Grain Postharvest Loss Prevention Project (GPLP)

ACTION RESEARCH

On-Farm Comparison of Different Maize Postharvest Storage Technologies in Central Tanzania

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Abbreviations and Acronyms

APHLIS	African Postharvest Losses Information System
ASARECA	Association for Strengthening Agricultural, Research in Eastern and Central Africa
BD	Bulk density
DWL	Dry Weight Loss
EC-JRC	European Commission’s Joint Research Center
FAO	Food and Agriculture Organization
GAC	Grain Analysis Computer (Trademark of DICKEY-john company, USA)
GCW	Grain Count and Weight
GPLP	Grain postharvest loss prevention project
HDPE	High Density Polyethylene
HSS	Hermetic Storage Systems
IITA	International Institute of Tropical Agriculture
LGB	Larger Grain Borer
LSV	Loss of Seed Viability
MSVWR	Modified Standard Volume/Weight Ratio
NGO	Non-Governmental Organization
NRI	Natural Resources Institute
PDGWL	Percent Damaged Grains Converted to Weight Loss
PHL	Post-harvest losses
PICS	Purdue Improved Crop Storage (hermetic storage bag)

PP without treatment – Polypropylene without insecticide treatment

PHL	Postharvest losses
PVC	Polyvinyl Chloride
SDC	Swiss Agency for Development and Cooperation
SSA	Sub-Saharan Africa
TGM	Total Grain Mass
UWL	Uncorrelated Weight Loss

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Abstract

The effectiveness of different storage technologies for maize under conditions of smallholder farmers were tested in Dodoma and Manyara regions of central Tanzania. Seven storage methods including the use of different hermetic storage containers (metal silos and plastic barrels with and without fumigation with phostoxin, PICS bags) and non-hermetic polypropylene (PP) bags combined with insecticide treatment (ZeroFly® bags with yarn treated with Deltamethrin and maize grain treated with Actellic Super) were tested. The storage methods were compared with traditional storage of untreated maize in polypropylene bags (PP bags). The study was conducted in two villages per region and it involved five farmers per village (total 20 replications). The dominant insect pests identified in the stored grains were the Maize weevil (Sitophilus zeamais) and the Red flour beetle (Tribolium castaneum). The hermetic storage and use of insecticides were effective in controlling insect population during storage. However, the insecticide-treatment of polypropylene yarn (ZeroFly®) did not control insect population under farmers' management. Grain damage and weight loss of maize stored in ZeroFly® bags and untreated maize stored in PP bags were significantly higher ($p<0.05$) at 30-week storage than grains in other storage treatments. Insect damage accounted for the largest portion (52-86%) of grain damage observed in all the storage treatments, and grain damage was more strongly correlated with S. zeamais population ($r=0.63$; $p<0.0001$) than T. castaneum population ($r=0.53$; $p<0.0001$). In conclusion, all the hermetic storage techniques tested were effective in preventing maize damage by insects for a storage period of 30 weeks (about seven months) and can be recommended. There was no significant difference between hermetic treatments (with or without phostoxin fumigation). Hence, hermetic storage alone can be recommended to farmers provided proper application of technologies is ensured i.e. metal silo, and plastic barrel are hermetic, and sound handling and management of the technologies by farmers i.e. proper placement and hermetic sealing of lids of metal silo and plastic barrels, no perforation of PICS bags.

Keywords: postharvest grain loss, maize, hermetic storage, on-farm validation, Tanzania.

1. Introduction

In the central Tanzania, maize is grown as both a food and cash crop by the majority of smallholder farmers and covers the largest land area under production in each of the seven regions in the Central Corridor. It is known to be one of the crops most severely affected by postharvest losses (PHL).

The dominant insect pests that attack stored maize are the larger grain borer (LGB), *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and the maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *Prostephanus truncatus* is more damaging than *Sitophilus zeamais*, particularly in small-scale and on-farm storage. However, its occurrence is seasonal. If the grain is dried at an appropriate moisture level of 12%-13%, storage insect pests can be controlled effectively with fumigants such as Phostoxin (Hodges, 1986). Phostoxin is commonly used in larger grain stores and is handled by authorized personnel. In Tanzania, farmers are allowed to use phostoxin if supervised by authorized extension agents. Farmers widely use a mixture of Pirimiphos-methyl (Actellic) and permethrin, commercially sold as Actellic Super (local name: Shumba).

More recently there has been a growing interest in the use of hermetically-sealed containers to control storage insect pests. The low oxygen concentration in hermetic storage structures causes insect mortality (Yakubu et al., 2011). Therefore, hermetic storage such as Purdue Improved Crop Storage (PICS) bags, super grain bags, metal silos, cocoons and others, are being promoted as cost-effective ways to control storage insect pests in Asia (Quezada et al., 2006). Recently, the technology was frequently tested for storage of a vriety of crops in different African countries Africa (Jones et al., 2011; Phiri and Otieno, 2008). Metal silos, also hermetically sealed but physically stronger, have been heavily promoted in Central America by the former POSTCOSECHA Programme (Bokusheva et al., 2012) but with the use of fumigation with phostoxin. The metal silo is now also promoted in Sub-Saharan Africa by programmes of the Swiss Development Cooperation (SDC) with the objective to use it with hermetic storage. However, the effectiveness of hermetic storage with the metal silo has only been proven under controlled trial conditions (de Groote et al., 2013) but not under farm conditions and handling by smallholder farmers.

This study was conducted in the Central Corridor of Tanzania (Manyara and Dodoma regions to: (i) test the effectiveness of different storage technologies for maize at conditions of smallholder farms; (ii) test the feasibility of small farmers applying the principle of hermetic storage; (iii) to get the farmer perceptions on the different storage technologies. The study hypothesized that hermetic storage could replace fumigation without losing maize grain quality.

The study was conducted in the framework of the Grain Postharvest Loss Prevention Project (GPLP) implemented by HELVETAS Swiss Intercooperation and funded by the Swiss Agency for Development and Cooperation (SDC), in collaboration with the International Institute of Tropical Agriculture (IITA) as the lead research partner.

2. Literature review

2.1 Production statistics of maize in some East and Southern African Countries

Maize production in the East African region has been on the increase in the period between 2004 and 2014. Tanzania is second to Ethiopia regarding yearly and average production by contributing about 674 million metric tons in 2014 (FAOSTAT, 2016). The output amounts to about 24% of the total East African maize production between 2010 and 2014. However, the average productivity of maize in Tanzania was the least within ten years (2005-2014).

2.2 Postharvest losses (PHL) of food grains

PHL commonly refers to the total of any form of quantitative and qualitative losses of food value after harvesting food crops till it reaches the consumers. PHL is one of the leading causes of food insecurity in the sub-Saharan Africa (SSA). The value of postharvest losses for cereals in Africa is estimated at more than 4 billion US$ annually or almost 15% of the total production value (World Bank, 2011). On-farm PHL of maize outweighs that encountered in the rest of the food chains in the SSA. In Tanzania, the majority of these losses are encountered during harvesting, drying, winnowing and threshing which is postharvest operation mostly conducted on-farm by farmers (Anonymous, 2016a). According to APHLIS[1] overall (from harvest to market storage), PHL weight losses for maize in Tanzania fluctuated between 16-23% across different regions. Based on a survey, Abass et al. (2014) reported farmers' estimates of 25-40% of total crop loss from the field until final marketing.

2.3 Insect pests of stored grains

Insect pests are responsible for major losses of stored grains. Some insect pests are also capable of damaging some storage structures thereby allowing spillage of grains and exposure to other pests' attack. The major storage insect pests of maize are maize weevil (*Sitophilus zeamais*), larger grain borer (*Prostephanus truncates*), red flour beetle *(Tribolium castaneum* and *T. confusum*) and lesser grain borer (*Rhyzopertha dominica*). (Fig. 2.1).

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[1] http://www.aphlis.net/index.php?form=losses_estimates&co_id=46&c_id=324

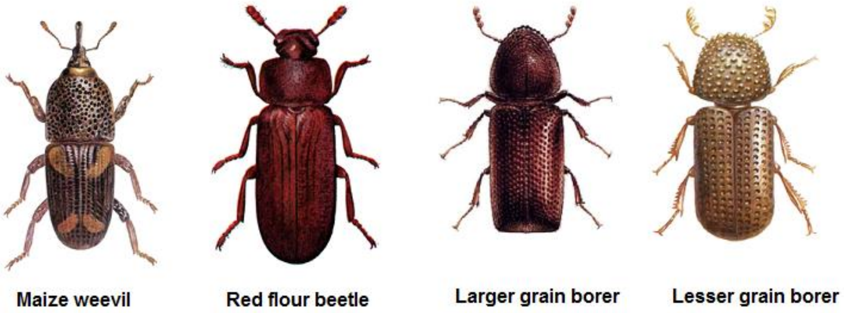

Fig. 2.1: Gallery of common maize grain insect pests (Source: USDA, 2016c)

Previous studies have indicated that the major environmental factors determining the survival of insect pests in grain storage facilities are related to the interstitial air quantity (or oxygen concentration), air temperature and relative humidity. Other minor factors are grain composition, the moisture content of grains before storage and nutrient content of the grain. Ability to control the gas environment of a storage device is, therefore, a major avenue to reduce the incidence and damages of insect pests in the granary. This particular feature is what makes hermetic storage a superior method of conserving the grain crop at the postharvest stage.

When the moisture content of grain is high, biological and biochemical activities of grains and that of storage insect pests is enhanced. Reed et al. (2007) reported that respiration rate measured as the rate of oxygen uptake with time was improved with higher grain moisture. Therefore, both the moisture content of the grain and that of the surrounding air (humidity) should be minimized and monitored (Jayas and White, 2003). Increased grain moisture content also significantly enhances mold spoilage (Brewbaker, 2003). Some other authors also reported that higher storage temperature which could have increased the respiratory activity of grains and pests caused increased absolute humidity of the interstitial air and consequently increased mold infection in stored maize (Paraginski et al., 2014). The problem of moisture condensation in larger metal silos is a critical factor in the onset of caking due to mouldiness (Paraginski et al., 2014).

2.4 Hermetic storage of grains in the sub-Saharan African countries

The hermetic storage systems (HSS) work by placing an airtight barrier between stored grains and the ambient environment. It helps to reduce or nearly eliminate gas and water vapour transmission between the grains and the surrounding air. Because of its perfect scalability, HSS has been used to handle few kilograms as well as many tons of grains by many farmers in many parts of SSA. From the survey study conducted by Moussa et al. (2014) in 2010 and 2012 in ten countries in West and Central Africa, 46% of respondents use some types of hermetic storage for their cowpeas, and about 44% of the quantity of cowpea stored on farms is in airtight containers.

Use of metal silos made out of galvanized steel has the advantage of its high mechanical strength, non-corrosive and excellent barrier properties against moisture and air exchange between the grains and surrounding. However, adoption of metal silo by smallholder farmers is still low due to its relatively high initial investment cost and limited availability of metal silo fabrication technology (Baoua et al., 2014). Flexible HSS (bags, cocoons) are now gradually being studied purposely to determine their technical and cost-effectiveness in reducing incidence PHL of grain across difference ecological conditions of SSA.

Recycled rigid containers have now been sought by farmers to provide low capacity hermetic containment of grains (Yakubu et al., 2016). These recycled containers are made from different plastic materials such as high-density polyethylene (HDPE), polyvinyl chloride (PVC) and metals. It is required that the recycled container should not be corrosive, or previously used for packaging tainting or toxic material, and must be adequately sanitized before used for storing maize (Yakubu et al., 2016).

