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APPLICATION OF MODIFIED ATMOSPHERES UNDER PLASTIC COVERS FOR PREVENTION OF LOSSES IN STORED GRAIN

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3) EXECUTIVE SUMMARY

The overall accomplishment of this project was the development of environmentally and user-friendly temporary or emergency grain storage facilities without the requirement of chemical pesticides, to be used by farmers organizations, cooperatives, grain processors and other intermediary parties where secure reserve stocks must be maintained yet permanent storage structures are lacking.

The research required evaluation of the applicability of using flexible plastic sheeting developed in Israel for modified atmosphere and gastight storage for paddy and corn stacked in the open in the Philippines. Storage cubes and silos manufactured from heavy duty plastic were used in order to provide an inexpensive solution to short and medium term preservation of dry paddy and corn and intermediate moisture content of paddy. Prevention of serious losses of grain in the stores was thus accomplished without the need for pesticides.

A series of preliminary trials were carried out in Israel with prototype plastic structures. Following this, a series of trials were carried out during the second and third years of the project, in the Philippines with paddy and corn. The Philippine investigations comprised both storage under modified atmospheres (MAs) using carbon dioxide flushing of corn, and biogeneration of MAs using gastight storage of corn and paddy without gas replacement. The phenomenon of moisture migration due to temperature gradients within the grain bulks was studied in Israel.

The field trials were accompanied by laboratory studies on the permeability of the plastic sheeting to gases (Israel), resistance to insect penetration (Israel and the Philippines), and resistance to rodent penetration (Israel).

A preliminary model was proposed to study the interdependent changes in gas concentrations, dynamics of insect population and amounts of grain consumed by the insects. Numerical experiments were run to assess the degree of gastightness of the structure expressed as permeation rate of oxygen through the storage membrane, size of grain mass, volume of the storage structure, number of initial insects/kg of grain, respiration rate of the insect population, birth and death rates of the different species, and the amounts of grain consumed. This model will enable prediction of safe storage periods under the different physical and biological variables described above.

Carbon dioxide treatment proved effective for insect control. In view of the frequent non-availability of CO_2 in the Philippines, particularly of food-grade, the adoption of CO_2 enriched atmospheres using CO_2 cylinders remains limited. Rodent penetration in field trials confirmed the laboratory findings that heavy duty sealed plastic tarpaulin cubes or heavy duty sealed plastic liners as silos provided an effective barrier to rodents when correctly set-up. Although CPE had lower permeability to gases than PVC it was more susceptible to insect and rodent penetration. In field trials in both Israel and the Philippines with elevated moisture content, moisture migration was observed. Use of agricultural wastes provided insulation from diurnal temperature fluctuations and was effective in preventing moisture migration.

The trials show that gastight storage provides an acceptable protection by maintaining the number of live insects below the threshold of economic damage. Weight losses in corn stacks under CO_2 purge were comparable to gastight storage in terms of preventing dry matter loss.

This study shows that gastight storage using enclosed plastic sheeting is a feasible alternative for outdoor safe storage of paddy and corn. In the Philippine climatic conditions the period of safe storage should not exceed four months. Under the Israeli climatic conditions wheat storage can be extended up to 4 years. Gastight storage can preserve the quality of wheat, corn and paddy and minimize insect damage with the added advantage of being flexible and transportable. The technology has strong potential for adoption by farmer organizations and cooperatives, private grain traders and millers in their post harvest operations.

4) RESEARCH OBJECTIVES

The general objective of this project was to provide alternative temporary or emergency storage facilities for use by farmers organizations, cooperatives, village grain merchants and other intermediary parties. These facilities were designed to provide affordable and user-friendly systems without the need of chemical pesticides. Specifically it aimed to:

- Study the applicability of sealed plastic liners for the preservation of stacked grain in warehouses and in the open.
- Develop a new technique for the application of modified atmospheres as well as the gastight storage principle in stacked grain stored within sealed plastic liners.
- Elucidate the feasibility of these techniques in storage programs for the prevention of deterioration by insects and microflora both for dry grain and also when intermediate moisture content grain (15-16%) is being stored.
- Provide an interim storage technology during the conversion period from bag to bulk storage.

5) METHODS and RESULTS:

5.1.EXPERIMENTAL DESIGN

The experimental design was based on gathering the information required for the development of a sealed grain storage technique within gastight plastic tarpaulins or plastic lined silos. The design comprised application of modified atmosphere using carbon dioxide flushing or the biogeneration of the modified atmosphere by storage under gastight conditions. The different stages of the experimental design are schematically presented in Fig. 1.

