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EFFICACY OF VELDT GRAPE (*Cissus quadrangularis* L.), LANTANA *(Lantana camara* L.) AND AFRICAN MARIGOLD (*Tagetes erecta* L.) AGAINST MAIZE WEEVIL (*Sitophilus zeamais Motschulsky*) IN STORED MAIZE (*Zea mays*. L) GRAIN.

MAGARAI REJOICE

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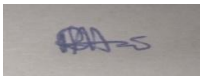
A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE BACHELOR OF AGRICULTURAL SCIENCE HONORS DEGREE IN CROP SCIENCE 2026

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SUBMISSION DATE: JUNE 2026

DECLARATION

I, Magarai Rejoice, (B231185B) declare that this dissertation herein is my original work and has not been submitted elsewhere for any degree or award. All sources used have been duly acknowledged.

Student's Signature:  Date: June 21, 2026.

SUPERVISOR

I have supervised the research project for the above mentioned student and I am convinced that the research can be submitted.

Supervisor's Name: Mr. J. Chitamba

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Chairperson's signature …… Date: June 21, 2026

ABSTRACT

Post-harvest losses caused by the maize weevil (*Sitophilus zeamais Motschulsky*) pose a serious threat to food security among smallholder farmers in Zimbabwe and across sub-Saharan Africa. Reliance on synthetic pesticides such as pirimiphos-methyl and deltamethrin is constrained by high cost, limited availability, environmental pollution, health risks, and the growing problem of pest resistance. This study evaluated the insecticidal efficacy of leaf powders derived from three locally available botanicals, namely *Lantana camara, Tagetes erecta,* and *Cissus quadrangularis*, against *S. zeamais* in stored SEEDCO 555 maize grains under laboratory conditions. A Completely Randomised Design (CRD) with six treatments replicated four times was used over an eight-week storage period. Treatments included individual botanical powders applied at 20 g per 200 g of maize grain, a mixed biopesticide at the same rate (6.67 g of each botanical), Actellic Gold Dust as a positive control, and an untreated negative control. Data were collected fortnightly on weevil mortality, grain damage, and grain weight loss. Results showed that all botanical treatments significantly ($p = 0.001$) increased weevil mortality, and reduced grain damage, and grain weight loss compared with the untreated control. *Tagetes erecta* and *Lantana camara* performed best among botanicals, achieving the highest weevil mortality (9.94 and 9.81 dead weevils per bottle, respectively) and the lowest grain damage and weight loss by week 8. Actellic Gold Dust remained the most effective treatment across all parameters. The study concluded that *Tagetes erecta* and *Lantana camara* leaf powders have the greatest potential as affordable, environmentally safe alternatives to synthetic pesticides for protecting stored maize from *S. zeamais* in smallholder farming contexts.

Keywords: *Sitophilus zeamais*, maize weevil, botanical pesticides, *Tagetes erecta*, *Lantana camara*, *Cissus quadrangularis*, stored maize, grain protection, postharvest losses, smallholder farmers.

DEDICATION

To those who have stood by me every step of the way, your constant love, encouragement, and belief in me have been my greatest strength. This work is lovingly dedicated to my cherished family, friends, and the wider community, whose guidance and support nurtured in me a deep respect for education and lifelong desire to learn. I also dedicate this to my spouse and children, whose patience, understanding, and sacrifices made it possible for me to follow my dreams. Your love and support mean more to me than words can truly express.

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LIST OF ACRONYMS AND ABBREVIATIONS

H_0	Null Hypothesis
%	Percentage
Mm	Millimetres
^oC	Degree Celsius
CRD	Completely Randomised design
G	Grams
Kg	Kilograms
ANOVA	Analysis of Variance
GenStat	General Statistics
LSD	Least Significance Difference
df	Degrees of freedom
SED	Standard Error of Difference
CV	Coefficient of Variation

CHAPTER 1

INTRODUCTION

1.1 Background of the study

"Maize (*Zea mays.* L.) is the most important staple crop" as mentioned by Rapholo Seroto Edith, **(**2020), and it plays a central role in national food security (Gadzirayi et al., 2006) Beyond its direct consumption by humans, maize is extensively used as livestock feed and as a key raw material in the food processing and confectionery industries.(Kasirayi and Munamato, 2016) It forms the basis of many traditional and commercial food products, including mahewu, breakfast cereals, spaghetti, cornflakes, maize meal, rice blends, and roasted maize snacks commonly known as *maputi* (FAO, 2019). The crop is predominantly grown in Natural regions I, IIa and IIb, where favorable climatic conditions allow yield of up to 50-70%. In contrast, production in the drier Regions III, IV and V contributes approximately 40-50% of the total output (Agritex, 2018). On global market, maize is ranked the third on most important cereal crops after wheat and rice (Mpombeye *et a*l., 2025a).

Under normal rainfall conditions, maize harvesting typically occurs between April and May, after which the grain is stored for household consumption and future planting. Despite considerable production levels, substantial post-harvest losses occur, particularly among smallholder farmers, due to insect infestation during storage (Muzemu *et al*., 2013). These losses degrade both the quality of grain and its quantity and may also compromise seed viability for subsequent planting seasons (Matthew *et al*., 2023) Insect pests of stored grain pose a serious threat to maize preservation, with significant implications for food security and economic stability, especially in resource limited communities (Rajashekar *et al*., 2014; Samuel, n.d.).

Smallholder farmers in Zimbabwe face major challenges in protecting stored maize from insect damage due to the high cost and limited availability of synthetic pesticides. Furthermore, chemical insecticides present hazardous effects to health of users and consumers, they are environmental pollutants, and promote pest resistance when used repeatedly (Obariagbon, n.d.). Consequently, communal farmers experience severe storage losses, which in some cases reach up to 50%, particularly in warm tropical climates, with

average losses estimated at around 20% (Nukenine, 2010; Derera *et al*., 2001; Dhliwayoand Pixley, 2003).

According to (Kasirayi and Munamato, 2016), "grain storage is essential for maintaining food supplies between harvest seasons while preserving grain quality and quantity. For rural households, storage ensures continuous access to food and the availability of seed for the next cropping cycle. Since maize production is seasonal, maintaining adequate reserves is critical to sustaining household's food security throughout the year. "The major insect pest responsible for post-harvest maize losses in Zimbabwe are the larger grain borer (*Prostephanus truncates*), and the maize weevils (*sitophilus zeamais*)" as said by Kern *et al*. (2018) and Mvumi *et al*. (2003).

To manage these pests, economically disadvantages farmers often rely on indigenous knowledge systems that utilize locally available materials and natural processes. These traditional practices remain highly relevant in modern agriculture and have been preserved through generations (Mpombeye *et al*., 2025b). Kasirayi andand Munamato (2016) said "indigenous knowledge, is defined by Chapungu and Sibanda (2015), as that knowledge accumulated over generations of living in a particular or locality and has been vital in responding to environmental challenges, including floods, diseases and pest infestations and their attendant" (Kasirayi andand Munamato, 2016).

Numerous studies have reported the effectiveness of traditional plant-based pest control methods in grain storage. These approaches involves the use of botanical pesticides derived from locally available plant species, which offer a cost-effective and environmentally friendly alternatives to synthetic chemicals (Matthew *et al*., 2023). The application of ethnobotanicals as a grain protectant promotes sustainable pest management while reducing health risks and environmental degradation associated with chemical insecticides.

Globally, maize ranks among the top cultivated cereals because it thrives under a wide range of weather patterns. It supplies significant calories for people and animals and industries convert it into products like starch, sweeteners, cooking oil and bioethanol (Kasirayi and Munamato, 2016). However, maize is highly vulnerable to deterioration during storage, primarily due to insect infestation (Bezabih et al., 2022a). Infestation commonly begins when grain moisture content falls between 18% and 20%, allowing pests such as maize weevils to penetrate and multiply within stored grain. Benson *et al*. (2024) mention that, "the maize weevil stands out as one of the worst pests of stored grain" worldwide and leads to major

financial losses especially in low income nations (Obariagbon, n.d.). When it feeds, grain loses much of its nutritional value and can become contaminated with dangerous toxins and allergens that threaten human health (Parugrug and Roxas, 2008).

