OVERVIEW

The Improved Seed Storage Project

Overview of Briefs and Case Studies

Seed is the foundation for the production of cereals and grain legumes that underpins farm family food security and income across Africa and Asia. Throughout Africa, in particular, farmers themselves produce an estimated 80–100% of the seed of both local and improved varieties. A recognition of the centrality of farmer-managed seed suggests that research and development practitioners need to support this important system and seed source. Farmers typically produce seed and grain in the same field, although there can be wide variation between crops and cropping systems. Methods for seed selection also vary, as seed might be selected in the field or after harvest, or from stored grain only at the time of planting.

The importance of storing seed in a smallholder context

There are many advantages for farmers in being able to store their own seed. Using seed from their own stores means that: a) farmers can sow varieties whose quality and management requirements they know well; b) they can access seed without having to lay out cash (in contrast to spending for seed purchased from agro-dealers and local markets); and c) their stored seed is always available on time and just nearby. Unfortunately, farmers often struggle to prevent losses in stored seed that may impede their ability to maintain quality seeds for upcoming plantings. Among other constraints, stored seed may be attacked by insects and pests; or it may lose its ability to germinate, perhaps due to high temperature or too much moisture.

Investing in good seed storage, that is, investing in efforts to help farmers save their seed "at the front end" (preventatively), should be seen as a strategic investment. Particularly with vulnerable farmers and in high stress regions, better seed storage options may mean less need for emergency assistance when times get tough "at the back end," when drought or flood or other stresses mean that multiple sowings, or more seed overall, might be needed to ensure that farmers can adequately sow their fields.

On-Farm Seed Storage Project overview

Recognizing the need for more critical thinking on seed storage options for smallholder farmers, the United States Office of Foreign Disaster Assistance (OFDA), supported a series of grants from 2009–2013 examining diverse seed storage methods across six countries and diverse crops (Table 1). All country case studies are available separately (see reference section). A learning workshop was also held in April 2013 in Bujumbura, Burundi to document and socialize lessons learned across the varied initiatives (CRS 2013).

In terms of general findings, field programs indicated some advances in reduction of seed storage loss, improved seed quality (viability and vigor) and ultimately yield. As examples, in Mozambique, farmers' combined use of 1.5 liter bottles, ash, and cooler box technology allowed for stabilized temperature

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and resulted in reported germination rate increases of 50–90% for maize (as fluctuations negatively impact germination). In Afghanistan, ventilation of traditional pit storage, rigorously combined with improved plant selection in the field and better seed handling practices (separating seed from tubers destined for consumption), cut potato storage losses down from 30% to 5% and resulted in marked yield increases, from 12 to 16 metric tons per hectare.

Table 1. Summary of seed storage interventions tested in OFDA-funded On-Farm Seed Storage Project: 2009–2013

Country	Crop	Technology tested	Implementing partner
Afghanistan	Potatoes	Ventilate underground pits; improved seed handling practices (separating tubers destined for seed and consumption)	Catholic Relief Services
Burundi	Beans (with farmers also extending to maize)	Various hermetic storage products containers PICS*, GrainPro bags, Food oil cans, clay pots	Catholic Relief Services
Burkina Faso	Cowpea and rice	Various hermetic products, the main one being PICS sacks (multi-layer, made of 2 polyethylene bags), also plastic bottles and painted clay pots	Catholic Relief Services
Ethiopia	Maize, sorghum and groundnuts	Below- ground storage pits	Mercy Corps
Ethiopia	Maize	Modification of above-ground granaries and below-ground storage pits	Goal
Mozambique	Maize	Storage in 1.5 liter bottles, with ash and cooler box of clay/bamboo	Aga Khan Foundation
Timor-Leste	Maize	Metal drums	Mercy Corps

** Purdue Improved Crop Storage*

Seed storage briefs

These storage briefs aim to synthesize some of the technical lessons from field experience in testing and encouraging adoption of seed storage technology. Brief no. 1 focuses on seed quality and the principles of seed storage technology. Brief no. 2 takes a closer look specifically at hermetic seed storage. Brief no. 3 provides an overview analysis of the economics and promotion of improved seed storage options.

These briefs are intended to be practical guides for field managers and implementers who have to make concrete decisions around seed storage programs. They should help practitioners design better on-farm seed storage proposals in consultation with famers, implement activities which better meet farmers' needs, and monitor and evaluate their activities more effectively. Each brief concludes with a reference section for further reading to encourage an ongoing learning process.

References

Catholic Relief Services, 2013. Documenting and Socializing Lessons Learned from 7 OFDA Grants on Household Seed Storage. Workshop held: April 15–19th 2013. Bujumbura, Burundi.

Purdue Improved Crop Storage, (n.d.): http://www.entm.purdue.edu/PICS2/

Case study documents

Quality Potato Seed through Improved Production and Storage in Ghor Province, Afghanistan. CATHOLIC RELIEF SERVICES (CRS), Afghanistan. 2013.

Quality seed through storage in Burkina Faso. CATHOLIC RELIEF SERVICES (CRS), Burkina Faso. 2013.

Strengthening Farmer-saved Bean Seed through Hermetic Storage in Burundi. CATHOLIC RELIEF SERVICES (CRS), Burundi. 2013.

Adaptation and Adoption of Improved Household Grain and Seed Storage in Southern and Eastern Ethiopia. GOAL, Ethiopia. 2013.

Enhancing Post-harvest Systems in Ethiopia. MERCY CORPS–Ethiopia. 2013.

MERCY CORPS, Timor Leste. 2013. Effective seed storage in Timor-Leste.

(not available- AGA KHAN FOUNDATION: Mozambique case study).

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BRIEF No. 1

Defining Seed Quality and Principles

Seed Storage in a Smallholder Context

This brief provides a robust definition of seed quality as it relates to grain crops grown by smallholder farmers. Emphasis is placed upon factors that may improve the quality of seed when stored and draws from examples featuring maize (Zea mays) *and beans* (Phaseolus vulgaris)*. Simple techniques for the measurement of seed quality, related to aspects such as moisture content, germination percentage and plant vigor, are described to assist farmers and extension workers when assessing the quality of their own seed.*

Defining seed quality

Seed quality is defined along two broad dimensions: seed quality per se and varietal quality. It is important to think of the two as quite distinct: It is seed quality which is particularly affected by storage technology.

Seed quality consists of the health, physiological and physical attributes, such as the absence/presence of disease, whether grains are fully mature (and not broken), and the absence/presence of inert material such as stones or dust weeds. The more seeds that germinate, the fewer overall that need to be sown. The quicker the germination, the less likely the emerging seedlings will be attacked by pests and disease, and the more they will be able to make use of limited moisture supplies in dry areas. Pests and diseases may also physically damage the seed, impairing germination and reducing plant vigor. The physiological condition of a seed, part of seed quality, refers to the state of the embryo and its ability to grow (seed germination). While many seeds are innately dormant after harvest, unable to grow even under favorable conditions, there are several attributes that may influence the number of seeds that will germinate (germination percentage). Superior quality seeds generally lead to more vigorous seedlings, which can produce more flowers (ears of corn or bean pods) and result in higher yields.

Key message

- Seed quality itself has a profound effect on the development and yield of a crop. Storage conditions can significantly affect seed quality. Storage conditions do not affect the variety quality, or the genetic make-up of the seed.

Variety quality refers to the genetics of seed. It may consist of attributes such as plant type, duration of growth cycle, seed color and shape. Genetics can determine whether the seed can adapt to local conditions, and often influence farmer and market demand. While some varieties may be affected differently by storage conditions than others, storage conditions will not affect the actual genetic composition of the seed.

Harvesting and threshing

Storage cannot enhance the quality of seed, that is, alter it in positive ways. It can, however, influence the aging process and the prevalence of diseases and pests. It is essential that grains of the highest quality available are selected for storage. In storage, seed quality can be maintained through the management of storage conditions in order to optimize physiological aging and to control diseases and pests.

Full-size grains, free from physical damage and pests and disease should be selected for seed. The process of selection begins in the field prior to harvest with the identification of fully-mature, vigorous, healthy plants from which to take the grains. In the case of maize and beans, the cob or pods (destined for use as seed) are harvested prior to the main crop and kept separately before removing the grains. Any damaged, diseased, pest-infested and off-type grains (i.e., of a different variety) can be removed at this time. For other crops, wheat or rice, for example, whole seed heads will need to be harvested and threshed.

Key message

- The selection of healthy, vigorous mother plants, mature full-size grains, free from physical, pest or insect damage is key to successful long-term seed storage.

Key principles of seed storage

In natural environments and when stored at ambient room conditions, seeds constantly respond to changing relative humidity, temperature and available oxygen. By maintaining seeds under controlled conditions of low humidity, temperature and oxygen, it is possible to lower metabolic activity, thereby reducing the aging process and increasing the longevity of the seed.

Since the life of a seed largely revolves around its moisture content, the moisture content of the seed as it is placed in storage and the relative humidity of the store are the most important factors influencing seed viability during storage. Before placing seeds into storage they should be dried to a safe moisture limit, although this varies considerably by crop (see Table 1). Very low moisture content below 4% may also damage seeds, due to extreme desiccation. At lower levels of humidity, seeds can usually be stored for longer periods. Harrington (1972) suggests as a rule of thumb that for every 1% reduction in seed moisture content the life of the seed doubles. This rule is applicable between moisture contents of 5–14%.