GrainPro produces the Super Grain Bag from flexible plastic films of extremely low oxygen permeability. It has been tested as an alternative to metal silos (Villers et al., 2008). However, the GrainPro technology suffers substantial damage from P. truncatus during long time maize storage trials in Kenya and Benin (De Groote et al., 2013; Ognakossan et al., 2013). The Purdue Improved Crop Storage (PICS) bag is an alternative hermetic technology initially adopted for cowpea storage (Baributsa et al., 2010). Its effectiveness in the control of several storage insect pests of grains has been studied widely. Baoua et al. (2014) reported the effectiveness of PICS in eliminating insect infestation by causing 95-100% insect mortality at all the eleven experimental sites located in three West African countries after 6.5 months storage. The seed qualities were not significantly different from the original seed before storage. Currently, the PICS technology is now more popular than any other flexible hermetic storage and could be found in the local markets of SSA countries.

2.5 Assessment of PHL of food grains

According to Jones et al. (2014), Different actors along the value chain of crops could view PHL from various perspectives. From economic and life science perspectives, PHL is considered from dry weight losses (DWL) while producers who store grains for seed also consider the loss of seed viability (LSV) due to damaged grains in addition to DWL. Grain marketers consider PHL as loss of revenue due to the combination of DWL and price discounts for damaged grains. Therefore, the concept of ‘total value loss’ was evolved to account for these three categories of losses (DWL, LSV and price discount).

3. Materials and methods

3.1 Selection of trial locations and farmers:

The trial was done in two regions of Tanzania: Dodoma and Manyara from October 2014 until May 2015. In each of the two regions, one district was selected: Hanang in Manyara, and Kongwa in Dodoma. In each district, two villages were selected based on maize production, agro-climatic conditions, access to road, maize being an important crop in the farming system, total village population of more than 250 residents and other criteria. In each village, five households were randomly selected based on ability to store the maize in the different conditions and to manage the experiment, and willingness to participate in the trial. Twenty (20) farmers were involved in the experimental trials in all four villages, and 80 farmers were interviewed during the perception survey.

3.2 Establishment of trial at farm sites

The trial comprises a comparison of the following storage technologies (treatments):

1) Metal silo of 500 kg capacity applying hermetic storage only (Filling: 90%);
2) Metal silo of 500 kg capacity with phostoxin treatment (active ingredient is aluminum phosphide, 57% w/w), (Filling: 90%);
3) Plastic barrel of 150 kg capacity applying hermetic storage only (not filled to the brim);
4) Plastic barrel of 150 kg capacity with phostoxin treatment (not filled to the brim);
5) ZeroFly® storage bag filled with 50 kg maize (Deltamethrin insecticide-treated yarn; 4 bags);
6) PICS® triple layer bags filled with 100 kg maize, hermetic storage only (2 bags).
7) Polypropylene bag filled with 100 kg maize; with Actellic Super treatment (common farmer practice), non-hermetic storage (2 bags)
8) Polypropylene bag without treatment (control) filled with 100 kg (2 bags)

Maize was stored using the eight technologies as follows:

- *Hermetic metal silo with and without phostoxin (Filling: 90% capacity)*

Metal silo is a flat-topped metal cylinder made out of galvanized metal sheeting (usually gauge 24 or 26) with a bigger top inlet and a lateral neat bottom located smaller outlet. Metal silos (500 kg maize storage capacity) were fabricated by the local artisans who were previously trained by master trainers selected by the GPLP project. The metal silos measured 160 by 80 cm in height and diameter, respectively. The metal silo was placed on a wooden pallet in the storage area (inside a house or store) to avoid high temperature fluctuations inside the silo which could lead to moisture condensation. The inlet (the main opening in the top) and bottom outlet is covered with a lid and sealed with a rubber band (Tefera et al., 2011). However, unlike in other experiments the oxygen in the silo was not depleted with the candle method (Tefera at al., 2011). This was to imitate possible farmers' practices since it is unlikely that smallholder farmers would be applying oxygen depletion inside the silo after filling. One metal silo was placed in each household for hermetic storage without the use of insecticide, and a second metal silo was pre-treated with two tablets of aluminium phosphide (57% w/w) by a qualified staff of the District Agricultural Extension Service.

- *Hermetic plastic barrel with or without phostoxin*

A plastic barrel is a flat-topped high-density polyethylene (HDPE) barrel used to transport liquids like Sorbitol, and so forth. The volume is about 150 litres, measuring 100 cm high and 50 cm diameter. The barrel was purchased at the local market in Babati town and modified by a local artisan by creating a bigger top opening with a lid made out of galvanized metal as used for fabrication of metal silos. The lid was lined with a rubber band to ensure hermetic sealing. Before use, the barrel was thoroughly cleaned with soap, sodium bicarbonate (2%) and hypochlorite.

The barrel was placed on a wooden pallet in the storage area inside a house or store to avoid high-temperature fluctuations inside the barrel which could lead to moisture condensation. The inlet (opening on the top) was covered with a lid and soap used to seal the inlet further to maintain hermeticity (Tefera et al., 2011). The barrel was not filled to the brim and oxygen in the barrel was not depleted. One plastic barrel was placed in each household for hermetic storage without the use of insecticide, and a second barrel was pre-treated with two tablets of aluminum phosphide (57% w/w) by a qualified staff (as for metal silo).

- *Hermetic PICS® Triple layer bags*

The Purdue Improved Crop Storage (PICS®) bag consists of two layers of polyethylene bags; these are then surrounded by a third layer of a woven polypropylene bag thereby creating a hermetically sealed environment in which harvested maize was stored. PICS bags were purchased from Pee-Pee Tanzania, Limited, Tanga, Tanzania. For the trial, two bags of 100 kg untreated maize were used per household. One bag was left unopened until the last sampling period (30 weeks) when the maize stored in it was sampled for laboratory analysis.

- *Non-hermetic ZeroFly® storage bags*

A ZeroFly® storage bag is a woven polypropylene bag in which insecticide, Deltamethrin (DM), is incorporated in the polypropylene yarns by the manufacturer. The active ingredient, DM, is expected to be released onto the surface of the material in a sustained manner so that the maize stored in the bags is continuously protected against insect infestation. ZeroFly® bags were supplied by Vestergaard, Lagos, Nigeria and shipped by airfreight to Tanzania. For the trial, each household used four bags of 50 kg untreated maize. One bag was left unopened until the last sampling period (30 weeks) when the maize stored in it was sampled for lab analysis.

- *Non-hermetic polypropylene bags with and without Actellic Super®*

Polypropylene bags are commonly used to transport and store grains. Maize treated with Actellic Super® according to manufacturer's guide was stored in two 100 kg polypropylene bags per household. One bag was left unopened until the last sampling period (30 weeks) when the maize stored in it was sampled for lab analysis. Actellic Super® (commonly known as Shumba) is a broad spectrum insecticide of low mammalian toxicity that contains Pirimiphos-methyl and Permethrin as the active ingredients. It is used to control a wide range of insects and mite pests in stored grains. The use of Shumba is a common storage practice of the farmers in the trial villages. Untreated maize stored in polypropylene bags was set up as a control for other containers.

All the storage containers were distributed to the participating farmers, and the farmers provided shelters to house the storage facilities for the trial. Shelled maize was purchased from each village for the experiment. The majority of the farmers in the four villages harvested maize by from July to September.

3.3 Measurement of temperature and relative humidity in the storage containers and trial environment

The relative humidity and temperature in the storage facilities were recorded using electronic data loggers in four representative trial treatments (Hermetic metal silo, Hermetic plastic barrel, PICS bag, and PP bag without treatment) and (for cost reasons) only in two out of five households per village (total of eight households). Data loggers (Dickson TK550) were kept inside the storage containers for the 6-hourly recording of temperature and humidity at 3 am, 9 am, 3 pm and 9 pm. Data was downloaded from the data logger at each sampling date. Also, the same data logger was placed in the trial rooms at the selected households to monitor environmental conditions.

3.4 Laboratory assessment of stored grain samples

Grain samples were obtained from storage container using different types and sizes of sampling spears manufactured by Seedburo Equipment Company, USA. Samples from the metal silos and plastic barrels were taken using a compartmentalized sampling spear (with 1.8 m aluminum probe of 12 openings) while samples from different types of storage bags (ZeroFly®, PICS, polypropylene) were taken using a smaller spear (with brass open handle probe of 6 openings). Samples were taken from the centre and four peripheral and equidistant points perpendicular to the centre of each storage container (Northern, Eastern, Southern, and West), thereby making a total of five samples per container.

- *Sample transfer from the field to the laboratory*

A representative sample from each trial (1 kg) was transferred into a labeled paper bag, sealed and then transported to the laboratory for further analysis. Samples were maintained at ambient conditions in the laboratory until analysed. The time lapse between sample collection and final lab analysis lasted an average of three weeks.

- *Grain moisture, temperature, and volumetric weight*

The moisture, temperature and volumetric weight of the stored grains were tested in the field using a hand-held grain moisture tester (Dickey-John GAC ® Plus, Illinois, USA). About 400-425 g of maize grains were filled into the loader of the tester and levelled for the automatic measurement of moisture, temperature and bulk density. The percentage grain moisture (%), grain temperature (°C) and volumetric weight (g/cm^3) were read directly from the meter.

- *Determination of insect population*

The number of each type of insect was evaluated in the laboratory by sifting a known weight of grains with laboratory round sieve with a mesh aperture size of 6 mm (Seedburo Equipment Company, USA). The insects sifted with the dirt out of the grains were identified and counted based on the insect type, stage of growth, and whether alive or dead.

In terms of insect identification, both the confused and red flour beetles are similar in appearance. They measure about 1/10 to 1/8 inch long and are flat, shiny, reddish brown, and elongated. Antennae segments of the confused flour beetle increase in size gradually from the base to the tip to form a club of four segments. The confused flour beetle has a straight-sided thorax, while the thorax of the red flour beetle has curved sides. The sides of the confused flour beetle head capsule are notched at the eyes so that a visible ridge is present. The sides of the confused flour beetle head capsule are notched at the eyes so that a visible ridge is present. This ridge is absent in the red flour beetle. In the red flour beetle, the last three segments at the tip of the antennae are abruptly larger than the preceding ones, forming a three-segmented club. The eyes of the red flour beetle are separated by less than two eye diameters while those of the confused flour beetle are separated by more than three eye diameters. Red flour beetles fly but the confused beetle do not fly.

- *Grain damage (broken, fungi infected, overheated, stunted, germinated, and so forth.)*

In the laboratory, samples were weighed and sieved to separate the impurities from clean grains. All impurities (insects as well as others unwanted materials) were weighed and recorded. The clean/sieved maize samples were divided using sample divider (rifle sample splitter with 14 chutes; Seedburo Equipment Company, USA), then a portion (about 250 g) was transferred onto the 1000 holed board to fill in all the 1000 holes. Extra grains and the board were removed leaving well-arranged 1000 grains. The 1000 grains were sorted into damaged (dg) and sound grains (sg).

The weight of undamaged grains (W*dg*), the weight of damaged grains (W*sg*), the number of undamaged grains (*Nsg*) and, the number of insect damaged grains (*Ndg*) were determined. Following Boxall (1986), the percent damaged grains (PDG) was calculated as:

$$PDG = \frac{Ndg}{Ndg + Nsg} \times 100 \qquad \text{Eq. (1)}$$

Also, percent weight loss (PWL) was computed by the count and weigh method using the equation:

$$PWL = \frac{[(Wdg \times Ndg) - (Wsg \times Nsg)]}{Wdg \times (Nsg + Ndg)} \times 100 \qquad \text{Eq. (2)}$$

Damaged grains were further separated into different categories according to the cause(s) of the damage: (i) insects and fungi only, (ii) germination and fungi only, (iii) rodents and fungi only, (iv) others damages and fungi only, (v) insects only, (vi) fungi only, (vii) germination only, (viii) rodents only, (ix) broken grains only, (x) overheated grains only and, (xi) stunted grains only.

