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DEPARTMENT OF CROP SCIENCE

Effectiveness of hermetic bags and botanical pesticides in reducing quantitative post-harvest losses of beans (*Phaselous vulgaris*)

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DECLARATION

I, **Mafunga Bridget** do hereby declare that this research project herein is my original work and has not been copied from any source without acknowledgement of the source. It has not been submitted before for any degree or examination at any other University.

Name: **MAFUNGA BRIDGET**

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I have supervised the research project of the above-mentioned student and I am convinced that the research project:

a) Can be submitted for marking

Project Supervisor: Dr. T. J. Chikuvire Signature _________________

Date:

b) Is authorized for marking

~~Project Supervisor: Professor C. Karavina~~ Signature __________________

Date:

I certify that I have checked the Research Project and I am satisfied that it conforms to Department of Crop Science Guidelines for Project Preparation and Presentation. I therefore authorize the student to submit this dissertation for marking.

Quality Controller: ________________________ Signature _____________

DEDICATION

I dedicate this wok to my father Mr. Elton Tazvivinga and my children Applesummer and Oblation Vareta.

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Almighty Lord for seeing me through these past three years and being my source of strength through the difficulties of running this project. Also, a very big debt of gratitude goes to my supervisor Dr. T. J. Chikuvire, I'm grateful for all the time and effort you invested in helping me make this project fruitful. Despite the challenges I faced to accomplish this project, you still made time to help me out, may the dear Lord bless you. Also, my special gratitude goes to Murereka High School headmaster Mr. Mandaza for giving me the permission to carry out my research project at the school premise. Finally, I would like to thank my dad Mr. E. Tazvivinga, brothers Temptation and Arnold Tazvivinga and my children Oblation and Applesummer Vareta for their moral and financial support.

ABSTRACT

Bean weevils are important storage pests of legumes worldwide, causing 60-90% losses among Zimbabwe's smallholder farmers. ~~rendered a worldwide pests of legume stored products. In Zimbabwe's, smallholder farmers, these insects may cause a very great post-harvest loss and also the insect have been recognized as an important constraint, with losses ranging to about 60-90 percent.~~ The majority of farmers do not apply any measures to control the pest while a few use synthetic pesticides that pose harm to users and the environment.~~While the majority of small holder farmers leave the grains untreated and this may lead to quantitative post-harvest losses. The minority of smallholder farmers are currently use synthetic pesticides in controlling the pest, while environmental and residual effects of these chemical are of increasing concern.~~ This study evaluated the effectiveness of hermetic bags and botanical pesticides in reducing quantitative post-harvest losses ~~of~~in beans caused by the weevils. ~~(*Phaselous vulgaris*).~~ Three types of hermetic bags were used in the study (triple, double and single hermetic bags). Also *Aloe barbadensis miller* (Aloe), *Azadirachta indica* (neem) and *Helianthus annus L.* (Sunflower) powder were used as botanical pesticides on the experiment. Shumba pesticides was used as positive control on the experiment. Before commencement of the experiment, the researcher cleaned the seed using winnowing method to remove all the impurities which may contaminate the results of the experiment. Also bean seed was refrigerated for 48 hours to ensure that all weevils were killed before the beginning of the experiment. In each hermetic bag, the researcher put 2kgs of bean seed and ordinary bags were used for sugar beans with botanical pesticides, shumba pesticide and negative control bag. In all bags, the researcher put 2kgs of sugar beans. The balance scale was used to weigh the bean seed. The treatments were arranged in a completely randomized design, and replicated three times. Bean weevil mortality was assessed at 2, 4, 6 and 8 week intervals. Also percentage weight loss and moisture content was assessed at 2, 4, 6 and 8 weeks intervals. . There was significant difference ($p<0.05$) in number of weevil mortality and grain weight loss among treatments. The results showed that hermetic bags were most effective especially triple and double hermetic bags as evidenced by high weevil mortality percentage, low or none multiplication percentage and maintenance of weight and moisture percentage. It concluded that hermetic bags have good properties to manage bruchids in legume storage and could be used as alternative control option.

Key words: botanical pesticides, grain weevils, hermetic treatments, mortality, multiplication, sugar beans and weight loss.

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CHAPTER 1

1.0 Background

Sugar beans (*Phaselous vulgaris*) are an important component of human diets in the world. The crop originated from Central South America (Jones and Corlett, 1992). Beans are leading source of protein and an important source of calories especially in the poorest continents. They are some principal factors responsible bean quality loss that include among other insect pest (CIAT 1989).

Ramirez *et al.,* (2013) pointed out that post production constraints include poor storage practices, pests and diseases resulting in losses. Kiaya (2014) also explains that in African countries, post-harvest losses are estimated to be 25% of the total crops harvested. The author argued that only high matured and undamaged grains should be stored as they may take time to be affected than damaged grains.

Jones and Corlett (1992) posit that optimal temperature, relative humidity and environmental changes may be regulated in the storage facilities in an effort to minimize loss of these grains. Lack of information pertaining to nature of losses and techniques to reduce post-harvest losses have been pointed out as constraints in reducing food losses. Lack of infrastructure for implementing loss prevention measures and lack of investment reduces the effectiveness of hermetic bags, pesticides and other methodologies which may be employed to curb loses. Most recently, the importance of food losses has been reasserted by African leadership with a commitment to reduce by half, the current level of post-harvest losses by 2025 as Kiaya (2014) explained. The author also highlighted that the Sustainable Development Goal has also targeted reduction of food losses along the production and supply chains.

1.2 Problem Statement

In bean production the supply chain, they are some post -harvest losses that are included from harvesting to the time of consumption which among others quality loss due to insect pest damage in particular the Bruchids which will be at the end quantitative loss. Some of the major magnitude of this is due to lack of knowledge of the smallholder farmers and inadequate technology as well as poor infrastructure. Farmers are ending up discarding the spoiled beans thereby losing income and becoming food insecure.

1.3 Justification

The results from this study will assist different organizations like the Ministry of Agriculture to disseminate correct information to small-scale farmers on how to keep their produce safe from Bruchids by using the effective techniques in order to reduce postharvest losses. Furthermore, reduction of post-harvest losses ensures that there is food security. This is generally the assurance that necessary food quantities are available in adequate quantities for consumption. For small scale farmers who want to venture in sugar beans farming, such a crop may increase chances of domestic income or foreign currency generation.

1.4 Main objectives

To assess the effectiveness of hermetic bags and botanical pesticides in reducing quantitative losses in sugar beans due to bean weevils damage.

1.5 Specific objectives

1. To determine the effect of hermetic bags (single, double and triple) and botanical pesticide powders (neem, aloe and sunflower on bean weevil mortality rate.

2. To determine the effect of hermetic bags and botanical pesticide powders on sugar bean weight loss and moisture content.

1.6 Hypotheses

1 There is no significant difference in using hermetic bags and traditional pesticides on the mortality of bean weevils.

2 Hermetic bags and botanical pesticides have no effect on sugar bean weight loss and moisture content.

CHAPTER 2

2.0: LITERATURE REVIEW

2.1 Sugar Beans

Sugar beans (*Phaselous vulgaris)* is an important food crop for humans and is one of the principal crops grown in Zimbabwe as a source of nutrition income and food security among other nutrients , It is rich in iron and zinc (95mg/kg and 38mg/kg respectively) as these were bio fortified in some varieties like NUA 45 (FAO 2013). As noted by Jones and Corlett (1992), beans originated from Central South America and are now grown in over 92 countries worldwide (CIAT 1989). Major producers are in Zimbabwe are found in all the 5 agro ecological regions but highest concentration is in regions 111,1v and v which are characterized by low rainfall and intermittent dry seasons and out of 60 districts in Zimbabwe 44 grow the bean crop.

Uses of crop

2.2 Post Harvest Loss (PHL)

FAO (2013) explained post-harvest loss as the degradation in both quality and quantity of food production from harvest to consumption. In reference to the quality aspect, Rambold *et al.,* (2011) postulated that nutrient and calorie composition will be reduced thus affecting the acceptability and edibility of the product. A major component that constitutes PHL is food loss which is explained by Regmi *et al.,* (2001) as the in advertent loss in food quantity because of infrastructure and management limitations of a given food value chain. This may arise as a result of a direct quantitative loss or arise indirectly due to qualitative loss.

Scenarios of qualitative loss may include reduced nutrient value and unwanted changes to taste, color, texture, or cosmetic features of food (Buzby and Hyman, 2012). Quantitative food loss can be defined as reduction in weight of edible grain or food available for human consumption. The quantitative loss is caused by the reduction in weight due to factors such as spillage, consumption by pest and also due to physical changes in temperature, moisture content and chemical changes as defined by FAO (1980).

2.2.1 Causes of Post-Harvest Loss

Food waste as another contribution to post-harvest food losses is elaborated by Quested *et al.*, (2009) as the loss of edible food due to human action or inaction such as throwing away wilted produce, not consuming available food before its expiry date, or taking serving sizes beyond one's ability to consume. Kader (2005) pointed out that with estimated food losses of about 30-50 % of total production, this translates to wasting 1.47-1.96 Gha of arable land, 0.75-1.25 trillion m^3 of water and 1% to 1.5% of global energy. The main attributes to post-harvest losses are intolerance of substandard food, inefficient farming systems, bad transport facilities, lack of management, poor storage and processing facilities which ensure that a larger proportion of harvested output is delivered to the markets (Hodges, Buzby and Bennett, 2011).

In developing countries, post-harvest losses mainly occur in the early and middle stages of the food supply chains with proportionally less amounts wasted at the consumer level. Poor state of their supply chains and premature harvesting are also constraints as harvesting beans before they develop fully affects quality and when they are dried, they become wilted, unattractive and may lack essential nutritional content. United Nations (2011) revealed that poor storage facilities, lack of infrastructure and lack of processing facilities pose a major threat to African countries as some farmers may lack information and expertise as to how post-harvest losses may be handled. Mvumi (1995) highlighted that small scale farmers may also lack adequate information about how easy and accessible methods like botanical pesticides may be used in an effort to eradicate these losses that arise even after experiencing bumper harvest.

2.3 Methods of Controlling Post-Harvest Losses

2.3.1 Hermetic Bags

This is the most basic method that is used to store beans for a certain period of time with minimal loss in quantity and quality. A hermetic bag is defined by Murdock *et al.*, (2017) as a sealed storage system that is in form of a bag where in it, there is an oxygen and moisture depleted atmosphere and carbon dioxide enriched inter granular atmosphere, produced by respiration of the living organisms in the dried food commodities and derived products.

