BORÉM, F. M., RIBEIRO, F. C., FIGUEIREDO, L. P., GIOMO, G. S., FORTUNATO, V. A., & ISQUIERDO, E. P. 2013. Evaluation of the sensory and color quality of coffee beans stored in hermetic packaging. Journal of stored products research, 52, 1-6.

DUMAN, A. D. 2010. Storage of red chili pepper under hermetically sealed or vacuum conditions for preservation of its quality and prevention of mycotoxin occurrence. Journal of stored products research, 46(3), 155-160.

GOYAL, R. K., & KORLA, B. N. 1993. Changes in the quality of Turmeric rhizomes during storage. Journal of Food Science and Technology.

LACEY, J., HILL, S.T., EDWARDS, M.A. 1980. Micro-organisms in stored grains: their enumeration and significance. Tropical Stored Products Information 39, 19–32.

LANE B., WOLOSHUK C. 2017 Impact of storage environment on the efficacy of hermetic storage bags. J. Stored Products Research. 72: 83-89.

NAVARRO, S. 2006 Modified Atmospheres for the Control of Stored-Product Insects and Mites. In: Insect Management for Food Storage and Processing, Second Edition. Heaps, J. W. Ed., AACC International, St. Paul, MN, pp. 105-146.

NAVARRO, S. AND DONAHAYE, E. 2005 Innovative Environmentally Friendly Technologies to Maintain Quality of Durable Agricultural Produce. p. 205-262. In: S. Ben-Yehoshua (Ed.), Environmentally Friendly Technologies for Agricultural Produce Quality, CRC Press, Taylor & Francis Group, Boca Raton, FL.

NAVARRO, S., CALIBOSO, F. M., SABIO, G. C., AND DONAHAYE, E. J. 1997. Quality conservation of paddy stored under gas-tight seal outdoors in the Philippines. In: Proc. Int. Conf. on Controlled Atmosphere and Fumigation in Stored Products. E .J. Donahaye, S. Navarro, and A. Varnava, Eds. Printco Ltd., Nicosia, Cyprus. pp. 159-168.

RIBEIRO, F. C., BORÉM, F. M., GIOMO, G. S., DE LIMA, R. R., MALTA, M. R., & FIGUEIREDO, L. P. 2011. Storage of green coffee in hermetic packaging injected with CO2. Journal of Stored Products Research, 47(4), 341-348.

SAS INSTITUTE INC. 2014. SAS/STAT® 13.2 User's Guide. Cary, NC: SAS Institute Inc.

VIJAYANAND P, RAO L J M & NARASIMHAM P 2001 Volatile flavour components of jamun fruit (*Syzygium cumini* L). Flavour and Fragrance Journal 16 (1) : 47-49.

WEAST R C, ASTLE M J, BEYER W H 1987 . Handbook of Chemistry and Physics. 67th Edition. CRC Press Inc. Boca Raton, Florida U.S.A.

WIKIPEDIA TDS 2018 (https://en.wikipedia.org/wiki/Total_dissolved_solids) (Accessed March 15, 2018)

WIKIPEDIA VAPOR PRESSURE 2018 (https://en.wikipedia.org/wiki/Vapor_pressure) (Accessed March 15, 2018).

Hermetic storage technology for handling of dry agricultural commodities: Practice, challenges, opportunities, research, and prospects in Zimbabwe

Brighton M. Mvumi*#, Alex A. Chigoverah

Department of Soil Science and Agricultural Engineering, Faculty of Agriculture, University of Zimbabwe, P.O Box MP 167, Mt Pleasant, Harare, Zimbabwe