Insect damaged grains were identified separately from broken or rodent damaged grains. Similarly, grains infected by fungi, with a slight change in colour were designated as fungi damaged grains. Kernels showing visible signs of sprouting, such as cracked seed coats through which a sprout emerged or is just beginning to emerge were designated as germinated grains.

3.5 Grain germination test

Scientists at the Biology Laboratory of St John's University, Dodoma carried out germination test for selected samples of maize three times at: 20 samples in December 2014 before storage (No Storage), 175 samples in March 2015 (18 weeks), and 175 samples in May 2015 (30 weeks). The germination test was aimed at understanding the effect of the different storage conditions on germination ability (or Seed viability) of the stored maize.

Two tons of sand substrata were used as media. Sand was sieved to remove roots, stones, pebbles and gravels of the size above 2 mm to get a soil texture that can easily support the germination process for the maize seeds; sieved sand was washed to remove any organic substances before sterilizing on a fire stove. The heated sand was spread inside aluminum sheets to cool.

A random sampling of 400 seeds from each lot was followed with sub-sampling of 100 seeds for sowing. The 100 seeds were sown in trays that were arranged on the benches near a source of sunlight. The sowing spacing between, and within rows in the try were set at 3 cm and 4 cm respectively. The seeds were sown 5 cm deep into the sand. The sand was irrigated before seed sowing. The planted seed lots were irrigated on a daily basis with clean tap water. The counting of germinated seedling was conducted on the fifth and the eight days of sowing. Counting of the number of germinated seeds out of 100 was done three times.

3.6 Data analysis

Data was entered in Excel spreadsheet and analysed using SPSS program and SAS programs. Means, standard deviation, and frequencies were used to in explaining the data pattern. Also one-way ANOVA was used to test the effects of treatments on storage parameters, grain quality, and grain damage. Percentage values were transformed to a new value (Y) using Arcsine transformation parameter (X) was done using the following equation:

$$Y = \left(Arc\sin\sqrt{(\text{Parameter}(X)/100)}\right)\times 180/3.14 \qquad \text{Eq. (3)}$$

The transformed variable was them used for analysis of coefficient of interaction. Significant differences in storage parameters were concluded when the coefficient of the interaction term was significant at $p < 0.05$.

4. Results and Discussion

4.1 Average atmospheric conditions at the experimental locations

The mean atmospheric temperature at the experimental sites ranged from 23 to 29ºC (Fig. 4.1). Dodoma region had higher temperatures (26-29ºC) than Manyara (23-27ºC) throughout the storage period (Annex 1).

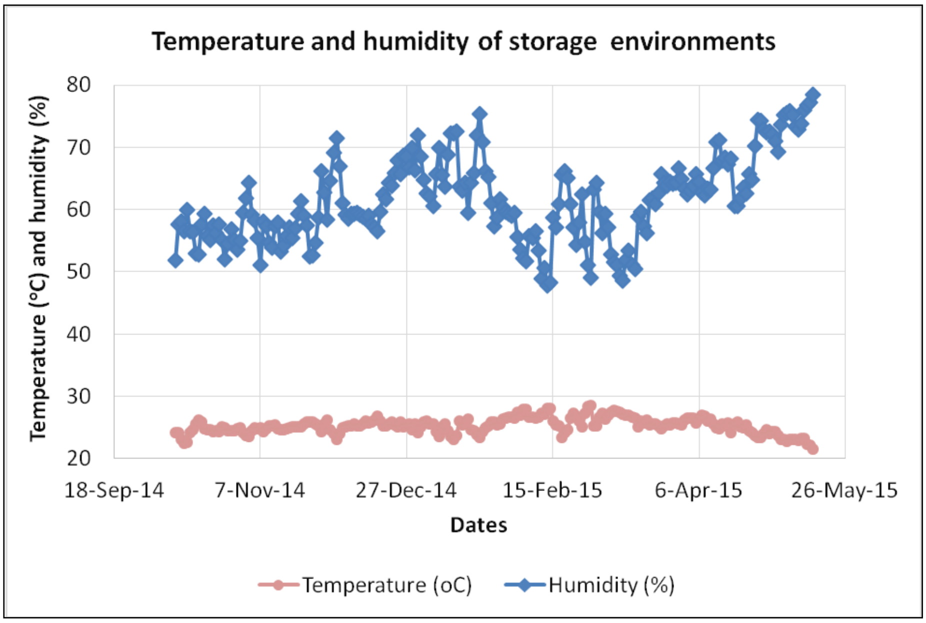

Fig 4.1: Average atmospheric temperature and relative humidity of trial locations

The relative humidity of the storage environment increased from 51.8% in October 2014 to 75.4% in mid-January 2015, and then it reduced to 49.4% in March 2015 before increasing to 78.4% at the end of the trial in May 2015. The temperature of the storage environment increased slowly from 25ºC in October 2014 to 28ºC in February 2015 and reduced gradually to 21ºC at the end of the storage period.

The atmospheric temperatures at the trial sites in Dodoma villages (Kibaigwa and Kinangali) were significantly higher (26.0±1.2ºC) than in Manyara trial sites (Endagaw and Endasaki) (23.4±0.9ºC) from October 2014 to May 2015 (Fig. 4.2, Table 4.1). On the other hand, the environmental humidity in Manyara region (70.5±4.3%) fluctuated more than in Dodoma region (66.5±3.4%) and was significantly higher than in Dodoma region most of the storage period except in March 2015. The risk of grain losses due to fungi infection may be higher in humid environments such as in Endasaki or Endagaw villages and a bit in Kinangali village.

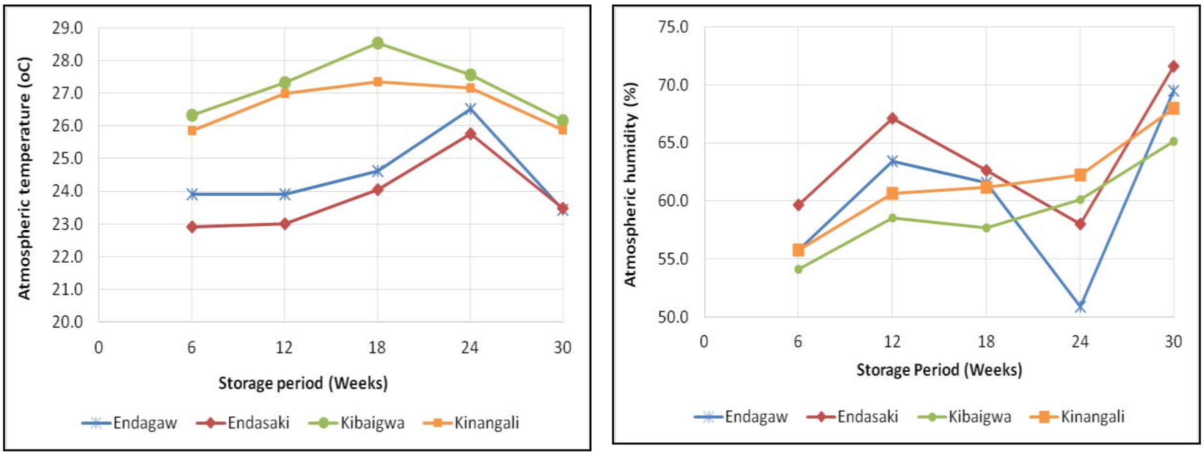

Fig. 4.2: Average atmospheric temperature and relative humidity of trial locations disaggregated by village

Table 4.1: Average temperature and humidity of trial villages over the trial period

Region	Village	Temperature (^{o}C)		Relative Humidity (%)	
		Mean	Grand Mean	Mean	Grand Mean
Dodoma	Kibaigwa	26.2±0.8a	26.0±0.9a	65.2±4.5b	66.5±3.4b
	Kinangali	25.9±1.1a		68.0±4.4b	
Manyara	Endagaw	23.4±0.2b	23.5±1.2b	69.5±11.9ab	70.5±4.3a
	Endasaki	23.5±1.7b		71.6±9.4a	

Figures in the same column followed by the same letters are not significantly different at $p<0.05$.

Grains with higher moisture content (Manyara region) (13.06%) than in Dodoma (12.06%) are more likely to be infected by fungi + insect damage (Table 4.2). Combining data in Tables 4.1 and 4.2 results in correlation matrix in Table 4.3 which indicates a positive correlation between grain moisture content and combined grain damage by fungi and insect. However, the correlation is negative in the case of fungi infection alone. Increased temperature also resulted in significant reduction in the combined damage ($p<0.05$). The result further corroborates that the contribution of insect to total damage was more significant.

Table 4.2: Grain moisture content, fungi infection & insect damage at week 30 of the trial period

Region	Village	Grain moisture content (%)		Fungi infection (%)		Fungi alone and Fungi & Insect Damage (%)	
		Mean	Grand Mean	Mean	Grand Mean	Mean	Grand Mean
Dodoma	Kibaigwa	12.44±0.39c	12.06±0.51b	0.31±0.25a	0.29±0.22a	0.27±0.30b	0.30±0.31b
	Kinangali	12.38±0.58c		0.21±0.20b		0.32±0.32b	
Manyara	Endagaw	13.03±1.08b	13.06±0.79a	0.23±0.15c	0.25±0.16b	0.43±0.31a	0.41±0.31a
	Endasaki	13.40±0.61a		0.23±0.21c		0.39±0.32a	

Figures in the same column followed by the same letters are not significantly different at $p<0.05$.

Table 4.3: Correlation between temperature, humidity and grain moisture content and type of grain damage

	Temperature (°C)	Relative Humidity (%)	Grain Moisture Content (%)
Fungi Infection	0.464	-0.722	-0.325
Fungi Infection + Insect damage	-0.957*	0.837	0.799

4.2 Temperature and relative humidity inside the storage containers measured with data logger

The results (Fig. 4.3) showed that the temperature and relative humidity inside the storage containers varied with storage time. The temperature in polypropylene bags increased more than the temperatures in other storage conditions, i.e. it rose from 24.7°C at six weeks of storage to 30.7°C by 30 weeks while it remained within the range of 24.2-26.5°C in all the other storage containers during the same period. As expected, the relative humidity reduced mostly in polypropylene bags, suggesting that the grains were drying in storage.

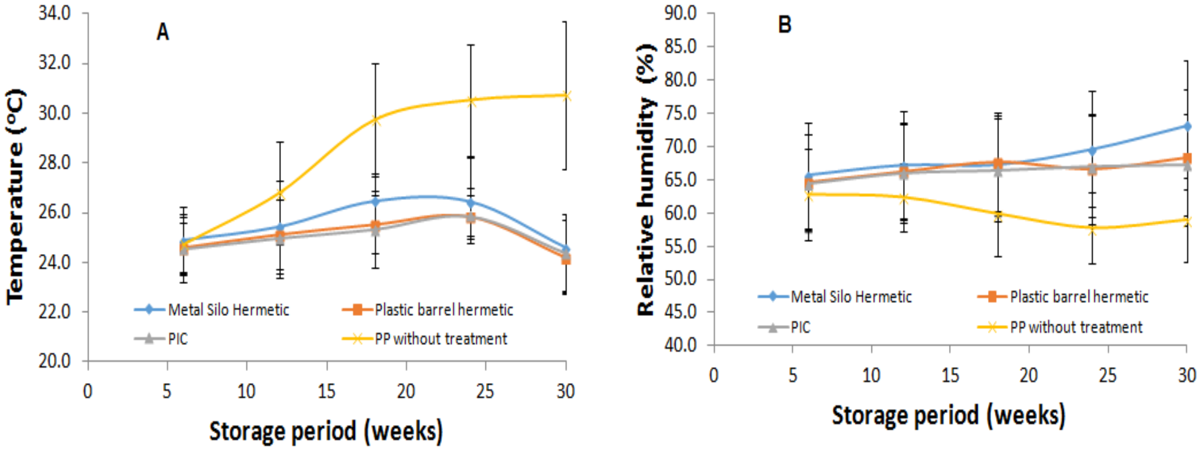

Fig. 4.3: Average temperature and relative humidity in the containers over the 30 weeks of maize storage

At the end of the trial (30-week storage), the temperature in polypropylene bags (30.7±3.0) was significantly higher than the temperatures in the metal silo (24.6±1.7°C), plastic barrel (24.2±1.5°C) and PICS (24.4±1.6°C) ($p<0.5$) (Annex 2).