In response to these challenges, research has increasingly focused on developing sustainable storage protection strategies that minimise overreliance to synthetic pesticides. The use of plant based pest control methods offers economic, environmental, and health benefits (Phokwe and Manganyi, 2023). Various botanical materials have demonstrated effectiveness in controlling storage pests, including eucalyptus leaves, *tagetes erecta*, garlic (*allium sativum),* neem (*azadirachta indica*) *tephrosia vogelii*, *lantana camara*, *euphorbia tirucalli*, basil, *combretum imperbe ash, cissus quadrangularis and lippie javanica* (Parugrug and Roxas, 2008).

Rajashekar *et al*. (2014) said "there is a need to develop cheaper and safer alternatives for insect pest control, including plant-based products". (Machekano, *H. et al.*, n.d.) and Rajashekar *et al*., (2014) also said "many products of botanical origin have been proved to show insecticidal activity against stored grain insects". Plant extracts have shown ovicidal, repellent, antifeedant and toxic in the insects (Matthew et al., 2023)**.** Rajashekar *et al*. (2014) said, *"*essential oils and their individual constituents have been known to play an important role as protectants of stored grains and proved to possess repellent and insecticidal properties" (Obariagbon, n.d.)

1.2 Problem statement

Limited studies have evaluated and compared the efficacy of *Lantana Camara*, *Tagetes erecta* and *Cissus quadrangularis* as botanical grain protectants against *Sitophilus zeamais* under Zimbabwean storage conditions. While the insecticidal properties of *Lantana Camara* and *Tagetes erecta* have been studied individually, limited research exists on their comparatives efficacy against *Sitophilus zeamais* under controlled conditions in Zimbabwe. Furthermore, no studies have examined the potential synergistic or antagonistic effects when these three botanicals are combined at reduced rates. Commercial synthetic pesticides are expensive, and most small-scale farmers cannot afford them for safeguarding maize in storage. In addition to their cost, chemical pesticides pose serious health risks to users and consumers, negatively affect the environment by eliminating beneficial organisms, and contribute to air and water pollution. In light of these challenges, this study seeks to assess

the most effective botanical pesticide as a sustainable and affordable alternative for controlling *c* infestations in stored maize.

1.3 Justification

Zimbabwe is experiencing increasing food insecurity, partly due to post-harvest losses. The identification of locally available, cost- effective botanical pesticides could significantly reduce these losses and improve household food security among communal farmers. The use of low-cost and locally available botanical pesticides to manage *Sitophilus zeamais* can significantly reduce post-harvest losses while maintaining the quality and quantity of stored maize. This approach has the potential to strengthen household food security and improve nutritional outcomes among smallholder farming communities. The high price of synthetic pesticides makes them inaccessible to most farmers, limiting their ability to protect stored grain. Furthermore, botanical pesticides are biodegradable, environmentally friendly, and align with sustainable agricultural practices.

1.4 Objectives of the study

1.4.1 Main Objective

- To determine the most effective biopesticide for controlling *Sitophilus zeamais* in stored maize grain.

1.4.2 Specific Objectives

- To determine the effects of *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* on the mortality of the *Sitophilus zeamais* in stored maize.
- To determine the effects of *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* on grain damage by *Sitophilus zeamais* during storage.
- To determine the effect of *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* on grain weight loss under storage conditions.

1.5 Research Hypotheses

H_0: *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* do not significantly influence the mortality of *Sitophilus zeamais* in stored maize grain.

H_0: There is no significant effect of *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* on grain damaged by *Sitophilus zeamais*.

H_0: There is no significant effect of *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* on grain weight loss during storage.

CHAPTER 2

LITERATURE REVIEW

2.1. Origin of maize

Maize (*Zea mays.*L.), commonly referred to as corn in some parts of the world, belongs to the grass family Poaceae. Although its exact origin is still debated, most evidence points to Central America as its origin. Historically records suggests that maize was first encountered by Europeans when Christopher Columbus arrived in Cuba in 1492 (Phokwe and Manganyi, 2023). Rotich (2019) stated, "it is believed to have been domesticated from the wild teosinte", a grass known to originate in the region of present-day Mexico thousands of years ago (Sharma et al., 2022). Over time, maize spread across the globe, particularly during the fifteenth century, becoming the most widely cultivated crop worldwide. (Farnham *et al*., 2003).

Today, maize production is dominated by regions such as North America producing 41%, Asia producing 28%, Europe with 10%, and the sub-Saharan Africa produce 6% contributing a small share (FAOSTAT, 2013). The crop was introduced into Africa around sixteenth century, and through trading with the Portuguese. Initially, it was not a major staple, but due to its high yield potential and adaptability, maize gradually replaced traditional crops (Bezabih et al., 2022b). It has replaced crops like African rice (*Oryza glaberrima)* due to its high yielding capacities. Scientific studies, including genetic analyses, have confirmed that modern maize evolved through selective breeding from its wild ancestor, teosinte (Nenna *et al*., 2023).

2.2 Economic importance of maize

Worldwide, maize is a leading cereal crop (Parugrug and Roxas, 2008). It covers a large cultivated area than any other crop in several regions. Across sub-Saharan Africa, maize has overtaken crops like sorghum and millet to become the main dietary staple. Many smallholder farmers use maize as the main source of food but they also use to generate income (Kasirayi and Munamato, 2016; Mboya, 2013)

Most maize harvested is eaten directly by people which makes it critical for food security. The crop is also common animal feed especially for chicken

s since it enhances the yellow colour of egg yolks (Adiaha, 2017). Beyond food and feed, maize supports many industries. It is an input for infant foods, beer production and processed goods including starch, glucose, syrups and alcoholic beverages (Mathew *et al.,* 2023).

Nutritionally, maize is rich in carbohydrates and provides moderate amounts of protein and fats. It also contains essential vitamins such as A, C, K and B-complex vitamins along compounds like beta-carotene and selenium (Gadzirayi *et al*., 2006). Corn can be eaten boiled or roasted and when ground into flour or processed into numerous food products.

2.3. Maize production in Zimbabwe.

In Zimbabwe maize is the main crop that occupies a large portion of cultivated land across different agro-ecological regions. It covers 50-70% of the cropped area in natural regions I, IIa, IIb, and 40-50% of the cropped area in natural regions III, IV, and V (Yewle *et al*., 2024). However, the production levels have been declining in recent years due to factors such as erratic rainfall, raising temperatures, and limited access to inputs such as fertilizer and quality seed.

Maize grows well in soil pH ranging from 5.5-7.5 and requires adequate moisture and warm temperatures throughout its growth stages. Germination typically occurs when soil temperatures range from 10-13ºC with optimal growth occurring at slightly higher temperatures of 16 and 32ºC. Maize yields across all Zimbabwean regions have fallen sharply because of shifts in temperature and rainfall patterns (Kasirayi and Munamato, 2016).

2.4 Storage and Post-harvest Pests

To keep food available year-round, maize must be stored properly. Yet most small-scale growers depend on local storage structures like granaries which usually fail to shield grain from pests and harsh environmental conditions. Materials like polythene bags are also commonly used but are prone to insect and fungal damage (Makaza and Mabhegedhe, 2016).

Chuma (2017) states that, “improved storage technology such as the hermetic metal silos and super grain bags” can be introduced to address these challenges. These technologies help reduce losses by limiting oxygen supply and preventing pest infestation (Chuma, 2017). Modern varieties such as hybrids often require careful handling and storage under controlled conditions to maintain quality and prevent spoilage (Bezabih *et al*., 2022a)

2.5 Post harvest pests in maize

Maize in storage faces heavy damage from several insects. Key pests are the rust-red flour beetle (*T. castaneum* Herbst), Angoumois grain moth, (*S. cerealla* Oliv.), (Nhamucho, 2020) said "the maize weevil (*S. zeamais*) and larger grain borer *(P. truncatus)* (Mpombeye *et al*., 2025a).

2.5.1 Red flour beetle (*T. castaneum*)

T. castaneum is a small reddish insect that feed mainly on the germ of grains, causing contamination and promoting mold growth. It is approximately 3-4mm in length and with the reddish coloration. The eggs are laid externally and have viscous texture, resulting in the adherence of flour particles to the container. The adult and larva primarily consume the cereal's germ. The pest causes harm to seed to seed and grains by consuming them internally, contaminates the grain with excrement, and encourages the growth of molds, rendering the grain unsuitable for human use (Muzemu, 2013).

