, as with most pests infesting stored produce, damage is not through direct feeding alone; in the case of this pest, damage to produce also arises from the accumulation of frass, insect cadavers and the spread of post harvest fungal pathogens (Longstaff, 1981; Ashworth, 1993).

#### **2.4 Control measures of *S. zeamais***

There is great need to minimize postharvest losses in stored maize. Maize is a seasonal crop and the produce in one harvest period must be stored for gradual consumption up until next harvest and in some cases retained seed for next season comes from that harvest. Maize is also kept for selling during off season when values rise. *S. zeamais* is a problematic pest to many farmers reducing both quality and quantity in a very short space of time. Food security is at great risk if the pest is left uncontrolled as it attacks grain even before harvest. It is at this juncture that different methods in reducing infestation or invasion by this pest have been and are being researched. Infestation by insect pests cause grain weight and quality losses as infested grain normally loose colour and nutritional value (Giga, 1993). It is therefore vital to

minimize unnecessary losses by preventing, protecting and curing stored maize against the deadly insect pests such as the maize weevil. Most Zimbabwe farmers rely on synthetic insecticides. Though effective and efficient, resource poor farmers cannot afford the ever increasing prices and in most cases the chemicals are not readily available in rural markets, also the uncontrolled use of the chemicals are a healthy hazard to human and the environment (White, 1995). Cultural, biological and botanical methods of controlling maize weevil are in practise.

#### **2.4.1 Chemical control**

Organophosphates and pyrethroids are applied either as dusts or as liquids to maize grain for long term protection. These chemicals protect with various efficacies. However, none will control all pest species, so a mixture of two is usually applied to the grain (Lorini *et al.*, 2006). The commercially available synthetic grain protectants currently in Zimbabwe include Shumba Super Dust®, Chikwapuro®, Ngwenya Yedura®, Actellic Super Chirindamura Dust®, Actellic Gold Dust®, and Phosphine fumigation tablets used in seed houses and commercial storage facilities.

The most widely used organophosphate grain protectants in Zimbabwe have the active ingredients fenitrothion (C<sub>9</sub>H<sub>12</sub>NO<sub>5</sub>PS) and pirimiphos-methyl (C<sub>11</sub>H<sub>20</sub>N<sub>3</sub>O<sub>3</sub>PS). In Chikwapuro®, Actellic Super Chirindamura Dust® and Actellic Gold Dust®, the organophosphate in the formulation is pirimiphos-methyl while in Hurudza Grain Dust® and Shumba Super Dust®, the organophosphate is fenitrothion. Synthetic pyrethroids in the dust formulation are deltamethrin (C<sub>22</sub>H<sub>19</sub>Br<sub>2</sub>NO<sub>3</sub>) and permethrin (C<sub>21</sub>H<sub>20</sub>Cl<sub>2</sub>O<sub>3</sub>). Actellic Chirindamura Dust and the Actellic Gold Dust have thiamethoxam as second ingredient. Fenitrothion is a contact organophosphate with acaricidal properties while pirimiphos-methyl

is a broad spectrum organophosphate they both protect grain by phosphorylation of acetylcholine at the cholinergic neuro-effector junctions resulting in the death of insect. Permethrin interferes with sodium ion channels of the insect disrupting neuron functions in the central nervous system resulting in muscle paralysis and death (Machingura (2014).

Inappropriate and excessive use of chemicals leads to insects being resistant and can be a hazard to human health. A good example is the active ingredient in Actellic, only 15g of the active ingredient is required per tonne and very few if any farmer work with the correct measurements.

#### **2.4.2. Cultural control**

Cultural methods always apply even to those who use any other control method. This method implies either as preventive, curative or both. *S. zeamais* infest maize whilst still in the field. Maize is susceptible to such pests therefore crop should not be left un-harvested for long. After shelling, screening and removing contaminants from the produce before storage is vital (Sinha et al).

Sanitation, use of resistant varieties, maintenance of storage structures and physical control has been used by resource poor farmers to keep their maize free from infestation.

Cleaning of storage structures and sealing of cracks, crevices and holes that might be in the floors prevents infestation. Where bags are used, disinfect bags by sunning before staking grain and there has to be proper staking of bags containing the grain to maintain hygiene to prevent insect damage in storage. It is also wise not to mix new with old grain. The use of sluggish material such as sand, ashes and powders or seeds will make survival of maize weevil difficult (Golobs and Webley, 1988). This is mostly done on small quantities of seed to be used in the next season. Movement of insect will be limited and material used may damage cuticle of insects leading to dehydration followed by death of insect.

Cultivation of traditional varieties which are resistant to insect damage minimizes storage losses greatly. The current high yielding hybrid varieties are more susceptible to maize weevil than traditional varieties. Other varieties to be grown are those that have good husk covers because insects do not easily get to the maize cob and hence reduce field infestation. According to Painter (1951) there are three types of varietal resistance namely non-preference, antibiosis and tolerance. Resistance to post-harvest insect pests is linked to antibiosis and non-preference (<http://www.fao.org>).

Grain must be stored when it reaches optimum moisture content and storage activities need to be done during low temperatures to reduce heat and fungal problems and the use of hermetic storage reduces oxygen increasing carbon dioxide leading to death of insects.

### **2.4.3. Biological control**

MacFarlane (1989) indicates the possible application of conventional biological control techniques in stored-grain pest control including control by use of predators, parasites, insects pathogens and sterile males, the use of pheromones for pest monitoring, mating disruption or enhance mass trapping and the use of resistant crop varieties. The main attraction of biological control is that it lowers the need for using chemicals and there is therefore no environmental pollution, which may affect non-target flora and fauna, when it succeeds, it offers a lasting solution of stem borer control from one introduction and this is a very helpful to both small-holder and large scale farmers (Wiedenmann and Smith, 1997)

Dustable powder formulation of conidia of *Beauveria bassiana* and *Metarhizium anisoplia* isolates control *S. zeamais* on stored and infested cereals (Kass 2003). According to Charles Adarkwa parasitoids significantly reduce *S. zeamais* in stored maize.

### **2.4.4. Botanical control**

This traditional method contributes significantly to food production and protection in sustaining livelihoods as it is an affordable and economically viable method (Amoabeng et al 2014, Mkenda et al 2015). Most of the plants are gathered locally from the wild e. g around



homesteads, roadsides, in farm fallows and forest reserves. According to Bell et al (1990), pesticidal plants can be directly toxic but often they act through repellence, growth regulators, and antifeedance or can stop insects from laying eggs.

