and logistical support received from the agricultural extension staff from the Ministry of Agriculture, Mechanisation and Irrigation Development in Murehwa and Insiza districts during the surveys.

References

APHLIS, 2014: The African Postharvest Losses Information System. APHLIS 2.2, 46pp.,

CHIGOVERAH, A.A. AND B.M. MVUMI, 2016: Efficacy of metal silos and hermetic bags against stored maize insect pests under simulated smallholder farmer conditions. Journal of Stored Products Research **69**: 170–189.

LARSEN, A. F. AND H. B. LILLEØR, 2014: Beyond the Field: The Impact of Farmer Field Schools on Food Security and Poverty Alleviation. World Development **64**: 843-859

MANDA, J. AND B.M. MVUMI, 2010: Gender relations in household grain storage management and marketing: the case of Binga District, Zimbabwe. Agriculture and Human Values **2**7: 85-103.

MLAMBO, S., MVUMI, B.M., STATHERS, T., MUBAIWA, M. AND T. NYABAKO, 2017: Field efficacy of hermetic and other maize grain storage options under smallholder farmer management. Crop Protection **98**: 198-210.

MUGANDANI, R., WUTA, M., MAKARAU, A. AND B. CHIPINDU, 2012: Re-Classification Of Agro-Ecological Regions Of Zimbabwe In Conformity With Climate Variability And Change. African Crop Science Journal. **20**: 361–369.

MUHOYI, E., MAKURA, J.T., NDEDZU, D., MAKOVA, T. AND O. MUNAMATI, 2014: Determinants of Food Security in Murehwa District, Zimbabwe. Journal of Economic and Sustainable Development **5**: 84-92.

MVUMI, B.M., 1997: Farmers' misconceptions on food grain conservation. Findings from farmer group discussions. The Zimbabwe Science News **31**: 62–64.

MUTISYA, D., KARANJA, D.R., KISILU, R.K. AND F. YILDIZ, 2016: Economic advantage of sorghum harvest at soft dough grain stage to prevent bird damage. Congent Food & Agriculture **2**: 1259141. http://dx.doi.org/10.1080/23311932.2016.1259141

MVUMI, B.M. AND T.E. STATHERS, 2003: Challenges of grain protection in sub-Saharan Africa: the case of diatomaceous earths, 31 March -11 April 2003 Proceedings of Food Africa Internet based Forum 1-6.

MVUMI, B.M. AND T.E. STATHERS, 2015: Food security challenges in Sub-Saharan Africa: The potential contribution of postharvest skills, science and technology in closing the gap. In: Arthur, F.H; Kengkanpanich, R.; Chayaprasert, W.; Suthisut, D. (Eds.) *Proceedings of the 11th International Working Conference on Stored Product Protection* 24-28 November 2014 Chiang Mai, Thailand.

MVUMI, BM., GIGA, D.P. AND D.V. CHIUSWA, 1995: The maize (Zea mais L.) post-production practices of small-holder farmers in Zimbabwe: findings from surveys. Journal of Applied Science in Southern Africa **1**: 115-130. DOI10.4314/jassa.v1i2.16858

NUKENINE, E.N, 2010: Stored Product Protection in Africa. Past, Present and Future. In: Carvalho, M.O.; Fields, P.G.; Adler, C.S.; Arthur, F.H.; Athanassiou, C.G.; Campbell, J.F.; Fleurat-Lessard, F.; Flinn, P.W.; Hodges, R.J.; Isikber, A.A.; Navarro, S.; Noyes, R.T.; Riudavets, J.; Sinha, K.K.; Thorpe, G.R.; Timlick, B.H.; Trematerra, P.; White, N.D.G. (Eds.), *Proceedings of the 10th International Working Conference on Stored Product Protection*, 27 June to 2 July 2010, Estoril, Portugal.

NYAGWAYA L.D.M., MVUMI, B.M. AND I.G.M. SAUNYAMA, 2010: Occurrence and Distribution of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Zimbabwe. International Journal of Tropical Insect Science 30, 221–231.

TAYLOR, J.R.N., 2003: Overview: Importance of sorghum in Africa. In: Belton, P.S. & Taylor, J.R.N. (Editors), Proceedings of Workshop on the Proteins of Sorghum and Millets: Enhancing Nutritional and Functional Properties for Africa. Pretoria, South Africa, 2–4 April 2003. AFRIPRO. http//www.afripro.org.uk/papers/Paper01Taylor.pdf. [Accessed 9 January 2018].

WORLD BANK, NRI, FAO, 2011: Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan African. The World Bank, 60371eAFR (60371), p. 116. Report No. 60371-AFR.

