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Protecting Grain Without Pesticides at the Farm Level in the Tropics

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Abstract

Three types of sealed structures for modified atmosphere storage of cereal grains stored in the open in tropical and subtropical climates were investigated. The advantage of sealed storage lies in the generation of an oxygen-depleted and carbon dioxide-enriched inter-granular atmosphere of the storage ecosystem to arrest insect development. The three types of structures assessed were: (a) weldmesh-walled silos; (b) frameless flexible envelopes (Volcani Cubes); and (c) a sealed granary (GrainSafe). These structures are based on different logistic principles but have a common structural component, namely, a flexible liner.

A series of experiments carried out in Israel to develop the plastic structures included studies on the permeability of plastic sheeting to oxygen and carbon dioxide, and resistance to insect and rodent penetration. Weldmesh-walled silos are suitable as medium-sized silos with a capacity of 60–1,000 t. A circular bag of plastic liner contained within a vertical wall consisting of galvanised weldmesh is used. The frameless flexible envelopes (Volcani Cubes) are designed for bag storage of small quantities (10, 20 and 50 t) of cereal grains. The plastic liner is made of an upper and a lower section which can be zipped together to form a gastight seal. The granary (GrainSafe) was designed to hold 540 kg nominal capacity of grain, and consists of a gastight cylindrical flexible plastic bag. The bag is inserted into a rigid white polypropylene board curved into a cylinder that forms a sheath surrounding the vertical sides of the flexible bag. Trials conducted with all three types of structures described in this paper in tropical and subtropical climates showed that sealed storage protected grain by maintaining the number of live insects below the threshold of economic damage without the need for pesticides.

STORAGE is an integral part of food security and its importance in many countries has been well documented (Anon. 1986; Bonner and Hirdy 1987; O'Dowd et al. 1987). Food grains consisting of cereals and pulses—stored at moisture contents permissible for safe storage—are the principal commodities dealt with in this presentation. Moisture content (MC) is the major factor determining the storage behaviour of grain (Pixton 1982). Initial grain deterioration due to moulds can be prevented if the MC is sufficiently low. However, the amount of moisture in dry grain bulks is sufficient to permit development of most stored grain insects (Howe 1965). Therefore, particularly in warm climates, periodic insect control measures are usually required to prevent loss of quality and quantity of stored grain (Semple 1985).

Throughout the developing world, the on-farm storage of harvested grain by small-scale farmers is critically important in providing food security for rural communities. In the past, traditional storage structures provided some protection against storage losses, particularly by insects and rodents, although annual losses at the village level—which are estimated to run at between 5 and 10%—were usually considered as inevitable. Attempts to reduce these losses through the introduction of modern storage technologies have consistently failed—being either socioeconomically unacceptable, or inappropriate to local climatic conditions and agro-technical practices (Donahaye and Messer 1992). A different approach has been the modification of existing structures or the construction of new structures in the conventional style but employing modified technologies to improve grain conservation without causing disturbing changes to village life. This was termed by Guggenheim (1978) as 'invisible' technology and the following study is based on this concept.

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A method considered for the prevention of storage losses is airtight storage. The considerable literature on sealed storage of grain termed 'airtight storage' or 'hermetic storage' is well summarised by Hyde et al. (1973) and De Lima (1980). The intrinsic advantage of the airtight storage of dry cereal grains lies in the generation—by the aerobic metabolism of insect pests and microorganisms—of an oxygen-depleted and carbon dioxide-enriched inter-granular atmosphere of the storage ecosystem. In this way, development of pests and diseases is arrested and storage damage minimised. This principle has been used since prehistoric times, perhaps unwittingly, in traditional underground storage structures that are still used, particularly in semi-arid regions of the Mediterranean basin and Sahel (Gilman and Boxall 1974; Curride and Navon 1986).

A phenomenon that discourages the use of airtight storage in hot climates is moisture migration and condensation, and this is especially accentuated in metal silos. So far, two approaches are known to reduce the intensity of this phenomenon: equalising grain temperatures, and insulation of the roof. Equalising 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 also 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, as well as intermediate grain storage for cooperatives and subsistence farmers, for grain in bags or in bulk, have been developed in Israel (Navarro et al. 1990). The influence of insulation materials in reducing the intensity of moisture migration under subtropical (Israel) and tropical (Philippines) climates has been investigated (Navarro and Caliboso 1996).