Synthetic chemicals are products with high knockdown effect on pest organisms but the earliest pesticide till the end of 2nd world war were poisons extracted from plants (Berge 1994). Plants are known to possess secondary chemical compounds which are used as a part of the plant's defence against plant-feeding insects and other herbivores (Lupina and Cripps, 1987). Some of such plant products affect nerve axons and synapses e.g. pyrethrins, nicotine and picrotoxinin; muscles e.g. ryanodine; respiration e.g. rotenone and mammein; hormonal balance; e.g. juvenile and molting hormone analogues and antagonist; reproduction and behaviour e.g. attractants, repellents and antifeedants (Bell *et al.*, 1990).

Traditionally, different parts of the neem tree and other plant leaves have also been used as grain protectants at farm level (Jilani & Ahmad, 1982). In Southern Africa, Zimbabwe included, farmers are using a variety of pesticidal plants in the fields, in grain and vegetables with varying success (Nyirenda *et al.*, 2011; Kamanula *et al.*, 2011) though only a few plant species have been commercialised (Mwine *et al.*, 2011). The plant should also show no potential to become weeds or host for plant pathogens and should, if possible, offer complementary economic uses. In addition, the insecticidal product should effectively control the range of pests encountered in local storage situations, be safe to use, pose no environmental hazard, be easy to extract, formulate and use with available skills (Kis-Tamas, 1990). A various botanical grain protectants in powder form are used to reduce weevil infestation in Zimbabwe. These include *Eucalyptus grandis* (Musundire *et al* 2014), *T. minuta* (Muzemu *et al*, 2013) *Jatropha curcas* (Constance et al 2013), *Lantana camara* (Furusa, 2008), *L. javanica* (Gadzirai *et al* 2006) and leaves

Chemical insecticides have been used extensively in grain storage facilities to manage stored products from insect pests (Kim *et al.*, 2012). Although the dependence on insecticides like organophosphates and pyrethroids and gaseous insecticides such as methyl bromide and phosphine are effective means of controlling the coleopteran pests, negative effects owing to their repeated use for decades have fostered environmental and human health concerns (Kim *et al.*, 2012).

The use of botanicals is seen to be an effective alternative and suitable for smallholder farmers for preserving stored grain from insect damage. In a study by Ivbijiro (1983), the application of neem seed powder *Azadiachta indica* to weevil infested maize grains prevented oviposition at the high dose while mortality of adult weevils reached 100% within five days.

#### **2.4.4.1 Eucalyptus**

It is one of the most cultivated tree genera globally and has more than 700 species. Eucalyptus species produce a pungent odour even before squashing the leaves which repel insects which according to Brito *et al* (2006) is an insecticidal property. Many studies on the efficacy of Eucalyptus species showed effectiveness in the control of *S. zeamais* in stored grain (Muzemu *et al* 2013, Mulungu *et al* 2007: Modgil and Samuels, 1998). Cimanga *et al* (2002) asserts that leaves of *Eucalyptus globules* cause high mortality of *S. zeamais* while the study by Machingura (2014) revealed that integrated pest management involving synthetic chemicals and *eucalyptus citriodora* leaf powder achieved 100% insect pest mortality.

#### **2.4.4.2. *Tagetes minuta* (Southern cone marigold/Mexican marigold)**

In Zimbabwe it is considered a crop weed and leaves can be irritant. Its roots are nematicide and insecticide, leaves are good insecticide effective to against a wide range of crop and soil pests and the whole plant can protect postharvest products against pests. The major

constituent of *T. minuta* is piperitone, which is an antioxidant having insecticidal activity (Dar *et al* 2011).

#### **2.4.4.3. *Jatropha curcas***

*Jatropha curcas* is a widely available tropical plant often used for fencing by many farmers. Its seed oil is used as biofuel and its potential as a biopesticide (Nash 2005). However *Jatropha* leaves contain phytochemicals tannin, cardiac glycosides, antraquinones, saponins and flavonoids (Trease and Evans 1998). These have strong activities against plant pathogens and pest (Karamanoil *et al* 2011) killing them by chelating and enzyme inhibition.

#### **2.4.4.4 *Lantana camara* (lantana/ black sage)**

This is a highly invasive shrub, forming dense thickets and repels insect pests in households. It is very effective in the control of *S. zeamais* in maize (Daisy 2014).

#### **2.4.4.5. *Lippia javanica***

It is commonly known as Lemon Bush, Fever Tea tree. It's a woody shrub found throughout eastern and southern Africa. It is used in pre- and postharvest management and ecto-parasite control on livestock. The plant is high on essential oils with fumigant effect and has contact toxicity of Perillaldehyde and Ipsdienone against *S. zeamais*. It is easily propagated from seed or cuttings and can be invasive. *Lippia javanica* have been used in controlling aphid population on cabbage (*Brassica capitata*) by 24.65%. The plant also has antibacterial, antifungal, antiprotozoal and insect-repellent activity and seems to repel antestia bug (Akunne *et al* (2013). According to Tapondjou *et al* (2005), *L. javanica* have also been evaluated to contain toxic substances against many microbes and insect pest.



