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Hermetic storage systems for maize stored on subsistence farms

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Abstract

Maize grown by subsistence farmers is a staple food for millions of people around the world, especially in Sub-Saharan Africa and Central America. Following harvest and shelling, maize is subject to storage losses caused by birds, rodents, fungi, and insects. The losses amount to millions of Mg per year of maize, which could be available with no additional inputs of land, seed, fertilizer and water. On-farm hermetic storage has the potential to substantially reduce these losses without the use of pesticides. This paper explains the basis of hermetic storage and presents the Iowa State University procedure for predicting the time required for 100% mortality of adult maize weevils in hermetically-stored maize, shows field data verifying the prediction accuracy, and describes four systems being successfully used for hermetic maize storage on subsistence farms: *Postcosecha galvanized steel silos, Purdue triple-bagging system, Grain Pro ultra hermetic bags, Recycled plastic food containers.* Based on purchase price, the steel silo is the least cost system. The two bagging systems cost three to four times as much. The recycled oil container is the most costly, in spite of its low purchase price.

Key words: maize storage, hermetic grain storage, postharvest grain loss, grain

Introduction

Maize is a preferred staple for about 900 000 of the world's poor consumers and about one third of all malnourished children (FARA 2009). In Kenya and Tanzania, maize contributes over one-third of people's daily caloric intake (World Bank 2011).

Storage losses of maize

On small farms, maize is hand harvested, dried, and placed in storage. Drying corn to 14% moisture or less is necessary to prevent growth of fungi. Storage in a secure container can prevent losses from rats and birds. Maize may be infested with insects such as maize weevils (*Sitophilus zeamais*) before harvest. Without proper management, losses of maize stored by subsistence farmers can be 100% of the crop. Local experts estimated that 22.4% of the 2008 maize crop in the countries of Southern and Eastern Africa was lost during storage (PHL Network 2011). Losses in the Kamuli district of Uganda are estimated at 40% (Musoke 2010).The value of postharvest losses of grain in Sub-Saharan Africa could be as much as US$ 4 billion out of a grain production value of US$ 27 billion for 2005-07. These losses represent a huge mass of grain that could be made available for food without use of additional land, seed, labor, water, and other inputs.

Hermetic grain storage

Hermetic grain storage systems strive to eliminate all exchange of gases between the inside and the outside of a grain storage container. If the gas exchange is low enough, living organisms such as insects within the container will deplete oxygen and produce carbon dioxide until they die or become inactive due to the low oxygen. Hermetic grain storage can be an appropriate method for many subsistence farmers. It eliminates the need for insecticides, which are costly and often inaccessible for these farmers. Misuse of insecticides by farmers is common and can cause health and environmental problems (Baributsa et al., 2010). If maize is dried to 14% moisture or less, storage fungi can be controlled. A robust container protects the maize from birds and rodents.

Yakubu et al., 2011 have developed a procedure to estimate the time required for complete mortality of adult maize weevils in a hermetically-sealed container of maize (Figure 1). Data from laboratory tests of hermetically-stored maize at Iowa State University formed the basis for this procedure. The area within the four points on Figure 1 (10°C to 27°C, 8 to 16% moisture) includes most maize storage conditions on farms in East Africa. The graph may be used to predict time to 100% adult weevil mortality in any hermetic storage container. An example illustrates the procedure: a 225-L (55-gal) barrel contains 162 kg of maize at 10% moisture stored at 20°C, and the maize contains 100 adult weevils per kg. Interpolating between points (Figure 1) predicts an oxygen utilization value of 0.114 cm^3 per weevil per day. On average, weevils die when oxygen level reaches 4%. Using container volume and assuming maize kernel density at 1.24 g cm^{-3}, along with the calculated oxygen utilization value, and assuming no leakage of oxygen into the barrel, the predicted time to 100% mortality is calculated to be nine days.