Their effectiveness is attributed to airtight conditions created during storage. Biological processes such as respiration and metabolic activities become highly constricted as the bags are sealed. Tubbs *et al.,* (2017) posit that in the hermetic bags, there is a generated modified environment that is created by the organisms that are present in the beans. These microorganisms consume or use oxygen during the respiration process and exhale carbon dioxide. As a result, the hermetic bags are saturated with carbon dioxide and less oxygen which makes it complex for any living organism to thrive, grow and develop in these bags. As these bags are tightly sealed, oxygen permeability into the bags is constrained and thereby reducing the lifespan and development of insects even molds thus preventing grain deterioration. Commonly used hermetic technologies include silos (metal and plastic), drums, cocoons, plastic bags, and other containers.

There are three different types of hermetic bags namely single, double and triple. Mutungi *et al.,* (2015) explained the single hermetic bag as the one that has one liner with multiple layers and examples are GrainPro Bag and Zipper. There are different types of double hermetic bags with some having one polypropylene bag and one liner with multiple layers (Mutungi *et al.,* (2015)). Examples of these may include AgroZ. Another type of double hermetic is the one that has one polypropylene bag and one liner with multiple layers impregnated with insecticides like AgroZ Plus. The other kind has one polypropylene bag impregnated with insecticides and one liner with multiple layers. These may include the ZoroFly hermetic storage bag. Mutambuki *et al.,* (2019) said that the triple bag has one polypropylene bag and two high density polyethylene liners. All these models prove that hermetic technology has some protection that it offers to the grains and may reduce post-harvest losses.

When the inner liner is pierced, the technology loses its efficacy, and the bag should be replaced. For brands that has triple bags, the second liner provides extra safety in case one of the two liners is damaged. Insects rarely damage the second liner of the triple-layer bags as Murdock *et al.,* (2012) highlighted. Among hermetic technologies, hermetic bags are the most widely used by small scale farmers in Sub-sectarian Africa and Asia.

2.3.1.1 Effectiveness of Hermetic Bags on Bean Weevil Survival

The use of hermetic bags to store grain has significantly increased in the past ten years, spearheaded by the development of the Purdue Improved Crop Storage (PICS) bag as explained by Murdock *et al.,* (2017). The wide usage of these bags is driven by the severity of storage losses at the farm level, the efficacy of the technologies, and other merits such as being chemical-free, cost-effective, easy to use; and locally available. Hermetic bags significantly reduce food safety risks posed by the conventional method of treating stored grains with insecticides.

Hermetic bags can achieve 100% insect mortality and reduce losses to less than 1% after several months for Phaselous *Vulgaris* as purported by De Groote *et al.,* (2013). Empirical evidence provided by this author suggests that hermetic bags are effective as they have contributed in improved food security and income; and the reduction of insecticide usage. However, Agricola (2011) advocated that there is little study and evidence pertaining to the adequate moisture content that has to be achieved for *Phaselous Vulgaris* before storage. This anonymity may result in loss after harvest due to too much moisture or too much drying.

Ndegwa *et al.,* (2015) has highlighted that there is also little knowledge on the effects of hermetic bags on the quality of common beans. Another study by Momanyi and Omwamba indicated that beans stored in hermetic bags had 22%, 33% and 18% higher total soluble sugars, invitro starch and protein digestibility respectively than those stored in polypropylene bags. This proves that hermetic bags are very effective to preserve beans after harvesting. Regardless, hermetic bags are usable for two or more storage seasons and still maintain their effectiveness and do not affect the chemical composition on the stored products. Little evidence related to preserving *Phaselous Vulgaris* using hermetic bags after harvest is available making it paramount to investigate the phenomenon.

Current Research in Food Science (2022) argued that PICS hermetic bags are superior to PPB bags as the experiment carried out reflected that nutrient and quality retention of common beans was superior in PICS hermetic bags. The research also explained that optimal starch and protein digestibility and tannin content was present, thus preserving quality in PICS hermetic bags. Another study depicted that hermetic bag were highly effective in controlling storage pests even after four months because grain damage was estimated to be 14% and only 4% loss in treatments. Weight loss due to insect pests was 1.7% among control farmers and 0.4% in the treatment group.

To maintain quality and effectiveness during storage in hermetic bags, grains must be dried to the recommended moisture content which is less the 16% for *Phaselous Vulgaris*. If the beans are stored when they are moist, there will be immense quality deterioration through germination loss. Mould growth rapidly increases if grains are not properly dried and stored, producing aflatoxin, which causes liver cancer and other health problems (Likhayo *et al.,* 2018). Finding affordable and most cost-effective drying methods and moisture assessment tools should be explored to improve the quality of grain stored in hermetic bags. Low-cost moisture assessment and drying devices have been developed as Walker and Davies (2017) emphasized but need to be disseminated to smallholder farmers.

2.3.2 Botanical Pesticides

Abatania *et al.,* (2012) defines these pesticides as naturally occurring chemical compounds extracted or derived from plants to manage field and storage crop pests. In different parts of the world, Weinzierl (2000) highlighted that there is empirical evidence that denotes the usage of botanical pesticides since time immemorial and before the commencement of usage of synthetic pesticides that are believed to be harmful to the society and humans at large. For small scale farmers in Africa, Karani *et al.,* (2017) explained that between 1994 and 2012, over 80% of the farmers exclusively employed traditional botanical methods in pest management. These pesticides have always provided crop protection and in this experiment, focus will be on three components which are neem, sunflower and aloe powder.

Adverse effects of synthetic pesticides as Weinzierl (2000) explained are the development of pest resistance, pesticide food contamination and environmental pollution problems. They also include the disruption of natural balance, toxicity to non-target organisms and the most important negative impact on human health especially small scale farmers that may lack information or adequate equipment to safely use synthetic pesticides. Traditional pesticides are easily available, lower in cost compared to synthetic pesticides, accessible and can be renewed sustainably as botanicals can be grown, multiplied and easily shared within local communities.

In countries like Benin, BPs such as *pyrethrins* and neem extracts are used to control cotton bollworm and in Uganda extracts from marigold (*Tagetes spp*) are used against Bruchids beetles of cowpeas neem (*Azadirachta Indica L.)*, worm seed (*Chenopodium ambrosioides* L.), cypress (*Cupressus lucitanica*) and marigold (*Tagetes minuta L.)* in management of important field and storage insect pest of common beans. These pests particularly include Ootheca (*Ootheca bennigseni)* and common bean weevil (*Acanthoscilides obtectus)*. Furthermore, Hegde (1995) reported toxicity, potentiality and effectiveness of botanical pesticides particularly *Tephrosia vogelii, Venonia amygdalina, Tithonia diversifolia* and *Lantana camara* in managing both field and storage insect pests of major economies, is effective.

To prepare powder formulation, plant materials are collected; either sun dried or oven dried and then pulverized into fine powder using pestle and mortar or electric mill. Wickison (2022) purported that even extracting oil from neem seed and mixing it with water is effective as a pesticide. The application rate of powder formulation ranges from 1-20 g/kg of the produce, but does not usually exceed 2% of the weight of produce as Karani *et al.,* (2007) explained. Adhikari *et al.,* (2020) have pointed out that neem based products are readily available to control a range of pests at varying life stages.

2.3.2.1 Effectiveness of Botanical Pesticides

In Africa, several studies have shown that these traditional pesticides are effective in controlling field insect pest of common beans. For instance, Mpumi (2016), reported that insecticidal properties of neem (*Azadirachta Indica L.)* are very effective in the management of important field and storage insect pest of common beans, for instance, the common bean weevil (*Acanthoscilides obtectus)*. Neem contains a chemical composition of *Azadirachtin* that works effectively against pests and insects.

Weinzierl (2000) purport that the biological components of traditional pesticides are dependent on the type of plant used on particular seeds or cereal. For instance, neem is considered as a food herbicide that is effective in protecting against pesticides. In addition, the correct part of the plant should be used. For sunflower powder, parts of the plant like stem and leaves are the ones that are dried up. If one may decide to use roots or the flower instead, it may reduce the effectiveness of sunflower powder against protecting the sugar beans from the bean weevil as Karani *et al.,* (2017) argued. The physiological state of the part used and the extraction solvent also play a major role on the effectiveness of traditional pesticides. The parts that are extracted have to be in good condition and with no infections such that some chemical properties that are relevant for crop protection may be eradicated or lessened.

Furthermore, statistical evidence shows that 80% of the farmers in Malawi, Tanzania, and Uganda exclusively employ traditional methods in pest management. In another study by Cobbinah *et al.,* (2012) depicted that in Northern Ghana, 90% of farmers regularly use traditional pesticides and in other countries outside Africa, report by Isman (2008) and Thacker (2002) show that China, Egypt, Greece and India have been using these pesticides for the past two millennia. According to these statistics, it is clear that traditional pesticides are effective not only in Africa but also globally.

2.4 Measurement of Post-Harvest Losses

2.4.1Weevil Mortality Rate

The bean weevil is a serious pest that affects quality through perforations of beans in storage. This pest reproduces fortnightly and, in this process, some percentage of the population may die due to botanic and synthetic pesticides that will be introduced in this experiment. This is the mortality rate. The researcher will be inside the net physically counting dead weevils as Orchard and Hodges (2012) posit. Mortality rate may be calculated as

$$Mortality\ Rate = \frac{D}{TP} * 100$$

……………………………………………………………………………………..… [3]

Where D is the number of dead weevils, TP is the total number of weevils in each bag. To find the mean mortality, an average may be calculated over the total number of bags used in this experiment.

2.4.2 Percentage multiplication of weevils.

A bean weevil reproduces and larvae hatches in within 14 days. Within the next 21 days, the larvae would have fully grown and repeats the reproduction process. Even after feasting on the grains, bean weevils leave eggs that will be hatched after some time. As the rate of multiplication of bean weevils affects immensely the rate of post-harvest losses, there is need to keep track of it so as to determine the rate at which hermetic bags and botanical pesticides hinder their multiplication rate. Karani *et al.,* (2017) posited that the multiplication rate may be calculated and recorded after every two weeks for eight weeks. Fortnight observations are paramount as this is the time necessary for larvae to hatch. Singh *et al.,* (1996) argue that the rate of multiplication may be calculated as:

$$Multiplication\ Rate = \frac{X}{XY} * 100$$

……………………………………………………………………………………. [4]

Where X is the difference between the initial number of weevils which is 20 and the final number of weevils which includes the dead weevils. XY is the total or final number of weevils.

