Effect of hermetic facilities on stored maize insect infestation and grain quality

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Abstract

Household food security in sub-Saharan Africa (SSA) is threatened by insect pests during grain storage and farmers often use synthetic pesticides. However, use of these pesticides is associated with development of resistance among targeted insect species and deleterious effects against untargeted species *inter alia*. The use of hermetic principles for pesticide-free grain storage is regarded globally as a potentially sustainable and environmentally benign alternative to synthetic pesticides. To assess the effectiveness of pesticide-free hermetic grain storage, a 12-month on-station experiment was conducted in two contrasting agro-ecological regions of Zimbabwe. The experiment was set in a completely randomized design consisting of three replicates of four treatments namely: hermetic metal silo, hermetic grainbag, polypropylene bags with and without synthetic pesticide. The last two served as positive and negative controls, respectively. For each set of treatments, there were two modes of infestation: natural and artificial. Artificial infestation involved adding unsexed adult insect species of *Sitophilus zeamais* and *Prostephanus truncatus* while in natural infestation, no insects were added. Non-destructive sampling was conducted monthly. Collected samples were assessed for insect numbers, species spectrum, insect damage and weight loss. Germination tests were conducted initially and at termination of the experiment. Hermetic treatments controlled grain damage and weight loss as compared to non-hermetic treatments. There were significant differences ($P<0.05$) for the two parameters between hermetic and non-hermetic treatments. Seed viability was also maintained in hermetic treatments with high germination percentages (>72%) compared to non-hermetic treatments (< 65%). Overall, hermetic facilities can effectively suppress insect development and consequently reduce losses and maintain seed viability during storage without use of pesticides. The hermetic technologies can be an effective grain protection alternative that enhances the livelihood of smallholder farmers. The results are discussed in the context of appropriateness of the technology for smallholder use in developing countries.

Keywords: synthetic pesticides, hermetic metal silo, hermetic grainbags, polypropylene bags, germination, grain storage

1. Introduction

Maize is one of the major cereal crops grown in sub-Saharan Africa (SSA) with production constituted mainly by smallholder farmers who rely on agriculture for their livelihood. Seasonality of grain production amid constant demand throughout the year gives storage a critical role to play in ensuring household food security and source of income until the next harvest. Granivorous insect pests pose a threat to household food security as they feed on stored grain resulting in quantitative, qualitative and economic losses. These losses translate to weight loss, loss of seed viability and reduced price value which affects the livelihood of farmers. Some farmers avoid incurring storage losses by selling grain soon after the harvest (Olayemi et al., 2012; Tefera and Abass, 2012; Utono, 2013) despite the low prices experienced during the early period of the storage season. Farmers often have to buy grain later at a higher price, consequently falling into the poverty trap (Tefera and Abass, 2012).

The majority of smallholder farmers in many parts of Africa use synthetic pesticides for grain protection against storage insect pests (Mvumi et al., 1995; Mvumi and Stathers, 2003). However, over the years, negative attributes have been associated with synthetic pesticide use including the presence of toxic residue in food products, toxicity against untargeted species and development of resistance by targeted species (Champ and Dyte, 1976; Giga and Mazarura, 1990; Subramanyam and Hagstrum, 1996; Guedes et al., 1996; Haines, 2000; Harish et al., 2013). Development of resistance is a natural evolutionary phenomenon of living organisms but accelerated by user failure to follow recommended application procedures; either deliberately or due to lack of adequate knowledge. This has posed a challenge as available effective chemical control options are becoming limited (Mvumi and Stathers, 2003; Collins, 2006; Fields, 2006) hence the need for alternatives is becoming increasingly essential (Fields, 2006; Navarro et al., 2008).

One environmentally benign alternative that has been identified by researchers is the application of the hermetic principles for grain storage purposes. This utilises metabolism of living organisms within airtight storage facilities resulting in an atmosphere of reduced oxygen concentration levels (hypoxia) and elevated carbon dioxide levels (hypercarbia) which is toxic to arthropods. The modified environment within the airtight storage facilities affects respiration of insects leading to reduced feeding activity, desiccation (Murdock et al., 2012; Navarro, 2012)and accumulation of toxic compounds within insect bodies (Chapman, 1971) consequently leading to death. Available hermetic grain storage facilities have a wide capacity range and include hermetic grain bags, metal silos, cocoons and underground bunkers. Metal silos and hermetic grain bags are among the options suitable for smallholder farmers and their use in Africa is still limited although their effectiveness in reducing storage losses has been confirmed by a number of researchers (Murdock et al., 2012; de Groote et al., 2013; Njoroge et al., 2014). However, the performance and appropriateness of the technologies need to be validated under different biophysical and socio-economic circumstances. The current experiment was conducted to investigate the effectiveness of hermetic storage facilities in reducing storage losses and preserving grain quality under simulated smallholder farmer conditions in two contrasting agro-ecological regions of Zimbabwe.