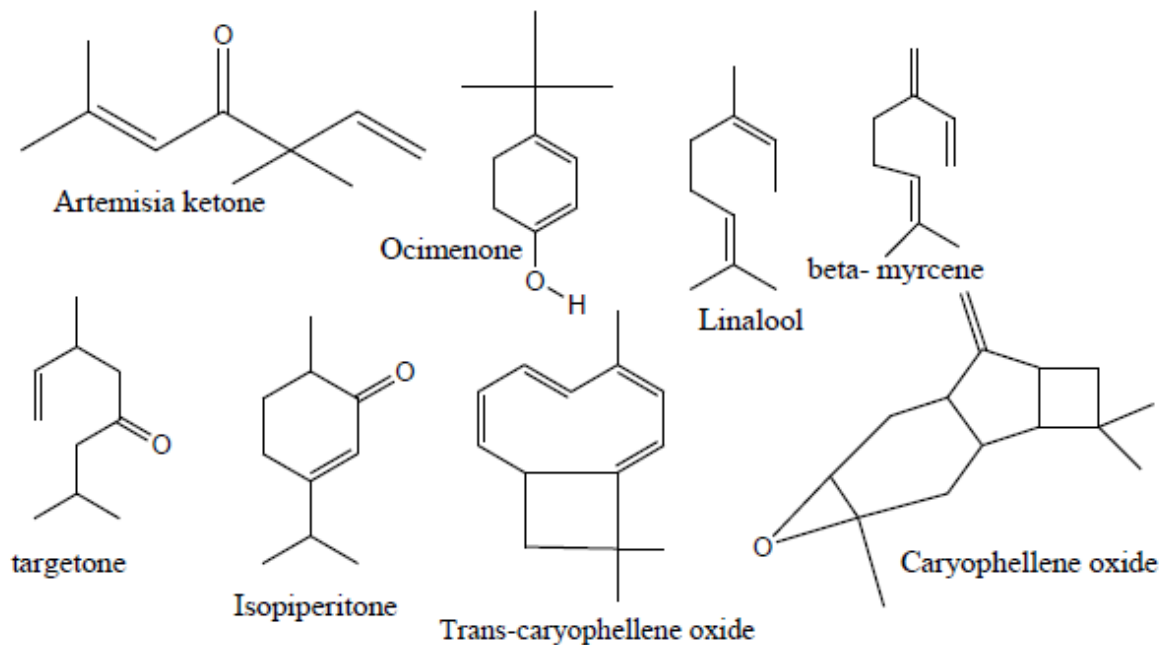
**Figure 2.3 *L. javanica* flowering**

Family: Belongs to Verbenaceae

It is a multi-segmented, hardy untidy shrub of the open grass and bushveld and it gives off an intense lemon scent when crushed. It is used for food, medicine, crafts and charms in Southern Africa and India. Traditionally the leaves have been used for their strong scent as an insect repellent in granaries, cupboards and also on wood to repel insects such as maize and rice weevils (Khare 2007). *L. javanica* leaves contain essential oil osdienen, which has been known to repel and intoxicate insects. The essential oil is rich in ipsdienone, which has been shown to repel even the European tree insect pests, pine shoot beetle and ash bark beetle (Pooley, 1998). According to Nzira (2009), combined presence of coumarone, gavanoids and essential oils in *L. javanica* have an additive effect on the repellent against insect pests. Also according to Chiu (1989) synthetic dusts like cypermethrin 1% dust is effective in protecting stored grain thereby reducing loss of grain weight. Hall (1990) and Parwada *et al* (2012) reported that ground plant extracts act by dehydrating and suffocating the weevil and also by reducing weevil movements thereby resulting in reduced grain damage and weight loss. Research by Aslam and Suleman (1999) showed that *L. javanica* leaf powder reduces relative humidity on the surface of grain inhibiting lying of eggs and larva development of weevils.

### **2.5.1 Chemical composition**

According to Chagonda *et al* (2000), *L. javanica* samples collected from three locations in Zimbabwe showed high amounts of limonene. Essential oils in *L. javanica* include myrcene, ipsenone, myrcenone, tagetone, linalool, isopiperitenone and limonene. Experiments by Shikanga and Combric (2010) revealed that infusions of *L. javanica* have high antioxidant activities. Essential oils in *L. javanica* have twelve compounds which vary according to ecological variations and population or chemotipic races however; myrcenine is the major component (Lukwa *et al* 2009). The essential oil has activity against primary and secondary postharvest pathogens. Polar extracts of *Lippia* species have potential as environmentally friendly alternatives for the control of various insect pests



**Figure 2.4 Structures of some of the major constituents of *L. javanica* oil.**

### 2.5.2 Parts used

Twigs can be used as insect repellants in grain stores. The essential oil is rich in ipsdienone, which has been shown to repel European tree insect pests, pine shoot beetle ash bark beetle (Pooley, 1998). However in this study, dry leaves were used where fresh leaves were dried and ground and sieved to a smooth powder and then used both in pre- and postharvest products. Leaves contain essential oils (oils- citral, neral and geranial) citrial and campor. The plant has also been used tropically for treating in strong concentrations, scabies in livestock. The lemon bush is rich in volatile oils including mycene, caryophyllene, linalool, cymene and ipsdienone and is farmed commercially in South Africa and Kenya.

## CHAPTER 3

### MATERIAL AND METHODS

#### 3.1 Study site

The experiment was carried out at farm 77 Chenjiri small scale commercial area in Sanyati. Sanyati is located in Mashonaland west province in northern central Zimbabwe about 136 km northwest of Kadoma. The coordinates of Sanyati are 17° 57' 0, 00" S, 29° 18' 27.00 E. Latitude 17.9500; Longitude 29.3073. (Mean annual rainfall 761mm. Mean annual temperature 21.6°C.

#### 3.2 Experimental design and treatments

The experiment was laid out in a Completely Randomised Design. Five treatments replicated 4 times. Actellic Gold Dust was used as a positive control (Table 3.1).

##### 3.1 Table of treatments

Treatment	Pesticide used	Rate of pesticide in 1kg maize
1	Untreated	0g
2	<i>L. javanica</i>	0.5g
3	<i>L. javanica</i>	10g
4	<i>L. javanica</i>	15g
5	Actellic Gold Dust	1g

##### 3.3. Source of *S. zeamais*, *L. javanica* and Actellic Gold Dust.

*S. zeamais* was obtained from Harare GMB laboratory and starved for 24 hours. Maize was locally grown and supplied by a farmer while *L. javanica* leaves were collected from surrounding bushes and Actellic Gold Dust was bought from the local market.

#### 3.4. Trial management

##### 3.4. 1. Containers used.

Plastic bottles were perforated right round using small nails. The holes were tiny such that no weevil could pass through them.

##### 3.4.2. Preparation of maize for the study

Twenty kilograms of Pannar 413 maize variety was obtained from a local farmer. The maize was winnowed and thoroughly selected removing all damaged grain and placed in deep freezer for 2 weeks to disinfect basal infestation. The maize was then air dried under protection to avoid re-infestation by insects. One kilogram of maize was introduced into each of the perforated twenty plastic bottles. Pannar 413 was used in the study because it is most susceptible to the maize weevil.

### 3.4.3. Preparation of the leaf powder

*L. javanica* fresh leaves were collected from the surrounding bushes. The leaves were dried in a well ventilated room at room temperature for 2 weeks. The dry leaves were then pounded to a smooth powder using the Kasa Maria pestle and mortar.

### 3.4.4. Experiment

Varying dosages of *L. javanica* leaf powder (0.5g, 10g, 15g (Adams scale was used) 1g Actellic God Dust and untreated maize) were introduced into the 5 plastic bottles containing maize and were replicated four times. A total of 20 bottles were used. Thorough mixing of grain and leaf powder was done to ensure uniform distribution of the leaf powder over the grain surface. The mixture was allowed to settle before introducing ten pairs of starved weevils into each bottle. A total of 500 weevils were used. The bottles were tightly closed and stored in the room in completely randomised design for three weeks.

