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Grainpro Cocoons™ as an alternative to phosphine fumigation for large scale grain storage in Zimbabwe

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ABSTRACT

Historically, storage insect pest management at commercial level has heavily relied on chemical control methods, centred on phosphine fumigation. Insect tolerance and/or resistance to phosphine have been reported globally. The Grain Marketing Board (GMB) of Zimbabwe is exploring alternatives to fumigants for pest management and is considering hermetic grain storage using GrainPro Cocoons™. The objective of the current study was to determine (a) the effectiveness of chemical-free hermetic storage of maize (*Zea mays* L.) using GrainPro Cocoons™ against storage insect pests compared to conventional phosphine fumigation and (b) the effect of the technology on grain quality during storage compared to existing practice. A field study was conducted in Zimbabwe at two large-scale storage sites, operated by GMB. There were two main treatments, namely hermetic cocoon and conventionally fumigated stack. Grain sampling was done at setting-up and at termination after four and eight months at the respective sites. Samples were analysed for moisture content, adult insect species and population, and percentage grain damage. Samples were also graded for quality according to Zimbabwean standards. There was insignificant live insect infestation in samples collected at termination at both sites in the cocoon. Live *Cryptolestes ferrugineus* (Stephens) was present in the fumigated stack samples after eight months of storage. Grain moisture content was maintained below 11.5% in both treatments. Damage levels in both the treatments were found below 1.5% and 2.5% after four and eight months of storage, respectively. There were no significant differences between the cocoon and fumigated stack for grain damage, while significant differences were recorded for moisture content and insect density ($P<0.05$). However, stored grain at termination for the two sites was maintained at Grade A (best grade) regardless of treatment. Results show that hermetic storage using cocoons can be an equally effective alternative to conventional fumigation against stored-maize insect pests.

Key words: Chemical-free pest management, Conventional phosphine fumigation*, ryptolestes ferrugineus*, Hermetic grain storage, *Sitophilus zeamais*, Storage-maize insect pests

Chemicals have been the most commonly used method for management of stored-product insect pest world over (Collins, 2006). Fumigants are the widely used option for disinfestation of dry agricultural commodities at commercial level (Nayak, 2012a). Phosphine and methyl-bromide (MB) were the most commonly used fumigants. The Montreal Agreement to phase out MB worldwide by 2015, left disinfestation of dry agricultural commodities solely reliant on phosphine. As compared to other fumigant options, phosphine offers numerous advantages – broad spectrum, low cost, easy to handle and free of chemical residues (Chaudhry, 1997; Collins, 2006; Nayak, 2012a). Given the major challenge associated

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with all chemical treatments where development of tolerance and/or resistance among targeted species is inevitable, phosphine has not been spared. Resistance to phosphine in field insects was first detected in an FAO global survey carried out during 1972-73 (Champ and Dyte, 1976). Over the years, studies have shown an increase in phosphine resistance frequency and severity (Chaudhry, 1997; Collins, 2006; Opit et al., 2012; Bajracharya et al., 2016).

In Zimbabwe, the Grain Marketing Board (GMB) is responsible for the strategic grain reserves of the country where staple grains are stored to cushion against production shortfalls thus ensuring adequate grain supply while imports are being mobilised. Pest management at the parastatal is centred on phosphine fumigation in concrete silos and on the stacks under tarpaulins. They also use residual insecticidal sprays on the tarpaulin surface and joints to limit re-infestation after fumigation. The parastatal buys grain from smallholder farmers, who constitute the majority of staple grain producers in Zimbabwe. Given reports of indiscriminate use of phosphine against grain storage insect pests by smallholder farmers (Muchechemera, 2015), who lack knowledge, infrastructure and safety wear required to carry out a successful fumigation, there is a high risk of insects developing tolerance and/or resistance to phosphine. This is the only available effective storage insect pest control option for GMB. Should strong resistance occur, it would be catastrophic not only for GMB but also for the nation at large as it would be a direct threat to national food security. It is essential for the parastatal to explore equally effective alternatives as back up to existing fumigation practice.