Evaluation of five storage technologies to preserve quality composition of maize in Nigerian markets

Grace Otitodun*, Adeola Ala, Samuel Nwaubani, Mobolaji Omobowale, Moses Ogundare, Grace Abel, Kehinde Ajao, Jafar Braimah, Akhere Olenloa, Olumuyiwa Kolayemi, Jonathan Ogwumike, George Opit, Klein Ileleji, Samuel G. McNeill

*Nigerian Stored Products Research Institute, P.M.B. 1489, Ilorin, Kwara State, Nigeria,
*Corresponding author: G. Otitodun (funkeotis@yahoo.com)
DOI 10.5073/jka.2018.463.193

Abstract

Maize needs to be stored using good and safe postharvest management measures that will maintain the quality as at harvest. Insects and moisture must be controlled in storage to ensure quality and methods to achieve this, such as the use of reduced-risk measures were evaluated in this study, conducted February–December 2016. The efficacy of Bularafa diatomaceous earth (DE), *Piper guineense* (Botanical), PICS bags, ZeroFly® bags and permethrin (Rambo™) in preserving maize quality in Nigerian markets was assessed. A sixth treatment comprised maize in untreated polypropylene bags. Study locations were in four markets in Ibadan, Ilorin and Oyo towns. Each market had a storehouse, which contained experimental 100-kg bags. In each storehouse, each technology had six bags, which were all sampled monthly except in PICS treatment where six bags were destructively sampled every four months. Data taken in February) and December) showed that quality of maize in PICS bags was best having the lowest percentage of insect damaged kernels, numerical based (%IDKNB), — 0.01 ± 0.01and 0.02 ± 0.01; %IDKWB— weight based were 0.00 ± 0.00 and 0.00 ± 0.00); % weight loss (0.01 ± 0.01; 0.01 ± 0.01), % number of discolored maize (0.02 ± 0.01; 0.01 ± 0.01) and % seed germination (96.77 ± 0.53; 98.37 ± 0.35) respectively. Treated and untreated maize had mean aflatoxin levels below limit of detection of 5 ppb in February and December (0.47 and 1.66), respectively and their proximate composition were within ranges reported in literature. By December, untreated maize had the highest %IDKNB (1.42 ± 0.22), %IDKWB (1.07 ± 0.18), % weight loss (0.36 ± 0.07) and lowest % seed germination (88.09 ± 0.98) when compared to the evaluated storage technologies Therefore, these five technologies can be incorporated in integrated management of storage insect pests in storehouses.

Keywords*:* Insect damage, Weight loss, Aflatoxin, Seed germination, Proximate composition.

Introduction

Maize (*Zea mays* L.) is an important cereal which ranks third in global production/consumption after wheat and rice (Asghar et al., 2010). It is a major cereal for livestock feed and human nutrition. It is also an important raw material for several agro-based industries (Akande and Lamidi, 2006). In addition, in a market that is not controlled, the value of any surplus maize in good condition tends to rise during the off-season period (Nagaraj et al., 2016); meaning maize can be an important cash crop. Maize has the disadvantage of being harvested in the wet season; hence, prone to damage by microorganisms in addition to the problems of insect infestation.

Sitophilus zeamais is a serious cosmopolitan field-to-store pest of maize in tropical and subtropical regions (Hagstrum et al., 2012). Damage caused by the insect becomes noticeable after the adult insect makes holes and deposits its eggs within the hole. Developmental stages of the insect take place within the grain after which the adult weevil bores its way out, leaving a characteristic emergence hole on the grain (Rees, 2004). In developing countries, maize production and consumption often falls below demand as a result of post-harvest losses due to storage pests and other agents (Aulakh et al., 2013). Post-harvest losses due to *S. zeamais* have been reported as an important constraint to grain storage in Africa (Edelduok et al., 2015), these losses threaten household food security and reduced market returns making stakeholders seek any type of option for protecting their grain during storage (Stathers et al., 2008). Despite success in controlling insect pests using synthetic insecticides, their persistence in the environment, the toxic residues they leave in food and development of resistance by insect pests require that more reduced-risk alternatives be sought (Ileke and Oni, 2011).

During storage, grain quality can remain at the initial level or decline to a level that may make it unacceptable for both food and planting purposes. This decline is due to many determinants: adverse environmental conditions during seed production and storage, pests (insects, rodents and micro-organisms), high moisture content, mechanical damage during threshing, long duration of storage, bad packaging, pesticides and biochemical injury of grain tissue (Jyoti and Malik, 2013).

Moreover, the change in color of seed grains, protein and carbohydrate degradation, and the production of mycotoxin reduce the quality of stored grains, and endanger human health (Pimentel et al., 2011). The preservation of quality and nutritional value of grain during the period of storage depends not only on the conditions of production and harvesting, but also on the maintenance of appropriate storage conditions of the grain.

Presently in Nigeria, control of insect pests in stored food products, maize inclusive, is by the use of synthetic insecticides which have some hazards such as pollution of the environment, toxic residues in stored grains, development of resistance in target species, pest resurgence, lethal effects on non-target organisms, direct toxicity to users and other health hazards in addition to the high cost of the insecticide cum inadequate skills in application, (Adedire et al., 2011). However, there are reduced-risk technologies such as botanicals (e.g. *Piper guineense* (Schum & Thonn), diatomaceous earths (DE), Purdue Improved Crop Storage (PICS) bags and ZeroFly® Storage Bags (hereafter referred to as ZeroFly bag) that are available in sub-Saharan Africa and can be used for proper preservation of grains without the negative effects associated with pesticides. Botanical such as *P. guineense,* which are inexpensive, relatively safe, and poses little or no hazard to human health and the environment have been used for postharvest insect pest control in grains (Asawalam et al., 2007; Otitodun et al, 2015).

