

**BINDURA UNIVERSITY OF SCIENCE EDUCATION
DEPARTMENT OF CROPSCIENCE**

EVALUATION OF CLOVE (*Syzygium aromaticum*) AND PEPPERMINT (*Mentha piperita*) EXTRACTS AS STORED MAIZE GRAIN PROTECTANTS AGAINST MAIZE WEEVILS (*Sitophilus Zeamais* L., COLEOPTERA: CURCULIONIDAE)



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DECLARATION

BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

The undersigned certify that they have read and recommended to the department of Crop Science, this thesis entitled:

Evaluation of clove (*Syzigium aromaticum*) and peppermint (*Mentha piperita*) extracts as stored maize grain protectants against maize weevils (*Sitophilus zeamais* L., Coleoptera: Curculionidae)SC.

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Date 02/09/26

DEDICATION

This project is dedicated to my parents, who have worked tirelessly to support my academic endeavors. I also dedicate this research project to my supervisor, who inspired me and instilled a spirit in me of perseverance and diligence in my studies.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the Lord God, for giving me the strength, wisdom and guidance throughout the completion of my research. Special thanks go to my supervisor Mr. J.C. Chitamba for his invaluable guidance, constructive criticism, and continuous support throughout the research process. I am deeply appreciative to my parents for their unwavering support, love and encouragement, which have been the main source of motivation. I am also grateful to my roommate, Keith, for his companionship and assistance. I also extend my heartfelt thanks to my uncle, Thomas for his encouragement and support which contributed to the successful completion of my work. Lastly, I appreciate my friends for their support and unconditional love during my work.

ABSTRACT

Post-harvest losses of caused by maize weevils (*Sitophilus zeamais*) are a major challenge affecting maize storage among smallholder farmers. The continuous use of synthetic pesticides has raised concerns due to their costs which are not affordable, environment pollution, weevil resistance and health risks to humans and livestock. This research focused on evaluating the effectiveness of clove (*Syzygium aromaticum*) and peppermint (*Mentha piperita*) extracts as botanical protectants against maize weevils in stored SC 529 and Klein Karoo (PGS63) maize varieties. The experiment was conducted as a 2×4 factorial treatment structure, laid in a Completely Randomized Design (CRD), with eight treatments replicated three times. Grain protectant type factor had 4 levels (clove powder, peppermint powder, Shumba Plus dust as a positive control and untreated maize grain as a negative control), while the variety factor had 2 levels (SC 529 and Klein Karoo PGS63). The data collected included weevil mortality, grain damage and grain weight loss over an eight-week storage period. There was no significant interaction ($P>0.05$) between grain protectant and variety on weevil mortality, grain damage and grain weight loss across all the sampling periods (week 2, 4, 6 and 8). Grain protectant type had significant effect ($P<0.05$) on weevil mortality, grain damage and grain weight loss, with clove extract demonstrating high effectiveness against *S. zeamais*, achieving 96% weevil mortality after eight weeks, which was statistically comparable to the synthetic pesticide Shumba Plus dust (100%). Peppermint extract showed lower effectiveness with 54% mortality after eight weeks and also some insects were not found which indicated the repellent effect. Grain damage and grain weight loss were significantly lower in cloves and Shumba-treated maize compared to peppermint-treated and untreated maize. Untreated maize recorded the highest grain damage and weight loss of 100%. Although some varietal differences were observed, SCSC 529 showed slightly greater resistance to weevil infestation than Klein Karoo PGS63. The study concluded that clove powder is highly effective, have high affordability and environmentally friendly alternative to synthetic pesticides for controlling maize weevils in maize grain storage. The use of clove powder can highly contribute to reduced post-harvest losses, improved grain quality and enhanced food security among smallholder farmers. Further research is recommended on dosage optimization which is also the concentration of the extracts, long-term storage performance which is the period of exposure and farmer adoption of botanical pesticides.

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Maize (*Zea mays*), is one of the most global grown cereal crops, which serves as a staple food and a major source of income for millions of smallholder farmers particularly in Sub-Saharan Africa. It serves as primary carbohydrates source and livestock feed. Nonetheless, maize production encounters considerable postharvest challenges especially during storage (Alam *et al.*, 2019) . Among the most damaging pests affecting stored maize is *Sitophilus zeamais* (Coleoptera: Curculionidae). The pest causes notable qualitative and quantitative damage to stored maize. Its distractive nature stems from its high biotic potential and its capacity to attack grains both in the field and in the storage (Abass *et al.*, 2013). The adult weevils penetrate into maize grains for egg laying. The larvae consume the grain resulting in reducing the grain quality and weight loss. This also causes substantial economic losses, diminished nutritional value and decreased marketability. The weevil thrives in warm and humid environments common in tropical and subtropical regions including Africa. Under inadequate storage conditions, infestations by *S. zeamais* can lead 30% to 40% grain losses (Tefera *et al.*, 2011).

To combat storage pests smallholder farmers frequently resort to synthetic insecticides and fumigants such as aluminium phosphide tablets. These chemicals are effective even though they come with various drawbacks including high costs, environmental contamination, human health risks and the development of insect resistance (Abdoulaye *et al.*, 2015). These challenges underscore the necessity for safer, more affordable and environmentally friendly alternatives. Botanical insecticides sourced from plant materials have emerged as promising substitutes for synthetic chemicals for there is a global demand for sustainable and ecofriendly alternatives to chemical control methods. These natural substances are typically biodegradable, accessible locally and less toxic to humans and non-target species (Hodges, 2015).

Essential extracts from clove (*Syzigium aromaticum*) and peppermint (*Mentha piperita*) are standout botanical options (Box, 2014). Clove extract is rich in eugenol, a compound recognized for its strong insecticidal and fumigant abilities, whereas peppermint extract contains menthol and other related compounds (Isman, 2020). Numerous studies have shown that plant extracts can effectively lower insect population density, boost mortality rates and reduce grain damage in

storage. For instance clove and peppermint essential extracts have been found to significantly impact the survival and reproduction of *S. zeamais*, thereby decreasing infestation level (Singh, 2017).

However their effectiveness differ based on maize variety, storage conditions and concentration levels utilized (Gorakhpur, 2011). In Zimbabwe, common maize varieties cultivated by farmers include SC 529 and Klein Karoo (PGS 63). Yet limited research has been conducted to investigate the effectiveness of botanical extracts on these varieties during storage. Variations in grain characteristics such as hardness and chemical composition, might affect susceptibility to pest infestations and the effectiveness of treatments. Consequently, this research aimed on assessing the effectiveness of clove and peppermint extracts as grain protectants against *S. zeamais* in SC 529 and Klein Karoo PGS 63 maize varieties especially among small holder varieties.

1.2 Problem statement

Post-harvest losses attributed to maize weevils present a significant challenge for smallholder maize farmers. The widespread usage of synthetic insecticides frequently proves unsustainable due to their high cost, health hazards and detrimental environmental effects. Although botanical extracts like cloves and peppermint have shown promise as alternative grain protectants, there is insufficient information regarding their comparative effectiveness in decreasing weevil population density, mortality, grain damage and weight loss across different maize varieties. The lack of knowledge hinders their broader adoption as sustainable pest management solutions.