Alternative pest management methods have been explored at a global scale, over the years, with the use of hermetic storage among the effective, sustainable and environmentally benign options (Navarro, 2012). Principles behind hermetic storage including gas hermetic fumigation (G-HF) were explained by Navarro (2012). Hermetic storage enables storage of dry agricultural commodities for both short and long term without the use of any chemicals. Modern large scale hermetic storage facilities consist of mainly flexible liners known as GrainPro Cocoons and Silo bags. Use of these hermetic plastic liners in comparison to conventional storage practices for storage of various grains is well-documented outside Africa (Navarro et al., 2002; Darby and Caddick 2007; Sabio et al., 2006; Bartosik et al., 2012). The GMB needs to consider hermetic storage as an alternative to existing practice. However, this would require empirical evidence which validates performance of the technology under local conditions taking into account the influence of bio-physical factors.

Trials were therefore conducted to investigate the effectiveness of hermetic storage using GrainPro Cocoons™ under Zimbabwean conditions. The objectives were to determine (a) the effectiveness of chemical-free hermetic specific storage of maize (*Zea mays* L.) using GrainPro Cocoons™ against storage insect pests compared to existing phosphine fumigation practice, and (b) the effect of the technology on grain quality during storage compared to existing practice. This paper reports preliminary results of on-going research in Zimbabwe.

MATERIALS AND METHODS

Sites and test grain

Storage trials were conducted at two GMB depots, viz. Marondera and Bindura in Zimbabwe, for four and eight months, respectively. Marondera (mean annual temperature 16.7°C and rainfall 900 mm) has cool sub-humid climate conditions, while Bindura (mean annual temp 19.4°C and rainfall 847 mm) experiences relatively warmer sub-humid conditions. Newly harvested shelled maize hybrid grain delivered by farmers to GMB during the 2014-15 storage season was used for the trials. 'Pioneer PHB 30G19' variety was used at Marondera depot, while 'Seed Co SC727' variety was used at the depot in Bindura.

Storage technologies and experimental layout

Trials evaluated the performance of hermetic and non-hermetic storage (standard practice) facilities. At each site, there were two treatments, GrainPro Cocoon ™ (hermetic) and conventional fumigated stack (non-hermetic).

Hermetic storage: A single 20 tonne capacity GrainPro Cocoon™ was installed outdoors at each site. It is made of flexible PVC as specified by Jonfia-Essien et al. (2008). Before installation, the ground was first cleared of all sharp objects that might damage the plastic liner and compromise its hermeticity. In Marondera, hard compacted ground with a 3 cm layer of sand spread on top was used, while in Bindura, there was a tarred surface. The hermetic GrainPro Cocoon™ consists of a bottom and top section brought together and sealed using a gas-tight zipper. The procedure of loading grain involved spreading the bottom section on the ground and stacking bagged grain inside. The grain was then stacked systematically in alternate layers of complete length-wise or breath-wise tiers (criss-cross stacking) to ensure stack stability. During stacking, polypropylene bags loaded with 50 kg grain were marked at each of the three levels: bottom (bottom layer), middle (1 m height) and top (top layer). Grain was sampled from the marked bags and placed at the four corners and middle giving a total of five bags per level and a total of 15 marked bags within the whole stack. The grain was stacked to the recommended height and dimensions of the loaded cocoon were 4.4 m × 3.4 m × 2 m, length (L), width (W) and height (H), respectively. After loading to capacity, the gas-tight zipper was closed and a sun-filtering shade was pitched 50 cm above the cocoon for protection from direct exposure to sunlight (ultraviolet radiation).

Non-hermetic storage: Bagged maize grain was stacked at each of the sites on timber dunnage. The stack was constructed in a similar manner to the hermetic stack and marked bags were positioned similarly at each of the three levels. The dimensions of the stack were 4.6 m (L) × 4.4 m (W) × 1.6 m (H). The stack at each site conformed to GMB management practice of phosphine fumigation under tarpaulins at 11 pellets/tonne of maize grain (GMB, Harare, 2010). Normal practice also involved use of a residual spray, Actellic 50 EC®, being sprayed on the surface of the tarpaulins to control re-infestation after the fumigation at intervals determined by the depot inspector. The stack in Marondera was fumigated once for the 4 months storage period, while in Bindura, it was fumigated twice within the eight months of storage. No residual spray was used in Marondera, but applied twice in Bindura.

Grain sampling and sample assessment

Sampling was done during storage facility loading to determine the quality of incoming grain, and at termination; which was after four months for Marondera and eight months for Bindura. During sampling, 1 kg grain was withdrawn from the marked polypropylene bags using short sampling probes. This means that at each site 15 samples were taken from each of the two treatments – GrainPro Cocoon™ and fumigated stack. Composite samples were also collected from the marked bags for quality grading according to GMB standards.