2.5.2 Angoumois grain moth (*S. cerealella*)

S. cerealella typically infests maize while still in the field, with larvae feeding inside the kernels and reducing grain quality. These larvae mature into adults, which then pupate and emerge as adults themselves. These adults' insects lay eggs on kernels that are not yet affected. Weight and quality decreases due to feeding by moth. Cribs that are affected by this parasite will have kernels with little perforations on the surface (Parugrug and Roxas, 2008).

2.5.3 The larger grain borer (*P. truncates*)

Among stored maize insects, the LGB (*P. truncates* Horn) causes the greatest damage. This pest is a member of the *Bostrichidae* family which mainly includes beetles that bore into wood (Matthew *et al*., 2023). Originally, the Central America was the first to report it as a pest of stored maize, and it's believed that this pest came in Africa in the late 1970s (Farrell, 2002). Both larvae and adults feed aggressively on grains, leading to substantial weight loss and quality deterioration. (Bezabih *et al*., 2022a). Losses caused by larger grain borer are both quantitative and qualitative. Quantitative losses primarily involve reductions in grain weight and volume, with some estimates placing weight loss as high as 26.4% (Parugrug and Roxas, 2008). Qualitative losses include discoloration of grains, off-flavors, and increase susceptibility to fungal and bacterial infections. The damage caused by this insect on maize and dried cassava can reach up to 36-40% and 70-80% correspondingly over a 6-month

storage period. In severe cases, losses can be extremely high, posing a serious uncertainty to food security (Kasirayi and Munamato, 2016).

2.5.4 Maize weevil (*S. zeamais*).

Among other storage pests, the maize weevil is also considered the most damaging. The pest is a threat to stored maize, exacerbating food insecurity among farmers (Mpombeye *et al*., 2025a). It belongs to family *Curculionidae* and is closely related to other weevil's species such as *Sitophilus oryzae* and *Sitophilus granarius.* Adult weevils' species are small typically 2-3.5mm long, with a characteristic elongated snout used for boring into grains. This pest has a densely pitted thorax, prominent legs, and has well developed wings that can fly readily. Adult *S. zeamais* typically display four between pale reddish-brown and orange-brown oval spots on each elytron. Additionally, there are four light reddish brown oval markings on the elytra (Muzemu *et al*., 2013). The long forward projecting rostrum on adult *S. zeamais* carries the mouth parts readily positioned for perforating plant tissue.

The insect has eight segmented antennae which are often carried in an extended position when the weevil is moving. The adult males have average rounded aedeagus with two longitudinal channels dorsally and the females with lateral rounded Y-shaped sclerite pointed. It targets mature maize crops prior to harvest, and also found in rice fields. It has the ability to infest unprocessed and come before wheat, oats, sorghum, and barley. Additionally, the pest has the ability to invade apple fruits while they are being stored. The life cycle of the maize weevil occurs largely within the grain. Female lay eggs inside the grain, sealing the entry hole afterward. The development stage occurs internally within the grain. An adult female burrow into the grains using its rostrum (Khatkar, 2019).

(Aghomo, (2016) said that "it then deposits a small oval white egg and covers the hole as it removes the ovipositor. The hole is sealed with a waxy secretion that creates a plug" (Tyagi *et al*., 2019; Deborah, 2024). (Aghomo (2016) also said "the plug quickly hardens and this provides the only visible evidence that the kernel is infested (Deborah, 2024). Only one egg is laid inside each grain (Deborah, 2024). When the egg hatches into a white, legless grub, it will remain inside the grain and begin to feed on the grain", and subsequently emerges as an adult by tunneling its way out. The larvae of maize weevils are white, fleshy and legless. The eggs, larvae and pupae stages of the maize weevil are all spent inside the kernel and are rarely seen. The adult weevil emerges by biting a circular hole through external layers of the kernel

(Cosmas, 2018). Adult maize weevil feeds and lives between four to five months (Ahmad *et al*., 2022). It is possible for there to be between five and seven generations in a year.

Heat is generated by the insect activities which results in the sprouting of grain, and cause additional damage (Makaza and Mabhegedhe, 2016b). The accumulation of frass, insect cadavers, and the dissemination of post-harvest fungal infection contribute to the deterioration of grain quality, rendering it unsuitable for human eating (Obariagbon, n.d).



Figure 2.1: Maize weevil (Sitophilus zeamais) (Ahmad *et al*., 2022)

When conditions are favourable, S.zeamais can finish its life cycle in roughly 36 days producing several generations yearly. The species passes through five developmental phases: egg, larva, pupa, pre-adult and adult with the larval stages causing the most damage to stored grain (Ahmad *et al*., 2022)

The lifespan can range from 6 to 12 months, depending on environmental factors such as temperature and humidity. “The complete development time of this species averages 36 days” as mentioned by Aghomo (2016).

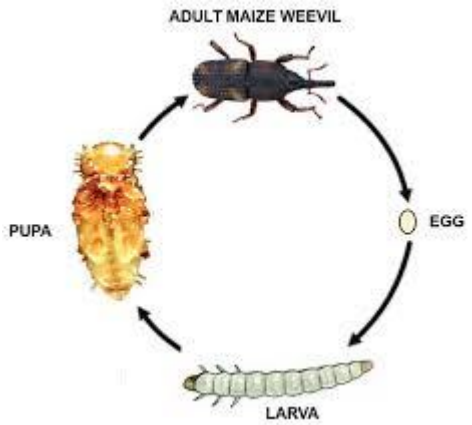


Figure 2.2: Life Cycle of *Sitophilus zeamais* Source: (Solomon and Azare, 1991)

2.6 Hosts of Sitophilus zeamais

While maize is its main target, the maize weevil also infests other grains like wheat, rice and sorghum and under some conditions attacks processed items. It can further damage legumes, almonds, sunflower seeds and products such as pasta (Phokwe and Mangayi, 2023b). Aghomo (2016) said it "commonly attacks standing crops in particular, maize before harvest, storage (Deborah, 2024). Although the maize beetle cannot readily breed in finely processed grains, it can easily breed in products such as macaroni and noodles, and milled cereals that have been exposed to excessive moisture" (Deborah, 2024).

2.7 Detection of damage

Early detection of *S. zeamais* is hard because the insect feeds within individual kernels. Grains that are infested typically have exit holes left by emerging adults. Aghomo (2016) also said "a possible indication of infestation in grain is when they are placed in water and they float to the surface" due to internal damage (Cosmas, 2018; Deborah, 2024). Aghomo (2016) reported that "in large stores of grain, an increase in temperature may be detected (Deborah, 2024). The most obvious sign of infestation is the emergence of adults" (Deborah, 2024). Both larvae and adults feed on grains, reducing them to powder and making them unsuitable for consumption or planting.

2.8 Economic importance of the maize weevils

S. zeamais is considered the main primary pest of stored maize since it can infest and damage intact, whole kernels in storage (Adiaha, 2017). According to Markham *et al*. (1994) and CABI (2005), *S. zeamais* has increasingly become a serious constraint to maize production and storage in many African countries. Both the adult insects and the larvae feed on maize

grains, causing extensive damage by reducing the grain into powder. As the pest feeds, it creates holes in previously healthy grains resulting in loss of grain quality, viability, and market value. Seeds whose embryos have been damaged fail to geminate, thereby affecting future crop establishment.

Ahmad *et al*., 2022 reported that the major damage caused by this pest results from feeding activities of adults as well as the development of eggs, larvae, and pupae inside the grain. Since many smallholder farmers depend on store grain as planting seed, maize weevil infestation poses a serious threat to food security and agricultural productivity. Gadzirayi et al. (2006) and Louwaars and De Boef (2012) observed that nearly 80%of seed used by small scale farmers are obtained from store grain reserves. Infested grains are often characterized by visible emergence holes caused by adult weevils. Under severe infestation, grains may heat up due to increased metabolic activity, sometimes leading to premature germination and further deterioration of grain quality.

2.9 Methods of storage

2.9.1 Temporary storage method of maize

(i) On aerial storage, (Aghomo, 2016) said “maize cobs, sorghum, or millet panicles are sometimes tied in bundles and suspending them from the tree branches, ropes, or inside the house”. Although this method is simple and inexpensive, it is unsuitable for storing very small or large quantities of maize. In addition, it offers limited protection against adverse weather conditions, insect pests, rodents and theft (Bezabih *et al*., 2022b)

(ii) Ground storage -Ground storage is mainly used as a temporary method where harvested grains are left on the ground. This method exposes the grain to insect pests, rodents, domestic animals, and harsh weather conditions. Farmers usually adopt this method when they lack transport or are occupied with other activities that prevent immediate transfer of grain to safer storage facilities (Gadzirayi *et al*., 2006).

