

Evaluation of the suitability and optimal use of postharvest storage bag technologies and a combination thereof for maize storage in Nigeria.

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Abstract

The severity of postharvest losses varies considerably depending on storage method and prevalence of storage insect pests known to bore into storage bags. Polypropylene (PP) bags used by smallholder farmers in Nigeria do not provide effective protection for stored produce due to insect boring activities. Deltamethrin incorporated polypropylene, ZeroFly® (ZF) and ZeroFly® Hermetic Storage Bags are technologies with potential to improve protection of stored food commodities against insect attack. Therefore, a 12-month study was conducted in Ibadan, Nigeria to determine the suitability and potential of combined postharvest bag technologies involving ZeroFly® (hermetic and non-hermetic) bags for smallholder farmers when exposed to *Sitophilus zeamais* and *Prostephanus truncatus* infestation pressure. Cleaned but un-fumigated 50-kg lots of maize were used to fill bags in each of the following 8 treatments — PP and ZF bags alone, diatomaceous earth-treated maize in PP and ZF bags, single and double hermetic liners in ZF bags, single hermetic liner in PP bags and lastly PICS bags. Results obtained over a 12-month period showed infestation by *S. zeamais*, *Tribolium castaneum*, *Cryptolestes ferrugineus* and *Liposcelis* spp and abundance of insect increased with storage period in PP and ZF bags without liner. The percentages of insect damaged kernels by number (IDK) were higher in PP and ZF bags without liner and were 5.4 and 16.9%, respectively; in ZeroFly bags with hermetic liners, these values were ~ 0.5%. The PP and ZF bags without liner also had higher weight loss values of 1.4 and 6.7%, respectively compared with ZeroFly bags with hermetic liners and PICS bags which had a relatively lower weight loss of ≤0.2%. These results indicate that the ZeroFly Hermetic bag mitigates insect infestations, thereby offering a suitable alternative towards achieving significant reduction in postharvest losses during storage.

Keywords: maize storage, ZeroFly® Hermetic bag, smallholder farmer, postharvest loss, integrated pest management

1. Introduction

Maize (*Zea mays* L.) is the most widely cultivated staple food that plays a key role in the food security and economic well-being of sub-Saharan Africa (SSA) population (Abate *et al.*, 2017). With more than 5 million ha of land planted with maize annually, Nigeria is the second largest producer after South Africa, in the continent of Africa and produces nearly 8 million tons annually (Abate *et al.*, 2015). The bulk of this production in Nigeria is by smallholder farmers who face numerous challenges after their grains are harvested from the field (Abdoulaye *et al.*, 2016). Postharvest storage has been indicated as a major constraint in the maize sector in West Africa (Baoua *et al.*, 2014) and every year across sub-Saharan Africa, unacceptable levels of food loss continue to occur (Costa, 2014). These losses are dependent not only on the management practices of the farmers but also on environmental conditions and prevalence of post-harvest insect pests. The larger grain borer (LGB) (*Prostephanus truncatus* (Horn); Coleoptera: Bostrichidae) along with maize weevil (*Sitophilus zeamais* Motschulsky; Coleoptera: Curculionidae) are the major insect threats to stored maize in Africa (Holst, 2000). Losses due to post-harvest pests of maize are estimated to average between 20 and 30% after 3 months of storage (Boxall, 2002). For *S. zeamais* and *P. truncatus* infestations, losses

of 21.5% have been estimated after 6.5 months of storage in woven polypropylene bag (Baoua *et al.*, 2014). Currently, the control of stored grain insect pests is predominantly by the use of chemical insecticides including fumigants (Ceruti *et al.*, 2008); this is the case in Nigeria and worldwide. Storage pests are fast developing resistance to phosphine (Lee *et al.*, 2001). Alternative control methods to reduce insecticide persistence or toxic residues in food and pest resistance are being sought (Ileke and Oni, 2011) and have encouraged the return and development of inert dust formulations (Korunic, 1998). Treatment with diatomaceous earth (DE) dust is an efficient insect control technique in integrated pest management programs of stored grain (Ceruti *et al.*, 2008). As DEs are inert, they offer long term effectiveness, are safe for consumption, and do not adversely affect grain quality (Korunic *et al.*, 1996). Polypropylene woven storage bags remain the conventional method of maize storage for smallholder farmers in Nigeria, which shows that bag technologies are culturally acceptable (Abdoulaye *et al.*, 2016). Due to the boring activities of insects into materials such as plastic films, adults of *P. truncatus* (Hodges, 1986; Ramirez Martinez and Silver, 1983) and *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae) (Riudavets *et al.*, 2007) may find it easy to penetrate untreated bags used to protect stored grains and cause damaging infestations. Consequently, the use of insecticide-treated bags has been recognized as a possible alternative to direct treatment of grains (Kavallieratos *et al.*, 2017). The deltamethrin incorporated polypropylene (PP) bag, ZeroFly® Storage Bag, is a new technology used to reduce postharvest losses caused by stored-product insect pests. Additionally, the ZeroFly® Hermetic Storage Bag is a novel technology that protects grains and seeds stored in it against both external and internal insect attacks. The ZeroFly® Hermetic Storage Bag is made of an outer woven deltamethrin incorporated polypropylene bag and an 80-µm thick multilayered recyclable mixed polymer hermetic inner-liner with a gas barrier. The use of hermetic grain bags to preserve durable commodities such as grains is practiced in several countries (De Bruin *et al.*, 2012). Hermetic storage bags such as the Purdue Improved Crop Storage (PICS) and SuperGrain bags have been evaluated in previous studies and found to be effective technologies for protection of stored grains (Baoua *et al.*, 2013; William *et al.*, 2017).