2. Material and Methods

2.1. Site description

The study was conducted at the Institute of Agricultural Engineering (IAE) at Hatcliffe Farm in Harare Province with humid sub-tropical climatic conditions (mean annual temperature of 18°C, 55% r.h., rainfall 825 mm)and Makoholi Research Station (MRS) in Masvingo Province with sub-tropical climatic conditions (mean annual temperature 20°C, 42% r.h., rainfall 614 mm).

2.2. Test insects and maize grain

Insect species *Prostephanus truncates* Horn and *Sitophilus zeamais* Motschulsky were obtained from an existing culture at the Entomology Laboratory in the Department of Crop Science, University of Zimbabwe. Maize grain (hybrid variety SC637) was obtained from the

IAE farm. This is a white semi-flint medium term maturing variety which is commonly grown in maize producing areas in Zimbabwe.

2.3. Experimental design and treatments

The experiment was set up in a completely randomised design consisting of four treatments, namely: hermetic metal silo; hermetic grainbag; non-hermetic polypropylene bag plus Actellic Gold Chirindamatura Dust®(AGCD) (pirimiphos-methyl 1.6% w/w + thiamethoxam 0.36% w/w), a registered commercial synthetic pesticide (treated positive control); and non-hermetic polypropylene bag minus pesticide (untreated negative control). Two modes of infestation were used: natural and artificial infestation. The latter was used just in case there was not going to be sufficient insect infestation to challenge the treatments. Each treatment was replicated thrice and arranged in a completely randomised design, housed in brick-under-asbestos ordinary rooms.

The hermetic facilities were used without application of any pesticide. Metal silos with a capacity of 100kg of similar material specifications and design to those which originated from South America were fabricated as per order by a local general engineering company. Hermetic grainbags (HGBs) of 40kg capacity consisting of two inner plastic liners with low oxygen permeability and an outer polypropylene bag were procured from Mash Agrik (Pvt) Ltd, a South African company. No pesticide was added to metal silo and HGB treatments. After loading grain, air was removed from the bags by squeezing the loaded HGBs and then tying the triple bags separately using rubber bands while the inlet and outlet of the metal silos were closed using lids and then sealed using packaging tape to effect a hermetic seal. The positive control treatment (AGCD) was applied at label rate. Each treatment replicate was 40 kg; and this allowed easy trying to create a hermetic environment in the case of the HGBs.

2.4. Infestation procedure

Natural infestation- unsterilized grain was used without addition of insects. Artificial infestation- the grain was disinfested by fumigation using Phostoxin® tablets at label rate. Mixed adult unsexed test insects were added to the treatments at a ratio of one insect species per 2kg of maize grain (20 *S. zeamais* and 20 *P. truncatus*). Both natural and artificial infestation were setup simultaneously at each site.

2.5. Sampling and sample assessments

Baseline grain samples were collected at trial setup and at 30-day intervals thereafter for twelve months from December 2012. Non-destructive sampling was conducted using double tube multi-slotted brass sampling spears. After sampling the hermetic treatments were then closed and re-sealed. The seal of the metal silo outlet was also checked and replaced if necessary. Samples of about 1 kg per replicate were collected at each sampling and assessed for insect damage, weight loss, insect species spectra and population (live and dead), and m.c.

2.6. Germination tests

The tests were carried out at the beginning and end of the experiment in the laboratory under room temperature according to the procedure outlined by ISTA, (2006) where 100 maize kernels were taken at random from the collected samples and then placed in petri dishes containing cotton wool. Water was added to moisten the cotton wool and the petri dishes were left in the laboratory for 7-10 days ensuring that the cotton wool was moist throughout the duration of the tests. Germinated and non-germinated seeds were counted, recorded and the percentage germination calculated for each of the treatments.

2.7. Data management and analysis

MS Excel was used to calculate % grain damage, % weight loss and % germination for each replicate. Loss assessment was conducted using the "Count and Weigh Method" (Harris and Lindblad, 1978. Data on number of insects were log-transformed (Log10), while percent grain damage and weight loss were angular transformed (arcsine √proportion) in order to stabilize the variance. A two- way analysis of variance (ANOVA) (treatment and time) was performed on transformed values using SAS (SAS Institute, 2010). Where significant differences were found, the Tukey's HSD test was used to separate the means at $p \leq 0.05$.