(iii) On open timber platforms, (Aghomo, 2016) said “a platform consists mainly of a number of relatively straight poles laid horizontally on a series of upright posts. Grains are stored on platforms in heaps, woven baskets or in bags” he went on to say “in humid countries, fires may be lit under elevated platforms; these dry the produce and deter insects” or other storage pests. This method helps to improve

aeration and reduce moisture circulation, although it may still expose grain to infestation if poorly managed (Yewlw *et al*., 2024).

2.9.2 Long term maize storage methods

(i) Storage baskets (cribs) –traditionally cribs are commonly used in humid regions where grains require continuous ventilation during storage. These structures are usually made from plant materials that deteriorate over time, often requiring replacement after two or three or three years. However, bamboo cribs may last longer if properly maintained. Cribs promote airflow which helps reduce moisture build up and fungal development (Parugrug and Roxas, 2008).

(ii) Calabashes, gourds, and Earthenware pots –small storage containers are mainly used for storing seeds and pulses grains (Deborah, 2024). These containers can be sealed air tightly using clay or wooden corks. When grains are adequately dried to below 12% moisture content, such storage systems effectively reduce spoilage and pest infestation (Phokwe and Manganyi, 2023a).

(ii) Jars- large clay jars are also used for grain storage in some communities. These jars usually have narrow openings and are sealed with clay lids of flat stones. They are mainly kept indoors and are suitable for storing seeds and legumes. To maintain grain quality, the jars should not be exposed to direct sunlight.

(iii) Solid wall bins –are commonly used in dry regions where grains can be sufficiently dried before storage. These bins may be constructed from timber, stone, mud, or clay. Stone bases are preferred because they reduce entry of rodents and termites. Mud or clay silos are often cylindrical or round to withstand pressure from stored grain. Termite mound soil is commonly used because it possesses better binding properties. These structures are durable and can remain functional for 30-50 years if properly maintained.

(iv) Underground storage –are practiced in regions such as India, Turkey, the Sahel, and parts of Southern Africa. Storage pits are mainly suitable for dry areas with low water tables and are intended for long term grain preservations. Their advantages include low construction costs, stable cool temperatures, protection from thieves and reduce insect and rodent problems. However, underground storage also has several disadvantages including poor grain viability, risk of water penetration, development of fermented odors, difficulty in inspection, and dangers associated with carbon dioxide accumulation within the pit (Yewle *et al*., 2024)

2.10 Control of insect pests of stored products

Managing insects' pests has been part of farming since agriculture began, as growers have always had to safeguard harvested crops. Adiaha, 2017 noted that insects' pests inflict heavy losses on stored commodities globally. Infestations usually start in the field prior to harvest and persist throughout storage. Farmers therefore employ both preventative and curative control measures. Preventatives measures include timely harvesting, crop rotation, use of resistant cultivars, good hygiene practices, and maintaining suitable storage environments. Other approaches such as biological, chemical, and botanical control methods are also used to suppress pest populations and reduce grain losses (Deborah, 2024).

2.11 Control of *Sitophilus zeamais*

2.11.1 Cultural methods of storage

The conventional methods are among the oldest approaches used in grain protection because they are relatively simple and affordable. It includes timely harvesting, store sanitation, and use of pest resistant cultivars. Gadzirayi *et al*., 2006 reported that materials such as ash and sand are widely used in African countries to protect stored grain against *S. zeamais.* Although these substances are not directly insecticidal, they fill spaces between grains and restrict insect movement and egg laying. They also act as desiccants by removing moisture from the insect body, eventually causing death through dehydration or suffocation.

Bezabih *et al*., (2022c) further noted that some types of sand rich in quartz damage the cuticle of insect larvae, leading to high mortality rates. Traditional methods such as suspending maize cobs over kitchen fires also help to prevent insect damage through smoke exposure (Mathew *et al*., 2023). Continuous sun drying of maize lowers grain moisture content, thereby reducing pest activity and multiplication. The cultivation of resistant indigenous cultivars also contributes significantly to reduce storage losses. Traditional maize varieties are often less susceptible to maize weevils compared to modern hybrids. Additional varieties to be grown are the ones with robust husk covers, since they give an effective protection against pest infestation, hence minimizing damage to the maize cob in the field. Sharma *et al*. (2022) classified varietal resistance into non-preference, antibiosis, and tolerance. Resistance against post-harvest pests is mainly associated with non-preference and antibiosis mechanisms. Good sanitation practices such as cleaning granaries before storage and sealing airtight bins are equally important in limiting oxygen supply and preventing weevil infestation.

2.11.2 Biological control

It involves the use of natural enemies to manage insect pests. Several beneficial organisms have been studied for the control of *S. zeamais.* According to Phokwe and Mangayi, (2023a) parasitoids such as *A. calandrae, L. distinguendus*, and *T. elegans* are effective natural enemies of maize weevils in tropical regions. These biological control agents are most effective when introduced early during the storage period. Wen and Brower (1994) found that *T.elegans* suppressed maize weevil populations by more than 90%. Repeated releases of *A. calendrae* significantly reduced weevil population build up during prolonged storage. Other biological agents like such as *bacillus thuringiensis* have also shown effectiveness against adult weevils (Anne *et al*., 2011). Cosmas (2018) emphasized that successful biological control depends on understanding the ecology, population dynamics, and life cycles of both pests and their natural enemies.

2.11.3 Uses of insecticides

Chemical treatments are still among the most common ways to control maize weevils. In Africa, organophosphates like pirimiphos-methyl, permethrin, bromophos and fenitrothion have been widely applied to protect grain (Mpombeye *et al*., 2025). Products such as Actellic Super are commonly used by smallholder farmers in several African countries (Adiaha, 2017). Although synthetic insecticides are effective, continuous misuse can lead to pest resistance, environmental contamination, and health risks to human and livestock. Consequently, there is growing interest in safer and sustainable alternatives (Golob, 2002; Ahmed and Yusuf, 2007; Singano *et al*., 2009).

Commonly used protectants in Zimbabwe are Shumba Super Dust, Chikwapuro, Ngwena Yedura, Actellic Super Chirindamatura Dust, Actellic Gold Dust, and Phosphine fumigation tablets utilized in seed houses and commercial storage facilities (Machingura, 2019). These products contain active ingredients such as fenitrothion (C9H12NO5PS), pirimiphos-mentyl (C11H20N303PS, deltamethrin, permethrin and thiamethoxam. These chemicals function by disrupting the insect nervous system. For example, organophosphates inhibit acetylcholine activity at nerve junctions, ultimately causing pest death, while pyrethroids interfere with sodium ion channels leading to paralysis (Machingura, 2019). However, excessive use and incorrect application rates may contribute to resistance development and health hazards among users.

2.11.4 Botanical control of *S. zeamais*

Botanical pesticides come from plants are prized for their ability to kill, repel or medicinally affect insects. They can be made into powders, liquid extracts or dried materials. These options are low-cost, easy to source locally and pose little environmental risk which makes them ideal for small scale farmers (Parugrug and Roxas, 2008). According to Bell *et al*. (2010) pesticidal plants may act through direct toxicity, repellence, feeding inhibition, growth regulation, or suppression of egg laying. Before the widespread use of synthetic pesticides, many plant derived substances such as pyrethrins, nicotine and rotenone were commonly used for pest management (Nenna *et al*., 2023). Plant naturally produce secondary metabolites that protect them from herbivorous insects (Mathew *et al*., 2023). Plant products have an effect on nerve axons and synapses such as pyrethrins, nicotine and picrotoxinin. They also affect muscles, like ryanodine, and respiration, such as rotenone and mammein. Also, they do affect hormonal balance, including juvenile and molting hormone analogues and antagonist. Additionally, they affect reproduction and behavior through attractants, repellents, and antifeedant (Muzemu, 2013).