*#Corresponding and presenting author: mvumibm@agric.uz.ac.zw

DOI 10.5073/jka.2018.463.121

Abstract

Storage pest management practices have relied on synthetic pesticides comprising: dust powders, liquid formulations and fumigants. Reduced efficacy against targeted species, negative health-related issues and increase in consumer awareness on potentially detrimental effects of synthetic pesticides have led to a shift towards safer and environmentally-benign alternatives. Hermetic technology is a pesticide-free storage alternative currently being used in Zimbabwe and other African countries. In the current paper, we review forms and characteristics of the hermetic technology available, organisations driving the technology, research and development (R&D) initiatives, and access and uptake trends in the country. The review draws out future prospects in terms of: stakeholder partnerships and roles, up-scaling/adoption options, R&D gaps, capacity building, and funding mechanisms for effective and sustainable uptake. Critical areas identified in the review include: the need for increasing the number of hermetic plastic liner brands available to enhance access and competitive pricing, improved distribution mechanisms for hermetic storage containers for easy access in remote areas, and generation of evidence-based efficacy data on the various hermetic storage containers in preserving quality of commercial, parent and foundation seed. Future opportunities include use of hermetic containers in the disinfestation of organic horticultural products using carbon dioxide gas hermetic fumigation. However, supporting policies are necessary to ensure sustainable adoption of the hermetic technology at subsistence and commercial scales.

Keywords: synthetic pesticides, pesticide-free storage, gas hermetic fumigation, hermetic technology adoption

Introduction

Agriculture is the primary source of livelihoods in developing countries accounting for up to 15 % of the Gross Domestic Product (GDP) in sub-Saharan Africa (SSA)(OECD, 2016). The crop sector constitutes 85 % of the total production value in SSA. Efficiency along the crop value chain is important to ensure that whatever is produced reaches the end user in optimum quality and quantity. Noxious pests and unfavourable ambient conditions are among factors that are associated with bio-deterioration of agricultural products along the value chain (Kumar and Kalita, 2017; Bradford *et al.*, 2018). Insect pests are among the major loss causing agents during the storage stage (Snelson, 1987; Muatinte *et al.*, 2014) and control strategies have been centred on synthetic pesticide use (Chaudhry, 1997; Daglish, 2006). However, negative attributes have been associated with use of chemical pesticides which include development of resistance by storage insect pests (Chaudhry, 2000; Boyer *et al.*, 2012), toxicity against untargeted species (Isman, 2006; Sarwar, 2015), health hazards to users (Aktar *et al.*, 2009) and health risks posed to consumers as a result of pesticide residues in food products (Navarro *et al.*, 2012). This has led to a paradigm shift towards research on, promotion, uptake and adoption of, environmentally-benign non-chemical pest control methods.

Hermetic storage is an environmentally-benign method being used globally for postharvest handling and disinfestation of agricultural commodities (Navarro *et al.*, 1993; Jayas and Jeyamkondan, 2002; Villers *et al.*, 2010). The method allows commodities to be stored without using any chemicals but by sorely utilising airtight storage conditions which deprive storage pests (arthropods and fungi) of oxygen leading to mortality as a result of asphyxiation (Villers *et al.*, 2006). Use of hermetic storage containers in Africa is increasing especially for handling of dry agricultural commodities at smallholder farmer level (Mvumi *et al.*, 2013; Murdock and Baributsa, 2014; Baoua *et al.*, 2015) and commercial sector (Jonfia-essien, 2012). However, hermetic technology use is not widespread in Zimbabwe although it is increasingly being adopted as a result of promotional activities by development agencies in partnership with various stakeholders including government, research institutions and farmers (Mvumi *et al.*, 2013). Hermetic storage options available on the commercial market in SSA are: small-scale storage options (hermetic bags) eg Purdue Improved Crop Storage (PICS) Bags, AgroZ® and AgroZ® Plus bags, SuperGrain™ Bags (SGB), ZeroFly® bags, Ecotact bags, metal silos and plastic silos; large-scale storage options eg GrainSafes, GrainPro Cocoons™, SiloBags; and transport options eg TranSafe Liners (TSLs) and SGB Oceans. Except for metal and plastic silos, hermetic storage containers readily available on the market in SSA are flexible plastic liners that are manufactured using high density polyethylene (HDPE) and polyvinyl chloride (PVC) (Baributsa *et al.*, 2010; Villers *et al.*, 2010) (Table 1). The hermetic containers are being used for storage and/or transportation of dry agricultural commodities like coffee, cocoa, spices, cereals and pulses (Jonfia-Essien et al. 2010; Villers et al. 2010; Mvumi et al. 2013; Baoua et al. 2015; Walker et al. 2018).