Based on the information provided above, a 12-month study was conducted to investigate the suitability and optimal use of combined postharvest bag storage technologies (hermetic and non-hermetic) in the presence of external *S. zeamais* and *P. truncatus* infestation pressure. This study was conducted in a storehouse, located within Arisekola-Bodija market (7°25'59 N, 3°54'43 E) Ibadan, Oyo State, Nigeria during the period February 2017 to January 2018.

2. Materials and Methods

2.1. Maize

A yellow variety maize called 'Swan 2' sourced from a single local farm at the Ijaye Farm Settlement (07°42'13 N, 3°44'10 E) Ibadan, Oyo State was used in order to ensure uniformity of maize used for the study. The moisture content of the maize ranged between 11–13% based on measurements by the John Deere moisture meter (SW08120, Illinois, US).

2.2. Treatments

The maize used was cleaned and un-fumigated. Batches of 50 kg of maize were placed individually in bags according to the various treatments as follows: i) three polypropylene (PP) bags filled with untreated maize; ii) three PP bags filled with Insecto® (Insecto Natural Products, Costa Mesa, California, USA) diatomaceous earth-treated maize (hereafter this treatment is referred to as PPDE bags). The diatomaceous earth (DE) was admixed at a rate of 50 g per 50-kg bag of maize (i.e. at a rate of 0.1% w/w or 1,000 ppm) (Nwaubani *et al.*, 2014); iii) nine triple layer PICS bags filled with untreated maize; iv) nine PP bags, each with a single hermetic liner (80 µm thick) filled with untreated maize (hereafter referred to as PP + 1 liner bag); v) three deltamethrin incorporated PP bags (ZeroFly® Storage bags) filled with untreated maize, hereafter referred to as ZF bags; vi) three

ZeroFly storage bags filled with Insecto® diatomaceous earth-treated maize filled (hereafter this treatment is referred to as ZFDE bags); vii) nine ZeroFly storage bags, with each having two PICS bag hermetic inner liners, filled with untreated maize (hereafter referred to as ZF + 2 liners bags) and viii) nine ZeroFly storage bags, with each having a single hermetic liner, filled with untreated maize (hereafter referred to as ZF + 1 liner bag).

2.3. Set up of treatments

For the different treatments there were three sub-replicates for each sampling event. Each stack of three or nine bags was placed on a wooden pallet (1.5 m x 1.5 m); pallets for the different treatments were a minimum distance of 2 meters apart from each another. Treatments involving ZeroFly storage bags were arranged on one side of the storehouse whereas PP bags of maize were set up on the opposite side to prevent ZF bags from influencing conditions immediately around PP bags. Altogether, there were forty-eight 50-kg bags of maize placed in the storehouse. Treatments in this study were not replicated but there are plans to conduct another two replicates in short order.

2.4. Storehouse infestation with *Prostephanus truncatus* and *Sitophilus zeamais*

Eight vials containing 100 g of maize each were infested with 20 unsexed, newly emerged adults of *P. truncatus* and *S. zeamais* separately in the laboratory and cultured for 1.5 months. The vials containing the adults and presumably the immature stages were placed in the storehouse, near pallets containing the eight treatments to create the required pest pressure on the storage bags. This procedure was repeated every 4 months.

2.5. Sampling and data collection

Bags of maize were sampled at the beginning of the study in February 2017. Monthly sampling was thereafter conducted on all 3 bags of each non-hermetic treatment (PP, PP + DE, ZF, and ZF + DE) from March 2017 to January 2018. For the hermetic treatments, three bags from each of the nine bags were randomly selected and destructively sampled after 4, 8 and 12 months — these treatments were PICS, PP + 1 liner, ZF + 1 liner, and ZF + 2 liners.

2.5.1. Moisture content

Moisture content in each bag sampled was estimated using four moisture measurement methods namely; i) a low cost moisture meter by the USDA-ARS Center for Grain and Animal Health Research, Manhattan KS, referred to in this study as the PHL meter, ii) a GIPSA-approved method (GAC 2100 Agri, DICKEY-john Corp., Auburn, IL.), iii) a commercial meter, the John Deere Moisture Chek PLUS, model SW08120 (AgraTronix Streebboro, Ohio), and iv) a standard oven-dry test method (ASABE standards). The average of three different readings with each meter, from each bag was calculated.