In referring to the use of plastic structures for the storage of grain we have considered that (a) loss prevention methods should not be very sophisticated; and (b) capital investment for the storage structure should be kept at a minimum. In addition, on-farm or farm-level storage of small quantities of grain are considered as important supporting aspects in that they supply source material for food reserves that are stored in bags in warehouses. In areas of development or where bumper crops are expected, extra storage space should be provided near the production site. Therefore, rapid construction and possible translocation of the storage facilities from one site to another would be advantageous.

This report forms part of a more comprehensive study designed to provide outdoor, alternative, temporary or emergency storage facilities for use by farmers' organisations, cooperatives, village grain merchants and other intermediary parties in the Philippines and other countries, where countryside storage forms an important component of the national grain reserve (Navarro and Caliboso 1996). Other sections of the study have been reported elsewhere (Alvindia et al. 1994; Caliboso et al. 1997; Navarro et al. 1997).

The storage facilities described in this report were designed as gastight structures to provide affordable and user-friendly systems for grain conservation without the need for chemical pesticides.

Materials and Methods

Weldmesh-walled silos

The silos were made up of two components—a weldmesh circular wall formed from sections bolted together to provide the structural enclosure, and an inner liner made of heavy-duty plastic tarpaulin—ultraviolet light-protected, and of food-grade quality. The lining came in two parts: the lower liner welded to form a continuous wall–floor unit and an upper liner forming a roof cone (Figure 1). After the ground was leveled and cleared of stones, weldmesh sections were bolted into place to form a circle around a floor–wall package within the perimeter. The package was then opened and the walls of the liner were tied to the weldmesh. These silos could then be equipped with aeration systems and loaded with grain, exactly from the centre point. The roof section was placed evenly over the grain using a pre-attached rope to pull and unfold the polyvinyl chloride (PVC) liner, which was zipped to the wall to obtain a gastight seal. The roof cone was secured to the metal weldmesh walls by ropes. The enclosures were also provided with hooks to be fixed to the wire mesh. The silos were designed to enable bulk storage or bag storage, with mechanical loading or unloading, with the intention of providing a useful transition phase between bag and bulk handling. The silos used in the experiments reported in this paper had a diameter of 5.2 m and a height of 2.2 m with a storage volume of 52 m^3 and a capacity of 35–40 t (Figure 1). Larger capacities from medium-size silos up to 1,000 t are also available.

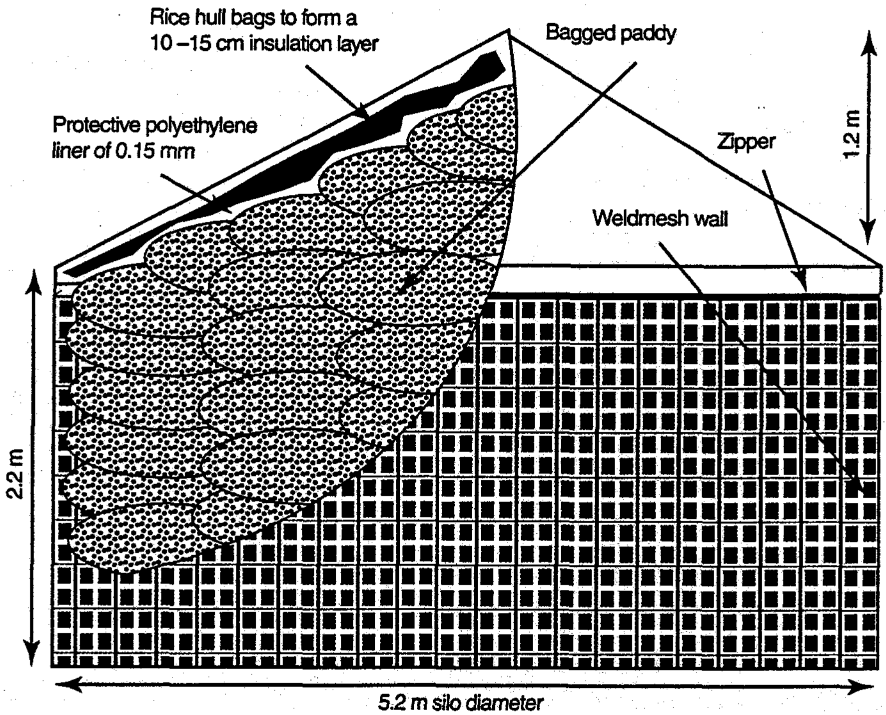

Figure 1. Weldmesh-walled silo for the gastight storage of grain in bags. Schematic representation of a 52 m^3 capacity silo suitable for storage of approximately 35 t of paddy.

