ON-FARM COMPERATIVE PERFOMANCE OF HERMETIC BAGS IN DRY BEAN (Phaseolus vulgaris (L.) STORAGE

A dissertation submitted in partial fulfilment of the requirements for the Master of Science Degree in Food Security and Sustainable Agriculture in Production

Bindura University of Science Education

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DECLARATION

I hereby declare that the research project entitled, on farm comparative performance of hermetic bags in dry bean (Phaseolus vulgaris (L) storage submitted to Bindura University of Science Education, Department of Agricultural Economics, Education and Extension is a record of an original work done by me under the guidance and supervision of **Professor Mvumi and Dr. Chikuvire** and this work is submitted in partial fulfilment of the requirements for the award of a Master of Science Degree in Food Security and Sustainable Agriculture. The results embodied in this thesis have not been submitted to any University or Institute for the award of any degree or diploma.

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DEDICATION

I dedicate this work to my family.

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ABSTRACT

Post-harvest losses remain one of the primary issue in agriculture especially amongst smallholder farmers who do not have enough knowledge of the innovations available at their disposal. Effectiveness of six different storage technologies on stored beans was evaluated during the 2019/20 storage season in Domboshava, Goromonzi District. Beans were stored for 32 weeks and grain sampling was at 8-week intervals. Grain samples were analysed in the laboratory for: insect numbers and species, insect damage, weight loss, moisture content, chaff content and seed viability after storing in the different technologies.. Data were subjected to Analysis of Variance and Fisher's test at 5% probability was used to separate significantly different means. Farmers' assessments were also analysed in the study with farmers perceptions on the performance of the bags under grain damage and grain weight loss. Price analysis was also considered in the study with the comparison of the baseline and the termination prices being analysed across the 4 treatments. The overall results indicated an increase in moisture content with storage length amongst all the treatment. Untreated treatment had the highest moisture content rise of around 1.4% whereas Grain Pro Super Bag had the lowest moisture content fluctuation of around 1% amongst the other treatments. Grain damage, weight loss and insect populations were lowest in Shumba plus, AgroZ Plus bags and PICS bags. Germination was also assessed for all the treatments at 2, 5 and 7 days. At 7 days, untreated, PICS bags, and Agro Z Plus had 100% germination whilst Shumba Plus had the lowest germination of 95%. Most respondents indicated that Shumba Plus was very good in controlling insect infestation, seed rot, presence of chaff as well insect damage in comparison to the untreated treatment which was perceived poor in all these tests. Beans stored in the Shumba Plus treatment had the highest termination price of $40, whereas AgroZ Plus, AgroZ, PICS bags had termination prices of $35, and $30 respectively. Grain pro Super grain bag and untreated had the lower termination prices than their baseline recording $12 and $10 from $15 respectively. Based on both the efficacy experiment and farmer assessments, the hermetic technologies Shumba Plus and AgroZ Plus and are recommended for on-farm smallholder use to reduce storage losses and help fight hunger at household level.

Keywords: hermetic, storage, grain loss, moisture content, insect pests.

LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	**Analysis of variance**
HDPE	**High density polyethylene**
PP	**Polypropylene**
RCBD	**Randomised complete block design**
KG	**Kilogram**
PICS	**Purdue Improved Crop Storage**
SSA	**Sub Saharan Africa**
UN	**United Nations**
PHL	**Post-Harvest Losses**
µm	**Micrometre**
^{o}C	**Degree Celsius**
g	**Gram**
ha	**Hectare**

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CHAPTER ONE
INTRODUCTION

1.1 Background

In 2015, United Nations (UN) set a target that by 2030, food losses should be reduced by 50% as part of the Sustainable Development Goal (SDG) agenda number 12 (UN, 2019). This was done in order to reduce food waste and losses that happens along the value chain from the field to the plate. In Sub-Saharan Africa (SSA), agriculture is the main source of livelihood in rural populations for income generation and improving household food and nutrition security. Common bean, Phaseolus vulgaris (L.) is a high value crop that is grown by smallholder farmers in Zimbabwe for income. They use money to buy food items and non-food items required by the household (Snapp et al. 2018). Common beans is also a food security crop that is rich in proteins, iron, copper, magnesium, zinc, calcium, potassium, and vitamins (Mojica and de Mejia, 2015). Global production of common beans is at 26 833 394 tonnes and much of the grain is produced in Africa (FAO, 2016).

Post-harvest losses (PHLs) play a major contribution to food insecurity as 30% - 40% of the food is lost after harvesting and before the consumer buys the crop (Deloitte 2018). PHLs has environmental, social and economic impact on the increased availability of food as this reduces income, increase unavailability of food and natural resources will be wasted on food that will not be consumed (World Bank, 2011) Reduction in PHLs is very crucial as 153 million are affected globally (Snapp et al, 2018). PHL due to insect pests in storage cause significant economic losses through reduced quality, quantity and grain value during marketing. The bean bruchid, Acanthoscelides obtectus Say (Coleoptera: Bruchidae) is known to cause economic losses in pulses and this causes farmers not to produce beans or they are forced to sell immediately after harvest when the prices on the market are not favourable (Ndegwa et al. 2016).

Market price usually increase within six months of storage and they also keep the seed to use as retained seed for the next season's planting. Bruchids reduce grain quality in storage by leaving perfectly round holes on beans which result in farmers facing price penalties during marketing. Smallholder farmers in SSA use retained seed for planting and the seed is stored for

6-9 months during which it is attacked by bruchids, thus affecting its viability (Brackmann et al. 2002). Reducing PHL is important in eradication of extreme poverty and hunger, as 870 million people suffer from undernourishment with 27% of these being in Africa (Jones et al. 2018). There is need for an innovative approach that reduces PHLs during storage to ensure sustainable food consumption. Chemical control that is being used by farmers has negative effects on the health and environment due to pesticide adulteration (Loko et al, 2018).

Hermetic storage is a technology now frequently used by smallholder farmers in Asia, West Africa and East Africa to protect farmer's grain from insect infestation through inhibiting entry of oxygen in the bags (Baributsa et al. 2014). Sealed storage have proven to maintain quality over longer periods in storage. Hermetic storage has resulted in 98% reduction in storage losses, maintain viability of seed, grain quality over time this contributing to food security, improving livelihoods of Smallholder farmers (Kumar and Kalita, 2017).

1.2 Problem statement

PHLs due to bruchids affect largely household food security in SSA through loss of crop nutritional value, income, value and volume harvested (Chauhan and Ghaffar. 2002). Bruchids attack in common beans during storage reduces seed quality and viability, leading to 8-22% weight loss (Snapp et al. 2018). Traditional storage methods are not effective in storing the grain to avoid insect infestation, therefore there is need to use efficient and cost-effective methods that farmers can adopt to reduce PHLs due to insect pests (Jones et al. 2018). Technological interventions play an important role in addressing PHLs due to storage pests as they can reduce losses to less than 1% for one storage season or longer (Abass et al. 2014). Use of chemicals is being practised but misapplication that end up causing resistance pose negative effects on the human and environmental health. However, in SSA, scientific literature on use and effectiveness of these hermetic technologies to reduce storage losses is scarce, especially with regards to dried bean storage.

1.3 Objectives

1.3.1 Main objective

The main objective of the study was to determine the effect of modifying the storage atmosphere using hermetic technology on storage insect infestation, damage and farmers perceptions over time in stored dried bean.

1.3.2 Specific objectives

The specific objectives were to:

1. Determine the effect of different hermetic storage technologies on insect infestation in common bean storage.
2. Determine the effect of different hermetic technologies on grain damage and grain weight loss.
3. Evaluate farmer perceptions on dried bean quality under different storage technologies over time during the storage season.

1.4 Research questions

1. Are hermetic storage technologies more effective than traditional (conventional pesticides) storage technologies in protecting dried bean against insect infestation?
2. Are hermetic storage technologies more effective than traditional storage technologies in protecting dried bean against grain damage, quality and weight loss over time?
3. What are farmer's perceptions on dried bean quality under different storage technologies over time during the storage season?

1.5 Justification

In an attempt to reduce PHLs in developing countries, many studies have been conducted to use cost-effective methods that are available locally that are practical and effective and which farmers can adopt. Modified atmosphere can be created by using materials that are impermeable to air such as metal silos and thick plastic bags. If oxygen depletes inside, the insects will stop feeding inside and die of suffocation thus controlling the grain from pest infestation (Bern et al, 2013). Hermetic storage bags are an effective way of creating an environment impermeable to air creating a modified atmosphere for stored grain. Using these technology interventions has be shown to be effective for controlling storage insect pests from causing damage in different commodities in storage (Baributsa et al, 2014). However, literature on the effectiveness of these modified storage technologies in legumes under on farm conditions, especially dried beans is scarce in SSA.

1.6 Scope / delimitation and limitation of study

The study was carried out in Ward 1 of Goromonzi district, Mashonaland East Province over 8 month's period because farmers usually store their grain for 8-12 months. The study confines itself to on-farm comparative performance of hermetic bags in dry bean storage. The climate of the area and tenure where these trials were done was homogeneous. However, since dried is a high value commodity, care was taken to ensure the grain was not misappropriated and the hosting households signed a custody agreement form.

1.7 Outline of Thesis

The study was introduced in Chapter 1, which also contains the problem statement, justification and study objectives. The relevant existing scientific literature was reviewed in Chapter 2, while Chapter 3 contain details of the general methodologies that was used to carry out the experiment. Chapter 4 and 5 result chapters describing the detailed experimental procedures and results for the field evaluation of different grain storage technologies. Chapter 6 contain the overall discussion, where the implications of the research was summarized, and the conclusion and broader recommendations outlined.

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CHAPTER 2
LITERATURE REVIEW

2.1: Introduction

The chapter covers information on the production statistics in Eastern and Southern Africa and the importance of bean production as a protein supplement to human diets. It goes on to elaborate on the biology of the bean weevil, Acanthoscelides obtectus. An in-depth analysis of different hermetic storage facilities; their modes of action as well as their comprising units follows before a concluding theoretical framework of the research approach is presented at the end.

2.2: Importance of beans

Common bean, Phaseolus vulgaris (L.) is one of the most commonly used protein source in human diets worldwide (Mendes et al., 2010) especially in developing countries (Freitas et al., 2016). Common bean is rich in high protein, complex carbohydrates, vitamin B components (thiamin, folic acid and niacin) and micro-nutrients (Anseeuw et al., 2012). On the other hand, bean production is a source of income, with a high demand in urban and rural areas as well as the international market (Anseeuw et al., 2012). Bean production also empowers women who are mostly responsible for its cultivation (Wortmann et al., 1998).

The major bean producers in Africa are Tanzania, Kenya and Uganda (Beebe et al., 2014). In Kenya average annual production of common beans is estimated at 436 279 tonnes (Abtew et al., 2016). Average yields per country are usually low as drought is the most common challenge for rain-fed crop production (Carvalho et al., 1998). In Ethiopia, the national average yield of common bean is 1300 kg/ha under smallholder production and 1 700 kg/ha under commercial farming (Darkwa et al., 2016). On the other hand, the production potential as estimated for Ethiopia in research fields is 3000 kg/ha and 4000kg/ha for smallholder and commercial farming systems respectively (Darkwa et al., 2016). Looking further down, current yields in Southern Africa are much lower than those of East Africa estimated at 600 kg/ha versus the attainable yield of 1.500 kg/ha (Chekanai et al., 2018). Like most other countries, smallholder common bean production in Zimbabwe is sustained by rain cropping. As such, crop yields are usually lower due to mid-season dry spells (Chekanai et al., 2018). Even though drought has been pinpointed as the main yield reducing component, African smallholder farmers are resource-constrained and they cannot afford irrigation (Darkwa et al., 2016; Vanlauwe et al., 2019). Besides drought, further losses are incurred due to insect pests attack at all the different life stages of the common bean production (Abtew et al., 2016).

Critical loss points continue into the storage season where both the intended nutritional benefits and the harvested yield is reduced by storage insect pests (Kaliramesh et al., 2013). Like most seasonal crops, after harvesting, the bean is usually dried, cleaned and stored for gradual consumption and or later sale (Mvumi and Stathers, 2003, Mlambo et al., 2017;). A considerable amount of losses are suffered at producer level as threshing, winnowing and transportation losses (Kaliramesh et al., 2013). Much higher losses are further incurred during storage as a result of failure by farmers to control storage insect pests (Schmale and Wa, 2006, Burks et al., 2011; Freitas et al., 2016;). The main insect pests of stored common bean are bruchids *Zabrotes subfasciatus* and *Acanthoscelides obtectus* (Say) (Schmale and Wa, 2006; Freitas et al., 2016). *Acanthoscelides obtectus* is of Mesoamerican origin (Berger et al., 2017). Damage by insect feeding reduces seed mass and germination capacity (Freitas et al., 2016) whilst faecal contamination by the larvae (Araújo et al., 2015) reduces nutrition and economic value of stored bean (Jones et al., 2018). Damaged grain characterised by adult emergence holes give the damaged grain an unattractive impression (Maharjan et al., 2017) hence it is sold at a giveaway price and farmers loose income (Jones et al., 2018).

