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# Pit silos require hermeticity to serve as an alternative low cost storage facility for maize grain by smallholder farmers

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## Abstract

Improved grain storage is important in reducing postharvest losses and ensuring food security particularly among smallholder farming communities. In this study, a survey was carried out to establish grain storage practices and farmer perceptions among smallholder communities using 60 farmers in Shurugwi District, Zimbabwe. This was followed by a pilot scale study to test the effectiveness of the pit silo as a low-cost storage system for resource-constrained smallholder farmers. Four storage systems (pit silo, hermetic bag, insecticide-treated polypropylene bag and untreated polypropylene bag) were tested at Chinhoyi University farm, Zimbabwe, from December 2017 to May 2018, then for the same period in 2018 to 2019, using a completely randomised design replicated four times. Survey results showed that 96% of the farmers stored their maize grain in unimproved facilities. Most farmers (90%) stored their grain harvests for less than 12 months. Grain that was stored in pit silos contained the highest moisture (12.7-13.8%) while that stored in hermetic and untreated polypropylene bag had the lowest moisture content (8.5-9.7%). Pit silos had higher insect pest infestation than hermetic and insecticide-treated polypropylene bags but had as much as three times fewer insects than untreated polypropylene bags. The highest (30%) and lowest (16%) grain weight losses were recorded under pit silo and hermetic bag storage, respectively. Germination percentage was also least in pit silo and greatest in hermetic bag storage. Pit silo stored grain contained higher concentrations of aflatoxins AFB1 (24.8 ppb) and AFG1 (6.4 ppb) relative to hermetic and untreated bag storage (0-0.8 ppb). The results of this study suggest that whilst pit silos perform better than unimproved systems such as untreated bags, further design work is required for it to match other efficient systems like the hermetic bag.



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**Key Words:** Pit silo, Hermetic, Grain storage, Weight loss, Smallholder farmers

## 1. Introduction

Maize (*Zea mays* L.), a staple food crop in Zimbabwe and other countries, is mainly produced seasonally, usually during one harvest and is consumed continuously. In most cases, production of the crop is frequently depressed due to abiotic and biotic constraints notably drought, floods, and pests attack. Damage and loss due to storage pests are among the major challenges faced by maize grain handlers in most parts of the world (Food and Agricultural Organisation, 2014). Storage losses are most severe in developing countries including sub-Saharan Africa in general, and Zimbabwe in particular, with such losses reaching as much as 25% in a single year (Tefera et al., 2011). Efficient grain storage therefore becomes a critical factor in both developed and developing countries especially those that subsist on maize, in securing food security within their nations and beyond (FAO, 2014). Apart from protection against pests, efficient storage should also minimise the risk of stored product quality loss including loss of viability and development of fungi that produce mycotoxins. Contamination of foods and feeds by mycotoxins has recently gained much attention worldwide due to its adverse effects on human and animal health, and consequent national economic implications. Richard and Abbas (2008) noted that ingestion of higher doses of aflatoxin can result in acute aflatoxicosis, which manifests as hepatotoxicity or in severe cases, fulminant liver failure.

Evidence shows that for a very long time maize grain has been stored in diverse storage systems for the provision of food in times of need (Olakojo and Akinlosotu, 2004). These storage systems can be above or below ground, and including granaries, bags, cribs, baskets, pots, ordinary room, silos and many others. Underground storage is a traditional method that can yield good results in controlling insects and other aerobic organisms in storage if hermetic conditions can be attained and maintained in the system. However, most smallholder farmers in sub-Saharan Africa frequently open their storage facilities to withdraw grain for household consumption, making it difficult to maintain hermetic conditions in these facilities. Pit silos are among some underground storage facilities that have been in use for many years in most parts of the world, particularly in the Mediterranean, Middle East, North and West Africa, India, Turkey, Sahelian countries and Southern Africa (Patty, 1927; Gilman and Boxall, 1974). The aim of underground storage was mainly for providing safe food reserves for prolonged periods especially in politically unstable countries. Underground storage is one traditional method which is widely practised with storage of different capacities varying from one to five tonnes (FAO, 2014). The use of pit silos has spread, with a range of developed systems from simple pits dug and having the products covered with soil to well-constructed pits lined with plastic and/or cement. The commonly used pit silo is cylindrical in form like a conventional tower silo with a V-shaped base and is known as a hopper bottom bin.