The higher the moisture content of seeds, the more they are adversely affected by higher temperatures, hence seed should be stored in a cool location. Harrington again suggests that for every decrease of 5°C in storage temperature, the life of a seed doubles. This rule is applicable between 0°C to 50°C.

Oxygen levels are more difficult to control in small-farm, low-cost stores unless some form of hermetically-controlled storage is used. Hermetic storage occurs where grain is placed in a sealed container, creating a low oxygen atmosphere. This process not only slows physiological aging within the seed, which might limit its germination potential, but the depletion of oxygen within the store significantly reduces insect and fungal growth and, thus, physical damage to the seed.

Key message

- Grain should be dry when placed in storage, with the preferred moisture content varying considerably by crop type.

Table 1. Select parameters for harvesting, threshing and storing seed

Crop	Indices for Harvesting Seed	Optimum Conditions for Threshing	Optimum Conditions for Storage
Cowpea[1]	When pods of 95% of crop are yellow-brown	9% moisture content	Moisture 7–8%, temperature 5°C–8°C
Maize[2]	Maturity is reached when a black layer is seen in the seed after taking a seed off the cob, and removing the bits of fibrous and papery tissue at its point of attachment to the cob. (The crop can be harvested at this point and will yield very good quality, but only if properly dried.)	Drying should be done on the cob, before threshing, since threshing is not possible at high moisture content levels.	Moisture content of 12–13% (can be determined by biting the seed – if it cracks, rather than being cut, it is ready for storage.)
Wheat[3]	Depending on the region and cultivar, optimum moisture content is 18–20%	13–22% moisture content	Moisture content should be less than 14.5%
Beans[4]	Moisture content should be no more than 18%	Moisture content should be no more than 14%	Optimum moisture content is 12%, unless cold storage (4°C–0°C) can be provided, in which case moisture content should be 5–6%
Rice[5]		Moisture content of 15–18% during threshing. If the seed moisture content is more or less, the chances of physical damage to the seed are greater.	12%

[1] *Dumet et al., 2008.*

[2] *http://www.infonet-biovision.org/default/ct/299/crops*

[3] *C. Guzman Garcia, pers. comm.*

[4] *Steve Beebe, pers. comm.*

[5] *http://irri.org/rice-today/dried-to-perfection*

Storage practices for quality seed

Decreasing temperature and seed moisture are effective means of maintaining seed quality in storage. However, neither is easily achieved under small-farm conditions in the humid and semi-humid tropics. Lessons from the OFDA-supported On-Farm Seed Storage Project (see introductory brief) result in key pointers as to how quality seed may be stored more efficiently under the recommended conditions.

Temperature: In all case studies undertaken, traditional storage practices involved drying and storing seed on the vine or cob in a rain-protected area, or drying and storing seed in a sack or purpose-built container, usually a woven basket or mud granary. In all cases, temperatures were not controlled, and were often high due to ambient temperatures or heat and smoke generated from the cooking area, which farmers believed deterred insects. High temperatures could have hastened the physiological aging of seeds stored in this manner.

Hermetically-sealed stores used in the case studies were generally well protected and placed in other containers in a shaded position. Embedding stored seed in a bigger container might have had some effect in reducing aging as extreme temperatures were avoided. The traditional pit stores used in Ethiopia served to regulate and reduce temperatures. This storage approach may be a useful one for high-temperature situations such as in the Sahel.

Humidity: Humidity was not controlled in any of the traditional storage practice cases. As grain was sometimes stored during a rainy season, the absorption of moisture was to be expected. In relatively enclosed storage vessels, sacks or basket granaries, humidity may rise further as moisture is trapped, increasing metabolic activity. In extreme cases, molds develop, which can adversely affect seed quality. Mold growth was reported as a major issue by many farmers. During Mercy Corps' work in Ethiopia, farmers reported losses of 73% in their traditional pit stores due to mold alone or mold combined with weevils.

Hermetically-sealed stores can reduce humidity by two means: the sealed container prevents the moisture from entering, and the low oxygen environment reduces grain metabolism and, thus, the internal production of moisture. If grain is well dried before being placed in hermetically-sealed stores, grain moisture content should not be an issue and seed viability substantially enhanced.

There is an interactive relationship between storage temperature and relative humidity on the physiological aging of seed: if the sum of temperature (in °C) plus the relative humidity (in percent) is 80, the seed will begin to deteriorate after 1–5 months. If the sum is 70, then the seed may be stored safely for 18 months (CIMMYT, n.d).

Pests: Under smallholder, tropical-farm conditions, pests, insects, rodents and birds present additional problems. They can rapidly destroy seed commonly stored in containers made of natural materials. This was demonstrated clearly in the Timor-Leste case study (*referred to in the introductory brief*) where maize cobs were commonly hung on rafters or branches. Insects easily penetrated the sheaths and ate the grains. Similarly, the cobs were frequently eaten by rats and mice. The overall consequence of such infestations was that grain could not be stored for more than four months. The use of metal containers was effective in controlling rodents, but less so in controlling insects. Insects were usually present, albeit in small numbers, at the time of storage and then multiplied rapidly in store. Previous work in many countries has shown that the use of natural insecticides or repellents is only partially successful. The introduction of hermetically-sealed containers seems to provide a solution to the insect problem, while providing an oxygen-free environment to delay seed aging.

Key message

- Exposure to insects, pests and high humidity is greatly reduced when grain is placed in a hermetically-sealed container. Placing the container in a shaded area or pit may lower the ambient temperature and further reduce physiological aging.

Five projects in Burkina Faso, Burundi, Ethiopia, Madagascar and Timor-Leste tested some form of hermetic storage under the OFDA On-Farm Seed Storage grant. All projects reported a marked reduction in damage caused by weevils in either maize or beans. Timor-Leste (Mercy Corps) estimated a reduction in maize seed losses of approximately 80%; Ethiopia (Goal) reported a reduction from 37 weevils/100g of maize to three weevils/100g of maize or a 90% reduction in infestation. Burundi (Catholic Relief Services) noted damage of stored beans was reduced from 20% to 8%, also resulting in a major reduction in the use of insecticides.

Key message

- Exposure to insects, pests and high humidity is greatly reduced when grain is placed in a hermetically-sealed container. Placing the container in a shaded area or pit may lower the ambient temperature and further reduce physiological aging.

Hermetically-sealed stores are not intended to control damage due to rodents. Farmers in the case studies took extra precautions to protect their hermetically-sealed containers from rodents through the use of metal silos, placing bags in metal drums, etc., to ensure the hermetically-sealed bags were not damaged. Thus, the use of hermetically-sealed containers indirectly reduced losses due to rodents.

Storage structures

Within the OFDA-funded seed storage project, a number of containers were used as hermetically-sealed stores ranging from purpose-built metal silos, to Purdue Improved Cowpea Storage (PICS)[6] or GrainPro bags[7], to 20-liter plastic containers or soft drink/mineral water bottles. Attempts to seal traditional containers such as clay pots were also made but largely failed.

Silos: Metal silos proved to be an effective means of storage although doubts were cast upon their adoptability given the high investment cost to smallholder farmers and the need for subsidies to acquire this technology. Also, the metal containers used were of a medium or large capacity – 35 kg or 70 kg – and more suited to grain storage than seed, where only 5 to 30 kg is needed. The 200-liter oil drums were similarly inappropriate, and further created difficulties in accessing grain due to the narrow entrance. One possible solution to that problem – removing the lid – gave rise to problems of re-sealing the drum.

Custom-made plastic bags: Both Purdue University and GrainPro market custom-made bags for hermetic-seed storage. While these were shown to be very effective in the Burkina Faso and Burundi case studies, their large size (50 kg), was excessive for the small quantities of maize or bean seed stored. Smaller bags are now being manufactured and may better suit smallholder farmer needs. Consistent access to appropriate storage bags, in the absence of project activities, remains a major constraint to adoption, as does cost (*see Brief 3*). Many farmers appeared reluctant to invest in the US$2–$3 cost of the bags although their reluctance may change when the value in maintaining high-quality seed becomes more apparent. Further research may also determine farmers' willingness to invest in hermetic seed storage bags given the need for careful handling and the prospect of replacing them often.

Used plastic containers: A range of recycled plastic containers were tested, with 20-liter cans and soft drink/mineral water bottles predominating. Some were effective, if the seal was sufficiently tight and maintained. Such containers were also well-suited to farmers' conditions where families stored only small quantities of seed. Plastic containers also allowed varieties to be stored separately, which is particularly important where varieties have different planting requirements. These containers were easily accessible at minimal cost, were robust, and could be used repeatedly over a number of years.

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[6] *As the use of such bags is now being tested on a range of crops, the meaning of the acronym has been modified from Purdue Improved Cowpea Storage to Purdue Improved Crop Storage. https://ag.purdue.edu/ipia/pics*

[7] *http://www.grainpro.com/?page=grainpro-supergrainbag*

Key message

- Of the range of storage modifications tested, hermetically-sealed storage containers proves most promising. While initial costs were frequently mentioned as a constraint to farmer adoption, projects demonstrated that several low-cost modifications can be adapted to individual household conditions and use.

