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Hermetic storage of maize grain in repurposed food oil containers to control maize weevils

Thomas J. Brumm*, Carl J. Bern and David F. Webber

Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa 50011, USA.

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Insect-related grain loss is a significant problem in Uganda and other countries in sub Saharan Africa. The maize weevil (*Sitophilus zeamais* Motschulsky) is one of the major insect pests that infests stored maize grain (*Zea mays* Linneaus). This study demonstrates the feasibility of hermetic or "air-tight" storage for protecting maize from maize weevil damage using low-cost repurposed food oil containers. Maize infested with weevils was obtained from a local market in Kamuli, Uganda. Quality characteristics determined before storage included live weevil numbers, moisture content, and kernel damage. Storage treatments, each done in triplicate in 10-L containers, included (1) hermetically sealed and (2) non-hermetically sealed maize grain. After 30 days of storage, 100% mortality of maize weevils was achieved in treatment (1), while the number of weevils increased by nearly a factor of three in treatment (2). Although, there were no significant differences between treatments in final moisture content, test weight, and damage, broken corn and foreign material was significantly higher in treatment (2) versus (1). This 30-day study using an experimental design with up to three replicated treatments demonstrated that repurposed food oil containers can be effectively used for hermetic storage of maize.

Key words: Grain quality, moisture, test weight, damage, broken corn and foreign material, postharvest losses (PHLs), hermetic storage, sub-Saharan, Uganda, Africa.

INTRODUCTION

One of the most widely produced grain crops globally is maize (CIMMYT, IITA, 2011). In 2011, 35 million ha of maize was cultivated in Africa, and more than 170 million ha was cultivated globally (FAOSTAT, 2014). Millions of smallholder farmers in Uganda and other developing countries depend on effective and sustainable maize production strategies to maintain food security. However, stored-product insects can cause postharvest losses (PHLs), estimated from up to 9% in developed countries to 20% or more in developing countries (Phillips and Throne, 2010). One strategy that can effectively address this global food insecurity issue is the reduction of PHLs (FAO, WFP, IFAD, 2012).

A strategy to reduce PHLs may provide an integrated approach to addressing world-wide food and energy needs (FAO, 2014; World Bank et al., 2011). By reducing PHLs, more maize grain can be made available without the requirement of additional labor, seeds, fertilizer, and land. The maize weevil (*Sitophillus zeamais* Motsch.) is one of the primary insects responsible for PHLs of maize

*Corresponding author. Email: tbrumm@iastate.edu. Tel: +1-515-294-5145.

Table 1. Data collected at both the beginning and end of the demonstration project.

Characteristic	Units	Method
Moisture content (MC)	% wet basis	Hand-held moisture meter
Grain weight in each container	kg	Electronic scale
Test Weight (bulk density) (TW)	lb bu^{-1} or kg hL^{-1}	Test weight apparatus
Broken corn and foreign material (BCFM)	Weight %	Hand screening and weighing
Damage, insect damage	Weight %	Visual inspection and weighing
Number (#) of live insects	# per kg	Visual inspection and weighing
Number (#) of dead insects	# per kg	Visual inspection and weighing

in the tropics, with the majority of PHLs occurring during storage (Longstaff, 1981, 1986; Jacobs and Calvin, 2001; Mlambo et al., 2017; Abass et al., 2018; Singano et al., 2019).

It is nearly impossible to keep maize weevils from stored maize. Harvested maize often contains weevil eggs at harvest, having been deposited by adults prior to harvest. Mechanical isolation (e.g., traditional granary and metal silo bins) can reduce or eliminate rodent and bird damage, but cannot control insects already in the grain, nor can it keep insects from entering the grain. Mesh bags, while in wide use, also cannot curtail insect infestation and additionally are subject to rodent damage. Treating maize with insecticides can be effective but is expensive and unsustainable, especially for smallholder farmers. Human safety in the handling and application of insecticides is of concern, as is the human consumption of treated maize.

Hermetic storage involves the use of air-tight container systems to eliminate gas exchange between the storage and external environments. It is commonly used in storage of grains and seeds and has been in use since early ages of grain storage. Hermetic storage of grains or seeds that have been infected with insects can cause oxygen levels to fall below 5%. This grain storage strategy also produces a corresponding increase in carbon dioxide levels that eliminates maize weevils (Gummert et al., 2004).

Although hermetic systems exist for maize storage, the availability and cost of containers can limit the utilization of this technology by smallholder farmers. Omotilewa et al. (2018) conducted a randomized controlled study of 1200 smallholder farmers in Uganda to evaluate maize variety choice and crop input use impacts of an improved grain storage technology. This technology included the Purdue Improved Crop Storage (PICS) bag that was used in the evaluation. The study results indicated that the PICS bags had short-term positive impacts on smallholder households' decisions to cultivate improved maize varieties that are high-yielding but more susceptible to insect pests in storage versus traditional low-yielding maize varieties. However, it was suggested that future research should consider how long-term use of PICS bags affect income, consumption, nutrition, and dietary diversity.