## 3.5. Data collection

### 3.5.1. Weevil mortality

Weevil deaths from each bottle were counted on day 22 and recorded. Insects were certified dead on seeing motionless legs when insect was tempered with or teased using a small smooth brush. Maize weevil mortality was assessed as:  $(\text{Number of dead insects} / \text{Total number of insects}) \times 100$ . To account for death by natural conditions other than the effect of the *L. javanica* leaf powder, data on percentage adult weevil mortality was corrected using Abbott's (1987) formula thus:

$$PT = (PO - PC) / (100 - PC)$$

Where,

PT = Corrected mortality (%)

PO = Observed mortality (%)

PC = Control mortality (%)

### 3.5.2. Grain damage

Damage assessment was done using count data on treated and untreated grain after storage for the period of three weeks. After three weeks, number of damaged grains (grains with characteristic holes) from each container were counted and recorded.

### 3.5.3. Reproduction of weevils

10 pairs of adult weevils were introduced to 1kg maize in each of the 20 bottles. On day 22, all the weevils in each container were counted including dead weevils and recorded. The

initial number of weevils was subtracted from the total. The difference reflected reproduction of *S. zeamais*.

#### **3.5.4. . Weight loss of grain**

Damaged grains were separated from undamaged grains. These were counted and then weighed. The undamaged grains were separately counted and weighed also. Percentage weight loss was calculated, using FAO (1985) method as follows:

$$\% \text{ Weight loss} = (UxNd - DxNu / Ux(Nd + Nu) \times 100)$$

Where,

U= Weight of undamaged grain

Nd = number of damaged grain

D = Weight of damaged grain

Nu = number of undamaged grain

#### **3.5. Statistical Analysis**

Analysis of variance (ANOVA) was done using Genstat version 14. The means were separated using LSD at 5% level of significance. Data was transformed using square root transformation before being analysed.



## CHAPTER 4

### RESULTS

#### 4.1 Effects of *L. javanica* leaf powder on weevil mortality in stored maize.

There were significant differences among all treatments on the mortality of *S. zeamais* in stored maize ( $P < 0.05$ ). However, there was no statistical difference between *L. javanica* at 15g and the synthetic pesticide (Actellic Gold Dust) which had the highest mortality of 85.25% and 97.25% respectively. The lowest mortality was obtained at untreated followed by 0.5g with 40.25% and 10g with 53.25%.

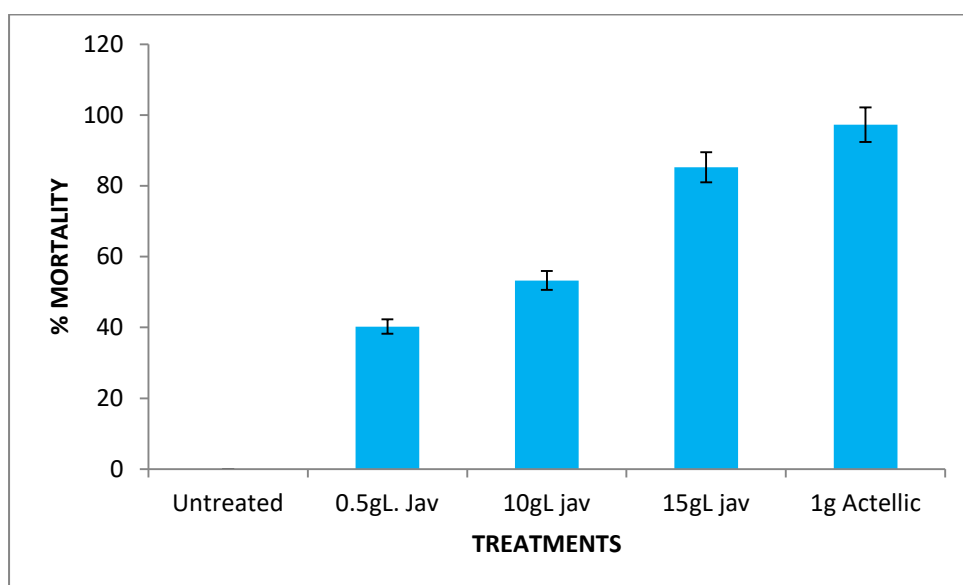


Figure 4.1 Effects of *L. javanica* leaf powder on weevil mortality in stored maize.

#### 4.2 effects of *L. javanica* on grain damage by *S. zeamais* in stored maize

There were significant differences among all treatments on grain damage by *S. zeamais* in stored maize ( $P < 0.05$ ). However, there was no statistical difference between *L. javanica* at 15g and the synthetic pesticide (Actellic Gold Dust) which had the lowest number of damaged grains of 4 and 2 respectively. The highest number of damaged grains of 357 was obtained at untreated followed by 0.5g with 90 damaged grains followed by 10g with 67 damaged grains.

