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Assessing the efficacy of hermetic storage bags against woven polypropylene bags by farmers in Ghana for maize grain storage

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The main insects that deteriorate stored maize grain in the tropics are maize weevils (*Sitophilus zeamais*). *S. zeamais* can cause significant post-harvest losses (PHL) in maize during storage. The objective of this study was to help farmers in Ghana appreciate and understand the benefits of using GrainPro bags compared to woven polypropylene bags (WPB) for storing maize grain. Eight farmers participated in the study, where 25 kg bags were loaded with 20 kg of naturally *S. zeamais*-infested white maize grain. The sealed bags were stored for 6 months at 28±6°C. A representative sample of 1 kg was taken from each bag for further analysis after homogenization. Percentages and ANOVA were calculated for all the quality parameters measured. The results showed that all the WPB bags were damaged, while the GrainPro bags remained intact. The damaged grain in WPB bags ranged from 91.9 to 94.4%, whereas in GrainPro bags, it ranged from 0.2 to 0.7%. Approximately 0 g of maize powder (fines) were produced within the GrainPro bags, compared to up to 73.7 g in WPB bags. *S. zeamais* mortality was 90% higher in GrainPro bags than in WPB bags. Therefore, GrainPro bags are suitable alternatives to WPB for maize storage.

Key words: Maize grain, GrainPro bags, Polypropylene bags, Hermetic storage, *Sitophilus zeamais.*

INTRODUCTION

Some controllable factors limit the production of maize in Sub-Saharan Africa (SSA) and many other developing nations. In developing countries, insects and rodents cause huge losses in quality and quantity of stored grain (Kamanula et al., 2010). The main insects that damage stored maize grain in the tropics are maize weevils (*Sitophilus zeamais*) (Rugumamu, 2012). *S. zeamais* (Figure 1) can inflict serious damage to maize grain that may lead to 20-50% or more losses when grain is stored for about 6 months (Mulungu et al., 2007; World Bank, 2011). Grain weight loss contributes largely to post-harvest losses (PHL) (Kumar and Kalita, 2017). Therefore, having effective grain storage systems can drastically reduce food losses and improve the livelihood of smallholder farmers.

Preventing pests' infestation is essential during storage to maintain food quality, make food accessible, and to stabilize food security and income security of farmers

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Figure 1. A diagram of a maize weevil (*S. zeamais*).

(Rosegrant et al., 2015). One of the available options to control pests infestation in SSA is to use synthetic pesticides. However, synthetic pesticides are expensive, may be adulterated or not readily available in markets (Njoroge et al., 2014). Also, synthetic chemicals may be ineffective and have detrimental health and environmental effects (Addo et al., 2002). The worse of it all is that the increased use has resulted in resistance among certain species that has reduced the effectiveness of the chemicals (Benhalima et al., 2004; Collins, 2006). Hermetic containers and bags are appropriate and effective alternatives to synthetic pesticides (Suleiman et al., 2018).

Another alternative to chemical use during grain storage is the hermetic metal bin. It is a galvanized metal sheet made into an airtight storage silo. A hermetic metal silo is effective against rodents, birds, molds, and insects to reduce grain losses (Tefera et al., 2011; SDC, 2017). Although metal silo is effective in controlling insects or pests' infestations to improve food security and incomes of farmers, it is expensive to buy or manufacture (Gitonga et al., 2013; De Groote et al., 2013). Hermetic bags including the Purdue Improved Crop Storage (PICS) bags, Super Grain Bags, and GrainPro bags are all effective at controlling insects and are less costly. Comparatively, hermatic bags reduce grain losses better than woven polypropylene bags (WPB) when storage conditions are similar (Baoua et al., 2013a, b).

Hermatic bags are extensively utilized in some SSA countries (Tanzania, and Kenya) because they are effective, simple, low cost, durable, easy to produce, and require small storage space (Baoua et al., 2012). However, hermetic bags have some disadvantages including high susceptibility to physical damages. These damages could be punctures from sharp end objects, abrasions, and perforations by insects and rodents (De Groote et al., 2013; García-Lara et al., 2013). These bags can also burst during transportation. The bags then lose their usefulness when they get damaged and further add extra cost to farmers.