2.5.2. Grain sampling

A brass grain probe (1.2-m open-ended trier) (Seedburo Equipment, Chicago, IL) was used to sample maize and a composite sample of ~ 350 g was taken from each bag and placed in a labeled Ziploc plastic bag for analyses. For each of the samples collected, data on number of insects of each species, percentage number and weight of insect damaged kernels (IDK), weight loss, seed germinability were taken. All maize samples collected were analyzed at Entomology Research Laboratory, Department of Zoology, University of Ibadan, Nigeria. The samples were sifted using a U.S. Standard #10 sieve (2 mm openings) (Seedburo Equipment, Chicago IL) on to a tray to recover both live and or dead insects. The species of insects were identified using a tripod magnifying lens and their numbers were recorded. A 250-g sub-sample was poured on a tray and kernels were examined visually. Kernels with insect exit holes or perforations were separated from undamaged kernels and the numbers in each category were recorded. Percentage of insect damaged kernels

(IDK) by numerical basis (IDKnb) and by weight basis (IDKwb) were calculated per 250-g sample (FAO): the method of Quitco and Quindoza (1986) was used:

$$\text{Percentage IDK (nb)} = \frac{Nd}{\text{Total grain count}} \times 100; \text{ Percentage IDK (wb)} = \frac{Wd}{250} \times 100$$

Where, Nd = Number damaged grain, Wd = Weight of damaged grain

2.5.3. Weight loss (%)

Weight loss due to insect damage was determined using the "count and weigh" method (Gwimmer *et al.*, 1996) and calculated as: % Weight loss = $\frac{[(Wu \times Nd) - (Wd \times Nu)]}{Wu \times (Nd + Nu)} \times 100$

Where, Wu is the weight of undamaged kernels, Nu is the number of undamaged kernels, Wd is the weight of damaged kernel and Nd is the number damaged.

2.5.4. Seed germinability (%)

Germination tests were conducted using the method of Baoua *et al.* (2014) with little modification — from each 250-g maize sub-sample previously referred to above, one hundred seeds were picked and 25 seeds were then placed in each of four petri-dishes that had moistened cotton sheets at their bases. The seeds were re-wetted and percent germination was determined after 5–7 days based on the number of seeds that sprouted.

Data were summarized using the SPSS version 20 software to evaluate means of the various response variables.

3. Results

The lack of replication in this study means analysis of variance (ANOVA) could not be conducted. Therefore, information presented in the results section describes only numerical differences between means based on three sub-replicates of each treatment, for each sampling event and not statistical differences. Information in this section also highlights notable patterns in the various response variables that were investigated.

3.1. Moisture content

There was a $\leq 4\%$ offset in the MC measure by the PHL, JD and GAC2100 meter compared to the oven-dry reference test. MC measurement for the PHL meter ranged from 11–15%; JD meter ranged from 12.5–15.3%; Oven-dry test ranged from 10.6–13% and GAC 2100 meter ranged from 11–14.4% based on data collected during the 12 months of the study, in all the treatments.

3.2. Insect infestation level

3.2.1. *Sitophilus zeamais*

The pattern for numbers of *S. zeamais* found in the different treatments during the study are shown in Figs. 1 and 2. Live weevil population grew progressively in the PP bags but grew more in the ZF bags after 5 months of storage (during and after June). The number of live *S. zeamais* was higher in ZF bags where 124 insects were found in October but this number decreased to 52 in January (Fig. 1A). There were no live adult *S. zeamais* in the PPDE and ZFDE samples during the first eight months of the study. In the ZFDE treatment, numbers of live *S. zeamais* did not increase substantially during the entire storage period. In the case of PPDE treatment, numbers of live weevil in bags did not exceed 2 during the period February to October, but the number increased numerically to 31 at the end of the experiment in January. On the other hand, the numbers of dead *S. zeamais* were numerically higher in the ZF bags than in the other three treatments except in October where more dead insects were found in PP bags (Fig. 1B). An average of 33 dead weevils per sample were found in ZF bags at the end of 12 months of storage, in January 2018 (Fig. 1B).

For the hermetic treatments, very low numbers of *S. zeamais* were found and did not exceed a mean of 4 in any of the four treatments (Fig. 2A). In the PICS bags, 3.7 live *S. zeamais* per sample were found after 12 months of storage (Fig. 2A). The mean number of dead *S. zeamais* in all the hermetic treatments during the 12 months of storage was ≤ 1 (Fig. 2B).

3.2.2. *Tribolium castaneum*

The pattern for numbers of *T. castaneum* found are shown in Figs. 3 and 4. In the PP treatment, the numbers of live *T. castaneum* were much higher during the period October to January (Fig. 3A). The numbers of live *T. castaneum* were lower in the PPDE, ZF and ZFDE bags in all the storage periods and did not exceed the highest number found of 4.3 insects per sample. The mean number of live insects per sample throughout the storage period was 4 in PPDE treatment whereas live insect was below 1 in ZF and ZFDE treatments, respectively (Fig. 3A). Expectedly, higher numbers of dead insects were found in PP bags during all the storage periods (Fig. 3B).

For the hermetic treatments, very low numbers of *T. castaneum* were found and did not exceed a mean of 6 in any of the four treatments (Fig. 4A). In the PICS bags, the number of live *T. castaneum* increased from 3.7 in September to 6 per sample in January (Fig. 4A). The mean number of dead *T. castaneum* in all the hermetic treatments during the 12 months of storage was 4 (Fig. 4B).