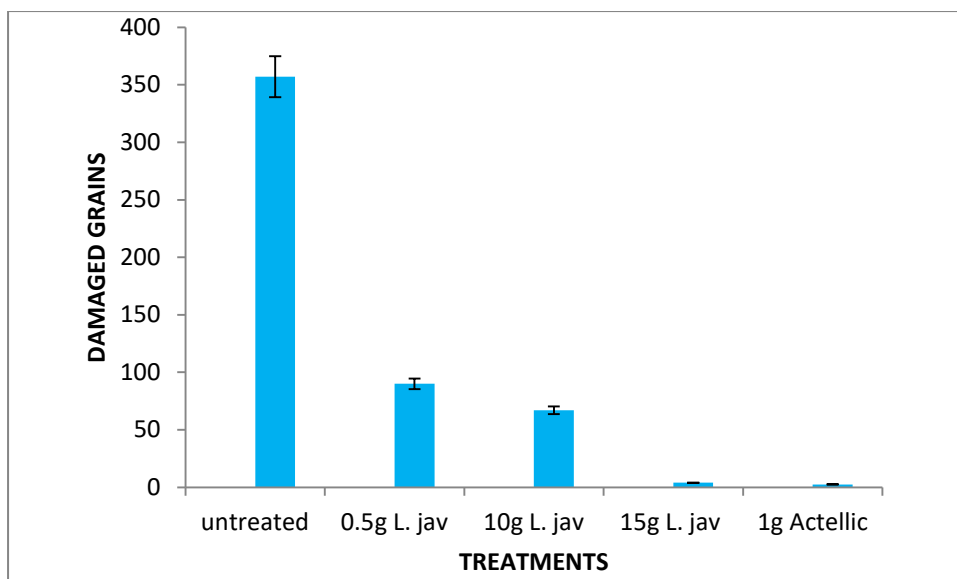


Figure 4.2 Effects of *L. javanica* leaf powder on grain damage by *S. zeamais*

### 4.3. Effects of *L. javanica* leaf powder on reproduction of *S. zeamais* in stored maize

There were significant differences among all treatments on the reproduction of *S. zeamais* in stored maize ( $P < 0.05$ ). However there were no statistical difference between *L. javanica* at 15g with the synthetic pesticide (Actellic Gold Dust) which had the lowest reproduction of 1.3% and 0 respectively. The highest reproduction was obtained at untreated followed by 0.5g with 31.5% and 10g with 8.5%

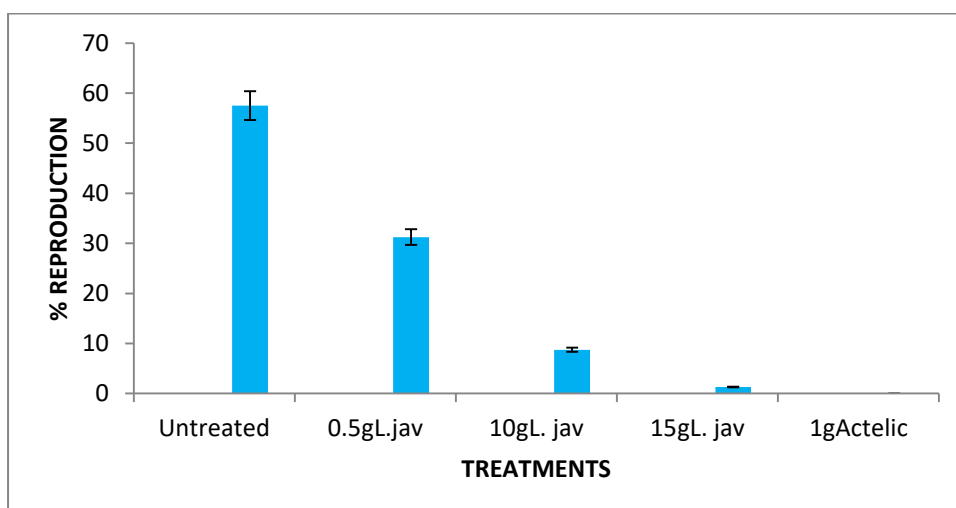
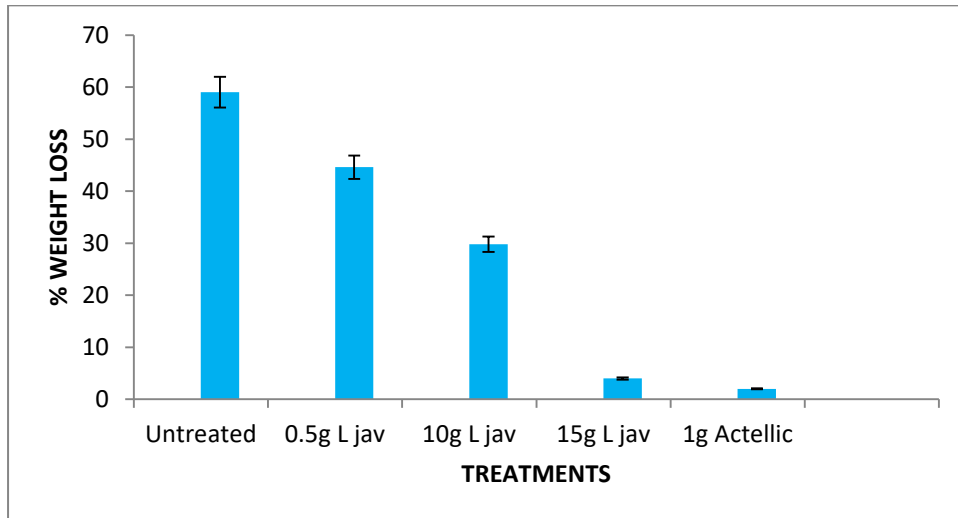


Figure 4.3 Effects of *L. javanica* on weevil reproduction

#### 4.4 Effects of *L. javanica* leaf powder on weight loss on stored maize.

There were significant differences among all treatments on weight loss due to damage by *S. zeamais* in stored maize ( $P < 0.05$ ). However there were no significant differences between *L. javanica* at 15g and the synthetic pesticide (Actellic Gold Dust) which had the lowest percentage weight loss of 4% and 2% respectively. The highest percentage weight loss was obtained at untreated followed by 0.5g with 44.6% and 10g with 29.8%.



#### 4.4 Effects of *L. javanica* leaf powder on weight loss on stored grain

## CHAPTER 5

### DISCUSSION

#### 5.1. Effects of *L. javanica* on mortality of *S zeamais*

Results from this study indicate that *L. javanica* leaf powder can be effectively used to control *S. zeamais* in stored maize. The results showed that mortality was dose dependent as more weevils were killed at high dosage levels. This agrees with sentiments by Khare (2007), which reveal that *L. javanica* leaves contain essential oil osdienen, which has been known to intoxicate insects, as such *S. zeamais* adult cannot survive in grains treated with optimal rates of Actellic Gold Dust and *L. javanica* leaf powder. Although the synthetic pesticide has higher mortality percentage, according to Mkenda et al (2015), plant pesticide treatments are more cost effective to use than synthetic pesticide as the marginal rate of return for the synthetic is no different from the untreated control. On the other hand the use of *L. javanica* facilitates ecosystem services at the same time effectively managing *S. zeamais* by killing. The labour cost of collecting and processing abundant plants in surrounding bushes are less than the cost of purchasing synthetic pesticides.