Frameless flexible envelopes (Volcani Cubes)

Frameless flexible envelopes were designed for stack storage in which the stack itself forms the rigid structure of the system (Figure 2). 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. The lower section was laid on the ground and the bags of grain were placed directly on the tarpaulin. Pallets were not required. The dimensions of the floor section determined the size of the stack to be built. After the stack had been built to the required height, the top tarpaulin was then placed over the stack to meet the lower section halfway up the side. Both the upper and lower sections were provided with a gastight multiple tongue and groove zipper, used to zip the sections together to form a continuous envelope.

The design was intended to be user-friendly with dimensions that did not require mechanical loading or high stacking. Special tension straps situated around the cube were designed to take up slack in the walls and pull the liner tight around the curve of the sacks at floor level (Figure 2). This was done to prevent rodents from gaining a tooth-hold on the slippery surface, thereby preventing damage to the hermetic seal.

The cubes were intended for bag storage in small quantities of approximately 10, 20 and 50 t of cereal grains. Dimensions of the 10 t cubes were 336 × 298 × 150 cm (length × width × height), giving a maximum storage volume of 15 m^3, and weighing 43 kg when empty. The 20 t cubes measured 447 × 336 × 200 cm (length × width × height) with a maximum storage volume of about 30 m^3 and weighing about 76 kg when empty (Figure 3).

The cubes were easy to erect and dismantle. For trucking operations, they could be transported with the grain load, and the sacks could be off-loaded directly into the cubes at their destination.

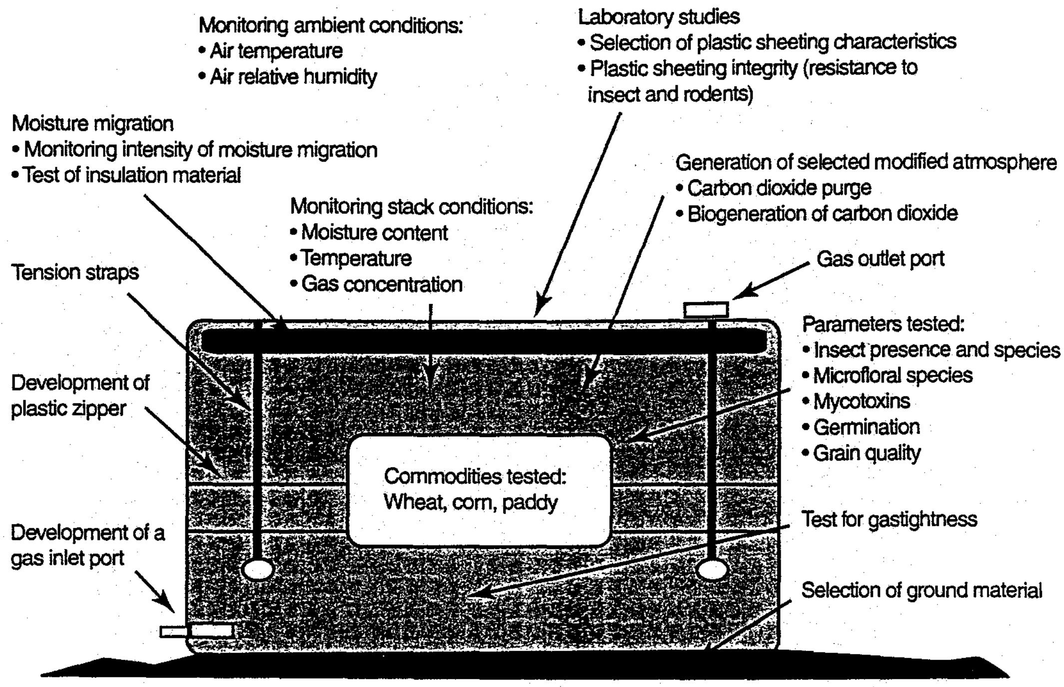

Figure 2. Schematic representation of the different experimental steps and parameters used in the development of the Volcani Cube for gastight storage of bagged grain.