2.4.3 Weight Loss

The weight loss in beans initially arises due to drying that has to happen before storage. For this reason, it is essential to measure moisture content after drying but before the grains are put into hermetic bags. This is because this portion of moisture content is not to be included in the experiment since it is not considered as part of post-harvest loss. During the process of the experiment, sugar beans will continue to lose weight possibly due to continued drying or infestation of the bean weevil. Weight loss as thus will be a depiction of post-harvest losses and is useful in this experiment to measure the effectiveness of hermetic bags and botanical pesticides. The Thousand Grain Method is a useful methodology where dry weight of a thousand grains will be measured at the beginning of the storage season. This will be compared against weight of thousand grains at intervals of two weeks until the eighth week of storage. After ascertaining weight loss, it will be multiplied by 1000 to get TGM. This can be summed up as:

$$TGM = \frac{10 * M * (100 - h)}{N} \quad \text{………………………………………………………………………. [6]}$$

Where: m is the mass of grain in sample, N number of grains in sample, H moisture content of grain.

$$\%\ Weight\ loss = \frac{(Initial\ TGM - Sample\ TGM)}{Initial\ TGM} * 100 \quad \text{……………………………….. [5]}$$

2.4.3.1 Moisture Changes

This is believed to be the biggest attribute to storage losses. When arranging grains for storage, it should always be noted that grains with low moisture levels maintains quality better than grain stored with higher moisture levels, as Suleiman *et al.,* (2018) revealed. Grain stored at 14% moisture content is believed to contain little moisture and there is no compromise of quality since moulds may not develop. Any grain stored with moisture content above 16%, has a likelihood of developing moulds accompanied by a strong musty odour during storage due to fungal infection. Grain spoilage results in qualitative loss from discoloration of grain, the release of odours, loss of seed viability, nutritional degradation and production of secondary metabolites (mycotoxins) which are detrimental to human and animal health, (Williams *et al.*,2014).

Due to the above mentioned facts, moisture changes should be recorded and analyzed in this experiment.

CHAPTER 3

3.0: MATERIALS AND METHODS

3.1 Study Site

The experiment was conducted [in a laboratory] at Murereka High School in Lion's Den (Makonde District). The area is located 24km from Chinhoyi town in agro-ecological region 2. Its GPS coordinates are 17^{o}16'00" South and 30^{o}2'00" East.

3.2 Experimental Design

A Completely Randomized Design (CRD) was used in this experiment with 8 treatments replicated 3 times and it was a one factor experiment.

3.3 Experimental Procedure

Before commencement of the experiment, the bean seeds were winnowed in order to remove all extraneous matter and broken seeds (Masaya, 2004). The seeds were then sterilized by refrigeration for 48 hours to kill all infesting (Muzemu *et al.*, 2013). After sterilization, the sugar beans seeds*)* were   sun-dried to 15% moisture content. The seeds were thereafter packed into hermetic bags and general sacks using the sample size of 2 kilograms and the respective treatments applied. After this, twenty bean weevils were introduced in all treatments. Mosquito nets were used to cover the bags for the duration of the experiment to prevent weevils from escaping and others from infesting the beans from the outside.

3.4 Preparation of Botanical Pesticides

Botanical pesticides were derived from plant leaves, and stems through powder formulation. Neem leaves were air dried at room temperature of 27 - 30 degree Celsius. Aloe leaves were sun dried since aloe needs more time and high temperatures to dry. Sunflower stems were taken already dried from the field after harvesting. The dried leaves were separately pulverized into fine powder using a pestle and mortar and then sieved using a 1mm sieve cloth to produce fine powder which was applied over the produce and mixed thoroughly before storage. Powders were kept in well labelled polythene bags at room temperature to avoid quality loss prior to usage. Shumba pesticide was purchased at Farm and City Hardware in Chinhoyi town.

3.5 Preparation of the room

The room in which the experiment was conducted was initially cleaned thoroughly using Calcium Chloride and powdered soap and allowed to dry. The walls were later wiped using mutton cloth dipped in 70% ethanol. The purpose of this procedure was to remove all impurities and dirt that may contaminate the experiment. Temperature in the room was 20.7^{o}C.

3.5 Insect Introduction

Bean weevils were obtained from already infested sugar beans at the Grain Marketing Board in Murereka. Twenty bean weevils were introduced in each treatment with no sexing done.

3.6 Data Collection

3.6.1 Weevil Mortality Rate

Mortality rate was assessed after every two weeks for eight weeks post introduction of the Bruchids. Both live and dead weevils were counted physically, with the live weevils returned into the respective bags. Mortality rate was calculated as:

$$Mortality\ Rate = \frac{D}{TP} * 100$$

Where D is the number of dead weevils and TP is the total number of weevils in each bag.

3.6.2 Percentage of Multiplication

Karani *et al.* (2017) highlighted that the multiplication rate may be calculated and recorded after every two weeks for eight weeks. The importance of noting multiplication was to determine if ever, weevils were able to increase in number under extreme conditions present in the bags. Fortnight observations were paramount as this was the time necessary for larvae to hatch. The percentage of multiplication was calculated as:

$$Percentage\ of\ Multiplication\ = \frac{X}{XY} * 100$$

Where *X* is the difference between the initial number of weevils which is 20 and the final number of weevils which include the dead weevils. *XY* is the total or final number of weevils.

3.6.3 Weight Loss

Grain weight was measured at two-week intervals using a digital scale using the formula:

$$TGM = \frac{10 * M * (100 - h)}{N}$$

Where: m is the mass of grain in sample, *N* number of grains in sample, *h* moisture content of grain.

3.6.4 Moisture Changes

Weinzierl (2010) posits that moisture changes should be recorded and analyzed. Weinzierl (2010) posits that grain moisture content is expressed as a percentage of moisture based on weight (weight basis) or dry matter (dry basis). Wet basis moisture content is generally used.

$$\text{Mw (wet basis)} = \frac{w - d}{w} * 100$$

Where w is wet weight, d is dry basis and M is moisture content on percent basis.

3.7 Data Analysis

Data were sorted, coded and entered into the GenStat package, 18th edition for analysis. Data was tested for normality using the Smirnov-Kolmogorov test prior to analysis hence there was no need for transformation. A one-way analysis of variance (ANOVA) at 5% level of significance was used to test the difference between treatments whereas the means were separated using the Least Significant Differences (LSD) at 5% level of significance.

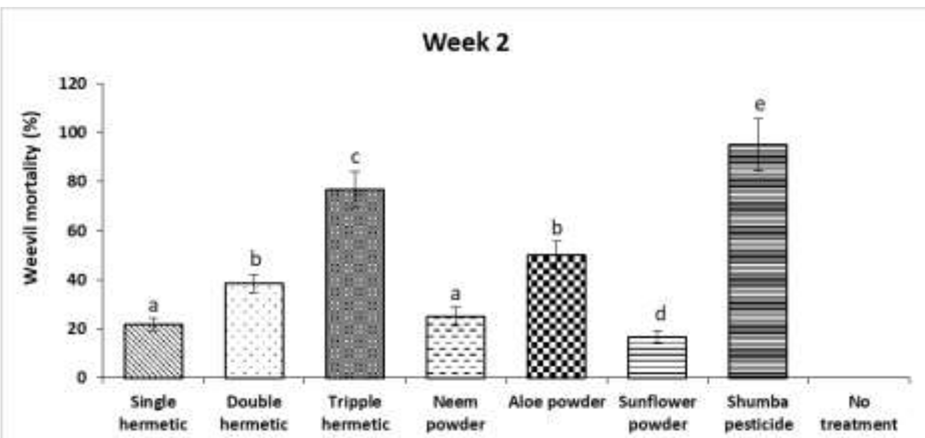
CHAPTER FOUR:

4.0 RESULTS

4.1 Weevil mortality and multiplication rate

4.1.1 Grain weevil mortality in sugar beans

The mortality of grain weevils in sugar beans with respect to different treatments over an eight week period is shown in Figs. 4.1 to 4.4. At Week 2, all the hermetic bags treatments were significantly different ($p < 0.05$). In addition, the botanical pesticides (Aloe, Neem and Sunflower) were also significantly different from each other ($p < 0.05$). There was no significant difference between the Single hermetic bag and Neem powder, as well as between the Double hermetic and Aloe powder respectively ($p > 0.05$). The Shumba pesticide had 95% weevil mortality whereas the No treatment had none (0%) (Fig. 4.1).



~~*Error bars represent standard error of the mean, different $^{a, b, c}$ superscripts denote significantly different means ($p < 0.05$).~~

At Week 4 (Fig. 4.2), the Shumba pesticide treatment had a 100 % weevil mortality whereas the No treatment attained the lowest mortality (11.6%). The Shumba pesticide and the Triple

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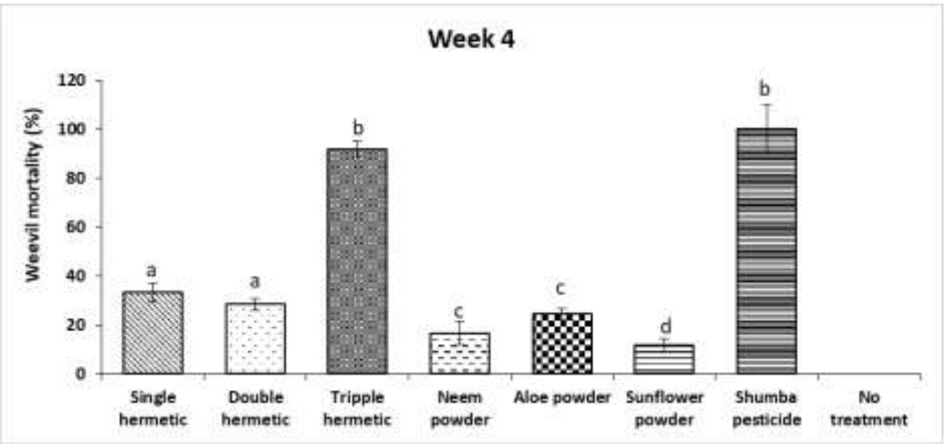
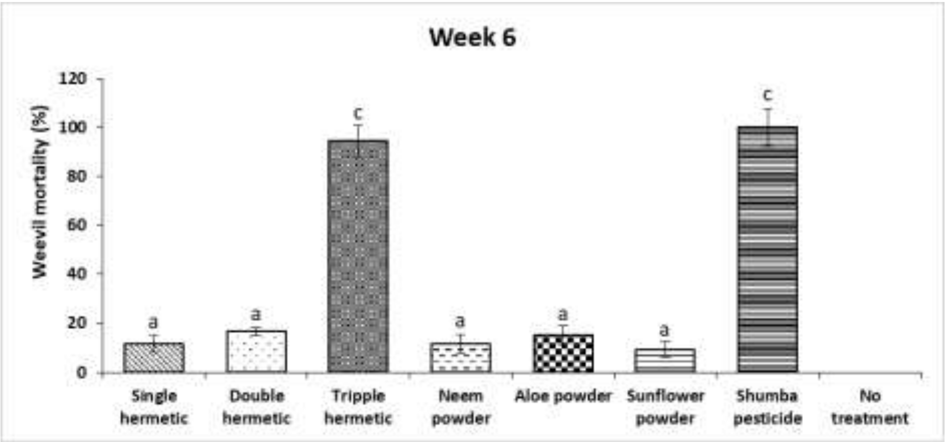
hermetic bag treatment were not significantly different ($p < 0.05$). However, the hermetic treatments were significantly different from the botanical pesticides ($p < 0.05$).