In contrast, Yakubu et al. (2016) found that used food oil containers are economically advantageous (less than $1.00 USD), readily available in African markets, and can be cleaned using soap and hot water and may perform effectively in hermetically storing maize grain for extended time periods.

The objective of this study was to research and demonstrate the preparation and use of readily available and inexpensive repurposed plastic food oil containers for hermetic storage of maize grain and seed for smallholder farm households in Uganda, Africa.

MATERIALS AND METHODS

Approximately 80.0 kg of weevil-infested maize grain were purchased from a local market in Kamuli, Uganda. The determination of maize quality characteristics (Table 1) was conducted prior to the experiment using equal triplicate representative subsamples obtained by use of a Boerner divider (Figure 1).

Moisture content (MC, % wet basis) was determined using a DICKEY-john Model DjGMT Handheld Moisture Tester (DICKEY-john, Inc., 2020) using a 500-g subsample. Test weight (TW) was determined using a Seedburo test weight scale and a 250-g subsample. Grain weight was determined with a Seedburo Model 9000AG Testweight Computer Grain Grading Scale (Seedburo, Inc., 2020). Broken corn and foreign material (BCFM) were determined by sieving a 250-g representative subsample with a 4.76-mm (12/64-inch) round-hole hand-held screen with the weight passing through the screen plus hand-picked non-maize material on top expressed as a weight percentage. Damage was determined by visual inspection according to procedural protocols in the USDA grain inspection handbook (USDA, GIPSA, FGIS, 2013). The amount of damaged kernels also was expressed as a weight percentage by dividing the total kernel sample weight (g) by the weight of insect damaged kernels.The number of live and dead insects/kg of maize was determined according to the method developed and applied by Yakubu (2011).

Six 10-L plastic containers (Figure 2) that previously held edible food oil were obtained from a local market for less than $1.00 USD each. The containers were inspected and pressurized using an air compressor tool to insure air tightness. The inside of the containers was scrubbed with hot water and dish detergent, and triple rinsed and dried. Three of the containers were randomly chosen for non-hermetic storage and then modified by cutting holes in the cap (Figure 3) and a 25.0 mm^2 (1.00 $in.^2$) square in the bottom and in the cap. The holes were covered with screen having approximately

Figure 1. A Boerner divider (Seedburo, Inc., Des Plaines, IL, USA).

Figure 2. A used food oil container, similar to those used in the study.

Figure 3. Modified (ventilated) container cap.

600 holes per cap opening (25.0 mm^2) with holes < 1 mm in diameter to allow air movement but also to eliminate the passage of weevils.

Each of the six containers was then filled with approximately 9.00 kg of infested maize and shaken during filling to homogenize the maize and ensure the maximum amount of maize possible was placed in the container. The three unmodified hermetic containers were sealed by laying three layers of 0.4-mm thick plastic (0.015-inch) over the cap opening and tightly securing the cap over the plastic. The three non-hermetic and three hermetic containers were stored out of the sunlight in a tamper-free room in Kamuli, Uganda, in which there was free movement of outside air. The maize container storage area temperature was carefully monitored during the 30-day storage period. The average ambient temperature was maintained at 20°C with a maximum of 25°C and a minimum of 15°C (Worldweatheronline, 2020).

The estimated hermetic storage time to achieve 100% weevil mortality was 7.5 days, based on the method described by Yakubu et al. (2011), using a moisture content of 13.7%, an average storage temperature of 20°C, and an assumed kernel density of 1.25 g cm^{-3}. The maize was stored for 30 days or four times the predicted time for 100% mortality. After 30 days, the containers were opened and representative samples were obtained from each container by use of a Boerner Divider. Quality characteristics of the maize within each container were measured as previously described (Table 2).

The experimental design included the comparison of maize quality characteristics, with two replications of initial treatments (0 day = 0 d) and three replications of final hermetic and non-hermetic treatments (30 day = 30 d). Significant differences among treatment means were determined using the SAS ANOVA Procedure (SAS, 2019) at the 95% probability level ($p < 0.05$).

RESULTS

The data in Table 2 show the average quality characteristics for initial (t = 0 d) and end-of-storage (t = 30 d) duration points for hermetic and non-hermetic

Table 2. Mean quality characteristics* for Initial (t = 0 d; for all containers) and End of Storage (t = 30 d; for maize stored in hermetic and non-hermetic containers).

