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FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

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Evaluation of the effectiveness of *Bidens pilosa* as a grain protectant against maize weevil (*Sitophilus zeamais*) in stored maize

A dissertation submitted in partial fulfillment of the requirements of the Bachelor of Agricultural Science Honors Degree in Crop Science

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By

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APPROVAL FORM

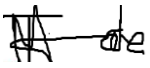
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DECLARATION

I, MELISA KAWONI, registration number B222911B, do hereby declare that this dissertation is my own original work and has not been copied from any source without due acknowledgement of the source.

DEDICATION

I dedicate this dissertation to family and friends in appreciation of their support and encouragement throughout the whole project period.

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First of all, l would like to appreciate Bindura University of Science Education for giving me the opportunity to undertake this program. My sincere thanks go to my main supervisor Dr Goche, for supervising this research project. In addition, I would like to warmly thank my family and friends for the important role they played in their encouragement and support. Above all, I thank the Almighty for giving me the strength to carry out this project.

ABSTRACT

Maize is one of the major staple food crops. However, maize weevil infestation causes large post-harvest losses during storage. Even though synthetic insecticides are frequently used to manage storage pests, there is a growing need for more sustainable alternatives. The study was conducted to evaluate the effectiveness of *Bidens pilosa* powder as a grain protectant against *Sitophilus zeamais* in stored *Zea mays*. The experiment was carried out under laboratory conditions at Astra Campus using a Complete Randomized Design (CRD) with six treatments replicated three times. The treatments consisted of 0g (control), 5 g, 10 g, 15 g, 20 g and 25 g of *Bidens pilosa* powder mixed with 10 g (33 kernels) of clean maize grains. Each experimental unit was infested with fifteen adult maize weevils. Data was collected on maize weevil mortality, grain damage and weight loss after 4, 6, 8 days of storage. The highest mortality was recorded in the 25 g treatment showing that increasing the concentration of *Bidens pilosa* powder significantly has an effect on maize weevil whilst the control treatment recorded the lowest mortality throughout the experiment. Grain damage and weight loss increased rapidly with storage duration in all treatments. The highest grain damage and weight loss were observed in the control treatment, whereas the lowest values were recorded in treatments with 20 g and 25 g of *Bidens pilosa*. Analysis of variance revealed highly significant differences among treatments for all measured parameters ($P < 0.001$). The coefficients of variations were below 20%, indicating the reliability of the results. The study concluded that *Bidens pilosa* powder is effective in controlling maize weevils and reducing grain damage and weight loss in stored maize. Higher concentrations of 20 g and 25 g provided the greatest protection against maize weevil infestation. Therefore, *Bidens pilosa* powder has potential for use as it is affordable, environmentally friendly and sustainable botanical grain protectant

Key words: *Bidens pilosa*, *Sitophilus zeamais*, post-harvest loss, weight loss and grain damage

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA- Analysis of variance

CV- Coefficient of variation

CRD- Complete randomized design

LSD- Least Significant Difference

SED- Standard error of Difference

g- Grams

%- Percentage

P- Probability value

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Maize (*Zea mays L*) is believed to have originated in central Mexico from wild grass and was transformed into a better source by native Americans (Edmeades *et al*., 2017). One of the most significant cereal crops in the world for both human consumption and animal feed is maize. Because of its potential output, it is referred to as the queen of cereals (Nand, 2015). Additionally, it is the main staple food in Africa, making a substantial contribution to the agricultural industry (Tefera *et al*., 2011). About 1.2 billion people worldwide rely on maize as a staple food, in 21 countries, it accounts for more than 20% of the calories consumed by human and providing food for over 300 million people (Okweche *et al*., 2013; Shiferaw *et al*., 2011).

It is grown for both commercial and subsistence purposes and it is typically produced in large quantities that need to be stored for later use (Cosmas, 2018). In countries such as Zimbabwe, maize is essential for producing livestock feed, ensuring household food security and generating revenue for smallholder farmers (FAO, 2021). Significant losses still happen after harvest, particularly during storage, despite intensified efforts to enhance maize production. Insects can infect and kill maize during storage, particularly if it is kept on a farm without the use of pesticides or control over moisture content (Midega *et al*., 2016).

The first invasive forces to engage with grains are post-harvest insect pests linked to cereals like maize. As a result, they pose a significant risk to the preservation of grain quality during storage (Chakraverty *et al*., 2003). In addition, their small size, eating habits and capacity to attack grain prior to harvest make them the most harmful of all (Talukder, 2009). The majority of these insect pests have cosmopolitan and polyphagous feeding habits (Chimoya and Abdullahi 2011). They contaminate their feeding media not only by direct eating but also

by extraction, self-molting and leaving behind dead bodies, body parts, webbing and an undesirable flavor or odor (Offor *et al*., 2014). Most of the time, insect pests also make stored grains, like maize more vulnerable to secondary attacks by diseases that cause illness including fungus (Tadesse, 1997). *Aspergillus niger, A. glaucus, A. candidus, Penicillium islandicum, P. citrinum, Fusarium semitectum* and yeasts are among the fungi that have been reported to be carried or vectored by maize weevils (Smalley, 1989). This is because many of them have hairs and indentations on their exoskeletons.