Sealed jars: Simple adaptation of traditional systems such as the hermetic sealing of clay pots for bean storage did not have satisfactory results. The method of sealing the pots with mud did not sufficiently keep out the oxygen, hence a hermetic seal was not achieved. An alternative means of sealing the pots, such as by using beeswax as a sealant, should be identified.

Watertight pits: Pit stores are used in Ethiopia to minimize insect damage, risk of fire and to prevent theft. However, temperatures measured in the On-Farm Seed Storage case study proved higher in the traditional pit (30°C) than in the above-ground granary (22°C). Grain moisture content was also higher at 17%, reflected in the frequent presence of molds, compared to 13% in the granary. The higher moisture rate was due to moisture entering from the surrounding soil of the pit. The seed from the traditional pits also had a low germination percent. Pit modifications took several forms but all involved adding a plastic or rubberized lining to prevent the entry of moisture. While not airtight, the lining did substantially reduce air movement. Farmers reported that the germination percentage of seed from the improved store was approximately 90% while that from the traditional store was only about 25%. This difference is attributed to a reduction in weevil damage and humidity, though further investigations are necessary.

Establishing moisture content, measuring germination, and estimating plant vigor

Further development of potential seed storage practices requires improved monitoring, data collection and analysis of seed quality, in addition to measuring seed loss. Three key metrics may be used together to give an indication of seed quality:

Moisture content: The overriding factor affecting seed aging is its moisture content. In non-hermetically sealed stores, the moisture content should be regularly monitored and the seed re-dried if it is above the recommended moisture content. For experimental purposes, moisture control is best achieved by using purpose-designed grain moisture meters with the probe placed near the center of the container. Where a meter is not available, there are a number of simple tests that give replicable and relatively accurate estimates of grain dryness. These include the "bite" and "salt" tests.

i. Bite test: Pinch the maize or bean seed between the finger and bite. If the seed is hard (bean) or cracks (maize) then it is fit to store. If the seed is soft then it needs to be dried/re-dried.

ii. Salt test: Fill a clean dry jar with salt, to the 1/4 level. Add the bean seeds to reach the 1/2 jar level and close the lid, sealing tightly. Shake the jar well and leave for 10 minutes. If, after 10 minutes, there is damp salt adhering to the inside of the jar, the bean seed is too moist (above the 13–15% level) and will need further drying. If there is no salt adhering to the inside of the jar, the seed is adequately dry for storage (David, 1998).

Germination: The viability of seed, or the percentage of grains capable of producing a plant at sowing, is estimated using a germination test. The expected germination percentage of good-quality seed varies with crop. For maize, the germination rate should be above 90%, while for beans, it should be above 80%. A simple method to estimate viability is provided by CIMMYT (n.d.):

i. Collect a sample of seed from the farmer near planting time, not just after the harvest. Ask the farmer how long s/he stores the seed, and examine the storage area. This will help you interpret the results of the germination test. Ask the farmer if s/he selects only good seeds for planting, or if s/he sows without removing damaged seeds. This information will allow you to select seed for the germination test which is similar to the seed the farmer will plant.

ii. You will need to collect about 500 seeds. If the grain is already shelled, push your hand well into the bag or pile with your fingers straight, and then close your hand to draw out the sample. Collect samples from five different places in the bag or pile (especially from the center). If the maize is still on the cobs, collect at least ten cobs from different places in the pile and take the grain from the central part of each cob.

iii. Examine the seed for insects, and for holes, cracks, or other damage. If the farmer sows only good seed, you should test only good seed.

iv. Count out 400 seeds and divide them into groups of 50. Moisten a paper towel so that it is damp but water does not drip from it when you shake it. Place the seeds on the paper towel in a line along the middle so that they are not touching. Fold the paper over the seeds, and then roll it up loosely. Place the eight samples of 50 seeds in an open plastic bag with the rolls placed vertically in a place where the temperature stays between 20–30°C. Check daily to be sure that the paper towels do not dry out. (You can also use a dish of wet sand for the test. Plant 400 seeds in groups of 50 about 2 cm deep and be sure that the sand does not dry out.)

v. After four days, count the number of germinated seeds on each towel or in the dish of sand. You should count only normal seedlings – those which have both roots and shoots. Make a second count on day six and your last count on day seven. The germination percentage is the total number of seedlings you counted multiplied by 0.25 (because you started with 400 seeds).

vi. Remember that the rate of emergence in the field will not be as high as the germination rate, since vigor is also important in allowing the germinating seedling to emerge. Remembering that soil crusting, the depth of planting, etc., will also affect the final emergence rate. You can get some idea of the field emergence rate by planting seeds in a small box of local soil at the depth the farmers will use.

Plant vigor: Rapid germination and vigorous seedlings are essential if plants are to develop quickly and establish a root system to tap available water resources and obtain the maximum amount of sunlight for growth. Thus seed showing potential for early, vigorous growth is desirable. However, the potential vigor of a seed is difficult to estimate since it is influenced by many external factors such as soil type and conditions, weather conditions, planting depth, as well as pest or disease damage. Moshatati and Gharineh suggest collecting a random sample of 25 seedlings from each seed-lot 14 days after emergence, measuring the length of each using a ruler, estimating seedling dry weight by drying the samples at 75°C for 24 hours, weighing, and then analyzing both the length and weight results by a statistical analysis of variance. Should there be no facilities for drying and accurately weighing the seedlings, the average length measured should provide some indication of plant vigor.

This brief has described several dimensions of seed quality and discussed precise measurement of select seed quality parameters. Key principles and practices for storage have been presented at length – keeping the moisture and temperature levels under control, keeping oxygen and pests out. Diverse storage methods are making progress in partially maintaining seed quality and results with the hermetically-sealed bags seem particularly promising. However, to control seed quality more effectively, practitioners need to be able to analyze its features more closely, inter alia, moisture content, germination percents and plant vigor.

References and further reading

CIMMYT (n.d.). Testing maize seed viability. http://maizedoctor.cimmyt.org/index.php/en/measurement-methods/168?task=view

David, S., 1998. Producing bean seed: handbooks for small-scale bean producers. Handbook 1. *Network on Bean Research in Africa, Occasional Publications Series, No. 29*. CIAT, Kampala, Uganda.

Harrington, J. F., 1972. Seed storage and longevity. Cited in: Kozlowski, T. T., *Seed Biology* 3:145–245. NY.

Hong, T.D. and R.H. Ellis, 1996. A protocol to determine seed storage behavior. *IPGRI Technical Bulletin No. 1*. International Plant Genetic Resources Institute, Rome, Italy. http://www.cbd.int/doc/case-studies/tttc/SeedStorage.pdf

Moshatati, A. and Gharineh, M.H., 2012. Effect of grain weight on germination and seed vigour of wheat. *International Journal of Agriculture and Crop Sciences* 4:458–460. www.ijagsc.com

Roberts, E.H., 1973. Predicting the storage life of seeds. *Seed Science and Technology* 1:499–514.

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BRIEF No. 2

Hermetic Seed Storage Technology

Principles, use, and economics – a practitioner's guide

Hermetic storage is the process by which oxygen is depleted and replaced by carbon dioxide, thus controlling grain storage pests without insecticide. A variety of storage types – from clay pots, to plastic bottles, to specially designed plastic bags, to metal silos – can achieve a hermetic seal with varying levels of effectiveness and cost per unit of seed/grain stored. Drawing from the experience with hermetic storage in different projects, this brief presents lessons learned, discusses the cost trade-offs and the role that storage can play in other aspects of on farm seed management such as seed selection, harvest and conditioning. Some brief recommendations are also provided, aimed at practitioners who are designing, monitoring, and evaluating hermetic storage activities.

Introduction: the centrality of farmer saved seed and seed management

Seed is the foundation for the production of cereals and grain legumes that underpins farm family food security and income across Africa. Throughout the African continent, farmers produce an estimated 80–100% of the seed of both local and improved varieties. The recognition of the centrality of farmer managed seed indicates that research and development practitioners need to support this important system and seed source (see Figure 1). Farmers typically produce seed and grain in the same field, although there can be wide variation between crops and cropping system. Methods for seed selection also vary, as seed might be selected in the field or after harvest, or from stored grain only at the time of planting.

Farmers often struggle to prevent losses in stored seed, which may impede their ability to maintain quality supplies for planting. Rather than taking a risk, farmers may decide not to store seed but rather to purchase from the grain/seed market prior to the next sowing season. On-farm hermetic storage prevents insect damage and helps farmers better manage their own seed, supporting increased food security in the region.

There are compelling reasons why farmers might not produce and save their own seed for different crops. These include (1) difficulty in storing seed, (2) reduced production due to disaster, (3) knowing that good quality seed can be sourced off farm, and (4) dissastisfaction with the variety. While some of these reasons are opportunistic and may benefit farmers, many times pest infestation and rotting of stored seed are easily avoidable with simple technologies. It is this constraint which this brief will focus on addressing.