Hermetic conditions work on a simple principle involving oxygen and carbon dioxide concentrations. Low oxygen concentration is created in these bags or containers that reduce insect development (Murdock et al., 2012; Suleiman et al., 2018). Within 1 month of storage, about 98% mortality of all insect pests can be achieved which reduces damage to grain by insects (Baoua et al., 2012). In a 6 months' storage study of maize grain, Bauoa et al. (2012) found that hermetic bags give protection to grain against insect infestations without any loss in quality. Similarly, PICS bags maintained grain quality more effectively compared to WPB (Williams et al., 2017).

The use of WPB in developing countries to store grain cannot wholly be condemned or eliminated. This is because they are readily available in the markets and less expensive compared to hermetic bags or silos. However, they are used with caution. To effectively control insects/pests, insecticides/pesticides such as Malathion, Deltamethrin, and Actellic super, and Phosphine (fumigant) are used. To prevent rodents' damage to WPB and hermetic bags, poison baits (Naik and Kaushik, 2017) and traps (Yee and Leung, 2009) can be used to control the rodents.

With the intention to reduce or avoid the overreliance on synthetic chemicals based on their toxicity and expensiveness, farmers have been advised to accept and use hermetic technology although relatively new in Ghana. Hence, farmers were allowed to participate in the use of GrainPro bags (hermetic bags) to appreciate the significance of hermetic technology. The objective of this study was to help farmers in Ghana appreciate and ascertain the benefits of using GrainPro bags compared to WPB in the storage of maize grain.

MATERIALS AND METHODS

Experimental set-up

Eight farmers were selected for this experiment. Farmers were selected from a town called Tontro in the Eastern region of Ghana where the study happened. Each farmer was provided with six bags, three each of GrainPro bags (hermetic) and WPB (non-hermetic) for the 6 months storage period. Hence, a completely randomized factorial design was used. Both types of bags had 25 kg storage capacity, and the GrainPro bag had a single layer (78±10% thickness) of high strength polyethylene (PE) with a barrier layer and 2 track PE zipper (GP, 2018). Similarly, the polypropylene bag was single-layered. The white maize grain used in the study was obtained from the farmers, and the grain had a natural *S. zeamais* infestation (Baoua et al., 2014). Damaged grain (grain with holes, and broken grain), foreign materials, and dead *S. zeamais* were sorted and discarded prior to loading the bags. Handpicking was the mode of sorting and was done by spreading small portions of the grain on a white cloth. The initial numbers of *S. zeamais* found in 1 kg of infested grains before the start of the research study was estimated to be 67±14. The GrainPro bags containing the grains were hermetically sealed with the 2 track PE zipper according to the manufacturer's instructions. The WPB containing the grains were firmly tied to prevent the escape of the *S. zeamais*. The grain used had an average moisture content (MC) of 14.0±0.5%, which was measured (triplicate) with DICKEY-JOHN (Auburn, IL) mini GAC® plus hand-held Moisture Tester (Minigac1P). The individual farmers stored the stacked bags in their storage rooms on raised platforms at a temperature of 28±6^{o}C.

The storage bags were opened after 6 months, and the content of each bag was homogenized. Homogenization was done by spreading and gently mixing the content of an opened bag on a clean rubber sheet. A representative sample sum of 1 kg (USDA, 2013) was taken from different sites of the homogenized bag for further analysis. A sieve of size 0.99 mm (99*10^{-5} m) was used to separate the powder by retaining the *S. zeamais* and grain. The mass of powder produced was measured (g/1 kg of the sample). The retained *S. zeamais* and grain were used to determine the percentage of damaged grain (i.e. by weight, grain with holes or devoured endosperm and/or germ caused by *S. zeamais*), grain weight loss (%), and percent mortality of *S. zeamais* (% Mortality = $\frac{Number\ of\ dead\ S.zeamais}{Total\ number\ of\ S.zeamais} * 100$).

