# Seed Storage in the Tropics under Gastight Sealed Conditions

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*Abstract*

The viability of seeds stored in gastight sealed structures in the open, under modified atmospheres, in tropical and subtropical climates was investigated. The essential advantage of sealed storage lies in the generation of an oxygen-depleted and carbon dioxide enriched intergranular atmosphere of the storage ecosystem to arrest insect development. In addition, the sealed storage prevents ingress of moisture into the already dry seeds when the ambient humidity of the surrounding environment rises. The two types of structures investigated were: a) frameless flexible envelopes for bagged grain (Volcani Cubes) of 5 to 150 tonnes; and b) a granary (GrainSafe) to hold 540 kg of cereal grain.

Under tropical conditions, when grain is stored in the open with no shade, ambient diurnal temperature fluctuations can create temperature gradients within the stack that cause convection currents to carry moisture to the upper layers of grain. In the granary a protective roof diminishes the effect of temperature gradients. However, to overcome this effect in the flexible envelopes, the use of a shade screen placed above the structure was investigated. This material described as a knitted thermal screen is formed from aluminum coated high-density polyethylene threads. Trials in Israel and the Philippines showed that the shade screens had a strong attenuating influence on temperature gradients. For dry paddy seeds, it was shown that after five months storage under a shade screen, no perceptible increase in moisture content was found at the top of the stack and the seeds remained in good condition. Under tropical climates this solution enables safe storage of maize and paddy seeds. Trials conducted with these two types of structures in tropical and subtropical climates showed that seeds are protected under sealed storage by maintaining the number of live insects below the threshold of economic damage without the need for pesticides.

PREVENTION of seed deterioration and degradation of their germination power under tropical climates is a difficult task. Molds and insects are the primary agents that reduce seed quality and lower germination power (Roberts, 1974).

Control of fungi can be achieved either by storage of seeds at low moisture content and temperature or by mold inhibitors (Christensen and Sauer, 1982). The use of grain preservatives, such as propionic acid, is restricted to feed grains since acid treatments destroy seed viability. Attempts have been made to show that some common fungicides reduce mould growth on maize seeds stored up to 16% moisture content by preserving seed viability longer than in untreated seeds (Moreno and Ramirez, 1985). The use of hermetic storage to preserve quality of maize seeds was investigated by Moreno *et al.* (1988). Hermetic storage of seeds modifies the atmospheric composition surrounding them by depleting the oxygen through insect, mould and seed respiration. The atmosphere within the storage container therefore becomes insecticidal, fungistatic or fungicidal. Moreno *et al.* (1988), showed that maize seeds with high or low moisture content were not invaded by fungi when stored under hermetic conditions and they maintained a higher viability than seeds with similar moisture contents not stored hermetically.

Seeds stored at moisture contents in equilibrium with relative humidities below 65% are not damaged by storage fungi since these organisms require higher moisture contents (Lacey *et al.*, 1980). Generally, the lower the moisture content and the lower the temperature, the longer the seed can be stored (Copeland and McDonald, 1985).

Under the high humidity of the tropics, microflora commonly invade stored seeds (Mendoza *et al.*, 1982). When stored in exposed structures, even in seeds with adequate moisture content to prevent deterioration, the condensation phenomenon causes their moisture to increase and the germination to decrease.

Studies have shown that the lower the temperature (within certain limits), the longer the seeds maintain their viability. A rule of thumb was proposed (Harrington, 1973) where the relationship between seed longevity and the seed temperature and moisture is expressed arithmetically. This rule states that a seed's life span in storage is doubled for each 5°C decrease in temperature (within the range of 0°C to 50°C) and for each 1 percent decrease in seed moisture (within the range of 5 to 14%). However, storage of seeds at low temperatures in the tropics is costly and the use of permanent storage structures such as cold storage may not be available or affordable for farmers due to the high investment cost. Therefore, the problems of maintaining seed viability in storage have always been an important concern to farmers and seed growers in the developing countries due to inadequate storage facilities.

In tropical climates, even when seeds are protected from the ambient humidity, if the structure is not well sealed and treated against pests using fumigants, insects can develop and cause damage (Semple, 1985). Although phosphine is the fumigant of choice for most applications especially under tropical climates, development of resistance to this fumigant has jeopardized its continued use (Zettler, 1997). Also there have been objective limitations to the use of phosphine such as its availability, and its effective and safe application in the rural communities of developing countries.

Under hermetic storage conditions, storage insects can develop a lethal storage atmosphere to themselves before they cause damage to the germination of seeds. Predictive models have been developed to determine the response of insects to gastightness levels (Navarro *et al.*, 1994).

