IJBSM February 2026, 17(2): 01-13

Article AR6667

Review Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2026.6667

# Beyond Metal Silos: Low-cost Hermetic Bags for Smallholder Grain Protection

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0009-0002-7709-5530

## ABSTRACT

This review was conducted in August, 2025 at Nigerian Stored Products Research Institutes, Ibadan, Nigeria to examine post-harvest losses and hermetic storage technologies for smallholder farmers in Sub-Saharan Africa. Post-harvest management plays a crucial role in preserving the quantity and quality of staple grains in developing countries, where over 500 million smallholder farmers produce the majority of food. This research article reviewed the transition from metal silos to low-cost hermetic bags as a sustainable and effective solution for post-harvest grain storage among smallholder farmers in developing countries. While metal silos offer effective protection, their high cost, technical complexity, and spatial demands limit adoption by smallholders. Hermetic bags, including prominent brands like Purdue Improved Crop Storage (PICS™), GrainPro, ZeroFly®, AgroZ®, Elite and Storezo, present cost-effective, flexible, and scalable alternatives. These bags create airtight conditions that induce hypoxia, stopping insect pests' development and grain spoilage without chemical use. Comparative studies show hermetic bags can reduce losses by up to 100% for major pests such as *Callosobruchus maculatus* and *Prostephanus truncatus,* with economic benefits ranging from 32–69% cost savings and favorable benefit-cost ratios (above 1.6), making them accessible to resource-limited farmers. Field trials across Sub-Saharan Africa and Asia confirm their efficacy in maintaining grain quality, reducing insect infestation, and lowering weight loss compared to traditional storage methods. However, challenges remain regarding the environmental impacts of plastic waste, variation in gas barrier properties among products, and liner durability. The article concluded that hermetic bags had evolved from alternatives to metal silos to essential components of smallholder post-harvest management. Future efforts must focus on developing biodegradable materials, standardizing performance metrics, improving reusability, and addressing recycling infrastructure to ensure sustainable adoption.

**KEYWORDS:** Hermetic bags, smallholder farmers, insect pest, low-cost storage

***Citation* (VANCOUVER)*:*** Oyewole and Raji, Beyond Metal Silos: Low-cost Hermetic Bags for Smallholder Grain Protection. *International Journal of Bio-resource and Stress Management,* 2026; 17(2), 01-13. HTTPS://DOI.ORG/10.23910/1.2026.6667.



***Data Availability Statement:*** Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

***Conflict of interests:*** The authors have declared that no conflict of interest exists.

RECEIVED on 03rd September 2025 RECEIVED in revised form on 15th January 2026 ACCEPTED in final form on 04th February 2026 PUBLISHED on 20th February 2026

## 1. INTRODUCTION

Post-harvest management of agricultural produce is a persistent challenge in developing countries, where smallholder farmers lack access to effective grain storage structures and technologies. As a result, many farmers are compelled to sell produce immediately after harvest to avoid spoilage, limiting their ability to benefit from higher off-season prices (Abass et al., 2014, Chigoverah and Mvumi, 2018, Bisheko and Rejikumar, 2023). Staples such as maize, wheat, rice, and beans are particularly vulnerable, with post-harvest losses in Sub-Saharan Africa (SSA) often exceeding 20%, primarily due to insect pest infestations (Okori et al., 2022). These losses are not only physical but also reduce quality and economic value, undermining household food security and farmer incomes (Stathers and Mvumi, 2020).

The causes of post-harvest losses are multifaceted, reflecting financial, managerial, and technical limitations across the value chain. Poor harvesting, drying, handling, and storage techniques increase the vulnerability of grain to pests and spoilage. For smallholder farmers, who already operate with minimal margins, such losses are especially damaging. Reducing post-harvest losses is therefore critical for improving food availability, strengthening household nutrition, and raising farmer incomes without necessarily increasing production (Bukchin-Peles, 2025, Ricker-Gilbert et al., 2022).

One technology that has attracted global attention is hermetic storage, which provides safe, chemical-free preservation of grain (Oyewole et al., 2025a). Hermetic systems function by creating airtight conditions where biological respiration from insects and microorganisms depletes oxygen and increases carbon dioxide, producing hypoxic environments that suppress insect survival and reproduction (Okparavero et al., 2024). This eco-friendly mechanism has positioned hermetic storage as an attractive alternative to conventional chemical treatments for grain protection (Mubayiwa et al., 2021).