In tropical region, weevils cause significant damage to stored maize (Compton and Sherington, 1999). According to Adesuyi (1997), the maize weevils, which feed on the germ of maize seeds, attacked and destroyed roughly 24.7% of the corn held in a conventional storage structure after six months. Larvae and adult weevils consume intact maize grains and grind them into powder. The weevil has been reproducing and destroying the grain in the store since the infestation started. The maize weevil's developmental activities frequently cause the grain in their excrement to be severely powdered and tainted. The market value and germination capability of the infected grains are affected because they get punctured and frequently become vulnerable to cracking and mould infection (Adedire, 2001).

Since the 1950s, maize grain has been protected from pests using a variety of storage techniques and pesticides often in the form of fumigants (Subramanyam and Hagstrum, 1995; Olakojo and Akinlosotu, 2004). The use of artificial chemicals to preserve food and food products has been shown to have detrimental effects on human health and results in fatalities (Nwosu and Nwosu, 2012). The extensive use of chemicals as insecticides to control storage pests is said to be of global concern because of the environmental risks involved, the emergence of chemical residues in food, the chemicals' broad-spectrum effects on non-target organisms and the high cost of purchasing the chemicals.

The development of alternative management options, such as the use of resistant maize varieties, plant products and biopesticides against storage pests has become the focus of study due to the growing public knowledge and concern for environmental safety (Abebe *et al*., 2009). Botanicals refer to the chemicals that are produced by plants and repel approaching insects, deter feeding and oviposition on the plant or disrupt the behavior and physiology of insects in various ways (Said *et al*., 2015). There are two primary methods for using these pesticidal plants for post-harvest protection. The first method, which is appropriate for organic farming and farmers in developing nations, involves using plant tissues or crude plants like aqueous or organic solvent directly. The second method involves identifying, isolating and chemically synthesizing the active chemicals (Talukder, 2006). With regard to the usage of plant-derived insecticides, such as plant powders, oils and extracts, current research efforts on the development of storage goods are concentrated more on ecologically acceptable, easily accessible and less expensive control strategies (Adedire, 2001).

Bidens pilosa, commonly known as blackjack is a widely distributed weed found in many tropical and subtropical regions. The plant *B. pilosa* L. is a crucial plant of the Asteraceae family and offers a variety of nutritional and ethnomedicinal applications (Shital *et al*., 2025). Flavonoids, polyacetylenes and essential oils with antimicrobial and insecticidal qualities are among the bioactive substances found in the plant, which has been long used medicinally (Bartolome *et al*., 2013). The usefulness of *Bidens pilosa* as a grain protectant against *Sitophilus zeamais* in stored maize, especially under local storage circumstances, is not well understood despite its availability and traditional use. Alternative control strategies that are safer, more economical and sustainable must be investigated in light of ongoing post-harvest losses brought on by maize weevils and the problems with synthetic pesticides. Thus, the purpose of this study is to evaluate the effectiveness of *Bidens pilosa* as a grain protectant

against maize weevils (*Sitophilus zeamais*) in stored maize. The study seeks to improve post-harvest losses for smallholder farmers.

1.2 Problem statement

For many people, particularly smallholder farmers, maize is a staple grain and a significant source of income. Insect pest infestation causes a significant amount of maize to be lost during storage, despite efforts to boost production. These post-harvest losses compromise national attempts to promote sustainable agricultural development, lower farmer earnings and jeopardize household food security. The maize weevil (*Sitophilus zeamais*), which feeds and reproduces inside grains, is one of the most damaging pests of stored maize. Serious quantitative and qualitative losses, seed viability, grain weight losses, contamination with frass and powdery residues are all consequences of this insect infestation. The use of synthetic chemical pesticides has been a major strategy for controlling maize weevils. Even while these substances work well, there are a number of issues with their ongoing. Some smallholder farmers do not have access to commercial pesticides and many cannot afford them. Furthermore, inappropriate use of synthetic can result in pesticide residues in food that has been preserved, pollute the environment and endanger human and animal health.

Alternative grain preservation techniques that are safe for people and animals accessible locally and environmentally beneficial and are therefore becoming more and more necessary. Because they are less harmful to people and animals and are simple for rural agricultural communities to employ, botanical insecticides made from plants have drawn interest as viable substitutes. Due to its bioactive chemicals, *Bidens pilosa*, a common weed found in many areas, has been shown to have insecticidal qualities. Nevertheless, there is little scientific data regarding its efficacy as a grain protectant against maize weevils in stored maize, despite its widespread availability and traditional use. Thus, the aim of this study is to

investigate how well *Bidens pilosa* works as a grain protectant against maize weevils in stored maize.