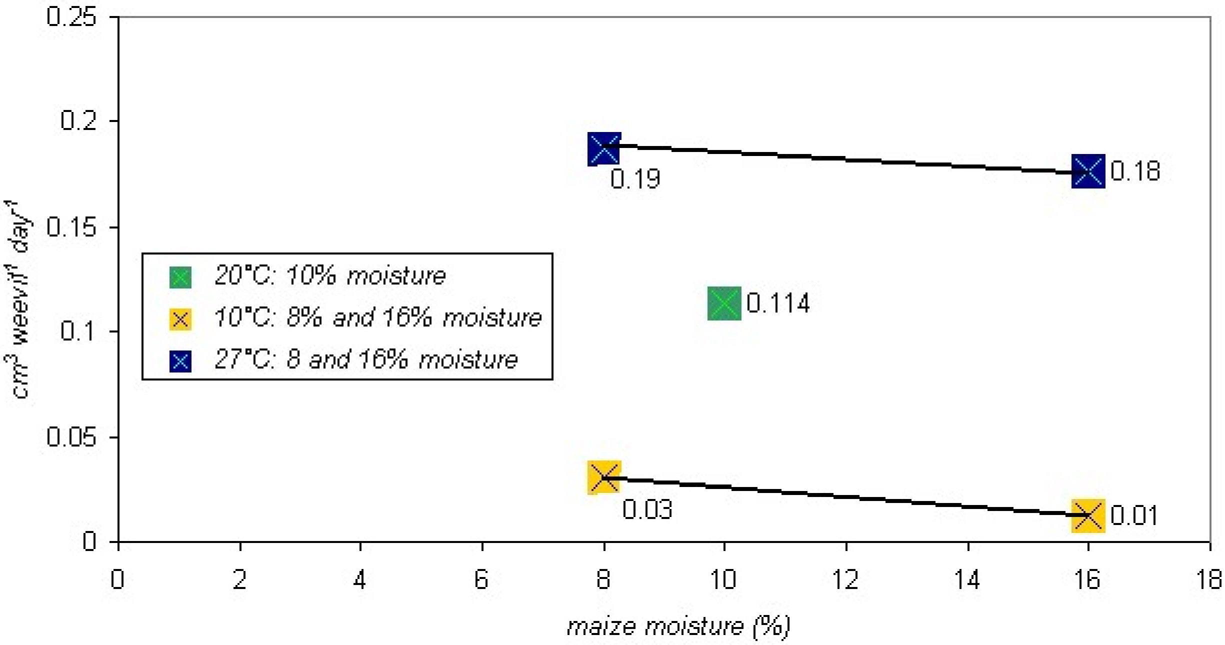

Figure 1. Average oxygen consumption of maize weevils in shelled maize.

Hermetic storage systems

Postcosecha galvanized steel silos

The Postcosecha galvanized steel silo was developed in Central America in about 1980 for on-farm storage of grain and seed. Postcosecha (postharvest in Spanish) is a development program begun in Honduras in the 1980s, which has evolved into a technology production and dissemination organization operating in Central America and elsewhere in developing countries. The Swiss Agency for Development and Cooperation supported the original silo construction programs in El Salvador, Nicaragua, Honduras, and Guatemala where nearly 600,000 silos were built by 2008 (Bravo-Martinez 2008).

Postcosecha silos are built locally using simple tools, 26-gauge (0.7-mm) galvanized steel sheets, and lead-based solder. Grain capacities range from 180 to 1360 kg (7 to 53 bushels) (Figure 2). Joints and seams use a 5-mm fold, which is crimped and soldered for strength and tightness. A 37-cm-diameter intake throat is built into the top of the silo for filling and inspection. The throat protrudes about 10 cm above the top and is fitted with a snug-fitting removable cap. A 15-cm-diameter outlet port for removal of grain is located with its center 10.5 cm above the floor. It protrudes about 15 cm and is also fitted with a snug fitting removable cap. The intake throat and outlet port caps can be sealed with locally available products such as tallow, grease, soft soap, beeswax, or a bicycle tire innertube strip (SDC 2013).

Bulk products such as maize, beans, sorghum, rice, wheat, barley, as well as seeds can be stored in silos. The product must be clean and dry (below 14% moisture for maize) before being placed in the silo to prevent fungal spoilage. The silo has no provision for mechanical aeration. At the farm the silo is placed on a 15-cm-tall wood platform in the shade, under a roof, or inside the house. The outlet port allows small quantities of maize to be removed as needed for food (Figure 3).

Figure 2: Postcosecha steel silos (Bravo-Martinez 2009).