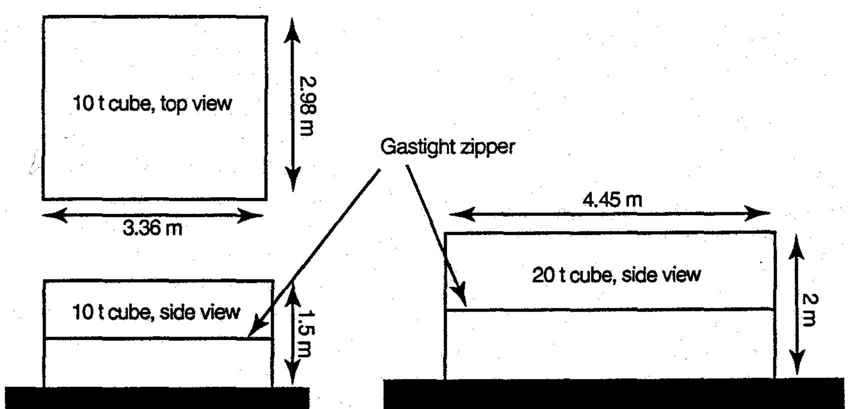

Figure 3. Plan of 10 t and 20 t capacity Volcani Cubes for gastight storage of grain in bags.

Sealed granary (GrainSafe)

The GrainSafe granary (Figure 4), for which a patent application has been submitted, was developed over a series of previous trials during which progressive modifications were carried out. It consisted of a cylindrical bag made from a PVC formulation, 110 cm high and 90 cm diameter (volume = 700 L), and had an upper conical collapsible sleeve for in-loading the grain. This sleeve was equipped with a welded strap and buckle so that when loading was completed the sleeve could be rolled over a horizontal wooden strut and firmly sealed using the pressure of the strap. The bottom of the bag was equipped with a cylindrical flexible sleeve (for unloading), 50 mm in diameter and terminating in a rigid, PVC screw-on cap. The bag was supported inside a rigid white polypropylene (PP) board, 115 cm high, 560 cm long and 1 mm thick, that was curved into a cylinder to form a sheath surrounding the vertical sides of the flexible bag.

To provide stability to the granary and to close the cylindrical PP sheath, the overlapping edges of the sheath were screwed together onto a wooden strut 135 cm long, 40 mm wide and 30 mm thick. An identical strut was then screwed to the outside of the sheath diametrically opposite the first one.

One necessary design aspect was the need to prevent the accumulation of rainwater on top of the bag where an inverted cone forms at the upper surface when grain is removed from the bottom. This was achieved by lifting the horizontal strut that seals the loading sleeve, and positioning it across the top of the granary. In this way the two holes at each end of the strut were fitted over pins screwed into the top of the vertical struts that serve to stabilise the PP sheath. Consequently, as grain was removed from below and the grain level dropped, the top of the bag remained suspended beneath the horizontal strut, but collapsed from the sides so that the volume of headspace remained minimal.

Results and Discussion

Weldmesh-walled silos

To date, most of our experience with such silos has been with bulk-stored wheat. In a trial carried out in the semi-desert region of southern Israel, 548 t of locally grown wheat was stored over a 30-month period (Calderon et al. 1989). The grain was aerated during three winters, to cool it while taking advantage of the arid environment, and the silo was sealed during the summers. The aeration regime cooled the grain to temperatures below 17°C, while the highest carbon dioxide and the lowest oxygen concentrations during hermetic storage were 10.6% and 5.8%, respectively. The overall loss of stored grain was 0.24% on an annual basis. Safe storage in this arid region using this type of storage structure was shown to be feasible.

In another study carried out in Israel, storage of 73 t of locally grown wheat for 48 months within a plastic silo was investigated (Navarro and Caliboso 1996). The silo was 7 m in diameter, formed by a structured wall consisting four sections of weldmesh forming a circumference of 22 m. The carbon dioxide concentration increased gradually up to about 10% and was accompanied by a decrease in oxygen concentration to a minimum of about 5%, followed by a gradual increase over the 48 months of storage. During the summer months, average temperatures ranged from 25–35°C and during the winter months they decreased to about 15–22°C. No significant moisture migration was observed. The average MC of samples taken during loading and unloading of grain showed very little change, varying between 10.6% at the start and 10.7% at the end of storage. During the second year there was a localised pocket of increase in MC close to the peak of the silo where recordings in November registered 12.7–13.0%. The average germination of initial samples of wheat was 99.5%, falling to 97% after 48 months of storage. An initial infestation, principally by *Rhyzopertha dominica*, was observed. Although, during the second year, there was an increase in the number of dead insects, at the end of storage period no live insects were detected in the deep layers of the bulk, while the average number of dead insects/kg was 3.7.