#### 5.2. The effects of *L. javanica* leaf powder on grain damage by *S. seamais*.

The results from this study revealed that the leaf powder and concentration level have significant effect on grain damage by *S zeamais*, decreasing with the increase in dosage of the leaf powder. At the rate of 15g/kg, *L javanica* leaf powder can reduce grain damage as effective as Actellic Gold Dust at label instruction. This concurs with the research on *Eucalyptus grandis* (Musundire et al 2014), *T. minuta* (Muzemu et al, 2013) *Jatropha curcas* (Constance et al 2013), *Lantana camara* (Furusa, 2008), *L. javanica* (Gadzirai et al 2006) as botanical grain protectants in powder form used to reduce weevil infestation. Also according

to Bekele et al., (1997), botanical pesticides represent an important potential for integrated pest management programs in developing countries as they are based on local materials. Plant materials with insecticidal properties provide small scale farmers with chemicals that are locally and readily available, affordable, relatively less poisonous and less detrimental to the environment for pest control reducing damage of grain as said by Talukder & Howse, (1995).

### **5.3 Effects of *L. javanica* on reproduction of *S. zeamais***

Results from this study revealed that *L. javanica* leaf powder can suppress egg production on *S. zeamais*. The leaf powder contains caryophyllene which suppresses ovipositional activities. Also negative effects on ovipositional rates results in fewer numbers of insects in treated grain. These leaf extracts negatively affect oviposition rate, fertility of eggs or larval growth and development of hatched eggs or a combination of two or all of these factors as given by Bell *et al*, (1990); resulting in fewer number of insects in the treated grain. This concurs with the findings by Aslam and Suleman (1999) that *L. javanica* leaf powder reduces relative humidity on the surface of grain inhibiting laying of eggs and larva development of weevils in stored maize.

### **5.4. Effects of *L. javanica* on grain weight loss**

Results from this study showed that as number of damaged grains reduces, weight loss decreases. Weight loss was highly observed on low dosages of *L. javanica* leaf powder and untreated grain. The results support the finding of (Kham and Marwat, 2004) who reported that the leaves bark and seeds of certain plants protect grain from damage by storage pests. There was significant decrease in grain weight loss in higher levels of dosage of treatments as compared to the untreated negative control. Minimal grain damage was observed on treated grain leading to little weight loss when compared to the untreated negative control and the same level as the positive control of Actellic Gold Dust Among the *L.*

*javanica* leaf powder treatment rates, highest grain weight loss was experienced in the maize grain treated with 0.5g over the 21 day exposure to *S. zeamais* whilst the grain treated with 15g *L javanica* leaf powder and the synthetic Actellic Gold Dust had least grain weight loss. High grain weight loss can be attributed to the low weevil mortality and high weevil survival as well as reproduction of the weevils resulting in high weevil population leading to higher grain damage hence high grain weight loss. The findings are in agreement with Chiu (1989) who observed that synthetic dusts like cypermethrin 1% dust is effective in protecting stored grain thereby reducing loss of grain weight. Hall (1990) and Parwada *et al*(2012) reported that ground plant extracts act by dehydrating and suffocating the weevil and also by reducing weevil movements thereby resulting in reduced grain damage and weight loss. The leaf powders of *L javanica* could also have reduced grain weight loss due to the fact that they reduce the relative humidity on the surface of the grain thereby inhibiting egg laying and larval development of the weevils.

## **CHAPTER 6**

### **6.0 Conclusion and recommendations**

*S. zeamaize* mortality increased as *L. javanica* leaf powder rates increased and can be used as natural pesticide in maize storage and can significantly reduce grain damage and reproduction of the maize weevil. The effective recommended rate of *L. javanica* is 15g/kg. Increase in rates can be of great help and will have no costs to farmers since *L javanica* is in abundance in the area. For the adoption of this technology, *L. javanica* should be air dried and ground into smooth powder and admixed with grain at 15g/kg at the beginning of the storage season.

## References

Abbott, W.S. (1951). A method of computing the effectiveness of an insecticide. *Journal of Economic Entomology* 18, 265-267.

Akunne, C.E., Ononye, B.U. and Mogbo, T.C. (2013) Evaluation of the Efficacy of Mixed Leaf Powders of *Vernoniaamygdalina* (L.) and *Azadirachta indica* (A. Juss) against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Advances in Bioscience and Bioengineering*, 1, 86-95.

Anjarwalla P.,Belmain S.,Sola P.,Jamnadass R.,Stevenson P.C.(2008). Handbook on Pesticidal plants. World ForestryCentre(ICRAF), Nairobi,Kenya.

Argyropoulou C., Daferara D. Tarantilis, P.A. Fasseas C. And Polissious M. (2007). Chemical composition of the essential oil from leaves of *L. citiodora* H.B.K.(Vebeaceae) at two development stages. *Biochemical systematic and Ecology*, 35: 831-837.

Ashworth,J.R. (1993). The biology of *Hestia elutella*. *Journal of stored Product Research* 29: 291-303.

Aslam M. and Suleman M. (1999). Pest management of storedfarm commodities. *The Nation*, 9: 5-5.

Bekele, A.J. Obeng-Ofiori, D. And Hassanali, A. (1997). Evaluation of *Ocimum kanjana* (*Ajabangira*)

Bell, A.E., Fellows, L.E. and Simmonds, S.J. (1990).Natural products from plants for the control of insect pests. In Hodgons, E. and Kuhr, R.J. (ED). *Safer insecticide development and use*. MaecelDekker, U.S.A.

Brito, J.P., Oliveira, J.E. and Bortoli, S.A. (2006). Toxicidade de oleos essenciais de *Eucalyptus* spp. Sobre *Callosobruchus maculatus* (Fabr, 1775) (Coleoptera: Bruchidae). *Revista de Biologia e Ciências da Terra* 6, 96–103.

Campel, J.F., (2002). Influence of seed size on exploitation by the rice weevil, *Sitophilus oryzae*. Journal of insect behaviour 15, 420-445.

Chagonda L.S., Makanda C.O., Chalchat J.C. (2000). Essential oils of wild and cultivated *L. javanica* (Spreng) and *Lippia oatesii* (Rolfe) from Zimbabwe. J. Essent. oil Res. 12(1) 1-6.

Charles, A Charles Adarkwa, Daniel Obeng -Ofori, Sabine Proyell, Matthias Scholler, Christoph Reichmuth, Carmen Buettner (2007): Potential of the parasitic wasp, *Lariophagus distinguendus* (Forster) (Hymenoptera:Pteromalidea) as a biological Control Agent for *Sitophilus zeamais* Motschulsky (Coleoptera:Curculionidae) in stored Maize.

Cimanga, K., Kambu, K., Tona, L., Apers, S., De Bruyne, T., Hermans, N., Totte, J., Pieters, L. and Vlietinck, A.J. (2002). Correlation between chemical composition and antibacterial activity of essential oil of some aromatic medical plants growing in the Democratic Republic of Congo. Journal of Ethnopharmacology 79, 213-220.