A phenomenon that discourages the use of airtight storage in hot climates is moisture migration and condensation that is especially accentuated in metal silos. So far, two approaches are known to reduce the intensity of this phenomenon: equalizing grain temperatures, and insulation of the roof. Equalizing grain temperatures by aeration is limited to climates with a cool season. Comparative data on the efficacy of aeration and the effect of insulation in preventing moisture migration in metal silos in the tropics, is lacking.

Above ground silos (concrete and metal) have been constructed with specifications to provide a seal for hermetic storage. Earlier designs did not provide a sufficiently effective seal (De Lima, 1980). The present approach to sealing existing above ground structures is more successful (Ripp *et al.*, 1984).

Plastic structures suitable for long-term storage systems, as well as intermediate grain storage for cooperatives and subsistence farmers for the storage of grain in bags or in bulk have been developed in Israel (Navarro *et al.*, 1990). For small-scale applications these plastic structures use flexible liners. The influence of insulation materials in reducing the intensity of moisture migration in subtropical (Israel) and tropical (Philippines) climates has been investigated (Navarro and Caliboso, 1996).

To overcome condensation that may occur in tropical climates a recent development has been the use of a reflective cover that reduces the intensity of temperature gradients (Donahaye *et al.*, 2000). Preliminary results provided encouraging data on the applicability of such an approach.

In the present report, tests carried out on grain stored outdoors in gastight structures will be summarized to demonstrate the feasibility of the hermetic storage technology in maintaining seed viability.

## Materials and Methods

### Frameless Flexible Cube-shaped Envelopes (Volcani Cubes Termed also GrainPro Cocoons)

Frameless flexible cube-shaped envelopes (Volcani cubes termed also GrainPro Cocoons) were designed for stack storage, in which the stack itself forms the rigid structure of the system. The cube-shaped structures were planned for use on open ground, and under rigorous field conditions. The Volcani cubes consisted of two sections: a lower floor-wall and an upper roof-wall. Navarro *et al.* (2000) described these facilities for storage of small quantities of approximately 10 and 20 tonnes of bagged cereal grains. Experiments carried out to determine the viability of seeds stored in Cambodia, Israel, Philippines, and Thailand are reported in this paper. The tested seeds were corn (maize), paddy, and wheat stored under the warm climate conditions.

Viability of seeds, moisture content, and insect infestation were tested by taking samples from the bagged commodities before the start of the trials and at the end. The samples were taken from three layers of the stacks consisted the upper, middle and the bottom layer. Each layer was sampled from five locations; four sides of the layer and from the center. Therefore, results reported in this paper consisted average of 15 samples in each trial. In most trials a stack that served as control was stored in non-hermetic conditions next to the Volcani cube.

**Testing Effectiveness of Reflective Covers to Avert Condensation**

In a search to find an alternative inexpensive and convenient method of insulating the stack from diurnal temperature fluctuations, the use of a shade-providing awning consisting of "Polysac - Aluminet" was investigated. This material is described by the manufacturer as a knitted shade cloth for use as a thermal screen and formed from aluminum coated high density polyethylene threads. The trials described here were undertaken to study the effectiveness and applicability of these screens in protecting the grain stacks. In order to obtain preliminary data on the method, the first trials were carried out in Israel using a 10-ton capacity cube containing wheat. Later trials were carried out both in Israel and the Philippines.

**Sealed Granary (GrainSafe)**

The granary described, and for which patent application has been submitted, was developed over a series of previous trials during which, progressive modifications were carried out (Navarro *et al.*, 2000). It consisted of a cylindrical bag made from a PVC formulation, 110 cm high and 90 cm diameter (volume: 700L), equipped with an upper conical collapsible sleeve for in-loading the grain stored in bulk. Because of its smaller size compared to the Volcani cube, a potential for outdoor storage trials exists for demonstrating the feasibility of hermetic storage in protecting seeds from pest infestations and reducing or averting the intensity of condensation that may occur in tropical climates. Initial experiments were carried with corn (maize) but no viability data were generated.

## Results and Discussion

### Frameless Flexible Envelopes (Volcani Cubes or GrainPro Cocoons)

*Corn storage trials carried out in Thailand and in the Philippines*

Table 1 summarizes results of viability of corn stored under hermetic and non-hermetic conditions. Two trials were carried out in Thailand; one lasted for 90 days and the other 280 days. Throughout the trials, temperature of the corn stored under hermetic and non-hermetic conditions ranged between 27° and 31°C. Corn stored under hermetic conditions remained without infestation in both trials whereas the control stack of corn stored for 90 days became infested with *Sitophilus zeamais* and *Tribolium castaneum*. In the 280 days storage trial, the level of infestation in the control was heaviest. In addition to *S. zeamais* and *T. castaneum*, insect populations of *Rhyzopertha dominica* and *Cryptolestes pusillus* adults were also found. The number of insects was between 3 and 79 adults/kg of corn. The dramatic drop in germination in the control of 290 days storage could be attributed to the heavy infestation that developed in corn.