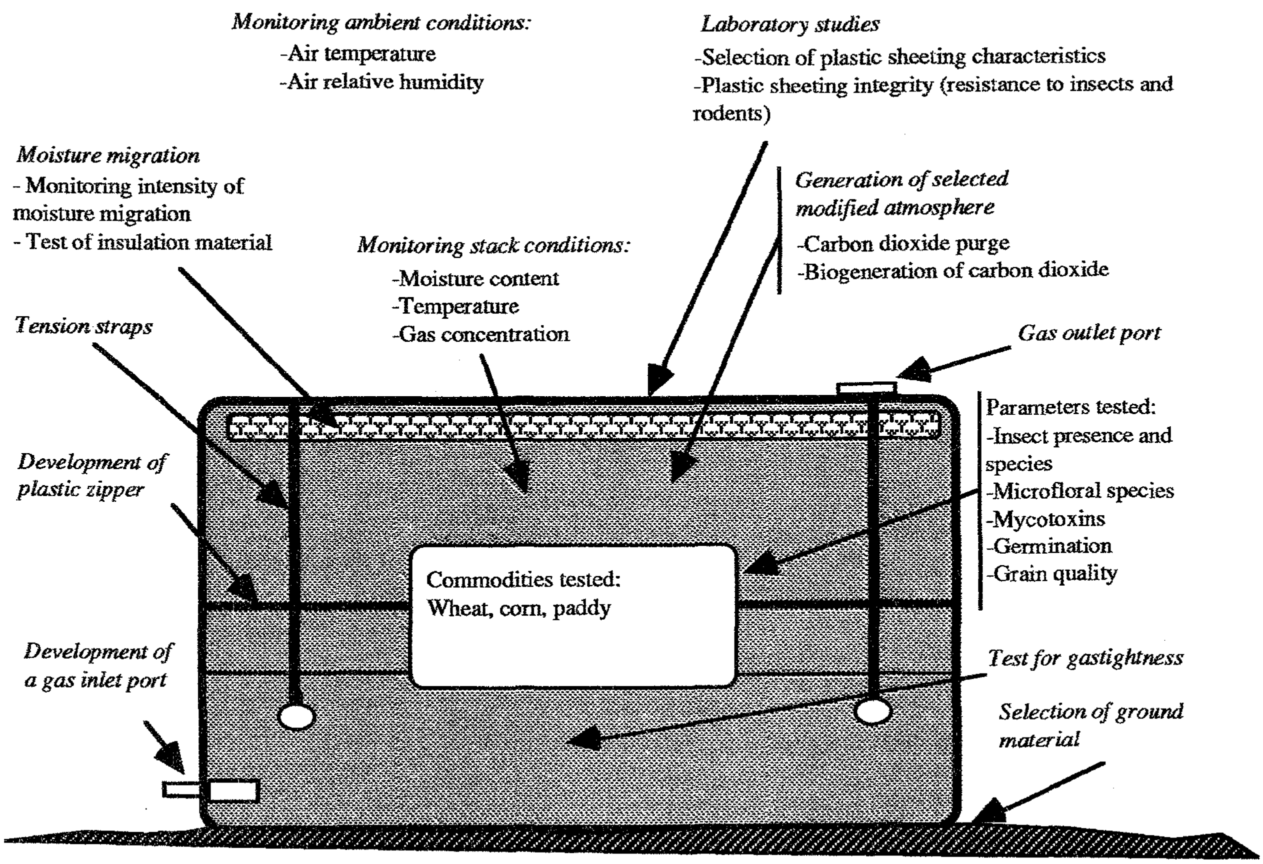


Fig. 1 Schematic presentation of the different experimental steps and parameters used in the development of the technology for prevention of losses in stored grain using modified atmospheres under gastight plastic covers.

5.2.- SPECIFIC OBJECTIVES OF THE EXPERIMENTAL DESIGN

5.2.1.- Laboratory scale studies:

5.2.1.1. *Selection of the plastic sheeting:* Tests were designed to identify plastic sheeting characteristics especially to determine permeability levels of atmospheric gases.

5.2.1.2.*Plastic sheeting integrity:* These experiments aimed at investigating the influence of population density on both ingress and egress of insects through the liners. Also to test the influence of liner material to rodent penetration.

5.2.1.3. *Predictive model:* An attempt was made to develop a preliminary model to simulate the interdependent changes in gas concentrations, insect population dynamics and amounts of grain losses from insects and pests under gastight conditions.

5.2.2.- **Field studies**

5.2.2.1. *Design, construction and test of experimental plastic enclosures.* Experimental flexible heavy plastic tarpaulins (referred herewith as tarps) for gas tight enclosure of bags and heavy duty plastic liners for silos for bulk or bag storage of grain were designed and tested for gastightness and retention of generated modified atmospheres.