Figure 3. Removing maize from silo (SDC 2013).

Postcosecha silos are built locally and sold to farmers by persons called "artisans." These artisans complete a short course covering all elements of building and selling silos. A 159-page publication covering all technical and business aspects of silo construction is available in several languages (SDC 2013). Local employment and commerce generated by silo construction is an important benefit of the Postcosecha development program. Storing grain in a silo also allows farmers to market surplus grain when prices are high, instead of at harvest when prices may be at yearly lows.

If clean maize at 14% moisture or below is placed in a silo and managed properly, losses during one year or more of storage will be near zero. If the silo is filled with maize and hermetically sealed, maize weevils and other insects will be kept under control. Insecticide tablets (Phostoxin, Detia, Quick Phos, Gastion) are also available for chemical control of insects in the silo. There is evidence that the caps on these silos often are not sealed well enough to kill insects due to lack of oxygen and insecticide tablets need to be used to keep the grain insect free (GrainPro Inc. Latinoamerica 2010).

Silos have an expected life of 25 to 40 years, with proper maintenance (Sieber 1999). A 1360-kg-capacity silo currently sells for $145 (Rodriguez-Corea 2011). Silos reportedly pay for themselves because of higher market process obtained for stored grain and because they prevent storage losses, which are traditionally over 20% of the harvest.

Purdue Improved Cowpea Storage (PICS) System

A team at Purdue University has developed the Purdue Improved Cowpea Storage and is promoting its use in Western Africa with funds from the Gates Foundation. The program uses a triple plastic bagging system developed by entomologist Larry Murdock (Forbes, 2007). The PICS system was developed for storage of cowpeas in West and Central Africa and the project goal is to have 50% of the farm-stored cowpea in hermetic storage without insecticides by 2012 (Baribusta et al., 2010).

PICS technology uses plastic bags to achieve hermetic storage of cowpeas and other grains.. Threshed cowpea grain, dried to an appropriate moisture level and free of crop debris, is placed into 50- or 100-kg capacity high-density polyethelene bags with 80-µm thickness. A first bag is filled completely, but with a 20- to 30-cm neck, which is tied securely. Then, this bag is surrounded by a second bag with the same thickness. The second bag's neck is also tied securely. Finally, these two bags are placed in a third woven nylon or polypropylene bag used for its strength. With the third bag tied securely, the container can be handled without bursting the inner bags, and is readily accepted by grain handlers who are accustomed to handling cowpea in this type of woven bag. Figure 4 is a PICS high-density polyethelene bag, and Figure 5 is a PICS woven outer bag. Over the past three years, over one million bags have been produced and sold through this program (Baributsa et al., 2010). The cost for two 100-kg polyethelene bags and one outer bag averages $3. Life is about two years (Baributsa 2011).

Figure 4. PICS 80-µm polyethelene inner bag.

Figure. 5. PICS woven outer bag.

GrainPro ultra-hermetic bags

GrainPro Inc. of Concord, Massachusetts, USA manufactures and markets an extensive line of ultra-hermetic bags designed to achieve hermetic storage conditions. The bags are used to store a wide variety of agricultural commodity products and also many types of seeds, and are marketed worldwide (Villers et al., 2010).

The SuperGrainbag III^{TM} is a type suitable for use by the small farmer to store maize on the farm. It is available with capacities of 30 to 100 kg of maize. Besides maize, it is applicable for coffee, paddy, milled rice, sorghum, millet, soybeans, wheat, cocoa, beans, peas, lentils, and all types of seeds. Product is placed in the 78-µm multilayer polyethylene bag with a proprietary barrier layer that makes its permeability to oxygen far lower than polyethylene alone. It uses a two-track zipper and is sealed using a zipper slider. The sealed bag is then placed in a protective woven outer bag (Figure 6). The SGB III^{TM} membrane has an oxygen transmission rate of 4.28 cm^{3}m^{-2}day^{-1} and a water vapor permeability of 2.14 g cm^{-2}day^{-1}. The 70-kg bag costs \$2.50 + shipping in 200-bag lots (GrainPro 2013). Outer protective bags cost about \$1US. Maize can be stored for up to two years in a storage cycle. With careful use, the bag will last for about five cycles. Punctures can be repaired with tape (Villers 2013).