Locally available hermetic storage options, use and scale

Various hermetic technology options are now available in Zimbabwe (Table 1). The hermetic technology was first promoted in the country by FAO in 2012 in eight districts focussing on metal silos and hermetic bags (Mvumi et al., 2013). The project included Government of Zimbabwe and an NGO (Practical Action) as implementing partners focussing on training artisans in the fabrication of hermetic metal silos and introducing both the silos and hermetic bags to smallholder farmers, as alternative grain protection methods. In the same year CIMMYT partnering Government of Zimbabwe, the private sector, an NGO and the University of Zimbabwe also embarked on a similar project in two districts. In 2013, GrainPro Philippines Inc, a green and not only for profit company, and one of the leaders in the manufacturing of hermetic products for handling dry agricultural commodities, partnered Farm & City, an agricultural inputs retailer as its sole distributor in Zimbabwe. This eased local availability of hermetic plastic liner products. Use of hermetic plastic liners is increasing with promotional work being carried out by more NGOs in smallholder farming communities (Table 2). Catholic Relief Services also imported PICS bags from Malawi in 2017 to assist farmers in reducing storage losses in the arid southern parts of Zimbabwe. The total national usage of hermetic bags is around 100 000 units per season based on estimates from various project interventions. This is a small figure in relation to the approximately 1.5 million smallholder farmers in the country especially considering that 70 % of the population rely on agriculture for their livelihood. Therefore, the product has potential for wide-scale adoption by more smallholder farmers.

Initially, hermetic storage options being used were mainly for household food security purposes. However, in 2015 WFP Zimbabwe realised the opportunity of enhancing smallholder farmers' income through grain aggregation and partnered Fintrac with funding from the USAID to promote community aggregated maize grain storage (Fig 1). This initiative allowed farmers to store grain soon after harvesting and then sell later to take advantage of favourable prices that exist during the lean season. The project donated GrainPro Cocoons™ (5 MT and 10MT) to farmers in two maize producing districts. However, sustainability of such commercial-oriented initiatives is usually hampered by fluctuating harvests, lack of business acumen and management capacity by communities, and conflicting objectives among community members. Ever since the WFP project, there has been a slow but gradual increase in use of GrainPro Cocoons™ by farmers and private sector. Anectodal evidence suggest that use of GrainPro Cocoons have enabled poultry farmers to store grain meant for stockfeed production for periods exceeding eighteen months with insignificant bio-deterioration. This increases the profit margins of farmers because they are able to buy grain soon after the harvest season when prices are low and then use the grain during the lean season when prices are high. On the other hand, SGB Premium is also being used for storing coffee by small-scale coffee producers in the Eastern Highlands of Zimbabwe. The use of SGBs for coffee storage is common in Latin America (Villers et al., 2010) while cocoons were tested at large-scale in storing cocoa beans in Ghana (Jonfia-Essien et al. 2008) and maize grain in Zimbabwe (Chigoverah et al. 2016) Maize seed is being exported to Asia and West Africa in TSLs to limit the effect of fluctuating weather conditions and insect pest development, hence preserving germination in transit. Silobags are also being used in large-scale storage of bulk maize and soyabean seed.

Fig. 10 Community aggregated maize grain stored in a 5MT GrainPro Cocoon in Gokwe South district, Zimbabwe (Source: Authors).

There is need to improve the distribution network for hermetic storage options especially in remote areas where the majority of smallholder farmers are located. Although Farm and City has a nationwide branch network, they have no presence at village level which results in farmers having to travel considerable distances to access hermetic bags at town or district centres. The company can enhance its distribution network by partnering with smaller agro-dealers who operate in smallholder areas. This will increase accessibility of these products to smallholder farmers and enhance adoption (Baributsa et al., 2010).Poor road networks and long distances from district centres of some of the communities can increase the final cost of products.

Tab. 6 List of hermetic containers available in Zimbabwe and their respective capacities (Compiled by authors, 2018).