2.2.1: Infestation and insect biology

Cross infestation is always common involving adult insects invading physiologically mature bean pods in the field and lay eggs which perpetuate under storage (Baldin and Lara, 2008; Njoroge et al., 2017). The two species *A. obtectus* and *Z. subfasciatus* often co-occur in overlapping niche in bean stores (Njoroge et al., 2017). *Acanthoscelides obtectus* is however more distributed in Eastern and Southern Africa including in Uganda and Zimbabwe (Mutungi et al., 2015a; Njoroge et al., 2017). *Acanthoscelides. obtectus* is dominant where cooler climates coincide with harvesting period and at high elevation whilst *Z. subfasciatus* prefers warmer climates coinciding with harvests under low altitude areas (Mutungi et al., 2015a). Most of the damage is caused by the larvae (Baldin and Lara, 2008). After egg hatching, the larvae penetrate the seed, develop from inside and emerge as adult weevils leaving a characteristic feeding chamber on the seed (Schmale et al., 2002).The adult weevil is short-lived for seven to 13 months and non-feeding (Ayvaz et al., 2010). After emerging from the seed, the adult weevil is mainly responsible for reproduction and the life cycle is completed in three to four weeks depending on prevailing conditions (Mutungi et al., 2015a; Njoroge et al., 2017). The female has a high reproductive capacity and several generation per year under favourable conditions are often observed (Njoroge et al., 2017). Eggs are deposited in clusters inside pods in the field or firmly attached on shelled dry bean seed. A single larvae infests each seed (Njoroge et al., 2017) however, sometimes, multiple infestations are possible (Schmale et al., 2002).

Figure 2.1 A photograph of the bean weevil, Acanthoscelides. obtectus, source (AgroAtlas, 2009)

2.2.2: Farm level storage technologies

At farm level, control of stored product insects is usually accomplished by synthetic pesticides, fumigants (Freitas et al., 2016), traditional technologies and lately the use of hermetic storage technologies has become popular. Pesticide use is the main arsenal farmers in Zimbabwe rely on for control of storage insect pests (Govereh et al., 2019). Since the introduction of synthetic pesticides, organophosphates (OPs) and pyrethroids have become the most extensively used pesticide group in crop protection leading to some of the earliest cases of pest resistance (Reyes et al., 2011). Most synthetic pesticides for stored product protection in Zimbabwe are a combination of organophosphate and pyrethroid based active ingredients, though combination are a way for improving the broad spectrum activity and managing pest resistance (Daglish and Nayak, 2012). In a few cases neonicotinoids are also being used (Mlambo et al., 2018).

It is agreed by different researchers that the introduction of pesticide in the 1960s boosted world food production. It has enabled storage of seasonally produced crops for extended storage periods by eliminating quality defecting and disease causing organisms from the food (Ortiz-Hernández et al., 2013). Some researchers, argue however, that introduction of synthetic pesticides even though leveraged on the losses, did not guarantee protection of stored grain as farmers continue to experience high storage losses (Isman, 2006). The pesticide revolution has also come with costs due to their indiscriminate effect on non-target organisms which has disturbed natural ecosystems. At the same time degradation products of synthetic pesticides, known as pesticide residues which are left on crops after harvesting and finding their way into food systems have become a cause of concern to consumers (Dubey et al., 2008). Henceforth, the drive for pesticide free, smart technologies like the hermetic technology (Tefera et al., 2011), has intensified (Freitas et al., 2016).

2.2.3: Hermetic storage

Hermetic bags consist of an inner high density polyethylene (HDPE) plastic envelope and an outer polypropylene bag (Freitas et al., 2016). Grain is loaded into the inner polyethylene envelop and once it is tied shut, the living insects inside grain will consume the available oxygen respiring carbon dioxide. The levels of carbon dioxide will continue to rise consequently leading to insect death due to desiccation (Murdock et al., 2012). The outer polypropylene bag gives strength to the unit, protects the inner plastic envelops and enables easy handling (Murdock and Baoua, 2014). Some hermetic bag brands available on different markets in Africa include Purdue Improved Crop Storage (PICS) bags, GrainPro Super grain bags, AgroZ Plus and AgroZ Ordinary bags as well as ZeroFly hermetic bags.

2.2.3.1: PICS Bags

These bags were formerly known as the Purdue Improved Cowpea Storage bag (Murdock and Baoua, 2014) and later changed to Purdue Improved Crop Storage bag when it was extended in use for storage of other grains other than cowpeas (Baributsa et al., 2012). The hermetic unit consists of two 80 µm HDPE plastics one inside the other and the two surrounded by a third woven polypropylene bag (Murdock and Baoua, 2014). The two inner HDPE plastics deprive grain inside of air such that once enclosed oxygen is depleted, insects would stop feeding, growing or reproducing and eventually die due to desiccation (Baoua et al., 2012; Murdock et al., 2012, Freitas et al., 2016;; Mutungi et al., 2015b). The bags are available in 50 and 100 kilogram (kg) capacities (Baoua et al., 2012).

Figure 2.2 : A photograph of the Purdue Improved Crop Storage (PICS) bag, source (Murdock and Baoua, 2014)

2.2.3.2: GrainPro Super grain bags

Super grain bags consist of a single HDPE layer inside an outer polypropylene bag (De Groote et al., 2013). The HDPE plastic has a 78 µm thickness and highly impermeable to oxygen (Baoua et al., 2013). Similar hermetic principle of oxygen depletion as PICS bags is used to control insects (Baoua et al., 2013; Mlambo et al., 2017). Capacities range from a portable 10 kg to 1000 kgs (Baoua et al., 2013).

Figure 2.3 A photograph of the GrainPro Super grain bag, source (GrainPro, 2019)

2.2.3.3: AgroZ bags

AgroZ bags come as ordinary hermetic bags as shown in Fig 2.4) and a specialized AgroZ Plus (below right). Both units consist of one polypropylene outer bag and a HDPE plastic inside. The mode of action is similar that once the bag is filled with grain and closed, oxygen inside the bag will be depleted by respiration of grain and the insects inside (Abass et al., 2018). The only difference is that AgroZ Plus is premium designed for maize and cassava storage; crops of which are liable to attack by the larger grain borer, *Prostephanus truncatus* (AgroZ, 2019; Mutambuki et al., 2018). The hermetic liner of AgroZ Plus bags has an insecticide, alpha cypermethrin incorporated in the central layer of the plastic (AgroZ, 2019). AgroZ bags come in standard 100 kg capacities, reusable for three seasons (AgroZ, 2019).

Figure 2.4 A photograph of AgroZ ordinary bags (top left) and AgroZ Plus bags (top right), source (AgroZ, 2019).

2.2.3.4: ZeroFly hermetic bags

The ZeroFly Hermetic technology relies on the concept of protecting stored products from both internal and external insect attack. The technology was first released as a deltamethrin incorporated woven polypropylene bag (Baban and Bingham, 2014; Paudyal et al., 2017) and later with an inner HDPE hermetic plastic ("ZeroFly® Hermetic Storage Bag," 2019). The bags are tailored to suit customer needs with capacities ranging from 10 to 1000 kg which come in any colour and customized prints as per customer request ("ZeroFly® Hermetic Storage Bag," 2019).

Figure 2.5 A photograph of the ZeroFly hermetic bags, source (Vesterguard, 2015)

2.2.4: Future thoughts

Despite all the advances in breeding for improved varieties, drought tolerance and crop protection, the world today faces serious food shortages (Phiiri et al., 2016). Most importantly, southern Africa is viewed as the region that will be hard hit by hunger mainly due to increasing human population, climate change and declining soil fertility problems (Steenwerth et al., 2014). More sustainable agricultural practices are needed to improve food security. Technological inventions also need to be well-suited to the smallholder farmer context in terms of affordability, ease of use, durability and provide guaranteed protection of the little a farmer may produce.

2.5: Conceptual/theoretical framework

Field-based learning platforms and innovation systems as described in (Mashavave et al., 2011) were followed as they are key in promoting stakeholder participation and learning leading to easier technology conceptualisation and adoption of new technologies . Three pillars of the learning platform were extension staff, farmers and researchers.

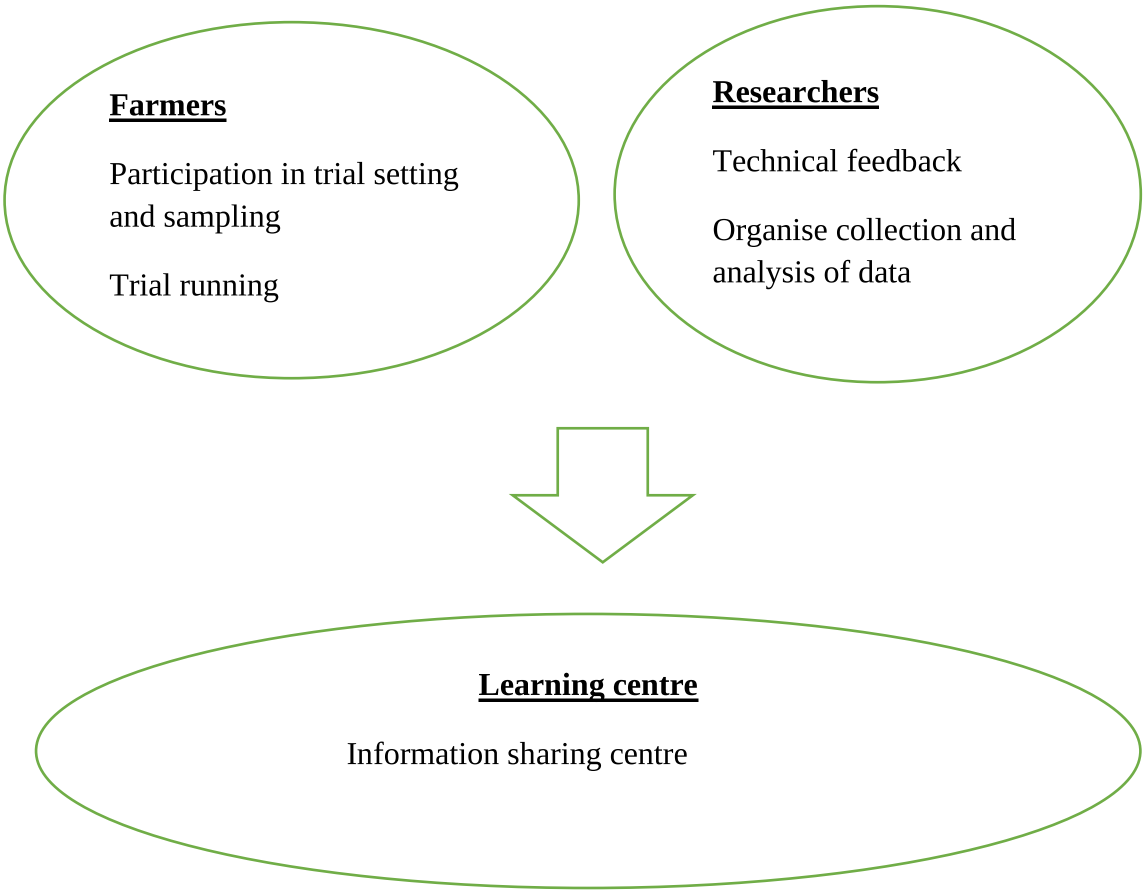

Figure 1 Conceptual framework of the field learning centre platform.

2.6: Summary of literature Review

Common bean production is integral to smallholder farming communities as a source of household food and nutrition as well as money earner since its demand is high both for rural and urban markets. Crop yields her hectare are low in Southern Africa, around 600 kg per hectare as compared to East Africa where smallholder production is pegged around 1 300 kg per hectare. Main challenges to production are seasonal droughts since the crop is mainly grown under rain-fed cultivation. The chief insect pest of storage, *A. obtectus* causes extensive nutritional and damage losses to stored common bean with losses ranging between 10 – 40 % in as few as six months of storage. Whilst synthetic pesticides have been the maim farmer arsenal in the fight against insect pests, this has not guaranteed protection of stored crops. On the other hand, as research for environmentally safer control strategies gather momentum, the hermetic storage technologies are gaining popularity as a safe and effective technology against insect pests of stored commodities including common beans. Various hermetic bag brands include Purdue Improved Crop Storage bags, Super grain bags, AgroZ ordinary hermetic bags, AgroZ Plus hermetic bags as well as ZeroFly hermetic bags. Hermetic bags restrict oxygen entry into the bag hence insects in grain are deprived of oxygen and die due to asphyxiation. It is however important to note that for these new technologies to be adopted they should be customised to the context of smallholder farmers so that they become affordable, durable and efficacious for protection of stored commodities. A learning centre approach was followed in the research to bring together farmers, researchers and national extension staff in the research so as to facilitate farmer learning of technology concepts that will smoothen the adoption process.

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CHAPTER THREE
METHODOLOGY

3.1: Introduction

Chapter 3 covers the study site characteristics, treatments and methodology used including experimental designs and data analysis tools that were used to achieve the study.

3.2: Study site

The experiment was carried out in Ward 1 of Goromonzi District of Zimbabwe in Mashonaland East province (Fig 3.1). The area is located in Natural Farming Region II characterised by 700 – 1000 mm mean annual rainfall and 18 – 27 ^{o}C mean annual temperatures (Mugandani et al., 2012). Common beans is one of the major crops grown for food and income in the area.