The higher temperature maintained inside the polypropylene bags containing untreated maize might have caused the large infestation by damage insects (*Sitophilus zeamais* and *Tribolium castaneum*) or vice versa, suggesting that the temperature inside hermetically sealed storage facilities may be more stable and can easily be controlled as less insect population would mean lower activities or energy dissipation and less heat.

Relative humidity was highest in metal silos with a range of 65.7-73.2% and lower in plastic barrels with a range of 64.4-67.3%, 64.43-67.3% in PICS bags and 62.8-58.9% in polypropylene bags (Annex 3). While relative humidity inside polypropylene bags reduced over time, the relative humidity in airtight containers (metal silo, plastic barrel, and PICS) was stable or increased over time. The gradual reduction in relative humidity inside polypropylene bags could be due to drying of the grains over time, which may reduce the possibility of dampness. On the other hand, the higher relative humidity as observed in the airtight containers (metal silo, plastic barrel & PICS) suggests a risk of the dampness of the stored grains, which may increase the possibility of fungi damage.

At week 30, relative humidity of the different treatments was significantly different ($p<0.05$). The relative humidity inside the metal silo was the highest (73.2± 9.8%) and was significantly greater than in polypropylene bags (58.9± 6.4%) which was the least. The relative humidity in airtight containers: metal silo, plastic barrel, and PICS bags were not significantly different from each other. However, the humidity of storage treatment correlated positively with total grain damage ($r=0.54$; $p<0.0001$). Similarly, humidity of storage treatment correlated positively with the (GAC) temperature of maize ($r=0.52$; $p<0.0001$) (Annex 4) This may imply that increases in humidity inside storage containers possibly enhanced the activities of agents of grain damage such as fungi infection but possibly not insects.

Regarding differences between regions, the relative humidity maintained inside airtight storage containers (metal silos, plastic barrels, and PICS) were significantly higher ($p<0.0001$) in Manyara than in Dodoma but we did not find any significant difference between the two regions for PP bags (Table 4.4).

Table 4.4: Differences in relative humidity and temperature inside storage containers by region

Climatic parameter	Storage treatment	Dodoma		Manyara		P-values
		Mean	SD	Mean	SD	
Relative humidity	Metal Silo Hermetic	61.68	4.08	75.32	5.43	<0.0001
	Plastic barrel hermetic	60.15	3.13	73.28	4.97	<0.0001
	PICS	60.02	4.35	72.47	3.90	<0.0001
	PP (without treatment)	58.52	2.70	62.28	7.43	0 .68
Temperature	Metal Silo Hermetic	26.39	1.15	24.75	1.66	0.001
	Plastic barrel hermetic	25.82	0.73	24.31	1.29	<0.0001
	PICS	26.00	2.51	24.03	1.33	<0.0001
	PP (without treatment)	28.68	3.80	30.62	4.05	0.06

Likewise, the temperature maintained inside hermetic storage containers (metal silos, plastic barrels and PICS) were significantly higher in Dodoma than in Manyara ($p<0.001$) but no significant difference was found between the two regions for PP bags. The result suggests that the use of hermetic containers in Manyara may pose higher risk than in Dodoma regarding fungi infection based on the higher humidity in hermetic containers. The implication is that farmers in more humid environment like Manyara need to be well aware of storing well-dried grains in hermetic containers.

4.3 Temperature, moisture contents and bulk density of stored grains measured with GAC tester

The grain temperature values with GAC tester were generally lower than data logger temperature values for the same period (Fig. 4.4). The GAC, in general, gave lower temperature readings than the data loggers. Nevertheless, the GAC tester confirms that the temperatures of untreated grains stored in polypropylene bags (ZeroFly and PP without treatment) were higher than the temperatures of treated grains stored inside polypropylene bags (PP Shumba) and grains stored in hermetic containers (PICS, metal silos and plastic barrels). This further supports the proposition that increased insect activities in the ZeroFly and ordinary polypropylene bags (PP without treatment) was responsible for the high temperatures in the two treatments.

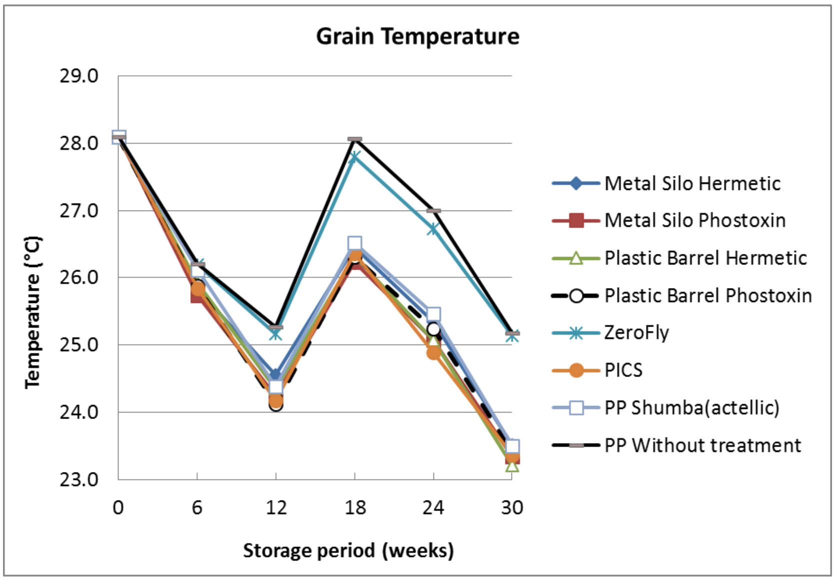

Fig. 4.4: Grain temperature over 30 weeks of storage (GAC readings)

Maize stored in hermetically sealed containers had higher moisture contents than grains in polypropylene bags (ZeroFly, actellic super-treated and untreated maize stored in polypropylene bags; Fig. 4.5). The lower moisture values corroborate the observed low RH in the polypropylene bags (Fig. 4.3). The moisture values for grains in hermetic conditions (metal silos, plastic barrels, PICS) exhibited an increasing trend from 12.5% at the time of storage to a range of 12.9-13.6% at 30 weeks storage. The moisture content of maize stored in non-hermetic conditions (ZeroFly, polypropylene bags) reduced until 18-week storage and increased after that.

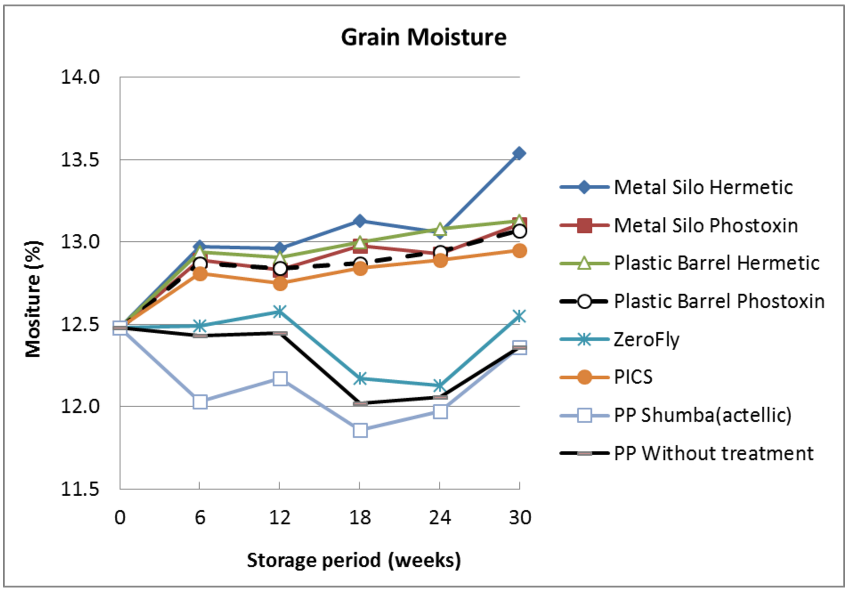

Fig. 4.5: Grain moisture over 30 weeks of storage (GAC readings)

The phenomenon of grain moisture increase in airtight containers could not be explained with much certainty as grain moisture should normally not increase inside storage containers. However, the increase of grain moisture could be a combined effect of respiration by the grains, producing water which under hermetic conditions remains in the container, and a possible condensation due to temperature fluctuations under hermetic conditions. In fact, during the field experiment, researchers observed high moisture condensation in some metal silos, plastic barrels and PICS bags in some households. The results also show that moisture content of the grains correlated with the temperature of storage treatment ($r=0.2$; $p<0.0001$). The correlation suggests that high temperature inside the storage containers, especially in hermetic storage containers, is likely to lead to increased humidity in storage.

Results revealed significant differences ($p<0.01$) between Dodoma and Manyara in terms of the moisture contents of grains in the different storage conditions at 30 weeks except for storage in ZeroFly (Table 4.5). With the average moisture contents of the grains in the two locations ranging between 12.18 and 14.05%, there is low possibility of damping, caking and fungal infection unless the moisture content is raised above the existing level due to a number of factors including leakages in the storage structures. The higher moisture contents of grains in hermetic storage containers in Manyara (14%) indicates that dampness of maize, caking and possibly fungi infection may become a problem in Manyara and other similarly humid environements when farmers adopt hermetic storage technologies.

Table 4.5: Moisture contents of stored grains by region at 30 weeks of storage

	Moisture Content (%)			
Storage treatment	Dodoma	Manyara	P-values	Mean
Metal Silo Hermetic	13.05±0.70	14.05±0.70	0.01	13.6±0.9a
Metal Silo Phostoxin	12.50±0.42	13.79±0.74	0.001	13.1±0.9ab
Plastic barrel hermetic	12.64±0.57	13.68±0.68	0.001	13.2±0.8ab
Plastic barrel Phostoxin	12.61±0.59	13.60±0.79	0.01	13.1±0.9ab
ZeroFly	12.35±0.34	12.82±0.39	0.18	12.6±0.4bc
PICS	12.33±0.44	13.66±1.30	0.001	13.0±1.2bc
PP Shumba	12.24±0.36	12.57±0.31	0.001	12.4±0.4c
PP without treatment	12.18±0.35	12.62±0.60	0.01	12.4±0.5c

Figures in the same column followed by the same letters are not significantly different at $p<0.05$.

Regarding the final moisture of grains at 30 week storage, maize stored in hermetically sealed containers (metal silos, plastic barrels, and PICS bags) had significantly ($p<0.05$) higher moisture contents, that ranged from 13.0-13.6% compared to the maize stored in the non-hermetic facilities (ZeroFly and polypropylene bags with or without insecticide treatments) which had moisture contents in the range of 12.4-12.6% (Table 4.5).

Bulk density (BD) measures the weight of grains to fill a specific volume. It is an index of quality during marketing. It is also an index for the selection of new maize varieties for processing into some food items e.g. as a proxy for endosperm hardness when evaluating new maize varieties. Typically, maize of moisture content between 12% and 16% are tested for bulk density during trading.

