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Efficacy of metal silos and hermetic bags against stored-maize insect pests under simulated smallholder farmer conditions

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A B S T R A C T

Pesticide-free hermetic grain storage is an environmentally-benign alternative to synthetic pesticides, currently being used in many countries. However, in some African countries knowledge gaps exist on the effectiveness of hermetic maize storage, particularly where the Larger Grain Borer (LGB), *Prostephanus truncatus* occurs. Trials simulating African smallholder farmer conditions were conducted at two sites in contrasting agro-ecological zones in Zimbabwe for up to 12 months during the 2013/14 storage season. There were two hermetic treatments: metal silos and hermetic bags; and two non-hermetic treatments: a registered synthetic pesticide and untreated control, in polypropylene bags. Two modes of infestation: natural and combined (natural plus artificial) were used as factors. Treatments were arranged in a completely randomised design and stored in ordinary rooms. Hermetic treatments were significantly superior ($P < 0.001$) to non-hermetic treatments in preserving germination, controlling insect population development, suppressing maize grain damage, controlling grain dust production and consequently limiting weight loss during storage. Hermetic bags were more effective than non-hermetic treatments in reducing storage losses despite the plastic liners having multiple insect-induced perforations of more than 300 holes per plastic liner at termination. However, there were no significant differences between metal silos and hermetic bags regardless of the mode of infestation. There was strong correlation between total insect population per kg and: percentage grain damage, percentage weight loss, and grain dust which indicate the importance of controlling insect pest development during storage to reduce losses. Results show that hermetic storage can be an effective pesticide-free alternative to synthetic pesticides in reducing grain storage losses under smallholder farming conditions, even where LGB occurs.
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1. Introduction

The livelihoods of the majority of sub-Saharan Africa's (SSA) population are directly dependent on agriculture. In SSA there is low agricultural productivity and low growth per capita agricultural output compared to global averages (FARA, 2006). Maize is among the major crops grown with production dominated by smallholder farmers. Increase in yields have been attributed to agriculture extensification (World Development Report, 2007), but given an ever-increasing population, feasibility of such an option is becoming unsustainable due to land scarcity (Bob, 2010; Stathers et al., 2013). Production-oriented efforts cannot meet food requirements without considering the post-production phase. Thus, the post-production phase, specifically storage is an important complementary component towards achieving household food and income security. Postharvest losses exceeding 20% have been reported in SSA mainly resulting from storage insect pest infestations (World Bank et al., 2011). These infestations result in economic, quantitative and qualitative losses, posing a threat to livelihood sustainability of already resource-constrained smallholder farmers. Predictions of decrease in maize yields (Auffhammer, 2011) and increase in insect pest severity and spectrum (Lumpkin, 2011; Stathers et al., 2013; Moses et al., 2015) as a result of climate change will translate to increased vulnerability of agriculture-dependent populations to poverty. This places importance on the need to protect whatever is harvested through use of effective grain storage management practices.

Although the direction is changing, past insect pest management strategies in grain storage were centred on synthetic pesticide use (Mvumi and Stathers, 2003; Collins, 2006). Cases of reduced efficacy due to development of resistance among targeted species,

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environmental and health-related concerns (Arthur, 1996; Collins, 2006; Harish et al., 2014), pesticide adulteration (Stevenson et al., 2012) and high cost associated with registration of new synthetic pesticides (Arthur, 1996; Sola et al., 2014), have resulted in limited effective chemical control options. The need for effective pest control options has increased to counter the threat to household food security posed by occurrence of *Prostephanus truncatus* (Horn) (Coleoptera; Bostrychidae) (Nyagwaya et al., 2010; Muatinte et al., 2014). *Prostephanus truncatus* is a highly destructive insect pest associated with high storage losses which can exceed 20% within six months of storage (Holst et al., 2000). Anecdotal reports from farmers suggest reduced efficacy of registered synthetic pesticides against grain storage insect pests, especially *P. truncatus*. Reduced synthetic pesticide performance against maize storage insects, *P. truncatus* and *Sitophilus zeamais* (Motschulsky) (Coleoptera; Curculionidae) has been reported in some African countries (Golob, 2002; Meikle et al., 2002; Mutambuki and Ngatia, 2012). This results in farmers incurring substantial storage losses despite having invested in protecting their harvest.

The need for extended storage periods to cater for household food security has increased owing to occurrence of frequent droughts in many parts of Africa; necessitating use of effective and environmentally-benign alternative methods to extend the storage period. Hermetic storage is one such alternative method researchers identified. The effectiveness of hermetic storage outside Africa at small-scale and commercial-scale, either as bio-generated or assisted modified atmospheres, is well-documented (Bailey, 1965; Varnava et al., 1995; Navarro et al., 2002; Quezada et al., 2006).