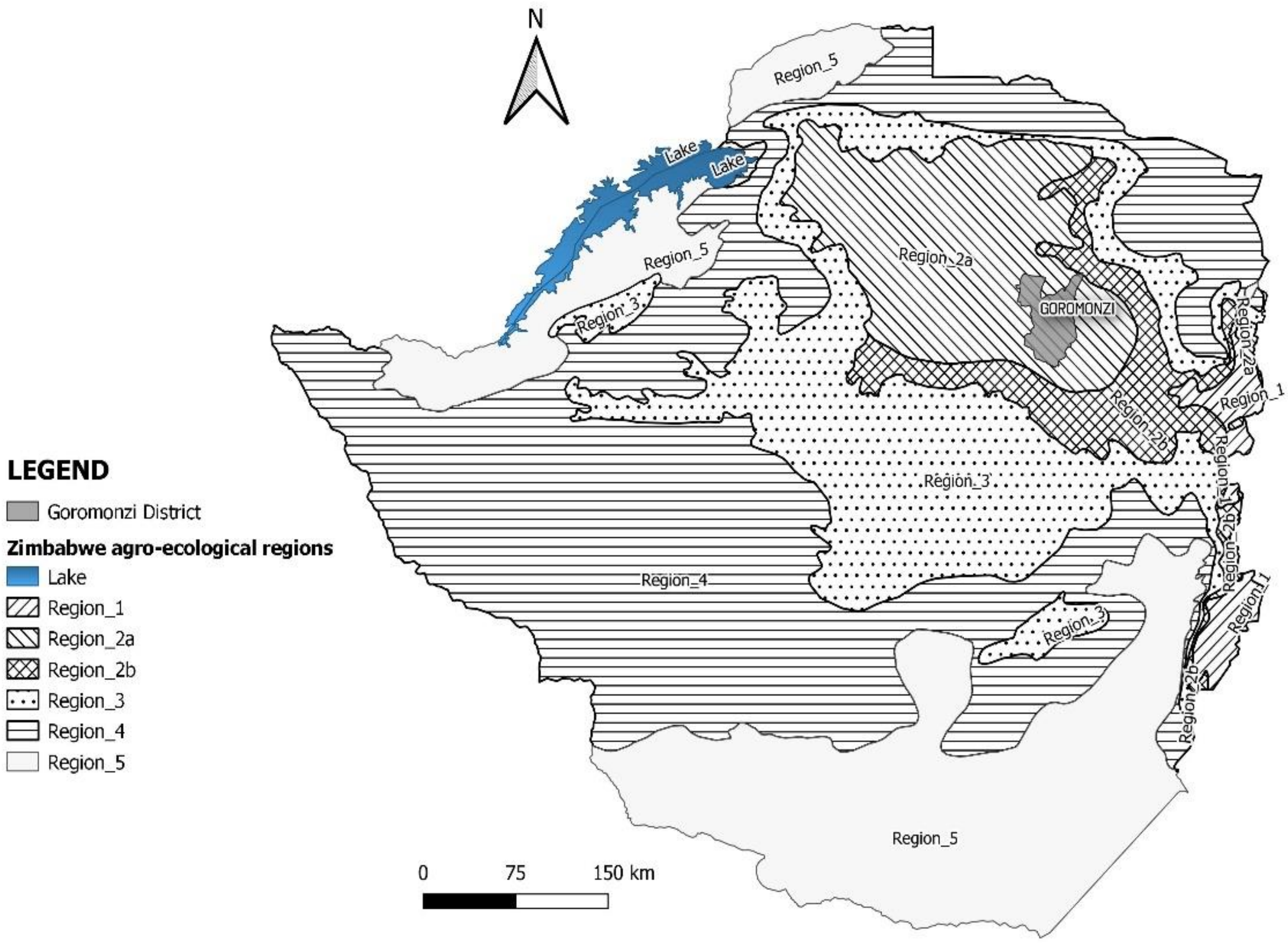

Figure 3.1 Study map showing the location of Goromonzi district in Natural Farming Region II of Zimbabwe

3.3: Field trial

A ward was selected based on bean production, agro-climatic conditions, access to road, common beans being an important crop in the farming system, four households were randomly selected based on ability to store the grain and to manage the experiment, and willingness to participate in the trial. Hosting and other surrounding farmers actively participated in trial-setting and sampling exercises so as to enable on-the-spot co-learning and dissemination of knowledge. Freshly harvested “Gloria” bean variety bought at one place was thoroughly mixed using shovels on a clean plastic sheet to achieve baseline uniformity of the parameters in the experiment. Grain was then divided into 25 kg portions per treatment, replicated four times. The trial was conducted from September 2019 storage season to April 2020.

3.3.1: Experimental design and treatment

The experiment was arranged in a randomised complete block design (RCBD) with six treatments replicated four times. Each household host was considered a block and replication factor. The treatments were four hermetic bag brands, a positive control (Shumba plus) and a negative control (untreated) as shown in Table 3.1.

Table 1 Treatments and their description as used in the field experiment

Treatment	Description	Composition
Shumba Plus	Commercial synthetic pesticide	Positive control (Pirimiphos-methyl 1.8 % + thiamethoxam 0.4 %) + 1 PP bag
AgroZ Ordinary	hermetic bag	1 HDPE + 1 PP bag
AgroZ Plus	pesticide incorporated hermetic bag	1 pesticide infused HDPE + 1 PP bag
Super grain bag	hermetic bag	1 HDPE + 1 PP bag
PICS bag	hermetic bag	2 HDPE + 1 PP bag
Untreated	control	Negative control (untreated) + 1 PP bag

HDPE-high density polyethylene; PP - polypropylene.

3.3.2: Sampling and sample analysis

Baseline samples were collected immediately after trial setup. Subsequent samples were collected at 8 week-intervals for a period of eight months. Samples were taken using a multicompartmented 1 meter long sampling spear after opening each bag, taking special care not to perforate the hermetic bags. A kilogram sample was drawn from each of the stored bags for sample analysis.

Sampling started with all the hermetic bags, then the untreated control and finally the pesticide treated positive control bag. This was done to avoid pesticide contamination of hermetic treatments which would bias the results. Before moving to the next household, the sampling spear was washed using water and a detergent and dried for the same reason of avoiding cross contamination of treatments.

The samples were brought to the Food laboratory at the University of Zimbabwe Department of Soil Science and Agricultural Engineering for analysis. Parameters of assessed were grain damage, insect populations (recording both live and dead), grain moisture content, chaff weight and grain weight loss. The procedure was that first, all samples were weighed to determine sample weight followed by sieving (using a 2 mm standard test sieve) to separate grain, chaff and insects. Insect numbers and chaff weight were recorded. Chaff weight comprised of both insect feeding dust and insect fruss; there was no further sieving possible to separate the two. Moisture content of beans was obtained as per International Seed Testing Association, using high oven drying method. 29g-30g sub- samples for grain moisture determination were taken as gain moisture and determined using the oven dry method.

Samples were then kept under freezer conditions (below -10 ^{o}C) to avoid further deterioration of samples during grain damage and weight loss analysis which took about a week to complete. Even after damage analysis was completed, samples were being kept safe in-case of the need to verify the results later. Grain damage was calculated as follows:

$$Grain\ damage = \frac{Nd}{(Nd + Nu)} \times 100$$

Grain weight loss was calculated using the formula:

$$Grain\ weight\ loss = [\frac{(NdWu - WdNu)}{\big((Nd + Nu) \times Wu\big)}]100\%$$

Where Nd = number of damaged grains, Nu = number of undamaged grains, Wd = weight of damaged grain, Wu = weight of undamaged grains. Formulas adopted from (Boxall, 1986).

For germination tests, random sampling of 500 seeds from each lot was followed with sub-sampling of 100 seeds for sowing. The 100 seeds were sown in petri dishes that were placed in an incubator at 28^{o}C. The sowing spacing between, and within rows in the petri dish at 3 cm and 4 cm respectively. The cotton wool was damp before seed sowing. The planted seed lots were watered on a daily basis with clean tap water. The counting of germinated seedling was conducted on the second, fifth and the seventh day of sowing.

3.3.3: Data analysis

Normality tests were conducted using Shapiro-Wilk test (VSN International, 2011) in GenStat 18. The data obtained was subjected to one-way analysis of variance by the F test, and significantly different means were further compared using Fischer's protected test at ($P < 0.05$), using the GenStat 18 statistical software (VSN International, 2011).

3.3.4: Ethical considerations

Because of the urban influence due to proximity to Harare, chances of misappropriation of the grain are high. A written consent was therefore obtained from the host farmers to ensure that obligations were met by both parties involved in the trials. Also in the written agreement, the hosting households were made to sign that the trial was not associated to any food aid or input scheme. Agritex extension officer was involved in witnessing and managing the trial on a day to day basis. The researcher sought clearance from the Ministry of Agriculture, which has the obligation to ensure clearance, to conduct the research. The focus of the researcher was on farm comparative performance of hermetic bags in dry bean storage therefore this was done to declare the research agenda, especially with the alignment towards highlighting that the research was strictly for academic purpose, therefore clearance became very important as it enable the research to be conducted with limited surveillance by village heads and people in the area.

3.4: Farmer perceptions

Besides the main experiment, a simple questionnaire (Appendix 1) was administered to determine smallholder farmers' assessment of the stored grain from the different treatments at the end of the storage period. The questionnaire was also used to determine the criteria that farmers usually use when assessing grain quality and market value. Twelve questionnaires were administered per site (Learning centre). With four learning centres, this gave a total of 180 questionnaires that were administered.

3.4.1: Respondent selection

Identification of respondents was done on the learning centre with the help of the extension officer. Purposive sampling was used where farmers that grow common beans were selected to respond to the questionnaire. Gender balance was done in selecting the respondents' inorder to see different farmer perceptions between male and female farmers.

3.4.2: Questionnaire administration

The questionnaire was designed by the researcher and the extension officer. These questionnaires were collected from September 2019- April 2020. The extension officer was trained on how to administer the questionnaire and a pre-test of the tool was done before administering the questionnaire. The questionnaire was administered after samples from the field trials were taken.

3.4.3: Data analysis

Survey data was analysed using SPSS version 21 (Arkkelin, 2014).

3.4.3 Ethical considerations

The questionnaire was purely academic and not related to any direct material benefits like inputs and food aid. No respondent benefited after giving responses. Before conducting the survey, a consent was signed and the respondent was notified on how long it was going to take to conduct the survey and the respondents had an opportunity to decline whenever they were not in agreement.

3.5: Summary

Field based learner centred trials were conducted in Goromonzi district using common beans. The trials evaluated the effectiveness of hermetic storage bag brands against storage insect pests of common beans chiefly *Acanthoscelides. obtectus*. Six treatments were used; four hermetic bag brands, a positive control (Shumba Plus) and a negative (untreated) control. The trials were conducted for a storage duration of eight months with sampling after every eight week intervals. Samples were analysed for insect populations, grain moisture content, chaff weight, grain damage and grain weight loss percentage. Data analysis was done using GenStat version 18 statistical package. Besides the main trial, a mini survey on grain quality characteristics based on treatment efficacy was conducted at the end of the storage duration. This was used to determine smallholder farmers' grain quality determinants and assessment.

3.6: References

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CHAPTER FOUR
RESULTS

Abstract

Effectiveness of six different storage technologies on stored beans was evaluated during the 2019/20 storage season in Domboshava, Goromonzi District. Beans were stored for 32 weeks and grain sampling was at 8-week intervals. Grain samples were analysed in the laboratory for: insect numbers and species, insect damage, weight loss, moisture content, chaff content and seed viability after storing in the different technologies. Data were subjected to Analysis of Variance and Fisher's test at 5% probability was used to separate significantly different means. Variation in moisture content started to occur beyond 16 weeks of storage. The overall results based on low moisture level maintenance showed that hermetic treatments gradually reduced moisture. Untreated treatment had the highest moisture content rise of around 1.4% whereas Grain Pro Super Bag had the lowest moisture content fluctuation of around 1% amongst the other treatments. Grain damage, weight loss and insect populations were lowest in Shumba plus, AgroZ Plus bags and PICS bags.

4.1 Introduction

FAO (2016) stated that world population has been predicted to reach 9.1 billion by 2050 and this will require a 70% increase in food production. Almost all of this growth will occur in less developed countries including Africa, Zimbabwe included. However, Africa is suffering from 20-30% PHLs of cereals valued at 4 billion dollars annually (Word Bank, 2011). Traditional storage practices in developing countries cannot guarantee protection against major storage pests of food crops like beans. Consequently, farmers receive low market prices for any surplus beans they may produce (Kimenju *et al.,* 2010).

Safe storage of beans at the farm level is crucial, as it directly impact on poverty alleviation, food and income security and prosperity for the smallholder farmers. Because of PHLs in storage, farmers are forced to sell grain soon after harvest when the prices are low. As well as providing food security at times of scarcity, effective been storage is an inflation-proof savings bank whereby beans can be cashed as needed or used directly as a medium of exchange for instance in payment for work such as field clearing and weeding. (Thamaga-Chitja *et al.,* 2004). Use of better technologies that reduce PHLs improve the quality of beans at the market. For this reason, there should be a strong focus on the extension/modification of existing store types as well as on the introduction of new storage types.