Summary of the trials carried out in the Philippines with corn and paddy

Corn

Temperatures recorded in the core of the silo were in the range of 28–30°C, but during the day they reached 35–40°C below the liner at the top of the silo. The initial average MC of the corn was 13.5% and after 6 months of storage it was 13.3%. Condensation was apparent at the top of the silo after storage for 4 months. The density of insects found at start of the trial was 3.0 live insects/kg of corn and 0.3 dead insects/kg, while at the end of storage the level of live insects/kg was 0.7 and dead insects/kg was 2.7. Weight loss in corn after 6 months of gastight storage was 0.37% compared with 5.07% in the control stack (Navarro et al. 1998a).

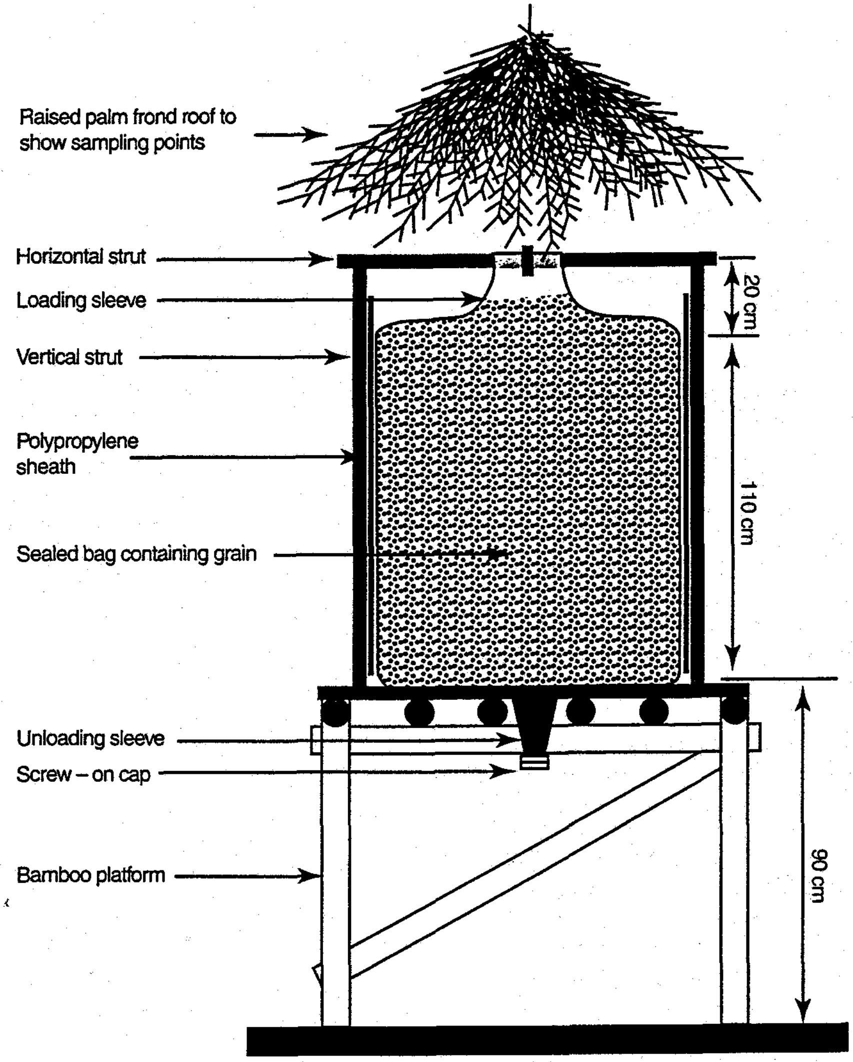

Figure 4. Section of a granary (GrainSafe) for sealed storage (700 L capacity) showing design features and sampling positions.

Paddy

The overall MC of paddy in bulk storage under gastight conditions in the silo did not change significantly during the trial. The rice hulls forming the top insulation layer initially absorbed water that condensed below the liner. This is evidenced by the fact that the MC of the rice hull, which initially averaged 7.97%, had more than doubled to 18.58% at the end of the 43-day trial. The initial density of live insects was reduced from 10.3 insects/kg to 1.3 insects/kg at the end of the trial. Germination of paddy did not change significantly over the storage period—the initial 95.3% was reduced to 94.8%. Weight loss was 0.13% in the gastight silo, compared with 3.75% in the control stack (Navarro et al. 1998a).