5.2.2.2. *Selection of ground material:* Comparative tests of different methods to protect the floor of plastic structures from underground rodent activity were carried out for selection of the best ground material to be used beneath the structures.

5.2.2.3. *Moisture migration:* Tests were conducted to identify the relationship between temperature gradients within the storage systems and different insulation materials, so as to reduce the intensity of this phenomenon.

5.2.2.4. *Application of modified atmosphere:* An injector port to facilitate the introduction of carbon dioxide or nitrogen was designed and tested.

5.2.2.5. *Generation of modified atmosphere:* Two methods of generating modified atmospheres were tested: the biogeneration of modified atmospheres using the gastight storage principle or injection of carbon dioxide (CO_2) gas from pressurized cylinders into the store.

5.2.2.6. *Long term storage of grain* : The feasibility of integrating the use of heavy duty plastic sheeting in storage programs was tested by designing a long-term storage trial.

5.2.2.7. *Storability of different commodities:* Wheat, corn and paddy served to test the applicability of the gastight plastic tarpaulins or liners.

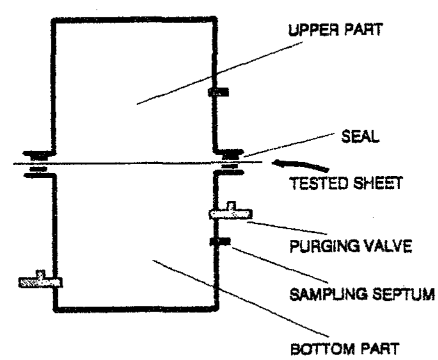
5.3.- **LABORATORY STUDIES**

5.3.1.- **Selection of plastic sheeting characteristics:**

Materials and methods

Previous work on storage under plastic has focused on the use of a PVC 0.83 mm thick "food quality" liner. Permeability tests for gases were carried out using the method described by Wohlgemuth (1985). The instrument constructed for this purpose consisted of two chamber sections holding between them the plastic sheeting to be tested (Fig. 2). Gas concentrations were measured using a gas chromatography. Four types of plastic with different permeability characteristics were tested: **i** - Polyvinyl chlorine based flexible plastic sheeting (PVCF); **ii** - PVC based improved sheeting (PVCI); **iii** - PVC based with reinforced fabric (PVCR); and **iv** - Chlorinated polyethylene (CPE) on polyester webbing.

Fig. 2 - Apparatus for measuring permeability of plastic sheets.



Results

Permeability tests in Table 1 indicate that carbon dioxide (CO_2) and oxygen (O_2) permeability ratings for PVCF and PVCR are relatively high compared with PVCI and CPE. Although gastight storage using PVCF is successful in medium to large scale storage structures the high surface area: volume ratio for small storage structures may enable insects to survive since rates of O_2 consumption and CO_2 production by insect metabolism within the stores may be counteracted by O_2 permeation and CO_2 egress through the plastic. With the aim of improving gastight performance of the trial sheeting. the permeabilities of several other materials were analyzed but these proved to have inferior permeability levels or other physical characteristics such as resistance to tear or rigidity. On the basis of these findings one 10 ton PVCI and two of CPE structures were fabricated and were tested at the ARO trial site in Bet Dagan.

Table 1 - Permeability levels of different plastic sheeting considered for the construction of storage enclosures.

Plastic material	Thickness (mm)	Gas	permeability (ml/day/m^2/mm)
PVCF	0.83	CO_2	2521
		O_2	87
PVCI	0.83	CO_2	2367
		O_2	68
PVCR	0.85	CO_2	3657
		O_2	210
CPE	0.83	CO_2	161
		O_2	51

5.3.2.- **Plastic sheeting integrity:**
Resistance of plastic sheeting to insect penetration (Israel and Philippines)

Materials and methods

Egress trials: The capability of the Lesser Grain Borer *Rhyzopertha dominica* (considered to be probably the most efficient "penetrator" of all stored-product insect pests), to bore their way out from plastic enclosures (egress) made of PVC (experiments in Israel) and CPE (experiments in the Philippines) were carried out. These experiments were done under gastight conditions while normal atmospheric conditions served as control. Heavy duty sheeting was cut to fit the diameter of openings of screw-cap kilner jars of 1 L capacity. Parallel tests were conducted with corn of 13.8% moisture content (m.c.), and paddy 13.2% m.c. Each jar was filled with 100 g grain, pre-conditioned for moisture content. The initial weight of grain was recorded for weight loss assessment. Groups of 100 and 1000 adults approximately one week old, were added to the grain and the jars were sealed. For the normal atmosphere that served as control, air conditioned at 70% relative humidity (obtained from a jar containing 57-83 g of $CaCl_2$ dissolved in 1450 ml water) was pumped in via an inlet port. The jars were inverted and held at 25-28^oC.

