13 Options for improving stored product protection in Southern Africa

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Introduction

Due to the favourable climate conditions in Southern Africa, durable staple food products such as cereal grains and pulses can be attacked all year round both in the field and during storage. Damage may be caused by insects, rodents, birds and – at higher moisture content – by microorganisms. High moisture content in storage can occur locally due to incomplete product drying, pest respiration, diurnal changes in relative humidity, moisture migration and condensation, moisture seeping from the ground or coming down through a leaky roof. Once fungi are established, they also increase moisture and temperature due to respiration and often also produce mycotoxins. These are a major threat to human and animal health because fungal attack and contamination with mycotoxins is not always easy to notice. Reducing postharvest losses can become crucially important in agricultural communities with insecure harvests due to climate change. The commercial farming sector in Southern Africa has access to modern storage facilities such as privately managed storage silos where grain is delivered immediately after harvest. It is in the resource-poor smallholder farming systems where stored product protection is a major constraint.

If a harvest is left in the field for too long, seed grains may be shattered and lost, and they may be attacked by insects, birds and rodents. And if the grain is too moist, germination capacity may be lost, or microbial development may contaminate the grains before they are stored. Thus, grain should be harvested as soon as it is mature.

Losses

In 2011, the World Bank estimated that postharvest loss in cereal grains are around US\$4 billion each year in sub-Saharan Africa (Sheahan and Barrett, 2017). This is a staggering amount of food loss in a continent, where there is a high prevalence of hunger due to various factors such as drought and climate change. Storage facilities in most Southern African Development Community (SADC) countries, particularly the smallholder producers, consist of traditional storage structures, which are inadequate to control insect infestations and fungal

Table 13.1 Maize postharvest losses (%) in the value chain from harvesting to farm storage in SADC countries in 2011

Country	Value chain					Total
	Harvesting/ field drying	Platform drying	Threshing	Transport	Farm storage	
Angola	6.4	4.0	1.3	2.4	4.6	18.7
Botswana	7.2	4.0	1.3	2.4	1.1	16.0
DR Congo	6.4	4.0	1.3	2.4	0.5	14.6
Lesotho	6.4	4.0	1.3	2.4	3.4	17.5
Malawi	6.3	4.0	1.4	2.4	8.2	22.3
South Africa	3.9	3.5	2.2	1.9	0.3	11.8
eSwatini (Swaziland)	6.4	4.0	1.3	2.4	4.5	18.6
Tanzania	6.4	4.0	1.3	2.4	5.0	19.1
Zimbabwe	6.4	4.0	1.3	2.4	4.8	18.9

Source: www.aphlis.net

growth during storage. Most grains are lost during postharvest handling and storage at the farm level in Africa, though the magnitude of losses varies (Sheahan and Barrett, 2017).

The scale and extent of postharvest loss varies due to different farming practices, climatic conditions, country and regional economics. The African Postharvest Losses Information System (APHLIS) provides estimates of postharvest losses in the SADC region (Table 13.1). Despite the introduction of APHLIS, direct measurements of postharvest losses are difficult and expensive and are therefore rare, with the most recent statistics dating back to almost a decade.

APHLIS estimates postharvest losses using postharvest loss profiles derived from peer-reviewed literature and seasonal factors obtained from local experts. The postharvest loss profiles (PHL profiles) quantify the expected loss – as a percentage at each stage of the postharvest chain – from harvesting to storage and market (Table 13.1). This loss data is obtained from scientific literature and broken down by crop, type of farm and climate type. Biotic and abiotic constraints as well as agricultural practices are the seasonal factors that are considered. These data are collected by APHLIS from official sources such as ministries of agriculture and statistics offices or by interviewing farmers or extension workers. The data from PHL profiles and seasonal factors in percentage losses are converted into absolute losses (in tonnes) through the use of an APHLIS algorithm (www.aphlis.net/en/page/4/how-aphlis-estimates-loss#/).

Pests

Some of the typical insect pests found in storage are the maize weevil, *Sitophilus zeamais*, as well as the lesser grain weevil or rice weevil, *S. oryzae*, the lesser grain borer, *Rhyzopertha dominica*, and in many locations also the larger grain

borer, *Prostephanus truncatus*. Pulses such as beans or cowpeas cannot be attacked by these grain pests due to their protective proteins. Typical pests in stored pulses are the cowpea weevil, *Callosobruchus maculatus*, and the bean weevil, *Acanthoscelides obtectus*. A list of 30 African stored product pest species can be found in Nukenine (2010). Insects have a great capacity for multiplication and if undisturbed can destroy a complete harvest within a few months. Storage of seed grains is necessary for periods usually between three and ten months. Given that infestation with stored product pests can already occur in the field prior to harvest, a good storage should not only prevent infestation but should also control any pre-existing minor infestation. This means that in most cases pest control is a need during storage.