1.3 Justification of the research

There is an urgent need for the pest management solutions that are effective, affordable and safe for people and the environment. Botanical extracts are locally producible and align with integrated pest management principles, yet their performance can be context dependent. Assessing clove and peppermint extracts on SC 529 and Klein Karoo PGS63 will generate variety specific evidence to guide small holders, extension services and policy makers. These results are going to indicate if these botanicals can effectively and reliably reduce *S. zeamais* damage under practical storage conditions and inform recommendations for adoption, formulation and further development.

1.4 Significance of the study

The investigation focuses on clove (*S. aromaticum*) and peppermint (*M. piperita*) extracts as protectants for stored maize against *S. zeamais*. It is confined to two maize varieties SC 529 and Klein Karoo, PGS 63 and evaluates outcomes relevant to smallholder storage conditions, weevil population density, mortality rate, grain damage and weight loss. This research will provide evidence on sustainable, cost-effective postharvest pest control options for farmers. Through evaluating the relative performance of clove and peppermint extracts the study will offer alternatives to synthetic insecticides that may reduce health risks and environmental contamination. It will also help to reduce postharvest losses and improve maize storage outcomes, which contributes to household food security and income stability. It is also important to inform extension programs and integrated pest management strategies by providing data on variety specific efficacy. It also helps contribute to the scientific literature on botanical insecticides and support policy and practical uptake where appropriate.

1.5 Research Objectives

1.5.1 Main Objective

To assess the effectiveness of clove and peppermint extracts as protectants for stored maize grain varieties against *Sitophilus zeamais*.

1.5.2 Specific Objectives

1. To evaluate the effect of clove and peppermint extracts on weevil mortality in different stored maize grain varieties.
2. To assess the levels of grain damage caused by weevils in different maize varieties treated with clove and peppermint extracts.
3. To compare the percentage of grain weight loss in different maize varieties treated with cloves and peppermint extracts.

1.6 Hypothesis

1. There is significant effect of clove and peppermint extracts on weevil mortality in different stored maize grain varieties.
2. There is significant difference in grain damage caused by weevils on different maize varieties treated with clove and peppermint extracts.

3. There is significant difference in grain weight loss on different maize varieties treated with cloves and peppermint extracts.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Maize (*Zea mays L.*) is a major global staple and an important source of food security for millions of people particularly in Sub-Saharan Africa. In Zimbabwe maize is crucial for household food security, livestock feed and income generation especially among small holder farmer (Paper *et al.*, 2014). Considerable post-harvest losses during storage are caused by insect pests, especially the maize weevil, *Sitophilus zeamais*. Infestation by the weevils does not only cause quantitative losses through weight reduction but also causes qualitative damage to grain, decreasing nutritional quality through grain perforations and increasing susceptibility to fungal infestation leading to reduced marketability (Tefera *et al.*, 2016).

There is a growing resistance of storage pests to synthetic pesticides which were the dominant method of control, together with environmental and health concerns which has led to an increased interest in plant-based alternatives such as clove (*Syzygium aromaticum*) and peppermint (*Mentha spp.*) extracts (Insects Journal, 2016). Botanical pesticides contain multiple bioactive compounds such as alkaloids, flavonoids, tannins and essential oils making it more difficult for pests to develop resistance. These are viewed as environmentally friendly, botanical pesticides are biodegradable and decompose quickly in the environment (Cosmas *et al.*, 2018).

Unlike many other synthetic pesticides, they do not persist for long periods in the stored grain ecosystems. This leads to reduced environmental pollution and contamination (Islam *et al.*, 2017). Another reason is their affordable to smallholder producers, many botanical pesticides are locally available plants which farmers can ground using a pestle and motor to produce fine powders for use at low cost compared to expensive commercial synthetic chemicals. They have gained more attention for their insecticidal, fumigant and repellent properties (Gorakhpur, 2011).

They also have reduced health risk conditions to humans and animals. Synthetic chemicals can leave harmful chemical residues on maize grains, posing health risks to consumers and livestock. Botanical extracts are less toxic to humans and mammals when used correctly, making stored maize safer for consumption (Kimenju *et al.*, 2004). They leave minimal residue problems in stored maize because botanicals breakdown rapidly, they leave fewer toxic residues on stored maize, which makes it important for food safety and export quality standards (Mossa, 2016b).

2.2 Description and biology of *Sitophilus zeamais*

The maize weevil, *S. zeamais* (Figure 2.1), is the most destructive pest of stored maize. It falls under the Curculionidae family and order Coleoptera. Its body length is 2-4mm with its head protruded into a snout, with mandibles at the end of the snout (Ojo & Omoloye, 2016). Generally, has reddish brown color (Alam *et al.*, 2019). The snout is long with clubbed segmented elbowed antennae and four light reddish brown oval spots on the elytra (Science, 2022). There may be five to seven generations within a year.



Figure 2.1: Maize weevil Source: (Ojo & Omoloye, 2016)

The lifecycle of *S. zeamais* is 36 days at 27 ± 10 and $69 \pm 3\%$ relative humidity on average. *S. zeamais* life cycle consists of 5 stages which are egg, larva, pupa, pre-adult and adult, with the larva instars being the most destructive stages on stored grains (Figure 2.2). According to (Ojo & Omoloye, 2016) the optimum temperature for oviposition is about 25°C with grain moisture contents of above 10%. Being dependent on environmental conditions like temperature and humidity, adults are capable of living up to 6-12 months.

An adult female burrow into the grains with the help of its rostrum (Risal *et al.*, 2026)). Up to 400 creamy white tiny eggs are laid by every female in cereal grains such as in maize. After about 5-9 days, eggs hatch to legless 4mm long larva that have 4 larval development instars that last 25 days with moderate temperature (Bbosa *et al.*, 2014). Under optimal environmental conditions of 30°C temperature with 14% humidity, quick development from eggs to adults may take from 30- 40 days while un-favorable conditions such as slightly higher temperatures and high moisture content delay the life cycle to 110 days. The larva is creamy white in color, with a sclerotized light brown head, legless, short, stout and matures in 3- 6 days (Ojo & Omoloye, 2016).The larva feed and its development inside the maize kernels takes about 25 days and the total development periods range from 35 to 110 days dependent on environmental conditions (Demissie *et al.*, 2011).

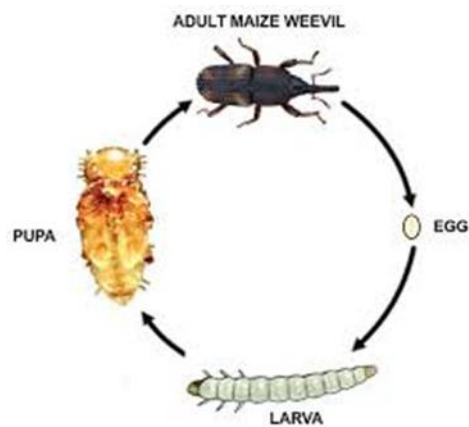


Figure 2.2: Life Cycle of *Sitophilus zeamais* Source:(Alam *et al.*, 2019).