At Week 6, the Shumba pesticide (100%) and Triple hermetic bag (94.4%) treatments had the most weevil mortality, and were not significantly different ($p < 0.05$). On the other hand, weevil mortality declined in all the other treatments. Neem, Aloe and Sunflower powders were not significantly different ($p > 0.05$). The Single and Double hermetic bags were not significantly different from the botanical pesticides ($p > 0.05$) (Fig. 4.3).

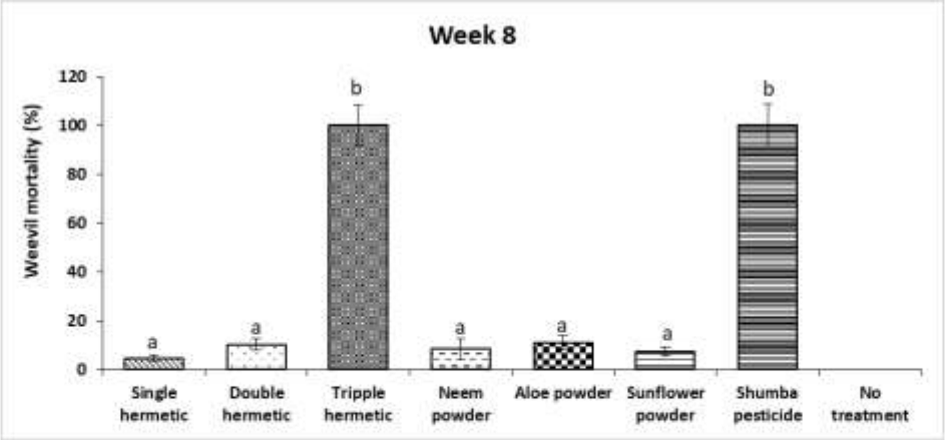


~~*Error bars represent standard error of the mean, different [a, b, c] superscripts denote significantly different means ($p < 0.05$).~~



~~*Error bars represent standard error of the mean, different [a, b, c] superscripts denote significantly different ($p < 0.05$).~~

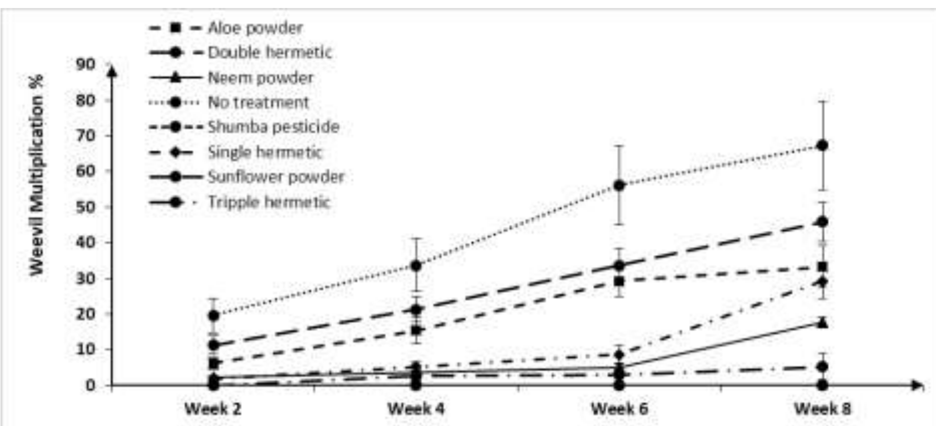
At Week 8 (Fig. 4.4), the Triple hermetic bag and Shumba pesticide maintained 100% weevil mortality, and were not significantly different ($p < 0.05$). In the remaining treatments, weevil mortality continued to decline with the No treatment recording the lowest weevil mortality of 0%. Overall, the Shumba pesticide and Triple hermetic bags treatments were effective in weevil mortality whereas there was no mortality recorded in the No treatment.



~~*Error bars represent standard error of the mean, different [a, b, c] superscripts denote significantly~~

4.1.2 Grain weevil multiplication in sugar beans

The multiplication percentage of grain weevils in sugar beans subjected to different treatments is shown in Fig. 4.5. The No treatment had the highest weevil multiplication rates at all weeks Week 2 (19.6%), Week 4 (33.7%), (56%) and Week 8 (67.3%) respectively. The No treatment was significantly different from other treatments at all weeks ($p < 0.05$). There was no weevil multiplication in the Shumba pesticide and Triple hermetic bag treatments throughout the experiment period. Neem powder had an overall lower weevil multiplication percentage amongst the botanical treatments (17.6%) and was better than the Single hermetic bag treatment. In addition, the Single hermetic bag and Aloe powder were not significantly different on the final day (Week 8) of measurement ($p < 0.05$) (Fig. 4.5).



~~*Overlapping error bars on each week represent denote significantly different means (p < 0.05).~~

4.2 Sugar beans weight and moisture content

4.2.1 Weight loss of sugar beans

Table 4.1 shows the percentage weight loss in sugar beans grain under different treatments. The No treatment attained the highest losses in grain weight for all weeks, Week 2 (11.7±3.18g), Week 4 (22.7±4.21g), Week 6 (30.8±7.09g) and Week 8 (35±7.26g) respectively. The Shumba pesticide treatment (1.5±0.01g) had the overall lowest grain weight loss at Week 8. Sunflower powder and the No treatment were not significantly different at Week 2 ($p = 0.2644$), whereas the Shumba pesticide was significantly different from other treatments at Week 6 ($p = 0.0264$) and Week 8 ($p = 0.0107$) respectively (Table 4.1).

Table 4.1: Weight loss in sugar bean grain for different treatments.

Treatment	Net Weight loss (g)			
	Week 2	Week 4	Week 6	Week 8
Single hermetic bag	$1.02±0.04^{a}$	$5.63±1.02^{a}$	$12.7±3.06^{a}$	$18.6±4.35^{a}$
Double hermetic bag	$0.53±0.01^{b}$	$2.53±0.06^{b}$	$6.24±2.14^{b}$	$9.5±2.76^{b}$
Triple hermetic bag	-	$1.25±0.03^{c}$	$3.33±1.73^{c}$	$5.17±1.93^{c}$
Neem powder	$2.6±0.05^{c}$	$4.67±0.94^{a}$	$7.5±2.38^{b}$	$15±3.28^{a}$
Aloe powder	$4.33±0.88^{d}$	$5.1±1.33^{a}$	$7.93±2.51^{b}$	$10.3±2.97^{b}$
Sunflower powder	$9.67±2.39^{e}$	$12.1±2.87^{d}$	$22.3±4.63^{a}$	$30±6.84^{a}$
Shumba pesticide (positive control)	-	-	$0.03±0.00^{d}$	$1.5±0.01^{d}$
No treatment (negative control)	$11.7±3.18^{e}$	$22.7±4.21^{e}$	$30.8±7.09^{e}$	$35±7.26^{e}$

$^{a, b, c}$ superscripts down a given column denote significantly different means ($p < 0.05$).

4.2.2 Moisture content in sugar beans

Table 4.2 shows the moisture loss in sugar beans grain subjected to different treatments. The negative control had the highest moisture loss at all sampling days, attaining values of 6.37±1.63, 4.81±0.34% and 1.24±0.08% for Weeks 2, 4 and 6 respectively. There was no moisture loss recorded at Week 8 for all treatments. In addition, at Week 6 there was no significant difference in the measured treatments ($p > 0.05$). Overall, total moisture loss from Week 2 to Week 8 was in the order No treatment > Sunflower ash > Aloe ash > Single hermetic bag > Neem ash > Double hermetic bag > Triple hermetic bag > Shumba pesticide (Table 4.1).

Table 4.2: Moisture loss in sugar bean grain with respect to different treatments

Treatment	Moisture loss (%)			
	Week 2	Week 4	Week 6	Week 8
Single hermetic bag	4.35±1.36[a]	3.49±1.22[a]	1.37±0.72	-
Double hermetic bag	2.48±0.26[b]	1.42±0.93[b]	-	-
Triple hermetic bag	1.02±0.13[c]	-	-	-
Neem ash	3.09±0.94[a]	1.63±1.05[b]	0.86±0.06	-
Aloe ash	5.61±1.07[a]	3.72±1.36[a]	1.42±0.91	-
Sunflower ash	6.14±1.58[d]	3.73±1.41[a]	1.27±0.18	-
Shumba pesticide (positive control)	0.83±0.06[e]	-	-	-
No treatment (negative control)	6.37±1.63[d]	4.81±1.83[a]	1.24±0.08	-

*Different [a, b, c,] superscripts down a given column denotes significantly different ($p < 0.05$).

CHAPTER 5: DISCUSSION

Commented [CK7]: This discussion is based on wrong results. I propose that the experimental design issues be clarified, results re-analyzed and then the discussion be properly done. As of now, this discussion is a futile exercise.

~~CHAPTER 5: DISCUSSION~~

5.1.1 Weevil mortality

Significant differences in percentage weevil mortality were found ~~between~~ among treatments, with the hermetic storage (particularly the triple hermetic bag) outperforming the non-hermetic treatments except Shumba pesticide during the entire 8 week storage period, suggesting the triple hermetic bag remained relatively hermetic throughout the experiment. The high performance of the triple hermetic bag in controlling the weevils could be explained on the basis that the triple bag is more hermeticity that the single and double. As noted by Chigoverah and Mvumi (2016), these technologies work on the principle of creating a modified environment within the storage bag, and are constructed of materials with very low oxygen permeability, thus the triple bag has the lowest oxygen permeability compared to the other hermetic bags. Thus, as revealed by Yakubu et al (2011), respiration by biological agents such as insects, mites, micro flora and the grain itself within the hermetic storage facility will deplete the oxygen and cause a build-up of carbon dioxide, suffocating any pests that might be present. The study indicated that triple hermetic bags treatments were effective in weevil mortality and even more effective than the botanical pesticides and the current study findings are in sync with studies by Mutungi et al. (2015) and Kumar et al (2017). The superior efficacy of the hermetic storage technologies as compared to the botanical pesticides in suppressing insect damage in stored grains suggests they can be recommended and promoted for beans storage.