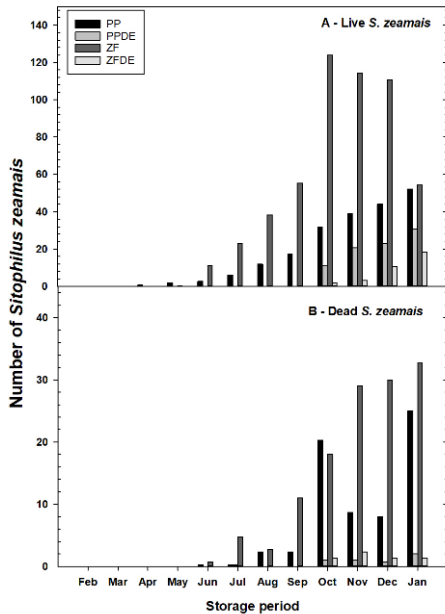


Fig. 1: Number (mean) of live (A) and dead (B) *Sitophilus zeamais* per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

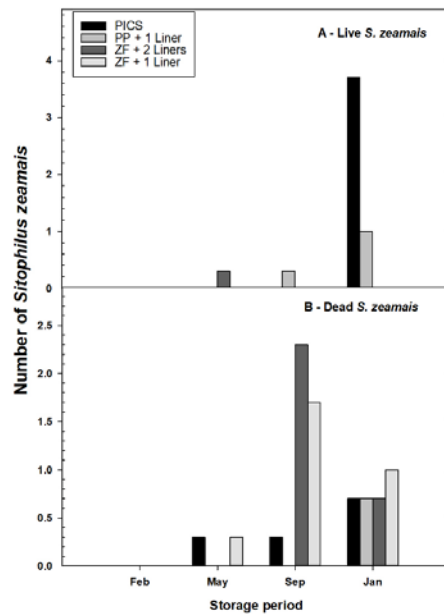


Fig. 2: Number (mean) of live (A) and dead (B) *Sitophilus zeamais* per 250 g of maize kernels in the hermetic treatments (PICS, PP + 1 Liner, ZF + 2 Liners and ZF + 1 Liner) sampled every four months.

3.2.3. *Cryptolestes ferrugineus*

The pattern for number of *C. ferrugineus* in non-hermetic treatments is shown in Fig. 5. There were no live *C. ferrugineus* from samples in all the four treatments during the first 5 months of storage in May. During the period August to January, more insects were found in the ZF treatment than in the other three treatments, and the number increased markedly from 47 in November to 69 in January (Fig. 5A). In contrast, there was no live or dead *C. ferrugineus* in all the different hermetic treatments during the entire storage period.

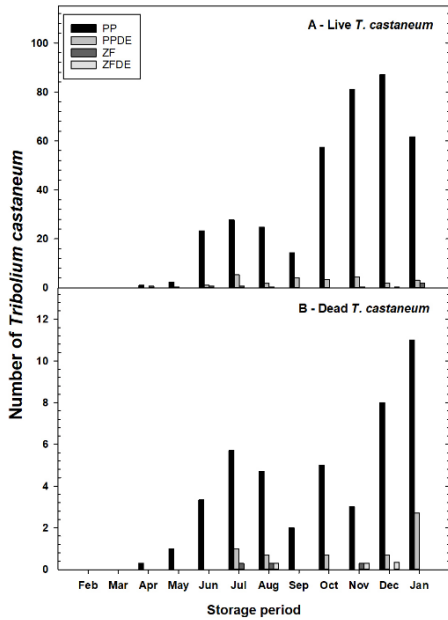


Fig. 3: Number (mean) of live (A) and dead (B) *Tribolium castaneum* per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

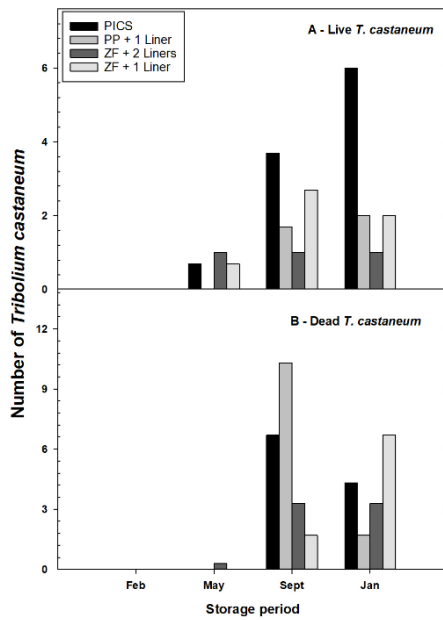


Fig. 4: Number (mean) of live (A) and dead (B) *Tribolium castaneum* per 250 g of maize kernels in the hermetic treatments (PICS, PP + 1 Liner, ZF + 2 Liners and ZF + 1 Liner) sampled every four months.

3.2.4. *Liposcelis* spp.

The pattern for numbers of *Liposcelis* spp. found in the different non-hermetic treatments is shown in Fig. 6. Lower numbers of live *Liposcelis* spp. were found in the PP treatment during the entire storage periods. Among the other three treatments, the ZFDE treatment had the highest number of live insects in July (29) but this decreased to 8 in December (Fig. 6A). *Liposcelis* spp. were not found in all the hermetic treatments.