The pit silo has been shown to be an effective storage system, for example in Argentina; grain that was loaded into silos at 12-13% moisture content was stored for two to three years with negligible loss (Hyde et al., 1973). In China, pit silos were adopted mainly because of an expanded production which called for additional, permanent storage structures that offered protection of grain from deterioration, with an open-ended storage time (International Agency for Research on Cancer, 2015). In the case of China, nitrogen is continuously pumped into these underground silos in order to create modified atmospheres hence preventing spoilage while enabling long-term storage of grain. Pit silo storage is not a new technology worldwide, with some early Iron Age food storage pits having been observed in kraals located in the cattle byre (Huffman, 2004). Undoubtedly, the construction of underground storage facilities may be laborious but the benefits of long storage periods outweigh these high initial costs in the long run. Despite the overwhelming evidence of its advantages over some widely used grain storage systems, it is not clear why underground storage seems have been abandoned especially after the *Mfecane* wars of South Africa in the later part of the second millennium AD. Overall, this study sought to determine the status of maize grain storage practices among smallholder farming communities in Zimbabwe and evaluate the effectiveness of the pit silo in reducing damage and loss while maintaining the quality of stored maize grain.

## 2. Materials and methods

### 2.1 Study site

The study consisted of two approaches, (1) a field survey to determine the status of grain storages practices among farmers in a smallholder farming set up in Zimbabwe, and (2) a pilot scale experiment to determine the effect of selected grain storage systems on damage and weight loss of maize grain, insect pest infestation and quality of stored maize grain at Chinhoyi University of Technology (CUT) Experimental Farm, Chinhoyi, Zimbabwe. The field survey was conducted in Shurugwi District during the months June and July in 2017. Shurugwi has a subtropical climate, with the summer season stretching from November to early April and winter from May to early August. The district is in Natural Farming Region III according to Zimbabwe's agro-ecological classification system and receives an average annual rainfall of about 650-800 mm during summer. Mean maximum temperature for the district is 37 ºC, dropping to about 0-6 ºC in winter (Ministry of Water Resources Development, 2004). The dominant economic activities in Shurugwi District are subsistence agriculture and mining (Madebwe and Madebwe, 2005). The survey sought to provide information of what the farmers were experiencing during storage of their maize grain in their respective areas. The pilot scale experiment was carried out at CUT's Hunyani Farm, Chinhoyi, Zimbabwe, from December 2017 to May 2018 and then December 2018 to May 2019. Hunyani Farm is in Zimbabwe's Natural Farming Region IIb which is characterized by mean annual rainfall of about 800 mm. The site's average temperature in the summer is 24 °C (average daily high peaks at 30 °C and average daily low is around 18 °C), and average winter temperature is 16.5 °C (average daily high around 23 °C and average daily low peaks at 10 °C).

### 2.2 Research design and procedures

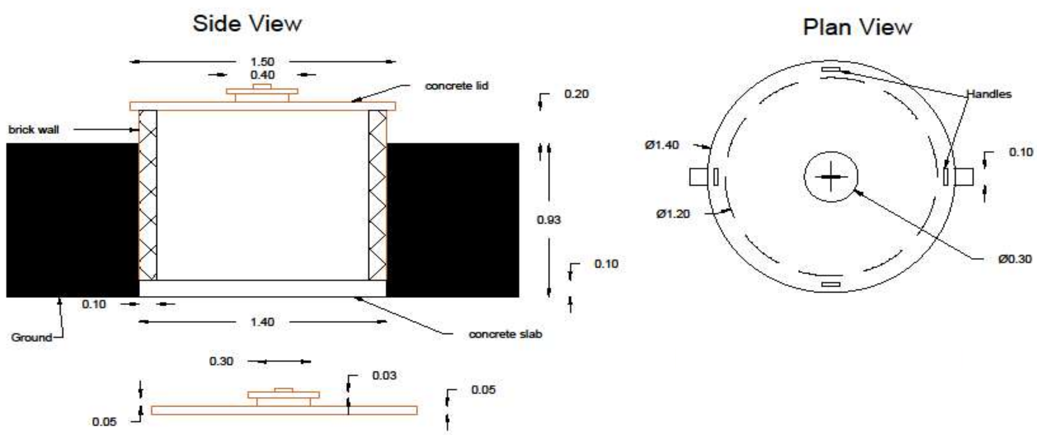
#### *2.2.1 Household survey*

Information about existing storage infrastructure and main problems encountered by farmers was collected using a household questionnaire and field observations. The questionnaire was administered to 60 purposively selected smallholder farmers, where information on crops grown, harvesting, processing and storage systems used by the farmers and the challenges they were facing was recorded.