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The crop focus of on-farm seed storage is generally on lower value food security crops that are relatively easy for farmers to manage. These include grain legumes and cereals, especially rice and wheat that are self-pollinated but also pearl millet and sorghum. Integrated seed sector development is aimed at integrating formal and farmer seed systems, and tends to have less focus on commercial and more focus on developmental seed systems (see Figure 2).

Farmers who are reliant on their own saved seed typically struggle to access seeed of new varieties that come from the formal seed sector (either the public or the commercial sector). Farmers who have problems storing seed between the harvest and the next planting season sometimes decide to not take the risk. Rather than storing their own seed, these farmers purchase seed off farm – usually from the grain market but increasingly from the commercial seed sector.

The direct effect of hermetic storage is that farmers are able to store more seed and maintain excellent quality. The indirect effects that are part of a seed management theory of change are that as farmers become more aware of seed as distinct from grain, and begin accessing new varieties, and begin producing seed separate from grain, they manage seed carefully and avoid accidental mixing of varieties.

Take-home message

- The vast majority of seed utilized by small-scale farmers in developing countries, especially cereals and grain legumes, is produced and stored on-farm. Major problems such as mold and insect damage can be avoided and higher seed quality retained through embracing more effective storage strategies such as hermetic storage technologies.

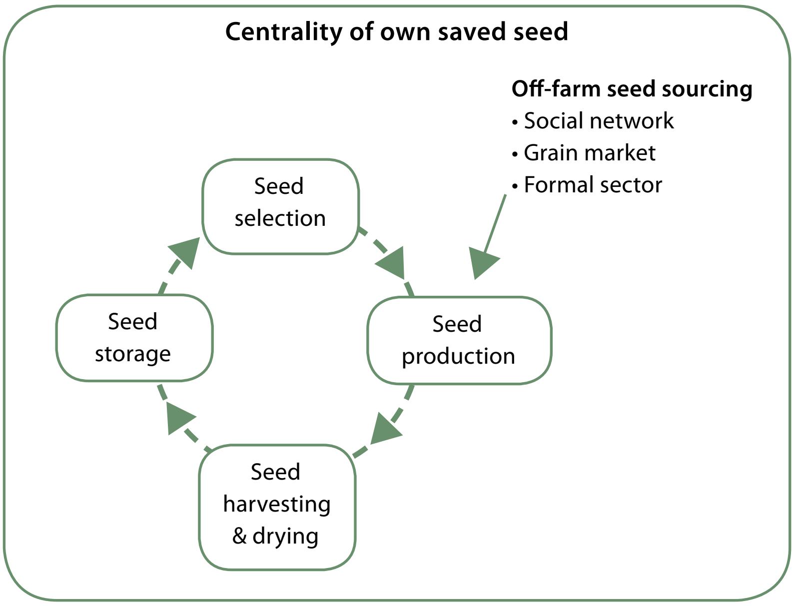

Figure 1: Key components for farmer managed seed

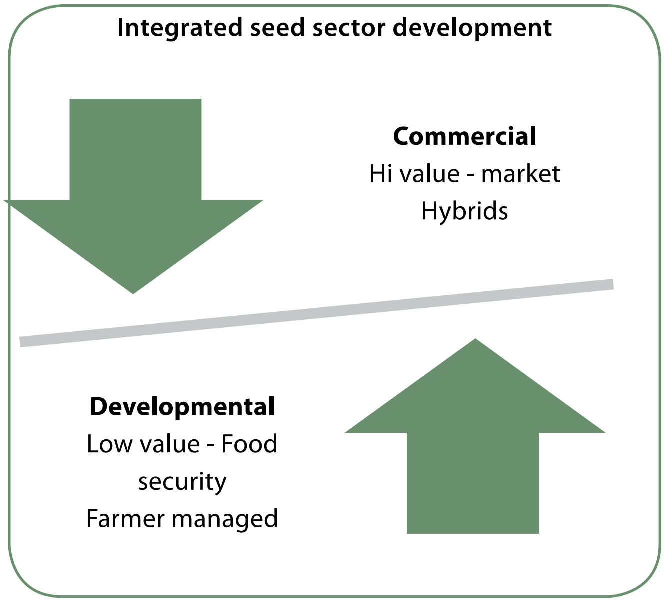

Figure 2: Adapted from Louwaars and de Boef (2012)

Principles of hermetic seed storage

Hermetic storage is a technology that enables farmers to store their own seed for long periods without loss due to insects and without using any insecticides. The technology consists of enclosing seed in air-tight containers that prevent or minimize gas exchange. Insect aerobic respiration depletes O_2 and increases CO_2. Insect feeding ceases, and therefore insects begin dying (Murdock et al., 2012). There is no need for insecticides. Additionally, hermetic storage can impede the growth of fungi as these organisms also need oxygen to proliferate (Quezada et al., 2006). This technique can maintain seed quality for up to one year of storage.

Humidity and managing moisture can be challenge. Hermetic storage both locks in and locks out moisture. Adequate drying of seed prior to storage is not a problem in the dry Sahelian climate, but can be a major problem in the humid tropics, especially during the first season harvest. In the humid tropics, simple moisture meters can be used to quantify seed moisture prior to storage (though small producers use more risky "bite" tests for dryness). Seed must be dry prior to storage, approximately 12–14% moisture. Drying seed is a real challenge in the humid tropics. High moisture contents in hermetically stored grain such as maize can lead to loss in germination and viability and thus dryness must be ensured (Weinberg et al., 2007). Hermetic storage can also keep seed dry in the event of flooding.

The simplicity and profitability of hermetic storage are resulting in significant adoption, but it cannot be assumed that farmers are already employing this technology everywhere and correctly. In seed storage assessments in Burkina Faso and Kenya, a significant number of farmers using hermetic storage also used insecticides as an added, albeit unnecessary, insurance. It is therefore important to emphasize both necessary (drying, proper sealing, avoiding bag puncture risk) and unnecessary practices (insecticide supplements) in hermetic storage education.

Take-home message

- Hermetic storage works by allowing the insects to naturally respire and exhaust oxygen levels in an airtight environment to the point where they cannot survive. Insecticide or fumigation is not necessary. However, many grains must first be properly dried to about 12–14% moisture to avoid loss in germination and viability.

Hermetic seed storage technologies – an illustration

Three types of hermetic seed storage containers are promoted for use by smallholder farmers. These include locally available containers, Purdue Improved Crop Storage (PICS) triple-layer sacks (Baributsa et al. 2012), and GrainPro Super Bags (Villers, Navarro, and de Bruin, 2008). PICS sacks are composed of two high-density polyethylene plastic liners and a printed woven polypropylene bag for reinforcement. GrainPro Super Bags are sold as a single polyethylene liner with a proprietary formula, for which farmers must generally purchase the necessary woven sack for reinforcement. Unlike local woven bags which simply "organize" grain without providing protection against insects, hermetic bags provide full protection against insects without the need for any additional treatment.

The most common locally available containers include simple water bottles and recycled vegetable oil containers. The 5 and 20 liter vegetable oil containers are quite popular in villages throughout Africa and are typically used to store water and local beverages. Figure 3 provides an illustration of a variety of vegetable oil containers that are available locally in many parts of Africa which can provide a hermetic seal.

PICS (Baributsa et al. 2013) and GrainPro sacks come in 50 and 100 kg sizes (See Figures 4 and 5). This is typically more seed than a farm household requires for storage, though the flexible material allows for compression to store smaller quantities such as 20–25 kg. However, the bags can be used to store seed from more than one household or more than one crop – with the different seed lots in separate, non-hermetic sacks, placed inside the larger PICS or GrainPro sacks. These sacks can also be used for effective long-term grain storage.

Take-home message

- Hermetic containers for seed storage include locally available plastic bottles and 20L jerry cans, as well as multi-layer Purdue Improved Crop Storage (PICS) triple-layer sacks and GrainPro SuperBags.

Figure 3: Locally available hermetic storage containers

Figure 4: PICS sack

Figure 5: GrainPro sack

Figure 5: GrainPro sack

Hermetic seed storage supply chains

Local containers rely on existing, informal supply chains. These containers can be recycled easily and are inexpensive, but are often needed for purposes besides seed storage and must be replaced every 2–4 years. Old, dilapidated local containers can also present problems with sealing and must be verified before use.

PICS sacks have established small but maturing supply chains in many cowpea regions of West and Central Africa, with about 1,000 participating vendors. However, there is need to develop and expand this chain to reach greater numbers of farmers. In East and Southern Africa, there have been limited efforts to disseminate the technology among farmers to stimulate demand and hence the need for supply chain development. As an initial step in developing supply chains, Purdue has identified plastic manufacturers in several countries. PICS bags are currently being produced in Kenya, Rwanda, and Uganda, while production is also being tested with manufacturers in Tanzania and Malawi. Supply chains will be driven by agro-dealers and others.

GrainPro bags, due to economies of scale in production and quality control, are manufactured solely in the Philippines for global distribution. The bags are slightly more expensive than PICS sacks and so the supply chain has focused on major distributors as well as pursuing large sales contracts with governments and non-government organizations. While the cost of many hermetic storage technologies is low and the returns for farmers look promising, a major challenge is providing incentives of sufficient economic returns for suppliers in order to maintain the supply chain.