Despite the fact that there are reduced-risk technologies available for grain preservation in sub-Saharan Africa, there is little information available on how effective these technologies are for preservation of grains such as maize in storage. This means it is important to evaluate the effectiveness of these reduced-risk technologies in the field. Therefore, the objective of this study was to evaluate five storage technologies — a botanical (*P. guineense*), Bularafa DE, PICS, ZeroFly® bag and permethrin (Rambo™) — to preserve the quality of maize in Nigerian markets.

Materials and Methods

Study Sites

The experiment was conducted during the period February–December 2016 in storehouses located in three grain markets — Eleekara market in Oyo and Arisekola market in Ibadan, Nigeria and Old Ago market in Ilorin, North Central Nigeria.

Maize Samples

Maize used for the experiment was obtained from Ijaye Farm Settlement in Akinyele Local Government Area, Ibadan Oyo State. The variety known as SWAN 2 is widely grown in Southwest Nigeria; Farmers in the settlement had applied aflasafe™ in fields used to produce maize for this study. Aflasafe contains a mixture of four atoxigenic strains of *Aspergillus flavus* of Nigeria origin (Agresults Online). Initial maize moisture content was determined by the ASABE. Maize was fumigated before use to ensure that there was no field to store transfer of insect pests. Fumigation was conducted at the Nigerian Stored Products Research Institute (NSPRI), Ilorin, Nigeria.

Storage Technologies (treatments)

Maize was stored for 11 months using five storage technologies — ZeroFly bags, PICS bags, diatomaceous earth (Bularafa DE), a botanical (*P. guineense*) and permethrin (Rambo™) — to assess their effectiveness in controlling stored product insect pests and were compared with untreated control.

Methodology

In each storehouse six 100-kg maize-filled bags were assigned to ZeroFly, DE, Botanical, Rambo and untreated control; each stack of six bags was on a separate pallet. Sixteen bags were assigned to PICS arranged on four pallets. Bags on pallets were arranged in such a way that they formed two layers. The pallets for each treatment were placed 1 m apart from each other. There were forty-six 100-kg bags per storehouse

The experimental design used was randomized complete block design (RCBD) with four replications and six sub-replications. Each market represented a replication.

Samples of maize were obtained using a 1.2-m open-ended Trier (grain probe) (Seedburo Equipment, Chicago, IL) with six openings, total of 700 g was taken from each bag during each sampling event.

In the PICS treatment, six bags were destructively sampled every 4 months — 1 bag with a sensor and 5 bags without sensors. The six bags to be sampled were randomly selected at the beginning of the study using randomization software

Seed germination, insect damaged kernels, weight loss and maize discoloration were determined monthly, Nutritional composition of maize (Proximate analysis) was determined at 4 months' intervals while aflatoxin levels were determined at the begining and end of the study.

Statistical Analyses

Statistical analyses were performed with SAS Version 9.3 (SAS Institute, Cary, NC). Treatment effects were assessed using analysis of variance methods (PROC MIXED). A repeated measures model in a randomized complete block design was utilized, with market as the blocking factor and month as the repeated factor. An autoregressive covariance structure was used to model the correlations within treatment and across months. An analysis of the aflatoxin level was conducted with the use of a square root transformation. A square root transformation was used to correct for heterogeneous variances and the lack of normality of the count response variable. The simple effects of treatment given month were assessed with protected planned contrasts (SLICE option in an LSMEANS statement). In the case of percent insect damaged kernel, weight loss, seed germination, discoloured grain and proximate composition, data analyses were conducted with the use of an arcsine transformation to stabilize variances but untransformed percentages are reported.

Results

Results presented on the study are in two categories; study involving four treatments (Botanical, DE, Rambo and ZeroFly) and study involving five treatments (Botanical, DE, PICS, Rambo and ZeroFly).

Percent number of insect damaged kernels (%IDKNB), weight of insect damaged kernels (%IDKWB), weight loss (%WL), seed germination (%SG), discolored grains (%DG), aflatoxin levels (AF) and proximate composition of maize preserved in Nigeria market with four treatments

In the study involving 4 treatments, mean values for %IDKNB, %IDKWB and %WL was significantly low in Rambo treatment by December, followed by DE, ZeroFly and Botanical compared to untreated control with the highest mean values (1.42 ± 0.22; 1.07 ± 0.18 and 0.36 ± 0.07), respectively (Fig 1A–C). Furthermore, in December, mean %SG was significantly high in all treatments (>96%) compared to untreated control with significantly low value — 88.09% (Fig. 2). With respect to %DG from March to December, ANOVA result shows no significant interaction between month and treatment and treatment alone (*P*>0.05) while significant difference occured in %DG within the months (Tab. 1).