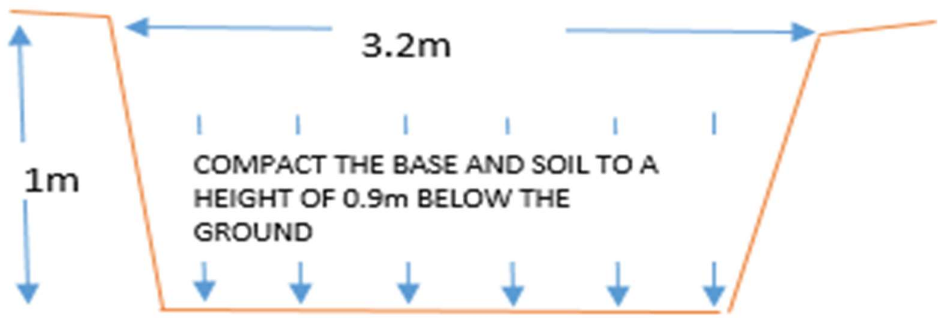
#### *2.2.2 Pilot scale experiment*

A pilot scale experiment was conducted over two seasons, following a completely randomised design with four treatments during the first season, three treatments during the second season and four replications in each season. The treatments during the 2017-2018 storage season were: (1) untreated hermetic grain storage in pit silo, (2) untreated hermetic grain storage in hermetic grain bag, (3) untreated polypropylene bag to emulate normal smallholder farmer storage system) and (4) insecticide-treated polypropylene bag storage. The insecticide-treated polypropylene bag was treated with Actellic Gold® dust (active ingredients pirimiphos-methyl 16 g $kg^{-1}$ + thiamethoxam 3.6 g $kg^{-1}$) at a rate of 500 g $ton^{-1}$. In the 2018/2019 study, the treated bag storage system was excluded. The hermetic and polypropylene bags were each filled with 50 kg of maize grain and stored in the warehouse under ambient conditions, just next to the pit silos at the CUT Experimental Farm. Pit silos were constructed with the objective of achieving hermeticity within so as to control insect pest infestation without use of pesticides (Figure 1).

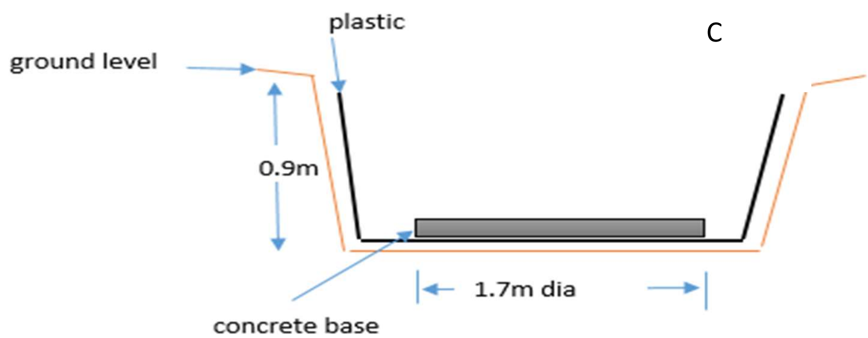
A



B


3.2m
1m
COMPACT THE BASE AND SOIL TO A HEIGHT OF 0.9m BELOW THE GROUND

C


plastic
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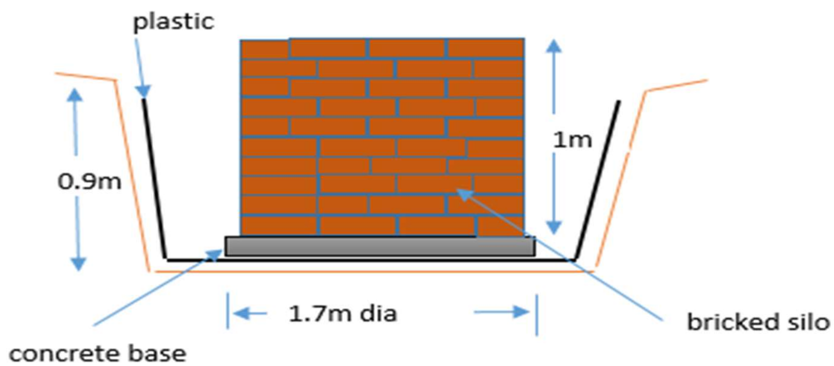
D


plastic
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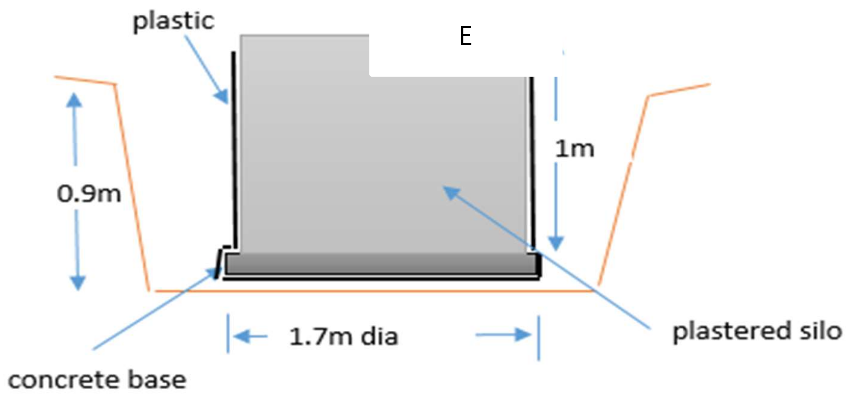
concrete base