Where supply chains are non-existent for hermetic bags, like the situation outlined in the Burundi case study, plastic bottles and jerry cans are the only locally available hermetic seed storage options. While awareness campaigns are critical to create demand, new products must become available in the market. Therefore, as supply chains are strengthened, Burundian farmers who prefer using hermetic sacks will have more options.

Take-home message

- Locally available plastic bottles and jerry cans are almost universally available hermetic storage options, while the strength of PICS and GrainPro supply chains is currently limited and varies regionally.

Economics of hermetic seed storage

Storage begins with the assumption that farmers have selected high quality seeds after harvest – poor quality seed from the start will not improve with storage. After seed quality is assured, evaluating the economic advantages of hermetic seed storage requires asking several key questions. The following inquiries may be a starting point:

- ? What are the losses during storage with current practices?
    - Do farmers understand these losses?
- ? How much seed must farmers purchase at planting time (at elevated prices) because they did not take the risk of storing or had to replace seed lost to pests and rotting?
- ? Do farmers still plant seed damaged in storage? If so, what negative effect does this have on resulting germination and plant vigor?
- ? Do farmers increase seeding rates due to damage in storage? If so, what is the wasted cost of this extra seed over the entire planting area?
- ? What is the cost of alternative hermetic options compared to current practices?

Benefits of hermetic storage which provide economic advantages to farmers include:

- Reduced physical losses,
- Ability to sell seed (and grain) over a longer period and achieve a better price,
- Improved quality of seed leading to lower seeding rates,
- Improved plant vigor, and – ultimately – improved yields.

Examples of economically advantageous hermetic storage range from cowpea seed in Burkina Faso, bean seed in Burundi, maize seed in Timor Leste, to pigeon pea seed in India. The CRS experience from Burkina Faso, outlined in the included case study, demonstrates that large PICS sacks have a significantly lower cost per kilogram stored than locally available containers. It should be noted that the average life span of the PICS and GrainPro bags is 2–3 years, which means that they must be replaced more frequently than most local containers. Hence, supply chain management becomes paramount to increase the availability of cost effective options for small producers. Figure 6 illustrates the storage cost per kg using different containers.

Concerning hermetic pigeon pea seed storage, Vales et al. (2013) compared storage in PICS and gunny sacks. There is a reported 1% bruchid infestation with PICS compared to 17% infestation in gunny sacks. They also report 88% germination in PICS compared to 69% in gunny sacks and increased seedling vigor in PICS, measured as increased length of the seedling radicle and plumule.

The best recorded economic investment in hermetic storage is with pulses – especially cowpea and pigeon-pea. The reason is that these crops are often devastated by bruchids and it is common for a farmer to lose 50% or more of these stored pulses when using traditional (non-hermetic/no use of pesticides) methods (Baributsa et al., 2010). Additionally, high value crops like cowpea can more than double in price, economically outperforming lower value maize storage. While maize also shows good results, they are not nearly as strong as the pulses (Jones et al., 2011). The economic benefits of hermetic grain storage have not yet been thoroughly investigated for rice, wheat, pearl millet and sorghum seed in the semi-arid tropics, as well as for groundnuts when stored in the shell.

Figure 4: Unit (kg) cost of hermetic storage in Burkina Faso

Type	Number	Weight	Price (US$)	Price/kg (US$)
PICS	179	100	1.70	0.02
VegOil	22	25	3.00	0.12
VegOil	446	20	2.50	0.13
VegOil	2,115	5	1.24	0.25
Mineral Water	1,484	1.5	0.25	0.17

Take-home message

- The economic benefits of improved seed storage are largely derived from reduced physical losses, reduced seeding rates, increased germination and vigor, and ultimately higher yields. These benefits must be compared for each crop with the costs of new vs. traditional storage practices.

Recommendations for designing hermetic storage activities

Important steps for a successful seed storage extension or intervention effort should include:

- Implementing a seed system assessment with a focus on seed storage,
- Describing current on-farm seed storage of food security crops and diagnose problems,
- Selecting priority crop for seed storage,
- Selecting hermetic storage technology,
- Identifying leverage points for investment.

The seed system storage assessment should be used to describe and diagnose current farmer storage practices. It should evaluate seed quality and problems with insect damage and fungal damage due to high seed moisture. It should establish a baseline of the quantity of seed in crops stored, the percent loss in storage, and include the frequency of hermetic storage and use of insecticides (alone or in combination with hermetic storage).

With an extensive understanding of the function and benefits of hermetic storage and how it may improve the lives of local producers, your effort may be well on its way.

References

D. Baributsa, I. Baoua, and L.L. Murdock. 2013. Purdue Improved Cowpea Storage (PICS) Bag: Size Matters! *Purdue Extension Bulletin* #E-263-W. http://extension.entm.purdue.edu/publications/E-263.pdf

D. Baributsa, I. Baoua, J. Lowenberg-DeBoer, T. Abdoulaye, and L.L. Murdock. 2012. Purdue Improved Cowpea Storage (PICS) Technology. *Purdue Extension Bulletin* #E-262-W. http://extension.entm.purdue.edu/publications/E-262.pdf

Baributsa, D., Lowenberg-DeBoer, Murdock, L. and Moussa, B. Profitable chemical-free cowpea storage technology for smallholder farmers in Africa: opportunities and challenges. Paper presented at 10th International Working Conference on Stored Product Protection. Estoril, Portugal (2010). http://pub.jki.bund.de/index.php/JKA/article/view/1319/1364.

Louwaars, N. & W. de Boef (2012) Integrated Seed Sector Development in Africa: A Conceptual Framework for Creating Coherence Between Practices, Programs and Policy. *Journal of Crop Improvement* 26:39–59. Taylor & Francis.

De Groote, H., et al., Effectiveness of hermetic systems in controlling maize storage pests in Kenya, *Journal of Stored Products Research* (2013). http://dx.doi.org/10.1016/j.jspr.2013.01.001

García-Lara, S., Ortiz-Islas, S., Villers, P. Portable hermetic storage bag resistant to Prostephanustruncatus, Rhyzoperthadominica, and Callosobruchusmaculatus (2013). http://www.grainpro.com/pdf/2013%20SGBIV%20Resistant%20fm%20Silverio.pdf

Jones, M., Alexander, C., and Lowenberg-DeBoer, J. (2011). An Initial Investigation of the Potential for PICS Hermetic Storage to Improve Maize Incomes for Rural African Small-Holders. Working Paper 11–3, Dept. of Ag. Economics, Purdue University, West Lafayette, IN, USA, November, 2011. http://ageconsearch.umn.edu/bitstream/115554/2/11-3PICS.Maize-2.pdf

Murdock, L. L., Margam, V., Baoua, I., Balfe, S., & Shade, R. E. (2012). Death by desiccation: Effects of hermetic storage on cowpea bruchids. *Journal of Stored Products Research*, 49, 166–170.

Navarro, S.,Donahaye, J.E., Fishman, S. (1994). The Future of hemetic storage of dry grains in tropical and subtropical climates. Paper presented at 6th international Working Conference on Stored Product Protection. Canberra, Austalia. http://bru.gmprc.ksu.edu/proj/iwcspp/pdf2/6/130.pdf

Navarro, S., Donahaye, J.E., Miriam Rindner, Azrieli, A. and Dia, R. (1999). Protecting grain without pesticides at farm level in the tropics (example of hermetic technology). Pp. 353–363. http://ftic.biz/pdf/1999aNavarro%20protecting%20grain%20QAAP.pdf

Quezada, M. Y., J. Moreno, M.E. Vázquez, M. Mendoza, A. Méndex-Albores, E. Moreno-Martínez (2006). Hermetic storage system preventing the proliferation of Prostephanustruncatus Horn and storage fungi in maize with different moisture contents. *Postharvest Biology and Technology*. 39: 321–326.

Vales, M.I. et al. (2013 in press) Effective and Economic Storage of Pigeonpea Seed in Triple Layer Plastic Bags. *Journal of Stored Products Research*.

Villers, P., Navarro, S., and de Bruin, T. (2008).Development of Hermetic Storage Technology in Sealed Flexible Storage Structures.CAF 2008. Conference Paper Presented for the Controlled Atmosphere and Fumigation Conference, Chengdu, China, September 21–26. http://www.grainpro.com/pdf/PU2015PV0708-CHENGDU-PAPER-CAF-Presentation-Development-of-Hermetic-Storage-Technology.pdf

Weinburg, Z.G., Y. Yan, Y. Chen, S. Finkelman, G. Ashbell, and S. Navarro (2007). The effect of moisture level on high-moisture maize (Zea mays L.) under hermetic storage conditions – in vitro studies. *Journal of Stored Products Research*. 44(2): 136–144.

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CRS CATHOLIC RELIEF SERVICES

BRIEF No. 3

Economics and Promotion

Insights for Program Design

Successfully promoting cost-effective seed storage technologies rests on the assumption that farmers make rational choices based on an understanding of the costs and benefits of different storage options. Benefits from reduced losses with improved seed storage mirror many benefits from reduced losses in grain storage. Additional unique benefits in seed storage include lower seed use (sowing rate) and better crop yield due to improved germination and vigor. Key factors in promoting seed storage include demonstrations of the technology, use of subsidies and collaborating with public and private actors.