Among hermetic storage systems, metal silos have shown strong effectiveness in reducing losses. However, widespread adoption remains low due to cost, technical, and practical barriers. Silos with a capacity of 100–3000 kg typically cost between \$35 and \$375 (Tefera et al., 2011), which is unaffordable for most smallholder farmers (Kumar and Kalita, 2017). Installation and maintenance require specialized skills often unavailable in rural areas (Affognon et al., 2015). Poor sealing compromises their effectiveness (Murdock et al., 2012), while their permanent nature requires land and foundations that many farmers cannot provide (Rembold et al., 2011). Farmers also cite high input costs for quality control, such as certified seeds and storage facilities, as additional barriers (Shiferaw et al., 2013). Consequently, smallholders often sell their produce immediately after harvest, only to repurchase it at inflated prices later, perpetuating poverty cycles (Eagle and Saleh, 2020).

In contrast, hermetic storage bags have emerged as a more affordable and flexible alternative. Cost analyses indicate that hermetic bags can be 32–69% cheaper than traditional storage systems (Yakubu et al., 2011). Widely available brands include Purdue Improved Crop Storage (PICS™), GrainPro Super Grain (SGBs IVR™), ZeroFly®, Elite, Storezo, and AgroZ® bags (Ignacio et al., 2023). Like silos, these bags suppress pest populations by lowering oxygen and raising carbon dioxide within sealed containers (Murdock et al., 2012, Murdock and Baoua, 2014). Hypoxic conditions halt larval feeding, prevent reproduction, and eventually kill eggs, larvae, and pupae (Baoua et al., 2014, Njoroge et al., 2019).

Hermetic bags also provide greater operational flexibility. They can be stored in varied locations, easily transported, and scaled according to seasonal harvests without requiring permanent infrastructure (Murdock and Baoua, 2014). This portability and lower cost make them well suited for smallholder farming systems where needs vary across seasons. For many resource-constrained farmers, hermetic bags represent not only a preferred but a necessary storage option.

Despite these advantages, challenges remain. Issues of durability, counterfeit products, and limited farmer awareness may undermine their effectiveness. Addressing these barriers is essential to enhance adoption and maximize the potential of hermetic storage technologies. The objective of this study is to examine the role of hermetic storage technologies in reducing post-harvest losses of durable crops among smallholder farmers in Sub-Saharan Africa. It focuses on evaluating the effectiveness and constraints of metal silos, and the affordability and operational advantages of hermetic bags.

## 2. OVERVIEW OF POST-HARVEST LOSSES IN SMALLHOLDER SYSTEMS

Post-harvest losses (PHLs) represent one of the most significant yet often overlooked challenges in global food security, particularly affecting smallholder farming systems in developing countries (Stathers et al., 2020). Despite considerable progress in food production, PHLs remain a significant concern, accounting for an average of 14% of food production in 2021 (Khan et al., 2024). However, this global average masks the disproportionately higher losses experienced by smallholder farmers, where inadequate storage infrastructure and limited access to modern post-harvest technologies create substantial economic and food security challenges (Oyewole et al., 2025b). Post-harvest grain losses include all losses, starting from grain harvesting before it is used for consumption or other purposes.

### *2.1. Causes of grain losses*

The principal causes of grain loss among smallholders include insect infestation, mold development, moisture fluctuations, and contamination by mycotoxins such as aflatoxins (Busso et al., 2016; Oyebamiji et al., 2024). High post-harvest losses decrease available food supplies, raise market prices, and reduce farmer incomes by wasting inputs and output potential, with studies reporting losses reducing gross margins by up to 40% (Pluato et al., 2024). Inadequate traditional storage systems, such as woven bags, harbor pests and do not prevent moisture ingress, whereas metal silos, despite their durability, are often financially inaccessible for smallholders (Kuyu et al., 2022; Ngoma et al., 2024). Other indigenous methods like clay pots and wooden cribs provide limited aeration control and pest resistance, underscoring the need for improved preservation solutions (Chidege et al., 2024).