4.2 Material and Methods

4.2.1 Description of study area

Refer to chapter 3.2

4.2.2 Research Design

Refer to Chapter 3.3.1

4.2.3 Sampling procedure

Refer to chapter 3.3.2

4.2.4 Data collection procedure

Refer to chapter 3.3.3

4.2.5 Data analysis procedure

Refer to chapter 3.3.3

4.2.6 Challenges encountered during data collection

The challenges which were encountered data collection were logistical hic ups related to conducting field trials and surveys. These challenges ranged from gaining entry to study site, geographical constraints such as travelling to access participants.

4.3 Results

4.3.1 Efficacy of the hermetic technology

Grain damage, weight loss and insect populations were lowest in Shumba plus, AgroZ Plus bags and PICS bags. This section looks at the comparative performance of the hermetic bags in terms of insect infestation. It also looks deeper into other fundamental effects of the bags on factors like moisture content, germination, chaff content as well as seed quality after storage which are all factors influenced by insect pest infestation.

4.3.1. Insect numbers

The Fig 1 below shows the number of each type of insect which was identified in the laboratory by sieving a known weight of grains. *Acanthoscelides obtectus* was the dominant insect species with a predator wasps associated with the bean weevil also being detected. Insects were high from 16 to 32 weeks mostly in untreated control, AgroZ, PICS and GrainPro bags. Significant differences only occurred at 24 (P = 0.006) and 32 (P = 0.004). At 24 weeks AgroZ and untreated had significantly high insect populations whilst at 32 weeks untreated, PICS and AgroZ had the highest significant insect populations. The bean weevil measure about 1/5th to 1/6th inch long and they are olive brown with grey brown spots on wings covers they infest only whole beans and other legumes.

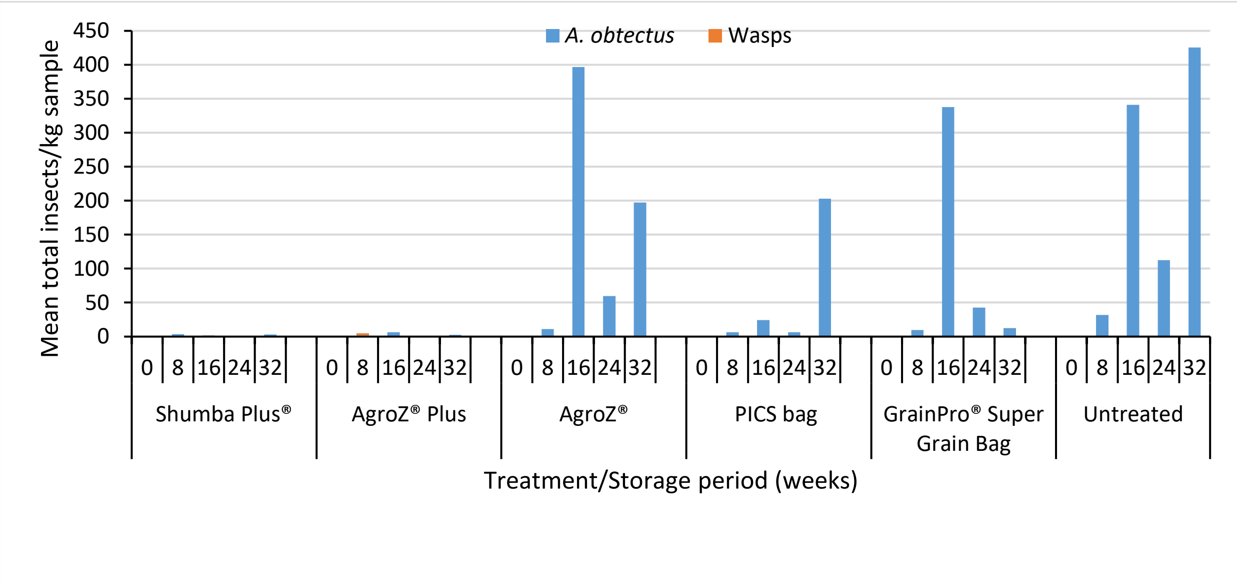

Figure 4.1 Mean total insects (±SEM) per kg of grain stored in different hermetic bags (n = 4)

At the start of the storage experiment, there was 0% presence of insects in beans from all samples. All hermetic bags significantly controlled insect infestations with no significant increase in any insect numbers between set up to 8 weeks. Insect development in untreated bag was zero at the start of the experiment. The percentages of insects were high from 16 to 32 weeks mostly in untreated control, AgroZ, PICS and GrainPro bags. Significant differences only occurred at 24 (P = 0.006) and 32 (P = 0.004). At 24 weeks AgroZ and untreated had significantly high insect populations whilst at 32 weeks untreated bag had the highest significant insect populations. In both bags, the *A. obtectus* was the most common with a total of the storage period.

4.3.2 Insect generated Chaff

Generally low chaff below 5% was produced as A. obtectus is not characterized by high chaff production as indicated by the Fig below. Differences in chaff content became significant at 8 weeks (P < 0.001) untreated and 16 (P = 0.023) weeks at which untreated and AgroZ had the highest chaff. Shumba Plus, AgroZ Plus and PICS maintained below 1 % chaff levels throughout the 32 weeks of storage. All hermetic treatments with lower grain damage levels managed to suppress grain dust production compared to the untreated bag.

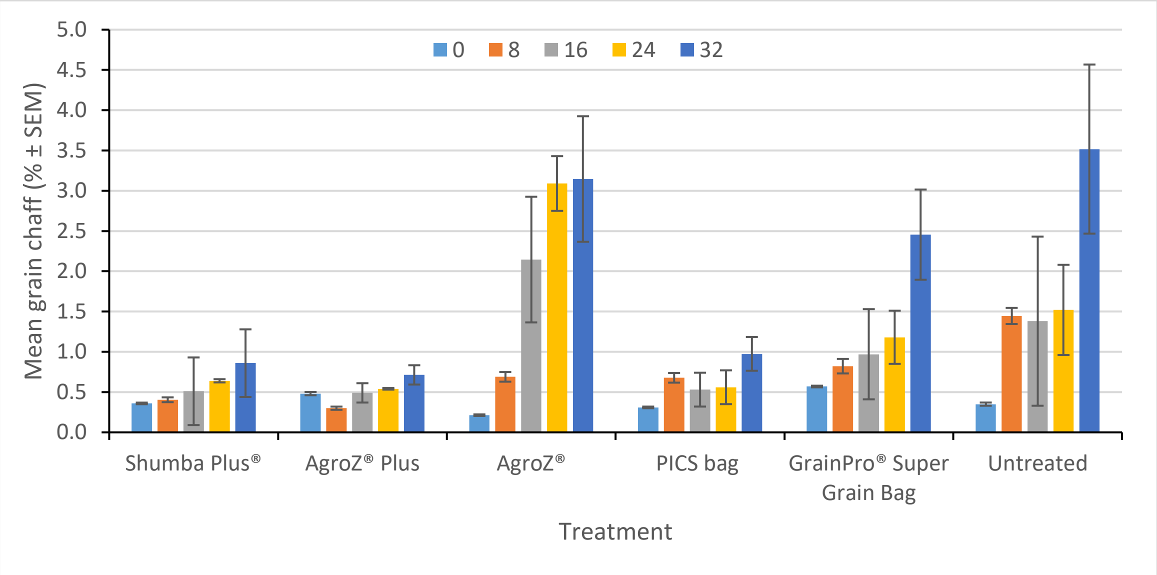

Figure 4.2 Mean grain chaff (±SEM) per kg of grain stored in different hermetic bags (n = 24)

4.3.3 Grain moisture content

Fig 4.3 highlights a general moisture increase as observed moisture increased from between 9 and 9.5% at start to 10% at 32 weeks. Untreated control however had a bit higher moisture consistency from 8 to 32 weeks. Differences in moisture amongst the treatments were significant at 8 (P < 0.001), 24 (P <0.001) and 32 (P < 0.001). At 8 weeks it was untreated and Shumba Plus with high moisture, at 24 it was untreated and AgroZ Plus and finally at 32 weeks it was untreated, PICS and AgroZ Plus and GrainPro bags in dissenting order.

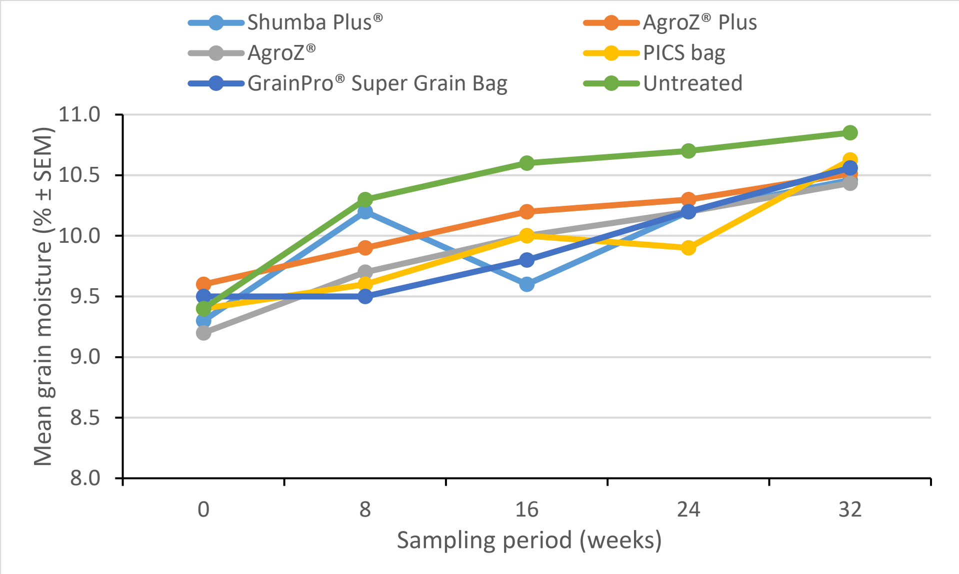

Figure 4.3 Mean grain moisture (±SEM) per kg of grain stored in different hermetic bags (n = 24)

4.3.4.1 Germination tests

The graph below shows the germination of test of beans, the germination test was aimed at understanding the effect of the different storage conditions on germination ability of the stored beans in hermetic bags and untreated bags.

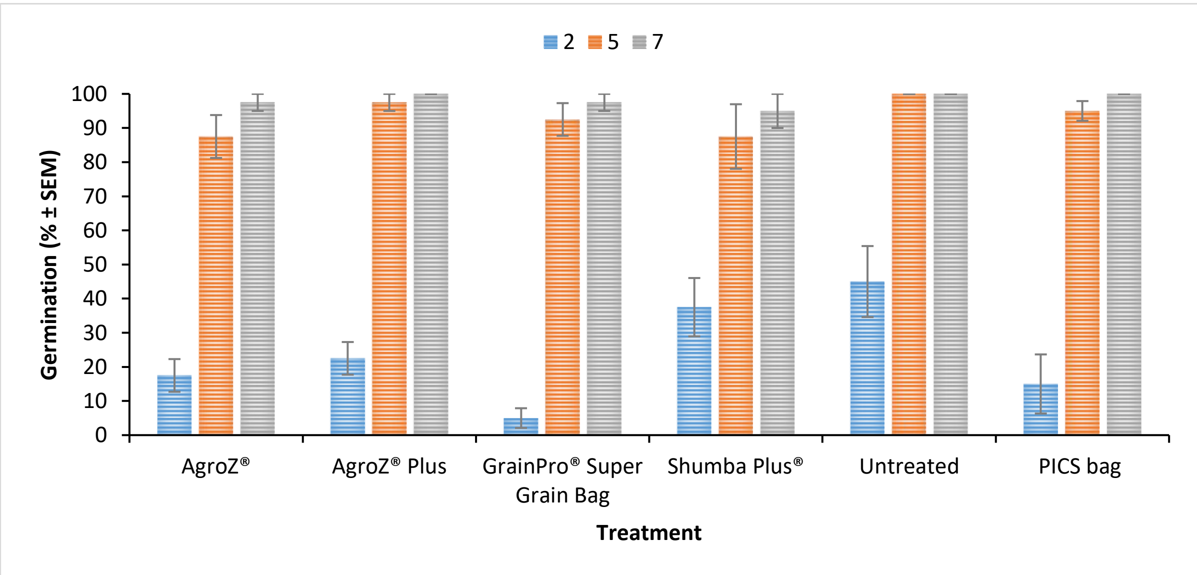

Figure 2 Mean total percentage germination (±SEM) per kg of grain stored in different hermetic bags (n = 4)

Counting of the number of germinated seeds out of 100 was done three times. Significant differences in germination percentage were found at day 2 (P =0.006) where untreated and

Shumba plus had over 30 % germination and AgroZ, AgroZ Plus, and PICS bag had less than 20% and lastly Super grain bag had less than 10%. On the fifth day AgroZ, Shumba Plus had less than 90% germination and AgroZ Plus, Super grain bag and Untreated and PICS bag had more than 90 % germination.