Viability of corn stored under hermetic (148 days storage) and non-hermetic (120 days storage) conditions in the Philippines did not indicate significant changes between the initial and final samples (Table 1). Recordings of mean weekly daytime temperatures revealed that temperatures inside the control stack kept under tarps was 28°C and those of the cubes were in the range of 29°C to 31°C. In the hermetic cube, the $CO_2$ level rapidly increased to 12% while the $O_2$ concentration sharply declined to around 7% over the first two weeks of storage. The insects found in corn were *S. zeamais, R. dominica, Oryzaephilus surinamensis, Latheticus oryzae, Lophocateres pusillus, Carpophilus* spp., *T. castaneum, Cryptolestes* spp., *Typhaea stercorea*, species of ants, crickets and cockroaches. No significant increase in population density of insects was noted in the hermetic sealed corn cubes, whereas the population in the control cubes increased considerably. The infesting populations were suppressed in the hermetic cube in comparison with populations that developed in the control stacks. In addition to insect infestation the control stacks suffered from mould infection and from rodent and bird attack. On the basis of viability tests, and insect infestations, storage under hermetic conditions was considered successful, in comparison with control stacks. (Navarro and Caliboso, 1996; Navarro *et al.*, 1998).

Corn seeds stored at moisture contents between 15.3% and 17.7% under hermetic conditions maintained a higher viability than seeds with similar moisture contents stored non-hermetically. Moreno *et al.* (1988) demonstrated this response of corn to hermetic conditions in the laboratory at 26°-27°C. Corn stored for 90 days at 15.3% moisture content, maintained a viability of 95% under hermetic conditions, compared to viability that dropped to 43% in samples kept under non-hermetic conditions. Corn seeds maintained 95% viability for 60 days storage under hermetic conditions while viability of the non-hermetic samples dropped to 23%. Although storage of seeds at higher moisture contents than the recommended critical levels for preservation of quality is not a common practice, it is clear that hermetic storage has a potential for better preservation than non-hermetic conditions. The feasibility of storing slightly wet seeds under hermetic conditions will need to be investigated using the hermetic storage technique in field trials. From the available information it is apparent that within certain limitations related to the duration of storage, hermetic storage could tolerate slightly moist seeds compared to non-hermetic conditions.

*Paddy storage trials carried out in the Philippines and in Cambodia*

Table 2 summarizes the results of viability of paddy stored under hermetic and non-hermetic conditions. Two trials were carried out in the Philippines, one lasted for 117 days and the other for 187 days. A similar pattern of temperature levels was observed in paddy stacks as in the corn trials. The average $CO_2$ concentrations recorded in the hermetic cubes of paddy were in the range of 10% to 15%. Initial and final counts of live insects revealed no population increase in the hermetic paddy cubes, whereas in the control stacks there was a marked increase in insect density, many of which were alive at the end of the storage period (Navarro and Caliboso, 1996; Navarro *et al.*, 1997). Viability of paddy stored under hermetic conditions did not change significantly during the trials. Only a slight reduction was observed in the viability of paddy in the control of trial II (Caliboso *et al.*, 1997) (Table 2).

Tests carried out in Cambodia lasted for 223 days during which period a slight increase in moisture content was observed in the hermetic and a significant increase of 2 percentage points of moisture content (from 13 to 15%) in the control stack (Table 2). This significant increase in moisture content apparently influenced the sharp decrease in viability of paddy from 95% at the start of the trial, to 66% at the end of the trial (Bunna, 2001). The increase in moisture content of paddy indicates the importance of having gastight sheet to avoid moisture diffusion.

*Wheat storage trials carried out in Israel*

Table 3 summarizes the results of viability of wheat stored under hermetic conditions in Israel. These two trials report results obtained with storage periods of 1440 and 450 days only under hermetic storage. In trial I, the initial moisture content was 10.6% and it increased at the end of the hermetic storage period of 1440 days, to only 10.7%. Viability of wheat changed only slightly from the initial 99% to 97% at the end of 1440 days.

In trial II the moisture content did not change throughout the 450 days of hermetic storage but remained at 11.4%. On the other hand viability of wheat dropped slightly from an initial level of 97% to 91%, at the end of the storage period. In both trials, insect populations were successfully controlled and the average $CO_2$ concentrations recorded the ranged between 10% and 15%.