From week two the effectiveness of single hermetic bags and neem powder in controlling weevils was the same. Similar weevil mortality was also observed on double hermetic bags and aloe powder with sunflower powder being the least effectiveness amongst all the botanical pesticides when compared to the hermetic bags. However as the storage period increases the effectiveness of single and double hermetic became similar to that of the all the botanical pesticides as observed on the weevils mortality rate after 2 months. The triple hermetic bags performance was similar to that of Shumba from week 4 up to week 8. The triple hermetic bags outperformed all the botanical herbicides during the whole storage period. However, most of the botanical pesticides and combinations as used in this trial are not well-documented. A few botanical pesticides reported being effective against storage insect pests include Eucalyptus leaves against Sitophilus spp. and T. castaneum (Mubayiwa et al, 2021) and Aloe spp. against storage moths (Vassilakos et al, 2019). Botanical pesticides are regarded as attractive alternatives to synthetic pesticides (Paudya et al, 2017) not due to their efficacy but because they are perceived by farmers as being relatively safe to human health and the environment, and locally available. As demonstrated in this research, there is still more work to be done if botanical pesticides are to significantly contribute to improved grain storage. More research is needed to determine which botanical species, and using what application methods and dosage are effective against which storage pests.

From week 6 to week 8 there was very low weevil mortality on all botanical pesticides and on single and double hermetic thus, there were no significant differences in performance. Studies by De Groote et al. (2013) and Mutambuki et al. (2014) in Kenya indicate that weevils can also thrived in grain treated with botanical pesticides with grain damage over 50% in a six months storage period. In this study the triple hermetic bags were the only effective hermetic system with higher weevil mortality after two months, while the single hermetic bags have the lowest of all the bags with weevil mortality of less than 10% below that of all the botanical pesticides. The reasons could be that as the storage period increases, the hypoxic conditions that kill the weevils in single bags decrease as well as the hypercarbic.

5.1.2 Percentage multiplication of weevils

There was no weevil multiplication in the Shumba pesticide and triple hermetic bag treatments throughout the experiment period. Regarding the performance of the triple hermetic bag, the current study results are in line with studies by Kumar et al (2017), Yakubu et al (2011). The triple bag was high hermetic and thus retarded the movement of oxygen into the stored grain from the outside environment, resulting in desiccation and death of weevils as a result of shut down in the production of metabolic water (De Bruin et al, 2012). In addition, terrestrial insects also lose water when they continually ventilate their tracheal linings when exposed to dry conditions. The results reported here demonstrates that triple hermetic bag, when used correctly, are very effective in controlling weevils. The triple hermetic bag treatments (suppressed pest build-up during the full length of the trial , but small weevils populations managed to develop in single and double hermetic bag treatments due to their relatively lower hermetic compared to the triple bag.

Neem powder had an overall lower weevil multiplication rate amongst the botanical treatments and was better than the single hermetic bag treatment. The performance of Neem can be as a result of its repellent effect, and this effect by neem products against insect pests has been reported by several authors like Yakubu et al (2011) and Mutungi et al. (2015). The authors reported that neem does not usually kill insects straight but rather it repels them and that could affect their growth and development. However the current study results are contrary to findings by De Groote et al. (2013) who found no significant differences in pest populations and grain damage between single, and triple hermitic bags when compared side-by-side under laboratory environments in Niger. Their study recommended that farmers can use any of the three hermetic bag versions, considering their availability and cost, and get the same level of efficacy in protecting their stored grain from insect damage.

The relatively high weevil multiplication rate in single and double hermetic bags can be attributed to possible low hermeticity due to the high temperatures which might have caused cracking and loosening of the elastic bands used to fasten the bags. The results may also suggest that this pest is able to survive under low oxygen conditions, which warrants further investigation. Previous studies showed that weevil's mortality is low at oxygen levels above 4% (Mutambuki et al, 2014). The current study did not have gas monitoring equipment, or a pressure test to determine the oxygen-carbon dioxide levels in the bags, and gas permeability levels of the individual hermetic bag to link with weevils' response. This equipment could have helped determine precisely the oxygen-carbon dioxide levels under which these insects survived or the possible changes in pressure, pointing to possible loss of hermeticity. However, the study results showing superiority of triple hermetic bag compared to botanic pesticides.

5.2 Sugar beans moisture and weight loss under different treatments

5.2.1 Weight loss

There was significant differences in weight loss under different treatments between treatments, with the hermetic storage (particularly the triple hermetic bag) outperforming the non-hermetic treatments except Shumba pesticide during the entire storage period. The triple hermetic bags have the lowest weight loss compared to the single and double throughout the whole storage period. Amongst the botanical pesticides neem powder was more effective in weevil control compared to the single hermetic bags but less effective when compared with the double hermetic bags. Sunflower powder was the least effective of all the pesticide with the highest weight loss recorded from week 2 to week 8. Shumba pesticide was more effective compared to all the types of the hermetic bags. The arrested insect pest development in the triple hermetic bags resulted in low grain damage and grain weight loss levels while the botanical pesticide treatments failed to suppress insect pest build-up, and experienced high grain weight loss due to insect feeding. These results suggest the insect pests may have built up resistance to the tested botanical pesticides, the product botanical pesticides was sub-standard, or that the high temperatures experienced during the trial could have led to reduced efficacy. The current study results concurred with other findings in some parts of Africa and Mexico where grain weight losses of at least 25% were reported during storage, hermetic storage facilities have been used resulting in weight loss reduction to about 10% (Chigoverah and Mvumi, 2016).

Hermetic bags and metal silos have also been evaluated under simulated smallholder farmer conditions in Zimbabwe (Chigoverah and Mvumi, 2016) using both natural and artificial introductions of storage insect pests. In both cases, hermetic storage was much more effective than synthetic pesticides. However, in the current trial, hermetic treatments were not highly effective compared to Shumba pesticide. In contrary to the current findings, according to Kumar et al (2017), while the hermetic bags do not eliminate all insects, their benefits outweigh the costs if stored for four months and they last four seasons. This in line with findings of other research that indicates the profitability of hermetic technologies to small-scale farmers if certain thresholds (mainly of size, storage loss and storage length) are attained (Mubayiwa et al, 2021).

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In conclusion, on weevil mortality rate, the use of hermetic bags especially triple hermetic is very effective. It out performs all non- hermetic treatments except for shumba pesticide. From the study it shows that triple hermetic is more effective in weevil mortality than double and single hermetic. Also botanical pesticides are less effective especially when the storage period increases the botanical pesticides will be less effective. This also applies to double and single hermetic bags. On weevil multiplication rate, there is no weevil multiplication in shumba pesticide and triple hermetic bags. Among botanical pesticides neem powder was very effective on controlling multiplication rate of weevils. Also neem powder was performing better than double and single hermetic bag treatments. On weight loss, the hermetic bags especially the triple hermetic bag outperforming the non-hermetic bags except for shumba pesticide during the entire weeks. Triple hermetic had low weight loss compared to the single and double. Amongst the botanical pesticides, sunflower powder was the least effective of the pesticide with the highest weight loss.

6.2 Recommendations

This study recommends the use of hermetic bags especially triple hermetic bags to increase the mortality rate, reduce losses in grain weight during storage as well as to reduce multiplication rate. Neem powder is also recommended to be used as it is more effective in controlling multiplication rate of weevils, but it seems it is affected by rate of application as the efficacy of plant extract decreases over time. Plant extracts need reapplication for them to offer persistence protection to bean grains against bean weevils (Golob, 2000). Chigoverah and Mvumi (2016) said botanicals degrade more rapidly than most chemical pesticides, some within few days and sometimes within few hours, these pesticides need to be applied more frequently. This rapid breakdown means less persistence. By so doing, on this study the efficiency of botanicals have been affected by rate of application.

Further research should be carried out to determine the period taken by hermetic bags to protect the grain since this study was carried out for short period. Future research should also be undertaken to determine mechanisms of action of each type of bag and this can help in the development of eco-friendly protectants of grains, since these bags may be recycled after use and may not pollute the environment, also may not disturb ecosystem. Also on botanical pesticides further research should be done to investigate the efficacy of other botanical pesticides since very few botanicals are documented. Other botanical pesticides such as sunflower powder used on the experiment are not well documented so further researches should be carried out to see the rates and efficacy of the pesticides. Also investigations should be done to determine mechanisms of action of each type of botanicals like sunflower and aloe powder and this can help in the development of eco-friendly protectants of grains, since these botanicals may not pollute the environment.

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2. Be consistent in your referencing style.

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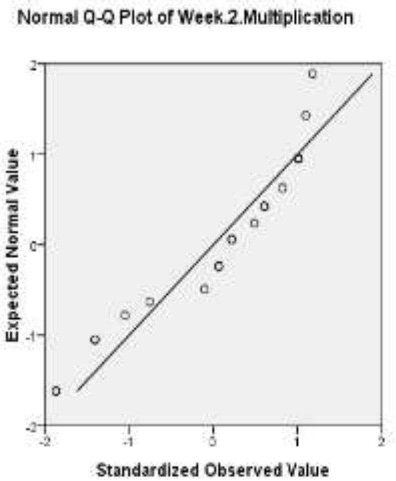
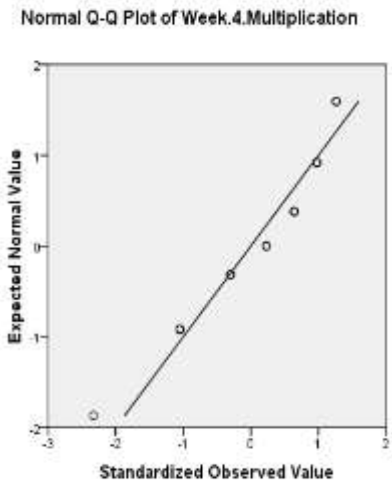
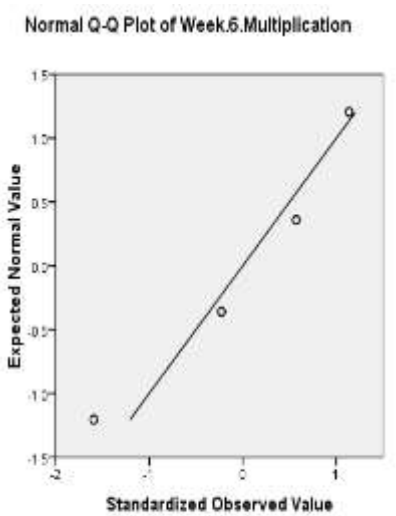
APPENDICES

