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.

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.

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.

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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

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.

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.

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.

[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.

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