4.3.4.2 Seed after Storage-Germination tests

The chart below shows significant differences in seed germination were found at day 7 (P = 0.045) only when untreated control recorded 50 % germination and other treatments had between 70 and 80%. Comparing baseline germination (average 100%) and germination at trial ending (average 75%), there was approximately 25 % decrease in germination percentage recorded.

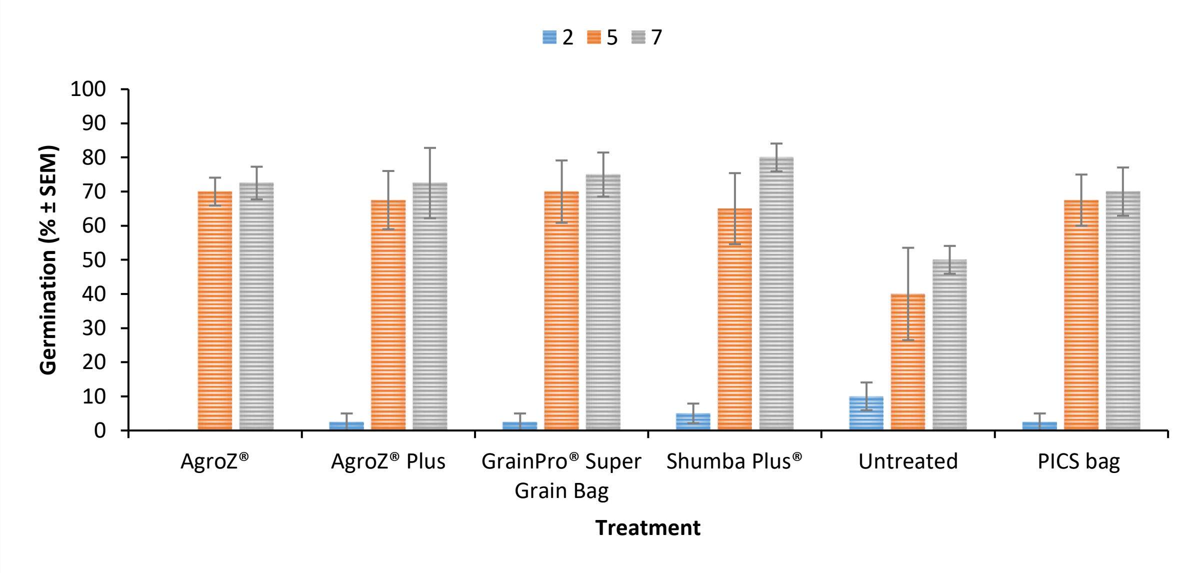

Figure 4.4 Mean percentage germination (±SEM) per kg of grain stored in different hermetic bags (n = 4)

4.3.5 Grain Damage

The fig shows the grain damage ratings from the six experiments. According to the chart the lowest damage below 10% was recorded in Shumba Plus, AgroZ Plus and PICS bags for 32 weeks. In other treatments damage began to rise from 16 weeks. 0, 8 (P = 0.033) untreated, 16 (P= 0.041), 24 (P = k0.002) untreated, 32 (P = 0.009) resulting in significantly higher damage in the untreated control, GrainPro and AgroZ bags. The highest damage mark of 70% was recorded in untreated control at 32 weeks. The researcher has observed that there are various causes or categories of damaged beans. The researcher has found out that the causes include insects and fungi, germination, rodents, broken beans, and stunted beans.

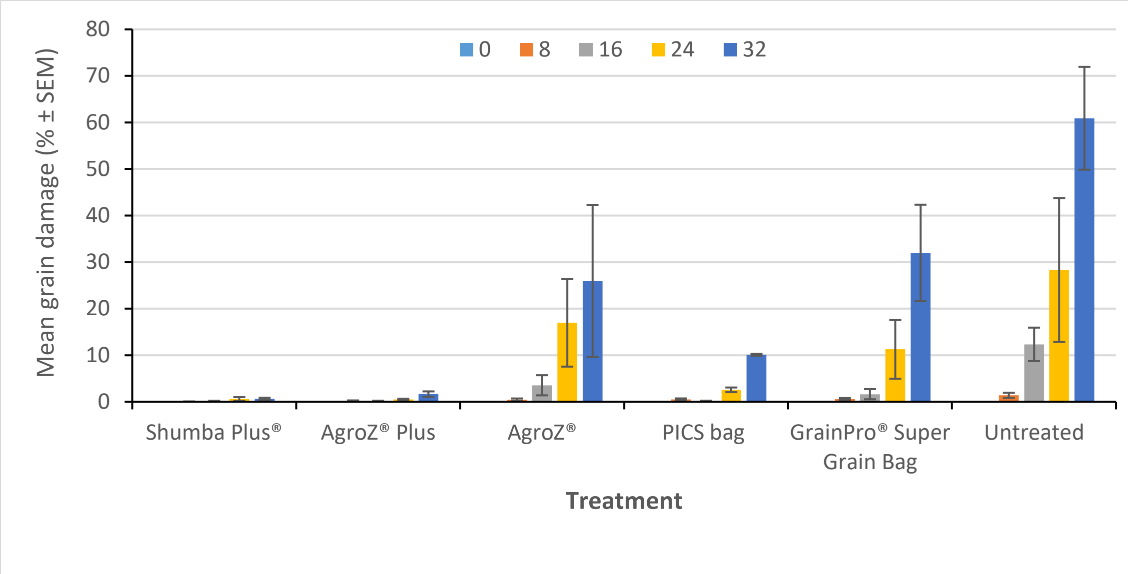

Figure 4.5 Mean grain damage (±SEM) per kg of grain stored in different hermetic bags (n = 4)

Majority of farmers stored for 6-12 months. Chigoverah, and Mvumi, (2016) highlighted that bean bruchids (Coleoptera: Bruchidae) are one of the main constraints of common bean production that cause heavy losses in terms of both quality and quantity of stored beans. Chigoverah et al (2016) mentioned that the bean bruchids, namely, the bean weevil, Acanthoscelides obtectus (Say), is reported as the major pests of common bean in Zimbabwe and other common bean growing regions of the world. The highest damage mark of 70% was recorded in untreated control at 32 weeks

4.3.6 Grain weight loss

The graph below shows grain weight loss over a period of 32 weeks. According to the above figures weight loss levels were maintained below 4% in five treatments except untreated control which recorded grain weight loss above 14% at week 32. Significantly high losses were noted in untreated control at 24 ($P < 0.001$) and 32 ($P < 0.001$) weeks. There was statistical difference at 32 weeks for treated bags, AgroZ and Super grain bag recorded more than 2% of grain weight loss while Shumba plus, AgroZ plus and PICS bag recorded less than 2% of grain weight loss. . Grain weight loss, refers to the disappearance of food and is usually expressed as a percentage weight loss (Boxall, 2002). At the end of the storage period, the effectiveness of treatments in controlling weight loss was as follows Shumba Plus, AgroZ Plus, PICS bag (<2%), Agro Z, Super grain bag (<4%), untreated control (<14%). There were no significant differences between hermetic treatments regardless of the mode.

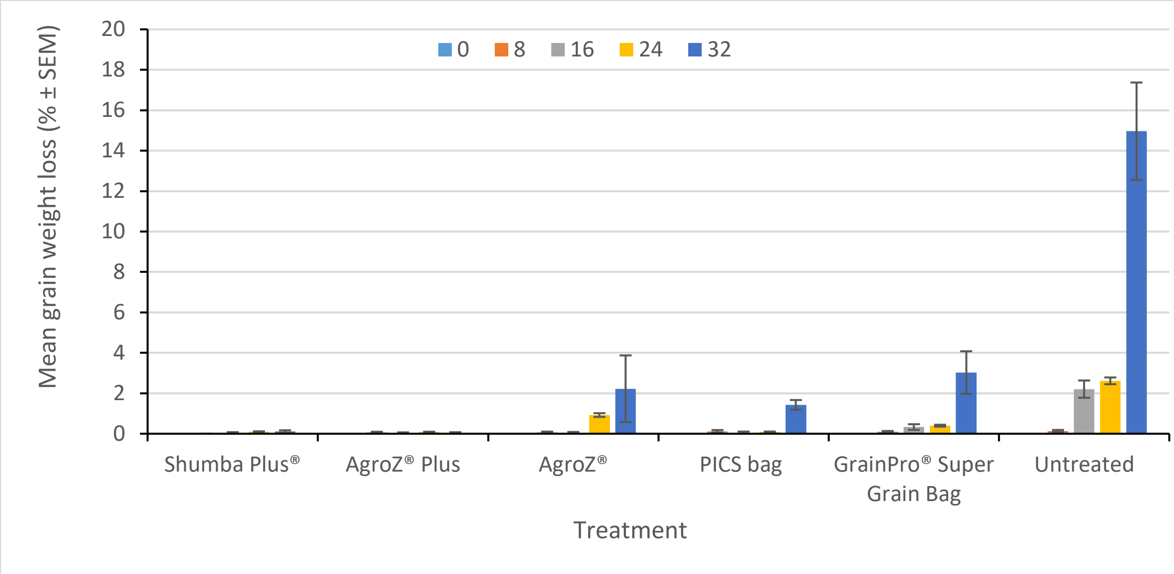

Figure 4.6 Mean grain weight loss (±SEM) per kg of grain stored in different hermetic bags (n = 4)

4.4 Discussion

This study revealed that the moisture contents is in equilibrium with a relative humidity. These conditions allow the insect egg eclosion and development of been weevil (Papa Christos and Savopoulos, 2014). In the untreated bag, the average of emerging bean weevils cause great physical damage which is a problem that requires an urgent solution, mainly in rural areas and smallholders farmers, where even beans with low moisture content results in severe insect postharvest losses, which in turn creates a direct problem for access to sound grains (Chigoverah, and Mvumi, 2016).

The researcher has also noted that, hermetic treatments were equally effective in suppressing grain damage and were more effective than untreated bag. The methods of assessing weight losses caused by insects can be used for assessing losses due to moulds, and inevitably, the estimates of losses due to insects often include an element of loss due to moulds (Chigoverah, 2016). Therefore, losses that were caused by growth of moulds were incorporated in weight loss.

Moisture content increased with time in both hermetic treatments and untreated bag. A fairly constant pattern was observed in hermetic treatments although slight fluctuations were observed during 32 weeks of storage. Untreated bag allow interaction of stored bean with dynamic external environment. Therefore, due to the rapid increase of humidity, the moisture content of beans increased slightly to the extent that there was no significant difference between hermetic treated bags after 32 weeks.

Moisture content and temperature are among the most critical factors that affect the quality of beans during storage. The normal harvesting moisture content for most bean farmers in Africa, and Zimbabwe in particular is 13–15% (David 1998). To maintain good quality beans during storage, grains must be protected from changes in moisture content and growth of insects and microorganisms such as fungi. This study demonstrated that moisture of bean grains stored in Shumba Plus, PICS bag, Super grain Agro Z and Agro Z Plus had a slight change over the whole storage period of 32 weeks, indicating lack of exchanges between the hermetic bags and the outside environment. The finding confirms from the study that showed the moisture content of grains stored in the hermetic bags slightly changed during storage (Mlambo, 2017). In contrast, this study showed that the permeability of untreated bag, grains gained moisture in response to ambient relative humidity. Among factors that influence insect infestation in grain storage ecosystem are water, temperature, and air, thus insect damage increases during storage

Chekanai, (2018) stipulated that the effectiveness of grain storage is greatly influenced by treatment technology storage period, and weight loss during storage duration. This study confirms that the grain weight loss levels observed in the bags is attributed to the type of storage and insect population in the bags. Bean grains stored in Shumba Plus, PICS Bags and AgroZ Plus maintained very low weight loss (0–1%) compared to the equivalent grains in Agro Z (0-2%), Super grain bag (1-3%) and untreated bag (2-14%) at 32 weeks after storage. The weight loss levels observed difference probably could be ascribed to differences in the evaluated Grain bag types. Chigoverah et al (2016) is of the view that hermetic bags are characterised by ultra-low oxygen permeability, greater toughness, and perforation resistance while retaining the original thickness. Higher losses were recorded in the grains stored in untreated bag. FAO (2016) is of the view that beans harvested with low moisture content do not lose weight very much.

The researcher has found out that testing seed germination quality is crucial to farmers who perpetually have funding challenges to buy good seeds for the next planting season. Failure of seed germination can amount to waste of farm labor time and cost. Substantial differences occurred in physical characteristics of common beans stored at different hermetic bags for 32 weeks. Fintrac, (2016) mentions that beans stored at high temperature and low relative humidity exhibit the greatest loss in moisture during storage and increased bean hardness.