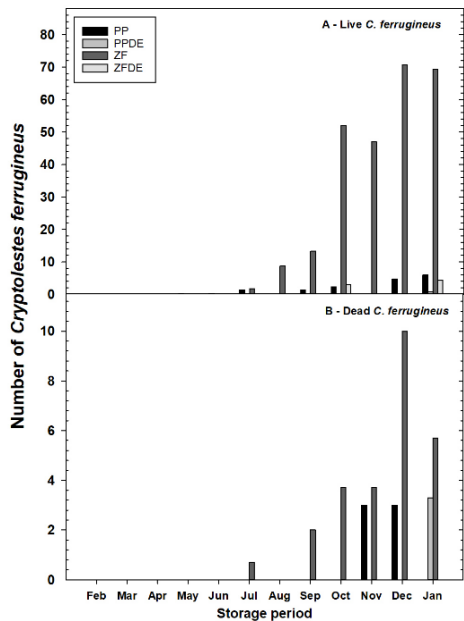


Fig. 5: Number (mean) of live (A) and dead (B) *Cryptolestes ferrugineus* per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

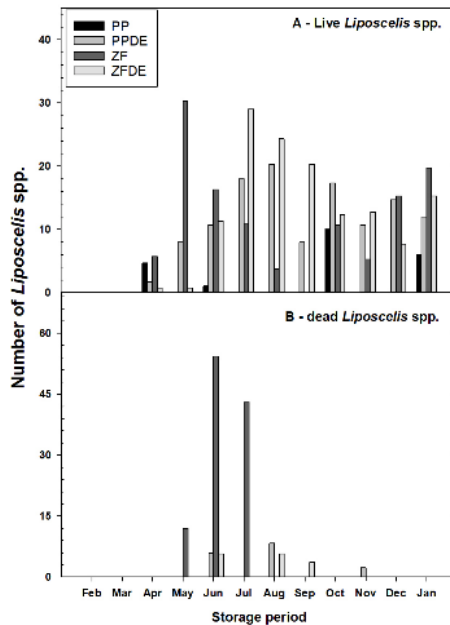


Fig. 6: Number (mean) of live (A) and dead (B) *Liposcelis* spp. per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

3.3. Percent Insect Damaged Kernels (% IDK)

The patterns for % IDK, by both numerical basis (IDKnb) and weight basis (IDKwb), are shown in Figs. 7 and 8. In the ZF treatment, IDKnb markedly increased from 0.2% in March to 16.9% in January (Fig. 7A). In the case of PP treatment, there was consistent increase in IDKnb from 0.4% per 250 g maize sample in May to 5.4% in January. In the PPDE and ZFDE treatments, IDKnb did not exceed 1.9 and 0.8%, respectively, over 12 months of storage (Fig. 7A). The IDKwb values were highest in the ZF treatment followed by PP treatment, and were 10.9% and 5.3%, respectively, at the end of storage in January 2018 (Fig. 7B).

For the hermetic treatments, IDKnb and IDKwb values were below 1% in all the four treatments (Fig. 8). With the exception of May, generally, ZF + 2 liners and ZF + 1 liner treatments had the lowest IDKnb and IDKwb values (Fig. 8A).

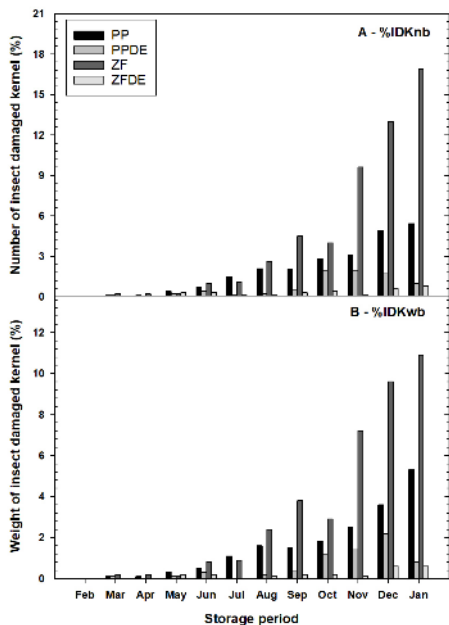


Fig. 7: Percentage number (A) and weight of insect damaged kernels (IDK) (B) (mean) per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

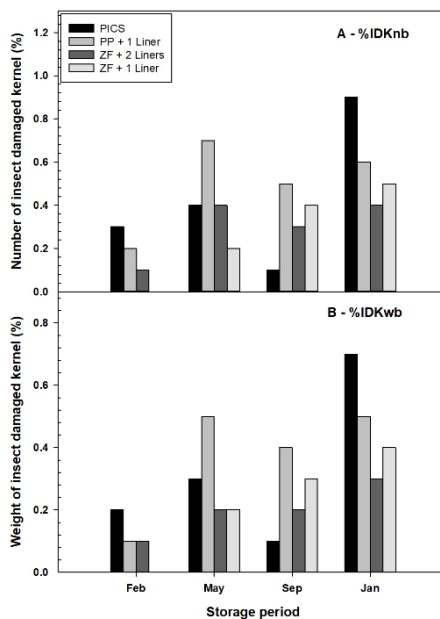


Fig. 8: Percentage number (A) and weight of insect damaged kernels (IDK) (B) (mean) per 250 g of maize kernels in the hermetic treatments (PICS, PP + 1 Liner, ZF + 2 Liners and ZF + 1 Liner) sampled every four month