Neem (*Azadirachta indica)* products have been widely reported to suppress insect reproduction and increase adult mortality. Neem seed powder effectively prevented egg laying and caused complete mortality of adult grain borers within five days (Parugrug and Roxas, 2008). In Zimbabwe and other Southern African countries farmers commonly use plants such as *Eucalyptus grandis*, as stated in the study done by Musundire *et al*. in 2014. The study conducted by Muzemu *et al*. (2013) focused on the species *Jatropha curcas* (Constance *et al*., 2013), *Lantana camara* (Furusa, 2008), and L. The leaves of *Javanica* plant were studied by Gadzirayi *et al*. in 2006. Ethnobotanicals are regarded as an important and appropriate option for small holder farmers to guide their grain against insect attack. In a study conducted by Parugrug and Roxas (2008) it was found that the use of neem seed powder from the *Azadiachta indica* plant on maize grains infested with grain borers resulted in the prevention of egg-laying at a high dosage. Additionally, the mortality rate of adult weevils reached 100% after a span of five days.

The present study focuses on three botanical species namely, *Cissus quadrangularis, tagetes erecta* and *Lantana camara* because of their reported pesticidal properties against storage insect pests.

2.12 Insecticidal plants used in the study

2.12.1 Lantana Camara

L. camara attracts significant research interest due to its wide global occurrence. It possesses various therapeutic and insect killing qualities (Rajashekar *et al*., 2014). Known locally as wild sage or red sage it ranks among the key medicinal plants worldwide (Sharma *et al*., 2000). Studies show Lantana demonstrates insecticidal effects (Phokwe and Manganyi, 2023b), nematicidal properties (Oamar *et al*., 2006) and communities use it traditionally against cancers and tumors. Rajashekar *et al*. (2014) reported that *L. camara* which has high levels of caryopyllene and germacrene D, reduced egg laying in *callosobruchus maculatus*. Similarly, Schmutterer (1990) and Ndomo *et al*. (2009) found that extracts and essential oils from this plant inhibit oviposition and lower fertility in many insect species

2.12.2 Cissus quadrangularis

This species is a perennial vine in the grape family, often called veldt grape and grows across tropical and subtropical Africa. *Cissus quadrangularis* belongs to the *Vitaceae* family. In Zimbabwe it is locally named *muvengahonye*. The plant has a distinctive four- angled stem and typically grows in open woodland, often twining around mopane trees (Cosmas, 2018). Traditional healers use it to treat various ailments especially parasitic worms which explains the local name *muvengahonye*. It also exhibits both medicinal and insecticidal activity. Phytochemical screening shows it contains abundant secondary compounds including flavonoids, triterpenoids, alkaloids, polyphenols and tannins (Parugrug and Roxas, 2008).

2.12.3 Tagetes erecta

Marigolds belonging to the *Tagetes* genus are some of the most popular ornamental flowers grown commercially because of their aesthetic appeal and strong market value. Beyond decoration, they gained research focus for phytoremediation and for producing allelopathic compounds (Mpombeye *et al*., 2025a). Farmers frequently plant them to control plant-parasitic nematodes using them as cover crops in rotations as intercrops or as green manure by plowing in plant residues. Their success as trap crops is well documented and scientists are increasingly exploring their potential as bio-herbicides

Marigolds also yield essential oils that exhibit strong antibacterial and antifungal activity. The fragrance and food industries use these oils extensively and they serve as natural insect repellents. Furthermore, marigold extracts offer a sustainable substitute for chemical pesticides in stored product protection (Phokwe and Manganyi, 2023a). Research has

characterised the chemistry and insect toxic effects of *T. erecta* from various organs such as flowers, roots and leaves. Key constituents found include β-caryophyllene, piperitenone, tetracontane, C33 botryococcane and decane (Sharma *et al*., 2022). According to Ravikumar (2010) hexane-based extracts from *T.erecta* blooms were highly toxic to aphids and fall armyworm (*Spodoptera frugiperda).* Parugrug and Roxas (2008) and Cosmas (2018) likewise noted that *T.erecta* demonstrated repelled maize weevil (*sitophilus zeamais*), though the effect did not last long.

CHAPTER 3

METHODOLOGY AND EXPERIMENTAL DESIGN

3.1 Study site description

The study took place at the researcher's homestead in Karoi Ward 10, Hurungwe District, Mashonaland West Province, located at a latitude of -16.827445 and a longitude of 29.716723. Annual rainfall ranges from 700 mm and 1000 mm. The study region is located within Agro-ecological region IIb of Zimbabwe. The site records average temperatures of 28°C and a mean winter temperature of 18°C. The lab temperature ranges from 25-30°C and relative humidity varied from 65-75% during experimental period. The room was kept aerated throughout the study. The trial was carried out in 2025-2026 season from February to May 2026.

3.2 Experimental design

A Completely Randomized Design (CRD) was adopted for the experiment featuring six treatments: grounded leaves of *Lantana camara, tagetes erecta* and *cissus quadrangularis,* a blend of the three botanical pesticides, Actellic dust as a synthetic control and untreated maize. Each treatment was replicated four times using bottles as experimental units.

3.2.1 Statistical model

The following statistical model was employed on a Completely Randomised Design during the experimental study:

$Yij = \mu + Ti + eij$

Where

Yij = observed value

μ = overall mean

Ti = treatment effect

eij = random error

Table 3.1: Treatments used during the experimental study

Treatment	Description
T1	Maize mixed with *lantana camara* leaf powder applied at 20 g per 200 g of grain
T2	Maize treated with *tagetes erecta* powder at 20 g per 200 g of grain
T3	Maize treated with *Cissus quadrangularis* powder at 20 g per 200 g of grain.
T4	Maize mixed with a combined botanical pesticide at 20 g per 200 g of grain (*lantana camara, tagetes erecta, cissus quadrangularis*) (6.67g of each botanical).
T5	Positive control consisting of 200 g maize treated with 4 g Actellic gold dust, a commercial synthetic pesticide thus synthetic pesticide).
T6	Untreated maize grain (200g)

3.3 Experimental procedure and materials

SEEDCO 555 maize variety obtained from local farmers was used. "The grain was sieved to remove dead seed, dirty and broken particles" following the method recommended by Geresu et al. (2020). "10 kg of grain was randomly sampled and stored in freezer at -4ºC for two weeks to kill any prior sources of the weevils' inoculum and eggs which might be ready pre-existing in the grain" supported by Geresu et al. (2020) . After 2 weeks sub samples of "200 g grain were put in plastic bottles with perforated cloths covers and perforated lids to prevent weevils from escaping and for aeration" supported by Geresu *et al*. (2020). The botanical pesticides leaves, *lantana camara, tagetes erecta* and *cissus quadrangularis* were used. *Lantana camara, tagetes erecta* and *cissus quadrangularis* fresh leaves were collected from the nearby shrubs. The leaves undergo a process of desiccation in a room with good air circulation, maintaining the ambient temperature, between 26ºC and 28ºC for a duration of two weeks. Subsequently, the desiccated leaves were pulverized into a fine powder utilizing the Kasa Maria pestle and mortar.

The powders were sifted through a wire mesh with a size of 0.2 mm in order to create a fine powder. 20 g of each botanical pesticide was used, used per 200 g of maize, with the measurements conducted using the Adams scale. In a mixed treatment, 6.67 g of each botanical was used to make it 20 g of mixed biochemical. The application rate of 4 g of Actellic Gold Dust was determined using proportional calculations based on the prescribed rate of 20 g per kilogram. Untreated maize was placed into plastic bottles, each containing maize, and this process was replicated four times. There was a total of 24 bottles used. To achieve consistent dispersion across the grain surface, a meticulous blending of grain and leaf powder was conducted.