The percentage of grain weight loss was determined by using the count and weigh method developed by Adams and Schulten (1978). The percentage of storage bags damaged (visible holes created in bags due to the frequent movements outside and into the bags by *S. zeamais*) was also calculated.

The determination of damaged bags was done based on the physical observation of holes in the bags.

Data analysis

Percentages were calculated, and the data set was presented in graphs and tables. For the ANOVA, Tukey-Kramer HSD was used to separate the means that were significantly different ($P < 0.05$).

RESULTS

Although eight farmers were used in the study, data from seven farmers were analyzed because there was unexpected damage to the experimental units of one farmer. As shown in Figure 6a, two of the GrainPro bags were damaged by mice during storage. Figure 2 shows the percent number of storage bags that were damaged by *S. zeamais*. The *S. zeamais* damaged (holes created due to frequent in and out movements) all the WPB used. All the GrainPro bags used were resilient to *S. zeamais* attack, and hence no damaged bag was recorded. In Figure 3, the percentage of grain damaged by *S. zeamais* was recorded. The damages consisted of holes created in the kernels, and consumption of the entire endosperm and germ (embryo) of the kernel. In most cases, only the grain bran and hull remained. The percentage of damaged grain in the WPB ranged between 91.9 and 94.4%. Compared to damaged grain in the GrainPro bags, the percentage was between 0.2 and 0.7%. Figure 4 shows the powder (flour/fines) produced in both types of storage bags. The powder or fines was produced due to *S. zeamais* feeding on the grain. The GrainPro bags recorded zero (0) gram of powder weight. In the WPB, due to the extensive grain damage, the weight of powder recorded ranged from 48 to 73.7 g.

In Figure 5, the percent of *S. zeamais* mortality was determined. 100% *S. zeamais* mortality was recorded in GrainPro bags (using stored grains). The number of live *S. zeamais* found in the WPB was extremely high, hence, *S. zeamais* mortality in WPB was between 5.0 and 8.4%.

Table 1 shows the number of dead and live *S. zeamais* in both types of bags and the percent mortality. Table 2 shows the means of the measured parameters recorded in the GrainPro and WPB. The mortality in GrainPro bags (100.0%) was significantly high ($P < 0.05$) compared to that of the WPB (7.2%). The mass of powder produced (g), the percentage of damaged bags, the percentage of damaged grain, and percentage of grain weight loss in the GrainPro bags were all significantly low in contrast to that of WPB.

DISCUSSION

N*umber* of damaged bags (%)

Grains, animal feed, flour, and many other products are packaged in WPB (indBAG, 2016). GrainPro bags are liners specially designed from high-density polyethylene with a barrier layer (Baoua et al., 2013a; GrainPro, 2017)