2.3 Economic Importance of *Sitophilus zeamais*

Sitophilus zeamais is a principal stored-maize pest worldwide, both the larvae and adults consume grain, causing internal and external damage leading to production of dusty frass (Alam *et al.*, 2019). Infestations often start in the field, especially for small and medium varieties and continue in storage, potentially producing major post-harvest quantitative and qualitative losses if uncontrolled. The quantitative losses occur when the weevils feed directly on maize kernels, reducing grain mass.

The *S. zeamais* reproduce very rapidly in stored maize making it one of the most distractive storage pests in tropical and subtropical regions. The weevil populations can increase

dramatically in stored maize grain. Studies report 300 weevils per 500g of maize grain if not treated which can cause 100% loss. Females lay eggs inside kernels, enabling rapid population growth and escalating damage over time (Gorakhpur, 2011). The larvae develop inside the grain consuming it from within. This leads to a significant reduction in overall stored grain quantity. Qualitative losses which lead to reduced grain quality where infested grains become hollow, powdery and weakened. The nutritional value and content are reduced due to feeding. The grain becomes unstable for human consumption or sale. Each infested kernel yields only one adult with internal feeding distracting the endosperm and causing weight reduction, poor nutritional value and reduced germination capacity (Ismail, 2019).

Heavy weevil infestation causes generation of heat and moisture through metabolic activities such as respiration leading to further quality loss through caking (Project *et al.*, 2010). This also leads to increased fungal or microbial growth for example to mycotoxigenic fungi. The infested consignments can be rejected and downgraded to international markets due to reduced marketability. Weevil damage leads to seed viability losses, the damage caused to the embryo reduces seed germination ability when in cases of seed retaining. Heavily infested seeds cannot germinate properly which affects planting material quality (Paper *et al.*, 2014).

Weevil infestation in maize leads to contamination and spoilage where the frass, dead insects and the webbing contaminate grain (Review, 2024). This lowers the grain value and its marketability. It can also promote mold growth under poor storage conditions. Insect activity increases grain temperature and moisture, which creates favorable conditions for fungal growth and further deterioration. (Kimenju *et al.*, 2004).

2.4 Use of Botanical Extracts in Stored Grain Protection

Botanical extracts being used as insecticides have attracted attention as substitutes for synthetic chemicals because they are safer to both human health and less persistent to the environment, often more affordable and accessible to small holder farmers (Barre & Jemal, 2022). These extracts are derived from plants that naturally produce bioactive compounds of defense against pests. These plant-derived formulations may exhibit insecticidal, repellent discouraging insects from infesting treated plants, and anti-feedant properties (Trivedi *et al.*, 2018). They act as contact and fumigant insecticides, causes toxicity through direct contact with treated grains or

through inhaling volatile compounds (Cosmas *et al.*, 2018). Various plant extracts substantially reduce maize weevil populations, mortality, grain injury, and weight losses for example clove and peppermint extract (David & Isaac, 2022). Plant extracts have also suppressed progeny emergence and repelled insects, thereby lowering infestation levels, these characteristics make them appropriate for smallholder farmers (Ismail, 2019).

2.5 Efficacy of Clove Extract Against *Sitophilus zeamais*

Cloves contain active constituents which are highly toxic such as eugenol (Box, 2014), which possess strong insecticidal and repellent activity. The eugenol acts as a neurotoxin which interferes with the insect nervous system (Box, 2014). It also affects enzyme activity within the weevil system leading to paralysis and death. It also reduces reproduction by distracting the reproduction system of the pest. Studies indicate clove extracts are highly toxic to maize weevils, with mortality increasing as concentration and exposure time rise after treatment (Barre & Jemal, 2022). At higher doses, clove essential extracts have shown effects comparable to some synthetic insecticides, producing high mortality over storage periods. At higher doses the treatment kills the weevils more rapidly while lower dose amounts require longer exposure to achieve similar effects. Mortality is mostly observed within a period of 72 hours. Recent work reports clove formulations reducing weevil survival by over 90% and cutting grain losses by more than 45% during extended storage (Barre & Jemal, 2022). These extracts also alter insect physiology and behavior, leading to reduced mobility and respiration, thus limiting feeding and reproduction (Okunlade *et al.*, 2023). These extracts also disrupt locomotion and physiological functions of the weevils. Sub-lethal exposure alters respiration and behavior which leads to reduced feeding and activity (Mossa, 2016a).

2.6 Efficacy of Peppermint Extract Against *Sitophilus zeamais*

Peppermint (*Mentha spp.*) contains bioactive compounds such as menthol and pulegone with insecticidal and repellent properties (Cosmas *et al.*, 2018). Peppermint extracts are effective through contact, ingestion and fumigation causing high mortality rates. Menthol and other related terpenes are major active compounds that disrupts insect physiological system (Mossa, 2016b). Presence of volatile compounds also contributes to repellency. It demonstrates strong repellent activity causing adult weevils to avoid treated grains (Mamoon-ur-rashid & Ali, 2022). Botanical

essential oils, including mint-derived oils, increase weevil mortality and reduce infestations with higher concentrations and longer exposure (Motsch *et al.*, 2015). Related *Mentha*-derived oils for example, pennyroyal oil have been effective in decreasing maize weevil populations and protecting stored grain, particularly when delivered via controlled-release systems. It acts as a fumigant, killing the insects through vapors in enclosed storage conditions (Cortese *et al.*, 2022).

2.7 Effect of Botanical Extracts on Weevil Population Density

Botanical extracts lower weevil population density through toxicity, repellency, and reproductive inhibition. They cause direct reduction in weevil adult population (Cortese *et al.*, 2022) Population density declines rapidly as mortality increases with dose and exposure time. Studies report significantly fewer live weevils on treated grain compared with untreated controls, botanical treatments reduce population growth and the emergency of progeny, which curbs infestation development over time (Motschulsky, 2023) Controlling population density is crucial to prevent exponential pest growth during storage. These extracts reduce oviposition in female weevils. They also reduce and inhibit egg hatchability and larval development. Some compounds acts as growth regulators, therefore they prevent immature stages of the insects from reaching adulthood (Jallow & Pitan, 2021). Another major effect is the reduction of offsprings, where treated grains show fewer emerging adult weevils compared to untreated grains. Other extracts reduce emergency of progeny by 70-90% depending on concentration (Caneppele & Rozado, 2016).

2.8 Effect of Botanical Extracts on Weevil Mortality

Mortality is a key measure of botanical insecticide effectiveness. According to research, plant extracts, including clove and peppermint, cause notable mortality in *S. zeamais*, with outcomes dependent on concentration and exposure duration (Del *et al.*, 2015)). Higher concentrations generally produce faster and greater mortality; some botanical treatments have achieved up to about 85% mortality within short experimental timeframes. These extracts damage the cell membranes and also alteration of enzyme functioning (Sousa *et al.*, 2023) This indicates very strong insecticidal potential as compared to synthetic pesticides. These extracts are very effective to an extent of causing high to complete mortality (Phokwe *et al.*, 2026). Their toxicity due to fumigant and contact combined with ecofriendly properties make them strong alternatives to synthetic pesticides in stored grain protection (Rajendran & Sriranjini, n.d.).