1.3 Justification

Post-harvest losses in maize due to insect infestations are major challenges, especially in developing countries where proper storage facilities and access to commercial pesticides are limited. Insect pests such as maize weevils have contributed to significant damage leading to reduced food availability, economic losses for farmers and increased vulnerability to food security. Early studies suggest that the plant extracts and powders from *Bidens pilosa* may have toxic, repellent or growth-inhibiting effects on various insect pests. However, there is lack of comprehensive research evaluating its specific effectiveness as a protectant of stored maize under different storage conditions. Investigating the insecticidal potential of *Bidens pilosa* can help develop a sustainable, low-cost alternative to synthetic pesticides for smallholder farmers. If proven effective, *Bidens pilosa* could be integrated into post-harvest pest management strategies, contributing to improved grain storage, reduced weight losses and enhanced food security.

1.4 Aims and Objectives

1.4.1 Aim

- To evaluate the effectiveness of *Bidens pilosa* as a grain protectant against maize weevils (*Sitophilus zeamais*) in stored maize.

1.4.2 Objectives

- To evaluate the impact of different concentrations of *Bidens pilosa* powder on maize weevil mortality.
- To determine the extent to which *Bidens pilosa* powder reduces grain damage and weight loss on maize storage.

1.5 Research hypotheses

H_0: There is no significant difference on the effect of different concentrations of *Bidens pilosa* powder on maize weevil mortality.

H_0: There is no significant difference on the effect of *Bidens pilosa* on grain damage and weight loss in stored maize.

CHAPTER 2: LITERATURE REVIEW

2.1: Overview of stored grain pests

According to Babarinde *et al*. (2008), insect pests are the primary cause of both quantitative and qualitative degradation of stored goods because they compete with humans limited food resources through direct feeding or by creating favorable conditions for microorganisms. According to (Abbas *et al*., 2014; Sori, 2014, Olorunmota *et al*., 2021; Suleiman, 2021), insect infestations of stored goods pose a significant danger to food security and storage entomology in the tropics. According to Onuminya *et al*. (2018), the damage may also lead to a decrease in the number and quality of cereal grains that are stored. Hagstrum *et al*, (2012) stated that stored-product pests are broadly categorized into primary and secondary pests based on their feeding behavior and capacity to infect intact grains. The population of stored grain pests is also significantly influenced by environmental conditions. In a short amount of time, ideal humidity and temperature can boost pest populations (Rees, 2004).

2.2 Maize Weevils *(Sitophilus zeamais*)

In most tropical and subtropical regions, *Sitophilus zeamais* is the main storage insect pest that causes the most harm to maize grains while they are being stored by small-scale farmers (Danho, 2002). They frequently cause problems in the fields of cereal grains in the southern and temperate zones, but if given the chance, they will contaminate the final goods. Although they have been recorded as a pest of cassava, rice, sorghum and wheat, they prefer maize. The devastation caused by maize weevils has been reported to range from 20 to 90% in untreated maize (Issa *et al*., 2011). The typical length of the maize weevil is 3mm (Siwale, 2007). It has four reddish stains on the elytra and varies in color from dull red-brown to black (Alleonia and Ferreira, 2006). Temperature affects the maize weevil's lifetime. Cooler climates have a longer life cycle than warmer ones (Cash, 2011). When an adult female

maize weevil bites into grain, deposits her eggs, seals the hole with a waxy (gelatinous) secretion, infestation takes place (Siwale, 2007). The maize weevil is regarded as the primary storage pest because it can completely damage a sound grain (Kanyamasoro *et al*., 2012). According to Abebe *et al*. (2009), it causes losses in maize grains that are considerably over 80% in untreated grains and 20% in treated grains. Due to their intense feeding habits, maize weevil adults and larvae can seriously harm maize grains (Kim and Kossou, 2003).

The weight of grains decreases as a result of the burrowing into the grains and feeding activities of the hatched progeny, which are the most obvious impacts of the maize weevil chewing on the grains. When stored at a moisture content greater than 15%, maize grain becomes more susceptible (Dari *et al*., 2010). As a result, mould that typically grow on grains at high relative humidity introduced mycotoxins (Zunjare *et al*., 2015). Consuming weevil-infested maize grains poses a health concern since aflatoxin can contaminate damaged grain (Pingali and Pandey 2001 and Kankolongo *et al*., 2009). When consumed in excess, aflatoxins in diet can be fatal (Akowuah, 2015).