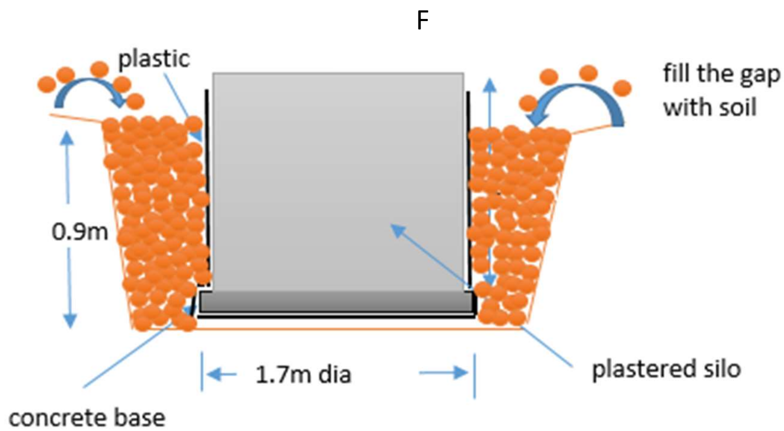




Figure 1: Diagrammatic illustration of the pit silo that was used in the experiment at Chinhoyi University of Technology Experimental Farm: (A) side and plan views, (B) cross sectional view of pit before construction, (C) cross sectional view of pit after plastic lining and cast base, (D) cross sectional view of constructed silo before plastering, (E) cross sectional view of constructed silo after plastering and (F) cross sectional view of silo after back filling. All dimensions are in metres.

All the maize grain used in the study was obtained from a single harvest at CUT farm and was refrigerated at 4 ºC for ninety days to disinfect and disinfest it in order to start the experiment with clean grain. Disinfestations involved treatment of maize grain using aluminium phosphine tablets at a rate of 10 tablets ton$^{-1}$ under an air-tight fumigation tent over a period of 14 days followed by removal of the tent to ventilate the grain for six hours outside the storeroom. The maize grain was then sieved to remove dead insects, chaff and some debris using universal laboratory test sieves of apertures 5.0 mm and 10.0 mm. Only clean grain with no visible signs of physical damage was used in the study. Prior to placement into the respective experimental units, 100-g samples of grain were withdrawn and tested for moisture content, insect pest infestation, grain weight and loss, viability and visual observations on colour and odour of the grain to provide baseline data. During the 180-day experimental period, the grain was checked after every 60 days.

Grain moisture content, insect pest infestation, grain quality (viability and aflatoxin contamination) as well as grain damage and weight loss were measured at the end of the pilot scale experiments. Grain viability was determined in accordance with International Seed Testing Association guidelines (International Seed Testing Association, 2006). One hundred (100) maize grains from each treatment and replicated four time were placed on moist cotton wool in petri-dishes and incubated for seven days at ambient conditions in the laboratory, ensuring that the cotton wool remained moist for the entire testing period. The number of grains that germinated were counted and recorded and then used to determine germination percentage. Detecting hidden infestation was done using the acid fuschin staining method. Maize grain weighing 40 g were randomly drawn from each experimental unit and then immersed in water for 60 seconds, and then in acid fuschin for 45 seconds. Thereafter, the sample was destained in water for 30 seconds and then examined under a dissecting microscope to detect weevil infestation on the gain. Percentage grain infestation was then determined.

Weight loss was determined using the Thousand Grain Mass method (Alonso-Amelot and Avila-Núñez, 2011). This method involves determining the number and total weight of grain in a particular sample. After winnowing and sieving of the maize grain in order to remove dead insects, chaff and debris, a sample of maize grain was randomly scooped from each experimental unit using a 250 ml volume beaker for determination of the 1000-grain weight as well as grain weight loss This procedure was done for both damaged and undamaged samples in order to determine grain weight loss. For each treatment, weighing and counting was done three times.

Determination of grain moisture content was done in the laboratory using a G-7 grain moisture meter version 1:1 (Delmhorst Instrument Co). At the end of the storage period, grain from all the three storage systems was tested for the presence of aflatoxins using the semi quantitative method described by (Coomes et al., 1965).

### 2.3 Data analysis

Survey data, mainly qualitative, were analysed using the Statistical Package for the Social Sciences (SPSS) version 16.0 (Corp., 2017). Quantitative data from the pilot scale experiment namely weight loss, percentage of weevil-infested grain and moisture content were subjected to analysis of variance using the GENSTAT Discovery Edition (VSN-International, 2011). Where statistical significance was detected, treatment means were separated using standard error of difference (SED) at 5% level.

## 1. Results

### 3.1 Field survey

Survey results indicated that most smallholder farmers in Shurugwi stored their maize grain in unimproved structures (Table 1). Out of the 60 farmers who were interviewed, 50% stored their maize grain in ordinary rooms whilst 28.4% stored their maize grain in traditional and standard granaries. A very small proportion (1.7 % each) of the farmers stored their maize grain in bins and metal silos. Traditional, standard and improved storages were also among the other storage facilities used for grain storage by farmers.