3.4 Grain weight loss

The general trend from July 2017 to January 2018 was for percentage weight loss to be highest in the ZF treatment followed by PP treatment (Fig. 9). In the ZF treatment, percentage weight loss increased substantially from 0.2% in August to 6.7% in January (Fig. 9). In the PP treatment, weight loss did not exceed 0.5% after 8 months of storage in September but increased to 1.4% at the end of the study in January (Fig. 9). Low weight loss values were found in the hermetic treatments with PP + 1 liner, ZF + 2 liners and ZF + 1 liner bags mostly having a low value of 0.1% and loss did not exceed 0.2% on average in the PICS treatment (Fig. 10).

3.5 Seed germination (%)

The initial mean germination rate for all the treatments (hermetic and non-hermetic) was 97.5% (Figs. 11 and 12). At the end of storage period, germination rates in ZF (87%) and PP (91.3%) were relatively the lowest compared to other treatments (Fig. 11). After 12 months, mean germination rates of samples collected from the hermetic treatments was similar to that obtained at the start of experiment (97%) (Fig. 12).

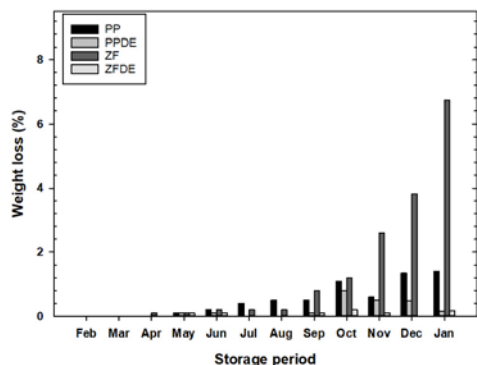


Fig. 9: Percentage weight loss (mean \pm SE) per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

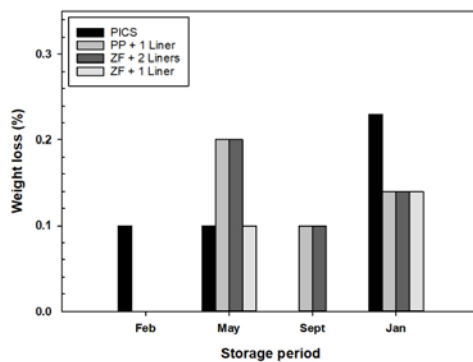


Fig. 10: Percentage weight loss (mean \pm SE) per 250 g of maize kernels in the hermetic treatments (PICS, PP + 1 Liner, ZF + 2 Liners and ZF + 1 Liner) sampled every four month

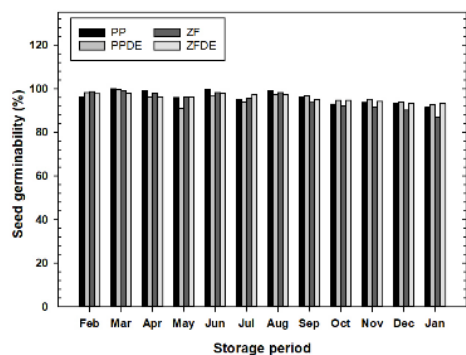


Fig. 11: Percentage seed germinability (mean) per 250 g of maize kernels in the non-hermetic treatments (PP, PPDE, ZF and ZFDE) sampled at monthly intervals over 12 months.

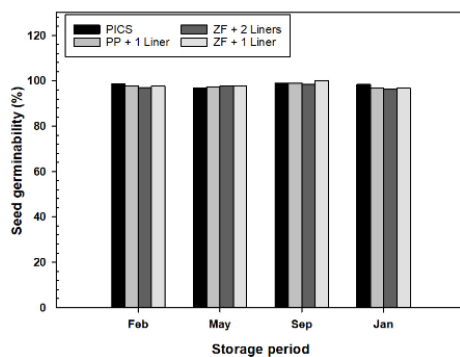


Fig. 12: Percentage seed germinability (mean) per 250 g of maize kernels in the hermetic treatments (PICS, PP + 1 Liner, ZF + 2 Liners and ZF + 1 Liner) sampled every four months

4. Discussion

Among the non-hermetic treatments, our data revealed that PPDE and ZFDE treatments were effective in reducing insect infestation and damage levels compared to the control treatment (untreated maize in PP bags). Maize treated with Insecto DE provided better protection for stored maize from *S. zeamais* infestation for up to 8 months during storage. In the PPDE and ZFDE treatments, mean weight losses of $\leq 1\%$ and $\leq 0.2\%$ respectively were observed after the 12-month storage period. Other studies have shown that stored grain insect pests can be controlled by commercially available DE formulations (Ashraf *et al.*, 2016). In the non-hermetic and no DE treatment, *S. zeamais* was the major damaging pest resulting in high IDK levels of 5.4% and 16.9% after 12 months of storage in PP and ZF bags, respectively. The ZF treatment (untreated maize in ZeroFly bags) was effective for up to 4 months of storage (June), but thereafter, levels of insects such as *S. zeamais* and *C. ferrugineus* increased markedly. Data obtained from this study correspond to those of (Paudyal *et al.*, 2017) who found high insect infestation levels in ZeroFly bags after 4 months of storage. The high level of infestation in ZeroFly bags after 4 months of storage may be due to pre-infestation of maize during bagging by insects at the egg or larval stage — maize used in this study was un-fumigated. Given that the newly-harvested grains can be infested after storage (Vela Coiffier *et al.*, 1997; Hagstrum, 2001), it is recommended by the manufacturer of ZeroFly storage bag that