### *2.2. Pest infestation and insect damage*

Storage pests represent the most immediate and visible cause of grain losses in smallholder systems. Among all biotic factors, insect pests are considered the most important and can cause huge losses in the grains (30%–40%) (Tapondjou et al., 2002; Sharma and Rathi, 2013; Abass et al., 2014). Some studies in Ghana reported that the maize losses due to insect infestation could be up to 50%, if all quantity losses, quality losses, and income losses due to early sale are considered in the estimation (Boxall, 2002). According to an economic model by Compton et al. (1997), each percent of insect infestation results in 0.6%–1% depreciation in the value of maize (Delgado et al., 2021). *Callosobruchus maculatus* (F.) alone, a common pulse weevil, has been found responsible for up to 24% losses in stored pulses in Nigeria (Tapondjou et al., 2002). Losses due to insects in stored maize have been reported from 12% to 44% in the western highlands of Cameroon (Nsobinenyui et al., 2017). The maize weevil (*Sitophilus zeamais*), and larger grain borer (LGB) (*Prostephanus truncatus*) are the major pests in the maize. About 23% losses were observed in maize grains stored for six months, mainly due to infestation of maize weevil and LGB in Benin (Kimenju and de Groote, 2010; Meikle et al., 2002). LGB originated in Central America and was accidentally introduced in Africa in the late 1970s (Mlambo et al., 2024). Nowadays, it is found in most parts of Africa and is considered the most threatening pest, as it causes extensive damage in a very short time (Tefera et al., 2011; Baoua et al., 2014). The sporadic nature of LGB makes even its control difficult: it does not infest all stores of the same area, and its recurrence in each year is not guaranteed. At the farm level storage, more than 30% of weight loss has been observed in maize due to these pests (Tefera et al., 2011; Baoua et al., 2014). Some studies on maize losses in Ghana estimated about 5% to 10% loss in market value due to infestation by only *Sitophuilus* spp., and 15% to 45% market value loss due to damage by LGB. Overall, these losses were equivalent to about 5% of the average household income in that area (Baoua et al., 2014). Abass et al. (2014) reported that after six months of maize storage, LGB was responsible for more than half (56.7%) of the storage losses, followed by losses due to grain weevil and lesser grain borer.

### *2.3. Mycotoxin*

Mycotoxin contamination is another big challenge, especially in the case of maize, which makes the food unsuitable for human consumption or animal feed. A large amount (25%–40%) of cereal grains are contaminated by the mycotoxins produced by storage fungi worldwide (Kumar et al., 2007). Molds and mycotoxins cause dry matter as well as quality loss, and are a hazard in the food value chain (Magan and Aldred, 2007). Aflatoxins, Fumonisins, Deoxynivalenol, and Ochratoxin are the most common and important mycotoxins, especially in maize (Kimanya et al., 2012; Suleiman et al., 2013; Suleiman and Kurt, 2015). Aflatoxins, produced as secondary metabolites by two fungi species, *Aspergillus flavus* and *A. parasiticus*, are considered the most dangerous group of mycotoxins, as they increase the risk of liver cancer and affect growth in young children (Turner et al., 2005; Suleiman and Kurt, 2015). Because of food contamination, about 4.5 billion people are exposed to aflatoxins in developing countries (Williams et al., 2004; Kumar et al., 2007). High concentrations of aflatoxin can lead to aflatoxicosis, which can cause severe illness and even death (Tefera et al., 2011). *Penicillium verrucosum* (ochratoxin), a major mycotoxigenic mold, is commonly found in damp cool climates (e.g., Northern Europe), and *Aspergillus flavus* is mostly observed in temperate and tropical conditions (Magan and Aldred, 2007).

Mold during storage damages the grains, as well as reducing grain germination. It also deteriorates the grain quality due to odour, increased fatty acid content, and reduced starch and sugar contents. Lipid peroxidation is another phenomenon that causes food deterioration and alters the taste and aroma, and may cause undesirable effects on human health (Kumar and Aldred, 2007). High oil content varieties of oil seeds demand particular attention during storage, as the high level of moisture degrades the vegetable oil and produces high fatty acids, which sometimes also results in self-heating (Fox and Fimeche, 2013). At the farm level, storage in developing countries, even rodents can damage a large portion of the crop, whereas fungi can be a major reason for spoilage at high relative humidity storage. Use of scientific storage structures and proper handling of grains can reduce storage losses to less than 1% (Tefera et al., 2011; Lipinski et al., 2013).

### *2.4. Socioeconomic impacts on smallholder farmers*

The impact of post-harvest losses extends far beyond the immediate loss of physical grain, creating cascading effects throughout smallholder farming systems. These losses directly reduce household food security by diminishing the quantity of grain available for family consumption throughout the year (Mesterházy et al., 2020). For many smallholder farmers who operate on thin profit margins, losing 20–50% of their harvest represents a devastating economic blow that can perpetuate cycles of poverty and food insecurity.

The economic impact is particularly severe because post-harvest losses often occur during the storage period when farmers typically plan to sell their grain at higher prices during lean seasons (Tibaingana et al., 2018). When forced to sell immediately after harvest due to inadequate storage facilities, farmers receive lower prices and forfeit the opportunity to benefit from seasonal price increases. This situation forces many smallholders into a cycle of selling low and buying high, further eroding their economic resilience (Hassan et al., 2021).