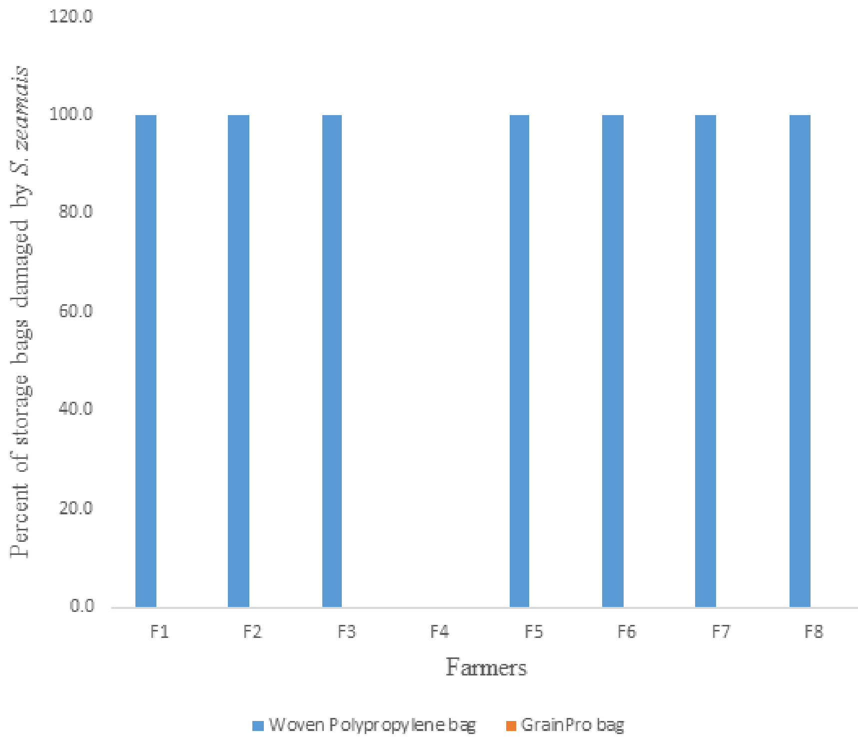

Figure 2. Percent of WPB and GrainPro bags damaged by *S. zeamais* during the 6 months of grain storage in Ghana.

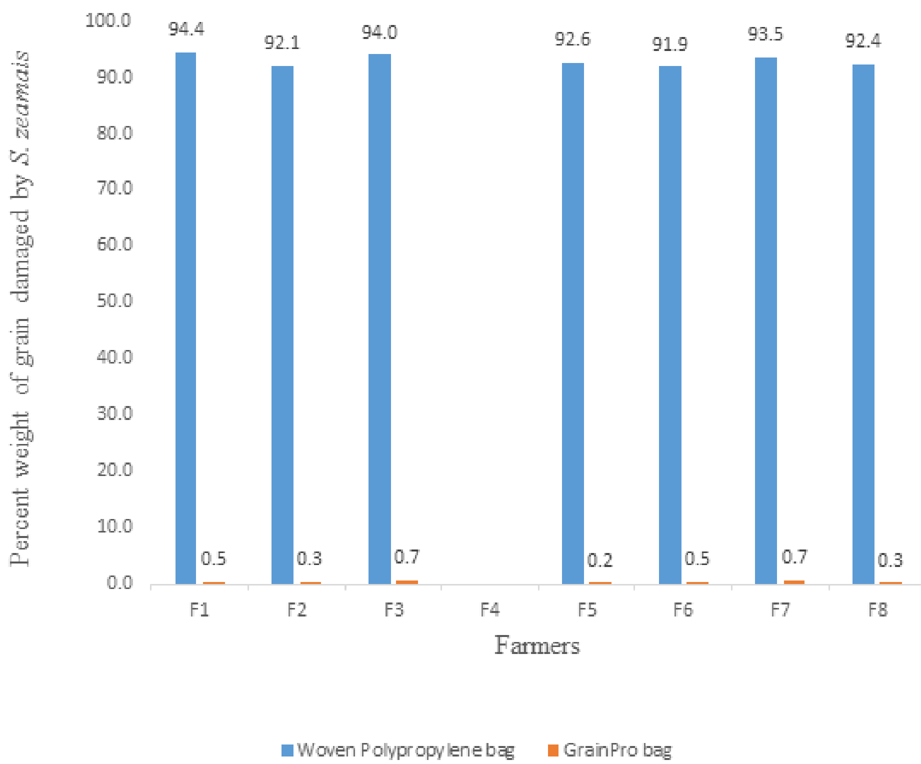

Figure 3. Percent of maize grain damaged by *S. zeamais* in both bags during the 6 months of grain storage in Ghana.