3. Results and Discussion

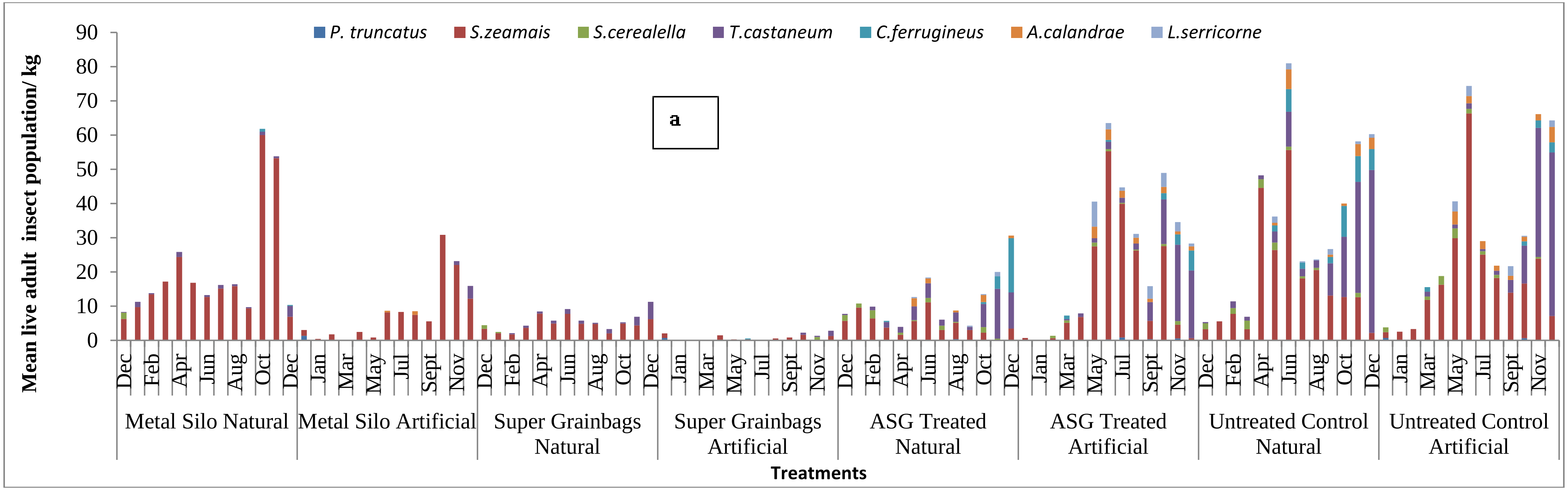
3.1. Live insect spectra and counts

Hermetic treatments suppressed insect development throughout the storage period as compared to non-hermetic treatments especially the HGBs treatments which had a population of (< 20insects/kg). *Sitophilus zeamais* was the predominant species at both sites in all the treatments although it was succeeded in non-hermetic treatments near the end of the storage period by secondary insect pest species namely *Tribolium castaneum* (Herbst) and *Cryptoleste ferrugineus* (Stephens) at both sites (Fig 1).

Hermetic storage facilities created a barrier against re-infestation hence prevent entering of insects during storage. This also contributed to the low live insect population together with the modified atmospheres created during respiration of living organisms within the facilities which negatively affected insect fecundity. Metal silo treatments had a higher insect population density compared to HGBs due to a larger headspace volume in the silos since 40kg of grain was loaded into each of the 100kg capacity silo. This was mainly because of shortage of grain at the time of setting the experiments. The headspace is directly proportional to the amount of oxygen available for use by living organisms within the facilities. Recommended practice is to almost completely fill hermetic containers with grain to reduce the headspace volume to grain mass ratio so as to reduce chances of insects multiplying and causing damage before a hypoxic atmosphere which suppresses insect development is created (Navarro *et al*., 1994). This could have triggered insect fecundity from October onwards where prevailing hot weather conditions favour insect development. *Sitophilus zeamais*, a primary insect pest was the predominant species in hermetic treatments during the entire storage period. Low population of secondary insect pests throughout the storage period can be an indication of existence of unfavourable conditions for development due to low grain damage and consequently less amount of grain dust which is their main diet. Interrelations within the grain storage ecosystem leads to ecological succession of insect species as grain deteriorate creating a conducive environment for some species while others find the same environment unfavourable (Arbogast and Mullen, 1988).