Collected samples were taken to the laboratory at the University of Zimbabwe for analyses. The samples were weighed and then sieved to separate grain from insects. Sieved insects were counted and recorded by species. Grain moisture content of samples was then measured using a GMK-303 CF digital moisture meter (GrainProInc, Subic Bay, Philippines). Sieved samples were sterilized by freezing in a freezer, to arrest further insect development before assessment. The samples were assessed for insect induced damage.

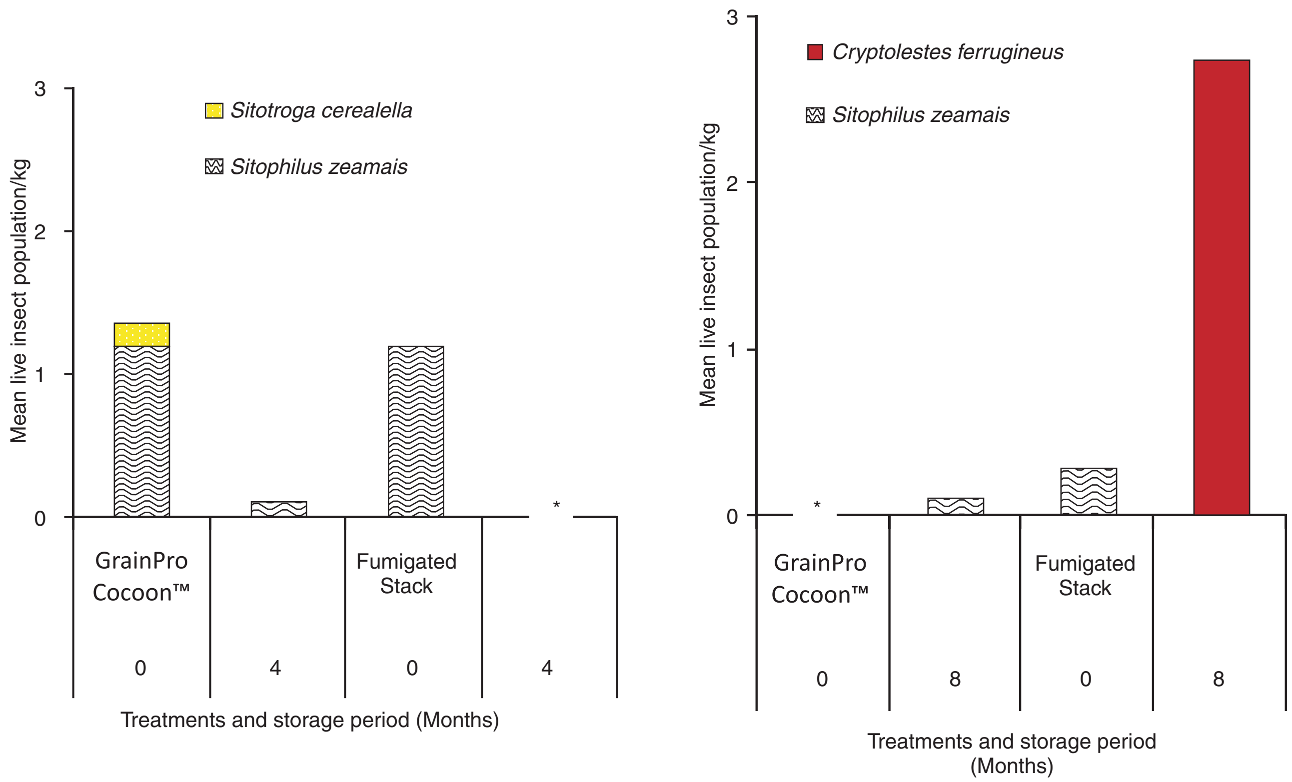

Fig. 1. Temporal mean live adult insect population/kg at a) Marondera (left) and b) Bindura (right) during the 2014/15 storage season (n=15) (*means zero adult insects/kg*)

Table 1 Comparison of means for total insect population/kg over time at Marondera and Bindura GMB depots