Frameless flexible envelopes (Volcani Cubes)

These envelopes have been developed to provide storage facilities at the farmer–cooperative level where bag storage is practiced. Much effort has been expended to render these envelopes 'user-friendly', so those members of the international aid community and others can use them without previous experience in grain storage.

A trial was carried out in Sri Lanka on the outdoor storage for 6 months of locally grown paddy using two such hermetically sealed flexible liners of 10 and 20 t capacity. Insect infestations failed to develop in either cube and only 0.33–0.64% dry weight was lost due to metabolic activity. One of the cubes contained paddy with a higher MC which caused condensation, mould development and losses estimated at 1.24%. Means for obviating this phenomenon were proposed (Donahaye et al. 1991).

In another trial carried out in Israel, 10.4 t of wheat heavily infested with common stored-product insect pests was stored in bags. Samples taken after 3 weeks of storage showed complete insect mortality. The average MC remained unchanged at about 11%. After 15 months of storage there was no indication of moisture migration. Germination was not impaired and remained at the level of >95%.

Summary of the trials carried out in the Philippines with corn and paddy

Corn

Recordings of mean weekly daytime temperatures logged from the observed cubes revealed that temperatures inside the control stack kept under tarpaulins (28°C) were much lower than those of the cubes (ranging from 35 to 42°C). The temperatures recorded 10 cm below the insulation were in the range of 29–31°C. During the opening of the cubes, moisture condensation was observed below the liners, especially on stacks stored for more than 4 months. This moisture condensation could have been due to low temperatures prevailing at night, which were not monitored. There was no increase in the average MC of corn held under gastight storage (Navarro et al. 1998a).

In the gastight cubes, the CO_2 level rapidly increased to 12% while the O_2 concentration sharply declined over the first 2 weeks of storage to around 7%. Carbon dioxide concentrations in the most of the gastight cubes rose to 12–16% and fluctuated within that range for most of the storage period. In two cubes, CO_2 concentrations reached 18% and 22%. These high concentrations indicate that mould activity occurred, due probably to moisture condensation. Because of the extended period of storage in these cubes (6 months), the rice hulls, that also served as an insulator, became saturated, leading to wetting of the top layer and sides of the cubes. The respiration of the wet grain and moulds contributed to the depletion of the oxygen and the increased evolution of CO_2. This lethal atmosphere subsequently led to the mortality of the insects in the cubes.

The insects found in corn were *Sitophilus zeamais*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis*, *Latheticus oryzae*, *Lophocateres pusillus*, *Carpophilus* spp., *Tribolium castaneum*, *Cryptolestes* spp., *Typhaea stercorea*, and species of ants, crickets and cockroaches. No significant increase in the population density of insects was noted in the gastight sealed corn cubes, whereas the populations in the control cubes increased considerably. On the basis of insect infestations and in comparison with control stacks, storage in the gastight cubes was considered successful.

The results indicate that weight loss in corn may be effectively reduced through gastight sealed cube storage. The control stacks suffered serious insect attack and consequently loss in weight was significantly higher than the treated stacks. The control stacks, in addition to insect infestation, suffered from mould infection and from rodent and bird attack (Navarro et al. 1998a).

Paddy

A similar pattern of temperature levels was observed in paddy stacks as in the corn trials. The temperature recorded at various points inside the gastight cubes indicated that temperature fluctuations were reduced due to the insulating properties of the grain mass (Navarro et al. 1998a). The average MC of gastight sealed paddy in two stacks increased slightly from the beginning to the end of storage, whereas no increase was noted in the rest. There was a real trend towards increase in MC in the two control stacks stored during the wet season and a decrease in MC of the control stacks stored in the dry season. These differences indicate the importance of having gastight sheet to avoid moisture diffusion. Field trials showed that there was no critical moisture build-up or localisation in any of the treatments or the control, except for one stack that exceeded the critical MC of 14% by 0.24%.

The average CO_2 concentrations recorded in the cubes of paddy were in the range of 10–15%. Lower CO_2 concentrations (6–7%) reported in three cubes were due to leaks in the plastic sheeting caused by mechanical damage.

Initial and final counts of live insects revealed no population increase in the gastight sealed 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. The results show that complete disinfestation of paddy in all the gastight sealed cubes was not achieved. In spite of the presence of a few live insects at the end of storage, all treatments in the trials were successful. This was matched by a much lower percentage weight loss in the treated cubes compared with the control stacks. The magnitude of loss recorded from the gastight sealed paddy cubes was about 18 times lower than in the control stacks, resulting in weight loss of 0.231% for the gastight cubes and 4.307% for the control stacks (Navarro et al. 1998a).