Farmers in Southern Africa are aware of the need for clean, undamaged seed for maximum germination (Ugandan, 2012). Chigoverah et al (2016) stated that bruchids damage from emergence holes negatively impacts seed germination. In this study bean seeds were sown in trays irrigated on daily bases and the differences in germination percentage were found at day 2 (P =0.006) were untreated and Shumba plus had over 30 % germination and AgroZ, AgroZ Plus, and PICS bag had less than 20% and lastly Super grain bag had less than 10%. On the fifth day AgroZ, Shumba Plus had less than 90% germination and AgroZ Plus, Super grain bag and Untreated and PICS bag had more than 90 % germination. Mlambo (2017) mentions that testing seed germination quality is crucial to farmers who perpetually have funding challenges to buy good seeds for the next planting season

4.5 Conclusion

Hermetic bags are better when it comes to pest infestation management, moisture level preservation, seed storage and chaff management compared to untreated or other traditional methods of grain storage, therefore it is of paramount importance to enhance their adoption amongst farmers. From the research findings, eeffectiveness of different storage technologies on beans showed future promise on PHL prevention except for the untreated bag. Effectiveness was measured by considering different factors such as grain damage and weight loss. Performance of Shumba Plus, AgroZ, AgroZ Plus, Super grain bag and PICS bag provided good results compared to the untreated bag despite of their weaknesses. Hermetic bags performed better and they are affordable and easy to find. Shumba Plus bags can be good to farmers whose production is high and who can afford the price. Education on hermetic technology and its impact on farmers need to be provided to the community to increase their awareness and knowledge of post-harvest management of beans.

4.6 References

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CHAPTER 5
RESULTS

Abstract

Post-harvest losses remain one of the primary issue in agriculture especially amongst smallholder farmers who do not have enough knowledge of the innovations available at their disposal. Effectiveness of six different storage technologies on stored beans was evaluated during the 2019/20 storage season in Domboshava, Goromonzi District. Beans were stored for 32 weeks and grain sampling was at 8-week intervals. Survey data was analysed using SPSS version 21 and excel. Most respondents indicated that Shumba Plus was very good in controlling insect infestation, seed rot, presence of chaff as well insect damage in comparison to the untreated treatment which was perceived poor in all these tests. Beans stored in the Shumba Plus treatment had the highest termination price of $40, whereas AgroZ Plus, AgroZ, PICS bags had termination prices of $35, and $30 respectively. Grain pro Super grain bag and untreated had the lower termination prices than their baseline recording $12 and $10 from $15 respectively.

5.2 Material and Methods

5.2.1 Description of study area

Refer to chapter 3.2

5.2.2 Research Design

Refer to chapter 3.4.1

5.2.3 Sampling procedure

Refer to chapter 3.4.2

5.2.4 Data collection procedure

Refer to chapter 3.4.2

5.2.5 Data analysis procedure

Refer to chapter 3.4.3

5.2.6 Challenges encountered during data collection

During questionnaire administration, some farmers' literacy levels were low so they couldn't write on the questionnaire. Also farmers had many attributes that were not related to storage and insect pests.

5.3 Results

5.3.1 Presence of insects

From the Fig 5.2 untreated grain was heavily infested with insects followed by AgroZ Plus bag as confirmed by respondents' ranking of treatments. Of the respondents, 51.3% indicated that untreated grain had a lot of insects while 71.8% indicated that Shumba Plus had less insect infestation. This indicates that Shumba Plus was very effective in controlling pest compared to the other treatments.

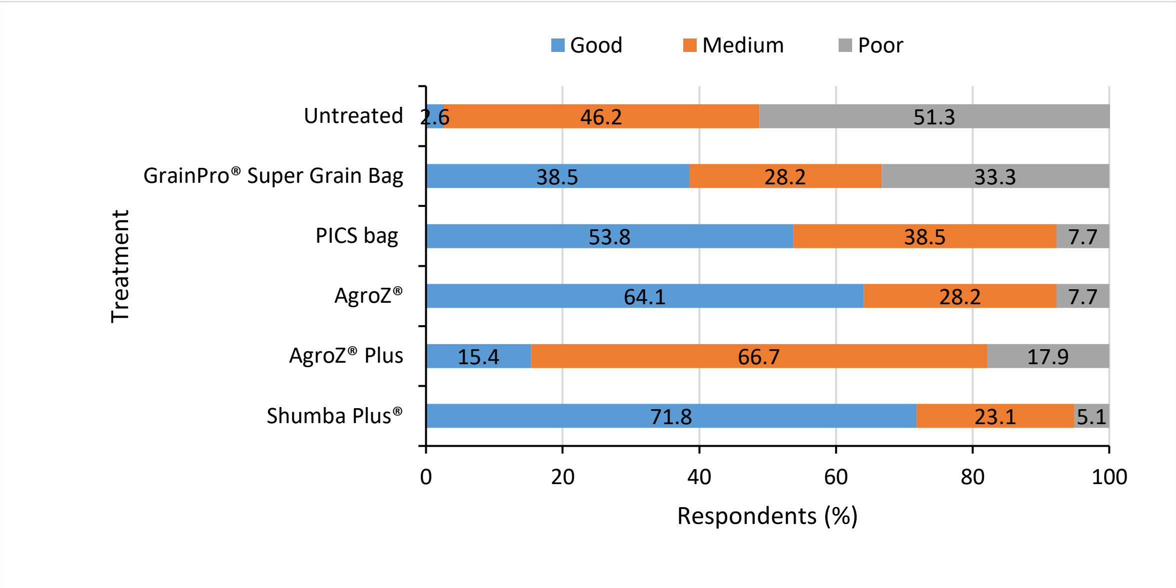

Figure 5.2 Percentage respondents for presence of insects in different hermetic bags (n = 180)

5.3.2 Rotten grain

Fig 5.3 shows the different treatments comparison in terms of presence of rotten grain. Untreated. Grain Pro Super Grain bag and Agro Plus had respondents indicating that they were poor in controlling issues of rotten seed (41%, 30.8% and 2.6 %) over the period of the experiment. Untreated treatment had the highest number of respondents 41% indicating that it was poor in terms of controlling grain spoilage. 66.7 % of the respondents indicated that Shumba Plus was good in controlling grain spoilage.

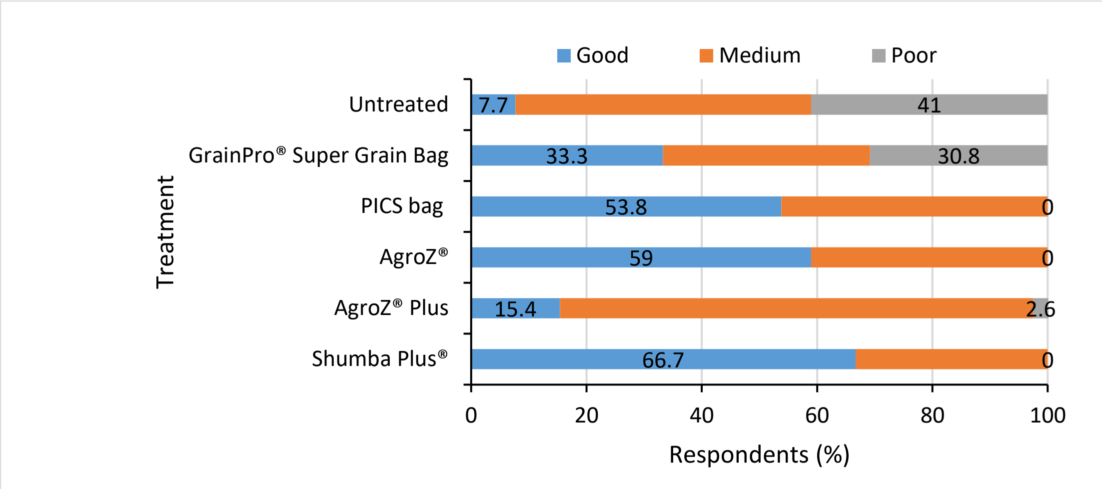

Figure 5.3 Percentage respondents for rotten grain in different hermetic bags (n = 180)

5.3.3 Presence of chaff

76.9% of the respondents according to the graph below perceived that Shumba Plus had the least amount of chaff and was very good in managing presence of chaff which harbours insects and also 43.6 % of the respondents indicated that Untreated was poor in managing presence of chaff (Fig. 5.3).

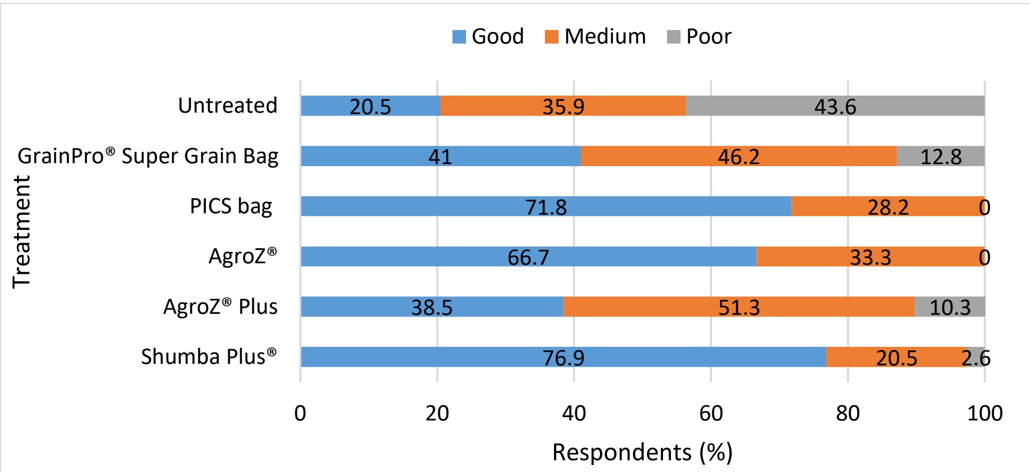

Figure 5.3 Percentage respondents for presence of insects chaff in different hermetic bags (n = 180)

5.3.1.4 Insect damage

Untreated was perceived to had the highest insect infestation of 23.1% compared to Shumba Plus which had 2.6%. Shumba Plus had the least insect damage with 82.1% of the respondents indicating that it was very good in managing insect damage (Fig. 5.4).

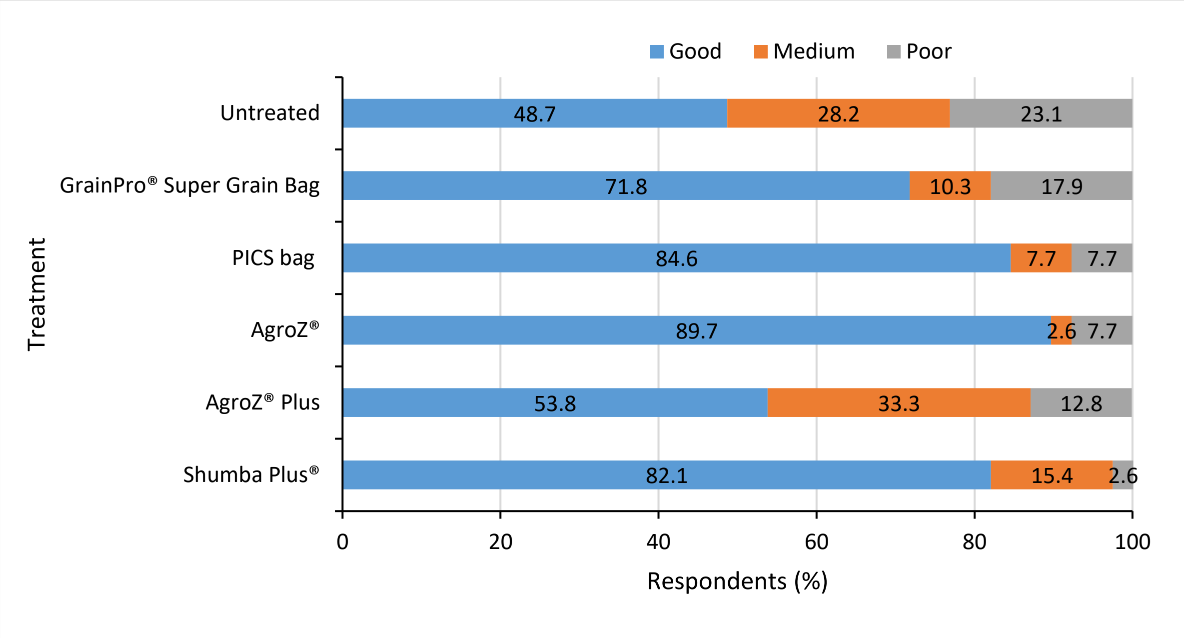

Figure 5.43 Percentage respondents for insect damage in different hermetic bags (n = 180)

5.3.1.5 Grain discolouration

The highest number of respondents (28.2%) indicated that untreated was poor in terms of seed colour management compared to Shumba Plus which had the highest number of respondents citing that it was good amongst the other treatments (79.5%) (Fig. 5.5)