Percent number of insect damaged kernels (%IDKNB), weight of insect damaged kernels (%IDKWB), weight loss (%WL, seed germination (%SG), discolored grains (%DG), aflatoxin levels (AF) and proximate composition of maize preserved in Nigeria market with five treatments

In the study involving 5 treatments, mean values of %IDKNB, %IDKWB and %WL were significantly low by December in PICS treatment, followed by Rambo, DE, ZeroFly and Botanical compared to untreated control with the highest mean values (1.42 ± 0.22; 1.07 ± 0.18 and 0.36 ± 0.07), respectively (Fig 3A–C). Also in December, mean %SG was significantly high in all treatments (>96%) compared to untreated control with significantly low value — 88.09% (Fig. 4A); significantly low mean values of %DC was recorded in PICS (Fig. 4B); aflatoxin estimates in maize samples from all treatments and untreated control was below 2ppb (Fig. 4C): Proximate composition values was within recommended range for maize (Tab. 2; Fig 5A–C).

Tab. 1. ANOVA for main effects treatment and month, and interaction (*) for percent discolored grains (% DG).

Variable	**Source**	**Four treatments**			**Five treatments**		
		df	***F***	***P***	***df***	***F***	***P***
% DG	Treatment	4, 12	0.38	0.819	5, 18	3.06	0.036
	Month	7, 309	0.91	0.013	3, 198	93.98	<0.001
	*	28, 309	0.91	0.599	15, 198	2.21	0.007

Tab. 2. ANOVA for main effects treatment and month, and interaction (*) for maize proximate composition.

Variable	Source	Proximate Composition		
		df	***F***	***P***
Moisture	Treatment	5, 15	5.82	0.004
	Month	3, 174	222.84	<0.001
	*	15, 176	3.62	<0.001
Energy	Treatment	5, 15	5.50	0.005
	Month	3, 180	7.57	<0.001
	*	15, 181	1.71	0.052
Crude Fibre	Treatment	5, 15	0.23	0.943
	Month	3, 176	10.02	<0.001
	*	15, 176	1.94	0.023
Fat	Treatment	5, 18	2.42	0.076
	Month	3, 171	5.98	0.001
	*	15, 172	3.10	0.000
Ash	Treatment	5, 118	3.92	0.003
	Month	3, 205	7.83	<0.001
	*	15, 206	2.19	0.008
Protein	Treatment	5, 15.2	0.75	0.598
	Month	3, 254	26.86	<0.001
	*	15, 270	1.08	0.374
Carbohydrate	Treatment	5, 64.8	1.59	0.174
	Month	3, 260	28.40	<0.001
	*	15, 270	1.15	0.312

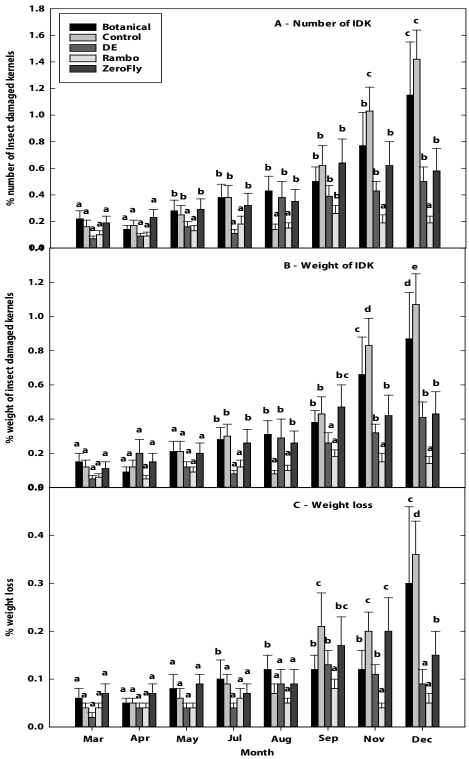

Fig. 1. Percent number of insect damaged kernels (A), percent weight of insect damaged kernels (B) and percent weight loss (C) of maize preserved with four treatments in Nigerian markets.

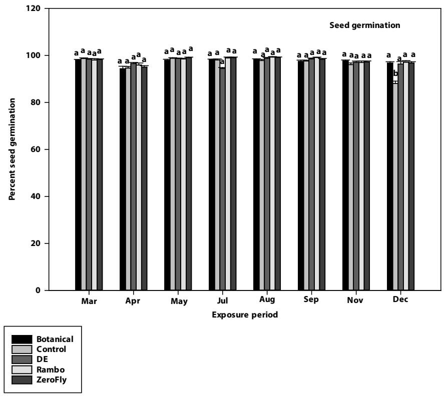

Fig. 2. Percent seed germination of maize preserved with four treatments in Nigerian markets.