Table 1: Maize storage structures commonly used by smallholder farmers in Shurugwi District.

| Storage system | Frequency | Percent |
|---|---|---|
| Ordinary room | 30 | 50.0 |
| Traditional granary | 7 | 11.7 |
| Standard granary (brick with foundation) | 10 | 16.7 |
| Improved granary (brick raised off ground and concrete) | 11 | 18.3 |
| Bin | 1 | 1.7 |
| Metal silo | 1 | 1.7 |
| Total | 60 | 100.0 |

Survey results also indicated that almost half (48.3%) of the interviewees stored moderate amounts of their grain on-farm whilst 41.7% and only 10% stored minimum quantities and significant quantities of maize grain, respectively (Table 2). Further, 30% of the smallholder farmers in Shurugwi District claimed that they experienced significant losses in storage whilst 63.3% recorded minimum losses (Table 2).

Table 2: Maize grain stored on-farm and the storage losses experienced by smallholder farmers in Shurugwi District.

| Magnitude | Quantity of grain stored | | Losses in storage | |
|---|---|---|---|---|
| | Frequency | Percent | Frequency | Percent |
| Minimum | 25 | 41.7 | 38 | 63.3 |
| Moderate | 29 | 48.3 | 4 | 6.7 |
| Significant | 6 | 10 | 18 | 30 |
| Total | 60 | | 60 | |

Generally, the majority (90%) of the farmers who were interviewed did not store their maize grain for more than 12 months (Table 3). Out of these, some 1.7% stored their maize grain for less than 5 months whilst 36.7% stored their grain for 5-7 months. Only 10% stored their maize grain for over a year.

Table 3: Duration of storage of maize grain by smallholder farmers in Shurugwi District.

| Duration in storage | Frequency | Percent |
|---|---|---|
| <5 months | 1 | 1.7 |
| 5-7 months | 22 | 36.7 |
| 8-12 months | 31 | 51.7 |
| >12 months | 6 | 10.0 |
| Total | 60 | 100.0 |

The majority (90%) of farmers interviewed admitted that they noted some changes in maize grain quality during storage leading to losses (Table 4). Some 68.3% of the interviewed farmers were not aware of the health risks that were associated with the consumption of contaminated maize grain whilst 31.7% indicated that they were aware of the health risks associated with consuming contaminated grain. When asked whether or not they were aware of the existence of alternative storage facilities for maize grain, 38.3% of the respondents expressed ignorance about such facilities while the rest testified that they had heard about such facilities.

Table 4: Smallholder farmers' knowledge of the existence of changes noted in maize grain during storage and knowledge of health risks associated with consumption of contaminated maize grain.

| | Changes noted in storage | | Knowledge of health risks | |
|---|---|---|---|---|
| Response | Frequency | Percent | Frequency | Percent |
| Yes | 54 | 90 | 19 | 31. 7 |
| No | 6 | 10 | 41 | 68.3 |
| Total | 60 | | 60 | |

### 3.2 Pilot scale experiment

*3.2.1 Grain moisture*

There was evidence of significant effects (P < 0.01) of storage system on the moisture content of stored maize grain in both storage periods (Table 6). In both storage periods, grain that was stored in pit silos had the highest moisture content (12.7% and 13.8% for 2017-2018 and 2018-2019, respectively) while that stored in hermetic (2017-2018) and untreated polypropylene bags (2018-2019) had the lowest moisture content (9.7% and 8.5%, respectively). Moisture content in grain stored in hermetic bags progressively declined with time while that stored in the pit silo and untreated polypropylene bags progressively increased (Figure 2). On the other hand, for hermetic and treated polypropylene bag storage, grain moisture content significantly (P < 0.05) declined with increased duration of storage. However, there was no evidence of changes in grain moisture content with increasing duration of storage when grain was stored in treated polypropylene bags.

Table 5: Effects of storage system on moisture content of maize grain stored over a period of 180 days in 2017-2018 and 2018-2019.

| Storage system | Grain moisture content (%) | |
|---|---|---|
| | 2017-2018 | 2018-2019 |
| Untreated polypropylene bag | 11.74 [b] | 8.50 [c] |
| Hermetic bag | 9.66 [d] | 11.15 [b] |
| Pit silos | 12.68 [a] | 13.75 [a] |
| Treated polypropylene bag | 10.72 [c] | - |
| | | |
| P value | <0.001 | 0.001 |
| Standard error of difference | 0.311 | 0.486 |

Means within a column followed by the same superscript letter are not significantly different at P ≤ 0.05

***Pest infestation***

There were significant differences (P < 0.05) in grain infestation by insects among the different storage systems during 2017-18 and 2018-19 (Table 7). In 2018-2019, the percentage of insect pest-damaged grain (hidden infestation) in the pit silo was higher than in both hermetic bag storage and treated bag storage but lower than untreated bag storage. In 2018-2019, the pit silo exhibited higher hidden pest infestation (41%) compared to polypropylene and hermetic bag storage where infestation was zero.