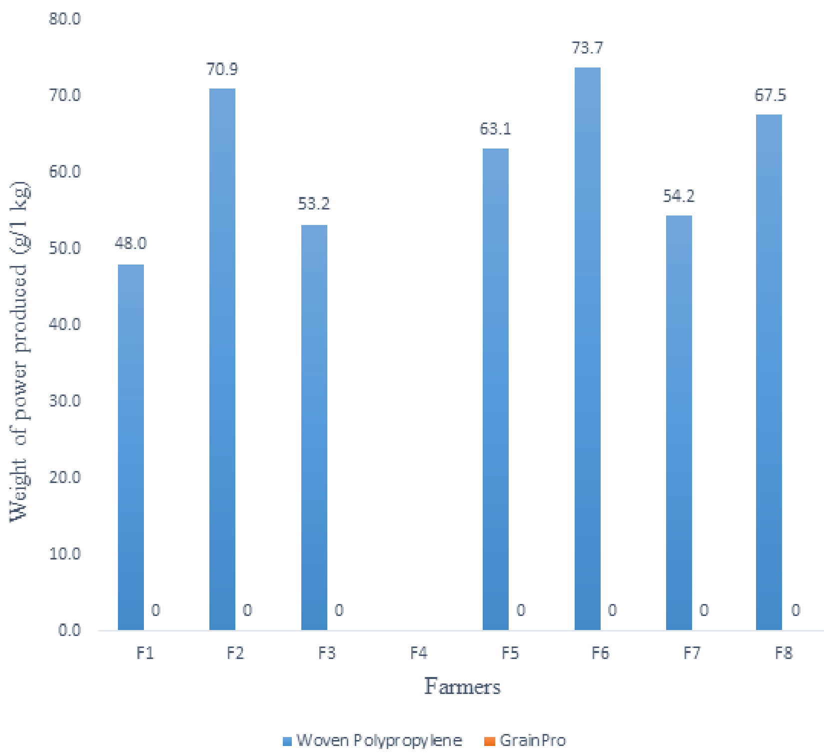

Figure 4. Weight (g/1 kg) of powder produced as a result of grain damaged by *S. zeamais* during the 6 months of grain storage in Ghana.

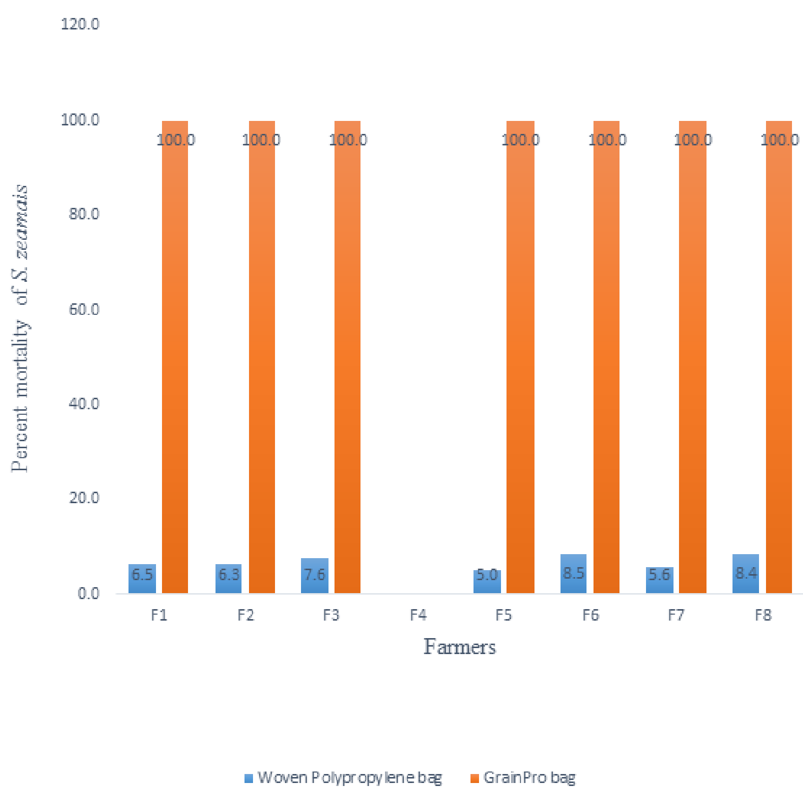

Figure 5. Percent mortality of *S. zeamais* in both storage bags during the 6 months of grain storage in Ghana.

Figure 6. Maize grain in (a) mice-damaged GrainPro bags, (b) intact WPB bags, and (c) in undamaged GrainPro bags during the six months of grain storage in Ghana.

Table 1. The average number of live and dead *S. zeamais* in 1 kg of grain, and percent mortality during the 6 months of grain storage in Ghana.