Figure 4.6 shows the changes in BD during storage. The BD of hermetically stored maize and maize stored in polypropylene (Shumba) decreased until 12 weeks storage before increasing until the end of the trial. The BD of the grains in ZeroFly and polypropylene bags decreased consistently from 775 kg/m^3 at the start of storage to 699.0 kg/m^3 and 673.5 kg/m^3, respectively, at the end of storage. This reduction in BD seems to be caused or influenced by insect damage in the form of loss in dry matter or kernel.

The BDs of grains stored in Dodoma at different storage conditions were all higher than in Manyara (Table 4.6).

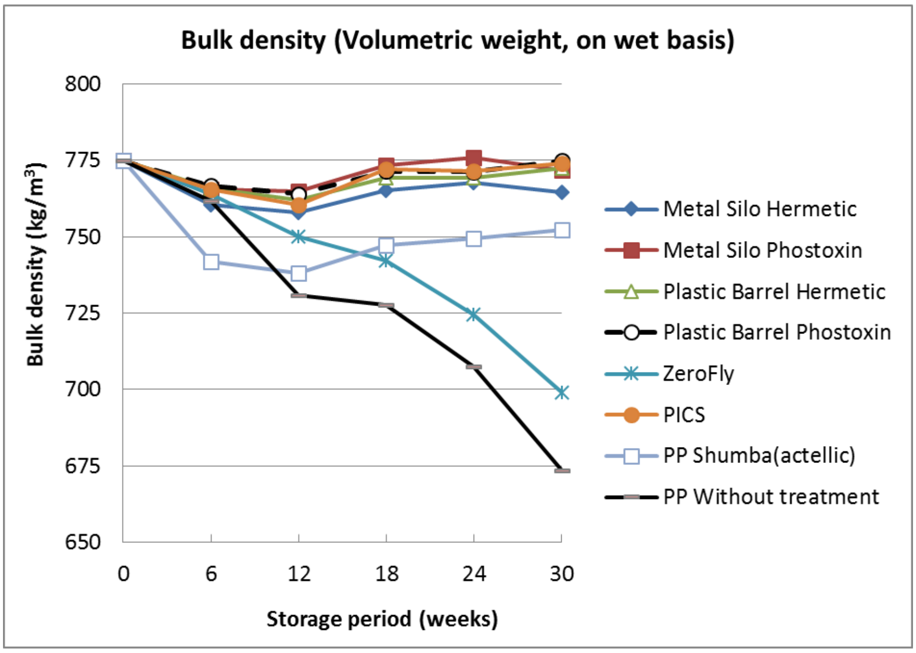

Fig. 4.6: Changes in the bulk density of stored maize

Table 4.6: Bulk density of stored grains by region at 30 weeks of storage

Storage treatment	Bulk Density (kg/m³)					
	Dodoma		Manyara			
	Mean	SD	Mean	SD	P-values	Mean
Metal Silo Hermetic	778.4	20.3	751.7	20.1	0.01	764.4±24.0a
Metal Silo Phostoxin	785.6	16.1	757.7	17.9	0.00	771.7±21.9a
Plastic barrel hermetic	785.8	13.9	759.3	15.6	0.00	772.5±19.8a
Plastic barrel Phostoxin	787.9	15.2	761.7	17.9	0.00	774.8±21.8a
ZeroFly	707.1	28.4	691.3	46.2	0.00	699.0±38.9b
PICS	788.2	14.1	759.8	23.0	0.20	774.0±23.7a
PP Shumba	765.5	13.7	740.4	12.7	<0.0001	752.3±18.2ab
PP without treatment	685.7	28.9	661.4	58.2	0.11	673.5±47.0c

Figures in the same column followed by the same letters are not significantly different at $p<0.05$.

Correlation analysis shows that grain bulk density had a strong negative correlation with insect population ($r=0.80$; $p<0.0001$) and the extent of insect damage ($r=0.75$; $p<0.0001$) while there was a weak correlation with moisture content ($r=0.10$; $p<0.001$). Therefore, insect damage (in the form of holes bored into the grains) was the most probable cause of the decrease in bulk density of untreated grains stored in ZeroFly and polypropylene bags. The reduction in the volume of the damaged grains possibly was not at the same rate as a reduction in kernel weight that occurred due to the activities of the boring insects. In other words, the loss in kernel weight had more influence on bulk density than dry matter concentration due to the moisture loss.

4.4 Changes in insect population during maize storage

In the current trial, two major maize spoilage insects that were identified were maize weevil (*Sitophilus zeamais)* and red flour beetle (*Tribolium castaneum*). The population of live adult maize weevil (*Sitophilus zeamais*) in the grain increased rapidly from 34 per 1000 grains at the beginning of storage to 318 and 138 per 1000 grains at 30 weeks of storage in ZeroFly and PP bags, respectively (Fig. 4.7).

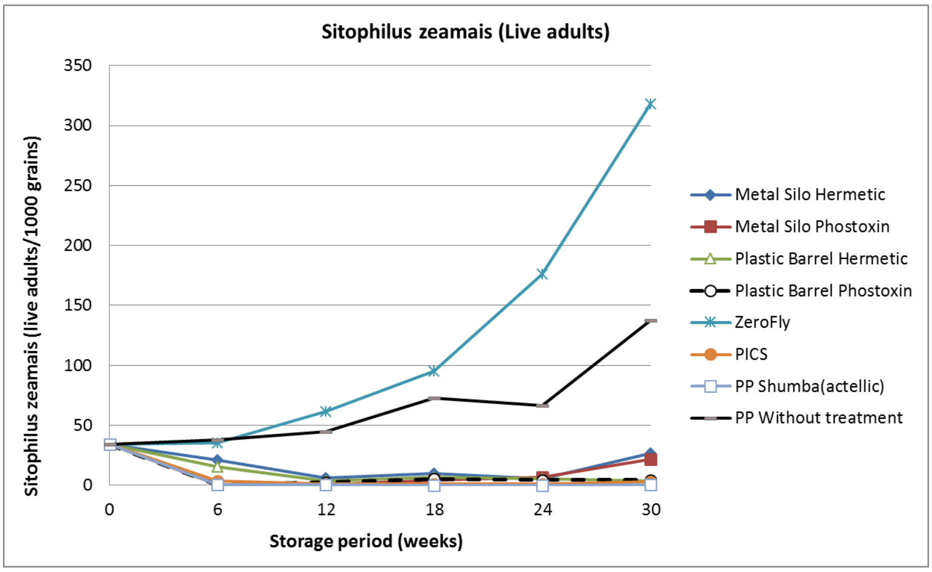

Fig. 4.7: Average population of live Sitophilus zeamais per 1000 maize grains as affected by different storage structure and time

On the other hand, the number of the maize weevil decreased to 0-7 per 1000 grains in all the other treatments at week 30. The initial decrease of maize weevil population was faster in treatments with phostoxin and PICS compared to the metal silo and plastic barrel without phostoxin. The result supports the hypothesis that oxygen depletion in the remaining air takes slightly longer for these two types of containers. The increase in insect population observed in metal silos at 30 weeks may be as a result of an infestation in a few metal silos during the opening of the containers for sampling.

The population of dead *Sitophilus zeamais* adults was highest in ZeroFly, rising to 214 per 1000 grains at week 24 and reducing to 190 at the end of the storage (Fig. 4.8). For the other treatments, the population of dead *Sitophilus zeamais* adults at 30 weeks of storage was 41 and 50 for the PP bags with and without Shumba, respectively, and between 8 and 27 for the hermetic treatments.

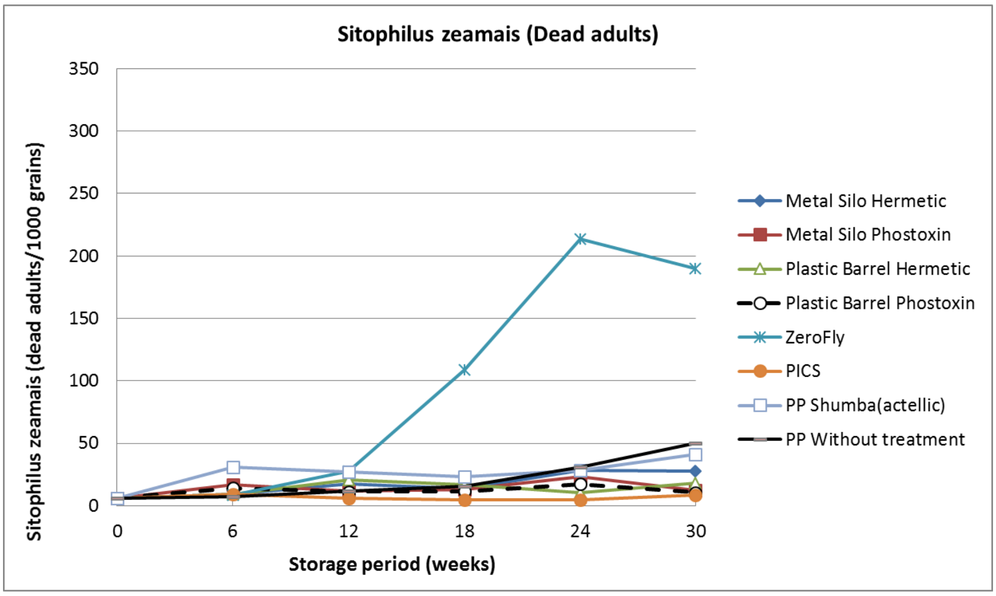

Fig. 4.8: Average population of dead Sitophilus zeamais per 1000 maize grain as affected by storage structure and time

The number of live Red flour beetle (*Tribolium castaneum*) adults remained low (0-13 insect per 1000 grains) in all airtight containers and insecticide-treated maize at 30 weeks while it increased to 64 and 66 in ZeroFly and PP bags (without treatment), respectively (Fig. 4.9).

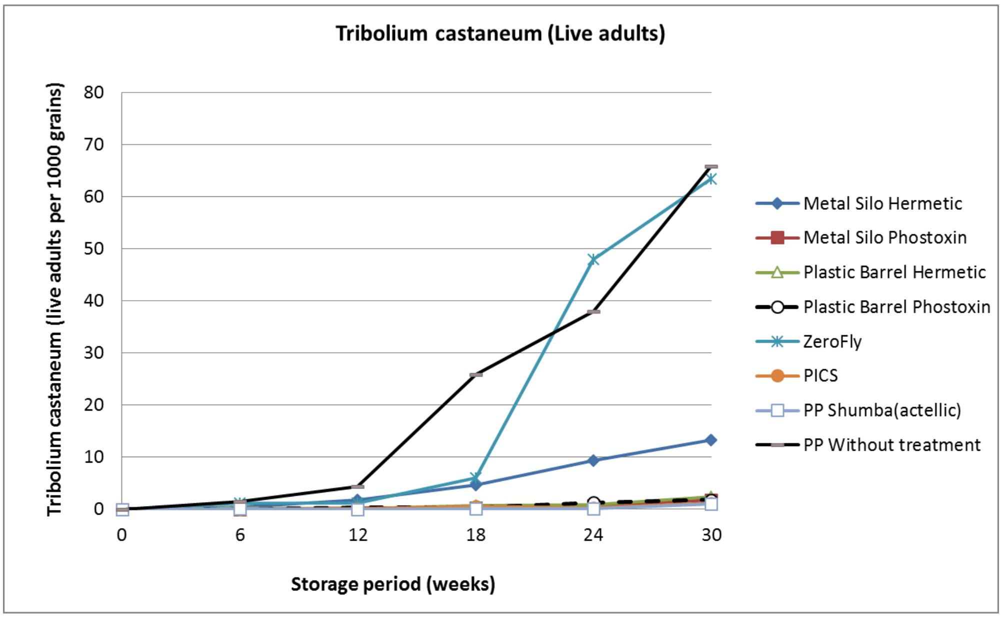

Fig. 4.9: Average population of live Tribolium castaneum per 1000 maize grains as affected by storage structure and time

The result suggests that hermetic conditions with or without insecticide were effective in preventing the multiplication of the Red flour beetle in stored maize, although the effectiveness of metal silo under the farmers' condition is uncertain and should be further investigated taking into account farmers' practices.