Research on the use of hermetic storage as an alternative grain storage option in Africa has increased, focusing mainly on the use of metal silos and hermetic bags (Murdock et al., 2012; Baoua et al., 2013; de Groote et al., 2013; Guenha et al., 2014). In SSA, hermetic storage containers are being promoted, but knowledge gaps exist in terms of their performance in comparison to the existing conventional storage practice of using synthetic pesticides especially over extended storage periods. Field research conducted so far has been over periods not exceeding eight months (Baoua et al., 2013; de Groote et al., 2013; Ognakossan et al., 2013; Baoua et al., 2014) with the majority of those studies only assessing performance of hermetic bags without comparing with conventional synthetic pesticides. Farmers in southern Africa store grain meant for household consumption for at least eight months. There is need for a comparative assessment of available small-scale hermetic storage containers with existing synthetic pesticides for at least eight months, especially in the presence of *P. truncatus*. This generates evidence that will facilitate uptake and sustainable adoption of the technologies among smallholder farmers. Trials simulating smallholder farmer grain storage conditions were therefore conducted to investigate the effectiveness of hermetic storage containers, namely; metal silo and Super Grainbag (SGB™) as alternatives to synthetic pesticides against stored maize grain insect pests.

Metal silos used were of similar design to those promoted in South America under the POSTCOSECHA program (Bravo, 2009; Tefera et al., 2011) but were made airtight and no pesticide was applied. Super grainbags, a hermetic technology, consist of a single high density polyethylene plastic liner with low oxygen permeability and housed inside a polypropylene bag to provide extra protection to the liner against damage (Villers et al., 2008). Both the metal silo and the SGB allow pesticide-free grain storage through creation of an environment of finite oxygen concentration when hermetically sealed. Living organisms within the stored grain enclosed deplete the oxygen through respiration thereby creating a hypoxic-hypocarbic environment (Navarro, 2012). The environment created reduces arthropods development and feeding activity and causes dessication consequently leading to death (Murdock et al., 2012).

2. Materials and methods

2.1. Site description and trial timing

Trials were conducted simultaneously in two contrasting agro-ecological zones in Zimbabwe: at the Institute of Agricultural Engineering (IAE) at Hatcliffe Farm in Harare province (17°45′S 31°10′ E), and Makoholi Research Station (MRS) in Masvingo province (19°50′S 30°46′E). Harare has cool sub-humid conditions (mean annual temperature 18 °C, 55% r.h, rainfall 825 mm) while Masvingo has hot semi-arid climatic conditions (mean annual temperature 20 °C, 42% r.h, rainfall 624 mm). The trials were conducted during the 2013/2014 season from December 2013 for 10 months at IAE and 12 months at MRS.

2.2. Test insects, maize grain and treatments

Primary insect pests, *S. zeamais* and *P. truncatus* were obtained from field populations. The insects were reared separately under laboratory conditions as outlined by Tefera et al. (2010) until required numbers of 7–21 day old adult insects were obtained. Maize grain ZS255 variety obtained from IAE at Hacliffe farm was used in the trials at both sites. The grain was thoroughly mixed to obtain a uniform batch before allocation to different treatments (Table 1).

There were two modes of insect infestation: natural and combined (natural plus artificial). Natural infestation relied on resident or existing insect infestation only. For the combined infestation, in addition to existing or resident infestation, test adult insects were introduced to each treatment replicate at a ratio of one adult insect species per two kg of grain: one adult *S. zeamais* and one adult *P. truncatus* per two kg of maize grain.

Hermetic treatments, the metal silo and Super grainbag I B™ (SGB), were used without application of any pesticide. Metal silos of 50 kg capacity were fabricated by trained artisans from IAE. The process of filling the respective silos involved loading grain into the silo after closing the outlet lid and sealing with a rubber band (Bravo, 2009). After loading to capacity a burning candle was then placed inside the silo (Tefera et al., 2011). The inlet lid was closed and sealed using a rubber band. Packaging tape was used on top of the rubber band as an extra seal. Placing a burning candle inside the silo accelerates the rate of oxygen depletion there-by creating a hypercarbic-hypoxic atmosphere. Hypoxic atmosphere refers to oxygen concentration of less than 21% (Mitcham et al., 2006). Burning a candle only facilitates depletion of oxygen to about 15% from 20.9% (Belcher and McElwain, 2008). This is never mentioned in studies involving metal silos hence it is important to emphasise that silo air-tightness and initial respiration of living organisms within the stored grain are essential. They allow further depletion of the remaining oxygen to levels which are toxic to stored grain insect pests and associated microflora. The SGBs used were bought from Farm and City, Grain Pro Inc.'s agent in Zimbabwe. Grain was loaded into SGB liners housed in polypropylene bags and sealed as outlined by de Groote et al. (2013). The hermetic treatments had two sets comprising of natural and combined infestation.

Non-hermetic treatments had maize grain loaded in 50 kg polypropylene bags. A registered synthetic pesticide (Chikwapuro®), which is a dust grain protectant was applied at label rate (0.05% w/w). After treating, grain was loaded into polypropylene bags and a set was closed without addition of insects while in the other set, test insects were added before tying with rubber bands. The synthetic pesticide acted as the positive control. For untreated

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