Farmers	*S. zeamais* in WPB			*S. zeamais* in GrainPro bags		
	Dead	Alive	% Mortality	Dead	Alive	% Mortality
1	13.3	192.7	6.5	66.7	0.0	100.0
2	14.0	208.3	6.3	67.7	0.0	100.0
3	14.3	174.3	7.6	74.0	0.0	100.0
4	-	-	-	-	-	-
5	15.0	287.0	5.0	64.7	0.0	100.0
6	16.7	180.0	8.5	68.0	0.0	100.0
7	15.7	264.0	5.6	69.0	0.0	100.0
8	19.3	212.0	8.4	72.0	0.0	100.0

Table 2. ANOVA showing significant differences between the use of GrainPro and WPB among the seven farmers during the 6 months of grain storage in Ghana.

Packaging bags	Mass of powder (g/1 kg grain)	Damaged bags (%)	Damaged grain (%)	Grain weight loss (%)	Mortality of *S. zeamais* (%)
GrainPro	0.0±0.0[b]	0.0 ± 0.0[b]	0.5±0.2[b]	0.2±0.1[b]	100.0±0.0[a]
WPB	61.5±9.4[a]	100.0±0.0[a]	93.0±1.0[a]	100.0±0.0[a]	7.2±2.4[b]
P-values	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Means ± standard deviation in the same column with different letters are significantly different at $P < 0.05$.

used to store mostly dried grains. The resilience of both storage bags to *S. zeamais* is not similar. This was exhibited in the results obtained in this study. All the WPB (100.0%) used to store the grain were susceptible to damage by *S. zeamais*. The damage was caused by *S. zeamais* in the infested grain. The *S. zeamais* perforated the bags and were seen moving back and forth the inside of the bags. This resulted in many larger holes been created in the bags.

In comparison, the resilience of GrainPro bags was

Figure 7. The quality of maize kernels stored in WPB (a) and GrainPro bags (b) during the 6 months of grain storage in Ghana.

shown in this study. None of the GrainPro bags was damaged by *S. zeamais*. This indicates that the mouthparts of *S. zeamais* are not robust enough to gnaw and perforate the GrainPro bags compared to WPB. In spite of this, the few GrainPro bags that were exposed accidentally to rodents were severely damaged (Figure 6b). Hermetic bags are comparable to many other improved storage methods. However, there are some disadvantages including high susceptibility to physical mishandling like punctures or perforations, and scratches which may be caused by insects or rodents or sharp objects (De Groote et al., 2013; Baoua et al., 2013 b; García-Lara et al., 2013).

Percentage of damaged grain

Due to late harvest of maize, grain gets infested in the field before harvesting commences (Kaaya et al., 2005; Lane and Woloshuk, 2017). Delaying harvesting can result in many pre-harvest losses including *S. zeamais* infestation (ICVolunteers, 2014). Maize weevils found in grain before harvest multiply rapidly due to favorable temperature and RH. *S. zeamais* if not killed through chemical treatment, then an appropriate storage bags should be used. The percentage of grain damaged in the WPB was from 91.9 to 94.4%. This shows that *S. zeamais* rapidly reproduced, and caused extensive kernel damage. Although storing grain in WPB is not expensive there is the need to apply an insecticide (De Groote et al., 2013; Maina et al., 2016). Since WPB is permeable to air, gases are exchanged between the environment and bags, and therefore *S. zeamais* survive, grow, and multiply.

In the GrainPro bags, the percentage of damaged grain ranged from 0.2 to 0.7%. GrainPro bags can deny weevils of oxygen (Murdock et al., 2012). *S. zeamais* die when denied of oxygen, and hence kernel damage due to *S. zeamais* is reduced or prevented. The values of damaged grain in GrainPro bags although low could be attributed to the feeding activities of the *S. zeamais* before their demise. Secondly, *S. zeamais* could survive under hermetic conditions in the first few days (Bern et al., 2010; Yakubu et al., 2011; Bbosa et al., 2017; Suleiman et al., 2018), and during this period their feeding activities might have resulted in kernel damage. Kernels found in the GrainPro bags were very clean and undamaged. Similar findings were reported by Lane and Woloshuk (2017), and Williams et al. (2017). These investigators reported low numbers of infested kernels in PICS bags while in WPB the number was significantly huge. Hermetic bags (GrainPro bags) are not entirely the panacea for reducing PHL because rodents can compromise the integrity of such bags. Rodents can cause bag damage, spillage, and grain damage which result in PHL (Figure 8b). Therefore, hermetic bags must be properly kept away from storage pests like rodents.