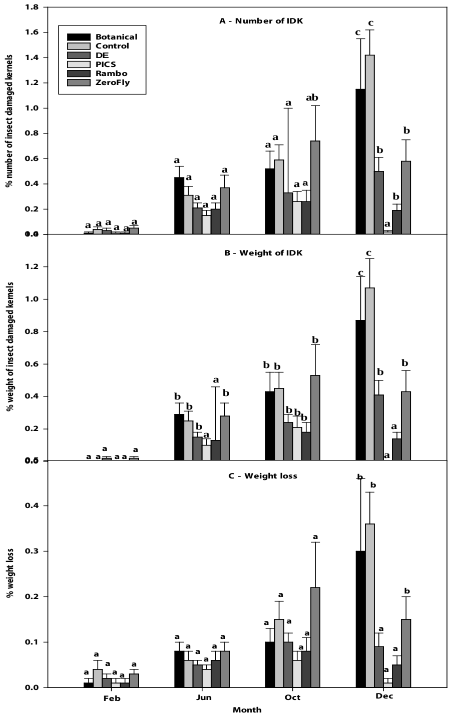

Fig. 3. Percent number of insect damaged kernels (A), percent weight of insect damaged kernels (B) and weight loss (C) of maize preserved with five treatments in Nigerian markets.

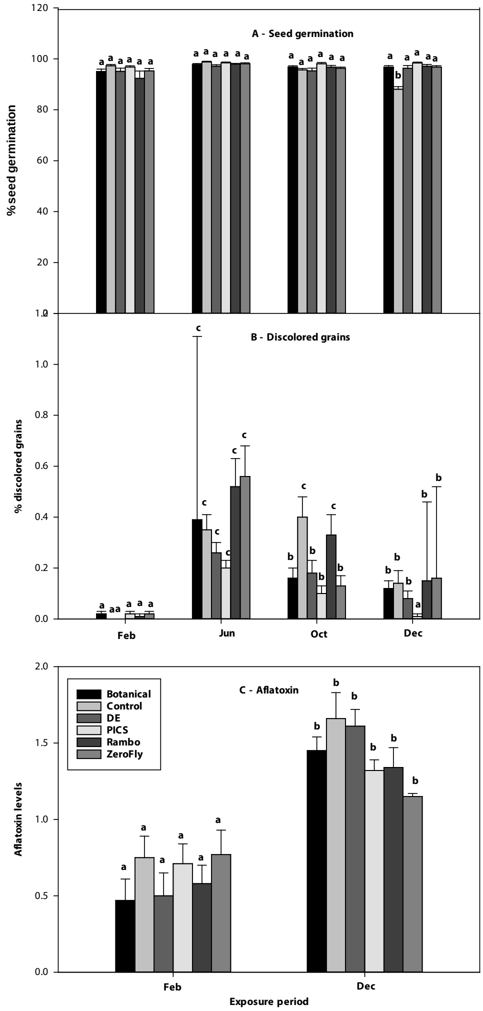

Fig. 4. Percent seed germination (A), percent discoloured grains (B) and mean aflatoxin (C) of maize preserved with five treatments in Nigerian markets.