2.3 Grain Storage and Post-Harvest Losses

One of the primary causes of food insecurity for smallholder farmers in developing nations is grain storage loss, which also contributes significantly to post-harvest losses (Manandhar *et al*., 2018). Philips and Throne, (2010) reported that preliminary storage losses are caused by bug and pest infestations, insufficient storage capacity and grain losses that add up to 20% of total production. Post-harvest quantitative lost during storage has been calculated to be between 15% and 25% (Ashish *et al*., 2018). Kumar *et al* (2017) found that insects including the lesser grain borer (*Ryzopertha dominica*), maize weevil (*Sitophilus zeamais*) and red flour beetle (*Tribolium castaneum*) can easily damage and eat stored grains. Due to their affordability, traditional grain storage methods like mud granaries and cribs are frequently

utilized in rural regions; yet, they typically offer limited protection against stored pests (Tefera *et al*., 2011).

2.4 Conventional Grain Protectants and their limitations

According to Tapondjou *et al*. (2002), synthetic pesticides significantly reduced post-harvest losses brought on by insect pests. Many conventional insecticides have been shown to be effective against curculionids, especially *S. zeamais*. For several months, stored maize grain can be shielded from *S. zeamais* damage by dusts of malathion, chlorpyrifos methyl, fenitrothion, methacrifos or pirimiphos methyl (Organo-phosphorus compounds) and deltamethrin (synthetic pyrethroids) (Longe, 2016). Brown, (1978) and Pery *et al.* (2013) stated that although these synthetic insecticides are effective, they can also have negative effects which include the emergence of resistance strains, the recurrence of main pests, secondary pest outbreaks and lingering effects on grain that has been stored. The use of synthetic chemical pesticides had numerous detrimental effects (Lee *et al*., 2001). Vasudha *et al*. (2012) explained that synthetic insecticides have intrinsic toxicities that put both the environment and consumer health at risk. Since plants are a rich source of bioactive compounds, there is a need for plants that could offer viable substitutes for the pest control drugs now in use (Rajashekhar *et al*., 2012). Furthermore, phosphine treatment-induced resistance in insects is a major worry (Bell and Wilson, 1995; Daglish and Collins, 1999 and Benhalima *et al*., 2004).

2.5 Botanical Grain Protectants

Botanical insecticides have long been promoted as appealing alternatives to synthetic chemical insecticides for pest management (Mishra and Dubey, 1994). Isman, 2006 stated that botanical pesticides are the most appropriate for post-harvest food protection in the context of organic food production. Plant tissues or crude products, including extracts from

organic or aqueous solvents, are employed directly as protectants for goods that are held in several nations (Talukder, 2006). Because of the active compounds in them, botanicals reported controlling the insects in a number of methods, including repellents and antifeedants, toxicants, chemosterilants and growth regulators (Guru *et al.*, 2022).

Higher plants produce a broad range of secondary metabolites, including phenolics, terpenes, alkaloids, lignans and their glycosides according to Lingampally *et al*. (2025). Therefore, in addition to being essential components of the plant's defense system, these bioactive compounds are also promising structural models for the development of lead molecules, which may be used as novel insect pesticides (Lingampally et al., 2025). Research has shown that plant powders and extracts can significantly reduce insect population growth, grain damage and weight loss when applied at appropriate concentrations (Abubakar *et al*., 2018). Isman, (2020) stated that plant-derived compounds act on multiple physiology pathways simultaneously, making it more difficult for insects to develop resistance.

2.6 Botanical Description and Distribution of *Bidens pilosa*

Bidens pilosa is an annual weed belonging to the Asteraceae family that grows in various tropical and subtropical locations (Idris *et al*., 2023). The plant is believed to have originated in tropical America, even though it is today extensively distributed throughout tropical and subtropical regions of the world, including Africa, Asia and Latin America (Bartolome *et al*., 2013; Xuan and Khanh, 2016). *Bidens pilosa* is highly adaptable and thrives in a wide range of ecological conditions and produces a large number of seeds makes it highly invasive and persistent in agricultural ecosystems (Xuan and Khanh, 2016). Bartolome *et al*. (2013) stated that *Bidens pilosa* has been used traditionally in herbal medicine for the treatment of numerous ailments, including infections, inflammation, wounds and digestive disorders.

2.7 Phytochemical Composition of *Bidens pilosa*

The insecticidal properties of *Bidens pilosa* are attributed to its rich phytochemical composition. Deba *et al*., (2008) reported the presence of alkaloids, flavonoids, terpenoids, phenolic compounds and essential oils in various parts of the *Bidens pilosa* plant. In *Bidens pilosa*, several phytochemicals have been linked directly or indirectly to insecticidal activity through multiple physiological and biochemical mechanisms (Idris *et al*., 2023; Olawale *et al*., 2025). Waititu *et al*., 2024; Li *et al*., (2021) revealed that polyacetylenes such as 1-phenylhepta-1,3,5-triyne exhibit strong insecticidal activity that can lead to paralysis and death of insect pests. Flavonoids such as quercetin and luteolin found in *Bidens pilosa* exhibit antifeedant, growth-inhibiting and toxic effects on insects thus reducing the feeding behavior and the development (Idris *et al*., 2023).