While an average of 6-11 dead adults of the Red flour beetle (*Tribolium castaneum)* per 1000 grains was found in ZeroFly and polypropylene bags, none or at most one dead adult beetle was found in hermetic storage containers and also in grains treated with insecticides (Fig. 4.10).

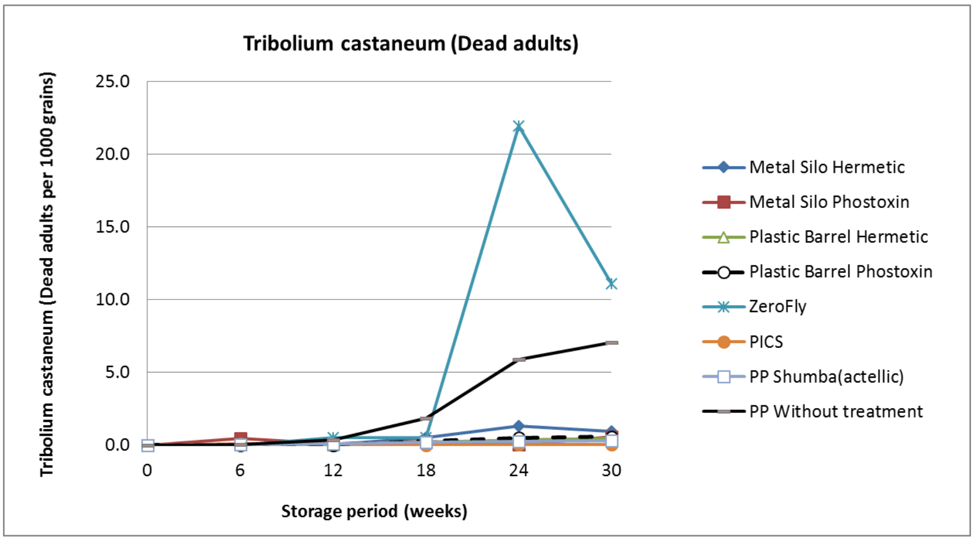

Fig. 4.10: Average population of dead Tribolium castaneum per 1000 maize grain as affected by storage structure and time

In ZeroFly and polypropylene bags, the dead adults at 24 weeks of storage were 6 and 22 per 1000 grains, respectively. The insecticide treatment of polypropylene yarn (ZeroFly) did not prevent an increase in the population of *Sitophilus zeamais* or *Tribolium castaneum* during storage as opposed to what was observed for insecticide-treated and hermetic storage. However, the proportionally high number of dead *Sitophilus zeamais and Tribolium castaneum* at the end of the storage (week 24 and 30) could be due to a retarding effect of the insecticide woven into the yarn of the ZeroFly bag.

Grain damage was more strongly correlated with *Sitophilus zeamais* population (r=0.63; p<0.0001) than *Tribolium castaneum* population (r=0.53; p<0.0001). Therefore, *Sitophilus zeamais* seems to be more important than *Tribolium castaneum* regarding the potential to cause food loss and economic damage to farmers' stored maize, especially in non-hermetic containers such as ZeroFly and polypropylene bags. The heavy insect infestation and the possible insect activities (dissipation of energy by the insects) could be responsible for the higher grain temperature observed in polypropylene and ZeroFly bags. Although we did not measure the temperature, humidity and oxygen concentration in non-hermetic bags, it is assumable that nearness of the temperature to ambient conditions could have caused reduced climatic parameters’ fluctuation thereby favoring increased pest activities over the storage period.

According to Xing et al. (2015), significant temperature fluctuation greater than ±4% from optimal points (25ºC) affects egg development time, hatching rate, larval growth and pre-pupal mass of insect pest. The laboratory study of Singh and Prakash (2015) indicated that influence of temperature and humidity on the activities/lethality of *Tribolium castaneum* depends on the stage of development. In addition, adult *T. castaneum*, which is the most destructive form of the insect, develop optimally under 25ºC (Singh and Prakash, 2015). Higher temperature observed with storage time could have retarded full development of some insect to adult. By implication, ambient conditions observed during the earlier part of this study appear to be more favorable to insect pest proliferation and activities. However, the scope of the current study did not include investigating the influence of atmosphere on the development of the insects to adulthood.

4.5 Grain damage and weight loss

The percent grain damage by storage treatment is shown in Fig. 4.11. At the time the grains were collected from the farmers before storage, grain damage was 11%. Many factors could be responsible for the level of damage before storage. These may include breakage of grains during predominantly manual shelling practices of the farmers, insect damage on the field or during home-drying before shelling, fungi infection and grain deformity, inmature grains before the unset of dry season, stunting resulting from poor soil nutrient or the genetic characteristics of the maize varieties grown by the farmers in the study area.

During storage, there was a rapid increase in grain damage in polypropylene (PP Without treatment) and ZeroFly bags (Fig. 4.11). The damage in the two containers (53.1% and 48.0%, respectively) was significantly higher ($p<0.05$) than the damage in the other storage treatments (Annex 5). The levels of grain damage in all the remaining storage treatments at 30 weeks, were in the range 11.9-15.4%, and were not significantly different (Annex 5).

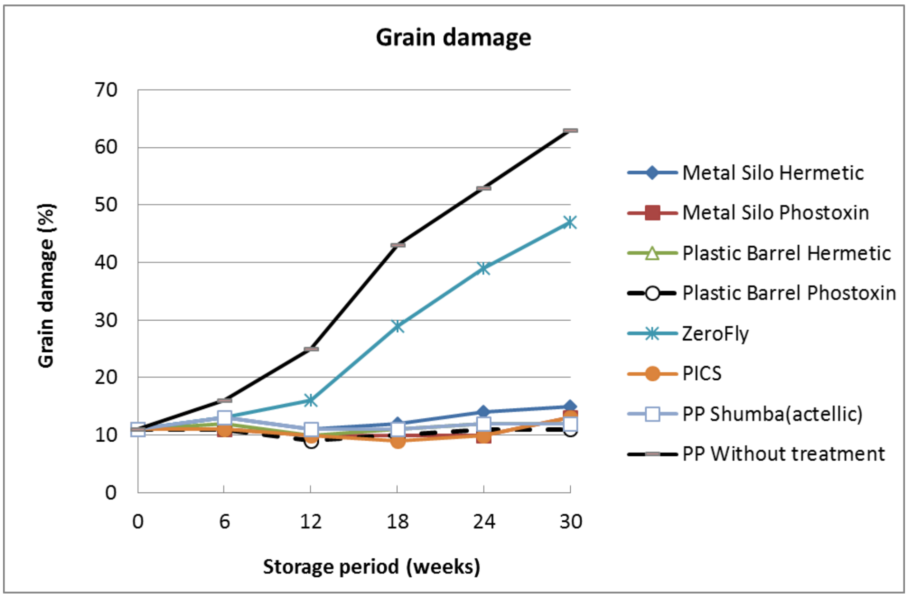

Fig. 4.11: Percent damaged grains in storage

Insect population was strongly correlated with grain damage (r=0.97; p<0.0001) (Annex 8). This was expected as large insect population cause higher damage. Therefore, preventing insect population from increasing is a critical factor for reducing grain damage. Also, insect population was slightly correlated with the humidity of storage treatments (r=0.55; p<0.0001), showing that a higher humidity in a storage container may increase insect population, and thereby increase grain damage.

Grain weight loss (dry weight basis) in polypropylene (PP Without treatment) and ZeroFly bags increased rapidly while weight loss did not change significantly in any of the remaining storage treatments (Fig. 4.12).

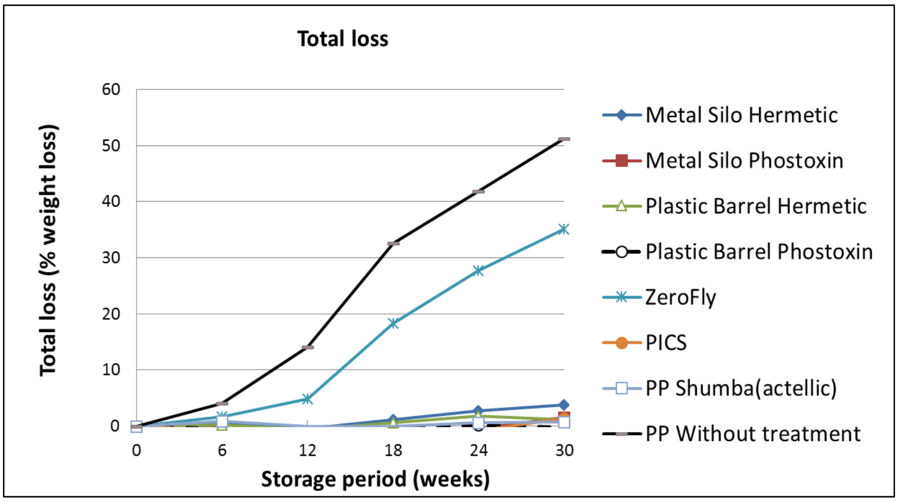

Fig 4.12: Percent weight loss (dry matter basis) in storage

At 30 week storage, weight loss was significantly higher ($p<0.05$) in untreated maize stored in ZeroFly (35.1%) and PP bags (51.2%) than in the other storage treatments, which ranged from 0 - 3.8% (Fig. 4.12, Annex 6).

4.6 Contribution of insect damage and fungi infection to grain spoilage of stored maize grain

Regarding the contribution of insect damage and fungi infection to grain spoilage, results showed that damage by insects was the major source of grain damage. Damage by insects was responsible for 52.4% out of the total 63.1% grain damage observed in PP without treatment while in the ZeroFly bags, insect damage was responsible for 38.3% of the total grain spoilage of 46.7 (Fig. 4.11 and Annex 7). Similar trends were observed for all the other storage technologies.

Similarly, Fig. 4.13 shows that fungi spoilage slightly contributed to total grain spoilage. Fungi infection increased with storage period in all the storage treatments. The severity of fungi spoilage at the end of 30 weeks in PICS bags was significantly higher ($p<0.05$) than in PP without treatment, which was the least (1.4%) (Annex 8). However, no significant difference was observed between fungi infection in PICS and any of the remaining storage treatments. Fungi infection could be a result of moisture condensation in airtight containers, especially in PICS bags.