The mixture undergoes a settling process prior to introducing 20 starving *S. zeamais* into each bottle. The initial generation of weevils were collected from a grinding mill. The rearing of unsexed pests was done for two weeks in a controlled environment to come up with a uniform population of pests. *S. Zeamais* undergo a 24-hour period of fasting prior to being exposed to the therapies. The newly emerged 20 weevils were put in each bottle for management. A total of 480 weevils were used. The bottles were securely sealed and stored at room temperature for a duration of eight weeks to assess the extent of damage and death of the *S. Zeamais.*

3.4 Data collection

3.4.1 Maize weevil mortality test

Weevil counts were conducted after every two weeks from the start of the trial for eight weeks. Mortality assessments occurred at week 2, 4, 6 and 8 following weevil introductions to each treatment. A weevil was recorded as dead if remained motionless after gentle stimulation with fine brush. Counts were performed during daylight hours when the weevils showed peak activity due to elevated temperature and humidity. Mortality percentage was calculated by dividing the number of dead weevils by the total weevils introduced then multiply by 100. In order to consider mortality resulting from causes other than the impact of the *Lantana camara*, *tagetes erecta* and *cissus quadrangularis* the leaf powders and the results on the percentage of adult weevil mortality was adjusted using Abbott's (1925) formula as follows:

$$\mathrm{PT} = \frac{\mathrm{PO} - \mathrm{PC}}{100 - \mathrm{PC}}$$

Where,

PT = Corrected mortality (%),

PO = Observed mortality (%)

PC = Control mortality (%)

3.4.2. Grain damage

Grain damage was evaluated by counting both treated and untreated kernels after storage's beginning at 2 weeks and repeating every two weeks for eight weeks. In each container, grains with visible exit holes were counted and the proportion of perforated seeds was calculated as a percentage.

$$\text{Perforated seeds} = \text{number of seeds in a jar} - \text{undamaged seeds}$$

$$\text{Percentage perforated seeds} = \frac{\text{Perforated seeds}}{\text{Total seeds in a jar}} \times 100$$

3.4.3 Grain weight loss

Weight loss percentage was determined by comparing grain mass before and after storage, following the method of Ileke and Oni (2011). Assessment used the Thousand Grain Method as outlined below:

$$\text{Percentage loss in weight} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Mass of grain at the beginning of storage period was compared with mass at the two weeks intervals during experiment.

3.5 Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using GenStat 18th edition. When treatment effects were significant, means were separated using Fisher's Least Significance Difference (LSD) test at the 5% probability level.

CHAPTER 4

RESULTS

4.1 Effects of *Lantana camara, tagetes erecta* and *cissus quadrangularis* on the mortality of *Sitophilus zeamais*

As shown in Table 4.1 treatments had a highly significant effect on weevil mortality (p=0.001). Mortality differed significantly among treatments (p=0.001) with storage time (2-6 weeks). Actellic recorded the highest mortality throughout the experiment (10 at all observation periods), followed by *Lantana camara*, *Tagetes*, *Cissus quadrangularis* and the mixed botanical treatment.

Table 4.1: Effects of *Lantana camara, Tagetes erecta* and *Cissus quadrangularis* on the mortality rate of *Sitophilus zeamais* in stored maize.

Treatments	2 weeks	4 weeks	6 weeks	8 weeks
Lantana Camara	7.39^{b}	8.61^{bc}	9.4^{ab}	9.81^{a}
Tagetes erecta powder	8.35^{b}	9.06^{b}	9.54^{ab}	9.94^{a}
Cissus quadrangularis	8.11^{b}	8.72^{bc}	9.22^{b}	9.62^{ab}
Mixed biopesticide (all biopesticides)	5.08^{c}	5.76^{d}	7.98^{c}	9.42^{b}
Synthetic pesticide (Actellic Gold Dust)	10^{a}	10^{a}	10^{a}	10^{a}
Untreated Control	0^{d}	0^{e}	0^{d}	2.14^{c}
Grand mean	6.49	7.03	7.78	8.49
P-value	0.001	0.001	0.001	0.001
LSD	1.172	0.993	0.94	0.937
CV%	12.2	9.5	8.1	7.4

Based on the range test at 5%, means followed by the same letters on the same column are not different from each other

4.2 Effects *Lantana camara, Tagetes erecta* and *Cissus quadrangularis* on number of grains damaged by *Sitophilus zeamais* during storage.

The significant p-value (p=0.001) indicated that treatments significantly reduced grain damage compared to the untreated control. Grain damage decreased progressively in all botanical treatments as the storage period extends whereas the control treatment showed increasing grain damage over time. Actellic completely prevented grain damage throughout the sampling period (0.0 at all sampling period). Among the treatments, *Tagetes erecta* recorded the lowest grain damage at week 8 (0.197), followed by *Lantana camara* (0,355), *Cissus quadrangularis* (0.712) and the mixed treatment (1.018). The untreated control recorded the highest grain damage (3.714) at week 8.

Table 4.2: Effects *Lantana camara, Tagetes erecta* and *Cissus quadrangularis* on number of grains damage by *Sitophilus zeamais* during storage.

Treatments	2 weeks	4 weeks	6 weeks	8 weeks
Lantana Camara	1.301^{c}	0.934^{b}	0.48^{a}	0.355^{ab}
Tagetes erecta powder	0.95^{b}	0.771^{b}	0.501^{a}	0.197^{a}
Cissus quadrangularis	1.281^{c}	1.012^{b}	0.902^{b}	0.712^{b}
Mixed biopesticide (all biopesticides)	1.537^{d}	1.531^{c}	1.376^{c}	1.018^{c}
Synthetic pesticide (Actellic)	0^{a}	0^{a}	0^{a}	0^{a}
Untreated Control	1.87^{e}	2.689^{d}	3.129^{d}	3.714^{d}
Grand mean	1.156	1.156	1.065	0.999
P-value	0.001	0.001	0.001	0.001
LSD	0.1636	0.2627	0.449	0.459
CV%	9.5	15.3	28.4	30.9

Based on the range test at 5%, means followed by the same letters on the same column are not different from each other

4.3 Effects of *Lantana camara, tagetes erecta* and *cissus quadrangularis* on maize grain weight loss under storage conditions

Table 4.3 confirms a highly significant treatment effect (p=0.001) in reducing grain weight loss. Weight loss generally decreased in all treated grains over the storage period while the untreated control showed a continuous weight loss from 3.993 at 2 weeks to 5.171 at week 8. Actellic completely prevented weight loss (0.0) throughout the sampling period. Among the botanical treatments, *Lantana* and *Tagetes* recorded the lowest weight losses by week 8 (0.604), followed by *Cissus quadrangularis* (1.39) and the mixed treatment (1.258).

Table 4.3: Effects of *Lantana camara, Tagetes erecta* and *Cissus quadrangularis* on maize grain weight loss under storage conditions

Treatments	2 weeks	4 weeks	6 weeks	8 weeks
Lantana Camara	2.678^{bc}	2.266^{b}	1.06^{ab}	0.604^{a}
Tagetes erecta powder	2.392^{b}	2.104^{b}	1.57^{b}	0.604^{a}
Cissus quadrangularis	2.791^{c}	2.53^{c}	2.01^{c}	1.39^{b}
Mixed biopesticide (all biopesticides)	3.493^{d}	3.156^{d}	2.63^{d}	1.858^{c}
Synthetic pesticide (Actellic)	0^{a}	0^{a}	0^{a}	0^{a}
Untreated control	3.993^{e}	4.439^{e}	4.84^{e}	5.171^{d}
Grand mean	2.558	2.416	2.02	1.604
P-value	0.001	0.001	0.001	0.001
LSD	0.4571	0.4282	0.853	0.6636
CV%	12	11.9	28.4	27.8

Based on the range test at 5%, means followed by the same letters on the same column are not different from each other

CHAPTER 5

DISCUSSION

5.1 Effects of Botanical Treatments on Mortality of *Sitophilus zeamais*

Findings from this work showed that every botanical treatment led to significantly higher *S. zeamais* mortality, p = 0.001, than the untreated control during the 8-week storage. Actellic Gold Dust produced 100% mortality, 10 dead weevils per bottle at each assessment, confirming it as the top performing treatment. Among the botanicals, *Tagetes erecta* and *Lantana camara* recorded the highest weevil mortality at week 8, 9.94 and 9.81 respectively, followed by *Cissus quadrangularis* (9.62) and the mixed biopesticide (9.42). The untreated control recorded zero mortality at weeks 2, 4 and 6 rising to only 2.14 at week 8, confirming active weevil proliferation in the absence of treatment (Table 4.1).

The insecticidal activity observed in all botanical treatments stems from their rich secondary metabolite profiles. *Tagetes erecta* contains β-caryophyllene, piperitenone, tetracontane and thiophene derivatives that exert neurotoxic effects by disrupting sodium and potassium ion channels in nerve cells leading to paralysis and death. The insect killing ability of *T. erecta* matches results reported by Parugrug and Roxas (2008), who found it repels and kills maize weevils. Compounds such as β-caryophyllene, piperitenone, tetracontane, and decane in *T. erecta* extracts interfere with insect nervous systems and are toxic to stored product pests (Sharma *et al*., 2022). Ravikumar (2010), as cited in the reviewed literature, further confirmed that hexane extracts from *T. erecta* flowers exhibited strong insecticidal activity. The aromatic oils present in marigold plants also appear to play a role in insect repellence and contact toxicity, which may explain the progressive increase in weevil mortality observed over time in this study.