Kehinde, 2024 stated that phenolic compounds including caffeic acid derivatives, contribute to repellent and toxic effects on insects. Furthermore, Ramabulana, (2020) revealed that phenolic compound interferes with the insect digestion by binding proteins and enzymes thus reducing nutrient absorption. The synergistic action of these compounds enhances the overall insecticidal potential of *Bidens pilosa*, making it effective against a range of stored product insect pests (Isman, 2006). Botanicals materials may act as repellents, discouraging insects from feeding or ovipositing on treated grains (Phokwe *et al*., 2024; Isman, (2006)

2.8 Evidence for insecticidal, repellent and pesticidal activities

A key study assessed the insecticidal activities of methanolic extracts of two weedy plants leaves *Bidens pilosa* and *Rumex dentatus* L. at different concentrations which were tested against three stored grain pests, Rice weevil (*Sitophilus orzyae*), Saw- toothed grain beetle (*Oryzaephilus surinamensis*) and Bean weevil (*Acanthoscelides obtectus*) compared with neem oil, a commercial product (Ahmed *et al*., 2021). Under laboratory conditions, *Bidens*

pilosa extract caused significant mortality, although mortality was lower than that produced by the other tested weed and also by the commercial neem oil at a comparable concentration. In that study, mortality increased with both concentration and exposure time (Ahmed *et al.*, 2021).

The development of repellents as alternatives to insecticides has expanded in recent years. However, their use in isopod pest control is limited. Beyond direct mortality, there is some evidence of repellent effect. Among them, (*E*)-7-phenyl-2-heptene-4,6-diyn-1-ol was isolated and identified as a repellent from the root of *Bidens pilosa* (Masashi *et al*., 2023). While isopods are not typical stored grain pests, the results show *Bidens pilosa's* secondary metabolites can influence insect behavior.

Although insecticidal and antifungal activity is shown, evaluation of its effectiveness as a protectant in stored maize, including against maize-specific pests for example *Sitophilus zeamais* remains underexplored and could be a niche research opportunity. Given the prevalence of storage pests in sub-Saharan Africa and the demand for eco-friendly and low-cost solutions, exploring *B. pilosa* is timely.

CHAPTER 3: MATERIALS AND METHODS

3.1 Study site

The experiment was carried out in the Biology Sciences Laboratory at Bindura University of Science Education Astra Campus in Bindura, Zimbabwe at a geographical location of latitude $17^0 18' 06''$ S and longitude of $31^0 19' 50''$ E. The site is in agro-ecological region two, at an altitude of 1118 m above sea level. It receives an average rainfall of 800 mm annually with a mean temperature of 28^0C. Temperature and relative humidity was maintained at approximately 25-30^0C and 60-70% relative humidity.

3.2 Experimental design

Complete Randomized Design (CRD) with six treatments namely 0 g (control), 5 g, 10 g, 15 g, 20 g and 25 g of *Bidens pilosa* powder, each replicated 3 times was used. A total of eighteen petri dishes were established containing 10 g (approximately 33 kernels) of clean maize and artificially infested with fifteen adult maize weevils *(Sitophilus zeamais*) maize. The dishes were then placed randomly on the laboratory bench to minimize environmental variations.

Table 3.1: Treatment structure

TREATMENT	DESCRIPTION
T1	Control
T2	*Bidens pilosa* at 5 g/10 g maize
T3	*Bidens pilosa* at 10 g/10 g maize
T4	*Bidens pilosa* at 15 g/10 g maize
T5	*Bidens pilosa* at 20 g/10 g maize

T6	*Bidens pilosa* at 25 g/10 g maize

3.3 Preparation of *Bidens pilosa*

Fresh *Bidens pilosa* plants were gathered from a place free of pollution. To get rid of dirt and debris, the leaves were properly cleaned with clean water. After that, the plant materials were in the shade for seven to ten days without being exposed to direct sunlight in order to preserve the active chemicals until a consistent weight was reached. A mortar and pestle were used to grind the dried leaves into a fine powder, which was then sieved to produce homogeneous particles.

3.4 Preparation of maize grains

In order to remove any hidden insect stage, clean, infestation-free maize grains were collected and disinfested by placing them in a deep freezer for approximately an hour. The grains were allowed to recover to ambient temperature and stabilize their moisture content after freezing. A digital balancing scale was then used to weigh the grains, yielding 10 g for each experimental unit.

3.5 Preparation of maize weevils

After being extracted from infested maize stocks, adult maize weevils (*Sitophilus zeamais*) were raised in a laboratory. In a scientific setting, the insects were raised on clean maize grains in ventilated containers.