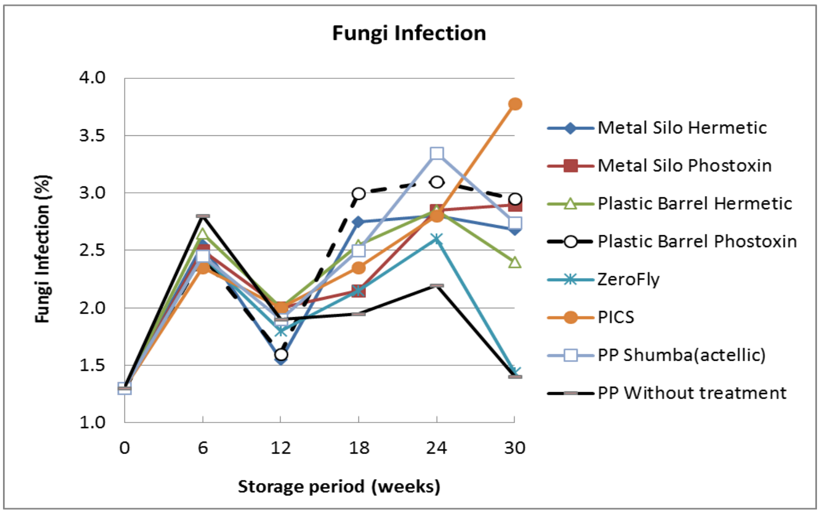

Fig. 4.13 Fungi infection of stored maize grains as affected by storage time and treatment

4.7 Effect of storage location on maize quality

Results showed that grain damage, *Sitophilus zeamais* population per 1000 grains and weight loss were significantly higher ($p<0.05$) in Manyara than Dodoma at 30 weeks' storage. Surprisingly, *Tribolium castaneum* population was less in Manyara than in Dodoma. Apart from PICS bags, we observed no significant differences between the two storage locations in any other storage treatment regarding fungi infection, grain damage, weight loss (%), *Sitophilus zeamais* population per 1000 maize grain and *Tribolium castaneum* population per 1000 maize grain (Annex 9). In summary, maize grains stored in the various storage containers in Dodoma seem to be of better quality after 30 weeks of storage than maize stored in Manyara.

4.8 Seed germination

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. Results suggest that germination was affected by storage treatment and location. Maize seeds at the onset of the trial showed 92% germination at eight days after planting. Not less than 80% germination rate was stipulated for commercial purposes in many parts of the world (Anonymous, 2016c; FAO, 2016). After 30 weeks of storage, all treatments met this requirement (on average over all locations) except ZeroFly and PP bags without treatment; germination rate was reduced on average to 67% and 59% for these two treatments, respectively (Annex 10).

Germination rate was slightly lower for all treatments for the more humid region of Manyara compared to drier Dodoma. Storage had a significant effect on percent grain germination ($p<0.0001$; Annex 11). We observed insignificant differences between seed germination at onset and that at 18-week storage ($p=0.9941$). However, the viability of seeds at 30 weeks was significantly reduced compared to that at onset and 18-week storage ($p<0.05$). Germination quality of stored seeds at 30-week storage was significantly affected by location ($p=0.0001$) and storage treatment ($p<0.0000$) but not by their interaction ($p>0.3$) (Annex 11).

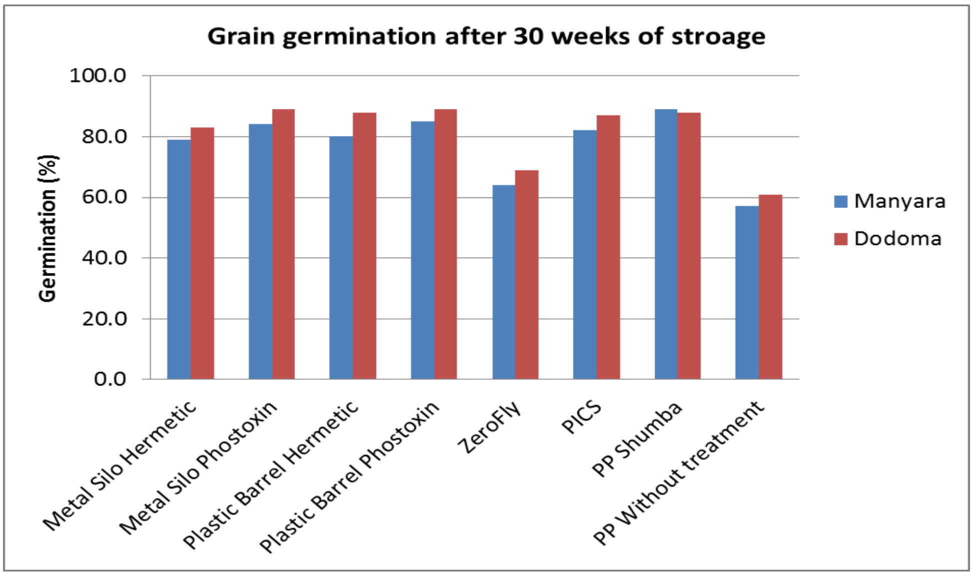

Figure 4.14: Effect of storage treatment on percent germination of maize grain after 30 weeks

5. **Farmers' perception**

Farmers (20 respondents: 6 female, 14 male; 70% between 40 and 60 years old) rated the hermetic storage technologies (metal silo, plastic barrel and PICS bags) without insecticide application as most *effective* to control storage pests. However, different to trial results, PP Shumba was not rated as effective. Farmers also *liked* the same hermetic technologies best. Metal silos were preferred compared to plastic barrels[2]. Even though PP bags without insecticide application did not control storage pests, farmers still liked them due to being a cheap technology. PP Shumba and above all ZeroFly bags were the least preferred. Farmers indicated that the Shumba treatment was disliked because it alters the taste of the grain.

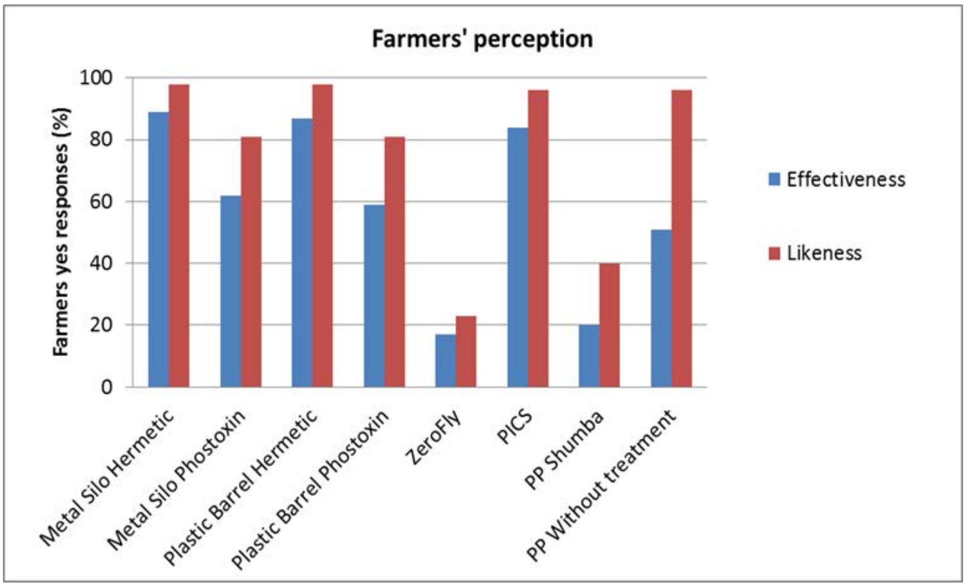

Figure 4.15: Farmers' perception on effectiveness and likeness of different storage treatments

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[2] The follow-up reveals that farmers are not willing to buy plastic barrels as the quantity stored (120 kg) is too small, and farmers prefer to buy hermetic bags for such small quantities.

6. Conclusions

Sitophilus zeamais and *Tribolium castaneum* were the most important insects found during the trial, and they posed significant risks to farmers by causing grain loss and economic damage to stored maize, especially in non-hermetic containers. As expected, insect infestation was high in polypropylene bags without insecticide treatment and also in ZeroFly bags. There was a strong correlation between the insect population and grain damage. Although there were many other agents of grain damage (fungi, grain breakage, and soforth), insects were responsible for the largest proportion of the grain damage. Therefore, controlling insect population could be the most important means of preventing food loss and waste of grains in storage.

All the hermetic storage technologies tested were effective in preventing maize damage by insects for a storage period of 30 weeks (about seven months) and can be recommended. Since there was no significant difference between hermetic treatments (with or without phostoxin) airtight storage alone can be recommended to farmers provided that: a) high quality of technologies is ensured i.e. metal silo, and plastic barrel are absolutely airtight and b) sound handling and management of the technologies by farmers i.e. proper placement and hermetic sealing of lids. Irrespective whether maize is initially fumigated with phostoxin or not, re-infestation of insects must be avoided during the intermittent opening of sealed containers to take out food during storage, as the farmers are likely to use the hermetic technologies. Sturdy hermetic containers like the metal silo and plastic drums have the advantage of not being damaged by rodents which is an advantage compared to some brands of hermetic bags.

High humidity or moisture condensation could become significant in airtight containers when adopted by farmers if the grain was not sufficiently dried i.e. to ≤13% moisture content. Stored grains may retain higher moisture contents and could increase the chances of fungi spoilage. Due to the slightly higher environmental humidity in some villages at high elevation in Manyara than Dodoma villages, farmers in Manyara face more risks of grain damage during storage than farmers in Dodoma. Hence farmers need to dry their maize adequately if they would adopt hermetic technologies.

The use of polypropylene bags with maize treated with Actellic Super, a traditional practice, was effective in controlling insect damage. However, the application of insecticides to staple food should be avoided hence hermetic storage without application of insecticides is to be preferred. Farmers clearly indicated that the treatment with Actellic Super is not liked because it alters the taste of the grain.

Storage of seeds for 30 weeks led to a significant reduction in germination, especially for non-treated storage methods (ZeroFly and PP bags). Hence the use of appropriate storage technologies is also important for farmers to keep their own seed viable for next planting season.

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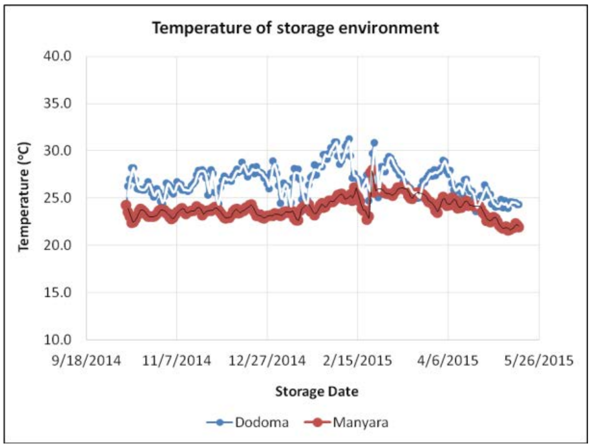
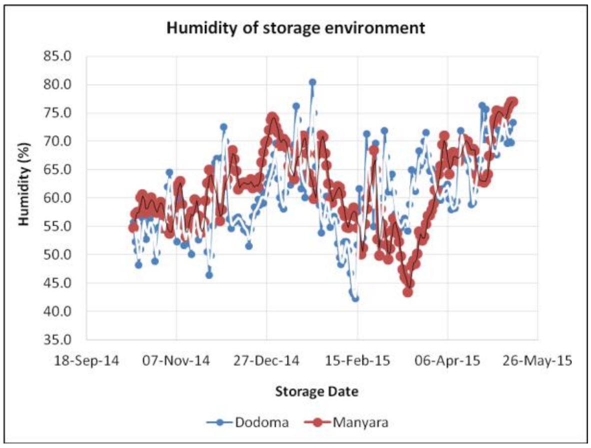
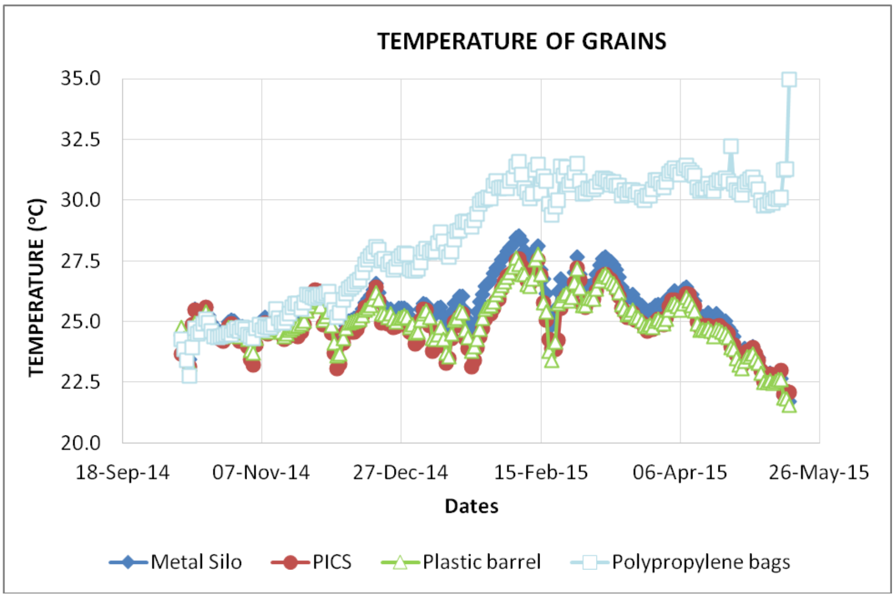
8. Annexes