Non-hermetic treatments had a high insect population and wide range of insect spectra. This can be attributed to the inability of the treatments to limit re-infestation during storage. *S. zeamais* was predominant for up to 10months after which secondary insect pests began to dominate. There was a low initial insect population in AGCD treatments which increased with time after about three months and this can be attributed to limited persistence of the pesticide with time and increasing infestation pressure emanating from the untreated control.

However, in all the treatments and across both sites *P. truncatus* population remained low throughout the storage period and this can be attributed to the behaviour of the insect pest whose occurrence is reportedly highly sporadic and variable spatially and temporally (Hodges et al., 2002; Hodges, 2002; Hill et al., 2002). The high aggregation tendency has implications on sampling strategies.


Mean live adult insect population/ kg
P. truncatus
S.zeamais
S.cerealella
T.castaneum
C.ferrugineus
A.calandrae
L.serricorne
a
Metal Silo Natural
Metal Silo Artificial
Super Grainbags Natural
Super Grainbags Artificial
ASG Treated Natural
ASG Treated Artificial
Untreated Control Natural
Untreated Control Artificial
Treatments

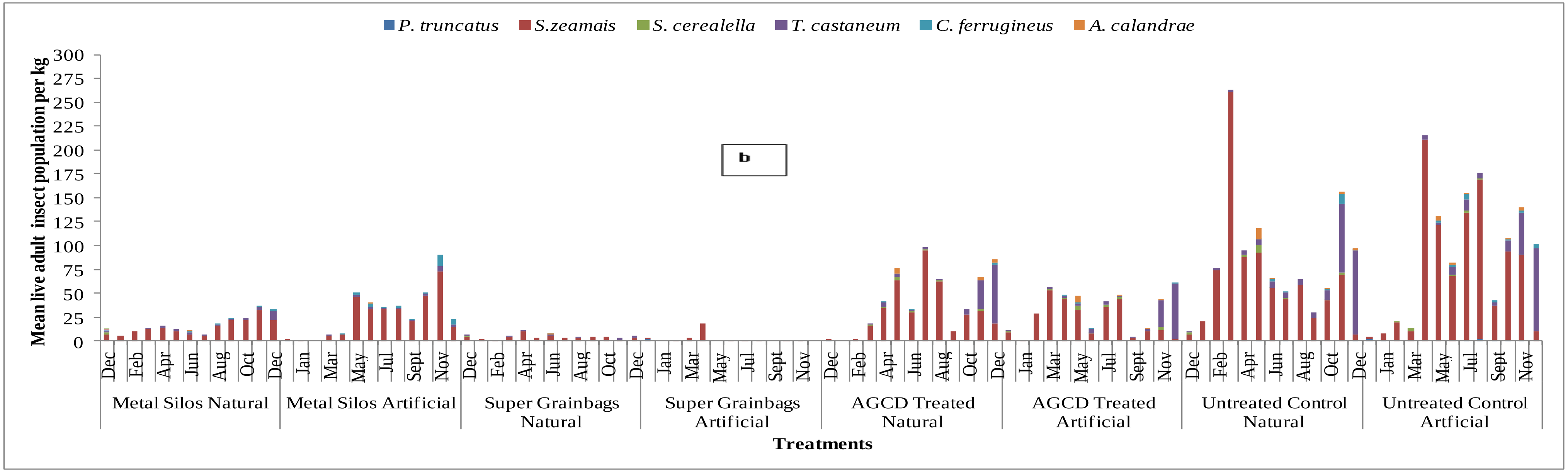


Figure 1 Mean live adult insect population per kg for a) IAE, b) Makoholi. (December 2012 to December 2013) (n=3)