2.9 Effect of Botanical Extracts on Grain Damage

Grain damage results directly from weevil feeding. Botanical treatments have been associated with significantly lower percentages of damaged kernels which is linked to decreased weevil survival which directly lowers feeding damage and kernel distraction, (Motschulsky, 2023). Grain damage indicators such as perforated grains, galleries and maize dusty powder are strongly positively correlated with weevil population levels. Treated maize typically shows fewer perforations and less internal damage than untreated grain, primarily because feeding and reproduction are suppressed (Ismail, 2019). These extracts reduce these damage indicators by lowering infestation and feeding activities. They deter feeding leading to minimal grain consumption. Increasing extract concentration is generally linked to reduced grain damage. As a result the treated maize grains show fewer holes and less internal distraction (Barre & Jemal, 2022).

2.10 Effect of Botanical Extracts on Grain Weight Loss

Weight loss during storage is an important economic concern and is closely tied to insect feeding and infestation intensity (Farhadi *et al.*, 2025). Botanical extracts have been shown to limit weight loss by controlling weevil populations due to their high effectiveness on weevil mortality, treated grain often retains more mass than untreated samples (Length, 2010). Higher dosages of plant extracts tend to correspond with lower weight loss, underscoring the need to identify optimal application rates (Cortese *et al.*, 2022). In untreated maize insect infestation can cause 20-30% losses in stored grain mostly in tropical regions as the environmental conditions are favorable for weevil surveillance. These extracts significantly lower the feeding intensity and insect population therefore reducing weight losses (Del *et al.*, 2015).

2.11 Comparative Studies of Botanical Extracts

Comparative research shows variation in efficacy among botanical extracts depending on species, concentration, and environmental factors (Trivedi *et al.*, 2018). Clove is frequently reported as highly insecticidal, largely because of its eugenol content, whereas peppermint provides both repellent and toxic effects (Length, 2010). Although both extracts are effective, differences in their capacity to reduce population density, mortality, grain damage, and weight loss justify comparative evaluations under specific conditions, such as different maize varieties (for example, SC 529 and Klein Karoo) and smallholder storage systems. According to (Sousa

et al., 2023), essential extracts with higher phenolic content such as clove are more effective on controlling weevils in maize grains in storage. Within the context of smallholder farmers, such comparisons help determine the most effective, affordable and environmentally sustainable grain protectant (Barre & Jemal, 2022).

2.12 Maize varieties and susceptibility

Proneness of stored maize grains to *S. zeamais* can vary significantly between different varieties, (Rahardjo *et al.*, 2017). This is controlled by factors such as the grain hardness, the size of the kernels, husk coverage in the field and also biochemical composition such as the protein, starch and phenolic levels, can influence pest development and surveillance (Vowoto, 1993). Varieties with harder endosperms are more resistant as compared to those with softer endosperms as they impede the weevil's ability to bore into the kernel (Motsch *et al.*, 2015). Evaluation of the efficacy of clove and peppermint extracts on different varieties is crucial as the varietal characteristics may interact with the protectants potentially affecting their performance (Nawaz & Chung, 2023).

2.13 Factors affecting the efficacy of botanical extracts

The efficacy of these botanical extracts during the control of *S. zeamais* is influenced by several interacting factors which determine the extent to which these extracts reduce grain damage, reduce weight loss, increase mortality and minimize weevil population density.

The period of exposure affects the overall performance of the extracts. An increase in exposure period of the weevils to treated grain is directly proportional to the toxicity and repellence effects. Mortality often increase within 24 to 72 hours after treatment and longer exposure periods may further suppress feeding and reproduction of the weevils (Cortese *et al.*, 2022).

The other factor is concentration of the botanical extracts applied; whereby higher concentrations have higher, stronger insecticidal and repellent effects because more bioactive compounds are available to act against the weevils. Increasing concentrations leads to higher adult mortality, reduction in grain damage and reduced progeny emergence. On the opposing hand, lower concentrations can lead to inadequate protection and requires repeated application.

Plant species and chemical composition also affect effectiveness of the botanical extracts. Different botanical extracts have different active ingredients and these vary in potency. Clove

contains eugenol which have very strong insecticidal properties whereas peppermint contains menthol with other volatile compounds that provide both toxicity and repellence properties. These compounds have different quantities and qualities which are dependent on plant variety (Chebet *et al.*, 2013).

Furthermore, the extraction, preparation and application method also affect their effectiveness. Under preparation, methods such as grinding can influence the concentration of active compounds being obtained. Also, the application method affects the distribution of the extracts within the grains, which affects how well they contact the pests. Uniformity in application improves protection whereas uneven distribution can leave untreated grain exposed to infestation.

In addition to the above the grain characteristics and variety also affect the general effectiveness of the botanical extracts as it contributes to treatment efficacy. The hardness of the grain and kernels and also the sizes and the biochemical composition of grains influence the entrance of weevils and reproduction in the kernels. Harder grain varieties are less prone to infestation.

Lastly, the duration of storage also affects the effectiveness because these extracts are biodegradable which makes them loose potency with time. Long storage periods can lead to reduced insecticidal activity which requires continuous application to maintain protection.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Study site description

The study was carried out in Ward 17, Saurombe village, Chimanimani district, Manicaland Province, latitude 19.7763 and longitude 32.6734, altitude 1.035metres. The site experiences average temperatures of 28⁰C in summer and 15⁰C in winter and annual rainfall ranging from 1000-1200mm. The study area falls in Natural Ecological Region 2 and is comprised of smallholder farmers who are into grain production, especially maize.

3.2 Experimental design

The experiment was a 2×4 factorial treatment structure, laid in a Completely Randomized Design (CRD), with eight treatments replicated three times. The two factors were grain protectant and variety. Grain protectant factor had 4 levels (clove powder, peppermint powder, Shumba Plus dust as a positive control and untreated maize grain as a negative control), while the variety factor had 2 levels (SC 529 and Klein Karoo PGS63). The treatment combinations are shown in Table 3.1.

Table 3.1: Treatment description for testing botanical substances against *Sitophilus zeamais*

Treatment	Description
T1 SC	Maize (SC 529) treated with grounded cloves at 20g/200g maize grain
T1 PG	Maize (Klein Karoo PGS63) treated with grounded cloves at 20g/200g maize grain
T2 SC	Maize (SC 529) treated with grounded peppermint at 20g/200g maize grain

T2 PG	Maize (Klein Karoo PGS63) treated with grounded peppermint at 20g/200g maize grain
T3SC	Maize (SC 529) treated with Shumba Plus dust at label rates
T3 PG	Maize (Klein Karoo PGS63) treated with Shumba Plus dust at label rates
T4 SC	Untreated SC 529 maize grain
T4 PG	Untreated Klein Karoo PGS63 maize grain

3.3. Experimental procedure

Sitophilus zeamais was obtained from untreated maize at Chimanimani Grain Marketing Board as sample pests and reared or cultured for 2 weeks. *S. zeamais* was starved for 24 hours before being introduced to treatments. Maize grain from the two varieties was obtained from farmers in Ward 17, Chimanimani district. Healthy maize grains were selected and broken kernels, dirt and debris were removed. The maize was properly dried to the required moisture percentage. The cloves buds, peppermint dried leaves and Shumba Plus dust were bought from the local market. SCSC 529 and Klein Karoo PGS63 varieties were selected to be used in the experiment since they are the most grown medium varieties in the area where the study was conducted and also their high susceptibility to the storage weevils. The maize grain was winnowed and thoroughly removed all damaged grain, and the selected grain was cleaned using clean water and then air dried under protection to avoid re-infestation by insects. Two hundred grams of maize grain were put into 300g small sacks.