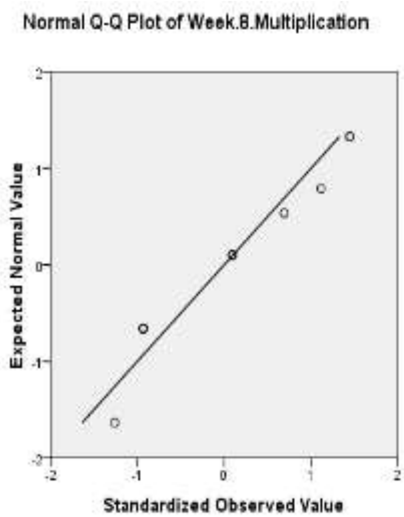
Appendix I: Normality Plots

Weevil Multiplication

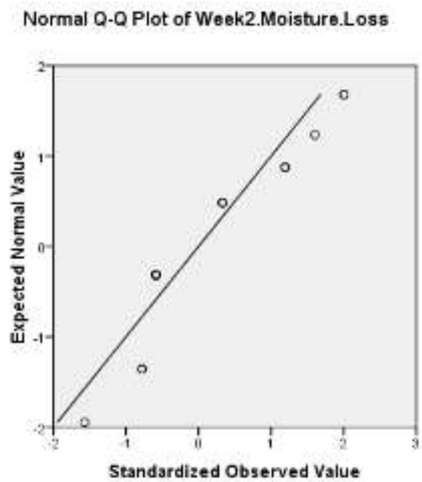


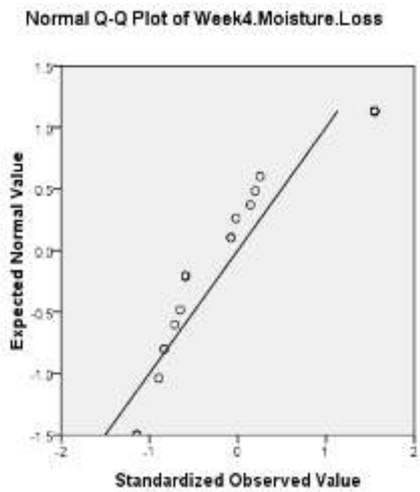


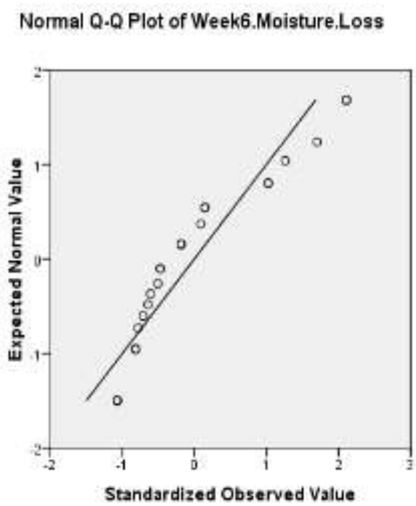


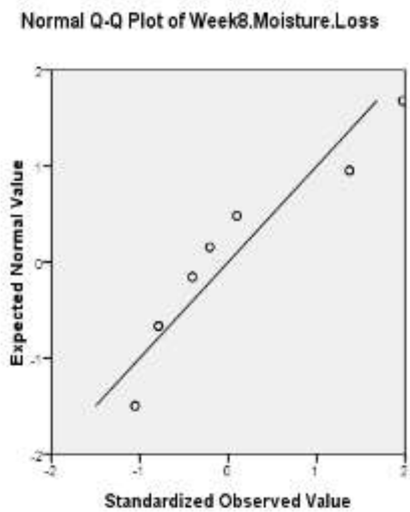


Moisture Loss

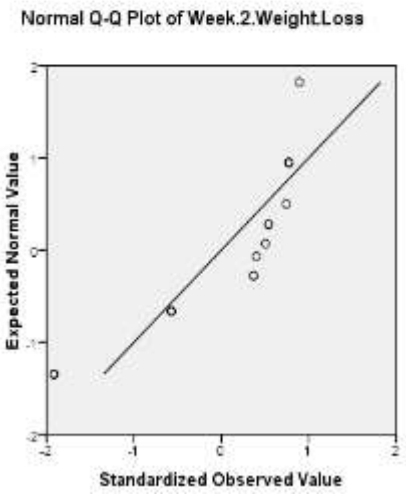


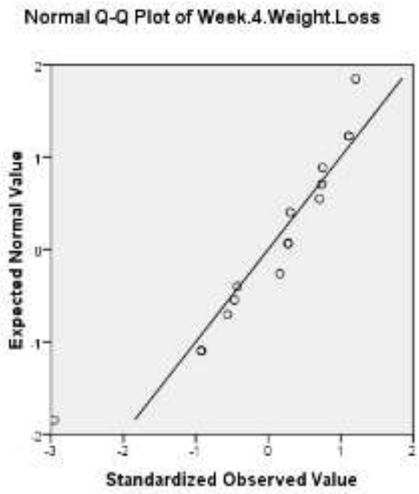


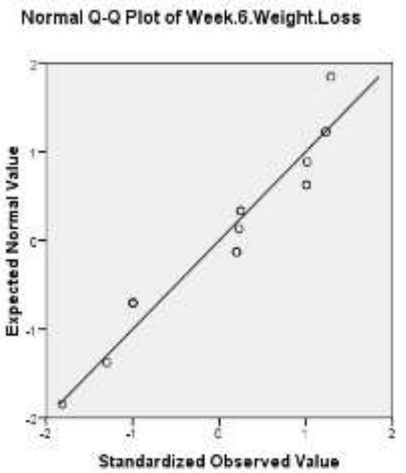




Weight Loss


Normal Q-Q Plot of Week.2.Weight.Loss
Expected Normal Value
Standardized Observed Value


Normal Q-Q Plot of Week.4.Weight.Loss
Expected Normal Value
Standardized Observed Value


Normal Q-Q Plot of Week.6.Weight.Loss
Expected Normal Value
Standardized Observed Value

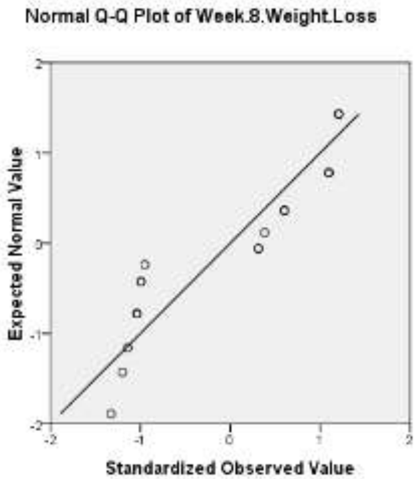

Normal Q-Q Plot of Week.8.Weight.Loss
Expected Normal Value
Standardized Observed Value

Table 3.1: Randomization of the sampling design

Treatment	Experimental Unit Number		
Single hermetic (SH)	5	16	18
Double hermetic (DH)	4	12	20
Triple hermetic (TH)	3	11	17
Neem powder (NM) (*Azadirachta indica)*	6	13	24
Aloe powder (AP)(*Aloe barbadensis miller)*	2	9	23
Sunflower powder (SP) (*Helianthus annus L.)*	1	10	22
Positive control (PC)	8	15	21
Negative control (NC)	7	14	19

Appendix II: Means for the analysed variables

Treatment		Percentage Multiplication				Weevil Mortality				Weight Loss				Moisture Loss			
		Wk 2	Wk 4	Wk 6	Wk 8	Wk 2	Wk 4	Wk 6	Wk 8	Wk 2	Wk 4	Wk 6	Wk 8	Wk 2	Wk 4	Wk 6	Wk 8
Single hermetic	Mean	2	5.3	8.7	29.2	21.6	33.3	11.6	4.66	1.02	5.63	12.7	18.6	4.35	3.49	1.37	0
	Std. Error	0.02	1.36	2.45	4.71	2.62	3.6	3.3	1.33	0.04	1.02	3.06	4.35	1.36	1.22	0.72	0
Double hermetic	Mean	0	2.66	3.09	5.21	38.3	28.3	16.6	10.2	0.53	2.53	6.24	9.5	2.48	1.42	0	0
	Std. Error	0	0.88	1.29	3.66	3.66	2.35	1.66	2.54	0.01	0.06	2.14	2.76	0.26	0.93	0	0
Triple hermetic	Mean	0	0	0	0	76.6	91.7	94.3	100	0	1.25	3.33	5.17	1.02	0	0	0
	Std. Error	0	0	0	0	7.33	3.33	6.34	8.46	0	0.03	1.73	1.93	0.13	0	0	0
Neem powder	Mean	2.33	3.6	4.89	17.6	25	16.6	11.6	8.33	2.6	4.67	7.5	15	3.09	1.63	0.86	0
	Std. Error	0.33	088	1	1.45	3.8	4.66	3.66	4.35	0.05	0.94	2.38	3.28	0.94	1.05	0.06	0
Aloe powder	Mean	6.14	15.3	29.3	33.2	50	24.3	15.1	10.8	4.33	5.1	7.93	10.3	5.61	3.72	1.42	0
	Std. Error	1.88	3.66	4.33	5.89	5.8	2.37	3.88	2.88	0.88	1.33	2.51	2.97	1.07	1.36	0.91	0
Sunflower powder	Mean	11.3	21.3	33.6	45.8	16.6	11.6	9.33	7.33	9.66	12.1	22.3	30	6.14	3.73	1.27	0
	Std. Error	2.66	3.57	4.66	5.52	2.66	2.66	3.15	1.66	2.39	2.87	4.63	6.84	1.58	1.41	0.18	0
Shumba pesticide	Mean	0	0	0	0	95	100	100	100	0	0	0.03	1.5	0.83	0	0	0
	Std. Error	0	0	0	0	10.6	9.88	7.63	8.61	0	0	0.00	0.01	0.06	0	0	0
No treatment	Mean	19.6	33.7	56.1	67.3	0	0	0	0	11.7	22.7	30.8	35	6.37	4.81	1.24	0
	Std. Error	4.72	7.33	11.2	12.3	0	0	0	0	3.18	4.21	7.09	7.26	1.63	1.83	0.08	0