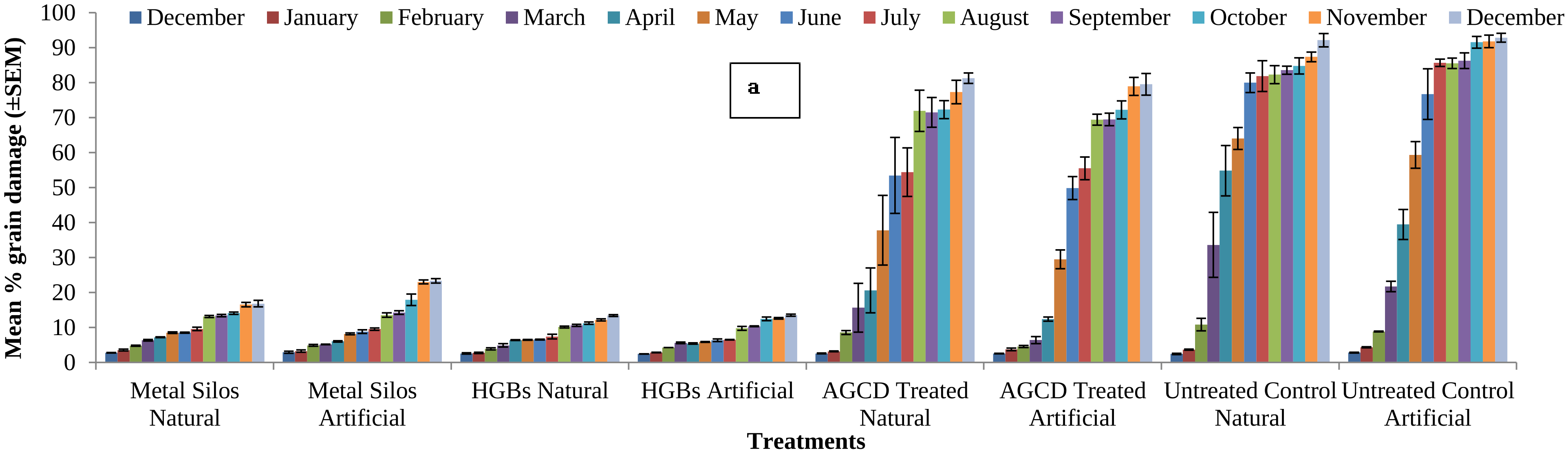
3.2. Gain damage and weight loss

Hermetic treatments suppressed insect damage more than non-hermetic treatments at both test sites (Fig 2). This can be attributed to the screening effect of hermetic facilities against re-infestation and reduced interaction between the biotic and abiotic components during storage. Although there were live insects within the hermetic facilities during the storage period (Fig 1), damage was still low after a year of storage and this can be attributed to the anti-feedant effect of hypoxic environments accompanied by controlled metabolism hence controlled insect damage (Murdock et al., 2012).

Non-hermetic treatments had high percentage insect damage due to high insect population. Insect damage translates to weight loss due to feeding of the insects on stored grain. There was a marked increase in damage with time. The positive control managed to effect control briefly but could not sustain the infestation pressure. There were significant differences for grain damage between hermetic and non-hermetic treatments (Table 1). Non-hermetic treatments (Untreated control and AGCD Treated) allow interaction of stored grain with the environment hence re-infestation could not be prevented this is in contrast to screening abilities of hermetic facilities.

Regardless of the mode of infestation, the damage trend was similar at both sites where the HGBs had the least damage and weight loss. This can be attributed to a low insect population throughout the storage period. Metal silos managed to control insect damage compared to non-hermetic treatments. The treatments at IAE incurred higher losses compared to those at Makoholi due to a wide insect spectra and favourable weather conditions for insect development that exist at IAE, Hatcliffe.

Utono, (2013) reported high correlation between Visual Damage Scale (VDS) and conventional count and weigh method where grain with high calculated losses had reduced price value. Hermetic treatments had low losses of (<24%) damage and according to the VDS by Utono, (2013), the grain is suitable for selling, home consumption and seed whereas the grain from non-hermetic treatments with high grain damage of (>57%) can neither be sold nor used as seed. Grain damage translates to weight loss due to insect feeding on grain and this is shown in Fig 3 where hermetic treatments also had low weight loss values and there were significant differences for weight loss among the four treatments (Table 1) with the HGBs being the most effective in controlling weight loss followed by Metal Silos, AGCD treatment with the untreated control being the least effective.


December
January
February
March
April
May
June
July
August
September
October
November
December
a
Mean % grain damage (±SEM)
100
90
80
70
60
50
40
30
20
10
0
Metal Silos Natural
Metal Silos Artificial
HGBs Natural
HGBs Artificial
AGCD Treated Natural
AGCD Treated Artificial
Untreated Control Natural
Untreated Control Artificial
Treatments