Table 6: Effects of storage system on hidden insect infestation of maize grain stored over a period of 180 days in 2017-2018 and 2018-2019.

| Storage system | Insect pest infested grain (%) | |
|---|---|---|
| | 2017-2018 | 2018-2019 |
| Untreated polypropylene bag | 21.56 [a] | 0.00 [b] |
| Hermetic bag | 4.51 [d] | 0.00 [b] |
| Pit silos | 7.89 [b] | 41.00 [a] |
| Treated polypropylene bag | 5.63 [c] | - |
| P value | 0.001 | 0.002 |
| Standard error of difference | 0.266 | 7.000 |

Means within a column followed by the same superscript letter are not significantly different at $P \leq 0.05$

*Grain viability and quality*

Grain viability, measured in terms of percentage of germinable kernels at the end of the storage period, varied significantly ($P < 0.05$) across the four storage systems (Table 8). Grain viability was lower in pit silo-stored grain (22.8% and 1.8% in 2017-2018 and 2018-2019, respectively) compared to all other storage systems (43.8-87%). Analysis of grain at the end of the 2018-2019 study period revealed that some aflatoxins (AFB1, AFB2 and AFG1) were present in the pit silo (Table 9). Grain that was stored in the pit silo contained significantly higher ($P < 0.05$) concentrations of aflatoxins AFB1 (24.8 ppb) and AFG1 (6.4 ppb) relative to hermetic and untreated bag storage. Except for AFB1 which was present in the untreated polypropylene bag (0.8 ppb) and absent in the hermetic bag, all other aflatoxins were completely absent in these two bag storage systems.

Table 7: Effects of storage system on viability of maize grain stored over a period of 180 days in 2017-2018 and 2018-2019.

| Storage system | Germinable maize grain (%) | |
|---|---|---|
| | 2017/2018 | 2018/2019 |
| Untreated polypropylene bag | 43.8 [a] | 84.5 [a] |
| Hermetic bag | 70.0 [a] | 87.3 [a] |
| Pit silos | 22.8 [c] | 1.8 [b] |
| Treated polypropylene bag | 59.5 [b] | - |
| P value | 0.011 | <0.001 |
| Standard error of difference | 11.17 | 2.61 |

Means within a column followed by the same superscript letter are not significantly different at $P \leq 0.05$

Table 8: Effects of storage system on aflatoxin contamination of maize grain stored over a period of 180 days in 2017-2018 and 2018-2019.

| Storage system | AFB1 | AFB2 | AFG1 | AFG2 |
|---|---|---|---|---|
| Poly grain bags | 0.8 [b] | 0.0 | 0.0 [b] | 0 |
| Hermetic bags | 0.0 [c] | 0.0 | 0.0 [b] | 0 |
| Pit silos | 24.8 [a] | 0.38 | 6.4 [a] | 0 |
| | | | | |
| P value | 0.010 | 0.422 | 0.013 | 0 |
| Standard error of difference | 6.05 | 0.306 | 3.10 | 0 |

Means within a column followed by the same superscript letter are not significantly different at $P \leq 0.05$

*3.2.3 Quantitative losses*

There was evidence of significant effects ($P < 0.001$) of storage system on maize grain weight loss during both 2017-2018 and 2018-2029 testing periods (Table 10). Grain weight loss was higher (23.1 and 24.3%) in 2017-2018 and 2018-2019, respectively in the pit silo relative to both hermetic and polypropylene bag storage (0.2-0.5%). The results of this study revealed that grain weight loss during the duration of storage varied with the type of storage system (Figure 5). For hermetic bag storage, weight loss was consistently lowest (10.8-16.9 %) throughout the storage period relative to pit silo (10.5-30.3%), untreated polypropylene bag (11.9-33.1%) and treated polypropylene bag (10.9-29.3%) storage. It is noteworthy that grain weight loss appeared to be rapid in the pit silo, reaching a maximum within the first 120 days of storage.

Table 9: Effects of storage system on weight loss of maize grain stored over a period of 180 days in 2017-2018 and 2018-2019.

| Storage system | Grain weight loss (%) | |
|---|---|---|
| | 2017/2018 | 2018/2019 |
| Untreated polypropylene bag | 21.67 [a] | 0.50 [a] |
| Hermetic bag | 13.29 [b] | -0.20 [b] |
| Pit silos | 23.09 [a] | 24.30 [a] |
| Treated polypropylene bag | 20.85 [a] | - |
| | | |
| P value | 0.004 | 0.001 |
| Standard error of difference | 2.697 | 2.58 |

Means with a column followed by the same superscript letter are not significantly different at $P \leq 0.05$