Annex 1: Temperature and relative humidity of trial regions

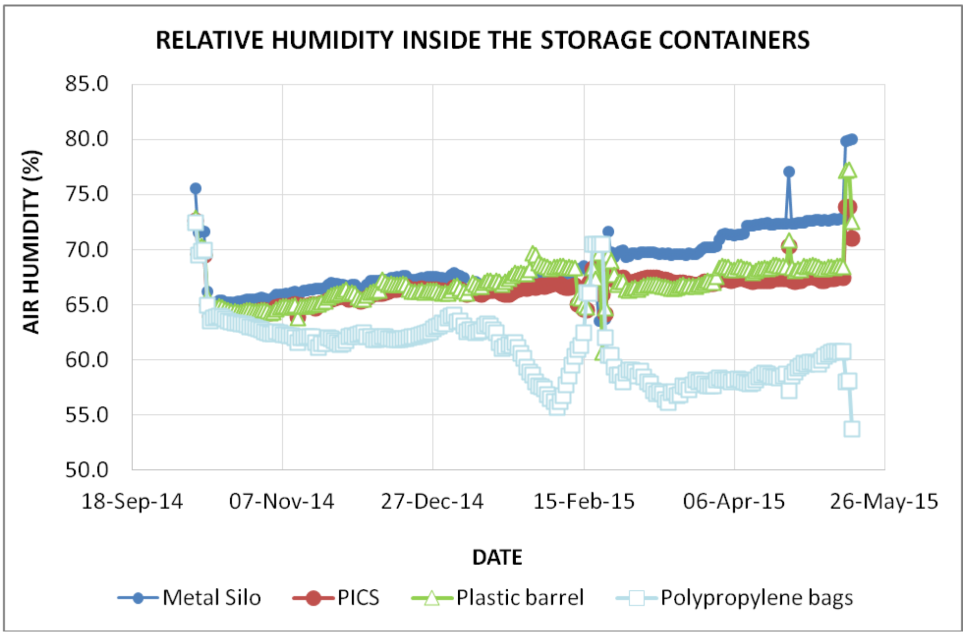




Annex 2: Temperature inside the storage containers (data logger)



Annex 3: Relative humidity inside the storage containers (data logger)



Annex 4: Correlation coefficients and P-values for storage parameters

Storage Index	MMC	SAA	TAA	SAA+T	BD	NI	NFI	NBG	NOG	SDG	TDMG	FTemp	HSTT	TSTT
Maize Moisture Content (MMC)	1.00	-0.07	-0.13	-0.10	0.10	-0.13	0.16	0.01	-0.02	-0.02	-0.10	-0.45	-0.46	0.72
Sitophilus Alive Adults (SAA)		1.00	0.45	0.96	-0.54	0.62	-0.11	-0.18	-0.04	-0.03	0.63	0.13	0.21	-0.02
Tribolium Alive Adults (TAA)			1.00	0.67	-0.44	0.52	-0.02	-0.22	-0.10	0.01	0.53	0.09	0.32	-0.13
Sitophilus Alive Adults+Tribolium (SAA+T)				1.00	-0.58	0.67	-0.10	-0.21	-0.06	-0.02	0.68	0.13	0.28	-0.07
Bulk density (BD)					1.00	-0.75	0.01	0.20	0.05	-0.19	-0.80	0.05	-0.38	0.09
No. Insects (NI)						1.00	-0.13	-0.19	-0.13	-0.03	0.97	0.09	0.55	-0.21
No. Fungi (NFI)							1.00	-0.06	-0.03	-0.07	0.02	-0.09	-0.06	0.05
No. Broken grains (NBG)								1.00	0.15	-0.27	-0.16	-0.07	-0.10	0.04
No. Overheated grain (NOG)									1.00	0.01	-0.10	0.13	-0.03	-0.04
No. Stunted grain (NSG)										1.00	0.03	-0.01	-0.03	0.15
Total damage (TDMG)											1.00	0.07	0.54	-0.18
Maize Field Temperature (FTemp)												1.00	0.52	-0.36
Average humidity of storage treatment (HSTT)													1.00	0.01
Average temperature of storage treatment (TSTT)														1.00

Annex 5: Percent damaged grains at 30-week storage

Storage treatment	% damaged grains
Metal Silo Hermetic	15.4c
Metal Silo Phostoxin	13.0c
Plastic barrel hermetic	12.1c
Plastic barrel Phostoxin	10.6c
ZeroFly	46.7b
PICS	12.6c
PP Shumba	11.9c
PP without treatment	63.1a

*Mean values followed by the same letters are not significantly different at $p<0.05$.

Annex 6: Percent weight loss (DM basis) at 30-week storage

Storage treatment	% weight loss
Metal Silo Hermetic	3.8c
Metal Silo Phostoxin	1.6c
Plastic barrel hermetic	1.2c
Plastic barrel Phostoxin	0.6c
ZeroFly	35.1b
PICS	1.4c
PP Shumba	0.8c
PP without treatment	51.2a

*Mean values followed by the same letters are not significantly different at $p<0.05$.

Annex 7: Insect contribution to grain spoilage at 30-week storage.

Storage treatment	% insect damage	Std Dev	Minimum	Maximum
Metal Silo Hermetic	5.7dc	6.0	1.0	22.7
Metal Silo Phostoxin	3.2dc	6.0	0.0	21.9
Plastic barrel hermetic	3.4dc	5.3	0.0	21.6
Plastic barrel Phostoxin	1.7d	2.2	0.0	8.8
ZeroFly	38.3b	19.9	0.1	74.0
PICS	1.9d	5.7	0.0	35.1
PP Shumba	2.4dc	3.3	0.3	15.7
PP without treatment	52.4a	15.5	20.5	94.8

*Mean values followed by the same letters are not significantly different at $p<0.05$.

Annex 8: Fungi infection contribution to grain spoilage at 30-week storage

Storage treatment	% fungi infection	Std Dev	Minimum	Maximum
Metal Silo Hermetic	2.8ab	1.9	0.6	7.9
Metal Silo Phostoxin	2.8ab	2.6	0.3	10.7
Plastic barrel hermetic	2.5ab	2.0	0.1	8.7
Plastic barrel Phostoxin	2.7ab	2.0	0.5	7.7
PICS	3.8a	6.3	0.4	40.5
ZeroFly	1.5ab	1.3	0.0	5.6
PP Shumba	2.7ab	2.3	0.4	8.3
PP without treatment	1.4b	1.4	0.0	6.2

Annex 9: Effect of storage environment on maize quality indices after 30-week storage

Storage treatment	Dodoma		Manyara		P-values
	Mean	Std Dev	Mean	Std Dev	
Fungi infection					
Plastic barrel hermetic	0.4	0.2	0.3	0.1	0.22
Metal Silo Hermetic	0.3	0.2	0.2	0.1	0.09
Plastic barrel Phostoxin	0.3	0.2	0.4	0.1	0.10
ZeroFly	0.0	0.0	0.1	0.1	0.00
Metal Silo Phostoxin	0.4	0.2	0.3	0.1	0.01
PICS	0.4	0.2	0.4	0.2	0.90
PP Shumba	0.3	0.2	0.3	0.1	0.10
PP without treatment	0.0	0.0	0.0	0.0	0.00
Sitophilus zeamais population per 1000 grains					
Metal Silo Hermetic	24.1	45.5	30.3	51.4	0.78
Metal Silo Phostoxin	17.1	30.8	31.9	46.6	0.41
Plastic barrel hermetic	2.0	2.1	5.6	7.4	0.17
Plastic barrel Phostoxin	3.5	3.3	4.9	8.2	0.62
ZeroFly	261.9	119.3	171.7	150.1	0.17
PICS	2.2	5.1	4.0	10.4	0.04
PP Shumba	0.3	1.0	0.5	1.8	0.71
PP without treatment	151.8	122.8	89.8	142.6	0.15
Tribolium castaneum population per 1000 grains					
Metal Silo Hermetic	26.1	37.8	3.1	8.8	0.10
Metal Silo Phostoxin	4.0	8.6	0.2	0.4	0.19
Plastic barrel hermetic	3.8	6.5	0.2	0.4	0.11
Plastic barrel Phostoxin	2.8	2.4	0.3	0.5	0.01
ZeroFly	55.1	60.3	29.0	34.6	0.11
PICS	1.5	5.8	0.4	0.9	0.11
PP Shumba	2.0	6.8	0.0	0.0	0.23
PP without treatment	59.5	51.6	52.4	51.0	0.66
Grain damage					
Metal Silo Hermetic	13.6	6.4	17.1	7.6	0.29
Metal Silo Phostoxin	10.1	5.1	15.8	8.2	0.09
Plastic barrel hermetic	10.4	3.7	13.9	7.8	0.22
Plastic barrel Phostoxin	9.5	3.4	11.7	3.4	0.22
ZeroFly	43.4	13.9	49.8	22.0	0.30
PICS	9.0	3.6	16.1	13.4	0.03
PP Shumba	10.4	4.3	13.3	4.2	0.06
PP without treatment	59.4	11.0	66.9	17.7	0.11
Weight loss (%)					
Metal Silo Hermetic	11.1	4.8	13.5	5.9	0.34
Metal Silo Phostoxin	8.3	3.9	12.4	5.6	0.08
Plastic barrel hermetic	8.6	0.9	10.7	1.8	0.30
Plastic barrel Phostoxin	7.9	2.9	9.2	2.6	0.26
ZeroFly	33.9	10.7	37.1	15.8	0.46
PICS	7.5	2.8	12.6	9.4	0.03
PP Shumba	8.7	3.3	10.5	3.4	0.11
PP without treatment	46.8	10.1	50.4	14.6	0.37

Annex 10: Germination of seeds at 30 weeks of storage

Storage treatment	% germination		
	Manyara	Dodoma	Mean
Metal Silo Hermetic	79	83	81
Metal Silo Phostoxin	84	89	87
Plastic barrel hermetic	80	88	84
Plastic barrel Phostoxin	85	89	87
ZeroFly	64	69	67
PICS	82	87	84
PP Shumba	89	88	87
PP without treatment	57	61	59

Annex 11: Factorial analysis of variance of the effect of location and storage methods on germination percent of store maize grain

General Linear Model Analysis of Variance for Germination Percent (G8C)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	50733.002[a]	31	1636.548	5.754	.000
Intercept	698109.840	1	698109.840	2454.387	.000
Village	4711.894	3	1570.631	5.522	.001
Storage	39073.239	7	5581.891	19.625	.000
Village * Storage	6907.364	21	328.922	1.156	.302
Error	34985.322	123	284.434		
Total	786614.640	155			
Corrected Total	85718.324	154			

a. R Squared = 0.592 (Adjusted R Squared = 0.489)