Appendix III: Analysis of Variance output for all variables

ANOVA		Sum of Squares	df	Mean Square	F	Sig.
Week 2 Mortality	Between Groups	3343.333	7	477.619	145.099	0.004
	Within Groups	52.667	16	3.292		
	Total	3396	23			
Week 4 Mortality	Between Groups	5096.292	7	728.042	249.614	0.023
	Within Groups	46.667	16	2.917		
	Total	5142.958	23			
Week 6 Mortality	Between Groups	7892	7	1127.429	252.881	0.096
	Within Groups	71.333	16	4.458		
	Total	7963.333	23			
Week 8 Mortality	Between Groups	11201.17	7	1600.167	391.878	0.157
	Within Groups	65.333	16	4.083		
	Total	11266.5	23			
Week 2 Weevil Multiplication	Between Groups	23816.67	7	3402.381	204.143	0.348
	Within Groups	266.667	16	16.667		
	Total	24083.33	23			
Week 4 Weevil Multiplication	Between Groups	2800	7	400	34.909	0.214
	Within Groups	183.333	16	11.458		
	Total	2983.333	23			
Week 6 Weevil Multiplication	Between Groups	882.292	7	126.042	4.84	0.491
	Within Groups	416.667	16	26.042		
	Total	1298.958	23			

Week 8 Weevil Multiplication	Between Groups	1401.958	7	200.28	38.149	0.712
	Within Groups	84	16	5.25		
	Total	1485.958	23			
Week 2 Weight Loss	Between Groups	463.538	7	66.22	60.337	0.016
	Within Groups	17.56	16	1.098		
	Total	481.098	23			
Week 4 Weight Loss	Between Groups	1774.458	7	253.494	225.745	1.376
	Within Groups	17.967	16	1.123		
	Total	1792.424	23			
Week 6 Weight Loss	Between Groups	2794.687	7	399.241	1.15E+03	4.162
	Within Groups	5.568	16	0.348		
	Total	2800.255	23			
Week 8 Weight Loss	Between Groups	4030.87	7	575.839	1.28E+04	0.935
	Within Groups	0.72	16	0.045		
	Total	4031.59	23			
Week2.Moisture Loss	Between Groups	28.003	7	4	41.926	0.728
	Within Groups	1.527	16	0.095		
	Total	29.53	23			
Week 4 Moisture Loss	Between Groups	81.323	7	11.618	3.49E+03	3.614
	Within Groups	0.053	16	0.003		
	Total	81.376	23			
Week 6 Moisture Loss	Between Groups	316.698	7	45.243	211.661	7.582
	Within Groups	3.42	16	0.214		

	Total	320.118	23			
Week 8 Moisture Loss	Between Groups	770.143	7	110.02	105.62	5.264
	Within Groups	16.667	16	1.042		
	Total	786.81	23			

Appendix IV: Multiple Comparison Tests for Mortality

Dependent Variable	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Week 2 Mortality	Single hermetic	Double hermetic	2	1.48137	0.196	-1.1404	5.1404
		Tripple hermetic	2	1.48137	0.196	-1.1404	5.1404
		Neem ash	-18.33333*	1.48137	0	-21.4737	-15.193
		Aloe ash	-19.33333*	1.48137	0	-22.4737	-16.193
		Sunflower ash	-20.66667*	1.48137	0	-23.807	-17.5263
		Shumba pesticide	2	1.48137	0.196	-1.1404	5.1404
		No treatment	-27.66667*	1.48137	0	-30.807	-24.5263
	Double hermetic	Single hermetic	-2	1.48137	0.196	-5.1404	1.1404
		Tripple hermetic	0	1.48137	1	-3.1404	3.1404
		Neem ash	-20.33333*	1.48137	0	-23.4737	-17.193
		Aloe ash	-21.33333*	1.48137	0	-24.4737	-18.193
		Sunflower ash	-22.66667*	1.48137	0	-25.807	-19.5263
		Shumba pesticide	0	1.48137	1	-3.1404	3.1404
		No treatment	-29.66667*	1.48137	0	-32.807	-26.5263
	Tripple hermetic	Single hermetic	-2	1.48137	0.196	-5.1404	1.1404
		Double hermetic	0	1.48137	1	-3.1404	3.1404
		Neem ash	-20.33333*	1.48137	0	-23.4737	-17.193
		Aloe ash	-21.33333*	1.48137	0	-24.4737	-18.193
		Sunflower ash	-22.66667*	1.48137	0	-25.807	-19.5263
		Shumba pesticide	0	1.48137	1	-3.1404	3.1404
		No treatment	-29.66667*	1.48137	0	-32.807	-26.5263

	Neem ash	Single hermetic	18.33333*	1.48137	0	15.193	21.4737
		Double hermetic	20.33333*	1.48137	0	17.193	23.4737
		Tripple hermetic	20.33333*	1.48137	0	17.193	23.4737
		Aloe ash	-1	1.48137	0.509	-4.1404	2.1404
		Sunflower ash	-2.33333	1.48137	0.135	-5.4737	0.807
		Shumba pesticide	20.33333*	1.48137	0	17.193	23.4737
		No treatment	-9.33333*	1.48137	0	-12.4737	-6.193
	Aloe ash	Single hermetic	19.33333*	1.48137	0	16.193	22.4737
		Double hermetic	21.33333*	1.48137	0	18.193	24.4737
		Tripple hermetic	21.33333*	1.48137	0	18.193	24.4737
		Neem ash	1	1.48137	0.509	-2.1404	4.1404
		Sunflower ash	-1.33333	1.48137	0.381	-4.4737	1.807
		Shumba pesticide	21.33333*	1.48137	0	18.193	24.4737
		No treatment	-8.33333*	1.48137	0	-11.4737	-5.193
	Sunflower ash	Single hermetic	20.66667*	1.48137	0	17.5263	23.807
		Double hermetic	22.66667*	1.48137	0	19.5263	25.807
		Tripple hermetic	22.66667*	1.48137	0	19.5263	25.807
		Neem ash	2.33333	1.48137	0.135	-0.807	5.4737
		Aloe ash	1.33333	1.48137	0.381	-1.807	4.4737
		Shumba pesticide	22.66667*	1.48137	0	19.5263	25.807
		No treatment	-7.00000*	1.48137	0	-10.1404	-3.8596
	Shumba pesticide	Single hermetic	-2	1.48137	0.196	-5.1404	1.1404
		Double hermetic	0	1.48137	1	-3.1404	3.1404
		Tripple hermetic	0	1.48137	1	-3.1404	3.1404
		Neem ash	-20.33333*	1.48137	0	-23.4737	-17.193
		Aloe ash	-21.33333*	1.48137	0	-24.4737	-18.193
		Sunflower ash	-22.66667*	1.48137	0	-25.807	-19.5263
		No treatment	-29.66667*	1.48137	0	-32.807	-26.5263
	No treatment	Single hermetic	27.66667*	1.48137	0	24.5263	30.807
		Double hermetic	29.66667*	1.48137	0	26.5263	32.807
		Tripple hermetic	29.66667*	1.48137	0	26.5263	32.807
		Neem ash	9.33333*	1.48137	0	6.193	12.4737
		Aloe ash	8.33333*	1.48137	0	5.193	11.4737
		Sunflower ash	7.00000*	1.48137	0	3.8596	10.1404
		Shumba pesticide	29.66667*	1.48137	0	26.5263	32.807
Week.4.Mortality	Single	Double hermetic	2.33333	1.39443	0.114	-0.6227	5.2894

hermetic	Tripple hermetic	5.00000*	1.39443	0.002	2.0439	7.9561
	Neem ash	-17.33333*	1.39443	0	-20.2894	-14.3773
	Aloe ash	-16.33333*	1.39443	0	-19.2894	-13.3773
	Sunflower ash	-20.00000*	1.39443	0	-22.9561	-17.0439
	Shumba pesticide	5.00000*	1.39443	0.002	2.0439	7.9561
	No treatment	-38.33333*	1.39443	0	-41.2894	-35.3773
Double hermetic	Single hermetic	-2.33333	1.39443	0.114	-5.2894	0.6227
	Triple hermetic	2.66667	1.39443	0.074	-0.2894	5.6227
	Neem ash	-19.66667*	1.39443	0	-22.6227	-16.7106
	Aloe ash	-18.66667*	1.39443	0	-21.6227	-15.7106
	Sunflower ash	-22.33333*	1.39443	0	-25.2894	-19.3773
	Shumba pesticide	2.66667	1.39443	0.074	-0.2894	5.6227
	No treatment	-40.66667*	1.39443	0	-43.6227	-37.7106
Triple hermetic	Single hermetic	-5.00000*	1.39443	0.002	-7.9561	-2.0439
	Double hermetic	-2.66667	1.39443	0.074	-5.6227	0.2894
	Neem ash	-22.33333*	1.39443	0	-25.2894	-19.3773
	Aloe ash	-21.33333*	1.39443	0	-24.2894	-18.3773
	Sunflower ash	-25.00000*	1.39443	0	-27.9561	-22.0439
	Shumba pesticide	0	1.39443	1	-2.9561	2.9561
	No treatment	-43.33333*	1.39443	0	-46.2894	-40.3773
Neem ash	Single hermetic	17.33333*	1.39443	0	14.3773	20.2894
	Double hermetic	19.66667*	1.39443	0	16.7106	22.6227
	Triple hermetic	22.33333*	1.39443	0	19.3773	25.2894
	Aloe ash	1	1.39443	0.484	-1.9561	3.9561
	Sunflower ash	-2.66667	1.39443	0.074	-5.6227	0.2894
	Shumba pesticide	22.33333*	1.39443	0	19.3773	25.2894
	No treatment	-21.00000*	1.39443	0	-23.9561	-18.0439
Aloe ash	Single hermetic	16.33333*	1.39443	0	13.3773	19.2894