Product drying, threshing and transportation

Depending on region and season, drying may take place in the field. However, in higher altitudes or fluctuating weather conditions, additional drying after harvest may be necessary. In many regions, grains are just dried on the ground protected from soil moisture by a plastic tarpaulin or a concrete surface. During sunny weather, drying maize to below 14% moisture content takes about five days. But, if the harvest is not protected from occasional rain, product drying may be insufficient and there is a risk of microbial development. Drying at ground level carries the risk of contamination with soil and other foreign particles as well as the risk of attack by rodents, birds, insects or theft. Thus, simple solar grain dryers that may be supported by furnaces in a rainy period could render grain drying more independent from weather conditions. Threshing and transportation from field to storage also pose a risk of contamination and postharvest loss. In some situations, the harvested ears/cobs are left to dry on the ground while smallholder farmers are awaiting transport to ferry the grain to the homestead for storage.

Investment in handheld moisture meters that can be used by smallholder farmers to monitor grain moisture levels at harvest, during drying and storage can mitigate postharvest losses arising from poorly dried grain. However, initial purchasing costs may be high for many farmers. Another option is to weigh samples of 100g and to dry them over a heater for about two hours before weighing again. If the new weight of the dried sample is 86g the moisture content of the grain would be some 14%. In fact, drying to only 13% moisture content may be more advisable because insects develop much slower, and there is even better protection from microbials.

Pest control

For decades after World War II, chemical pest control was the preferred option in most countries of the world. However, over the last 30 years hardly any new pesticide became available for stored product protection. Many old products lost authorization in industrialized countries due to potential health risks for

users and bystanders, while others caused the development of insect resistance, posed a threat to the environment or left residues that are no longer tolerated.

In Zambia and Malawi, farmers surveyed by Kamanula et al. (2011) reported serious pest damage, with *C. maculatus* and *Sitophilus* spp. being the major pests of beans and maize, respectively. It was found that 50% of farmers surveyed in eastern Zambia and all farmers surveyed in northern Malawi used synthetic pesticides. While there may be still a rather widespread use of pesticides, the mid- and long-term availability of synthetic pesticides and a prominent future role of these agents in Southern African stored product protection is not very probable.

In many rural African communities, plants and botanicals are traditionally used for both medicinal purposes and pest control. This led to a large interest in studying the efficacy of various botanicals in different formulations. In most cases where a dose dependent efficacy could be proven, plant extracts and pure compounds were identified. Of course, their cheap availability for small-holder farmers and their biodegradability are among the advantages of botanicals. A risk in the use of plant extracts is that they may change organoleptic properties such as the smell and taste of protected stored products and may also affect users and consumers. Thus, before making recommendations, the potential health risks associated with using one or another plant extract should be determined. However, in combination with improved product drying and storage, botanicals may still have a role to play in future stored product protection.

A certain efficacy against stored product pests is also attributed to plant ashes and desiccating dusts such as kaolin or diatomaceous earths (DE). Plant ashes may contain a large number of chemical compounds and may thus be a potential health hazard to users. Kaolin consists of crystalline particles and health risks associated with the inhalation of these particles must be analyzed. Thus, within this group of compounds the DE may be most promising. DE are fossil remnants of aquatic algae that occur in thick layers at sites formerly covered by fresh or saltwater. Ground DE is used to filter fruit juices or beer as well as an abrasive agent in toothpaste. Fine DE dust can remove fatty acids from the insect cuticle and thus increase the permeability of membranes leading to desiccation of stored product insects. Various DE products were authorized in Europe and North America and may be even more effective at higher temperatures and as a nontoxic insecticide on surfaces around storage structures. However, just lipophilic DE products ground to fine dusts below some 30 µm were found to be effective.

Traditional storage structures

Traditional storages that can be large clay pots with or without a lid or made solely of wood or of sticks and mud or bricks, do provide various levels of ventilation for passive drying and often some precaution against rodents but mostly little protection against insects. Improved traditional storage structures have been developed in Southern Africa such as the Tanzanian *kihenge*. The

kihenge is constructed from bamboo or wooden sticks and sealed by plastering with a mixture of mud, cow dung and ash. It is kept under a shelter to protect it from adverse weather conditions and is raised on legs with rodent guards to protect it from rodent infestation. Another example is the improved Zimbabwe brick granary that is constructed from brick, concrete slabs, wire mesh and thatch. The *gorongosa* mud silo is another improved mud silo that is used in Mozambique. It is kept sheltered from adverse weather conditions, and contact with ground moisture is prevented by placing it on rocks or wooden pallets. Another example is the *ngokwe* traditional silo for storage in Malawi that is made of interwoven split bamboo and covered with a conical shaped grass roof, and it is also raised off the ground.