Daisy, O. (2014). Grow your own pesticidal plants. African Dryland Alliance for Pesticidal plant technologies (ADAPPT).

FAO/WHO, (1980). Pest Residues in Food. *Joint meeting of the FAO Panel of Experts on Pesticide Residues in Food and the Environment and the WHO Expert Group on Pesticide Residues, Rome, 6-15 October 1980.*



FAO (1997). <http://www.fao.org/inpho/maize> (Internet information Accessed on 23 August, 2007)

FAO STAT (2009). Food and Agriculture Organization of the United Nations, FAOStat. <http://faostat.fao.org/docrep/016/i2727e/i2727e00.htm>

Gadzirayi.C.T., Mutandwa, E. and Chikuvire T.I. (2006). Effectiveness of maize cob powder in controlling weevils in stored maize grain. *Afr. Stud. Q* 8:22-26

Giga,D.P.,Smith,R. H.(1985).Oviposition markers in *Callosobruchus maculatus* (F) and *Rhodesianus*(pic.)9Cleopectera: Bruchidae): asymmetry of interspecific responses. *Agric. Ecosyst Environ*12:229-233.

Golob, P. and Hanks, C.(1990). Protection of farm stored maize against infestation by *Prostephanus truncatus* in Tanzania. *Journal of Stored Products Research* **26**, 187-198.

Hall, D.W. (1970). Handling and storage of food grains in tropical and sub tropical areas. FAO. Rome. Italy.

Hill,S.D. (1987). *Agricultural insect Pests of the tropics and their control*. 2<sup>nd</sup> edition. Cambridge University Press 30-50 pp

Ivbijiro, M.F.(1990). The efficacy of seed oil of *Azadirachta indica* juss and *Piper guineense* schum and thonn on the control of *Callosobruchus maculatus*f. *Insect Science and its application*.11:2, 149-152.

Jacob,S. and Calvin D. .(1988). Weevils on stored grain. Entomological Note, College of Agricultural Science. Pennsylvania State UniversityUS Department of Agriculture. 2001.

JilaniJilani, G. and Ahmad, H. (1982). Safe storage of wheat at farm level. *Progressive Farming* **2**, 11-15.

Jones, F.J.W. and Jones, M.G. (1966). Pest of field Frogs. Edwards Anold Ltd London pp305-310.

Kamanula,J.,Sileshi,G. W., Belmain, S.R., Sola,P.,Mvumi,B.M.Nyirenda,S.P. and Stevenson,P.C.(2011). Farmers insect management practices and pesticidal plant use in the protection of stored maize and beans in SouthAfrica, *International Journal of Pest Management*,**57**,41-49.

KaramanoilK.Bouligaraki P.,Constanantinidou H.I.A., Lindow S. E. (2011). Polyphenilic compounds on leaves limit iron availability and affect growth of epiphytic bacteria. *Ann. Appl. Boil.* 159:99-108.

KassKassa, Adane (2003), Development and testing of mycoinsecticides based on submerged spores and aerial conidia of the entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisoplae* (Deuteromycotina: Hyphomycetes) for control of locusts, grasshoppers and storage pests.

Khare, V. M. Kachare,B.V. Andpatil,C.S.(1987). Effect of vegetable oils on pulse beetle (*Callosobruchus chinensis*) in pigeonpea. *Current Research Reporter.* 3; 2, 53-58.

Kis-Taumas, A. (1990). Study on the production of possibilities of botanical pesticides in Developing African countries. UNIDO, Viena Australis.

Longstaff, B.C.(1981). Biology of the grain species of the genus *Sitophilus* (Coleoptera, Curculionidae): A critical review. *Protect Ecol.* 2:83-130.

Lorini Lorini, I., Bacalthuk B., Beckel, H., Deckers, D., Sundfeld, E., dos Santos, J. P., Biagi, J.D., Celaro, J.C., Faroni LRD'A, Bortolini L, de OF, Sartori M.R, Sartori, M. R., Elias M. C., Guedes R.N.C., da Fonseca, G.R., Scussel, V.M. (2006) (eds.). *Proceedings of the 9th International Working Conference on Stored Product Protection, 15 to 18 October 2006, Campinas, Sao Paulo, Brazil. Brazilian Post-harvest Association-ABRAPOS.*

Lukwa N., Molgaard P., Furu P and Bogh C(2009). *Lippie javanica* (Burm F spreng; its general constituents and bioactivity on mosquitoes. *Trop Biomed* 26(1); 85-91

Lupina, T. and Cripps H., (1987). The photoisomers of piperine. *Journal Analytical Chemistry*, 70(1):112-113

Mabett, T. (2007). Feed your crop and fight the pest: African farming. March/April pp. 19-20

Macfarlane McFarlane, J.A. (1989). Guidelines for pest management research to reduce stored food losses caused by insects and mites. Overseas Development and Natural resources Institute Bulletin No. 22. Chatham, Kent, UK.

Machingura J.,(2014). Insecticide susceptibility status of *Prostephanus truncatus* (horn) and *Sitophilus zeamais* (Motschulsky) in Zimbabwe and assessment of enhancement of grain protection through incorporation of Eucalyptus leaves.

Manica Post (2014) Post Harvest losses. July 25).

Mkenda, P.,Mwanauta, R.,Stevenson,P.C., Ndakidemi, P., Mtei,K and Belmain,S.R.(2015). Extracts from field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides. PLoS ONE. 10(11):e0143530.

Modgil,R. Samuels, R(1998). Efficacy of mint and eucalyptus leaves on the physico-chemical characteristics of stored wheat against insect infestation. Food/Nahrung 42:303-308.

Morris, M.I. (2001). Assessing Benefits of International Maize Breeding Research: An overview of Global Maize impact study: In Pingoli , P.L.(ed). CIMMYT 1999-2000. Meeting world maize needs, Technological Opportunities and Priorities for the public sector. Mexico D.F. CIMMYT. 25-27

Mulungu,L.S.,Lupenza, G., Rueben, S.O.W.M., Misangu, R.N.(2007). Evaluation of botanical products as stored grain protectant against maize weevil, *S. zeamais* ( L) on maize. J. Entomol. 4: 258-262.