Manufacturer	Product	Use	Available capacities (based on maize)	Commodities being handled	Source
GrainPro Philippines Inc	SuperGrainBag Farm SuperGrainBag Premium GrainSafe GrainPro Cocoon	Crop Storage	50 kg 50 kg, 90 kg 1.3 MT 5 MT, 10 MT, 20 MT	Dry cereals and pulses All dry agricultural commodities (cereals, pulses, oilseeds, spices, retained seed)	Farm & City Pvt Ltd (has countrywide distribution network)
	TranSafe Liners	Transportation	20 Ft	Commercial seed maize	
Ministry of Lands Agriculture and Rural Resettlement	Metal Silos	Crop Storage	50 kg, 100 kg, 0.5 MT, 1 MT, 3 MT	Dry cereals and pulses	Manufacturers
Peak Trading Pvt Ltd	Metal Silos	Crop Storage	50 kg, 100 kg, 0.5 MT, 1 MT, 3 MT	Dry cereals and pulses	Manufacturers
Farmyard Investments	Metal Silos	Crop Storage	50 kg, 100 kg, 0.5 MT, 1 MT, 3 MT	Dry cereals and pulses	Manufacturers
Local artisans	Metal Silos	Crop Storage	50 kg, 100 kg, 0.5 MT, 1 MT, 3 MT	Dry cereals and pulses	Manufacturers
SiloBag International	SiloBags	Crop Storage	200 MT	Dry cereals and pulses	RadZim Pvt Ltd

Tab. 7 Promotional activities of hermetic storage options by development partners.

Product	Promoting Agency
SuperGrainBag	FAO (2013, 2018/19), CIMMYT (2013/14), Action Contre La Faim (2015/16, 2018/19), World Vision (2016-18), German Agro Action (2016), Action Aid (2017/18)
Metal Silo	FAO (2012-15), CIMMYT (2013/14), Action Contre La Faim(2015/16, 2018/19), Oxfam (2017)
GrainSafe	German Agro Action (2016)
GrainPro Cocoons	WFP (2015/16)

Availability of metal silos is also a challenge. Even though artisans have been trained in some communities, low demand has resulted in most of the artisans switching to fabricating high demand products like watering cans and cooking pots. Furthermore, metal silo manufacturing companies are few in the country and the Government of Zimbabwe through Ministry of Lands Agriculture and Rural Resettlement (MLARR) have conducted capacity building initiatives to private companies to increase the number of service providers. Despite these efforts, there are only a few manufacturers and they cannot service the sparsely distributed smallholder farming communities. This has resulted in MLARR also providing the service through its Postharvest Department which is centrally located in Harare. There is need for more players to enable farmers to easily access the product. However, both Farm & City and RadZim are strategically located to be able to fully service the commercial sector and farmers near major towns and district centres.

Hermetic plastic liners being distributed by Farm and City and RadZim are imported from the Philippines and Latin America, respectively. The products are charged import duty which increases cost which in turn is transferred to the end-users. Cost is usually a major adoption factor especially for resource-constrained African smallholder farmers who tend to opt for low-cost pest control alternatives regardless of the efficacy of the product (Nukenine *et al.*, 2010).The issue can be addressed by enforcing tax exemption on imported hermetic plastic liners. There is only one brand of hermetic bags (SGB) currently available in the country; hence the need for more players to come on board to avoid monopoly on the market. Competition can also lower prices thereby enhancing affordability by smallholder farmers. In East Africa local manufacturing of hermetic bags has also lowered costs (Baributsa *et al.*, 2010) and enhanced perennial supply of the product on the market. There is need for local plastic manufacturers to also consider venturing into this line of business.

Evidence-based performance of hermetic technology

Research findings have reported hermetic storage products namely SGBs, metal silos (Chigoverah and Mvumi, 2016; Mlambo *et al.*, 2017; Nyanga and Ambali, 2017), and GrainPro Cocoons (Chigoverah *et al.*, 2016) to be effective in suppressing storage pest-induced bio-deterioration of maize and pulses under simulated and field conditions. Metal silos and SGBs were also reported to be more effective than conventional pesticides in suppressing storage insect pests development and consequently preserving germination of commodity maize grain over a storage period of up to one year (Chigoverah and Mvumi, 2016). These findings have led to widespread acceptance of the technology by government, farmers, private sector and development agencies. However, knowledge gaps exist on the reusability of the hermetic containers across storage seasons, maintenance of hermeticity at the Cocoon zipper, performance of plastic liners in areas with severe rodent and *P. truncatus* infestation, performance of other hermetic technology options like SiloBags, GrainSafes and TSLs under local conditions although unconfirmed reports suggest that they are effective in comparison to non-hermetic methods. Furthermore, most research has been centred on commodity grains namely maize and pulses; thus, there is need to generate evidence-based performance data on other commodities like spices, herbs, seed (commercial and foundation), dried fruits and stock feeds.