Storage in woven polypropylene bags

In many countries, woven polypropylene bags are used for storage and trade. These bags are stored in various types of buildings. Also, jute bags are available in certain regions.

For example, Kamanula et al. (2011) indicated that bags were the major storage method for 54 and 97% of maize and beans, respectively in northern Malawi, whereas in eastern Zambia, 81% of the maize grain was stored in granaries while 82% of beans was stored in bags. Studies by Kankolongo et al. (2009) indicated that most household surveyed in the southern, central, Lusaka, Copperbelt and northwestern provinces of Zambia used bags for maize storage, often without the application of chemical pesticides. Due to these storage conditions, all farmers surveyed in northern Malawi reported pest damage on maize with 93% reporting damage on beans. In eastern Zambia, almost all farmers reported pest damage to maize and beans. As much as 80% pest damage was reported in five provinces of Zambia.

Basically, woven bags are suitable for transportation but offer no protection against insect attacks. Volatiles emitted from stored products attract insects into the storage bag. Thus, if feasible, it may be advantageous to store sufficiently dried products in an insect-proof enclosure or, better, even under hermetic conditions.

Hermetic storage structures

Hermetic storage means that the harvest is stored under gas-tight conditions. A gas-tight enclosure does not emit any attractive odours that could lure pests into the storage. While rodents and birds can learn quite fast how to chew or peck open gas-tight sacks, insects are kept away from a hermetic storage if there are no attractive volatiles emitted. In case insects were sealed in with infested grain, they will reduce the oxygen available in the interstitial atmosphere until they suffocate. Young adult beetles of species like lesser or larger grain borer usually leave the grain and search for light. These adults can penetrate plastic layers after hatching from inside to outside. This would be a risk during the

first weeks until anoxia leads to control of insect pests. Hermetic metal silo bins, however, could withstand rodents, birds and insects. Anoxic conditions are able to control all animal pests in grain and would lead to fungistatic conditions in a dry environment because all microorganisms tolerant to low moisture contents are fungi depending on respiration. Without oxygen even the formation of mycotoxins is stopped (Riudavets et al., 2018).

Hermetic metal silo bins (indoors/shaded)

Hermetic metal silo bins could be produced by local craftsmen in different sizes. Under hermetic conditions, respiration in the storage bins depletes the oxygen present and leads to anoxic conditions without the application of any pesticide. This effect was already known to the Romans who left written reports of underground hermetic storage in the first century AD. The typically bottle-neck shaped pits for underground hermetic storage can be traced in Northern Africa back to early Iron Ages (approx. 700 BC, Hill et al., 1983).

To benefit from the advances of a truly hermetic storage, a silo should be filled to the top in order to minimize the free headspace that would otherwise be a reservoir of oxygen. Thus, several smaller silo bins could be better than few large ones in order to balance out yearly fluctuations in harvest. Usually, the metal silo bin is built with feet that keep it standing upright and stable at some distance from the ground with a conus at the bottom from which the grain can be retrieved and a lid at the top for filling. The silo bin should be placed indoors or at least in a shaded space to avoid strong diurnal pressure changes that could damage the gas-tight seal. Strong temperature fluctuations could also

Figure 13.1 Metal silo bins from local production in Tanzania; hermetic seal feasible

Photo: C. Adler

lead to condensation within the silo bin. All openings need to be thoroughly checked and sealed. A pressure test should be used to test the gas-tightness in a silo bin prior to loading it with grain. White paint on the outside of the silo bin could reduce warming by light and the risk of condensation inside as well as improve gas-tightness around openings. After grain loading, the full silo bin should remain closed for at least two months in order to allow hermetic conditions to control insects that might have been brought in with the harvest.

Metal drums

Metal drums such as former water or oil drums could be used for grain storage, provided they are clean and can be sealed to a high degree of gas-tightness. Metal drums may be cheaper to purchase but would need to be stored safely to protect from damage or theft.

Hermetic triple layer bag

Hermetic triple layer bags such as the Purdue Improved Crop Storage (PICS) bag have been promoted in sub-Saharan Africa for a number of years now. Repeated testing showed that compared to the use of insecticides and storage in woven polyethylene bags, damage and losses by insect pests were considerably lower.