Total (live + dead) insect population/kg at Marondera							
	Initial (baseline)			Final (4 months)			Treatment × Time interaction
	S. zeamais	*S. cerealella*	Total insects/kg	*S. zeamais*	*S. cerealella*	Total insects/kg	
GrainPro Cocoon™	1.5±0.50	0.2±0.09	2.6[a]	3.6±1.19	0	3.6±1.19[a]	2.6[a]
Fumigated stack	0.9±0.30	0	1.8[a]	2.67±0.50	0	2.67±0.50[a]	1.8[a]

Total (live + dead) insect population/kg at Bindura									
	Initial (Baseline)				Final (8 Months)				Treatment × Time interaction
	S. zeamais	*C. ferrugineus*	*T. castaneum*	Total insects/kg	*S. zeamais*	*C. ferrugineus*	*T. castaneum*	Total insects/kg	
GrainPro Cocoon™	0.1±0.06	0	0	0.1±0.06[a]	2.8±1.45	0	0	2.8±1.45[a]	1.5[a]
Fumigated stack	0.4±0.16	0	0	0.4±0.16[a]	3.6±1.68	2.8±0.87	1.7±0.0.37	8.2±1.81[b]	4.3[b]

Means within a column for each site are compared and separated using LSD test ($P<0.05$) and different alphabetical letters indicate significant differences. ANOVA output $F_{1,56}=0.486$ (not significant) at Marondera; ANOVA output $F_{1,56}=0.01$ (significant) at Bindwal

Data management and statistical analyses

Data were organized in MS Excel to calculate adult insect population/kg and percentage grain damage. Following failure to meet normality assumptions, data were transformed using arcsine square root for percentage grain damage and log (X+1) for insect population/kg (de Muth, 2014). Statistical analysis was then performed in GenStat 14 using ANOVA. Where significance was found, the LSD test was used to separate treatment means.

RESULTS AND DISCUSSION

Insect population and spectrum

The grain had an initial live insect population of less than 2 adult insects/kg in Marondera and less than one adult insect/kg in Bindura, regardless of treatment. The live adult insect species present initially were primary insect pests, *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae) and *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) (Fig 1). The low initial live insect population was a result of newly harvested grain being used for the trials. At termination, live insect population was reduced to less than one insect/kg in the cocoon and undetectable in the fumigated stack in Marondera and in the cocoon in Bindura. The primary live insect infestation was less than the economic threshold of 2 adult insects/kg throughout the storage period at both sites. Live *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Cucujidae) was present in the fumigated stack at termination after eight months of storage. This can be attributed to either reduced efficacy of phosphine against the insect species or incoming live infestation. Cases of resistance or tolerance to phosphine by *C. ferrugineus* have been reported elsewhere (Nayak et al., 2010; Nayak et al., 2012b; Tay et al., 2016).

Table 2 Comparison of treatment means over time for percentage grain damage at two GMB depots (n=15)

Site	Storage period (months)	Treatment	% Mean grain damage (± SEM)		ANOVA
			Initial	Final	
Marondera	4	GrainPro Cocoon™	0.2 ± 0.04[a]	1.0 ± 0.12[a]	$F_{1,58} = 0.89$
		Fumigated stack	0.2 ± 0.04[a]	1.2 ± 0.16[a]	
Bindura	8	GrainPro Cocoon™	0.4 ± 0.10[a]	1.7 ± 0.32[a]	$F_{1,58} = 0.559$
		Fumigated stack	0.5 ± 0.05[a]	1.9 ± 0.35[a]	

GMB, Grain Marketing Board. Means within a column for each site are compared and separated using LSD test (P<0.05) and different alphabetical letters indicate significant differences.

Table 3 Mean grain test density over storage time and grading according to GMB standards (n=3)

Site	Storage period (months)	Treatment	Mean test density (kg/hl) (± SEM)		Grade
			Initial	Final	
Marondera	4	GrainPro Cocoon™	74.4 ± 1.32	74.7 ± 0.22	A
		Fumigated stack	76.6 ± 1.31	76.4 ± 0.46	
Bindura	8	GrainPro Cocoon™	75.0 ± 0.45	71.9 ± 0.38	A
		Fumigated stack	75.1 ± 0.38	71.7 ± 0.34	

1 kg/hl = 10 kg/m^3.