the grains be pre-fumigated because the bags are designed to give protection to commodities by preventing the entry of insect pests, thereby facilitating preservation of cereal grains and grain legumes. Additionally, as a result of the *S. zeamais* infestation pressure in the storehouse, it is possible that the repeated sealing and unsealing of the ZeroFly bags during grain sampling might have compromised the deltamethrin barrier and consequently allowed easy access of insects into the bags (Paudyal *et al.*, 2017). In this study, *S. zeamais* was the major damaging pest eventually causing weight loss of 1.4% and 6.7% after 12 months of storage in PP and ZF bags, respectively (January 2018 weight losses). Comparatively, in all the hermetic treatments, insect infestation was effectively suppressed resulting in fewer insect damaged kernels and lower weight losses due to the low oxygen environment created by the hermetic technologies. Also few live insects were found in maize treated with DE dust throughout the storage period, this may be a result of the killing action or repellency of the diatomaceous earth.

One of the main purposes of storing grain is to ensure seed availability and viability, both of which are important to farmers. In all the eight treatments, germination rates of maize stored in all the hermetic treatments for 12 months were similar to that observed at the beginning of the study. This is consistent with the data obtained by Yakubu (2012) who stored maize hermetically for a period of one year and concluded that the hermetic conditions contribute to preservation of seed quality. The lowered oxygen concentration within the bags thus does not appear to affect the viability of maize seed (Baoua *et al.*, 2014). On the other hand, germination rates of seeds in the PP and ZF bags were greatly reduced at the end of the 12-month storage period. This is most likely a result of higher insect infestation.

Conclusion

The suitability and performance of hermetic storage bag technologies used in this study in mitigating insect infestation and preserving maize was much better than the non-hermetic methods over the 12-month storage period. Based on data from this study, hermetic storage technologies are effective and need to be more widely adopted for improved food quality and security.

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References

- ABATE, T., FISHER, M., ABDOULAYE, T., KASSIE, G.T., LUNDUKA, R., MARENDA, P., AND ASNAKE, W., 2017: Characteristics of maize cultivars in Africa: How modern are they and how many do smallholder farmers grow? *Agriculture & Food Security* 6:30. DOI 10.1186/s40066-017-0108-6
- ABATE, T., MENKIR, A. BADU-APRAKU, B., ABDOULAYE, T., ABDULLAHI, I., OGUNBLE, A., ONYIBE, J., ADO, S. AND OLAOYE, G., 2015: Maize variety options for Africa: Nigeria. CIMMYT. IITA. DTMA. Series: Maize variety options for Africa.
- ABDOULAYE, T., AINEMBABAZI, J.H., ALEXANDER, C., BARIBUSTA, D., KADJO, D., MOUSSA, B., OMOTILEWA, O., RICKER-GILBERT, J., AND SHIFERAW, F., 2016: Postharvest Loss of Maize and Grain Legumes in Sub-Saharan Africa: Insights from Household Survey Data in Seven Countries. Purdue Extension: EC-807-W. www.extension.purdue.edu
- BAOUA, L., AMADOU, L., LOWENBERG-DEBOER, J. AND MURDOCK, L., 2013: Side by side comparison of GrainPro and PICS bags for postharvest preservation of cowpea grain in Niger. *Journal of Stored Products Research* 54, 13–16.
- BAOUA, L.B., AMADOU, L., OUSMANE, B., BARIBUTSA, D. AND MURDOCK, L.L., 2014: PICS bag for post-harvest storage of maize grain in West Africa. *Journal of Stored Products Research* 58, 20–28.
- BOXALL, R.A., 2002: Damage and loss caused by the larger grain borer *Prostephanus truncatus*. *Integrated Pest Management Reviews* 7, 105–121.
- CERUTI, F.C., LAZZARI, S.N., LAZZARI, F.A. AND PINTO JUNIOR, A.R., 2008: Efficacy of Diatomaceous earth and temperature to control the maize weevil in stored maize. *Scientia Agraria, Curitiba* Vol 9, No 1 p. 73–78
- COSTA, S.J., 2014: Reducing food losses in Sub-Saharan Africa (improving post-harvest management and storage technologies of smallholder farmers.) An 'Action Research' evaluation trial from Uganda and Burkina Faso. August 2013 – April 2014.