Future prospects

There is potential for increased use of hermetic technology in Zimbabwe judging by increase in sensitisation initiatives and positive feedback from end users (Nyanga and Ambali, 2017). However, supporting policies are essential to enhance participation of more industry players. Policies which include removal of, or reduction in, import duty tax on hermetic plastic liners and metal silo sheets can significantly reduce costs. Metal sheets constitute the largest proportion of the total cost of the metal silo averaging 60% (Kimenju et al., 2009). The Government of Zimbabwe included metal silos in the country's economic blueprint document (ZIMASSET) as key agricultural equipment that can be useful in enhancing household food security (ZimVac, 2014). There has been lobbying by stakeholders for the country to formulate a Postharvest Policy which if in place can also enhance promotion and uptake of hermetic storage options.

Hermetic technology presents various opportunities especially in the handling of oilseeds like groundnuts and sesame, and disinfestation of organic horticultural products (Navarro, 2010). Groundnuts are usually stored in shells (Harish *et al.*, 2014) which is inefficient in terms of space utilisation. Shelled groundnuts are less bulky but are susceptible to insect infestation and aflatoxin contamination. Hermetic storage (Gas Hermetic Fumigation) has been reported to be effective in storing shelled groundnuts and other oilseeds (Navarro and Navarro, 2014).

Financial constraints faced by local companies and farmers willing to invest in hermetic technology can negatively affect uptake and adoption. Intervention by financial institutions offering credit to both companies and farmers can catalyse availability and adoption of hermetic containers. Farmer groups can also approach retailers of hermetic bags with a payment plan which can facilitate access to the bags on credit terms for payment upon marketing of their harvested commodities. Similarly, trained artisans need access to quality equipment for manufacturing metal silos. They need to be facilitated to approach financial institutions as associations or groups and access soft loans. They also need to be trained in agribusiness so that the investment is sustainable. Given that agricultural production is seasonal in SSA, most farmers face financial challenges at the onset of the storage season hence end up selling their crops at a lower price. Moreover, lack of appropriate storage technologies also force farmers to sell soon after harvesting to minimise risks associated with prolonged storage (Tefera and Abass, 2012). Capacitating farmers with effective storage facilities enables selling at a higher price during the lean season thereby enhancing household income security. A credit facility will enhance livelihoods and also stimulate demand for the storage products among both smallholder and larger-scale farmers.

Hermetic storage cannot be effective as a standalone postharvest loss reduction strategy but should be complemented by sound crop postharvest management practices and continuous training of both artisans and farmers. There is need to capacitate users on recommended handling practices for both commodity and hermetic storage containers. Users should be made aware that commodities to be stored for long periods of time should be adequately dried prior to loading into the storage containers. Furthermore, some hermetic storage options should be placed in clean spaces free from sharp or overhanging objects and wild animal species. This is critical for hermetic plastic liners which are susceptible to damage by sharp objects and storage pests. Followups of trained personnel followed by refresher training workshops are essential to reinforce the skills and promoting co-learning from practice. Standardised manufacturing procedure for metal silos is critical to ensure optimum performance of the product and avoid sub-standard material. There is need for MLARR to come up with standardised fabrication and testing procedures that will be used during training of artisans to minimise faulty products.

There is an increase in awareness by consumers on the benefits associated with hermetic storage and demand is likely to increase. This might lead to an increase in the manufacturers and suppliers of hermetic storage products. Henceforth, MLARR should engage Standards Association of Zimbabwe formalise hermetic standards for metal silos and hermetic plastic liners. This will enable Government of Zimbabwe to effectively monitor in future the quality of products available on the market. Inferior hermetic bags have been reported in West Africa leading to PICS bags manufacturers branding their bags for easy identification by customers (Baributsa *et al.*, 2010). Standardisation will be key to branding of the hermetic products.

References

Aktar, M. W., Sengupta, D. and A. Chowdhury., 2009. Impact of pesticides use in agriculture: their benefits and hazards. Interdisciplinary Toxicology 2: 1–12.

Baoua, I. B., Amadou, L., Abdourahmane, M., Bakoye, O., Baributsa, D. and L.L. Murdock., 2015. Grain storage and insect pests of stored grain in rural Niger', Journal of Stored Products Research 64: 8–12.