Initial total (live and dead) insect population was also low at less than 2 insects/kg at both sites. There was an increase in the total insect population on termination at both sites (Table 1). *Sitophilus zeamais* was the predominant primary insect species at both sites. Secondary pests, *C. ferrugineus* and *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) were also present in the fumigated stack at termination after eight months of storage in Bindura. The presence of secondary insect pests can be attributed to inability of the non-hermetic fumigated stack to restrict incoming infestation, unlike the insect-proof hermetic Cocoon™. Efficient hermetic storage facilities restrict movement of insects within the storage media thus preventing entry of insects from outside. Treatment × time interactions were not significant for treatment comparisons for Marondera, while for Bindura the differences were statistically significant (P<0.05). Overall, both treatments managed to suppress insect development at both the sites. The results show that hermetic storage using Cocoons™ can be used as a resistance breaker to eliminate phosphine resistant insect populations in phosphine resistance management programs.

Grain damage and quality

The initial grain damage was less than 0.6% at both sites (Table 2). There was an increase in grain damage with time on termination at all sites regardless of treatment. There were no significant differences between treatments at both sites. Grain damage was less than 1.4% at Marondera after four months of storage and less than 2.0% at Bindura after eight months of storage in both the GrainPro Cocoon™ and fumigated stack. Low damage levels can be attributed to low insect activity during storage since insect population and grain damage are positively correlated. Both treatments were effective in suppressing grain damage and there were no significant differences for treatment comparisons (P>0.05). Navarro et al., 2002 reported effectiveness of flexible plastic liners in suppressing insect induced cereal grain damage (maize, wheat and paddy) for up to eight months of storage in tropical countries.

The grain had a test density of more than 70 kg/hl (or 700 kg/m^3) throughout the storage period at both the sites. The maize maintained its quality during storage, as indicated by the grade at termination (Table 3). This shows that both treatments were effective in preserving grain quality in storage. The good quality can be attributed to a constant low insect population maintained during the storage. Grain damage due to insect infestation results in grain weight loss (de Groote et al., 2013) which has a negative effect on grain test density. Hermetic storage revealed that it can be used as an alternative to existing GMB practice without compromising the quality of stored grain. Our results support findings by Jonfia-Essien et al. (2008) and Guenha et al. (2014).

Table 4 Comparison of treatment means over time for percentage grain moisture content at two GMB depots (n=15)

Site	Storage period (months)	Treatment	% Mean grain moisture content (±SEM)*		ANOVA
			Initial	Final	
Marondera	4	GrainPro Cocoon™	11.3 ± 0.04^a	11.2 ± 0.08^b	$F_{1.58}$ < 0.01
		Fumigated stack	11.1 ± 0.06^a	9.9 ± 0.13^a	
Bindura	8	GrainPro Cocoon™	10.6 ± 0.07^a	10.9 ± 0.12^b	$F_{1.58}$ = 0.03
		Fumigated stack	10.7 ± 0.04^a	10.4 ± 0.10^a	

GMB, Grain Market Board. Means within a column for each site are compared and separated using LSD test (P<0.05) and different alphabetical letters indicate significant differences.

Grain moisture content

The maximum moisture content permissible by GMB is 12.5%. The grain moisture content was below the recommended level throughout the storage period at both sites (Table 4). The low moisture content can also be attributed to low insect activity. Insects are known to convert carbohydrates to metabolic water and heat during aerobic respiration (Murdock et al., 2012), which is associated with accumulation of moisture in storage. However, there were changes in moisture content in both the cocoon and fumigated stack. The change was more pronounced in the fumigated stack than the Cocoon™ at Marondera. This is because non-hermetic facilities allow interaction of stored grains with the dynamic atmospheric conditions which results in changes in moisture content. In addition, the trial in Marondera was terminated during the dry season, whereas that in Bindura was terminated just after the wet season. Continuous exposure of stacked grain to sunlight can result in a reduction in grain moisture content under tropical climates (Kennedy and Devereau, 1994). Grain stored in the cocoon maintained higher moisture content levels than the fumigated stack. This can be attributed to the ability of the hermetic cocoon to restrict interaction of stored grain with external environmental conditions. There were significant differences ($P<0.05$) between the two treatments for grain moisture content at both Marondera and Bindura depots (Table 4).

CONCLUSION

Both the GMB fumigation practice and hermetic storage using GrainPro Cocoons™ effectively controlled storage insect pest development and suppressed insect-induced grain damage while preserving grain quality. Performance of GrainPro Cocoons™ under local conditions is encouraging and can be recommended as a potential alternative to existing practice. However, there is need to investigate further and under field conditions, the effectiveness of larger capacities (Mega Cocoons™) which have a different sealing mechanism.

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