Mass of powder (fines) and grain weight loss

In the GrainPro bags, no powder was produced which might be attributed to the early demise of all the *S. zeamais.* Because of the early demise of the *S. zeamais,* the kernels remained undamaged (whole grains without holes) and safe for consumption and possible germination

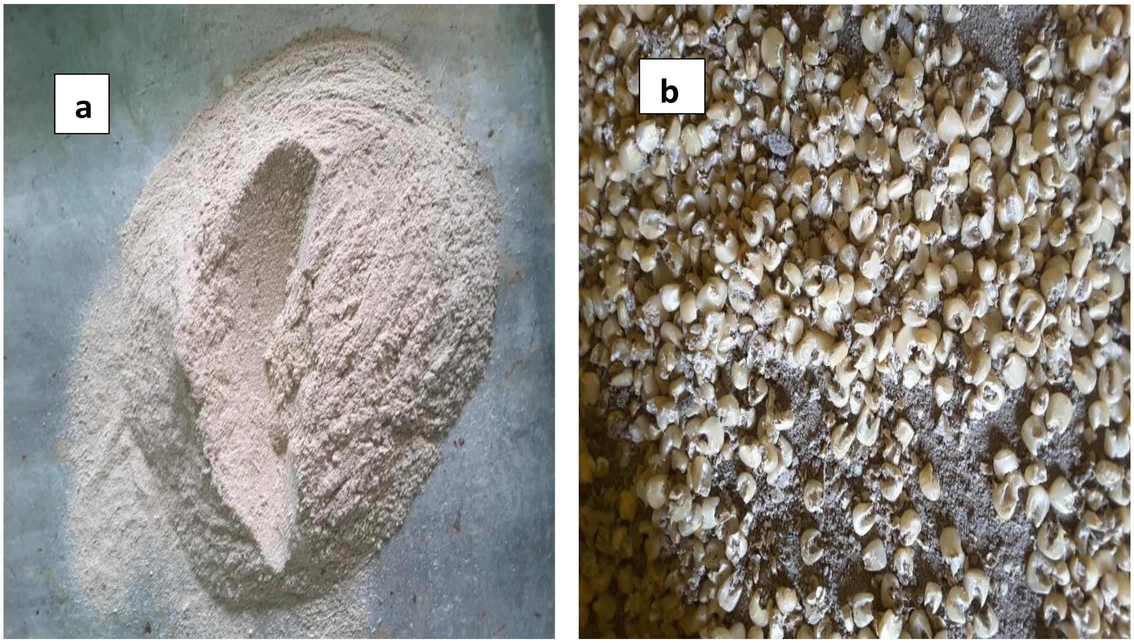

Figure 8. Powder (flour) produced in WPB due to *S. zeamais* (a), and kernel spillage due to mice attack on GrainPro bags (b) during the 6 months of grain storage in Ghana.

(Figure 7b). The mass of powder in WPB was between 48.0 and 73.7 g, which could be ascribed to the extensive grain damage (Figure 7a) caused by *S. zeamais*. The extensive feeding activity of *S. zeamais* on the grain might have resulted in the huge mass of powder produced (Figure 8a). The massive mass of powder exposes the ineffectiveness of WPB as a suitable storage package; especially when the grain is already infested before storage. It was not surprising that the kernels found in WPB had only the hull and bran remnants without the endosperm and embryo. The *S. zeamais* completely devoured the entire endosperm and germ (embryo) in all kernels. The powder produced means the grain had been rendered useless both as food and seed. Grain infestations cause quality and quantity losses limiting food accessibility to humans and animals (Rajendran, 2005; Suleiman et al., 2018).