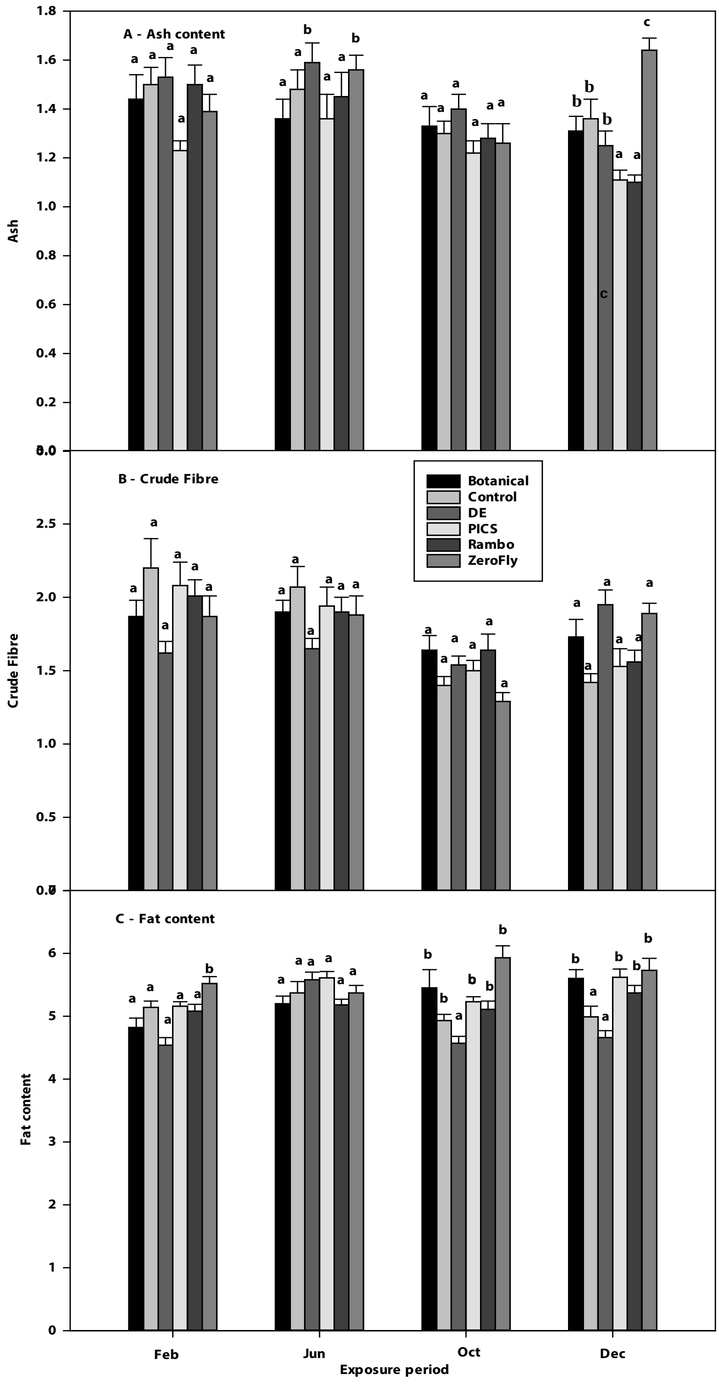

Fig. 5. Ash content (A), Crude fibre (B) and Fat content (C) of maize preserved with five treatments.

Discussion

Quality of stored maize is dependent on activities of associated insect pests. It is their feeding activity that brings about losses such as insect damaged kernels, loss in grain weight, reduced seed viability and mold growth amongst others. Grading is therefore based on these physical parameters (World Bank and FAO, 2011).

Our investigation showed that insect damaged kernels and weight loss tend to increase as month of storage increases. This could be attributed to increase in insect activities with length of storage time. This observation corroborates the report by Reed et al., (2007) that insect infestation can result, not only in grain damage as understood by shorter storage times, but can also affect the actual weight of the grain, leading to lower market prices and reduction in nutritional value of the grain.

In the five treatment study, PICS had the lowest % IDKNB, % IDKWB, weight loss and moisture content by December, after 11 months of storage (0.02, 0.00, 0.01 and 8.6%). This result confirmed earlier observations reported by Baoua et al., (2014) and Mutungi et al., (2014) that grain damage due to insect and grain weight loss is relatively lower in PICS compared to other tested grain bags because oxygen level has been depleted. High seed germination was also maintained.

In the four treatment study, Rambo treatment had the lowest % IDKNB, % IDKWB, weight loss and moisture content by December, after 11 months of storage (0.19, 0.14 and 0.05% respectively) compared with botanical, DE and ZeroFly. This could be attributed to the active ingredient Permethrin, which has been reported to affect insect nervous system by creating multiple potentials across the membrane and disrupt signal transmission in the insect (Bonny et al., 2014).

In both studies, ZeroFly bags had significantly lower values for percent IDK and weight loss with increasing storage period compared with untreated control. For example, by December in the study involving four treatments, IDKNB, IDKWB and weight loss for ZeroFly was 0.58, 0.43 and 0.15% compared to untreated control with 1.42, 1.07 and 0.36% respectively. This could be attributed to reduction in insect activities as reported by Paudyal et al., (2017) that ZeroFly bag can cause direct effects on knockdown and mortality and sub lethal effects such as reduced progeny production.

Other treatments like DE and botanical also affected insect activities in one way or the other, which invariably led to reduction in IDK, weight loss and maintained seed germination compared to untreated control. Rajapakse, 2006 reported that major action of plant powder against adult insect is through either fumigation or direct contact. Although storage of botanical treated maize in polythene lined bags could possibly improve its efficacy. Diatomaceous earth on the other hand, works by physical abrasion and adsorption of the epicuticular wax of insects by silica (Athanassiou and Steenberg, 2007; Otitodun et al., 2015).

Aflatoxin is one of the most common and important mycotoxins found in maize (Suleiman et al., 2013). Despite the fact that a significant increase was observed in aflatoxin levels from February through December, the values were all below detection limit of 5 ppb for maize meant for further processing (USDA-GIPSA, 2015).

The proximate composition results are in agreement with reports by some scientists. For example, in our study, the moisture content was observed to increase with month of storage; this consequently led to increase in both percent number and weight of IDK in control treatment. This observation corroborated the report by Child, (2007) that when a combination of favorable factors leads to increased insect development there is a co-related increase in the damage to materials through eating, despoiling, burrowing and other activities. Additionally, high moisture content leads to storage problems, respiration and reduction in germination (Suma et al., 2013). The percentage ash content observed in our study ranged between 1.10–1.59%. This is in agreement with the range of 0.70–2.50% reported from different maize hybrids in Nigeria (Keshun, 2009). The percentage protein recorded was found closely related to those reported on different maize varieties in Nigeria. In 2005, Ijabadeniyi and Adebolu reported protein content of three maize varieties grown in Nigeria within the range of 7.71–14.60%. Although some values were found a little higher and can be attributed to environmental factors. Yadav and Yadav, (2002) from their investigation reported fat content from stored maize to range between 3.98–5.45%. This confirmed the fat content range of 4.54–5.73% recorded from all the treatments and control in our study to be adequate; samples from ZeroFly bags had the highest fat content (5.73%) by December. The crude fibre value of 1.29–2.20% obtained from all samples is in agreement with the report on stored maize by Aminogo and Oguntunde (2000) where they observed crude fibre to be in the range of 0.8–2.35%. Maize is known and reported to be high in carbohydrate and as such, it is a good source of calories (Nuss and Tanumihardjo, 2011). Carbohydrate content of the maize studied was found to be within the range of 72–73% and corroborate report on stored maize varieties by Mlay et al., (2005) and 69.67–74.55% as reported by Ullah et al., (2010).