Moreover, the uncertainty created by unpredictable losses makes it difficult for farmers to plan effectively for household nutrition and income generation. Women, who often manage household food stores and nutrition, are disproportionately affected by these losses, as they must navigate the challenge of feeding their families with reduced grain supplies.

## 3. EVOLUTION AND DEVELOPMENT OF HERMETIC STORAGE BAGS

Hermetic storage is not a new concept and has been recorded from prehistoric times when grain was stored underground in pits (Ignacio, 2023). Hermetic bags are an adaptation of the traditional and other forms of hermetic storage systems, such as underground pits, clay pots, jerry cans, silos, or drums. Underground pits were considered as a traditional method of storage that provides an airtight, chemical-free, and safe means to store dry crops (Nimbkar et al., 2022). The development of hermetic bags started in the 1980s with the PICS in Africa and the Cocoon in Israel (Murdock and Baributsa, 2014; Olorunfemi and Kayode, 2021). GrainPro's SuperGrainbas™ emerged out of this effort to develop solutions for smallholder farmers. Hermetic bags were developed to help smallholder farmers in developing countries reduce post-harvest losses due to insects. Unlike some of the other hermetic storage methods, such as jerrycans or drums, hermetic bags can be easily scaled up cost-effectively. The PICS technology was developed by Purdue University to address storage pest infestations on cowpeas (*Vigna unguiculata*, L. Walp.) in West and Central Africa (Baributsa et al., 2010, 2014). Cowpea farmers in West Africa lose a substantial portion of their harvest (from 10% to as high as 100% after only a few months) during storage due to insect pests (*Callosobruchus maculatus,* Fabricius) (Moussa et al., 2011). PICS bags were developed to provide farmers with a chemical-free and cost-effective storage method.

Existing storage methods, such as granaries, ash, sand, botanicals, metal drums, jerrycans, and insecticides, had shortcomings (Baributsa and Ignacio, 2020). Some of these methods were ineffective, costly, not scalable, and posed health risks. Providing a safe and cost-effective method to store grain would improve food security and also allow farmers to tap into better grain prices during the lean season. PICS II bags come in three different sizes: 25 kg, 50 kg, and 100 kg bags. Each bag is made of two high-density polyethylene (HDPE) liners that are fitted inside a PP woven bag (Baoua et al., 2018). PICS bags are manufactured by 15 plastic companies around the world. 80% of PICS manufacturers are located in SSA, while the rest are in Asia and Latin America, as the latter are newly emerging markets for the PICS technology.

The development of hermetic bags by GrainPro started with the deployment of large-scale plastic storage structures (cocoons) for long-term grain storage. These cocoons come in different sizes of up to 300t (Baributsa and Ignacio, 2020). Over time, GrainPro developed intermediate and small storage systems, which are based on the hermetic principle. The small-scale hermetic storage system of GrainPro is the SuperGrainbags™, which are storage containers suitable for subsistence farmers (Jonfia-Essien et al., 2010). GrainPro hermetic systems became commercially available in the early 1990s, and today they are in use in more than 32 countries around the world (Villers et al., 2008). The SuperGrainbags™ were initially used for storing rice seeds as part of the 5-year project of the International Rice Research Institute (IRRI) in the Philippines (Villers et al., 2006). Each SuperGrainbags™ is a thin single multi-layered plastic liner, which is transparent and has low oxygen permeability. The capacities of SuperGrainbags™ can range from 60 kg to 1000 kg; 60–90 kg capacity being the most common (Villers et al., 2006, 2008). GrainPro bags are manufactured in Subic Bay in the Philippines and shipped around the world. In the last 5 years, several other brands of hermetic bags (Table 1 and Figure 1) have emerged, innovating on or imitating existing ones. These include ZeroFly® hermetic


Figure 1: Hermetic bag storage brands considered in the study: (a) GrainPro, (b) PICS™, (c) Elite, (d) ZeroFly®, (e) AgroZ®, and (f) Storezo (Baributsa and Ignacio, 2020)

Table 1: Characteristics of hermetic bags currently being sold in the African market

| Type of hermetic bags | Woven bag (PP) | Liners | Examples |
|---|---|---|---|
| Triple bags | One PP bag | 2 HDPE inner liners | Purdue improved crop storage (PICS) |
| | One PP bag | 2 HDPE inner liners | Elite bag light duty double liner |
| Double bags | One PP bag | 1 liner with multiple layers | AgroZ |
| | One PP bag | 1 liner with multiple layers impregnated with insecticide | AgroZ plus |
| | One PP impregnated with insecticide | 1 liner with multiple layers | ZeroFly® hermetic storage bag |
| Single bag | No | Yes (1 liner) | GrainPro bag zipper |

Source: (Baributsa and Ignacio, 2020)

storage bag, AgroZ bag, and Elite bag. AgroZ and Elite are manufactured in East Africa, while ZeroFly bags are imported from outside Africa.