Quality characteristics	Storage Period (0 and 30 day)		
	Initial (t = 0 d)	End of storage (t = 30 d)	
	All containers	Hermetic containers	Non-hermetic containers
Moisture content (MC) (% d.b.)	$13.7^a \pm 0.12$	$14.4^a \pm 0.26$	$14.7^a \pm 0.36$
Test weight (TW) (lb/bu)	$53.8^a \pm 0.60$	$53.6^a \pm 0.36$	$52.6^a \pm 0.42$
BCFM (wt. %)	$0.70^a \pm 0.10$	$0.53^a \pm 0.05$	$1.20^b \pm 0.39$
Damage (wt %)	$33.9^a \pm 2.55$	$35.5^a \pm 1.94$	$36.5^a \pm 1.97$

*Expressed as means ± standard deviation. Values with different letters within a row indicate significantly different mean values ($p < 0.05$).

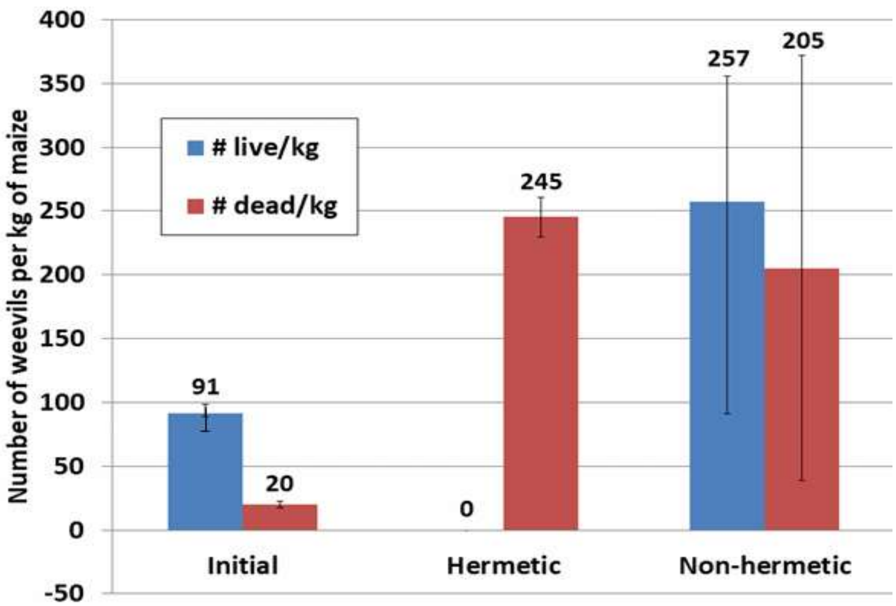

Figure 4. Average number of live and dead maize weevils and standard deviation (error bars) per kg of maize at Initial (t = 0 d; for all containers) and End of Storage (t = 30 d; for hermetic and non-hermetic containers).

repurposed food oil storage containers used in the study. The data results depicted in Figure 4 show the average numbers of live and dead weevils kg^{-1} of maize before and after the 30-day storage period for the hermetic and non-hermetic containers. There were no live weevils in the hermetic containers at the end of the storage period, while the number of live weevils increased significantly by almost three-fold in the non-hermetic containers ($p < 0.05$). While there was a significant increase in the average total number of weevils in the hermetic containers ($p < 0.05$), none of the adult weevils survived the storage period.

The results shown in Figure 4 indicate that the hermetically sealed containers functioned effectively in eliminating live maize weevils and preserving maize quality versus the non-hermetically sealed containers. Hermetic storage of maize in repurposed food oil containers resulted in 100% mortality of all adult maize weevils. The results in Table 2 show there were no significant differences in MC, TW, or Damage ($p < 0.05$). However, there was a significant increase in BCFM in the non-hermetic storage treatments ($p < 0.05$) due to the greater numbers of live weevils present.

DISCUSSION

Repurposed 10-L or 20-L food oil containers may be appropriate for some smallholder farmers to hermetically store their maize crop. Quellhorst et al. (2018) surveyed farmers in the Cul-de-Sac Plains area of Haiti and found that 75% of them stored less than 100 kg of maize. These farmers can hermetically store all of their maize in 11 or less 10-L containers, or six or less 20-L containers.

Furthermore, these containers can be reused several times and will provide more protection from rodents and birds than mesh bags. Many containers would be needed to store a crop of several tons of maize. Consequently, such large quantities of grain render the smaller 10- and 20-L containers unrealistic for farmers that require storing large quantities (> 100 kg) of maize per growing season.

However, a much smaller amount of maize saved for seed is subject to the same postharvest losses from maize weevils. These smaller and affordable 10- to 20-L repurposed containers could be used to protect maize seed until planting. Although reports indicate that maize seed germination rate was not negatively impacted by certain hermetic storage vessels including repurposed plastic containers (Afzal et al., 2017; Abass et al., 2018), Singano et al. (2019) found that germination rate was severely reduced in maize seed stored in hermetic metal silos and polypropylene bags.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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