Introduction: Intervening in post-harvest systems in developing countries

Post-harvest aid interventions in developing countries have generally been clustered in two phases. Initial development assistance focused on central storage systems and quality control at purchase points (Hall 1969). Later aid trends placed emphasis on marketable surplus and improving traditional post-harvest practices (De Lima 1975, 1987). Both types of interventions gave prime attention to technical solutions rather than underscoring the social and economic basis for post-harvest practices.

Supporting post-harvest seed and grain technologies may appear economically beneficial at the design phase of a project and even during the project phase when there are subsidies provided to producers, suppliers, and consumers for post-harvest technologies.[1] However, when subsidies and project support ends, consumer demand and adoption of the technology can falter and the supply chain for the technology may also fail. This occurs when post-harvest technology cannot be produced or supplied profitably to the farmer without the subsidy or when the farmer cannot afford the cost of the post-harvest technology without the subsidy. Several of the cases studies financed in the On-Farm Seed Storage Project (see *introductory brief*) involved subsidies and are examined in the following pages. While it may be premature to assess the sustainability of these seed and grain storage technologies and project approaches, the significant levels of the subsidies could prove problematic to transfer onto producers and consumers post-project.

Farmers may reject a technology for a combination of economic and social reasons. Also, the local environmental conditions and enabling environment may be insufficient. A key weakness in the design of many post-harvest initiatives is that the benefits do not accrue fast enough for participants to recognize the value of the technology. Farmers may also not recognize or be willing to accept the associated investments of time and money needed to continue with the technology.

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[1] *In this brief, we focus on the material aspects of seed storage technology. Technology as a concept also has an equally strong knowledge component: e.g., how to use improved practices, if they are effective, if the user finds such practices acceptable.*

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Key message

- Improved storage technologies may be technically effective but not economically viable. In both the short and the long term, any technical gains have to be weighed against other factors which may affect technology use and function. Key is whether farmers are willing to absorb costs, when subsidies are withdrawn, and whether the environment exists to sustain the technology when a project ends.

Helping farmers to understand the cost and benefit of grain and seed storage technology

For technology to be adopted, farmers need to understand how to use the technology, and how to quantify its benefits. NGOs and practitioners can help farmers make decisions on whether and when to invest in new technologies based on sound economic analysis of the opportunities and challenges of the investment.

With the right information, economic assessment of grain and seed storage can be estimated before and measured exactly after the technology introduction. Returns to farmers for seed and grain storage are similar, with seed requiring a few extra considerations. As seed and grain are stored together for many crops, it is often difficult to separate seed from grain in a cost benefit analysis. Estimating dry weight loss, quality loss, and price gain per unit of stored seed/grain are major factors for determining economic benefits of new technologies. These need to be balanced against the cost of the technology, i.e., money, labor, and in-kind contribution.

Largely ignored by practitioners but vitally important to farmers, one must also consider the opportunity cost (or time-value) of money during the storage period. This is the cost to finance storage as opposed to selling the seed/grain immediately after harvest. (Note also that prices markedly dip just at harvest, as opposed to selling later, so there are numerous factors to balance.) By not selling after harvest and deciding to store, a farmer effectively loans himself the money that he could have made selling the grain early. He could have used this revenue for many things such as school fees, health care or investments in other income generating activities (such as animal rearing), and therefore the time value of this money must be taken into account. Incorporating the methods from Jones, Alexander, and Lowenberg-DeBoer (2014), it is possible for practitioners, in consultation with farmers, to *plan ahead* which variables will be necessary for analysis and *execute* a before-and-after assessment of economic benefits to storage.

Fundamental questions to ask for an economic analysis regarding stores and market conditions:

A series of basic questions can help orient initial economic analysis relatively quickly:

- **Overview storage plan**

? What is the immediate price of the commodity at harvest (base price) and what is the price after the storage period (i.e., in the planting season, after prices typically rise)?

? What is the length of the desired storage period (i.e., how many months)?

? What quantity (kg) does the farmer need to store?

These questions can tell you how much of a *total value* increase the grain stock could have if well preserved. We will use an Ethiopian pit storage case study as an example for calculation (case referenced in *introductory brief*). Sorghum prices are noted in the intervention period to increase from US $0.189/kg to about US $0.405/kg eight months later. This is a 114% increase in price. Farmers in the trial for new Pit Storage Bags, a plastic liner impeding typical grain losses from moisture and mold contamination, store about two metric tons (2000 kg) of grain after harvest. Therefore the value of the grain is US $378 (2000 * 0.189) at harvest, which rises to US $810 (2000 * 0.405) after eight months of storage. This is a revenue increase of US $432.

In reality, a farmer may not sell 100% at harvest or 100% in the period of the best prices (typically after significant storage, before the following harvest). Rather, many farmers sell smaller quantities as cash is needed. The simplified example above should be used as an illustration to help farmers assess their maximum potential earnings with storage. A more incremental approach to calculating the return on investment may be necessary to reflect more realistic selling practices.

Next, questions regarding the cost and performance of old and new storage technologies should be considered:

- **Old Technology**

? What is the total cost, per year, of the old technology? (materials + labor)

? What are the weight (kg) losses (%) in the storage period using the old technology?

? Is there a price reduction (%) for remaining grain that has visible damage compared to clean grain? (i.e., is the price $0.30/kg for clean undamaged grain, and 10 to 20% lower for grain with the damage level allowed by this technology?)

- **New Technology**

? What is the total cost, per year, of the new technology? (materials + labor)

? What are the weight (kg) losses (%) in the storage period with the new technology?

? Is there a price reduction (%) for remaining grain that has visible damage (compared to clean grain)?

The cost of the technology should include all materials and labor (e.g., digging pits) and should depreciate for the number of years of useful life. If insecticide is applied to bagged maize, then one must consider both the cost of the insecticide and the cost of the bags used. NOTE: It is important to remember, for example, that even if a US $100 metal silo can be used for 15–20 years, the depreciated cost per year ($5–7) may not reflect the difficulty for many cash- and credit-constrained farmers to pay this large US $100 sum up-front.

The effectiveness of the technology to preserve grain quality considers both components of revenue, namely quantity and price. Weight (quantity) loss occurs, for example, as storage begins with a 100kg bag of maize and then, after six months of storage and insect infestation, the bag weighs 95kg. Price loss occurs when damaged

Key message

- Practitioners must start by understanding the losses incurred by farmers and the value of these losses to the farmer. They must plan ahead to ensure they are collecting the basic economic variables needed to provide proper economic evidence of technology benefits. This includes physical loss and quality (price) loss in grain/seed with both old and new technologies as well as the relative costs of those technologies (i.e., the cost of investing in the new technology relative to the cost of investing in the old technology). Also important is the change in price of grain/legumes from harvest to planting during storage. If this does not occur, the economic value of the post-harvest technology can be greatly over or understated and this has ramifications for technology design, promotion, and ultimately level of adoption.

grain is not offered the same price as undamaged grain. In Ghana, maize with 20% damaged grains after many months of storage was shown to receive about a 15% lower price than undamaged maize (Compton et al., 1998). Additionally, a key point in the Burundi case study (listed in the introductory brief) is that hermetically stored, high quality bean seed received a premium price – indicating that quality is appreciated and rewarded in the market.

Computing the financial and economic returns to storage technology

Here we share an example (a theoretical one) of how financial and economic returns in the use of a given technology might be practically computed. (Example from Compton et al., 1998).

Assume a farmer has 500kg of maize and currently uses a storage technology (like insecticides) that allows 5% weight loss and results in a 15% lower price for the remaining damaged maize. After storage, this farmer would have a final revenue of:

Quantity after storage loss: (500kg - 25kg [5% weight loss]) = 475kg

Price after storage loss: ($0.30/kg - $0.045/kg [15% price loss]) = $0.255/kg

Revenue after storage loss: ($475/kg x $0.255/kg) = $121.13

This $121.13 in revenue with damaged grain compares to $150 if no losses occurred. Therefore the *total value loss* is not just the 5% in weight loss. For a marketing producer it is the combined (compounded) loss in price and quantity that, in this example, is actually 19.25% total value loss.[2]

The cost of the new (more effective) technology is then compared to see if the benefits of preventing this storage loss exceed the costs of the storage investment. This should be explained to farmers in a simple way to help them understand how they may be experiencing losses in both quantity and price with older technologies. They will then have more information to decide whether adopting a new technology that reduces these losses will be more profitable.