The development of these hermetic bags was mostly driven by the realization of the growing demand for safer and affordable storage technologies among smallholder farmers. AgroZ bags are double-layer bags (one-liner and one woven bag) developed by A-to-Z Textile Mills Ltd (Tanzania). The liner is co-extruded, combining HDPE, Metallocene Linear Low-Density Polyethylene (MLLDPE), and low-permeability barrier layers limiting the passage of oxygen (Baributsa and Ignacio, 2020). Another hermetic bag developed by A-to-Z Textile Mills Ltd is the AgroZ bag Plus, which is a premium product, an insecticide-treated hermetic storage bag, specifically designed to control larger grain borer (*Prostephanus truncatus,* Horn). The ZeroFly hermetic storage bag is manufactured by Vestergaard and is composed of an outer PP bag impregnated with deltamethrin and an inner multilayered recyclable PE bag with a gas barrier. Elite Innovations (K) Ltd, based in Kenya, also developed a double-liner hermetic bag made from HDPE called Elite Bag Light Duty Double Liner (Ignacio, 2023). The manufacturers' specifications of all the hermetic bags discussed are shown in Table 2.

## 4. PROPERTIES OF COMMERCIALLY AVAILABLE HERMETIC STORAGE BAG LINERS

Commercialization of hermetic storage bag technology has increased largely as a result of scaling the local product supply chain and multiple manufacturers entering the global market. Currently, hermetic storage bags are available in different sizes (50 and 100kg holding capacity), configurations (single-, double- and triple-liner) and inner liner types (single or multilayer) (Baributsa and Ignacio, 2020). Manufacturers and distributors make competing claims about the performance of their bag brand, such as hermeticity (gas tightness) of gas barrier liners, and efficacy in controlling biological activity.

The gas barrier liner of a hermetic bag consists of either a single or double layer of high-density polyethylene or a multilayer extruded film containing a gas barrier layer. The outer bag is generally a woven polypropylene (PP) bag designed to provide strength and protection for the gas barrier liner during handling and for holding the grain weight (Okolo et al. 2017; Baributsa and Ignacio, 2020). Alternatively, the inner liner could be a single or multilayered film designed to provide a gas barrier, the most critical component of the hermetic bags.

Table 2: Manufacturers' specification of six hermetic storage bag liners

| Gas barrier liner product | Manufacturer (Source) | Gas barrier liner material | Dimension (cm×cm) | Capacity (kg grain) | Thickness (mm) |
|---|---|---|---|---|---|
| AgroZ® | A to Z Textile Mills Ltd (Tanzania) | Multilayer liner (co-extruded liner combining HDPE, mLLDPE and low permeability gas barrier layer) | 130×80 | 100 | 0.09 |
| GrainPro | GrainPro Inc. (USA) | Multilayer liner (co-extruded liner of high-strength PE with gas barrier layer) | 110×72 | 69 | 0.08 |
| Storezo | Storezo (India) | Multilayer liner (co-extruded liner of specialty laminated blend of polymers with ultra-high gas barrier layer) | 130×75 | 75 | 0.08 |
| ZeroFly® | Vestergaard (Switzerland) | Multilayer liner (co-extruded liner of recyclable PE with gas barrier layer) | 130×80 | 100 | 0.08 |
| Elite | Elite Innovations (Kenya) | 2 HDPE liners | 137×70 | 105 | 0.08 |
| PICS™ | Elite Innovations (Kenya) | 2 HDPE liners | 137×70 | 100 | 0.08 |

Source: Ignacio et al. (2023)

The gas barrier liners of six commercially available hermetic storage bag products (PICS™, Elite, GrainPro, AgroZ®, ZeroFly®, and Storezo), commonly used in Sub-Saharan Africa and Asia, were considered for this study. The inner bag liner of hermetic storage bags is designed to limit the permeability of water vapor and gases (oxygen, carbon dioxide). Selke et al. (2004) defined barrier property as the resistance of packaging film to diffusion and sorption of a substance, which can be expressed in terms of permeability. The permeability of a packaging material provides a measure of the rate at which a certain gas or vapor can penetrate the packaging material (Chelladurai et al., 2016) (Table 3).