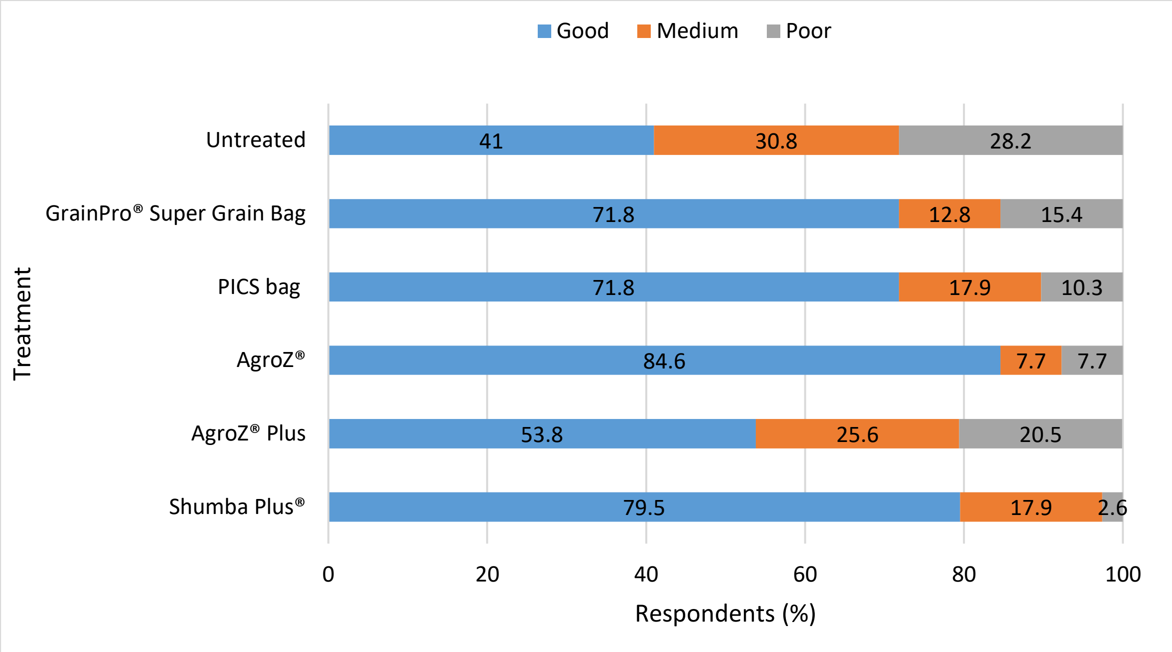

Figure 5.5 Percentage respondents for grain discoloration in different hermetic bags (n = 180)

5.3.2 Price changes under different storages with marketing period

From Fig 5.6 the baseline price for the grain from all the treatments was the same at the beginning of the experiment. However, at the termination period, Shumba plus@ had the highest termination price of around $40 USD/20 kg bucket with Agro Z@ Plus having around $35 USD. Agro Z and PICS bag had the same prices of $35 USD at the termination period. All these treatments reflect a price increase from the baseline price except the untreated control which had the least price at the termination period of around $10 USD.

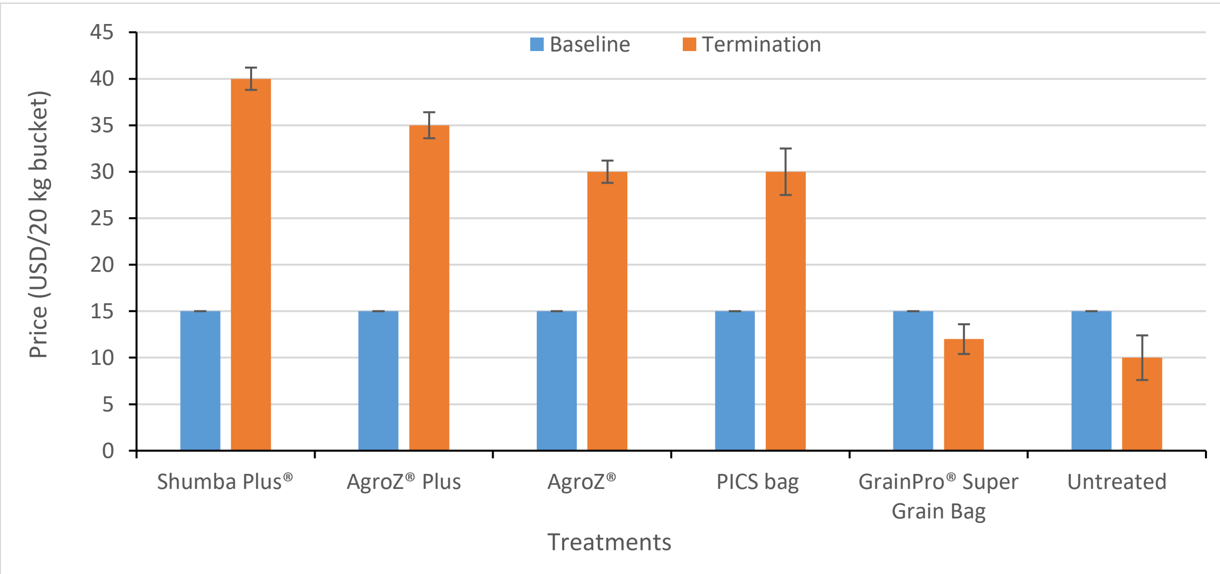

Figure 5.6 : Prices over time in different hermetic bags (n = 4)

5.4 Discussion

As the bean marketing season sets, they will be huge supply which denotes a much lower baseline price of $15 USD. As the season progresses, market prices rise due to decreased supply in the market. The longer the storage capability of the farmer the more likely they are to fetch a higher price with the progression of the market (Mlambo et al, 2017). Furthermore the storage technology which produces high quality at the end of the survey period the higher the price it fetches on the market. Pests have a tendency of reducing grain quality hence decreasing the price of the produce on the market. The ability of the storage technology to store the beans in their harvest quality, and weight as well as moisture content is critical for pricing.

5.5 Conclusion

Hermetic bags are better when it comes to pest infestation management, moisture level preservation, seed storage and chaff management compared to untreated or other traditional methods of grain storage, therefore it is of paramount importance to enhance their adoption amongst farmers. From the research findings, eeffectiveness of different storage technologies on beans showed future promise on PHL prevention except for the untreated bag.

5.6 References

Mvumi, B. M., Chigoverah, A. A., Koza, T., Govereh, J., Chuma, T., Dzvurumi, F., Mfote, D. and T. Tefera, 2013. Introduction, testing and dissemination of grain storage technologies for smallholder farmers in Zimbabwe: A partnership approach. In 11th African Crop Science Conference Proceedings. 14-17 October 2013, Entebbe, Uganda. African Crop Science Society, 585– 591

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CHAPTER 6
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

PHLs remains one of the greatest draw back to success of may agriculture activities in the Sub-Saharan parts of Africa. These account to over a quarter of losses incurred of the total of the harvest. Hermetic technologies are a clean and efficient means to curb this hindrance, posing a double at one go function of storage as well as curative in pest infestation management furthermore preserving grain quality without the use of any other chemical or additive. The current chapter looks at the research summary, conclusion and recommendations of the research study.

6.2 Research summary

The study investigated the comparative performance of hermetic bags and was experimental in nature with 6 treatments. Of the 6, one was an untreated control which in turn represented the tradition methods used to store grain. The study focused on comparison of pest infestation, germination, moisture content, germination and seed after storage across the six treatments. It also investigated weight loss and seed damage as well as farmers perceptions on the use of hermetic bags as an innovation in grain storage and prevention of post-harvest losses.

6.3 Conclusions

Storage losses due to pest damage and weight losses as well as losses in the germination percentage and quality losses through fungal and aflatoxin infestation are a serious problem that threatens the food security, nutrition and livelihood of rural communities who rely heavily on traditional storage systems. Use of insecticides is never fully employed due to economic reasons as well as the fact that most of these issues occur on the farm and the damage almost goes unnoticed most times by the famers. Moreover, farmers who decide to use insecticides should take proper caution when using the chemicals as they have cost implications, health and environmental effects.

However, hermetic storage innovations are capable of stopping destructive losses due to insect pest damage even for produce that may enter storage with some level of pre-storage infestation arising from field infestation or improperly cleaned storage structures. The technology also maintains moisture levels, minimizing weight loss and grain damage as well guarantying high germination rates to seed storage.

6.4 Policy implication and recommendations

There is great need to sensitize farmers on the usefulness and effectiveness of hermetic technologies so that there is an increased uptake in all areas. This implies the joint force of all public and private stakeholders in spearheading the initiative.

There is also need to look at improvement of the hermetic technologies in order to make them less susceptible to rodent attacks as well as influence of the external environment which might influence the moisture content balance. A limitation with the hermetic technology as demonstrated in this study is that it might require pre-storage precautions that relates to the ability to sustain a constant relative humidity while storing grain with high moisture content. Therefore, frequent monitoring during storage is recommended.

6.5 Areas for further research

Further research is needed to establish the effect on nutritional composition of stored produce such as beans in hermetic bags during multi-month of postharvest storage. There is also need to factor in economic comparisons of using the traditional against the hermetic technologies and the viability of employing each of these and their implications on the farmer's balance sheet.

7. Appendices

Appendix 1: Farmer perceptions and prices over time

POST HARVEST LEARNING TOOL, 2019/2020 STORAGE SEASON

SECTION A: Evaluation of storage technologies

Criteria/Attributes	Rank	Shumba plus	Agro Z bags	Agro Z plus bags	PICS bags	Super grain bags	Untreated control

Section B: Adoption of storage technologies

1. From the attributes that you have listed, rank the grain per treatment using this scale,

A = Good quality

B = medium quality

C = Poor or heavily infested

2. What technologies do you think can be adopted based on the results of the 2019/20 storage season (List them).
3. What challenges do you think can be encountered when adopting some of these technologies?
4. Do you think there is need to put in place some modification to some of these technologies?
5. How much would you sell a bucket of maize from each treatment for? [Fill in the table]

Treatment	Price/bucket
T1	

T2	
T3	

T4

T5

T6

6. What other technologies need to be tested in future trials?

Appendix 2: Statistical analyses results

Analysis of variance

Variate: Damage1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1.6455	0.5485	2.07	
Block.*Units* stratum					
Treatment	5	4.3793	0.8759	3.31	0.033
Residual	15	3.9717	0.2648		
Total	23	9.9965			

Message: the following units have large residuals.

Block 1 *units* 6 0.85 s.e. 0.41

Tables of means

Variate: Damage1

Grand mean 0.53

Treatment	AgroZ®	AgroZ® Plus
	0.44	0.21
Treatment	GrainPro® Super Grain Bag	PICS bag
	0.58	0.51
Treatment	Shumba Plus®	Untreated
	0.03	1.39

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	15
s.e.d.	0.364

Least significant differences of means (5% level)

Table	Treatment

rep.	4
d.f.	15
l.s.d.	0.776

Stratum standard errors and coefficients of variation

Variate: Damage1

Stratum	d.f.	s.e.	cv%
Block	3	0.302	57.3
Block.*Units*	15	0.515	97.6

Fisher's protected least significant difference test

Treatment

	Mean
Shumba Plus®	0.0343 a
AgroZ® Plus	0.2142 a
AgroZ®	0.4352 a
PICS bag	0.5123 a
GrainPro® Super Grain Bag	0.5787 a
Untreated	1.3889 b

Analysis of variance

Variate: Damage2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	2005.3	668.4	4.16	
Block.*Units* stratum					
Treatment	5	2482.3	496.5	3.09	0.041
Residual	15	2411.8	160.8		
Total	23	6899.5			

Message: the following units have large residuals.

Block 4 *units* 6   29.50   s.e. 10.02

Tables of means

Variate: Damage2

Grand mean 10.03

Treatment	AgroZ®	AgroZ® Plus
	16.98	0.48
Treatment	GrainPro® Super Grain Bag	PICS bag
	11.26	2.56
Treatment	Shumba Plus®	Untreated
	0.57	28.31

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	15
s.e.d.	8.966

Least significant differences of means (5% level)

Table	Treatment
rep.	4
d.f.	15

l.s.d.	19.111

Stratum standard errors and coefficients of variation

Variate: Damage2

Stratum	d.f.	s.e.	cv%
Block	3	10.555	105.2
Block.*Units*	15	12.680	126.4

Fisher's protected least significant difference test

Treatment

	Mean
AgroZ® Plus	0.48 a
Shumba Plus®	0.57 a
PICS bag	2.56 a
GrainPro® Super Grain Bag	11.26 ab
AgroZ®	16.98 ab
Untreated	28.31 b

Analysis of variance

Variate: Damage3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	22.88	7.63	0.56	
Block.*Units* stratum					
Treatment	5	453.91	90.78	6.69	0.002
Residual	15	203.61	13.57		
Total	23	680.40			

Message: the following units have large residuals.

Block 1 *units* 6 -8.00 s.e. 2.91

Tables of means

Variate: Damage3

Grand mean 2.99

Treatment	AgroZ®	AgroZ® Plus
	3.54	0.17

Treatment	GrainPro® Super Grain Bag	PICS bag
	1.62	0.15

Treatment	Shumba Plus®	Untreated
	0.13	12.32

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	15
s.e.d.	2.605

Least significant differences of means (5% level)

Table	Treatment
rep.	4
d.f.	15

l.s.d. 5.553

Stratum standard errors and coefficients of variation

Variate: Damage3

Stratum	d.f.	s.e.	cv%
Block	3	1.128	37.7
Block.*Units*	15	3.684	123.3

Fisher's protected least significant difference test

Treatment

	Mean
Shumba Plus®	0.131 a
PICS bag	0.148 a
AgroZ® Plus	0.166 a
GrainPro® Super Grain Bag	1.621 a
AgroZ®	3.535 a
Untreated	12.322 b

Analysis of variance

Variate: Damage4

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	3		990.5	330.2	0.82	
Block.*Units* stratum						
Treatment	5		10507.7	2101.5	5.19	0.009
Residual	12	(3)	4854.7	404.6		
Total	20	(3)	15703.8			

Message: the following units have large residuals.