Baributsa, D., Lowenberg-Deboer, J., Murdock, L. and B. Moussa, 2010. Profitable chemical-free cowpea storage technology for smallholder farmers in Africa : Opportunities and challenges. 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. and White, N. D. G. (Eds), Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June - 2 July 2010, Estoril, Portugal. Julius Kuhn-Institut, Berlin, Germany, 1046–1052.

Boyer, S., Zhang, H. and G. Lemperiere, 2012. A review of control methods and resistance mechanisms in stored-product insect. Bulletin of Entomological Research 102: 213–229.

Bradford, K. J., Dahal, P., Van Asbrouck, J., Kunusoth, K., Bello, P., Thompson, J. and F. WU, 2018. The dry chain : Reducing postharvest losses and improving food safety in humid climates. Trends in Food Science & Technology 71: 84–93.

Chaudhry, M. Q., 1997. A review of the mechanisms involved in the action of phosphine as an insecticide and phosphine resistance in stored-product insects. Pesticide Science 49: 213–228.

Chaudhry, M. Q. 2000. Phosphine resistance. Pesticide Outlook 11: 88-91.

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: 179-189.

Chigoverah, A. A., Mvumi, B. M., Muchechemera, C. and J. V. Dator, 2016. Grainpro CocoonsTM as an alternative to phosphine fumigation for large scale grain storage in Zimbabwe. In: Navarro S, Jayas DS, Alagusundaram K, (Eds.) Proceedings of the 10th International Conference on Controlled Atmosphere and Fumigation in Stored Products (CAF2016), CAF Permanent Committee Secretariat, Winnipeg, Canada, 297–303.

Daglish, G. J., 2006. Opportunities and barriers to the adoption of potential new grain protectants and fumigants. In Lorini, I., Bacaltchuk, B., Beckel, H., Deckers, D., Sundfeld, E., dos Santos, J. P., Biagi, J. D., Celaro, J. C., Faroni, L. R. D., Bortolini, L. O. F., Sartori, M. R., Elias, M. C., Guedes, R. N. C., da Fonseca, R. G., Scussel, V. M.. (Eds) Proceedings of the 9th International Working

Conference on Stored Product Protection, 15-18 October 2006, Campinas, São Paulo, Brazil. Brazilian Post-harvest Association - ABRAPOS, Passo Fundo, RS, Brazil,. 209–216.

Harish, G., Nataraja, M. V, Ajay, B. C., Holajjer, P., Savaliya, S. D. and M. V. Gedia, 2014. Comparative efficacy of storage bags, storability and damage potential of bruchid beetle. J Food Sci Technol 51: 4047–4053.

Isman, M. B. 2006. Botanical insecticides, deterrants and repellents in morden agriculture and an increasingly regulated world. Annual Review of Entomology 51: 45–66.

Jayas, D. S. and S. Jeyamkonda, 2002. Modified atmosphere storage of grains, meats, fruits and vegetables. Biosystems Engineering 82: 235–251.

Jonfia-Essien, W. A., 2012. Recent Developments in the storage of dry cocoa beans in Ghana. In Navarro, S., Banks, H. J., Jayas, D. S., Bell, C. H., Noyes, R. T., Ferizli, A. G., Emekci, M., Isikber, A. A., and Alagusundaram, K. (Eds) Proceedings of the 9th International Controlled Atmosphere & Fumigation Conference (CAF), 15-19 October 2012, Antalya, Turkey. ARBER Professional Congress Services, Turkey,. 129–135.

Jonfia-Essien, W., S. Navarro. and P. Villers. 2010. Hermetic storage : A novel approach to the protection of cocoa beans. African Crop Sci J. 18:59–68.

Jonfia-Essien, W. A,, S. Navarro, and J. V. Dator, 2008. Effectiveness of hermetic storage in insect control and quality preservation of cocoa beans in Ghana. In: Jinjun W, Navarro S, Leesch J, Yuejin W, Banks J, Batchelor T, Yulin A, Klementz D, Hongyu Z, Ren Y, Noyes R, Yanan W, et al. (Eds) 8th International Conference on Controlled Atmosphere and Fumigation (CAF), 21-26 September 2008, Chengdu, China. CAF Permanent Committee Secretariat, Winnipeg, Canada, pp 305–310.