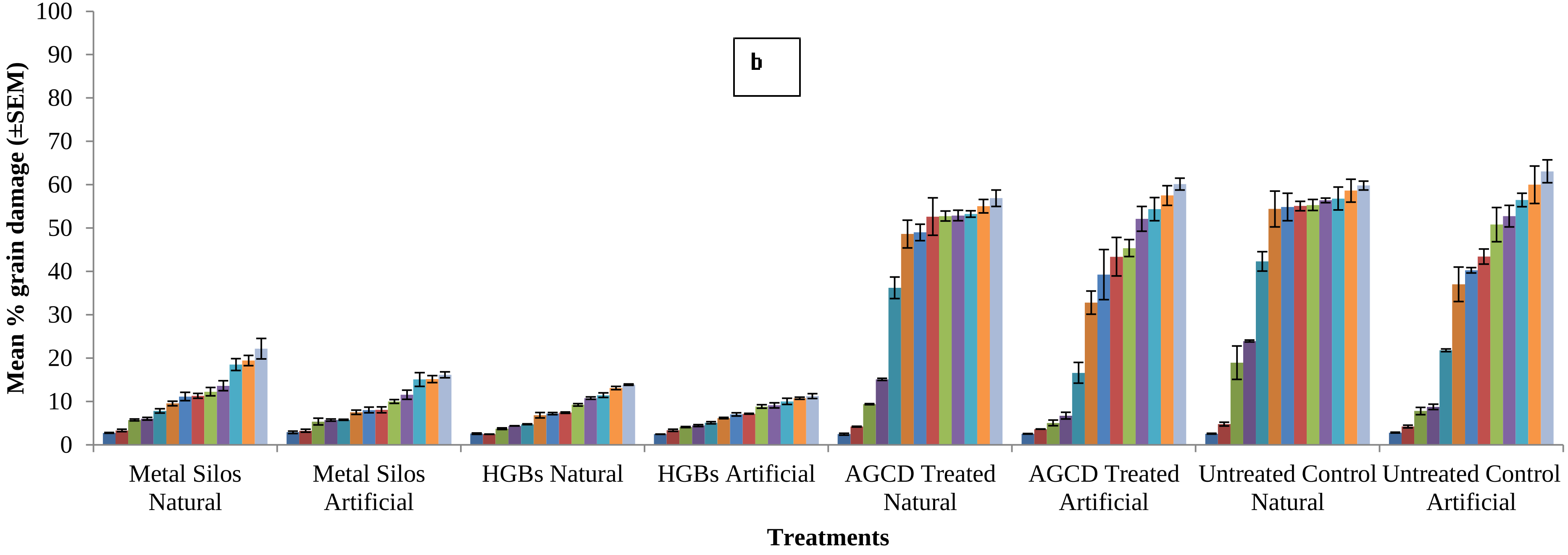


Figure 2 Mean insect grain damage (%) (±SEM) at a) Institute of Agricultural Engineering, Hatcliffe Farm, Harare; b) Makoholi Research Station. (December 2012 to December 2013) (n=3)[HGBs = Hermetic Grain Bags; AGCD = Actellic Gold Chirindamatura Dust]