3.6 Measurements

The assessment indicators measured were:

1. **Maize weevils' mortality**

   Dead and live insects were counted in each container and it was calculated as follows:

Mortality (%) = Number of dead weevils × 100

15

2. **Grain damage Assessment**

   Damaged and undamaged grains were observed and calculated using the following:

   Damage (%) = Damaged grains ×100

   Total grains

3. **Weight Loss Determination**

   It was calculated using the standard count and weight loss

   Weight loss (%) = Initial weight – final weight after infestation × 100

   10

3.7 Data analysis

All collected data was subjected to analysis of variance (ANOVA) using GenStat 17thEdition software. Where significant differences were detected, mean separation was done using the Least Significance Difference Level (LSD) test at 5% significance level ($p \leq 0.05$) on all significant data.

CHAPTER 4: RESULTS

4.1 Effects of different concentration of *Bidens pilosa* powder on maize weevil mortality after 4 up to 8 days

There were highly significant differences among treatments as indicated by the P-value (<0,001) after 4 and 8 days of exposure under 6 treatments T1 (control), T2 (5 g of *Bidens pilosa*), T3 (10 g of *Bidens pilosa*), T4 (15 g of *Bidens pilosa*), T5 (20 g of *Bidens pilosa*) and T6 (25 g of *Bidens pilosa*). The results in table 4.1.2 indicate that maize weevil mortality increased significantly with the increase in concentrations of *Bidens pilosa* powder, with the 25 g treatment (T6) providing the highest level of control.

Table 4.1.2: Effects of different concentration of *Bidens pilosa* powder on maize weevil mortality after 4 up to 8 days

Treatment	Maize weevil mortality after 4 days	Maize weevil mortality after 8 days
T1	4.5^{c}	11.1^{c}
T2	17.8^{b}	40.0^{b}
T3	28.9^{a}	51.1^{a}
T4	40.0^{ab}	62.2^{ab}
T5	44.4^{a}	73.3^{a}
T6	53.3^{a}	93.3^{a}
Grand mean	31.5	55.2
P-value	<0.001	<0.001

SED	5.13	4.44
LSD	11.18	9.67
CV%	20	9.9

4.2: Effects of *Bidens pilosa* powder on grain damage after 4, 6 and 8 days

There was a highly significant differences among treatments as shown by the P-values (<0.001). After 4 days of treatment, T1 (the control) recorded the highest grain damage of 14.17% as shown in table 4.2.1, while the lowest was recorded in T6. Higher concentrations, particularly T5 and T6 provided the greatest protection against damage by maize weevils. This trend indicates that the higher the concentrations of *Bidens pilosa* powder the lower the feeding damage by maize weevils during storage.

Table 4.2.1: Effects of *Bidens pilosa* on grain damage after 4, 6 and 8 days

Treatment	Grain damage after 4 days	Grain damage after 6 days	Grain damage after 8 days
T1	14.17^{a}	25.23^{a}	32.30^{a}
T2	12.10^{ab}	19.20^{b}	25.23^{b}
T3	8.10^{bc}	14.17^{c}	20.20^{c}
T4	6.10^{cd}	11.10^{d}	16.20^{d}
T5	3.00^{de}	7.10^{e}	10.10^{e}
T6	2.00^{e}	3.00^{f}	6.10^{f}
Grand mean	7.58	13.30	18.36

P-value	<0.001	<0.001	<0.001
SED	1.011	1.308	1,300
LSD	2.203	2.851	2.832
CV%	16.3	12.0	8.7

4.3: Effects of different concentrations of *Bidens pilosa* on weight loss in maize storage after 4, 6 and 8 days.

There was a highly significant differences among treatments at all observation periods as indicated as indicated by the P-values (0.001). The results indicate that after 4 days of storage, the control (T1) recorded the highest weight loss of 5.33% as indicated by the table 4.3.1 whilst the least was recorded in T6. These findings indicate that an increase in concentration of *Bidens pilosa* significantly reduce weight loss caused by *Sitophilus zeamais* infestation.

4.3.1: Effects of different concentrations of *Bidens pilosa* on weight loss in maize storage after 4, 6 and 8 days

Treatment	Weight loss after 4 days	Weight loss after 6 days	Weight loss after 8 days
T1	5.33^{a}	10.33^{a}	15.33^{a}
T2	4.33^{b}	8.33^{b}	11.33^{b}
T3	3.33^{b}	6.33^{bc}	9.33^{bc}
T4	2.33^{c}	4.67^{cd}	6.67^{c}
T5	1.33^{c}	3.33^{d}	4.67^{cd}

T6	1.00[c]	2.00[d]	2.67[d]
Grand mean	2.94	5.83	8.33
P-value	<0,001	<0,001	<0.001
SED	0,430	0.430	0.471
LSD	0.938	0.938	1.027
CV%	17.9	9.0	6.9

CHAPTER 5: DISCUSSION

5.1: Effects of different concentration of *Bidens pilosa* powder on maize weevil mortality

The results showed that maize weevil mortality increased significantly with increasing concentration of *Bidens pilosa* powder and exposure duration. The highest mortality levels were recorded in treatments with higher concentrations (T5 and T6), while the control (T1) consistently recorded the lowest mortality levels as shown by table 4.1.2. Mortality further increased from day 4 to day 8, suggesting that prolonged exposure improved the insecticidal effectiveness of the powder. The increased mortality that was observed in treated grains was initiated by the presence of bioactive compounds such as alkaloids, flavonoids, tannins, terpenoids and phenolic compounds that are found in botanical insecticides. Isman (2006) stated that these compounds may interfere with insect respiration, feeding, nervous coordination and reproduction.