## 4. Discussion

*4.1 Smallholder farmer perception and status of maize grain storage practices*

The results of this study indicated that the majority of the interviewed farmers had unimproved storage facilities, mainly untreated polypropylene bags stored in ordinary rooms. This agrees with (Fox, 2013) who noted that most communities in developing countries have poor storage infrastructure and therefore, experience high losses of stored maize grain. This is probably due to the constrained financial resources typical of these smallholder farmers, causing the farmers to opt for cheap but insecure storage systems. Poor storage structures by farmers could also be linked to the fact that some farmers lack proper knowledge on the benefits of storing their harvests in improved storage facilities (Bala et al., 2010). The present study also revealed that nearly half of the interviewees stored minimum quantities while only 10% stored significant quantities of their grain harvests. This is most likely related to poor storage facilities which were found to be in common use by most household in the study area, discouraging farmers from storing large quantities of grain after harvesting. It then follows that farmers most probably avoided retaining large quantities of grain as they would inevitably suffer high losses due to inefficient storage facilities. This scenario is most likely to put the farmers at the mercy of some middlemen who would take advantage of farmers' desperation to quickly offload their grain harvest to avoid storage losses. It can therefore, be suggested that there is need for smallholder farmers whose livelihoods largely depend on their single annual harvests to adopt improved grain storage facilities as a safeguard against poor crop harvests caused by unreliable weather conditions and also huge grain losses caused by poor storage systems (FAO, 2014).

About a third of the farmers indicated that they experienced significant losses of their stored grain whilst the rest suggested that their losses ranged from minimum to moderate. These losses are most likely due to storage insect pest attack, which have previously been reported to be in the range of 30 to 40% in developing countries (Kumar and Kalita, 2017). However, it has been shown that losses reported in literature could be lower than what is actually experienced in traditional storage structures, sometimes reaching 60-100% for crops such as maize grain (Costa, 2014). It is important to note that in the present study, the majority of the farmers stored their grain for periods less than 12 months. Ideally, farmers would not need to store grain for much more than a year because the new harvest would produce new grain. However, avoiding storage of grain for much longer periods may be a strategy by these farmers to avoid losses that would be associated with long term storage. The longer the period in storage, the more vulnerable the maize grain becomes to storage pests attack (World-Bank, 2011). It can be suggested that the reasons for farmers to store their harvests for shorter periods as showed by the results of this present study may be related to the use of unimproved storage structures among smallholder farming communities. Comment: In this 2$^{nd}$ paragraph, some of the reasons being advanced to explain the tendency by farmers to store their harvests for shorter periods of time have already been alluded to in the first paragraph!!

Only 10% of the interviewees claimed that they did not see any changes in their maize grain during storage. On the other hand, survey results indicated that over 60% of the farmers who were interviewed lacked knowledge on the health risks associated with consumption of contaminated maize grain. Only 31% claimed knowledge about consuming contaminated grain. It can therefore, be suggested that there is need to increase awareness to farmers about the adverse implications of continued consumption of stale grain particularly that infected with aflatoxins (Kang'ethe et al., 2017). Both pre- and post-harvest periods can be targeted to address issues of aflatoxins and fumonisin contamination to guard against both plant infection and grain contamination (Munkvold, 2003).

### *4.2 Effects of storage systems on maize grain*

This present study showed that storage of maize grain in the pit silo over a period of 180 days resulted in rapid elevation of grain moisture content while the moisture content of grain that was stored in hermetic bags progressively declined with duration of storage. Interestingly, with regards to grain moisture content, the pit silo-stored maize grain accumulated more moisture than the farmers' normal practice of storing grain in untreated polypropylene bags. The increase in grain moisture content under pit silo storage suggest that the silo was not air-tight and moisture was probably introduced into the grain through exposure to high relative humidity in the sampling environment. Similar results were observed by (Navarro and Donahaye, 1993) although they could not quantify the losses. However, this contradicts a number of authors who claim that pit silos have worked perfectly well in maize grain storage particularly in the Sahelien countries (Gilman and Boxall, 1974; Currid and Navon, 1989). This could be because of the semi-arid climate that is associated with the region between the Middle East and sub-Saharan Africa. The type of soils where the pits were constructed is gravelly and rocky underneath hence they allow water to freely flow underground. Our observations were that despite all the waterproofing measures done during pit construction; moisture still found its way from the soil into the pits. More so, the issue of water gradient exacerbated the situation as the pits were constructed at a low-lying site hence moisture could have easily collected in them. Based on the findings of the specific study, it can be suggested that the current pit silo design will need alteration with particular attention on increasing the waterproofing features. The hermetic storage system is becoming a most preferred option by many farmers for storing cereals, pulses and other crops because of its effectiveness in reducing storage losses to less than 1% (Villers et al., 2010). In the untreated polypropylene bags, which represented normal smallholder farmer practice, grain moisture content rose slightly with an increase in the number of days in storage probably due to insect pests' activity initially.