- DE BRUIN, T., VILLERS, P., WAGH, A., AND NAVARRO, S., 2012: Worldwide use of hermetic storage for the preservation of agricultural products. In: 9th International Controlled Atmosphere & Fumigation Conference. Antalya, Turkey, October 15-19.
- GWINNER, J., HARNISCH, R., AND MUCK, O., 1996: Manual on the prevention of post harvest seed losses, post harvest project, GTZ, D-2000, Hamburg, FRG, p. 294.
- HAGSTRUM, D.W., 2001: Immigration of insects into bins storing newly harvested wheat on 12 Kansas farms. *Journal of Stored Products Research* 37, 221-229
- HODGES, R.J., 1986: The Biology and Control of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). A destructive storage pest with an increasing range. *Journal of Stored Products Research* 22, 1-14.
- HOLST, N., MEIKLE, W.G., AND MARKHAM, R.H., 2000: Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. *Journal of Economic Entomology* 93, 1338-1346.
- ILEKE, K.D. AND ONI, M.O., 2011: Toxicity of some plant powders to maize weevil, *Sitophilus zeamais* (Coleoptera: Curculionidae) on stored wheat grains. *African Journal of Agricultural Research* 6 (13): 3043-3048.
- KAVALLIERATOS, N.G., ATHANASSIOU, C.G., AND ARTHUR, F.H., 2017: Effectiveness of insecticide-incorporated bags to control stored-product beetles. *Journal of Stored Products Research* 70, 18-24
- KORUNIC, Z., 1998: "Diatomaceous earths: a group of natural insecticides." *Journal of Stored Products Research* 34 (2/3): 87-97.
- KORUNIC, Z., FIELDS, P.G., KOVACS, M.I.P., NOLL, J.S., LUKOW, O.M., DEMIANYK, C.J., SHIBLEY, K.J., 1996: The effect of diatomaceous earth on grain quality. *Postharvest Biology and Technology* 9, 373-387
- LEE, B.H., CHOI, W.S., LEE, S.E. AND PARK, B.S., 2001: Fumigant toxicity essential oil and their constituent compounds towards the rice weevil, *Sitophilus oryzae* (L.). *Crop protection* 20: 317 - 320
- NWAUBANI, S.I., OPIT, G.P., OTITODUN, G.O., AND ADESIDA, M.A., 2014: Efficacy of two Nigeria derived diatomaceous earths against *Sitophilus oryzae* (Coleoptera: Curculionidae) and *Rhyzopertha dominica* (Coleoptera: Bostrichidae) on wheat. *Journal of Stored Products Research* 59: 9-16.
- PAUDYAL, S., OPIT, G.P., OSEKRE, E.A., ARTHUR, F.H., BINGHAM, G.V., PAYTON, M.E., DANSO, J.K., MANU, N. AND NSIAH, E.P., 2017: Field evaluation of the long-lasting treated storage bag, deltamethrin incorporated, (ZeroFly® Storage Bag) as a barrier to insect pest infestation. *Journal of Stored Products Research* 70, 44-52
- QUITCO, R.T. AND QUINDOZA, N.M., 1986: Assessment of Paddy Loss in Storage. Unpublished terminal Report. NAPHIRE 46PRAMIREZ MARTINEZ, M., SILVER, B.J., 1983: Deterioration and damage produced in corn grains in Mexico by *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). In: Oxley, T.A., Barry, S. (Eds.), *Biodeterioration*, vol. 5. John Wiley, New York, pp. 582-591
- VELA COIFFIER, E.L., FARGO, W.S., BONJOUR, E.L., CUPERUS, G.W., AND WARDE, W.D., 1997: Immigration of insects into on-farm stored wheat and relationship among trapping methods. *Journal of Stored Products Research* 33, 157-166.
- WILLIAMS, S.B., MURDOCK, L.L. AND BARIBUSTA, D. 2017: Storage of Maize in Purdue Improved Crop Storage (PICS) Bags. *PLoS ONE* 12(1): e0168624. doi:10.1371/journal.pone.0168624
- YAKUBU, A., 2012: Reducing Losses to Maize Stored on Farms in East Africa Using Hermetic Storage. Graduate Theses and Dissertations. Paper 12532. Iowa State University

Insecticide treated packaging for the control of stored product insects

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Abstract

Improper or poor post-harvest handling and storage of stored grains contributes significantly to product loss, and bagged stored grain presents an option for safe storage and handling. Bagged grain is intended to maintain quality and safety, while protecting it from infestations. The objective of this research was to determine the effect of deltamethrin-treated packaging material on adults and larvae of common stored product pests. Adults or larvae of several species of stored product insects were exposed to deltamethrin-treated packaging for time intervals ranging from 1 h to 4 weeks. The percentage of affected *Prostephanus truncatus*, *Callosobruchus maculatus* and *Rhyzopertha dominica* adults was < 98% after 60 minutes of exposure to treated packaging. Mortality of adult *Trogoderma granarium* was about 33% after 1 day of exposure, and increased to 93% after 7 day of exposure. Direct mortality of *T. granarium* larvae exposed to the deltamethrin-treated packaging for 8 h was about 15%, but increased to 50% when larvae were exposed for 72 h. *Tribolium castaneum*, *Oryzaephilus surinamensis*, and *Trogoderma inclusum* larvae continually exposed to the deltamethrin-treated packaging resulted in > 96% larval death within 1-2 weeks. The major primary stored product insects were highly susceptible to the deltamethrin-treated storage bags, but there was variation in susceptibility between species