Figure 6. SuperGrainbag III^{TM}

Recycled plastic containers
Used containers are readily available at low prices in markets in sub-saharan Africa. One common type container is made of plastic and originally contained edible oil (Figure 7). Used 10-L plastic oil containers like the one in Figure 7 are available in Kamuli, Uganda for US$1 each. They will hold 7.74 kg of maize. In order to test the concept of using recycled edible oil containers for hermetic maize storage, an experiment was conducted comparing 10-L hermetically-sealed containers and identical containers with screen caps. Weevil-Infested maize was purchased in the local market and stored in the 10-L used but cleaned edible oil containers under two conditions: (1) hermetically sealed (airtight) and (2) open to air infiltration but closed to insect migration in or out of the container. Three containers at each condition were stored at ambient temperature (approximately 22°C) for four weeks. The weight, quality characteristics and degree of infestation (live and dead insects) were determined before and after storage.

After four weeks of storage, the total number of adult weevils more than doubled in the hermetically sealed containers and increased by more than four times in the open containers (Figure 8). However, the hermetically sealed containers resulted in 100% adult weevil mortality. In the open containers, approximately 50% of the weevils were alive and actively feeding on the maize, which resulted in significant quality deterioration compared to hermetic storage.

Figure 7. Recycled 10-L edible oil container, Kamuli, Uganda.

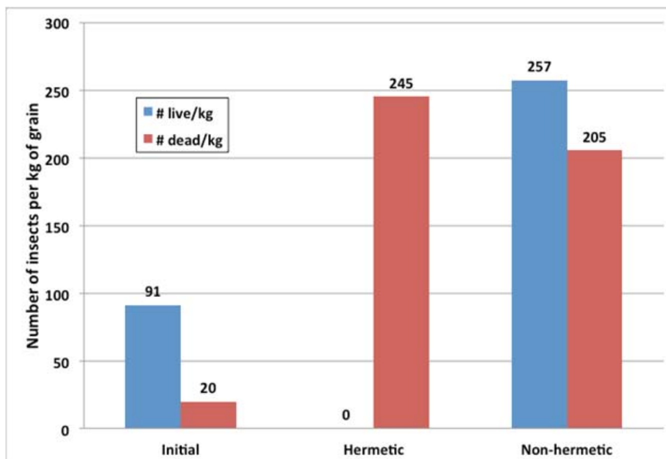

Figure 8. Recycled oil container experiment results.

Rat problems
Maize stored in bags may be subject to damage by rats. Figure 9 shows a maize storage bag in Zimbabwe with a hole made by rats. The rat problem was solved by placing the bag containing maize inside a plastic barrel (Dowell 2011).

Estimating storage costs
Table 1 summarizes capacity, cost, and life estimates for the four storage systems discussed. The last column shows storage cost in dollars per metric ton per year, based only on original container cost. By this measure, the Postcosecha Steel Silo has the least cost and, in fact, costs only 6 to 37 % of the other systems. There is a huge investment initially, but then the container probably lasts beyond the working life of the farmer. Because of this long life, a market for used silos is likely to exist. Costs for the two bag systems ($12 to $15 per metric ton per year) depend heavily on the assumed life of the bags, which relies on proper management. In spite of its low purchase price, low capacity drives up the cost of the recycled oil container to between 3 and 16 times the other costs.

Figure 9. Rat damage to maize storage bag in Zimbabwe (Dowell 2011).

Postcosecha galvanized steel silos, the *Purdue triple-bagging system*, *Grain Pro membrane bags*, and *Recycled plastic food containers* are all in use for storage of maize on subsistence farms. Original cost and life vary considerably among the four. With proper management, all should be able to provide effective grain storage and resulting control of insects.

Table 1. Maize Storage Container Costs.

Container Type	Maize Capacity kg	Cost US$	Useful Life Years	Storage cost US$/Mg/year
Postcosecha Steel Silo	1360	145	25 to 40	4.26 to 2.67
Purdue Triple-Bagging	100	3	2	15.00
GrainPro Super Grainbag™	70	3.50	5	10.00
Recycled Oil Container	7.74	1	3	43.06

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