Kimenju, S.C., de Groote, H., and H. Hellin, 2009. Preliminary Economic Analysis: Cost Effectiveness of the Use of Improved Storage Methods by Small Scale Farmers in East and Southern Africa Countries. International Maize and Wheat Improvement Center (CIMMYT), pp. 5-16.

Kumar, D. and P. Kalita, 2017. Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. Foods 6, 1–22.

Mlambo, S., Mvumi, B. M., Stathers, T., Mubayiwa, M. and T. Nyaboko, 2017. Field efficacy of hermetic and other maize grain storage options under smallholder farmer management. Crop Protection. 98: 198–210.

Muatinte, B. L., Van Dien Berg, J. and L.A. Santos, 2014. Prostephanus truncatus in Africa : A review of biological trends and perspectives on future pest management strategies. African Crop Science Journal 22, 237–256.

Murdock, L. L. and D. Baributsa, 2014. Hermetic storage for those who need it most -subsistence farmers. 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, 310–323.

Mvumi, B. M., Chigoverah, A. A., Koza, T., Govereh, J., Chuma, T., Dzvurumi, F., Mfote, D. and T. Tefera, 2013. Introduction , testing and dissemination of grain storage technologies for smallholder farmers in Zimbabwe : A partnership approach. In 11th African Crop Science Conference Proceedings. 14-17 October 2013, Entebbe, Uganda. African Crop Science Society, 585–591

Navarro, S., 2010. Commercial applications of oxygen depleted atmospheres for the preservation of food commodities, Case Studies. In Novel Food Processing Technologies: Innovations in Processing, Packaging, and Predictive Modelling, 321-350.

Navarro S., Finkelman, S., Donahaye, E., Dias, R. and M. Rindner, 1993. Integrated storage pest control methods using vacuum or CO2 in transportable systems, 1-8.

Navarro, S. and H. Navarro, 2014. The biological and physical aspects of hermetic storage: A critical review. 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, 337–354.

Navarro, S., Timlick, B., Demianyk, C. J. and N. D. G. White, 2012.Controlled or modified atmospheres. In Hagstrum, D. W., Phillips, T. W., and Cuperus, G. (Eds) Stored Product Protection. Kansas: K-State Research and Extension, pp 1–11.

Nukenine, E. N., Adler, C. and C. Reichmuth, 2010. Efficacy of Clausena anisata and Plectranthus glandulosus leaf powder against Prostephanus truncatus (Coleoptera: Bostrichidae) and two strains of Sitophilus zeamais (Coleoptera: Curculionidae) on maize. Journal of Pest Science 83, 181–190.

Nyanga, L. K. and C.P. Ambali, 2017. Postharvest management technologies for reducing aflatoxin contamination in maize grain and exposure to humans in Zimbabwe. IDRC Final Report Project Number 107838, pp 41.

OECD, 2016. Agriculture in Sub-Saharan Africa: Prospects and challenges for the next decade. In OECD-FAO Agricultural Outlook 2016-2025. Paris. OECD Publishing, pp. 59–95.

Sarwar, M., 2015. The dangers of pesticides associated with public health and preventing of the risks. International Journal of Bioinformatics and Biomedical Engineering 1, 130–136.

Snelson, J., 1987. Grain Protectants.: Grain Protectants. Australian Centre for International Agricultural Research, Canberra, Australia.

Tefera, T. and A. Abass, 2012. Improved postharvest technologies for promoting food storage , processing , and household nutrition in Tanzania. Institute of Tropical Agriculture, pp 20

Villers, P., de Bruin, T. and S. Navaro, 2006. Development and applications of the hermetic storage technology. In Lorini, I., Bacaltchuk, B., Beckel, H., Deckers, D., Sundfeld, E., dos Santos, J. P., Biagi, J. D., Celaro, J. C., Faroni, L. R. D., Bortolini, L. O. F., Sartori, M. R., Elias, M. C., Guedes, R. N. C., da Fonseca, R. G., Scussel, V. M.. (Eds) Proceedings of the 9th International Working Conference on Stored Product Protection, 15-18 October 2006, Campinas, São Paulo, Brazil. Brazilian Post-harvest Association - ABRAPOS, Passo Fundo, RS, Brazil,pp. 719–729.

Villers, P., Navarro, S. and T. De Bruin, 2010. New Applications of Hermetic Storage for Grain Storage and Transport. 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. and White, N. D. G. (Eds), Proceedings of the 10th International Working Conference on Stored Product Protection, 27 June - 2 July 2010, Estoril, Portugal. Julius Kuhn-Institut, Berlin, Germany. 446–451.