In developing countries, especially in Nigeria, where maize production is mostly by low-resource and unskilled farmers, affordable and easy to use storage measures needs to be advocated to reduce postharvest losses. Based on results from our study, using better agricultural practices and adequate storage technologies can significantly reduce quality losses attributed to insect activities and help strengthen food security, poverty alleviation and increase returns to small holder farmers and aggregators. Therefore, use of easy to apply and reduced-risk storage technologies such as botanicals (*P. guineense*), diatomaceous earths (Bularafa DE), PICS bag, and ZeroFly bag are recommended to small and medium holder farmers and grain aggregators for storage of maize in Nigeria. However, further work would be required to access the duration of insecticidal action of botanical treated maize stored in polythene lined polypropylene bags.

Acknowledgement

We thank the sponsors of this project, the United States Agency for International Development (USAID) for the funding and United States Department of Agriculture-Foreign Agriculture Service (USDA-FAS) for their administrative role. Any mention of trade names or commercial products in this publication is only for the purpose of providing specific information and does not imply recommendation or endorsement by Nigerian Stored Products Research Institute, University of Ibadan, International Institute of Tropical Agriculture, Purdue University, University of Kentucky and Oklahoma State University.

References

ADEDIRE, C.O., OBEMBE, O.O., AKINKUROLELE, R.O. AND ODULEYE, O., 2011. Response of *Callosobruchus maculatus* (Coleoptera: Chysomelidae: Bruchinae) to extracts of cashew kernels. Journal of Plant Disease and Protection Vol. **2**,**118**: 75–79.

AGRESULTS ONLINE. Nigeria Aflasafe™ Pilot. www.agresults.org

AKANDE, S.R. AND LAMIDI, G.O., 2006. Performance of quality protein maize varieties and disease reaction in the derived-savanna agro-ecology of South-West Nigeria, African Journal of Biotechnology Vol.**19, 5**: 1744–1748.

AMINOGO, E.R. AND OGUNTUNDE, A.O., 2000. Functional properties and nutritive composition of maize (Zea mays) as affected by heat treatments. Journal of Food Science Technology Vol. **1, 37**: 11–15.

ASAWALAM, E.F., EMOSAIRUE., S.O., EKELEME, F. AND WOKOCHA, R.C., 2007. Insecticidal effects of powdered parts of eight Nigerian Plant Species against Maize weevil *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). Electronic Journal of Environmental Agriculture and Food Chemistry Vol. **6, 11**: 2526–2533.

ASGHAR, A., ALI, A., SAYED, H.W., KHALIQ, T. AND ABID, A.A., 2010. Growth and yield of maize (Zea mays) Cultivers affected by NPK Application in Different proportion. Pakistan Journal of Science Vol. **4, 62**: 211.

ATHANASSIOU, C.G. AND STEENBERG, T., 2007. Insecticidal effect of *Beauveria bassiana* (Balsamo) Vuillemin (Ascomycota: Hypocreaes) in combination with three diatomaceous earth formulations against *Sitophilus granarius* (L.) (Coleoptera: Curculionidae). Journal of Biological Control Vol **3, 40:** 411–416.

AULAKH, J., REGMI, A., FULTON, J.R AND ALEXANDER, C., 2013. Estimating post-harvest food losses: Developing a consistent global estimation framework; roceedings of the Agricultural and Applied Economics Association 2013 AAEA and CAES Joint Annual Meeting; Washiongton, DC, USA. 4–6 August.

BAOUA, I.B., AMADOU, L., OUSMANE, B., BARIBUTSA, D. AND MURDOCK, D.D., 2014. PICS bag for post-harvest storage of maize grain in West African. Journal of Stored Products Research **58:** 20–28.

BONNY, D., NAMRATA, S.S., SAMIR, H.S., 2014. Acute permethrin neurotoxicity: Variable presentations, high index of Suspicion. Toxicology Reports, **1**: 1026–1028.

CHILD, R.E., 2007. Insect Damage as a Function of Climate. In: Museum Microclimates. National Museum of Denmark. ISBN 978-87-7602-080-4.

EDELDUOK, E.G., AKPABIO, E.E., EYO, J.E AND EKPE, E. N., 2015. Evaluation of the insecticidal activities of cotyledon powder of melon, Citrullus vulgaris

Schrad against the maize weevil, Sitophilus zeamis Motschusky. Journal of Biopesticides and Environment: 50–57.