3.3.1. Preparation of cloves and peppermint leaves

The cloves and peppermint bought from the local market were pounded to a smooth powder using the Kasa Maria pestle and mortar. The powder was then sieved using a wire mesh of size 0.2mm to obtain a fine powder. Weigh the required amount of clove powder and peppermint

powder according to the desired treatment concentration of 20g and measured using the Adams scale. Application rate of 4g Shumba Plus dust was used basing on proportionate calculations from recommended rate (20g/kg). Untreated maize was measured exactly 200g and introduced into the twenty-four small sacks. The eight treatments were replicated for three times. Thorough mixing grain, clove and peppermint powder was done to ensure uniform distribution over the grain surface. The mixture was then allowed to settle before introducing ten starved *S. zeamais* into each sack to make a total of 240 weevils. The sacks were left tightly closed and stored in the storage back which is airtight and closed tightly to prevent insect entry. The mixtures were left in the room for two weeks and observe the damage and mortality of the *S. Zeamais*. The area was well cleaned and kept far from other maize bags to prevent movement of other pests into the treatments such as rodents. The treatments were stored under normal storage conditions and observed periodically. The small sacks were not too tight to allow for the pests to escape in terms of repellent effect if there is any.

3.4 Data collection

Physical weevil counting was carried out on weekly intervals from the date of setting the experiment for eight weeks. Insects were certified dead on seeing motionless legs when insect was tempered with or teased using a small smooth brush. Weevil mortality was assessed as: (Number of dead insects/Total number of insects) x 100. To account for death by natural conditions other than the effect of the clove and peppermint powder, data on percentage adult weevil mortality was corrected using Abbott's (1987) formula thus:

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

Where,

PT = Corrected mortality (%)

PO = Observed mortality (%)

PC = Control mortality (%)

3.4.1. Grain damage.

Damage assessment was done using count data on treated and untreated grain after storage from day number 14 and then on two weeks intervals for eight weeks. Numbers of damaged grains (grains with characteristic holes, broken or chipped grains) from each sack were counted and recorded.

$$\text{Percentage grain damage} = \frac{\text{Perforated/holed kernels}}{\text{Total kernels in a sack}} \times 100$$

3.4.2 Grain weight loss

Damaged grains were separated from undamaged grains, counted and then weighed. The undamaged grains were separately counted and weighed also. Percentage weight loss was calculated, using the count and weigh method as follows:

$$\% \text{ Weight loss} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100$$

3.5 Statistical Analysis.

the data on weevil mortality, grain damage and grain weight loss was subjected to analysis of variance (ANOVA) using GenStat statistical package, version 16th edition. The means were separated using the least significant difference (LSD) at 5% level of significance.

CHAPTER 4: RESULTS

4.1 Effect of grain protectant type and variety on weevil (*Sitophilus zeamais*) mortality in stored maize grain

There was no significant interaction ($P>0.05$) between grain protectant type and variety on weevil mortality. However, grain protectant type had a highly significant effect ($P<0.001$) on weevil mortality with the synthetic pesticide (Shumba) having the highest mortality of 100% after 8 weeks, followed by cloves (96%). Peppermint had the lowest mortality (54%) compared to the other two protectants (cloves and Shumba) in 8 weeks. The lowest mortality was obtained from the negative control (untreated) (0%), as shown in Table 4.1.

Table 4.1: Effects of different grain protectants on weevil mortality

Treatment	Time (weeks)			
	2	4	6	8
Cloves	34.33 ^c	44.33 ^c	65.00 ^c	96.00 ^c
Peppermint	11.67 ^b	21.00 ^b	33.00 ^b	54.00 ^b
Shumba	99.33 ^d	100.00 ^d	100.00 ^d	100.00 ^d
Untreated	0.00 ^a	0.00 ^a	0.00 ^a	0.00 ^a
Grand mean	36.33	41.33	49.50	62.50
p-value	<.001	<.001	<.001	<.001
LSD	2.461	2.290	2.632	2.998
CV%	5.5	4.5	4.3	3.9

Means followed by the same letter are not significantly different from each other at 5% significance level.

Variety had significant effect ($P=0.027$) on weevil mortality at week 2 sampling interval, with SC 529 having a higher weevil mortality of 37.33% than Klein Karoo PGS63 which had 35.33%

(Figure 4.1). However, variety had no significant effect ($P>0.05$) on weevil mortality at weeks 4, 6 and 8.

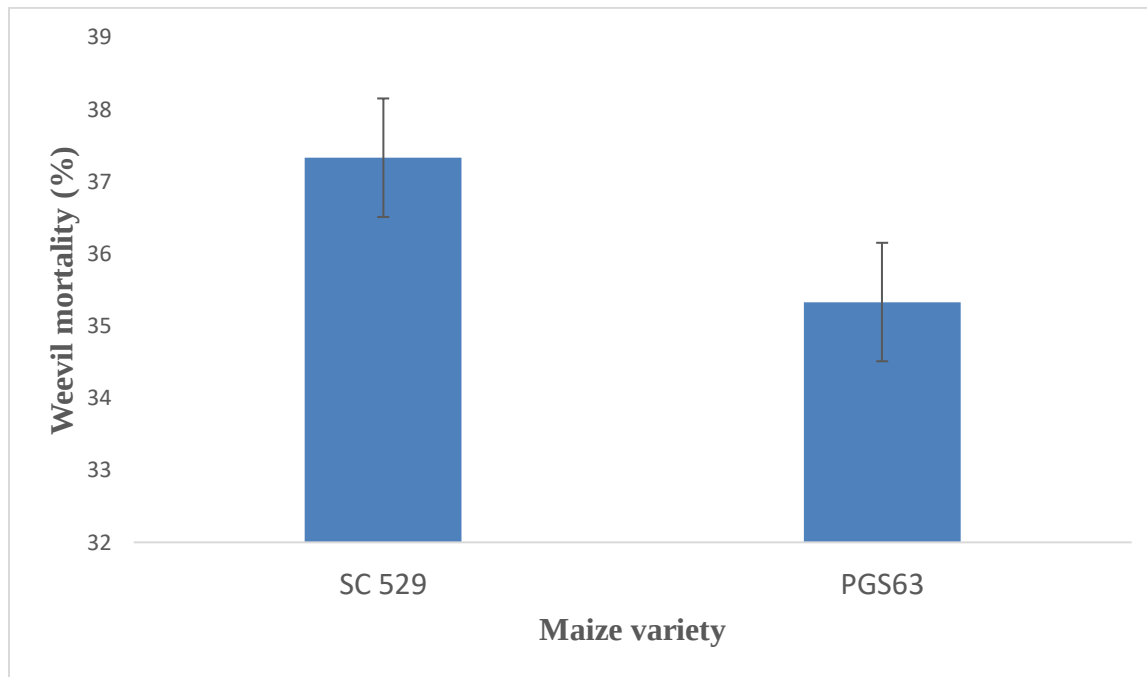


Figure 4.1: Effect of maize variety on weevil mortality at week 2 sampling period

4.2 Effect of grain protectant type and variety on grain damage in stored maize grain

There was no significant interaction ($P>0.05$) between grain protectant type and variety on grain damage. However, grain protectant type had a highly significant effect ($P<0.001$) on grain across all the sampling periods (weeks 2, 4, 6 and 8), with Shumba exhibiting the least damage (0%), followed by Cloves (1.67%) and Peppermint (16.33%) while the untreated maize grain had the highest percentage of grain damage (100%) after 8 weeks (Table 4.2).