The higher the grain weight loss or mass of powder, the massive the grain uselessness. Recently, Walker et al. (2018) found that grain when hermetically stored reduces grain weight loss. Grain storage was completely ineffective and unsafe when WPB were used. However, the hermetic bags were effective at protecting the stored grain against *S. zeamais,* as similarly reported earlier (Murdock et al., 2012; Baoua et al., 2014; Suleiman et al., 2018).

Percent *S. zeamais* mortality

The 100.0% mortality in GrainPro bags shows that *S. zeamais* were not able to survive in the bags. The high mortality reveals that grain could be stored safely in GrainPro bags without *S. zeamais* attacks. Thus, the life cycle and multiplication of *S. zeamais* that were within the GrainPro bags were curtailed. In a situation where harvested grain becomes infested before storage, it would be most convenient and appropriate to store the grain in hermetic bags (GrainPro bags). Findings from Murdock et al. (2012), and Murdock and Baoua (2014) showed that the effectiveness of using hermetic technology depends on oxygen (O_2) depletion and the rise in carbon dioxide (CO_2) concentrations. This is due to the respiratory ability of the insects and grain. In this study, *S. zeamais* in the GrainPro bags might have been denied O_2. This is because O_2 concentration in airtight bags depletes with time, and CO_2 concentration increases with time (Yakubu et al., 2011; Murdock and Bauoa, 2014; Bbosa et al., 2017; Suleiman et al., 2018).

In WPB, many live *S. zeamais* were found, and the percent mortality was very low (5.0 to 8.4%). The *S. zeamais* had access to oxygen, hence respired, multiplied and caused serious kernel damage through their rigorous feeding activities. According to Throne (1994), the development of *S. zeamais* spans about 35 days. Therefore, under optimum conditions, many generations of *S. zeamais* might have occurred within the 6 months of storage. The favorable temperature and humidity might have enhanced the propensity of the female *S. zeamais* to deposit many eggs (Throne, 1994). Hence a large number of *S. zeamais* in WPB. The low mortality recorded in WPB was not surprising. The reason might be that the rate of *S. zeamais* multiplication far exceeded the rate of mortality. A study in a warmer environment

(Arkansas) by Lane and Woloshuk (2017) asserted that the insect population was distinctively high in WPB compared to PICS bags. The results obtained in this current study affirm that assertion.

Statistical comparison of woven polypropylene and GrainPro bags

The mean *S. zeamais* mortality was significantly higher in the GrainPro bags than woven polypropylene bags (100 and 7.2%, respectively). The mass of powder produced (g), the percentage of damaged bags, the percentage of damaged grain, and percentage of grain weight loss were significantly low in the GrainPro bags compared to woven polypropylene bags. Based on the measured parameters, GrainPro bags proved a better method for storing grain even if the grain was previously infested. *S. zeamais* could not survive in the GrainPro bags, and therefore, the grain quality and quantity were maintained. The woven polypropylene bags, in this case, were similar to the three indigenous methods discussed earlier. Thus, they were not efficient in controlling *S. zeamais,* most especially when grain was previously infested. This study supports many findings that have reported on the efficacy of hermetic bags (Murdock et al., 2012; Njoroge et al., 2014; Amadou et al., 2016; Bbosa et al., 2017; Lane and Woloshuk, 2017; Suleiman et al., 2018). Likewise, Walker et al. (2018) recently reported that a hermetically stored maize grain had reduced insect infestation and grain weight loss. The hermetic bags also have a useful lifespan of mostly two to four years (CIMMYT, 2011; Ndegwa et al., 2016), and therefore farmers reduce storage cost as bags are reused.

Conclusions

A good storage results in good quality grain and high market value for the commodity. Income levels of farmers could increase to reduce the poverty levels of farmers in Sub-Saharan Africa through good storage methods. The maize grains were safely stored in GrainPro bags compared to WPB. The 100.0% *S. zeamais* mortality could be the reason why grain damage was reduced in the GrainPro bags. Farmers could make good earnings by storing grain in hermetic bags, most importantly if protected from rodents. Utilization of synthetic chemicals and indigenous pseudo-effective methods should be replaced with hermetic bags. Profit margins of farmers could increase when grain quality and quantity are maintained. Additionally, hermetic bags are reusable, which further benefits farmers.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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