Results of maize seed germination tests revealed that seed viability was reduced by storage in the pit silo compared to all other storage systems. Therefore, it was important to determine the viability of seed that was stored under different systems. Based on the seed viability test results from the present study, reduction in seed viability after 180 days of storage, especially in pit silo storage implies that such seed cannot be relied upon for planting.

When maize grain was analysed at the end of the 2018/2019 study period, it was observed that some aflatoxins accumulated in the pit silo with AFB1 and AFG1 occurring at concentrations of 24.8 ppb and 6.4 ppb, respectively. These aflatoxins were particularly higher in pit silo stored maize grain, were above the Codex Alimentarius and EU minimum standards and grain as well as its byproducts that contain these levels of aflatoxins are not acceptable for both human and livestock consumption (FAO, 1995). The results of this study suggest that the pit silo was not hermetic as evidenced by higher aflatoxin accumulation, pest infestation and grain moisture content relative to other storage systems. Lack of hermeticity allows moisture migration due to convection currents which creates hot spots at the centre of the grain, and also development of aerobic conditions in the grain mass and this ultimately results in spoilage. In fact, moulds require high moisture content to produce aflatoxins (equilibrium relative humidity >85%), implying that the grain moisture content should be >16.6% (at 25°C). Insect activity increases moisture content and also promotes mould activity. While the majority of farmers in Shurugwi professed ignorance about the risks associated with the consumption of contaminated grain, the results from the present study suggest that there is need to raise awareness, particularly about the need to use grain storage systems that prevent aflatoxin contamination. The results of this study suggest that without further improvement particularly to make it hermetic, an inevitable limitation of the pit silo is its proneness to aflatoxin contamination. Evidence of re-infestation, coupled with elevated moisture in the pit silo probably created favourable conditions for mycotoxin accumulation.

Performance of the pit silo in terms of preventing insect pest infestation was inconsistent, with lower percentage hidden infestation in 2017-2018, and higher infestation during 2018-2019 relative to normal farmer practice (untreated polypropylene bag). The results of 2017-2018 were more revealing, showing a general increase in insect infestation with increased duration of storage and being most rapid in the untreated bag storage which reached a peak of 30% at the end of the study period. This may be attributed to the effect of re-infestation and multiplication of insect pests within storage. In hermetic bag storage, insect pest infestation was low as the airtight environment creates a self-inhibitory environment over the storage period. However, it appears the pit silo storage failed to create a hermetic environment and allowed re-infestation by migrating populations of storage insect pest infestation of the stored maize grain. For underground pit silos, observations through visual assessment of the stored grain showed evidence of changes related to insect infestation and moulding as suggested by (Soujanya et al., 2013). Changes mainly noted were discolouration and holing of the maize kernels. In the treated polypropylene bag, increased levels of insect pest infestation with duration of storage may be explainable by the fact that the grain protectant that was used to treat the bags degraded with time and thus allowed for insect pest re-infestation of the grain. In hermetic bag storage, maize grain infestation was greatly suppressed, and this may be attributed to the airtight environment within the bag. The hermetic storage bag is gaining popularity since it eliminates use of pesticides in storage, among other advantages (Okolo et al., 2017, Alemu et al., 2021).

Maize grain weight loss was lower (10.8-16.9%) under hermetic bag storage and higher (10.5-33.1%) in all other storage systems, being most rapid in the pit silo. These observations further suggest that in its current form, the pit silo is not an effective system of maize grain storage. These losses may be related to the failed by the pit silo and polypropylene bag to prevent infestation of stored grain by insect pest and therefore subjecting it to damage and loss. Generally, grain weight loss increased across all treatments as the days in storage increased from 60 to 180 days. The World-Bank (2011) reported that after six months of storage, maize grain was damaged in the storage structures by insect pests especially in traditional granaries. This probably supports the reason why the majority (90%) of the interviewees, due to poor storage facilities, stored their maize grain for periods less than a year, leaving most of households being prone to food insecurity. Storage is a critical stage of the maize supply chain as several studies have reported maximum losses at this stage (Bala et al., 2010, Aulakh et al., 2013, Majumder et al., 2016). Notably, storage pests have been reported to constitute a larger share of the maize grain losses during storage, ranging from as low as 15% to a mean maximum of 40% (Boxall, 2002, Tapondjou et al., 2002). Surprisingly, a smaller proportion of the interviewees (37%) claimed that they experienced significant losses in storage whilst 63% claimed minimum losses. Even though 61.7% expressed great need for better storage facilities their major hindrance is inability to acquire the resources due to high initial costs. General Comment: The discussion needed to flow chronologically according to the reported results. In this case, the same survey results are being discussed over and over again.

## 5. Recommendations

Based on the results of this study, the pit silo, while being a promising alternative and is regarded as a cheaper and efficient storage facility, requires some major design improvements to make it hermetic and prevent moisture migration into the grain, pest infestation and aflatoxin accumulation. Further studies should also investigate species-specific infestations of insect pests in the pit silo.

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