Table 4.2: Effects of different grain protectants on weevil grain damage

Treatment	Time (Weeks)			
	2	4	6	8
Cloves	18.33 ^b	16.33 ^b	10.00 ^b	1.67 ^a
Peppermint	33.00 ^c	24.67 ^c	20.00 ^c	16.33 ^b
Shumba	0.67 ^a	0.00 ^a	0.00 ^a	0.00 ^a
Untreated	97.00 ^d	99.67 ^d	100.00 ^d	100.00 ^c
Grand mean	37.25	35.50	32.50	29.50
p-value	<.001	<.001	<.001	<.001
LSD	3.199	3.238	1.935	3.120
CV%	7	7.5	4.9	8.6

Means followed by the same letter are not significantly different from each other at 5% significance level.

Variety had significant effect ($P=0.005$) on weevil grain damage at week 2 sampling interval, with SC 529 having a lower grain damage of 35.5% than Klein Karoo PGS63 which had 39% (Figure 4.2). However, variety had no significant effect ($P>0.05$) on weevil grain damage at weeks 4, 6 and 8.

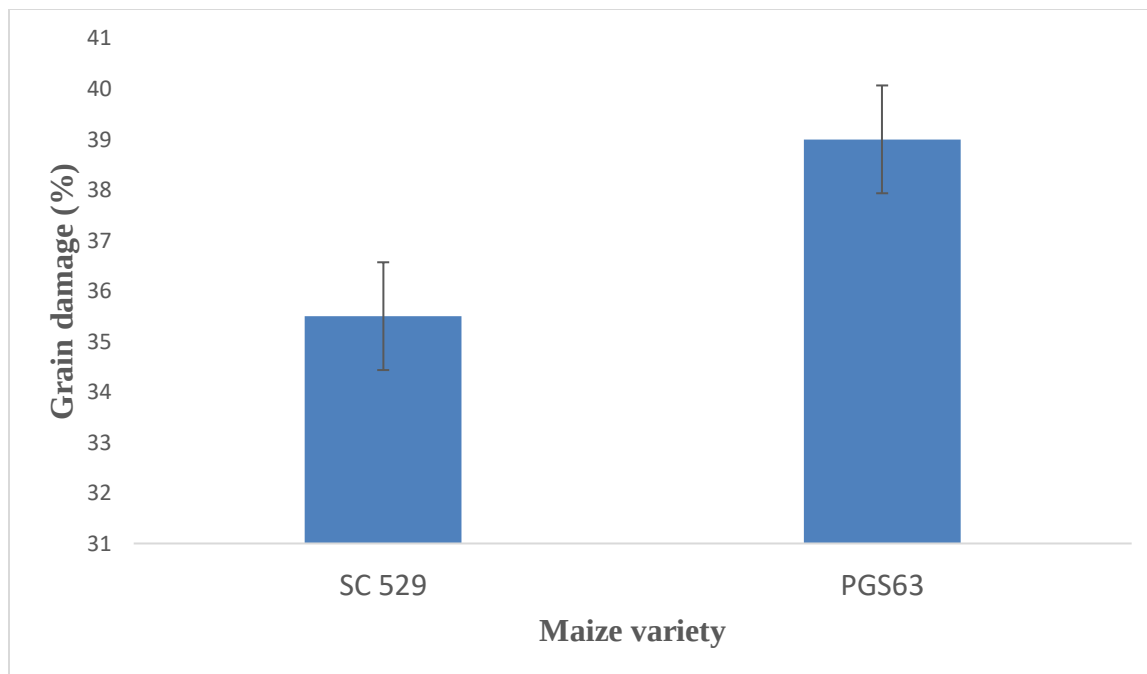
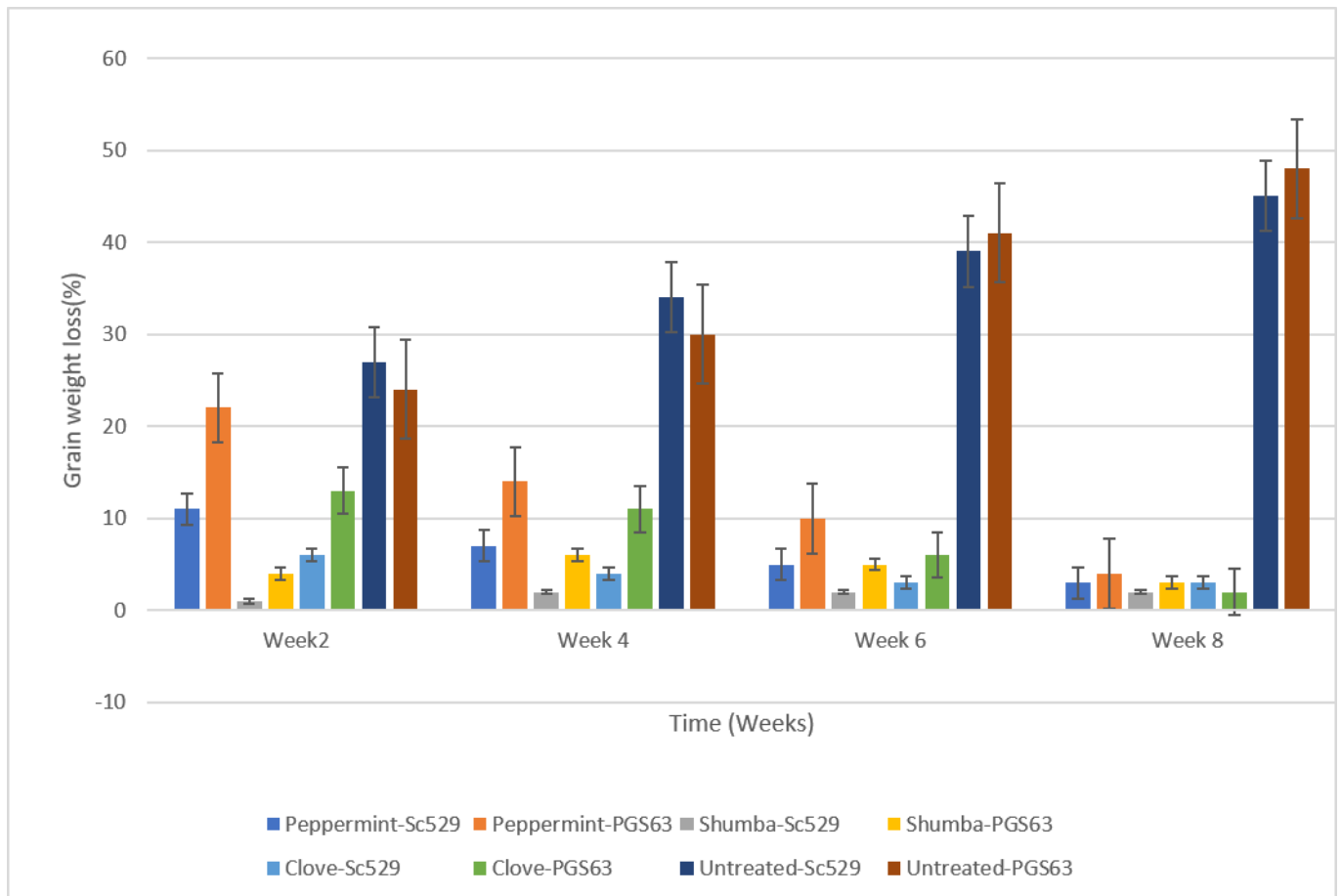