Sealed granary (GrainSafe)

In a test carried out with GrainSafe containing corn, insect infestations were established by introducing laboratory-reared lesser grain borer, *Rhyzopertha dominica*, and red flour beetle, *Tribolium castaneum*, at an infestation level of 1,800 individuals of each species (6 insects/kg) (Navarro et al. 1998b). Daily readings of CO_2 and O_2 concentrations in the granary showed that after the insects had been 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%. For the following 20 days both O_2 and CO_2 concentrations remained stable (Figure 5).

Calculation of these changes in oxygen concentration in hermetic storages was based on a model developed to determine the influence of different initial insect populations (Navarro et al. 1994). For this purpose a fixed O_2 ingress rate equivalent to about 0.24%/day was chosen for a structure with a volume of 10 m^3. For these given values, changes in oxygen concentration in response to different initial insect populations are illustrated in Figure 6. Accordingly, a cyclic change in concentration is obtained as a result of O_2 ingress and the ability of insects to survive at low O_2 levels. These theoretical cyclic changes in O_2 concentration were also observed in different laboratory and field studies (Oxley and Wickenden 1963; Hyde et al. 1973; Navarro et al. 1990). Under the conditions governing the numerical experiment, the model calculates that there is a residual insect population even after an extended storage period of 1 year. This is shown by the continuing fluctuations in O_2 levels before a steady-state is reached (Figure 6). This result is corroborated by field observations that a residual population may remain when the grain is re-exposed to normal atmospheric air, though under the hermetic conditions and restricted O_2 supply their reproductive capacity is limited.

Daily average temperatures within the granary (10 cm below the top and bottom centre) over the 2-month storage period dropped from 36°C to 26°C. These

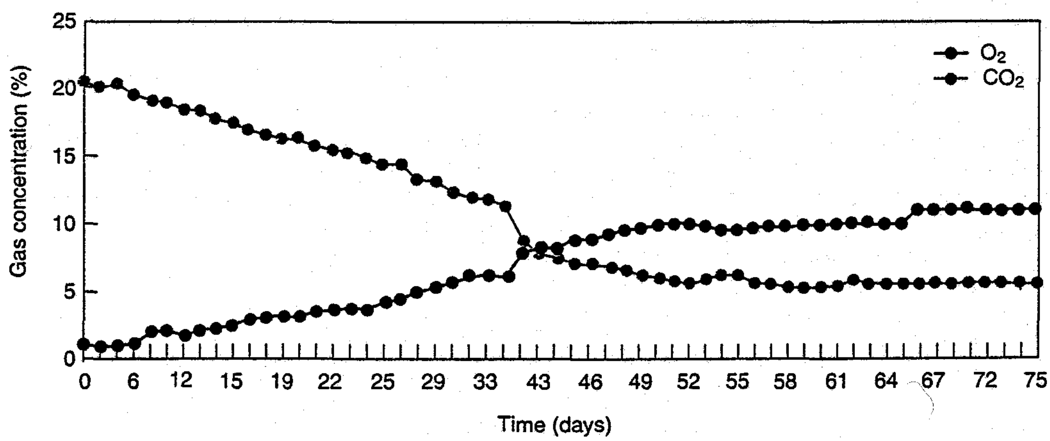

Figure 5. Oxygen and carbon dioxide concentrations in the granary (GrainSafe) during 10 days of hermetic storage without insect infestation, and 64 days storage following the introduction of adult *Rhyzopertha dominica* and *Tribolium castaneum* at a population level of 6 adult insects/kg.

findings indicate that, for the first month, grain temperatures were favourable for development of both the insect species used to infest the grain. Average daily temperature gradients from the outer surface at the north, south and top centre, to a depth of 10 cm, showed that for the most of the storage period, average temperature gradients were no greater than 2.5°C. This low gradient reduced or eliminated the possibility of moisture migration to the upper surface.

The atmospheric compositions in the granary over the 6-week unloading period showed that the increases in O_2 concentration after each grain removal were relatively small, amounting to a maximum of 1.8%, with a similar decrease in CO_2 concentration of up to 1.4%.

In spite of favourable temperatures for the development of insects, at the end of 2 months of storage and during the 6 weeks of unloading, the initial populations of *Tribolium castaneum* and *Rhyzopertha dominica* were successfully controlled without the use of pesticides.