Young adult beetles like the lesser grain borer, *Rhizopertha dominica*, and the larger grain borer, *Prostephanus truncatus*, tend to leave the grain in search for mating partners and new oviposition sites. These insects can easily penetrate plastic liners from inside to outside in their search for light. If young adult beetles penetrate a hermetic bag, this would stop the depletion of oxygen inside the bag, leaving openings for emission of attractive volatiles and future infestation by stored product pests. One or a few small openings in a stored bag are not easy to detect by the grain owner; thus, faulty sacks would not be distinguished from gas-tight ones. Over time, this may lead to damage and losses.

Hermetic vacuum bags

First experiments on vacuum grain storage were reported in the 1930s (Blanc, 1938; Hyde, 1973). Tests with multilayer vacuum bags showed that vacuum can maintain a pressure of the compressed bag material on the grain for many months (Adler et al., 2016). The reduction of oxygen by application of a vacuum leads to faster control of pests infesting the grain and could thus minimize the risk of insects puncturing the bags from inside. In experiments at 20°C, all stages of *Sitophilus granarius* were controlled at a low infestation rate with 0.5 bar vacuum within five weeks, while hermetic storage alone led to control within eight weeks (Adler, unpublished data). At higher temperatures, these times would be shorter. On the other hand, punctured bags would be visible by their softness and the respective grain could be used up first or repacked in a new vacuum bag before any damage occurs.

Figure 13.2 Small hermetic vacuum bags for laboratory testing; hermetic big bags will be tested in Tanzania soon

Photo: C. Adler

Advantages and disadvantages of the various hermetic structures are given in Table 13.2.

Agriculture policies

Agricultural policies targeting smallholder farmers access to markets could reduce postharvest losses caused by biotic and abiotic constraints during storage. For instance, the Eastern Cape provincial government Rural Enterprise Development Hubs (Red Hubs) in South Africa connects production, processing and marketing to improve the competitiveness of rural economies and communities (www.ecrda.co.za). The Red Hub concept creates a communal and external market resulting in increased farm incomes that can be reinvested into the smallholder farming operations such as crop production, product drying, threshing, transportation and storage. This Red Hub concept is important given the increased maize production by smallholder farmers, which has not been matched by investments in storage infrastructure.

Table 13.2 Advantages and disadvantages of hermetic structures

<i>Hermetic structure</i>	<i>Advantages</i>	<i>Disadvantages</i>
Metal silo bin	Solid, long-lasting structures Multiple use Good protection vs. pests	Higher initial investment Risk of condensation
Hermetic metal drum	Smaller, flexible and cheaper structures	Needs protection against theft
Hermetic triple-layer bag	Flexible and cheaper structures Bags can be used for transportation and sale Already available to farmers	Needs regular investment Plastic waste Punctures not easily detected Less protection against birds, rodents and insects (from inside)
Hermetic vacuum bag	Vacuum leads to faster control Flexible and cheaper structures Pressure of material shows protection from pests and decay Grain from damaged bags can be utilized first Big bags available	Vacuum pump needed Plastic waste Less protection against birds and rodents Not yet available for practical use

The Malawi Farm Input Subsidy Programme is the largest known subsidy scheme of chemical protectants which subsidizes maize storage chemicals, inorganic fertilizer and improved seed varieties. However, on average, storage was found to be more profitable with hermetic triple bags compared to chemical storage protectants (Jones et al., 2014), thus indicating the need for partnerships among farmers, researchers and policymakers in order to introduce targeted and most effective interventions that reduce postharvest losses.

Lack of clear knowledge on the extent of postharvest losses and information on losses in agricultural commodities other than cereal grains is a major challenge in Southern Africa. Therefore, agricultural policies should also promote public-private partnerships and cooperation with international development partners that undertake such assessments. For example, the Swiss Agency for Development and Cooperation partnered with Tanzania in a Grain Postharvest Loss Prevention Project for smallholder farmers, while the German Corporation for International Cooperation GmbH (GIZ) has conducted a rapid assessment of food losses along the maize value chains in South Africa, Malawi and Zambia.

Indigenous knowledge systems should be taken into consideration through participatory action research in order for interventions to be more readily adopted in reducing postharvest losses in Southern Africa. Understanding cultural practices is also important, for example, in some countries or regions farmers may prefer to display their harvest openly while in others farmers prefer to keep their harvest indoors. Participatory action research also ensures responsiveness to the needs of both women and men farmers in reducing postharvest losses across agricultural commodities and helps in monitoring the effectiveness

of the interventions. From today's perspective, hermetic storage and hermetic vacuum storage appear the most promising technologies in order to reduce postharvest losses, particularly in staple foods produced by smallholder farmers in Southern Africa.

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Further readings

- <http://solarmaize.com/>
<http://cleanleap.com/new-open-sourced-grain-drying-technology-east-africa>
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