Strong mortality under *L. camara* treatment agrees with Rajashekar *et al*. (2014), who showed *L. camara* leaves control stored grain pests like *S. zeamais*. Its insecticidal properties are linked to secondary metabolites such as lantadene A and B, ursolic acid, and volatile terpenoids (Sharma *et al*., 2000; Caroprese *et al*., 2011). Abdel *et al*. (2005) also confirmed the insecticidal action of Lantana camara against various stored grain pests. Furthermore, Adebayo and Gbolade (1994) reported that L. camara containing caryophyllene and germacrene D in large amounts exhibited ovipositional suppression on *Callosobruchus maculatus*, suggesting that both contact toxicity and repellence mechanisms contribute to the

observed mortality. These compounds likely penetrate the insect cuticle or are inhaled, interfering with the nervous system and causing paralysis and death. These diverse mechanisms explain the high weevil mortality observed.

Moderate mortality with *C. quadrangularis* at all time point's likely stems from its secondary chemicals including flavonoids, triterpenoids, alkaloids, polyphenols and tannins. These constituents are documented to have insecticidal and feeding deterrent effects on many insects. While less studied in the context of stored grain pests compared to the other two botanicals, the results suggest sufficient bioactivity to cause significant weevil mortality relative to the untreated control.

The combined botanical treatment consistently gave lower mortality than the single plant treatments. This unexpected result could be attributed to antagonistic interactions between active ingredients from the three species which may have diluted individual compounds to levels below their effective dose. Bell *et al*. (2010) noted that pesticidal plants may act through multiple mechanisms including direct toxicity, repellence, feeding inhibition and growth regulation, and that such interactions can be complex. Schmutterer (1990) and Ndomo *et al*. (2009) also confirmed that botanical extracts and essential oils may have varying antioviposition and fertility-reducing effects depending on concentration and combination. A lower individual concentration per plant in the mixture, 6.67 g per botanical versus 20 g for individual treatments, likely reduced the effective dose of each active compound below its optimal insecticidal threshold.

The progressive increase in mortality over the eight week period suggests that the insecticidal effects are cumulative, with sublethal doses accumulating to lethal thresholds (Lipuna and Cripps, 2007). This pattern likely reflects cumulative exposure to botanical toxins as the powders-maintained contact with weevils over extended periods, causing sublethal and lethal effects that accumulated over successive weeks. Matthew *et al*. (2023) noted that plant extracts have ovicidal, repellent, antifeedant, and toxic effects on insects, which may manifest more fully with prolonged exposure. The observed trend is also consistent with the findings of Bezabih *et al*. (2022a), who reviewed the effectiveness of plant-based biopesticides in reducing post-harvest losses in stored grains, noting that efficacy often improves with duration of contact. The lower efficacy of the mixed treatment likely results from antagonistic interactions or dilution of active compounds below effective concentrations, (Schmutterer, 1990; Ndomo *et al*., 2009).

5.2 Effects of Botanical Treatments on Grain Damage Caused by Sitophilus zeamais

Every botanical treatment significantly cut grain damage, $p = 0.001$, relative to the control. At week 8, *Tagetes erecta* showed the least damage (0.197), then *L. camara* (0.355), *C. quadrangulari*s (0.712) and the mixed botanical (1.018). Actellic kept damage at zero throughout while damage in the untreated control rose steadily to 3.714 by week 8 (Table 4.2)

The low grain damage recorded under *Tagetes erecta* and *Lantana camara* treatments is consistent with their high weevil mortality rates and is supported by findings from Phokwe and Manganyi (2023), who reported that medicinal plants provide biocontrol against *S. zeamais* through reduced feeding activity and adult mortality. The reduction in grain damage is a direct consequence of high weevil mortality, as fewer live weevils translates to reduced grain boring and feeding activity. Since adult maize weevils use their elongated rostrum to bore into grains and lay eggs internally (Siwale *et al*., 2009), any treatment that increases mortality will correspondingly limit the number of eggs laid and thus reduce grain damage.

The untreated control showed a continuous and progressive increase in grain damage, consistent with the reproductive capacity and destructive feeding behavior of *S. zeamais*. The maize weevil is regarded as the worst stored grain pest since it infests intact whole kernels (Throne and Eubanks, 2002). Mpombeye *et al*. (2025a) also confirmed that it poses a major risk to stored maize and can create serious food security problems for smallholder growers. Muzemu *et al*. (2013) further noted that storage losses can reach up to 50% in warm tropical climates, and the increasing grain damage trend observed in the untreated control in this study corroborates those findings.

The slightly higher grain damage recorded for *Cissus quadrangularis* compared to *Tagetes erecta* and *Lantana camara* suggests a slower onset of toxic action, possibly because the bioactive compounds in *C. quadrangularis* required longer exposure periods to achieve equivalent levels of weevil suppression. Nevertheless, the significantly lower damage compared to the untreated control highlights its potential utility as a botanical protectant. Bell *et al*. (2010) noted that pesticidal plants may require varying exposure durations and application rates to achieve maximal efficacy depending “on the nature and concentration of active compounds present in the extracts as mentioned by (Michael et al., 2026).

The relatively higher grain damage in the mixed biopesticide compared to individual botanicals parallels the mortality findings and further supports the hypothesis of antagonistic interactions at lower individual concentrations. Obariagbon (n.d.) noted that plant powders and oils exhibit variable efficacy depending on concentration and mode of application, and the dilution effect in the mixed treatment may have reduced overall pest suppression capacity.

5.3 Effects of Botanical Treatments on Maize Grain Weight Loss

Weight loss trends closely matched mortality and damage results. All botanical treatments had significantly less weight ($p = 0.001$) than the untreated control during storage. At week 8, *L. camara* and *T. erecta* both had the lowest lost (0.604%), followed by *C. quadrangularis* at 1.39% and the mixed treatment at 1.858%. The control lost weight continuously rising from 3.993% in week 2 to 5.171% in week 8. Actellic prevented any detectable loss across the trial (Table 4.3)

The weight loss observed in the untreated control is consistent with documented losses attributed to *S. zeamais* feeding activity. Nukenine (2010), Derera *et al*. (2001), and Dhliwayo and Pixley (2003) noted that average losses of around 20% have been estimated under warm tropical storage conditions, and in severe cases losses can reach 50%. The progressive weight loss in the control reflects the destruction of grain tissue by both adults and larvae feeding internally and externally, consistent with the life cycle description of *S. zeamais* in which larvae develop entirely inside the kernel, consuming the endosperm and leaving the grain as a hollow shell (CABI, 2010; Tefera *et al.*, 2010).

The low weight loss under *Lantana camara* and *Tagetes erecta* further confirms their superiority among the botanical treatments. Rajashekar *et al*. (2014) reported that *L. camara* leaf powder effectively managed stored grain pests and reduced associated losses. Similarly, Parugrug and Roxas (2008) documented the insecticidal action of *T. erecta* against storage insects. The chemical compounds in these plants appear to act rapidly enough to suppress weevil populations before substantial grain damage and weight loss can occur.

Although *Cissus quadrangularis* recorded higher weight loss than *Lantana camara* and *Tagetes erecta,* it still provided significant grain protection relative to the untreated control. This suggests a potential role for *C. quadrangularis* in integrated pest management strategies, possibly in combination with other botanicals at optimized individual doses. The mixed biopesticide treatment showed a weight loss value (1.858%) that was higher than the individual botanical treatments, again reflecting the dilution effect noted in the mortality and

grain damage analyses. Bezabih *et al*. (2022a) emphasized that the effectiveness of plant-based biopesticides depends heavily on concentration and preparation method, and that inadequate concentrations of active ingredients are a key limitation of botanical grain protectants.

Collectively, the weight loss data highlight the importance of using botanicals at sufficient individual concentrations to achieve meaningful grain protection. The results align with the broader body of literature showing that plant-based grain protectants can substantially reduce storage losses when properly applied, offering a viable and affordable alternative to synthetic insecticides for resource-constrained smallholder farmers (Matthew *et al*., 2023; Mpombeye *et al*., 2025b; Phokwe and Manganyi, 2023).