Table 3: Physical characteristics of hermetic storage bag products

| Hermetic storage bag brand | Components | Material |
|---|---|---|
| AgroZ® | Outer bag | woven polypropylene |
| | Inner liner bag | Multilayer liner |
| GrainPro | Outer bag | woven polypropylene |
| | Inner liner bag | Multilayer liner |
| Storezo | Outer bag | woven polypropylene |
| | Inner liner bag | Multilayer liner |
| ZeroFly® | Outer bag | woven polypropylene |
| | Inner liner bag | Multilayer liner |
| Elite | Outer bag | woven polypropylene |
| | Inner liner bag | 2 HDPE liners |
| PICS™ | Outer bag | woven polypropylene |
| | Inner liner bag | 2 HDPE liners |

Source: (Ignacio et al., 2023)

Ignacio et al. (2023) evaluated the gas barrier performance of six commercially available hermetic storage bag liners (AgroZ®, Elite, PICS™, GrainPro, Storezo, Zerofly®) using ASTM standard methods. Oxygen transmission rate (OTR) and water-vapor transmission rate (WVTR) were measured to determine each liner's capacity to maintain hermetic conditions for controlling biological activity in stored grains. Significant differences ($p<0.05$) in OTR and WVTR among brands were reported, providing benchmark values for establishing ASABE engineering standards for hermeticity in smallholder storage applications (Table 4).

Table 4: Barrier properties of hermetic bag gas barrier liners

| Hermetic bag storage | OTR, $cm^3/(m^2 - day)$ | WVTR, $g/(m^2 \cdot day)$ |
|---|---|---|
| AgroZ® | 0.37±0.05 | 2.68±0.16 |
| GrainPro | 0.81±0.49 | 2.62±0.08 |
| Storezo | 0.81±0.11 | 2.55±0.35 |
| ZeroFly® | 1.20±0.07 | 3.04±0.10 |
| Elite | 1393.21±156 | 2.19±0.19 |
| PICS™ | 1,210±175.66 | 1.43±0.11 |

OTR: Oxygen transmission rate; WVTR: Water vapour transmission rate; Source: (Ignacio et al., 2023)

## 5. ECONOMIC AND ENVIRONMENTAL CONSIDERATIONS

If the cost of interventions for post-harvest management are too high, they will not be affordable and attractive to many smallholders who are more vulnerable to food losses along the value chain. Cattaneo et al. (2021) and Sheahan and Barrett (2017) recommend the evaluation of both the costs and benefits of interventions and the trade-offs between objectives. Generally, farmers, as rational economic agents, will only be able to invest in reducing losses if the marginal benefits of a given intervention are greater than the marginal costs. Ndegwa et al. (2015) concluded that Kenya's use of hermetic bags for maize storage, for example, had a benefit-cost ratio of 1.6, meaning that farmers could recover their capital by storing their produce for a period of four months. Anonymous (2018) carried out similar studies in Ethiopia, where the results showed that the use of hermetic bags, such as Purdue Improved Crop Storage (PICS) bags that are reusable for two or three seasons, made the storage of maize profitable.

Environmentally, hermetic bags have a lighter carbon footprint compared to metal silos since the production and transport of plastic bags require less energy than metal fabrication and distribution. However, they raise concerns related to plastic waste accumulation, necessitating innovations such as biodegradable bags and the development of recycling infrastructures (Dijkink et al., 2022). Metal silos, while durable and reusable, embed larger upstream environmental costs. Sustainability implications highlight the need for integrating waste management practices for hermetic bags alongside optimizing designs for durability and reuse. Recycling programs and biodegradable materials offer pathways to address environmental impacts while maintaining efficacy in grain protection.

## 6. FIELD EVIDENCE ON LOW-COST HERMETIC BAGS AS ALTERNATIVES TO METAL SILOS

Likhayo et al. (2016) conducted on-farm trials with 32 farmers across eight villages in Naivasha and Nakuru, Kenya, from December, 2013 to September, 2014 to assess hermetic storage technologies under farmer-managed conditions. The study compared metal silos and SuperGrain IV-R bags with standard woven polypropylene bags, with and without Actellic Super dust. Over the 270-day storage period, grain moisture content remained stable in all treatments. Metal silos and SuperGrain IV-R bags effectively suppressed insect populations, prevented cross-infestation, and minimized grain losses (1.5% and 1.8%, respectively). Meanwhile, untreated polypropylene bags allowed rapid insect population growth, leading to 32% weight loss after 270 days. The findings demonstrate that metal silos and SuperGrain IV-R bags provide substantial benefits in reducing storage losses and maintaining grain quality, offering valuable solutions for farmers and food security stakeholders.