		Double hermetic	18.66667*	1.39443	0	15.7106	21.6227
		Triple hermetic	21.33333*	1.39443	0	18.3773	24.2894
		Neem ash	-1	1.39443	0.484	-3.9561	1.9561
		Sunflower ash	-3.66667*	1.39443	0.018	-6.6227	-0.7106
		Shumba pesticide	21.33333*	1.39443	0	18.3773	24.2894
		No treatment	-22.00000*	1.39443	0	-24.9561	-19.0439
	Sunflower ash	Single hermetic	20.00000*	1.39443	0	17.0439	22.9561
		Double hermetic	22.33333*	1.39443	0	19.3773	25.2894
		Triple hermetic	25.00000*	1.39443	0	22.0439	27.9561
		Neem ash	2.66667	1.39443	0.074	-0.2894	5.6227
		Aloe ash	3.66667*	1.39443	0.018	0.7106	6.6227
		Shumba pesticide	25.00000*	1.39443	0	22.0439	27.9561
		No treatment	-18.33333*	1.39443	0	-21.2894	-15.3773
	Shumba pesticide	Single hermetic	-5.00000*	1.39443	0.002	-7.9561	-2.0439
		Double hermetic	-2.66667	1.39443	0.074	-5.6227	0.2894
		Triple hermetic	0	1.39443	1	-2.9561	2.9561
		Neem ash	-22.33333*	1.39443	0	-25.2894	-19.3773
		Aloe ash	-21.33333*	1.39443	0	-24.2894	-18.3773
		Sunflower ash	-25.00000*	1.39443	0	-27.9561	-22.0439
		No treatment	-43.33333*	1.39443	0	-46.2894	-40.3773
	No treatment	Single hermetic	38.33333*	1.39443	0	35.3773	41.2894
		Double hermetic	40.66667*	1.39443	0	37.7106	43.6227
		Triple hermetic	43.33333*	1.39443	0	40.3773	46.2894
		Neem ash	21.00000*	1.39443	0	18.0439	23.9561
		Aloe ash	22.00000*	1.39443	0	19.0439	24.9561
		Sunflower ash	18.33333*	1.39443	0	15.3773	21.2894
		Shumba pesticide	43.33333*	1.39443	0	40.3773	46.2894
Week.6.Mortality	Single hermetic	Double hermetic	4.00000*	1.72401	0.034	0.3453	7.6547
		Triple hermetic	7.00000*	1.72401	0.001	3.3453	10.6547
		Neem ash	-17.00000*	1.72401	0	-20.6547	-13.3453
		Aloe ash	-16.33333*	1.72401	0	-19.9881	-12.6786
		Sunflower ash	-22.33333*	1.72401	0	-25.9881	-18.6786
		Shumba	7.00000*	1.72401	0.001	3.3453	10.6547

	pesticide					
	No treatment	-49.00000*	1.72401	0	-52.6547	-45.3453
Double hermetic	Single hermetic	-4.00000*	1.72401	0.034	-7.6547	-0.3453
	Triple hermetic	3	1.72401	0.101	-0.6547	6.6547
	Neem ash	-21.00000*	1.72401	0	-24.6547	-17.3453
	Aloe ash	-20.33333*	1.72401	0	-23.9881	-16.6786
	Sunflower ash	-26.33333*	1.72401	0	-29.9881	-22.6786
	Shumba pesticide	3	1.72401	0.101	-0.6547	6.6547
	No treatment	-53.00000*	1.72401	0	-56.6547	-49.3453
Triple hermetic	Single hermetic	-7.00000*	1.72401	0.001	-10.6547	-3.3453
	Double hermetic	-3	1.72401	0.101	-6.6547	0.6547
	Neem ash	-24.00000*	1.72401	0	-27.6547	-20.3453
	Aloe ash	-23.33333*	1.72401	0	-26.9881	-19.6786
	Sunflower ash	-29.33333*	1.72401	0	-32.9881	-25.6786
	Shumba pesticide	0	1.72401	1	-3.6547	3.6547
	No treatment	-56.00000*	1.72401	0	-59.6547	-52.3453
Neem ash	Single hermetic	17.00000*	1.72401	0	13.3453	20.6547
	Double hermetic	21.00000*	1.72401	0	17.3453	24.6547
	Triple hermetic	24.00000*	1.72401	0	20.3453	27.6547
	Aloe ash	0.66667	1.72401	0.704	-2.9881	4.3214
	Sunflower ash	-5.33333*	1.72401	0.007	-8.9881	-1.6786
	Shumba pesticide	24.00000*	1.72401	0	20.3453	27.6547
	No treatment	-32.00000*	1.72401	0	-35.6547	-28.3453
Aloe ash	Single hermetic	16.33333*	1.72401	0	12.6786	19.9881
	Double hermetic	20.33333*	1.72401	0	16.6786	23.9881
	Triple hermetic	23.33333*	1.72401	0	19.6786	26.9881
	Neem ash	-0.66667	1.72401	0.704	-4.3214	2.9881
	Sunflower ash	-6.00000*	1.72401	0.003	-9.6547	-2.3453
	Shumba pesticide	23.33333*	1.72401	0	19.6786	26.9881
	No treatment	-32.66667*	1.72401	0	-36.3214	-29.0119

	Sunflower ash	Single hermetic	22.33333*	1.72401	0	18.6786	25.9881
		Double hermetic	26.33333*	1.72401	0	22.6786	29.9881
		Triple hermetic	29.33333*	1.72401	0	25.6786	32.9881
		Neem ash	5.33333*	1.72401	0.007	1.6786	8.9881
		Aloe ash	6.00000*	1.72401	0.003	2.3453	9.6547
		Shumba pesticide	29.33333*	1.72401	0	25.6786	32.9881
		No treatment	-26.66667*	1.72401	0	-30.3214	-23.0119
	Shumba pesticide	Single hermetic	-7.00000*	1.72401	0.001	-10.6547	-3.3453
		Double hermetic	-3	1.72401	0.101	-6.6547	0.6547
		Triple hermetic	0	1.72401	1	-3.6547	3.6547
		Neem ash	-24.00000*	1.72401	0	-27.6547	-20.3453
		Aloe ash	-23.33333*	1.72401	0	-26.9881	-19.6786
		Sunflower ash	-29.33333*	1.72401	0	-32.9881	-25.6786
		No treatment	-56.00000*	1.72401	0	-59.6547	-52.3453
	No treatment	Single hermetic	49.00000*	1.72401	0	45.3453	52.6547
		Double hermetic	53.00000*	1.72401	0	49.3453	56.6547
		Triple hermetic	56.00000*	1.72401	0	52.3453	59.6547
		Neem ash	32.00000*	1.72401	0	28.3453	35.6547
		Aloe ash	32.66667*	1.72401	0	29.0119	36.3214
		Sunflower ash	26.66667*	1.72401	0	23.0119	30.3214
		Shumba pesticide	56.00000*	1.72401	0	52.3453	59.6547
Week.8.Mortality	Single hermetic	Double hermetic	0	1.64992	1	-3.4977	3.4977
		Triple hermetic	5.00000*	1.64992	0.008	1.5023	8.4977
		Neem ash	-22.66667*	1.64992	0	-26.1643	-19.169
		Aloe ash	-19.00000*	1.64992	0	-22.4977	-15.5023
		Sunflower ash	-28.00000*	1.64992	0	-31.4977	-24.5023
		Shumba pesticide	5.00000*	1.64992	0.008	1.5023	8.4977
		No treatment	-62.33333*	1.64992	0	-65.831	-58.8357
	Double hermetic	Single hermetic	0	1.64992	1	-3.4977	3.4977
		Triple hermetic	5.00000*	1.64992	0.008	1.5023	8.4977
		Neem ash	-22.66667*	1.64992	0	-26.1643	-19.169
		Aloe ash	-	1.64992	0	-22.4977	-

		19.00000*				15.5023
	Sunflower ash	-28.00000*	1.64992	0	-31.4977	-24.5023
	Shumba pesticide	5.00000*	1.64992	0.008	1.5023	8.4977
	No treatment	-62.33333*	1.64992	0	-65.831	-58.8357
Triple hermetic	Single hermetic	-5.00000*	1.64992	0.008	-8.4977	-1.5023
	Double hermetic	-5.00000*	1.64992	0.008	-8.4977	-1.5023
	Neem ash	-27.66667*	1.64992	0	-31.1643	-24.169
	Aloe ash	-24.00000*	1.64992	0	-27.4977	-20.5023
	Sunflower ash	-33.00000*	1.64992	0	-36.4977	-29.5023
	Shumba pesticide	0	1.64992	1	-3.4977	3.4977
	No treatment	-67.33333*	1.64992	0	-70.831	-63.8357
Neem ash	Single hermetic	22.66667*	1.64992	0	19.169	26.1643
	Double hermetic	22.66667*	1.64992	0	19.169	26.1643
	Triple hermetic	27.66667*	1.64992	0	24.169	31.1643
	Aloe ash	3.66667*	1.64992	0.041	0.169	7.1643
	Sunflower ash	-5.33333*	1.64992	0.005	-8.831	-1.8357
	Shumba pesticide	27.66667*	1.64992	0	24.169	31.1643
	No treatment	-39.66667*	1.64992	0	-43.1643	-36.169
Aloe powder	Single hermetic	19.00000*	1.64992	0	15.5023	22.4977
	Double hermetic	19.00000*	1.64992	0	15.5023	22.4977
	Tripple hermetic	24.00000*	1.64992	0	20.5023	27.4977
	Neem ash	-3.66667*	1.64992	0.041	-7.1643	-0.169
	Sunflower ash	-9.00000*	1.64992	0	-12.4977	-5.5023
	Shumba pesticide	24.00000*	1.64992	0	20.5023	27.4977
	No treatment	-43.33333*	1.64992	0	-46.831	-39.8357
Sunflower powder	Single hermetic	28.00000*	1.64992	0	24.5023	31.4977
	Double hermetic	28.00000*	1.64992	0	24.5023	31.4977
	Tripple hermetic	33.00000*	1.64992	0	29.5023	36.4977
	Neem ash	5.33333*	1.64992	0.005	1.8357	8.831
	Aloe ash	9.00000*	1.64992	0	5.5023	12.4977
	Shumba pesticide	33.00000*	1.64992	0	29.5023	36.4977
	No treatment	-	1.64992	0	-37.831	-

		34.33333*				30.8357
Shumba pesticide	Single hermetic	-5.00000*	1.64992	0.008	-8.4977	-1.5023
	Double hermetic	-5.00000*	1.64992	0.008	-8.4977	-1.5023
	Tripple hermetic	0	1.64992	1	-3.4977	3.4977
	Neem ash	-27.66667*	1.64992	0	-31.1643	-24.169
	Aloe ash	-24.00000*	1.64992	0	-27.4977	-20.5023
	Sunflower ash	-33.00000*	1.64992	0	-36.4977	-29.5023
	No treatment	-67.33333*	1.64992	0	-70.831	-63.8357
No treatment	Single hermetic	62.33333*	1.64992	0	58.8357	65.831
	Double hermetic	62.33333*	1.64992	0	58.8357	65.831
	Tripple hermetic	67.33333*	1.64992	0	63.8357	70.831
	Neem ash	39.66667*	1.64992	0	36.169	43.1643
	Aloe ash	43.33333*	1.64992	0	39.8357	46.831
	Sunflower ash	34.33333*	1.64992	0	30.8357	37.831
	Shumba pesticide	67.33333*	1.64992	0	63.8357	70.831

*. The mean difference is significant at the 0.05 level.