The percent return which farmers make on their storage investment should be calculated for each possible technology. The equation is as follows:

$$\textbf{Financial Rate of Return (\%)} = \frac{\textbf{(Potential Revenue at Harvest - Revenue after Storage)}}{\textbf{(Potential Revenue at Harvest + Storage and Marketing Costs)}}$$

A final important consideration is the *time value* of money, also known as the rate of opportunity cost of capital (OCC) or the discount rate. You may also think of this as the rate of interest on a loan. While OCC rates in developed economies are generally estimated at about 2–10%, the low credit availability in most developing countries requires a much higher OCC rate. Informal annual interest rates in developing countries may be 25–50%, and in some cases up to 100% (Buckley 1997; Stewart et al., 2010). Poorer farmers most likely face higher OCC rates. Hence, as a test, it is more robust to use 25% OCC for better-off farmers and even 50% OCC for poorer farmers. If storing for six months, then the simplified *annual* OCC rate of 25% or 50% would be discounted by half (6/12 months = 1/2). The procedure to determine economic returns on storage, considering this time value of money, is as follows:

$$\textbf{Economic Rate of Return (\%) = Financial Rate of Return (\%) - Annual rate of OCC (\%) * ((months of storage)/12)}$$

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[2] *This is computed as (100% - 5%) * (100% - 15%) = (95%) * (85%) = 80.75% of retained value OCC (%) * ((months of storage)/12)*

The economic rate of return for each technology should be above zero to recommend this technology for income generating purposes. This positive value means it has broken the "profitability threshold" described by each level of OCC. If the economic return is below zero, this means the farmer should not invest in the storage technology and should consider other investment possibilities to earn income (such as livestock rearing). It is important to remember that new technologies may be efficient in reducing losses, but may not be worth the investment. Farmers may be better off selling grain immediately at harvest than making a storage investment and waiting six to nine months to achieve a return (especially those with higher OCCs).

The economic rate of return of both the old and new technology should be compared to see which is higher, and therefore, which is more profitable for farmers. For example, in the Ethiopian storage pit case study, both the old and new technology had positive economic returns of under 25% and 50% OCC using old and new technologies respectively. This means grain storage could be profitable, even considering the time value of money, with fairly high losses using old technologies and with very low losses using new technologies. The new technology clearly outperformed the old technology, however, and the increased cost of investment was justified given the comparative economic advantage. This advantage was apparent even without information on price discounts, which would have further underscored the benefits of increased storage protection. For a detailed example of one profitability determination, see Table 1 (with Appendix 1 showing the actual formulas for calculations).

Table 1: Simplified spreadsheet example for use in data analysis software (such as Microsoft Excel)

	Sell at Harvest	Storage Product A	Storage Product B
Harvest (kg)	100	100	100
Months stored	–	6.0	6.0
Dry weight losses (%)	–	2.0%	5.0%
Quantity marketed (kg)	100	98	95
Price at harvest ($/kg)	0.30		
Commodity price for clean, undamaged grain after storage period ($/kg)		0.50	0.50
Total price discount for grain damage present (compared to clean grain) (%)	–	5.0%	20.0%
Final price received after storage ($/kg)		0.48	0.40
Commodity revenue ($)	30.00	46.55	38.00
Total technology cost (for total quantity stored for entire storage period) ($)	–	3.00	1.00
Rate of OCC (ex. 25% or 50%)	–	25%	25%
Total OCC adjustment ($)	–	4.13	3.88
Economic gain on storage ($)	–	9.43	3.13
Economic return to storage (%)	–	28.6%	10.1%

Source: Adapted from Jones, Alexander, and Lowenberg-DeBoer (2014).

Key message

- Total value losses considering quality (price) loss can greatly exceed physical loss and indicate greater benefits of storage technologies. Financial rates of return and economic rates of return (considering the time value of money) can be easily computed given adequate information. Practitioners can help farmers make investment decisions based on sound financial and economic analysis.

Computing returns on storage investment (for seed)

The returns on seed storage are computed the same as above, with the addition of improved germination, plant vigor, and yield values. Resulting yields (of the same seed) stored using old and new storage technologies may be tested, though significant care is necessary to provide the exact same growing conditions to isolate the effect of the seed management. The value of this yield increase can be quantified using market grain prices. The resulting yield gains from maintaining undamaged and high quality seed may drastically exceed the monetary cost of preserving the seed grain itself. An economic benefit may also be evidenced in reduced sowing rates. This latter value can be quantified by using the quantity saved and the prevailing price for seed of that quality.

As illustrated by the profitability equations, estimating returns on storage can be difficult and such analysis may be conducted poorly by practitioners. Typically the returns are grossly overestimated because the opportunity cost of capital – the cost of not selling seed or grain at harvest as opposed to selling or using it many months later – is not factored into the analysis to reduce the estimated benefits. Before helping farmers to understand the benefit of a technology, the sponsoring and implementing organizations should do a simple but careful scenario analysis to estimate returns under different contexts.

Key message

- Economic returns on seed storage should significantly exceed returns for grain storage due to the multiplying effect of improved germination, vigor, and resulting yields. However, these returns can be difficult to quantify as the analysis requires collecting data over several seasons and, for some crops, multiple years. Sometimes, simple proxies like qualitative assessments of changes in seed security and seed quality among participating farmers, may give more useful insights than efforts to quantify precise returns to seed storage.

Promoting storage technology

The discussion of storage technology is often driven from an engineering and economic perspective and much less a social perspective. We should remember that culture plays a significant role in linking technology and society. How technologies are identified and adopted takes into account the economic as well as the political, social and cultural dynamics. A first step in the direction of identifying appropriate technologies is to explore which particular parties and interests are mobilized around change or adherence to specific technologies. The final selection of a technology cannot be reduced to the single interest of one actor, but instead results from a dynamic balance of power among and between a range of social actors.

Training, communication, and effective demonstrations

For farmers to adopt a technology they need to understand how to use the technology. The more common means of familiarization include: hands-on direct training for farmers; promotion and media campaigns; and technology demonstrations. The case studies united under the On-Farm Seed Storage Project (full list, *introductory brief*) describe how direct farmer training and demonstration of the technologies were key activities of the project. However, it is difficult to assess the extent to which training and demonstrations enabled farmers to understand how to properly use the technology (for example, how to maintain a hermetic seal and its importance) or to value the benefits of the technology (for example, the impact on germination and yield from well stored seed).

A summary of some key activities to promote grain and seed technology is found in Table 2. Direct farmer training refers to classic farmer training based on a structured curriculum and involving a series of related training events.

Promotion and media campaigns refer to activities that communicate the storage technology and its benefits. Technology demonstration refers to a set of discrete activities that may be a sub-set of farmer training, and which puts emphasis on assessing the benefit of a storage technology – that is, letting farmers observe directly some of the concrete results.

Table 2: Common means for promoting grain and seed storage technology

	Direct Farmer Training	Promotion & Media Campaigns	Technology Demonstration
Key Question	Is the technology understood and contextually appropriate? Can farmers manipulate the technology to achieve its maximum benefit?	Are famers aware of the technology? Do farmers know where to go to get more information?	Do farmers grasp the potential benefits of the technology?
Key Outcome	A critical mass of farmers are exposed to and trained on the storage technology.	Farmers demand more information about the technology and make follow-up inquiries to key informants based on the ad campaign.	Farmers see, and implicitly and explicitly understand the benefits and value of the technology.

Technology demonstrations may be difficult to conceptualize and execute but can be very effective in creating farmer demand for information relative to a technology and for the technology itself. For seed storage technology, the most common means of demonstration is to compare germination rates of seed selected, handled, and stored with the new technology with rates of seed managed under the standard technology. Effort should be made to employ these demonstrations effectively, that is, to record carefully the different germination rates and resulting yields. These comparisons provide critical information in determining the success of a seed storage program.

Key message

- For farmers to adopt a technology, they need to understand how to use the technology and value the benefits. The more common means of familiarization include: hands-on direct training of farmers, promotion and media campaigns, and technology demonstrations. Storage technology benefits accrue over time, and discrete, well-organized trials showing reduction in post-harvest loss, improvement in germination and improvement in yield are all necessary for farmers to appreciate the value of the benefits of improved grain and seed storage.

Using subsidies to create demand-side interest and supply-side incentives

Subsidies can promote access for a new technology by directly subsidizing consumers through vouchers to stimulate demand. Subsidies can also be used to promote availability of a new technology by providing a direct subsidy to a manufacturer/producer in order to stimulate supply by lowering the cost of production, and thus, lowering the price. It is common for subsidies in agriculture programs to include both demand- and supply-side subsidies. The challenge is to identify the optimal point for both the demand- or supply-side subsidy. If employed, the subsidy should be enough to stimulate demand and supply, and the functioning of a value chain for the goods and services subsidized, but not too much as to lead to a market failure when the subsidies are reduced or terminated. Country-based projects of the On-Farm Seed Storage Project made use of rather high subsidies for some of its storage technologies (Table 3). The projects focused principally on proof of concept in technical design rather than on issues of cost recovery and sustainability. Programs aiming principally for longevity would probably make more conservative use of subsidies.