Block 1 *units* 6	35.29	s.e.	14.22
Block 4 *units* 3	37.26	s.e.	14.22

Tables of means

Variate: Damage4

Grand mean 23.26

Treatment	AgroZ®	AgroZ® Plus
	25.98	1.63
Treatment	GrainPro® Super Grain Bag	PICS bag
	35.58	14.83
Treatment	Shumba Plus®	Untreated
	0.62	60.89

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	14.222

(Not adjusted for missing values)

Least significant differences of means (5% level)

Table	Treatment

rep.	4
d.f.	12
l.s.d.	30.988

(Not adjusted for missing values)

Stratum standard errors and coefficients of variation

Variate: Damage4

Stratum	d.f.	s.e.	cv%
Block	3	7.418	31.9
Block.*Units*	12	20.114	86.5

Fisher's protected least significant difference test

Treatment

	Mean
Shumba Plus®	0.62 a
AgroZ® Plus	1.63 a
PICS bag	14.83 ab
AgroZ®	25.98 ab
GrainPro® Super Grain Bag	35.58 bc
Untreated	60.89 c

Analysis of variance

Variate: Insects0

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.	0.		
Block.*Units* stratum					
Treatment	5	0.	0.		
Residual	15	0.	0.		
Total	23	0.			

Tables of means

Variate: Insects0

Grand mean 0.00

Treatment	AgroZ®	AgroZ® Plus
	0.00	0.00
Treatment	GrainPro® Super Grain Bag	PICS bag
	0.00	0.00
Treatment	Shumba Plus®	Untreated
	0.00	0.00

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	*
s.e.d.	0.000

Least significant differences of means (5% level)

Table	Treatment
rep.	4
d.f.	*
l.s.d.	*

Stratum standard errors and coefficients of variation

Variate: Insects0

Stratum	d.f.	s.e.	cv%
Block	3	0.000	0.0
Block.*Units*	15	0.000	0.0

Fisher's protected least significant difference test

Treatment

Warning 2, code UF 2, statement 124 in procedure AMCOMPARISON

Multiple comparisons cannot be calculated for Treatment as its standard errors are zero.

Analysis of variance

Variate: Insects1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3054.5	1018.2	3.24	
Block.*Units* stratum					
Treatment	5	2258.1	451.6	1.44	0.267
Residual	15	4706.4	313.8		
Total	23	10019.0			

Message: the following units have large residuals.

Block 2 *units* 6 51.54 s.e. 14.00

Tables of means

Variate: Insects1

Grand mean 11.20

Treatment	AgroZ®	AgroZ® Plus
	11.03	4.44

Treatment	GrainPro® Super Grain Bag	PICS bag
	9.77	6.46

Treatment	Shumba Plus®	Untreated
	3.47	32.04

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	15
s.e.d.	12.525

Least significant differences of means (5% level)

Table	Treatment
rep.	4
d.f.	15

l.s.d.	26.697

Stratum standard errors and coefficients of variation

Variate: Insects1

Stratum	d.f.	s.e.	cv%
Block	3	13.027	116.3
Block.*Units*	15	17.713	158.1

Fisher's protected least significant difference test

Treatment

Warning 3, code UF 2, statement 159 in procedure AMCOMPARISON

Fisher's protected LSD is not calculated as variance ratio for Treatment is not significant.

Analysis of variance

Variate: Insects2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	1163808.	387936.	5.20	
Block.*Units* stratum					
Treatment	5	735295.	147059.	1.97	0.142
Residual	15	1118861.	74591.		
Total	23	3017964.			

Message: the following units have large residuals.

Block 4 *units* 6 467.91 s.e. 215.91

Tables of means

Variate: Insects2

Grand mean 184.66

Treatment	AgroZ®	AgroZ® Plus
	396.74	6.18
Treatment	GrainPro® Super Grain Bag	PICS bag
	337.73	24.40
Treatment	Shumba Plus®	Untreated
	1.85	341.04

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	15
s.e.d.	193.120

Least significant differences of means (5% level)

Table	Treatment
rep.	4
d.f.	15

l.s.d.	411.626

Stratum standard errors and coefficients of variation

Variate: Insects2

Stratum	d.f.	s.e.	cv%
Block	3	254.275	137.7
Block.*Units*	15	273.113	147.9

Fisher's protected least significant difference test

Treatment

Warning 4, code UF 2, statement 159 in procedure AMCOMPARISON

Fisher's protected LSD is not calculated as variance ratio for Treatment is not significant.

Analysis of variance

Variate: Insects3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	3016.	1005.	0.65	
Block.*Units* stratum					
Treatment	5	39153.	7831.	5.08	0.006
Residual	15	23122.	1541.		
Total	23	65291.			

Message: the following units have large residuals.

Block 2 *units* 3 90.55 s.e. 31.04

Tables of means

Variate: Insects3

Grand mean 37.01

Treatment	AgroZ®	AgroZ® Plus
	59.43	0.25
Treatment	GrainPro® Super Grain Bag	PICS bag
	42.50	6.43
Treatment	Shumba Plus®	Untreated
	1.09	112.37

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	15
s.e.d.	27.762

Least significant differences of means (5% level)

Table	Treatment
rep.	4
d.f.	15

l.s.d. 59.173

Stratum standard errors and coefficients of variation

Variate: Insects3

Stratum	d.f.	s.e.	cv%
Block	3	12.944	35.0
Block.*Units*	15	39.262	106.1

Fisher's protected least significant difference test

Treatment

	Mean
AgroZ® Plus	0.25 a
Shumba Plus®	1.09 ab
PICS bag	6.43 ab
GrainPro® Super Grain Bag	42.50 ab
AgroZ®	59.43 bc
Untreated	112.37 c

Analysis of variance

Variate: Insects4

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	3		928370.	309457.	4.89	
Block.*Units* stratum						
Treatment	5		599393.	119879.	1.89	0.169
Residual	12	(3)	759457.	63288.		
Total	20	(3)	1927548.			

Message: the following units have large residuals.

Block 4 *units* 6   555.38   s.e. 177.89

Tables of means

Variate: Insects4

Grand mean 181.23

Treatment	AgroZ®	AgroZ® Plus
	197.15	2.68
Treatment	GrainPro® Super Grain Bag	PICS bag
	125.16	333.43
Treatment	Shumba Plus®	Untreated
	3.31	425.67

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	177.888

(Not adjusted for missing values)

Least significant differences of means (5% level)

Table	Treatment
rep.	4

d.f.	12
l.s.d.	387.584

(Not adjusted for missing values)

Stratum standard errors and coefficients of variation

Variate: Insects4

Stratum	d.f.	s.e.	cv%
Block	3	227.104	125.3
Block.*Units*	12	251.571	138.8

Fisher's protected least significant difference test

Treatment

Warning 5, code UF 2, statement 159 in procedure AMCOMPARISON

Fisher's protected LSD is not calculated as variance ratio for Treatment is not significant.

Analysis of variance

Variate: Loss0

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.010985	0.003662	0.52	
Block.*Units* stratum					
Treatment	5	0.048772	0.009754	1.38	0.287
Residual	15	0.106026	0.007068		
Total	23	0.165784			

Message: the following units have large residuals.

Block 1 *units* 6	0.13	s.e.	0.07
Block 3 *units* 4	0.14	s.e.	0.07

Tables of means

Variate: Loss0

Grand mean 0.08

Treatment	AgroZ®	AgroZ® Plus
	0.07	0.06
Treatment	GrainPro® Super Grain Bag	PICS bag
	0.10	0.12
Treatment	Shumba Plus®	Untreated
	0.00	0.14

Standard errors of differences of means

Table	Treatment
Rep.	4
d.f.	15
s.e.d.	0.059

Least significant differences of means (5% level)

Table	Treatment
Rep.	4

d.f.	15
l.s.d.	0.127

Stratum standard errors and coefficients of variation

Variate: Loss0

Stratum	d.f.	s.e.	cv%
Block	3	0.025	29.9
Block.*Units*	15	0.084	101.9

Fisher's protected least significant difference test

Treatment

Warning 6, code UF 2, statement 159 in procedure AMCOMPARISON

Fisher's protected LSD is not calculated as variance ratio for Treatment is not significant.

Analysis of variance

Variate: Loss1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.010985	0.003662	0.52	
Block.*Units* stratum					
Treatment	5	0.048772	0.009754	1.38	0.287
Residual	15	0.106026	0.007068		
Total	23	0.165784			

Message: the following units have large residuals.

Block 1 *units* 6	0.13	s.e.	0.07
Block 3 *units* 4	0.14	s.e.	0.07

Tables of means

Variate: Loss1

Grand mean 0.08

Treatment	AgroZ®	AgroZ® Plus
	0.07	0.06
Treatment	GrainPro® Super Grain Bag	PICS bag
	0.10	0.12
Treatment	Shumba Plus®	Untreated
	0.00	0.14

Standard errors of differences of means

Table	Treatment
Rep.	4
d.f.	15
s.e.d.	0.059

Least significant differences of means (5% level)

Table	Treatment
Rep.	4

d.f.	15
l.s.d.	0.127

Stratum standard errors and coefficients of variation

Variate: Loss1

Stratum	d.f.	s.e.	cv%
Block	3	0.025	29.9
Block.*Units*	15	0.084	101.9

Fisher's protected least significant difference test

Treatment

Warning 7, code UF 2, statement 159 in procedure AMCOMPARISON

Fisher's protected LSD is not calculated as variance ratio for Treatment is not significant.

Analysis of variance

Variate: Loss2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	19.617	6.539	2.60	
Block.*Units* stratum					
Treatment	5	18.603	3.721	1.48	0.255
Residual	15	37.736	2.516		
Total	23	75.955			

Message: the following units have large residuals.

Block 4 *units* 6	4.56	s.e.	1.25

Tables of means

Variate: Loss2

Grand mean 0.76

Treatment	AgroZ®	AgroZ® Plus
	0.94	0.08
Treatment	GrainPro® Super Grain Bag	PICS bag
	0.59	0.26
Treatment	Shumba Plus®	Untreated
	0.10	2.62

Standard errors of differences of means

Table	Treatment
Rep.	4
d.f.	15
s.e.d.	1.122

Least significant differences of means (5% level)

Table	Treatment
Rep.	4
d.f.	15

l.s.d.	2.391

Stratum standard errors and coefficients of variation

Variate: Loss2

Stratum	d.f.	s.e.	cv%
Block	3	1.044	136.5
Block.*Units*	15	1.586	207.4

Fisher's protected least significant difference test

Treatment

Warning 8, code UF 2, statement 159 in procedure AMCOMPARISON

Fisher's protected LSD is not calculated as variance ratio for Treatment is not significant.

Analysis of variance

Variate: Loss3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	3	0.017026	0.005675	1.08	
Block.*Units* stratum					
Treatment	5	0.297835	0.059567	11.38	<.001
Residual	15	0.078488	0.005233		
Total	23	0.393350			

Message: the following units have large residuals.

Block 2 *units* 6 -0.12 s.e. 0.06

Tables of means

Variate: Loss3

Grand mean 0.11

Treatment	AgroZ®	AgroZ® Plus
	0.13	0.03

Treatment	GrainPro® Super Grain Bag	PICS bag
	0.08	0.04

Treatment	Shumba Plus®	Untreated
	0.02	0.34

Standard errors of differences of means

Table	Treatment
Rep.	4
d.f.	15
s.e.d.	0.051

Least significant differences of means (5% level)

Table	Treatment
Rep.	4
d.f.	15

l.s.d. 0.109

Stratum standard errors and coefficients of variation

Variate: Loss3

Stratum	d.f.	s.e.	cv%
Block	3	0.031	28.8
Block.*Units*	15	0.072	67.8

Fisher's protected least significant difference test

Treatment

	Mean
Shumba Plus®	0.0165 a
AgroZ® Plus	0.0294 ab
PICS bag	0.0407 ab
GrainPro® Super Grain Bag	0.0837 ab
AgroZ®	0.1285 b
Untreated	0.3412 c

Analysis of variance

Variate: Loss4

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	3		33.988	11.329	1.60	
Block.*Units* stratum						
Treatment	5		624.726	124.945	17.67	<.001
Residual	12	(3)	84.863	7.072		
Total	20	(3)	740.753			

Tables of means

Variate: Loss4

Grand mean 3.91

Treatment	AgroZ®	AgroZ® Plus
	2.27	0.08
Treatment	GrainPro® Super Grain Bag	PICS bag
	3.57	2.44
Treatment	Shumba Plus®	Untreated
	0.11	14.96

Standard errors of differences of means

Table	Treatment
Rep.	4
d.f.	12
s.e.d.	1.880

(Not adjusted for missing values)

Least significant differences of means (5% level)

Table	Treatment
Rep.	4
d.f.	12
l.s.d.	4.097

(Not adjusted for missing values)

Stratum standard errors and coefficients of variation

Variate: Loss4

Stratum	D.F.	s.e.	cv%
Block	3	1.374	35.2
Block.*Units*	12	2.659	68.1

Fisher's protected least significant difference test

Treatment

	Mean
AgroZ® Plus	0.082 a
Shumba Plus®	0.109 a
AgroZ®	2.269 a
PICS bag	2.442 a
GrainPro® Super Grain Bag	3.571 a
Untreated	14.961 b