Murata, M. Imamura, T. Miyanoshita,A. (2008). Infestation and development of *Sitophilus* species in pouch-packed spaghetti in Japan- Journal of Economic Entomology, 101:1006-1010

MurdMurdock, L.L., Shade, R.E., Kitch, L.W., Hnesing, W., Moar, O.L., Chamblish, E.E., Wolfson, J.L. (1997). Post Harvest Storage of Cowpea in Sub-Saharan Africa. In: Singh, B.B., Mohan Raji F.R., Dashed K.E., *et. al.*, editors. Advances in Cowpea Research. IITA, Ibadan, Nigeria: IITA/JICAS Publication; 1997. 302-312 pp.

Musundure, R., Mazodze, F., Macheka, L., Ngadze, R., Mubaiwa, J., Manditsera, F. (2013). *Eucalyptus grandis* and *Tagetes minuta* leaf powders effectively protect stored maize against *S. zeamais* without affecting grain organoleptic properties.

Mutiro, C.F., Giga, D.P. and Chetsanga, C.L (1995). Post Harvest damage to maize in small farmers stores. Zimbabwe Journal of Agricultural Research, 30; 1, 49-58

Muzemu, S., Mvumi, B.M., Nyirenda, S.P.M., Sileshi, G.W., Sola, P., Kamanula, J.F., Belmain, S.R. and Stevenson, P.C. (2012). Pesticidal effects of indigenous plants extracts against aphids and tomato red spider mites. African Crop Science Conference Proceedings, 10, 169-171.

Mwine, T.J. Phd thesis. (2011). Evaluation of pesticidal properties of *Euphorbia tirucalli* L. (Euphorbiaceae) against selected pests. Ghent University, Belgium.

Nash, J.M. (2005). Crop prevention and storage in cool temperate climates. Oxford Pergamon Press, pp. 54-57.

Norman, A.G. (1995), corn and corn improvement. Academic Press Inc pp 149-150.

Nuepane, F.P.(1995) Review of Agricultural entomology country profile-Agricultural entomology in Nepal CAB,International.

Nyirenda, S.P., Sileshi, G., Belmain S.R.Kamanula, J.F., Mvumi, B., Sola P., Nyirenda, G.K.C. and Stevenson, P.C.(2011). Farmers ethno-ecological knowledge of vegetable pests and pesticidal plant use in northern Malawi and eastern Zambia. African Journal of Agricultural Research, 6, 1525-1537.

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

Parwada C., Gadzirayi C., Karavina C., Kubiku F., Mandumbu R. and Madumbu B.Z.(2012). *Tagetes minuta* formulation effect *Sitophilus zeamais* (weevils) control in stored maize grain. International Journal of Plant Research, 2(3): 65-68. DOI: 10.5923/j.plant.20120203.04

Pooley E. (1998). A Field Guide to Wild Flowers of the Highveld Strunk. Cape Town Pp 560.

Rouanet, G. (1992). Maize. The Tropical Agricultural Maize. Macmillan Press Ltd London.

Sauza E.L.D., Lima E.D.O., Freire K. Sousa C.P (2005). Inhibitory action of some essential oils of some essential oils and phytochemicals on the growth of various moulds isolated from foods. Braz. Archive. Biol.technol.48 (2).245-230.

Sinha, R. N.,(1984). Effects of weevil(Coleoptera, curculionidae) infestation on abiotic and biotic quality of wheat. J. Econ. Entomol. 77: 1483-1488.

Shikanga E. A. and Combrick S. (2010). Southern African *Lippia* herbal infusions. Journal of Botany Volume 76 (3):567-571.

Shikanga E, Regnier T, Combrinck S, Botha B. Polar *lippia* extracts as alternatives for the postharvest control of Guazatine®-resistant strains of *Penicillium digitatum* in citrus. *Fruits*. 2009; 64(02):75-82

Talukdar, F. A. And House, P.E.(1995). Evaluation of *Aphonamaxis polytachya* as a source of repellents, antifeedants and protections

Tapondjou AL, Adler C, Fontem DA, Bouda H, Reichmuth C (2005). Bioactivities of cymol and essential oils of *Cupressus sempervirens* and *Eucalyptus saligna* against *Sitophilus zeamais* Motschulsky and *Tribolium confusum* du Val.J. *Stored Prod. Res.* 41: 91-102.

Trease, G.E., Evans, W.C. (1998). *Pharmacognosy*. Macmillan publishers, Brailiar Tiridel, Canada.

Trematerra, P., Valente A., Athanassiou C.G., Kavallieros N.G. (2007). Kernel-kernel interactions and behavioural responses of the adults' maize weevil *S. zeamais* Motshusky (Coleoptera: Curculionidae). *Applied Entomology and Zoology*, 42(1): 129-135.

Throne, J.F. 1994. Life history of immature maize weevil (Coleoptera: Curculionidae) on corn stored at constant temperature and relative humidity in the laboratory. *Environmental Entomology* 23, 1459-1471

Van Wyk, B.E. and Gerick, N.(2000). *People's plants. A guide to useful plants of Southern Africa*. Briza Publications. Pretoria.

Wari, C.M. Kega, V.M. and Onyango, R. (1990). Evaluation of an improved pyrethrum formation in the control of maize pest in Kenya. *Review of Agricultural Entomology* 18:15-17.

White, N.D.G. (1995). Insects, mites and insecticides in stored grain ecosystems. Marcel Dekker. NY, U.S.A., PP 132-168.

Wiedenmann, R. N. And Smith, J.W. (1997). Novel associations and importation biological control: the need for ecological and physiological equivalencies. *Insect Sci. Applic.* 17: 51-60.



## APPENDICES

### Appendix 1:

1. Analysis of variance on the effect of *L javanica* leaf powder on weevil mortality five weeks after treatment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREAT	4	211.8972	52.9743	183.46	<.001
Residual	15	4.3312	0.2887		
Total	19	216.2285			

### Appendix 2:

2. Analysis of variance on the effect of *L javanica* on number of damaged grain

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREAT	4	762.539	190.635	116.02	<.001
Residual	15	24.646	1.643		
Total	19	787.185			

### Appendix 3:

3. Analysis of variance of effect of *L javanica* leaf powder on weevil reproduction 5 weeks after treatment

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREAT	4	137.2347	34.3087	42.21	<.001
Residual	15	12.1912	0.8127		
Total	19	149.4258			

**Appendix 4:**

4. Analysis of variance on the effect of *L javanica* leaf powder on weight loss five weeks after treatment.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
TREAT	4	478102.	119526.	79.10	<.001
Residual	15	22666.	1511.		
Total	19	500768.			