Amadou et al. (2016) evaluated triple-layer Purdue Improved Crop Storage (PICS) bags for protecting *Hibiscus sabdariffa* grain from *Spermophagus* sp. bruchids. Over six months, grain stored in traditional woven polypropylene bags saw a 33-fold increase in pest population, emergence holes rising from 3.3 to 35.4 per 100 seeds, 8.6% weight loss, and a significant drop in germination. In contrast, PICS bags completely prevented insect population growth, grain damage, and weight loss, while maintaining seed germination. The study demonstrates that PICS bags effectively safeguard *H. sabdariffa* grain post-harvest against major insect pests. Ng'ang'a et al. (2016) also conducted participatory on-farm trials in eastern Kenya to evaluate the effectiveness of Purdue Improved Crop Storage (PICS™) triple-layer hermetic bags for maize storage under smallholder farmer conditions. Over 35 weeks, PICS bags, woven polypropylene, and jute bags were filled with shelled maize and stored in farmers' own facilities. PICS bags maintained stable oxygen and carbon dioxide levels, preserved grain moisture, and prevented insect infestation, with weight loss kept below 1%. In contrast, polypropylene and jute bags allowed rapid insect population growth, leading to severe grain damage (77.6% and 82.3%) and high weight losses (41.2% and 48.5%) by the end of storage. The results confirm that PICS bags provide strong air-barrier properties and effectively prevent storage pest damage, making them a reliable technology for reducing maize losses in rural on-farm storage systems.

Chigoverah and Mvumi (2018) evaluated the performance of four hermetic bag brands, namely SuperGrain Bag IV-R, SuperGrain Bag Farm, PICS bag and Kuraray bag, against *Prostephanus truncatus* in stored maize over 90 days under both resident and incoming infestation scenarios. Ordinary plastic bags served as controls. Each 50kg bag was either internally infested (50 adult insects placed inside) or externally infested (50 adults placed outside the bag). In externally infested treatments, all insects died of starvation and no internal infestation occurred. In contrast, internally infested bags experienced perforations on plastic liners, with ordinary plastic bags suffering the highest damage (151 insect holes) compared to hermetic liners (<40 holes). Although live adults were absent from grain collected via probe sampling, some survived in the bottom 5 cm of grain in all liners. No significant performance differences were found among hermetic bag brands for grain damage, weight loss, gas composition, or germination. The findings indicate that while hermetic bags prevent incoming infestations, all tested brands remain vulnerable to liner perforation by resident *P. truncatus*.

Tivana et al. (2021) evaluated high-density polyethylene containers (PC), Super Grain Bags (SGB), and polypropylene bags (PB) for storing cowpea grain in both on-station and on-farm trials. Initial infestation was 117 insects $kg^{-1}$ with 27% grain damage. After six months on-station, PB had over 1300 insects $kg^{-1}$ and 79% damage, while SGB and PC had lower infestations (573 and 364 insects $kg^{-1}$) and less damage (40% and 36%). However, SGBs were perforated after four months, compromising hermeticity. Combining PC+SGB further reduced infestation (257 insects $kg^{-1}$) and damage (34%). Farmers preferred PC and PC+SGB systems. On-farm results confirmed polyethylene containers' effectiveness in limiting pest multiplication and grain loss, making them suitable for smallholder storage.

Bakoye et al. (2020) compared five post-harvest storage technologies for cowpea preservation in Niger over an eight-month period, including four hermetic bags (PICS™, SuperGrainbag™, AgroZ®, and EVAL™), an insecticide-treated woven polypropylene (ZeroFly®) bag, and a regular woven polypropylene bag. Naturally infested cowpea stored in hermetic bags recorded 97–100% mortality of *Callosobruchus maculatus* adults, with no additional grain damage or weight loss, and only a modest germination decline of 10–16%. In contrast, ZeroFly® and woven bags experienced substantial insect population growth (35.7% and 78.6%, respectively), high weight losses (27.3% and 25.2%), and significant germination reductions (37.0% and 28.8%). Abrasions were observed on hermetic bag liners after storage, indicating potential limitations for reuse. The results confirm that hermetic storage technologies are highly effective for reducing cowpea losses in the Sahel, though durability improvements are needed to enhance bag reusability.

Baributsa et al. (2020) assessed the performance of four hermetic storage technologies, SuperGrainbag™, AgroZ® bag, EVAL™, and Purdue Improved Crop Storage (PICS™) bags, alongside an insecticide-treated woven polypropylene (ZeroFly®) bag and a regular woven polypropylene (PP) bag as a control in northern Benin over seven months. Maize naturally infested with insects was stored in each system, with hermetic bags maintaining oxygen levels between 0.5±0.0% and 1.0±0.3% (v/v) throughout the storage period. Results showed no insect damage or weight loss in hermetic bag-stored maize, while ZeroFly® and PP woven bags recorded weight losses of 6.3% and 10.3%, respectively. Grain moisture content in hermetic bags remained stable, whereas it declined by about 30% in ZeroFly® and PP woven bags due to dry ambient conditions. The findings highlight hermetic storage technologies as highly effective in preventing insect-related losses and preserving maize quality, offering a viable solution for smallholder farmers and development agencies in the Sahel.