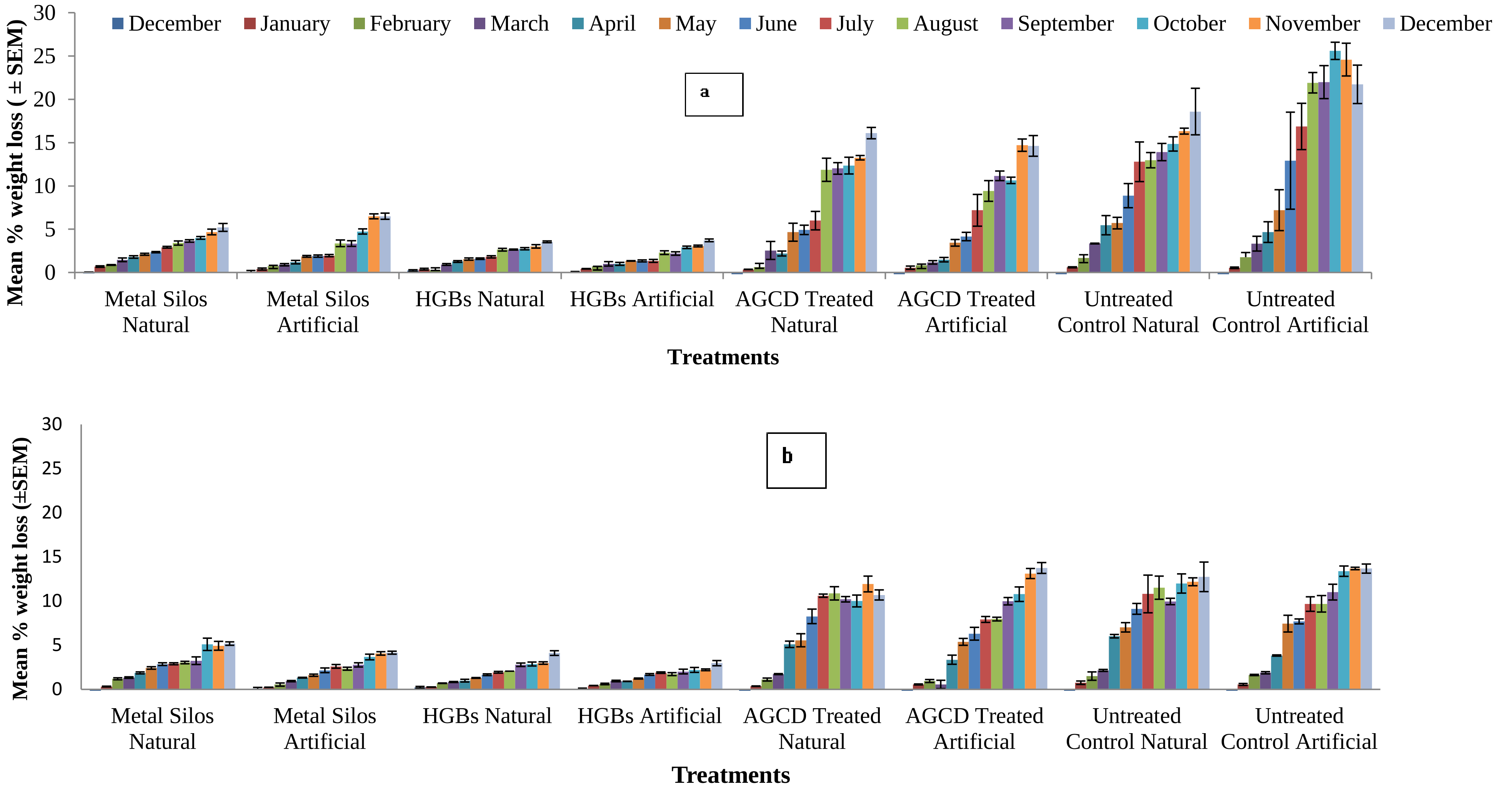


Figure 3 Mean grain weight loss (%) (±SEM) at a) Institute of Agricultural Engineering, Hatcliffe Farm, Harare; b) Makoholi Research Station. (December 2012 to December 2013) (n=3) [HGBs = Hermetic Grain Bags; AGCD = Actellic Super Gold Chirindamatura Dust]

Table 1 Percentage grain damage, weight loss and germination of maize after 12 months storage for IAE and MRS.

Treatments	% Grain Damage	% Weight Loss	% Germination
Metal Silos	10.11[c]	2.45[c]	86.08[a]
HGBs	7.40 [c]	1.64[d]	90.57[a]
AGCD Treated	38.72[b]	6.37[b]	71.21[c]
Untreated Control	48.12[a]	8.94[a]	61.16[c]
SE	1.09	0.24	14.09
Location			
IAE	29.60[a]	5.31[a]	75.14[a]
MRS	22.57[b]	4.39[b]	79.38[a]
SE	0.77	0.17	4.67

Values with the same letter within a column are not significantly different at (Tukey's HSD 5%)

3.3. Germination

Hermetic treatments preserved germination after 12months of storage with a germination of (>72%) compared to non-hermetic treatments (<62%) (Fig 4). There were no significant differences between the two hermetic treatments and between the two non-hermetic treatments (Table 1).HGBs had the highest germination at the end of the storage period for both sites, and this can be attributed to low insect population translating to low insect damage and consequently minimal seed damage. Metal silos had a higher germination percentage compared to non-hermetic treatments. AGCD (<62%) treatments had higher germination percentages than the untreated control (<48%). There were no significant differences between sites, although MRS had higher germination percentages (Table 1).

Germination is one of the most studied parameter in grain storage since it is among the best ways of investigating grain soundness and or grain quality (Pomeranz, 1982). Given that the majority of smallholder farmers use grain from previous harvest for seed (Dhliwayo and Pixley, 2003), storage facilities which preserve seed viability can enhance productivity under the smallholder farming system through use of quality seed.

The results corroborates to previous studies where both metal silos (de Groote et al., 2013) and hermetic bags namely Purdue Improved Crop Storage (PICS) bags (Murdock et al., 2012; Baoua et al., 2013; Njoroge et al., 2014), IRRI Super bags (Ben et al., 2009) and GrainPro bags (Baoua et al., 2013) managed to preserve grain quality, reduce grain damage and weight loss as compared to the conventional bag storage system. Majority of smallholder farmers in Zimbabwe use bag storage hence the hermetic storage facilities used in this study are ideal in terms of capacity and appropriateness of use under existing infrastructure.