Conclusions

Weldmesh-walled silos and Volcani Cubes

1. For dry corn and paddy stored in sealed plastic enclosures outdoors in the Philippines, moisture migration was observed.
2. This was effectively prevented by an insulating upper layer of bags containing rice husks.
3. The gastight storage trials provided acceptable protection by reducing live insect populations below the threshold of economic damage.
4. Analysis of quality parameters showed that gastight storage in plastic enclosures is safe and feasible for the outdoor storage of corn and paddy.

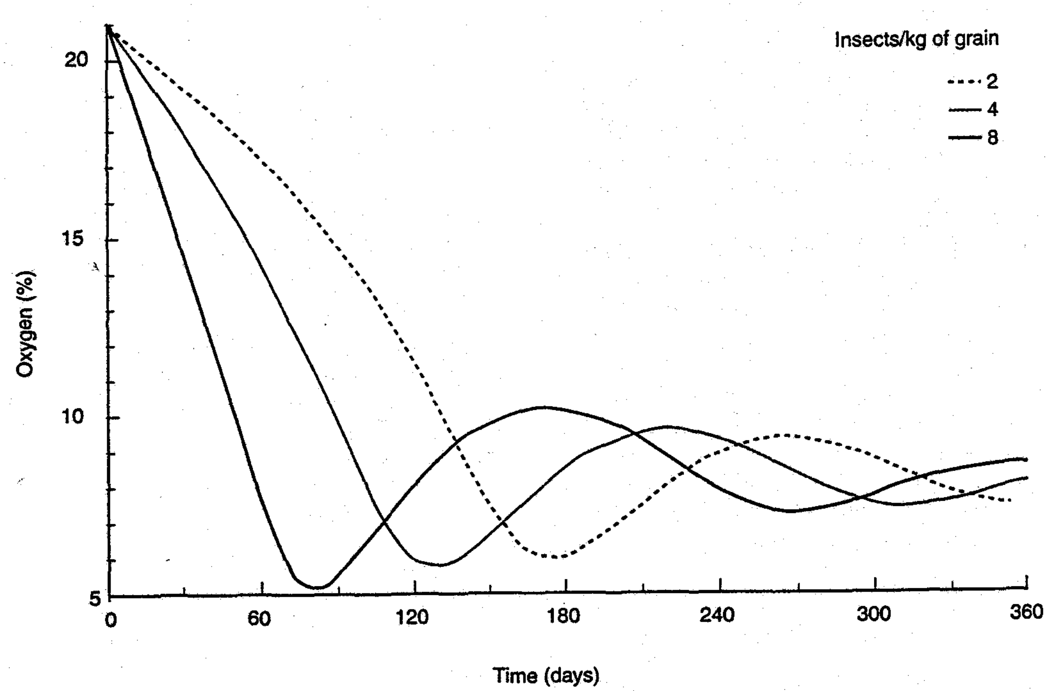

Figure 6. Calculated oxygen concentrations in a 10 m^3 grain mass containing different infestation levels of insects—having an oxygen intake of 157 µL/insect/day—using a sealed liner with an oxygen ingress rate of 0.24%/day (Navarro et al. 1994).

5. Under Philippine climatic conditions the period of safe storage without significant condensation damage did not exceed 4 months.
6. The technology has strong potential for adoption by farmers and cooperatives in their postharvest operations.

GrainSafe granary

1. This trial clearly showed that, under Israeli conditions, dry corn could be safely stored for 5 months in the sealed granary, without the need for chemical control, even though it was periodically opened to permit partial removal of its contents.
2. The level of gastightness and the construction design contributed to a minimal change in gas composition within the granary during each unloading.
3. A residual insect population survived, but could not develop to a level causing economic damage.
4. Gas concentrations indicate adequate sealing to a level that prevented grain damage.
5. Gas losses throughout the emptying process of 100 kg per week caused an increase in O_2 concentration at an average rate of 1.8% per discharge. However, this unloading rate did not adversely influence the storage potential of the corn.
6. The granary was shaded with a roof cone of plant material, resulting in minimal temperature fluctuations, while condensation was not detectable at the top surface of the granary.
7. The initial 10.1% MC of the corn did not significantly change throughout the storage period.
8. The granary still has to be field tested in target countries, both to examine it under local conditions and to evaluate its acceptability from the socioeconomic viewpoint.

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