FOOD AND AGRICULTURAL ORGANIZATION AND WORLD BANK, 2011. Missing Food: the Case of Post-harvest Grain Losses in sub-Saharan Africa. The International Bank for Reconstruction and Development/The World Bank. Food and Agriculture Organization. Report No. 60371-AFR: 116.

[GIPSA] Grain Inspection, Packers, and Stockyards Administration and [FGIS] Federal Grain Inspection Service Grain Inspection Handbook, Book II: Grain Grading Procedures 2013 US Department of Agriculture.

HAGSTRUM, D.W., PHILLIPS, T.W. AND CUPERUS, G., 2012. Stored Product Protection. Kansas State University, ISBN 978-0-9855003-0-6.

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 Agriculture Research. Vol. 13, 6: 3043–3048.

JYOTI AND MALIK, C.P., 2013. Seed Deterioration: A Review. International Journal of Life Sciences Biotechnology and Pharma Research. Vol. 2, 3: 374–385.

KESHUN, L., 2009. Effects of particle size distribution, compositional and colour properties of ground corn on quality of disllers dried grains with solubles. Journal of Bioresource and Technology 100: 4433–4440.

MLAY, P.S., PEREKA, A.E., BALTHAZARY, S.T., PHIRI, E.J., HVELPLUND, T., WEISBJERG, M.R. AND MADSEN, J., 2005. The effect of maize bran or maize mixed with sunflower cake on the performance of small holder diary cows in urban and semi-urban area of Morogoro, Tanzania. Journal of Livestock Research and Rural Development Vol 1, 17: 2.

MUTUNGI, C., AFFOGNON, H., NJOROGE, A., BARIBUTSA, D. AND MURDOCK, L., 2014. Storage of mung bean (Vigna radiate (L.) Wilczek) and pigeon pea grains (Cajanus cajan (L.) Millsp) in hermetic triple-layer bags stops losses caused by Callosobruchus maculatus (F.)(Coleoptera:Bruchidae). Journal of Stored Products Research 58: 39–47.

NAGARAJ., 2016. Grain Crop Drying. www.fao.org/docrep/015/i2433-/i2433-10.

NUSS, E.T. AND TANUMIHARDJO, S.A., 2011. Quality Protein Maize for Africa: Closing the Protein Inadequacy Gap in Vulnerable Populations. Journal of Advance Nutrition 2: 217–224.

OTITODUN, G.O., OPIT, G.P., NWAUBANI, S.I., OKONKWO, E.U. AND GAUTAM, S.G., 2015. Efficacy of Nigeria-Derived Diatomaceous Earth, Botanicals and Riverbed Sand against Sitophilus oryzae and Rhyzopertha dominica on Wheat. Journal of African Crop Science Vol. 3, 23: 279–293.

PIMENTEL, M.R., MOLINA, G., DIONISIO, A.P., JUNIOR, M.R.M. AND PASTORE, G.M., 2011. The Use of endophytes to obtain bioactive compounds and their application in biotransformation process. International Journal of Biotechnology Research 1: 11.

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 toinsectpestinfestation. Journal of Stored Products Research 70: 44– 52.

REED, C., DOYUNGAN, S., LOERGER, B. AND GRETCHELL., 2007. Response of storage molds to different initial moisture contents of maize (corn) stored at 25 °C and effect on respiration rate and nutrient composition. Journal of Stored Products Research 43: 443–458.

REES, D., 2004. Insects of Stored Products. CSIRO Bulletin 42.

STATHERS, T.E., RIWA, W., MVUMI, B.M., MOSHA, R., KITANDU, L., MNGARA, K., KAONEKA, B. AND MORRIS, M., 2008. Do diatomaceous earths have potential as grain protectant for small-holder farmers in sub-Saharan Africa? The case of Tanzania. Journal of Crop Protection 27: 44–70.

SULEIMAN, R.A., ROSENTRATER, K.A. AND BERN, C.J., 2013. Effects of deterioration parameters on storage of maize: A review. Journal of Natural Science Research Vol. 9, 3: 147–165.

SUMA, A., KALYANI, S., SINGH, A.K. AND RADHAMANI, J, 2013. Role of Relative Humidity in Processing and Storage of Seeds and Assessment of Variability in

Storage Behavior in Brassica spp. and Eruca sativa. The Scientific World Journal: 1–9.

WHITE, N.D.G., AND J.G. LEESCH., 1995. Chemical Control. In: Integrated Management of Insects in stored products. (Ed.): B. Subramanyam, D.W. Hagstrum. Marcel Dekker, New York: 287–330.

YADAV, S.S. AND YADAV, R.P., 2002. Studies on some quality traits of maize (Zea mays L.) genotypes. In: Advance Maize Production. Techchnology and Quality Improvement. Proceedings of National Seminar on Science- Industry Interface on Maize Production, Processing and Utilization, HPKV, Palampur, Nov 3–4, 2000: 181–183.