4. Conclusion

The results show that pesticide-free hermetic storage facilities can be used to reduce storage losses. Hermetic storage has potential to contribute to smallholder farmers' food security where about 50% were reported to using synthetic pesticide wrongly (Mvumi et al., 1995). Both HGBs and metal silo treatments were more effective than non-hermetic treatments in reducing grain damage and storage losses. However, the potential of the metal silos was not fully realized since recommended practice was not fully adhered to. It is recommended to place a burning candle on the surface of grain in a loaded metal silo to enhance oxygen depletion and reduce the head space volume as much as possible by loading to capacity. The effect of *P. truncatus* on the storage systems was not discernible because of the failure of the pest population to establish in the trial. Hence further investigations are required to determine the impact of the pest.

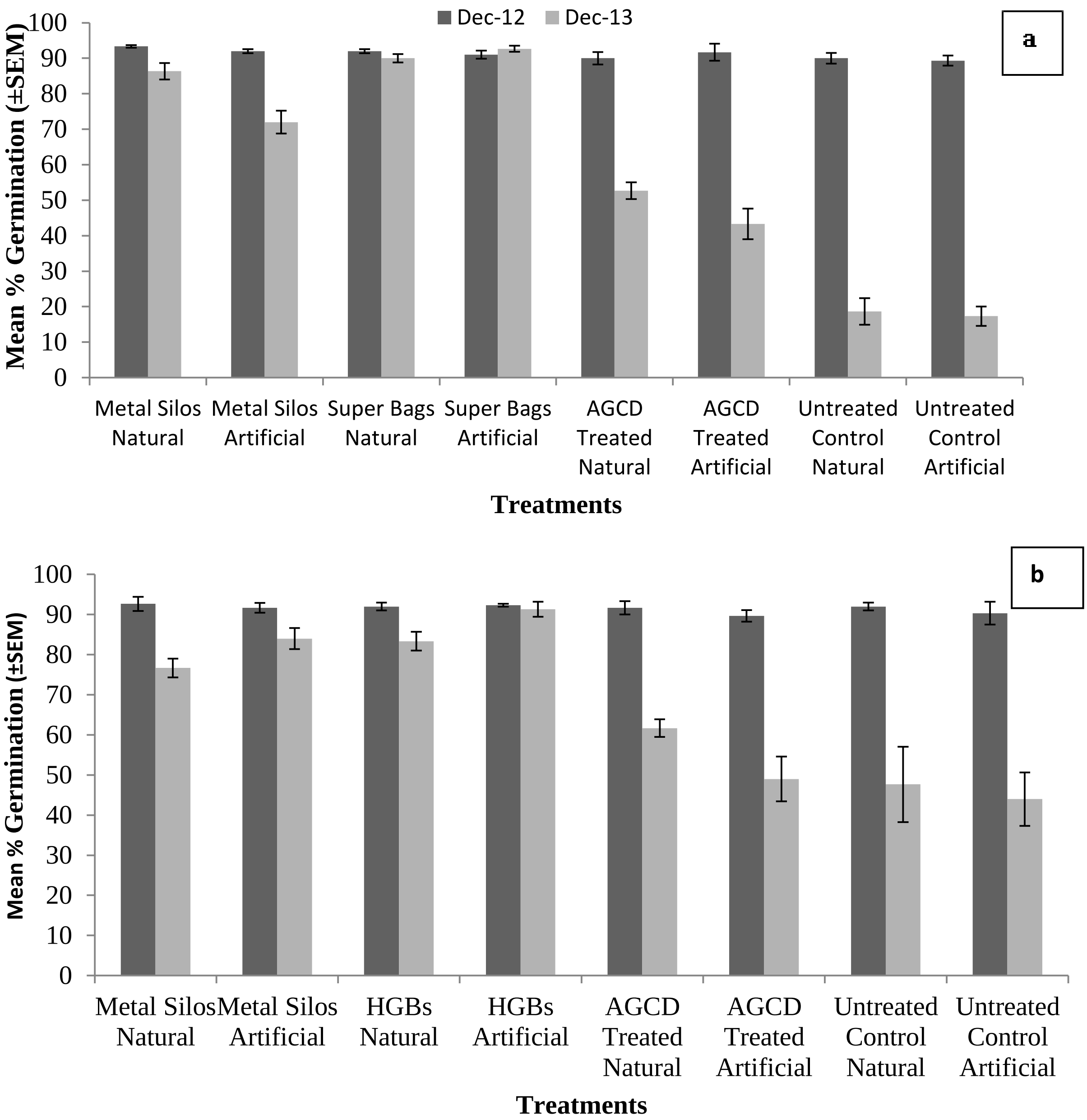


Figure 4 Mean percentage germination (±SEM) for (a) IAE, (b) Makoholi. (n=3)

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