Figure 4.2: Effect of maize variety on weevil grain damage at week 2 sampling period

4.3 Effect of grain protectant type and variety on grain weight loss in stored maize grain

There was highly significant interaction ($P < 0.001$) between grain protectant type and variety on grain weight loss at weeks 2, 4 and 6 sampling periods and significant interaction ($P = 0.003$) at 8 weeks. However type of variety influenced weight loss, SC529 variety generally experienced lower grain weight loss than the Klein Karoo PGS variety with higher grain weight loss.



The grain protectant had significant effect, the untreated control recorded the highest grain weight loss whilst the synthetic pesticide Shumba constantly recorded the lowest grain weight loss.

loss. Among the botanical treatments, clove powder performed better with the steady decline in weight loss compared to peppermint powder with higher weight loss.

Table 4.3: Pesticide effect on grain weight loss against time.

Treatment	Time (Weeks)			
	2	4	6	8
Cloves	10.00 ^b	7.67 ^{bc}	4.33 ^a	2.3 ^c
Peppermint	16.50 ^{ab}	10.7 ^b	7.50 ^b	3.7 ^a
Shumba	2.7 ^c	4.3 ^c	4.0 ^c	3.2 ^b
Untreated	25.7 ^{abc}	32.3 ^a	41.2 ^a	46.8 ^a
Grand mean	13.79	13.67	15.71	17.79
p-value	<.0001	<.0001	<.0001	<.0001
LSD	4.8	5.9	4.2	3.8
CV%	70.13	86.48	113.36	138.79

Means followed by the same letter are not significantly different from each other at 5% significance level.

CHAPTER 5: DISCUSSION

5.1 Effects of different grain protectants on weevil (*Sitophilus zeamais*) mortality

The results demonstrated a highly significant effect of grain protectant type on weevil mortality across all sampling periods ($P < 0.001$), with no significant interaction between protectant and maize variety. Shumba Plus dust achieved 100% mortality by week 4 and maintained it through week 8. Clove powder performed comparably well, reaching 96% mortality by week 8, while peppermint powder achieved only 54% mortality at the same period. The untreated control recorded 0% mortality.

These findings align with previous studies showing that clove powder, primarily due to its high eugenol content, exhibits strong insecticidal, fumigant, and repellent properties that disrupt the nervous system and physiological processes of *S. zeamais*, leading to high mortality rates with increased exposure time (Jairoce et al., 2016; Huang et al., 2002; Sousa et al., 2023). The progressive increase in mortality over the eight weeks is consistent with the time-dependent toxicity of botanical extracts (Barre et al., 2022; Adegbola, 2023). Peppermint powder, while showing some effect, was notably less effective, likely due to its primary action as a repellent (via menthol and other volatile compounds) rather than a strong lethal agent at the tested concentration (20 g/200 g grain). Its efficacy may also decline over time as volatile compounds evaporate (Derbalah, 2011; Eesiah et al., 2022).

The superior performance of the synthetic Shumba Plus was expected, but the near-equivalent efficacy of clove powder highlights its potential as a viable alternative, especially considering cost, availability, and reduced environmental and health risks associated with synthetic insecticides.

5.2 Effects of maize variety on weevil mortality

Maize variety had a significant effect on weevil mortality only at week 2 ($P = 0.027$), with SC 529 recording higher mortality (37.33%) than Klein Karoo PGS 63 (35.33%). No significant

varietal differences were observed at later sampling intervals. This early difference suggests that SC 529 may possess slightly greater inherent resistance, possibly due to harder kernel texture or biochemical factors that increase weevil stress when combined with protectants (Sserumaga et al., 2021; Pandey et al., 2023). However, the lack of sustained varietal effect indicates that protectant type was the dominant factor influencing mortality over the full storage period.

5.3 Effects of different grain protectants on grain damage

Grain protectant type had a highly significant effect on grain damage at all sampling periods ($P < 0.001$), with no significant protectant $\times$ variety interaction. By week 8, Shumba Plus recorded 0% damage, clove powder 1.67%, peppermint powder 16.33%, and the untreated control 100%. The substantial reduction in damage with clove and Shumba treatments is directly linked to high weevil mortality, which limited feeding and reproduction. Clove's strong fumigant and contact toxicity effectively suppressed infestation development, whereas peppermint's moderate performance allowed more surviving weevils to continue causing damage (Sousa et al., 2023; Jairoce et al., 2016).

5.4 Effects of maize variety on grain damage

Variety significantly affected grain damage only at week 2 ($P = 0.005$), with SC 529 showing lower damage (35.5%) than Klein Karoo PGS 63 (39%). No significant varietal differences were observed thereafter. This early advantage for SC 529 is consistent with the mortality data and may reflect initial physical resistance to weevil penetration (Sserumaga et al., 2021). Overall, protectant application largely overshadowed varietal differences in determining final damage levels.

5.5 Effects of grain protectants and variety on grain weight loss

A highly significant interaction between grain protectant type and variety was observed for grain weight loss at weeks 2, 4, and 6 ($P < 0.001$), and a significant interaction at week 8 ($P = 0.003$). This indicates that the protective effect of different treatments varied somewhat depending on the maize variety. Across treatments, weight loss was lowest in Shumba Plus and clove treatments and highest in peppermint and untreated controls. The interaction suggests that varietal characteristics (such as kernel hardness and composition) modulated the ability of the

protectants—particularly the Botanicals—to limit feeding damage and mass loss over time.

The strong negative relationship between weevil mortality and weight loss is evident: higher mortality in clove and synthetic treatments directly translated to lower weight loss (Kumar & Kalita, 2017). Untreated grain suffered severe losses due to unchecked weevil population growth, feeding, and associated secondary issues such as frass accumulation and potential fungal activity.

5.6 Overall discussion

Clove powder at 20 g/200 g grain proved highly effective, achieving results close to the synthetic standard for mortality, damage, and weight loss. Peppermint powder provided moderate protection, primarily through repellency, but was insufficient for long-term control at the tested rate. The limited and early-only influence of variety suggests that both SC 529 and Klein Karoo PGS 63 are susceptible to *S. zeamais* under poor protection, but SC 529 may offer slight early advantages. These findings support the use of clove as a sustainable, locally accessible alternative to synthetic insecticides for smallholder farmers in regions like Chimanimani district (Stathers et al., 2020; Surgi et al., 2021).