5.4 Comparative Performance and Practical Implications

For all three measures, mortality, grain damage and weight loss, *Tagetes erecta* and *Lantana camara* were the top botanical treatments. By week 6 and week 8 their results were close to Actellic Gold Dust indicating that given enough contact time, these plants can offer nearly full protection for stored maize against S. zeamais at 20 g per 200 g grain (Table 4.1, 4.2, 4.3).

Both plants are widely available in Zimbabwe, making them practically accessible to smallholder and communal farmers who lack financial resources to purchase synthetic pesticides (Kasirayi and Munamato, 2016). The use of locally available botanical pesticides is consistent with indigenous knowledge practices documented by Chapungu and Sibanda (2015), who defined such knowledge as the accumulated understanding and skills developed by local communities to cope with environmental challenges such as pests. Mpombeye *et al*. (2025b) similarly highlighted the value of locally sourced botanical formulations as sustainable pest management solutions for smallholder farmers in sub-Saharan Africa.

In addition, these plant-derived treatments present fewer environmental and human health risks compared to manufactured chemicals like pirimiphos-methyl and deltamethrin are potent, they can endanger applicators and consumers, contaminate ecosystems and drive resistance in pest populations with frequent use (Golob, 2002; Ahmed and Yusuf, 2007; Singano *et al.,* 2009). Using botanical grain protectants supports ecofriendly pest control and lowers the dangers linked to continued dependence on chemical insecticides (Amoabeng *et al.,* 2014; Mkenda *et al*., 2015).

The mixed botanical blend underperformed relative to single plant treatments, which has a key implication for field use. This indicates that blending several plants at reduced individual does not automatically create stronger or combined effects. Future work should test improved mixing proportions and increased overall dosages to assess if a combined formulation can equal or surpass single plant effectiveness. Identifying the specific compounds in each species that kill insects would also help develop more effective, shelf stable botanical products

CHAPTER 6

CONCLUSION AND RECOMMANDATIONS

6.1 Conclusion

This study evaluated the insecticidal efficacy of leaf powders derived from *Lantana camara*, *Tagetes erecta,* and *Cissus quadrangularis* against *Sitophilus zeamais* in stored maize grain over an eight-week period. All three botanical treatments significantly ($p = 0.001$) reduced weevil mortality, grain damage, and grain weight loss compared to the untreated control, confirming that the three plant species possess pesticidal properties effective against *S. zeamais*. *Tagetes erecta* and *Lantana camara* were the most effective botanical treatments achieving the highest weevil mortality (9.94 and 9.81 dead weevils per bottle, respectively) and the lowest grain damage (0.197 and 0.355 damaged grains, respectively) and weight loss (0.604% each) by week 8. *Cissus quadrangularis* demonstrated moderate but significant insecticidal activity, offering useful grain protection despite somewhat lower performance compared to the other two botanicals.

The mixed biopesticide treatment, prepared by combining all three botanicals at equal proportions (6.67 g each), consistently recorded lower efficacy than individual botanical treatments across all three parameters. This outcome is likely attributable to a dilution effect reducing each active compound below its effective insecticidal threshold and to potential antagonistic interactions among the combined plant compounds. Actellic gold dust (synthetic positive control) remained the most effective treatment achieving complete weevil mortality and zero grain damage and weight loss throughout the experiment. However, its high cost and associated health and environmental risks make it inaccessible and unsuitable for most smallholder farmers.

Tagetes erecta and *Lantana camara* leaf powders applied at 20 g per 200 g grain represent viable, affordable, and environmentally safe alternatives to synthetic pesticides for the management of *S. zeamais* in stored maize grain among smallholder farmers in Zimbabwe.

6.2 Recommendations

To farmers

- Adopt *Tagetes erecta* and *Lantana camara* leaf powders as affordable and accessible alternatives to synthetic pesticides for protecting stored maize grain against *Sitophilus zeamais*, particularly at an application rate of 20 g per 200 g of grain.

To researchers

- Establish the best application rates for *T. Erecta* and *L. camara* powders in real field or farm storage settings to confirm these lab results and create practical dosing guidelines for growers.
- Investigate the potential synergistic effects of *Tagetes erecta*, *Lantana camara*, and *Cissus quadrangularis* when mixed at higher total rates and varying individual proportions to identify combinations that may produce additive or synergistic efficacy without the dilution effect observed in this study.
- Phytochemical analyses of the three plant species should be conducted to identify and characterize the specific bioactive compounds responsible for insecticidal activity against *S. zeamais*, which would facilitate the development of more standardized and potent botanical formulations.
- Assess the efficacy of these botanicals against other major storage pests found in Zimbabwe including "the larger grain borer (LGB), (*Prostephanus truncatus*. Horn) and the rust-red flour beetle (*Tribolium castaneum*)" as mention by Kern *et al*. (2018) to broaden their applicability in integrated pest management programs.
- Storage duration studies extending beyond eight weeks should be undertaken to determine the longevity of insecticidal activity of *Tagetes erecta* and *Lantana camara* leaf powders given that grain is typically stored for six months or more in smallholder farming systems.
- Field trials under farmer storage conditions.
- Testing on other maize varieties.

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APPENDICES

Appendix 1: Analysis of variance of weevil mortality at 2 weeks

Variate: %_WEEVIL_MORTALITY_AT_2_Weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	253.2099	50.6420	81.34	<.001
Residual	18	11.2065	0.6226		
Total	23	264.4165			

Appendix 2: Analysis of variance of weevil mortality at 4 weeks

Variate: %_WEEVIL_MORTALITY_AT_4_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	277.3964	55.4793	124.07	<.001
Residual	18	8.0488	0.4472		
Total	23	285.4452			

Appendix 3: Analysis of variance of weevil mortality at 6 weeks

Variate: %_WEEVIL_MORTALITY_AT_6_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	259.5090	51.9018	129.72	<.001
Residual	18	7.2016	0.4001		
Total	23	266.7106			

Appendix 4: Analysis of variance of weevil mortality at 8 weeks

Variate: %_WEEVIL_MORTALITY_AT_8_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	194.2517	38.8503	97.58	<.001
Residual	18	7.1668	0.3982		
Total	23	201.4185			

Appendix 5: Analysis of variance of grain damage at 2 weeks

Variate: %_GRAIN_DAMAGE_AT_2_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	8.28069	1.65614	136.51	<.001
Residual	18	0.21837	0.01213		
Total	23	8.49906			

Appendix 6: Analysis of variance of grain damage at 4 weeks

Variate: %_GRAIN_DAMAGE_AT_4_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	16.17664	3.23533	103.47	<.001
Residual	18	0.56285	0.03127		
Total	23	16.73949			

Appendix 7: Analysis of variance of grain damage at 6 weeks

Variate: %_GRAIN_DAMAGE_AT_6_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	24.71142	4.94228	54.10	<.001
Residual	18	1.64435	0.09135		
Total	23	26.35577			

Appendix 8: Analysis of variance of grain damage at 8 weeks

Variate: %_GRAIN_DAMAGE_AT_8_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	38.03302	7.60660	79.70	<.001
Residual	18	1.71800	0.09544		
Total	23	39.75103			

Appendix 9: Analysis of variance of weight loss at 2 weeks

Variate: %_GRAIN_WEIGHT_LOSS_at_2_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	38.29217	7.65843	80.90	<.001

Residual	18	1.70399	0.09467
Total	23	39.99617	

Appendix 10: Analysis of variance of weight loss at 4 weeks

Variate: %_GRAIN_WEIGHT_LOSS_at_4_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	42.43514	8.48703	102.15	<.001
Residual	18	1.49557	0.08309		
Total	23	43.93072			

Appendix 11: Analysis of variance of weight loss at 6 weeks

Variate: %_GRAIN_WEIGHT_LOSS_at_6_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	54.1178	10.8236	32.82	<.001
Residual	18	5.9359	0.3298		
Total	23	60.0537			

Appendix 12: Analysis of variance of weight loss at 8 weeks

Variate: %_GRAIN_WEIGHT_LOSS_at_8_weeks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
PESTICIDES	5	69.6321	13.9264	69.79	<.001
Residual	18	3.5916	0.1995		
Total	23	73.2238			

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