Walker, S., R. Jaime, V. Kagot, and C. Probst, 2018. Comparative effects of hermetic and traditional storage devices on maize grain: Mycotoxin development, insect infestation and grain quality. J Stored Prod Res. 77:24–44.

Zimvac, (2014). Zimbabwe Vulnerability Assessment Committee 2014:Rural livelihoods assessment report. Harare, Zimbabwe.

Evaluation of hermetic technologies in the control of insect infestation and mycotoxin contamination in stored maize grains

Jacqueline Namusalisi*[a], Catherine N. Kunyanga[a], Anani Bruce[b], Hugo De Groote[b]

[a]Department of Food Science, Nutrition and Technology, University of Nairobi, P.O. Box 29053-00625 Kangemi, Kenya

[b]International Maize and Wheat Improvement Center (CIMMYT), P.O Box 1041-00621 United Nations Avenue, Nairobi – Kenya

* Corresponding author: namujq.jay@gmail.com

DOI 10.5073/jka.2018.463.122

Abstract

Grain losses due to moulds during on-farm storage increase food insecurity, result in economic losses, negatively affect farmers' livelihoods, and increase exposure to mycotoxins that can harm human and animal health. Hermetic storage technologies provide a reliable solution for maize grain that may also preserve food safety. Several studies report the effectiveness of these technologies against post-harvest insects in Africa but provide limited evidence on effectiveness against mould proliferation and mycotoxin contamination. Hermetic technologies were superior to farmer practice in reducing insect infestations and mycotoxin accumulation. Among hermetic technologies, there were no significant differences (P>0.05) in performance between metal silos and hermetic bags for mycotoxin accumulation and insect infestation regardless of the mode of infestation. In non-inoculated grain, fungal populations were varied but included mycotoxin-producing *Aspergillus* and *Fusarium* spp., indicating that the grain was naturally contaminated and acted as a good reservoir for these fungi. Mycotoxin levels increased with higher moisture even in non-inoculated grain. Meanwhile, aflatoxin and fumonisin levels at 4 months were not significantly different from baseline values in dry inoculated grain across all storage technologies (P>0.05), indicating that hermetic technologies can prevent mycotoxin contamination in dry grain for at least 4 months of storage. Aflatoxin and fumonisin were significantly higher by 1.69 ppb and 0.25 ppm respectively in non-inoculated grains at high moisture indicating the need to adequately dry grain before storage in hermetic technologies. This trend was observed collectively in all the technologies registering 2.03 ppb and 0.311 ppm respectively. In inoculated grains at high moisture, there was an increase in aflatoxin in both hermetic treatments and the control by 5.7 ppb and 12.14 ppb respectively. Therefore, a trial was conducted to compare hermetic technologies with farmer practice in their effectiveness against both insect infestation and mycotoxin contamination.

Keywords: Insect infestation, mycotoxin contamination, stored maize, hermetic storage, food security

1. Introduction

Maize (*Zea mays* L.) can conveniently be classified as the most important cereal crop owing to its nutritional value and utilization of its by-products. Grain losses due to insect pests during on-farm storage increase food insecurity, result in economic losses, negatively affect farmers' livelihoods, and increase exposure to mycotoxins that can harm human and animal health (Obeng-Ofori, 2008). Among these mycotoxins, the two commonest and highly toxic mycotoxins compound encountered in maize in the tropical and sub-tropical region of the world are aflatoxins and fumonisins (Krska *et al.,* 2008). Aflatoxins are toxic metabolites produced by fungal species during their growth under favorable conditions of temperature and moisture. The major aflatoxin producing species are *Aspergillus flavus* and *Aspergillus parasiticus*. The main cereals affected are maize, sorghum, rice and wheat and other crops like groundnuts and cassava. Aflatoxin-producing fungi have very few nutritional, environmental and reproductive requirements, and that is their strategy to survive and develop (Wu *et al.,* 2011). Fumonisins are mycotoxins produced by the grain moulds *Fusarium verticilliodes* and *Fusarium proliferatum,* which is frequently a universal inhabitant of corn. Fumonisins are categorized as, B1, B2 and B3 and are usually found to be greater than 1