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The study evaluated the effectiveness of clove (*Syzygies aromaticum*) and peppermint (*Mentha x piperita*) extracts as stored maize grain protectants against *Sitophilus zamias* in SC 529 and Klein Karoo (PGS63) maize varieties. The findings demonstrated that botanical extracts can play an important role in reducing post-harvest losses caused by maize weevils under smallholder farmer storage conditions.

Results showed that clove extract was highly effective in controlling maize weevils, producing high mortality rates that were comparable to the synthetic pesticide Shumba Plus dust after eight weeks of storage. Clove-treated maize grain also recorded very low grain damage and minimal grain weight loss, indicating strong protective effects against *S. zamias*. The high efficacy of cloves was attributed to the presence of eugenol, which possesses insecticidal, fumigant and repellent properties.

Peppermint extracts also showed some protective effects against maize weevils, although its performance was lower than that of cloves and the synthetic pesticide. Peppermint treatments resulted in lower weevil mortality and relatively higher grain damage and grain weight loss compared to cloves. This suggests that peppermint may be more suitable as a supplementary or short-term control measure due to its repellent action and rapid evaporation of volatile compounds.

The study further revealed that maize variety had some influence on weevil mortality, with the SC variety appearing slightly more resistant to weevil attack than the Klein Karoo variety. However, varietal differences had no significant effect on grain damage and grain weight loss when pesticides were applied.

Overall, the study concludes that clove extract is an effective, environmentally friendly and affordable alternative to synthetic pesticides for controlling *S. zamias* in stored maize grain. Its use can help smallholder farmers reduce post-harvest losses, improve grain quality and promote sustainable grain storage practices.

6.2 Recommendations

Smallholder farmers are advised to adopt clove (*S. aromaticum*) powder as a botanical grain protectant for stored maize because it effectively reduces weevil population, grain damage and weight loss in stored maize therefore reducing post-harvest losses.

Additionally, I recommend farmers to use peppermint extract mainly as a supplementary or short-term grain protectant since its effectiveness decreases over time compared to cloves as it has high repellent effect which does not contribute to mortality of the weevils.

Furthermore, extension officers and agricultural institutions should educate farmers on the preparation, application and safe use of botanical pesticides such as clove and peppermint powders for stored grain protection.

Beyond these primary recommendations, further research should be conducted using different concentrations and combinations of clove and peppermint extracts to determine the most effective dosage rates for long-term maize storage.

Future studies should also investigate the effectiveness of these botanical extracts under different environmental conditions and storage systems commonly used by smallholder farmers.

Moreover, researchers should evaluate additional maize varieties to determine varietal resistance to *S. zeamais* and their interaction with botanical grain protectants.

The government and agricultural stakeholders should promote the use of environmentally friendly botanical pesticides as part of integrated pest management strategies to reduce dependence on synthetic chemicals on stored maize.

Further studies should assess the economic feasibility, shelf life and farmer acceptability of botanical pesticides for wider adoption in rural farming communities.

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Appendix

Anova tables

Analysis of variance

Variate: Weevil_mortality_at_2_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	35409.333	11803.111	2920.36	<.001
Factor_2_Variety	1	24.000	24.000	5.94	0.027
Factor_1_Pesticides.Factor_2_Variety	3	17.333	5.778	1.43	0.271
Residual	16	64.667	4.042		
Total	23	35515.333			

Analysis of variance

Variate: Weevil_mortality_at_4_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	33436.000	11145.333	3184.38	<.001
Factor_2_Variety	1	0.000	0.000	0.00	1.000
Factor_1_Pesticides.Factor_2_Variety	3	1.333	0.444	0.13	0.943
Residual	16	56.000	3.500		
Total	23	33493.333			

Analysis of variance

Variate: Weevil_mortality_at_6_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	33078.000	11026.000	2384.00	<.001
Factor_2_Variety	1	0.000	0.000	0.00	1.000
Factor_1_Pesticides.Factor_2_Variety					
	3	12.000	4.000	0.86	0.479
Residual	16	74.000	4.625		
Total	23	33164.000			

Analysis of variance

Variate: Weevil_mortality_at_8_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	39042.000	13014.000	2169.00	<.001
Factor_2_Variety	1	6.000	6.000	1.00	0.332
Factor_1_Pesticides.Factor_2_Variety					
	3	18.000	6.000	1.00	0.418
Residual	16	96.000	6.000		
Total	23	39162.000			

Analysis of variance

Variate: Grain_damage_at_2_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	31705.833	10568.611	1546.63	<.001
Factor_2_Variety	1	73.500	73.500	10.76	0.005
Factor_1_Pesticides.Factor_2_Variety					
	3	21.833	7.278	1.07	0.392
Residual	16	109.333	6.833		
Total	23	31910.500			

Analysis of variance

Variate: Grain_damage_at_4_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	35171.333	11723.778	1674.83	<.001
Factor_2_Variety	1	2.667	2.667	0.38	0.546
Factor_1_Pesticides.Factor_2_Variety	3	17.333	5.778	0.83	0.499
Residual	16	112.000	7.000		
Total	23	35303.333			

Analysis of variance

Variate: Grain_damage_at_6_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	37650.000	12550.000	5020.00	<.001
Factor_2_Variety	1	0.000	0.000	0.00	1.000
Factor_1_Pesticides.Factor_2_Variety	3	48.000	16.000	6.40	0.005
Residual	16	40.000	2.500		
Total	23	37738.000			

Analysis of variance

Variate: Grain_damage_at_8_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	40731.333	13577.111	2088.79	<.001
Factor_2_Variety	1	10.667	10.667	1.64	0.218

Factor_1_Pesticides.Factor_2_Variety					
	3	12.000	4.000	0.62	0.615
Residual	16	104.000	6.500		
Total	23	40858.000			

Analysis of variance

Variate: Grainweight_loss_at_2_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	37165.125	12388.375	7623.62	<.001
Factor_2_Variety	1	165.375	165.375	101.77	<.001
Factor_1_Pesticides.Factor_2_Variety					
	3	91.458	30.486	18.76	<.001
Residual	16	26.000	1.625		
Total	23	37447.958			

Analysis of variance

Variate: Grainweight_loss_at_4_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	40031.167	13343.722	4709.55	<.001
Factor_2_Variety	1	73.500	73.500	25.94	<.001
Factor_1_Pesticides.Factor_2_Variety					
	3	73.833	24.611	8.69	0.001
Residual	16	45.333	2.833		
Total	23	40223.833			

Analysis of variance

Variate: Grainweight_loss_at_6_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	41690.125	13896.708	10758.74	<.001
Factor_2_Variety	1	26.042	26.042	20.16	<.001
Factor_1_Pesticides.Factor_2_Variety					
	3	28.125	9.375	7.26	0.003
Residual	16	20.667	1.292		
Total	23	41764.958			

Analysis of variance

Variate: Grainweight_loss_at_8_wks

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum					
Factor_1_Pesticides	3	43654.000	14551.333	12472.57	<.001
Factor_2_Variety	1	2.667	2.667	2.29	0.150
Factor_1_Pesticides.Factor_2_Variety					
	3	4.000	1.333	1.14	0.362
Residual	16	18.667	1.167		
Total	23	43679.333			

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