Mutambuki and Likhayo (2021) evaluated the performance of six maize storage technologies over 36 weeks, including hermetic ZeroFly® (laminated and non-laminated) bags, Purdue Improved Crop Storage (PICS) bags, non-hermetic ZeroFly® bags, woven polypropylene (PP) bags treated with Actellic Gold® Dust, and untreated PP bags. The study found that hermetic bags and Actellic Gold® Dust-treated PP bags effectively minimized insect damage (<4%) and weight loss (<3%), whereas untreated PP bags experienced severe deterioration (81.1% damage, 25.5% weight loss). ZeroFly® hermetic bags showed faster oxygen depletion and $CO_2$ accumulation compared to PICS bags. Grain germination rates declined from 90% to about 60% in treated storage, but dropped to 4.7% in untreated controls. Across all technologies, aflatoxin levels remained below the safety threshold of 10 ppb. The findings demonstrate that hermetic storage and chemical-treated PP bags provide effective protection against insect pests, preserve grain quality, and can contribute to improved food security.

Dijkink et al. (2022) analyzed the impacts of hermetic bag use for maize storage in sub-Saharan Africa, focusing on food loss prevention, economic viability, and greenhouse gas (GHG) emissions. Data from five field trials were grouped into 50-day storage intervals to compare regular bags (with or without pesticides) and hermetic bags. Results showed that after 100 days of storage, maize in standard or pesticide-treated bags suffered significant insect damage, while hermetic bags limited losses to around 2%. Economically, hermetic bags were most beneficial when maize was stored for over 100 days and sold in markets with high seasonal price variations; in countries with low price gaps, the investment was harder to recover. Beyond direct profits, hermetic bags offered health and environmental benefits by reducing pesticide use and aflatoxin risks. The study highlights hermetic bags as a valuable technology for minimizing post-harvest losses and supporting food security, even when immediate financial gains are variable.

Ngwenyama et al. (2022) assessed the performance of five hermetic bag brands, GrainPro SGB IVR™, PICS, AgroZ® Ordinary, AgroZ® Plus, and ZeroFly® for storing three maize varieties in two agro-ecological zones in Zimbabwe over two seasons. All hermetic bags significantly outperformed Actellic Gold Dust®-treated and untreated polypropylene bags in minimizing grain damage and weight loss, with no significant efficacy differences among hermetic brands. Rodent damage was noted in some hermetic bags, highlighting the need for rodent control. Insect pest abundance (*Sitophilus zeamais*, *Sitotroga cerealella*, *Tribolium castaneum*, *Cryptolestes* spp.) correlated positively with damage and losses. The white hybrid maize suffered significantly more losses than the biofortified orange and local varieties. The study concludes that all tested hermetic bags are effective for smallholder farmers to reduce storage losses, eliminate pesticide use, and enhance food security.

Opoku et al. (2024) assessed the performance of ZeroFly®

Hermetic (ZFH) bags versus polypropylene (PP) bags for storing maize in three poultry farms in Ghana over six months. Predominant pests were *Sitophilus* spp. and *Sitotroga cerealella*, with PP bags recording far higher infestation (149.67 insects/500 g) than ZFH bags (4.67 insects/500 g). Insect-damaged kernels reached 67.67% in PP bags versus 5% in ZFH bags, while weight loss exceeded 30% in PP bags but remained under 0.3% in ZFH. Both bag types kept aflatoxin (<15 ppb) and fumonisin (<4 ppm) below safety thresholds, but ZFH maintained moisture stability and preserved higher crude protein, fat, and carbohydrate content. The study concludes ZFH bags better conserve maize quality for feed and food, with further research recommended on poultry performance using maize from each storage method.

## 7. CONCLUSION

Hermetic bags marked a paradigm shift in smallholder grain storage, providing an affordable and accessible alternative to metal silos. They ensured effective pest control, with studies reporting up to 100% mortality of major pests, while delivering economic benefits through 32–69% cost savings. Despite challenges such as plastic waste management, these innovative, low-cost solutions were vital for reducing post-harvest losses and enhancing farmer livelihoods Hermetic bags became indispensable to sustainable post-harvest management in developing countries.

## 8. ACKNOWLEDGMENT

The authors acknowledge the valuable contributions of colleagues, researchers, and institutions whose support and resources facilitated the completion of this work.

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