The results agree with studies that were conducted by Demissie *et al*. (2008), who reported that botanical insecticides significantly increase mortality of *Sitophilus zeamais* in stored maize. Furthermore, Silva *et al*. (2005) stated that powdered plant materials cause high mortality of maize weevils under laboratory conditions. The increase in mortality with exposure duration of time observed in this study indicated that prolonged contact between insects and *Bidens pilosa* powder enhanced toxic effects. According to Ribeiro et al. (2017), botanical powders may act through contact toxicity. Moreover, Phokwe and Mangayi (2023) highlighted that medicinal plants possess biodegradable compounds capable of effectively control storage pests whilst reducing environmental and human risks that is associated with synthetic pesticides.

5.2: Effects of different concentration of *Bidens pilosa* powder on Grain damage

The study showed that grain damage increased progressively with storage duration but decreased significantly with increasing concentrations of *Bidens pilosa* powder. This was shown by the control treatment (T1) which recorded the highest grain damage whereby treatments with higher concentrations recorded the lowest damage values throughout the experiment as indicated by table 4.2.1. The reduction in grain damage that was observed was also associated with the reduced feeding activity and increased mortality of maize weevils. As insect populations decrease, fewer grains were perforated and damaged through feeding activities.

These results correlate with reports by Lale (2002), who stated that botanical protectants reduce grain damage by suppressing insect feeding and reproduction. Demissie *et al*. (2008) reported that treated maize grain recorded lower grain damage compared to untreated controls due to reduced insect survival and reproduction. The gradual increase in grain damage was due to continued activity of surviving insects during storage. However, the extent of damage remained substantially lower in treated grains rather than in untreated control, illustrating the protective potential of *Bidens pilosa* powder.

5.3: Effects of different concentration of *Bidens pilosa* powder on weight loss

Weight loss increased with storage duration in all treatments, although significantly lower values were recorded in grain treated with higher concentrations of *Bidens pilosa* powder. The untreated control (T1) recorded the highest weight loss throughout the experiment, while higher treatment concentrations recorded the lowest weight loss values as shown by table 4.3.1. Weight loss in stored maize is as a result of insect feeding, grain perforation and powder formation caused by maize weevil infestation. Therefore, reduction in weight loss

observed in treated grains gives a conclusion that *Bidens pilosa* powder effectively minimized the feeding damage and grain deterioration.

The findings support the work of Golob and Webley (1980), who reported that botanical materials used as grain protectants significantly reduce post-harvest losses and grain deterioration during storage. Similar research was also stated by Getahun and Wondimu (2020), who observed lower weight loss in maize grains treated with botanical powders compared to untreated grains. The lowest weight loss values that were recorded at higher concentrations indicates that the effectiveness of *Bidens pilosa* powder increased with dosage. According to Obeng-fori and Amiteye (2005), higher concentrations of botanical protectants generally provide better grain protection because they increase insect exposure to active compounds. The results also agree with Mamoon-ur-Rashid and Ali (2021), who highlighted that botanical powders significantly reduce grain weight loss by limiting insect feeding and infestation levels in stored grains.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study demonstrated that *Bidens pilosa* powder is effective in controlling maize weevils, grain damage and also weight loss in maize grains. The effectiveness of the treatments increased with the increasing concentration levels and duration of exposure. The results illustrated that maize weevil's mortality was significantly high as the concentration of *Bidens pilosa* powder increased. The highest concentration (T6) with 25 g of *Bidens pilosa* recorded the greatest mortality levels after both 4 and 8 days of exposure, while the untreated control recorded the lowest mortality. This gives evidence that *Bidens pilosa* possesses insecticidal properties capable to suppress maize weevil populations in stored maize.

The study further reveals that grain damage was significantly reduced by increasing concentrations of *Bidens pilosa* powder. Treatments with higher concentration recorded lower percentages of damaged grains compared to the control treatment (T1). Although grain damage increased with storage duration, the rate of damage remained low in treated grain especially in T5 and T6. Moreover, weight loss of stored maize grains increased with storage time in all experimental units but the increase was substantially lower in grains treated with higher concentrations of *Bidens pilosa* powder.

6.2: Recommendations

Based on the results and findings of this research, the recommendations to farmers are;

- In order to control maize weevils in stored maize farmers are encouraged to use *Bidens pilosa* as a grain protectant.
- Higher concentrations of *Bidens pilosa* powder, particularly T5 and T6 are recommended because they provided the highest maize weevil mortality and the lowest grain damage and weight loss.