**Results on Reflective Covers to Avert Condensation**

The trials in Israel showed that the reflective covers had a strong attenuating influence on the development of temperature gradients and condensa-

**Table 1** Viability of maize (corn) stored under hermetic and non-hermetic conditions

| Country | Storage condition | Length of trial (days) | Initial germination (%) | Germination at end of trial (%) | Moisture content (%) at start of trial | Moisture content (%) at end of trial |
|---|---|---|---|---|---|---|
| Thailand | | | | | | |
| *Trial I* | hermetic | 90 | 97 | 98 | 12.4 | 12.2 |
| | non-hermetic | 90 | 97 | 95 | 12.4 | 11.5 |
| *Trial II* | hermetic | 280 | 97 | 81 | 12.2 | 13.6 |
| | non-hermetic | 280 | 98 | 0 | 12.2 | 13.6 |
| *From* Sukprakarni *et al.* (1998) | | | | | | |
| Philippines | | | | | | |
| | hermetic | 148 | 94 | 92 | 13.2 | 13.6 |
| | non-hermetic | 120 | 88 | 87 | 12.0 | 12.0 |
| *From* Navarro and Caliboso (1996) | | | | | | |

tion at the top of the Volcani cubes placed in the open, as long as a space for free movement of air was provided between the cover and the plastic liner. This was confirmed in the Philippines, but field trials with 18% MC paddy showed that this insulating effect was not sufficient to prevent a gradual build-up of moisture at the surface layer. However, for dry paddy, it was shown that after five months storage under a reflective cover, no perceptible increase in moisture content was found at the top of the stack and the grain remained in good condition (Donahaye *et al.*, 2000). These findings clearly indicate that for seed stored in tropical conditions in the open, the use of reflective covers provide a practical solution to the inevitable condensation process of unprotected surfaces.

**Sealed Granary (Grain Safe)**

In a test carried out with GrainSafe containing corn, daily readings of $O_2$ and $CO_2$ concentrations in the granary showed that after insects were introduced, there was a gradual drop in $O_2$ concentration to 5.5% within 40 days, coupled with an increase in $CO_2$ concentration to 11%. (Navarro *et al.*, 2000). Average daily temperature gradients of the outer surface showed that for most of the storage period, they were no greater than 2.5°C. This low gradient reduced or eliminated the possibility of moisture migration to the upper surface. In spite of favorable temperatures for development of insects, at the end of two months storage and during the 6 weeks of unloading, the initial populations of *T. castaneum* and *R. dominica* were successfully controlled without the use of pesticides. GrainSafe has several advantages over the Volcani cube; a) its small capacity of 540 kg is better suited for on-farm storage, then the larger Volcani cube; b) The granary is shaded with a roof cone of plant material, resulting in minimal temperature fluctuation since condensation is not detectable at the top surface of the granary; c) The construction design causes minimal change in gas composition within the granary during each

**Table 2** Viability of paddy stored under hermetic and non-hermetic conditions

| Country | Storage condition | Length of trial (days) | Initial germination (%) | Germination at end of trial (%) | Moisture content (%) at start of trial | Moisture content (%) at end of trial |
|---|---|---|---|---|---|---|
| Philippines | | | | | | |
| *Trial I* | hermetic | 117 | 98 | 99 | 12.1 | 12.3 |
| | non-hermetic | 117 | 98 | 98 | 9.7 | 11.6 |
| *Trial II* | hermetic | 183 | 94 | 93 | 10.8 | 10.6 |
| | non-hermetic | 117 | 95 | 92 | 12.2 | 12.8 |
| *From* Navarro and Caliboso (1996) | | | | | | |
| Cambodia | | | | | | |
| | hermetic | 223 | 97 | 91 | 13 | 14 |
| | non-hermetic | 223 | 95 | 66 | 13 | 15 |
| *From* Bunna (2001) | | | | | | |

**Table 3** Viability of wheat stored under hermetic conditions

| Country | Storage condition | Length of trial (days) | Initial germination (%) | Germination at end of trial (%) | Moisture content (%) at start of trial | Moisture content (%) at end of trial |
|---|---|---|---|---|---|---|
| Israel | | | | | | |
| *Trial I* | hermetic | 117 | 98 | 99 | 12.1 | 12.3 |
| *Trial II* | hermetic | 183 | 94 | 93 | 10.8 | 10.6 |
| *From* Navarro and Caliboso (1996) | | | | | | |

unloading. The feasibility of this structure therefore, deserves further in-depth investigation to explore its potential for seed storage under tropical climates and for on-farm storage.

## Conclusions

1. Laboratory and field trials showed that viability of seeds was better preserved under hermetic than non-hermetic conditions.
2. Insect infestations were controlled without the need for pesticides.
3. Shade screen over the Volcani cubes for hermetic storage averted condensation under tropical conditions.


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