Table 3: Summary of On-Farm Seed Storage Project interventions and subsidy use

Country	Description of technology	Estimated total cost (in US$) of technology – labor and materials	Percentage of technology cost subsidized by project – estimate
Afghanistan	Ventilated underground pit for potatoes	22	35
Ethiopia	Above-ground improved storage with modifications for maize and sorghum	100	50
Timor-Leste	Meta drum for maize	35	80
Burundi	Variety of hermetic storage products – the main one being PICS sacks (multi-layer, made of 2 polyethylene liners and one outside woven polypropylene bag)	2	100
Burkina Faso	Variety of hermetic storage products – the main one being PICS sacks (multi-layer, made of 2 polyethylene liners and one outside woven polypropylene bag)	2	100

Voucher schemes, by which storage technologies are partially paid for by a voucher provided by the implementing NGO, were a common feature in all of the On-Farm Seed Storage Project case studies. Studies on vouchers and demand-side subsidies consistently underline the need for effective targeting mechanisms to ensure that voucher schemes benefit a specific set (i.e., specific demographic) of non-users of the technology. Without careful attention to targeting, vouchers could be unintentionally skewed to reward certain farmers or be deliberately allocated in ways that strengthen existing power relations and/or favor specific political interests. Demand-side subsidy schemes should have transparent mechanisms and a degree of 'ritual' – in design and implementation approach – to garner support and buy-in from local customary institutions. A valuable means to assess the extent of technology uptake and scaling potential is to track the percent of farmers (and their demographics) that pays full price for the technology or adopts the technology without receiving a clear subsidy. Storage investments that have significant upfront costs, such as the improved crib concept by GOAL Ethiopia (about US $100 per unit), may present significant cash flow challenges. Cost challenges can be alleviated to some extent by credit programs such as internal savings and lending schemes which help some farmers acquire capital to make storage investments.

Supply-side subsidies – i.e., covering part of the production, marketing, and demonstration costs of seed storage manufacturers or seed storage technology vendors – were also used in all of the project case studies. It is difficult to say at what point a supply-side subsidy actually undermines market development for the technology or whether the subsidy should be built into production, marketing, and demonstration costs of the producer/vendor, or whether the subsidy should be applied to buyers (via voucher, for example). Yet all these issues and options present important considerations for practitioners in program design. Internal savings and lending schemes can also be implemented to address potential capital constraints for entrepreneurs in the storage business (as producers or suppliers of storage technologies).

Key message

- Direct subsidies are targeted at consumers through vouchers and/or targeted at manufacturers to help reduce costs of production, marketing or demonstrations. Subsidies can significantly help technology promotion and adoption in the near term, but an abuse of or dependence on subsidies will damage the potential for long-term viability.

Collaborating pluralistically – developing healthy and effective public and private partnerships

Pluralistic agricultural advisory services refer to the emergence of a variety of service providers, formed as a result of public–private partnerships such as through contracts to the private sector partner and non-governmental organizations (NGOs). Creating synergies among a variety of agencies and actors involved in agricultural development has come to the forefront as technology promotion becomes more linked to values such as decentralization, cost recovery, and commercialization.

Pluralism, in principle, may overcome constraints in funding and expertise. However, in practice, pluralism requires not simply common interests and sharing of knowledge, but practical inter-agency coordination. Initial areas of action which need to be coordinated are outlined in Table 4. To function pluralistically and leverage the resources of other actors, it is necessary to have a basic understanding of the wider systems in which agricultural knowledge and innovations are generated, disseminated, and adopted by farmers. Based on this wider understanding, points of synergy with particular seed storage technologies can be identified and these leverage points can be built into project design.

Table 4: Framework for assessing pluralistic collaboration with on-farm seed storage technology

Central Element	Key Question
Resources	Have practical procedures for planning, priority setting, and coordination with a variety of agricultural service providers been defined?
Information	To what extent have the benefits of the storage technologies been communicated with the diverse stakeholders / agricultural service providers?
Decision-Making	To what extent is the technology and program intervention an iterative process, that is, flexible and responsive to emerging needs and opportunities?
Delivery Mechanisms	To what extent does the technology and program intervention focus on more generalized asset production and transfer versus context-specific knowledge provision?
Accountability	To what extent is the technology and its promoters accountable to farmers and how can this accountability be strengthened?

Key message

- Pluralistic collaboration through public-private partnerships can be an advantageous way to promote farm technologies. However, synergies and leverage points must be explicitly identified in project design.

This brief has reviewed in considerable detail the processes for calculating costs and returns of seed and grain storage technology. It has also focused on the varied and pluralistic mechanisms for promoting seed storage widely among farmers. In both themes, the main message is clear. Farmers need transparent and comprehensible information in order to make rational adoption decisions. Use of a storage technology goes well beyond its technical effectiveness. Farmers need to know if the technology will pay off – in the short and long term – and eventually without subsidy.

References

Birner, Regina, Kristin Davis, John Pender, Ephraim Nkonya, et al., 2006. From Best Practice to Best Fit: A Framework for Designing and Analyzing Pluralistic Agricultural Advisory Services. IFPRI Discussion Paper 37. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/sites/default/files/publications/rb04.pdf

Buckley, G., 1997. Microfinance in Africa: Is it either the problem or the solution? *World Development* 25, 1081–1997.

Compton, J.A.F., Floyd, S., Magrath, P.A., Addo, S., Gbedevi, S. R., Agbo, B., Bokor, G., Amekupe S., Motey, Z., Penni, H. and Kumi, S., 1998. Involving grain traders in determining the effect of post-harvest insect damage on the price of maize in African markets. Crop Protection 17, 483–489.

De Lima, C.P.F. 1987. Insects, Pests, and Post Harvest Problems in Tropics. Insect Science and Its Applications, 8, p. 673–678.

Giel, Ton., 2013. Financing Innovation at the Smallholder Level. http://www.capacity.org/capacity/opencms/en/topics/gender-and-social-inclusion/financing-innovation-at-the-smallholder-level.html. Article is based on Ton, G., de Grip, K., Klerkx, L., Rau, M.L., Douma, M., Friis-Hansen, E., Triomphe, B., Waters-Bayer, A. and Wongtschowski, M. 2013. Effectiveness of Innovation Grants to Smallholder Agricultural Producers: An Explorative Systematic Review.

GFRAS, 2012. The New Extensionist: Roles, Strategies, and Capacities to Reduce Hunger and Poverty. http://www.gfras.org/images/activities/new_extensionist/GFRAS_NEW_EXTENSIONIST-Position-Paper_copy.pdf

Hall, D.W., 1969. Food Storage in Developing Countries. *Journal of the Royal Society of Arts*, 1969, p. 562–579.

Jansen, K. and Vellema, S. What is technography? NJAS – Wageningen *Journal of Life Sciences,* Volume 57, Issues 3–4, February 2011, Pages 169–177.

Jones, M., Alexander, C., and Lowenberg-DeBoer, J., 2014. A simple methodology for measuring profitability of on-farm storage pest management in developing countries. *Journal of Stored Products Research*. (Forthcoming).

Stewart, R., Van Rooyen, C., Dickson, K., Majoro, M., De Wet, T., 2010. What is the impact of micro-finance on poor people? A systematic review of evidence from Sub-Saharan Africa. Technical Report, EPPI-Centre, Social Science Research Unit, Institute of Education, University of London (ISBN: 978-1-907345-04-3).

Appendix 1: Brief 3 – Storage Technology Financial Analysis Table Template for Microsoft Excel

The worksheet below presents in greater detail a framework for comparing costs and returns of using one storage product or another. The template suggested has been designed for use with Microsoft Excel.

	A	B	C	D	E
1		Sell at Harvest	Storage Product A	Storage Product B	Explanation of Formula
2	Harvest (kg)				enter as parameter for each technology
3	Months stored	–			enter as parameter for each technology
4	Dry weight losses (%)	–			enter as parameter for each technology; weight loss in grain from beginning to end of storage period
5	Quantity marketed (kg)	=B2	=C2*(1-C4)	=D2*(1-D4)	calculates remaining grain weight left after dry weight losses
6	Price at harvest ($/kg)				enter as parameter for selling at harvest
7	Commodity price for clean, undamaged grain after storage period ($/kg)				enter as parameter at point of time after each technology's storage period; meant to compare price for top quality grain with price of lower quality (damaged) grain
8	Total price discount for grain damage present (compared to clean grain) (%)	–			enter as parameter for each technology; if top quality grain is $0.20/kg and the Storage Tech. A grain sample is valued at $0.18/kg, then enter «10%» discount; if same price is the same as top quality grain then simply enter «0%»
9	Final price received after storage ($/kg)		=C7*(1-C8)	=D7*(1-D8)	calculates technology grain sample price with discount applied; redundant if final price known with certainty, but useful when only a known discount formula is available to estimate (ex. Compton et al. (1998) estimates a 0.75% price discount for every 1% grain damage in Ghanaian maize)
10	Commodity revenue ($)	=B5*B6	=C5*C9	=D5*D9	calculates final grain weight times final grain price (Revenue = Price x Quantity)
11	Total technology cost (for total quantity stored for entire storage period) ($)	–			enter parameter for each technology, depreciated for storage period
12	Rate of OCC (ex. 25% or 50%)	–			enter parameter for each population; see text explanation; could represent the annual interest rate on a loan in that area or expected percent annual gain from investment in other activities like livestock
13	Total OCC Adjustment ($)	–	=C12*(C3/12)*(B10+C11)	=D12*(D3/12)*(B10+D11)	calculates the adjustment necessary to incorporate the time value of money invested by purchasing storage technology and the grain value of harvest (and not investing that money somewhere else during the harvest months)
14	Economic return on storage ($)	–	=C10-B10-C11-C13	=D10-B10-D11-D13	calculates the net economic gain the farmer receives, after costs and adjusting for the time value of money
15	Economic return on storage (%)	–	=C14/(B10+C11)	=D14/(B10+D11)	calculates the percent gain (return) on the storage investment

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