- Smallholder farmers should be encouraged to utilize *Bidens pilosa* powder since it is readily available locally, eco-friendly and possibly less expensive than synthetic insecticides.
- Further studies should be conducted to determine the long-term storage effectiveness of *Bidens pilosa* powder, the active chemical compounds that are responsible for insecticidal activity and the effectiveness of *Bidens pilosa* under large-scale storage conditions.

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APPENDICES

Analysis of variance

Variate: MWM_after_4 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	4927.66	985.53	24.95	<.001
Residual	12	473.93	39.49		
Total	17	5401.59			

Analysis of variance

Variate: MWM_after_8 days

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	12075.28	2415.06	81.71	<.001
Residual	12	354.68	29.56		
Total	17	12429.97			

Analysis of variance

Variate: GD_after_4 dys

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	355.164	71.033	46.31	<.001
Residual	12	18.407	1.534		
Total	17	373.571			

Analysis of variance

Variate: GD_after_6 dys

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	982.007	196.401	76.49	<.001
Residual	12	30.813	2.568		
Total	17	1012.820			

Analysis of variance

Variate: GD_after_6dys

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	982.007	196.401	76.49	<.001
Residual	12	30.813	2.568		
Total	17	1012.820			

Analysis of variance

Variate: WL_after_4 DAYS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	43.6111	8.7222	31.40	<.001
Residual	12	3.3333	0.2778		
Total	17	46.9444			

Analysis of variance

Variate: WL_after_6 DAYS

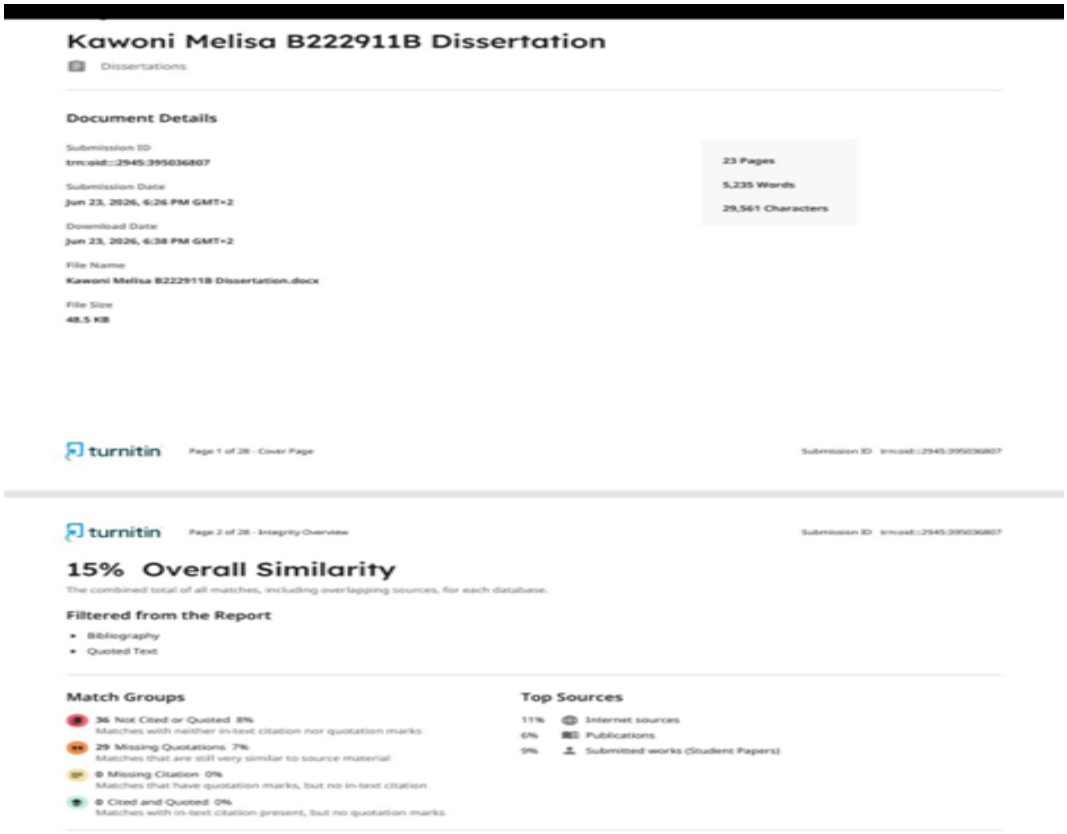
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	147.1667	29.4333	105.96	<.001

Residual	12	3.3333	0.2778
Total	17	150.5000	

Analysis of variance

Variate: WL_after_8 DAYS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	322.0000	64.4000	193.20	<.001
Residual	12	4.0000	0.3333		
Total	17	326.0000			



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