Ingress trials: The word ingress refers to the ability of *R. dominica* to bore its way into a sealed plastic enclosure. For this trial heat welded PVC pouches (15 cm L x 12 cm wide were filled with 40 g of paddy (13.2% m.c.) or with 40 g of corn (13.8% m.c.) The filled pouches were then heat sealed. Following heat sealing, each plastic pouch containing paddy was placed inside a 4 liter capacity jar containing 40 g paddy and each pouch containing corn was placed in a 4 liter jar containing corn. The grains in the jars were artificially infested with 1,000 adult *R. dominica*. Each jar was covered with a piece of filter paper which was cut to the size of the mouth of the jar.

Over three storage intervals jars were withdrawn monthly and inspected for the number of holes in the plastic and other damage. Following three months of storage the grain in the remaining jars was sieved, insects were counted and the final weight of the grain was recorded.

Results and Discussion:

Egress trials:

CPE : Living infestations of *Rhyzopertha dominica* at initial densities of 100 and 1000 adults bored their way out of the CPE plastic sheeting within a month under normal atmospheres. In paddy kept under a gastight atmosphere, full mortality was observed for the low density population (100 insects/jar) after three months. For the high density population complete mortality was achieved within one month. In such conditions no insects penetrated the plastic probably due to stress under the low oxygen and high carbon dioxide concentrations.

Similar experiments carried out with corn kept gastight showed complete control for low density population kept within the jars within one month. Whereas high density population permitted survival after 2 months of storage. This survival was attributed to incomplete sealing of the jars. Deep scratches were made to the CPE within one month and air penetrated through bored plastic within 3 months.

PVC: Under normal atmospheric conditions with the same insect species and same initial population densities penetration holes were observed even within one month. However, under gastight storage, although a few light scratches were observed, no penetration was recorded even after 3 months of storage of corn. While trials with paddy did not show any scratches to the plastic.

Trials carried out with paddy left a very light residual insect population. This was attributed to leaks that may have remained due to incomplete sealing of the jars. Whereas trials with corn resulted in complete mortality within two months at both densities of insect population.

Ingress trial:

Results of the ingress experiment using corn showed that of the nine PVC pouches examined, only one was bored by *R. dominica* . The other pouches sustained scratches only. Similarly, the investigations on paddy showed that only light scratches were sustained by the PVC pouches.

The advantage of using PVC over CPE for hermetic storage of both paddy and corn is supported by the above data on both ingress and egress studies.

Resistance of heavy duty plastic sheeting to rodent penetration (Israel)

Materials and methods:

Test animals: Two species of commensal rodents, the house mouse *Mus musculus* and roof rat *Rattus rattus* were employed. Wild animals of the two species were trapped in the field. They were then transferred separately to special cages and supplied with food and water.

The tests with both species were undertaken in the rodent laboratory and rodent breeding room of the Plant Protection Service at Bet-Dagan. The temperature of the rooms during the test was 15-28^{o}C.

Test materials: The same heavy duty plastic sheeting as used in the field trials and tested for insect penetration were employed, namely:.

1 - PVC sheeting 0.83mm thick

2 - CPE on nylon webbing sheeting 0.83 mm thick

The sheeting were cut into squares. Then 50 g of wheat was inserted between two such squares which were placed between two sets of aluminum frames (dimensions: 15x15 cm) that were screwed together to seal the edges of the plastic between them forming pouches. The pouches were prepared for exposure to the rodents in two different manners:

1- under tension

2 - with folds on both sides of the frame.

After acclimatization of the captured animals for 4 weeks, the frames containing the plastic sheeting were exposed in a standing position in the cages to the two species of rodents separately, thus providing them with maximum opportunity to gnaw at the plastic on each side.

Observations were made one day after the start of each exposure and then continued at weekly intervals for a month.

To obtain hungry rodents the animals were held with limited food and their willingness to attack the plastic sheeting under tension was studied. For this purpose average daily food consumption of mice and rats in the cages were determined. Then the plastic sheeting under tension were exposed to mice fed with 50 per cent of the pre-determined average daily food consumption, and to rats fed every other-day. The exposures continued for one month.

Results and discussion

Damage levels of the different plastic materials exposed in the two different positions to mice and rats are shown in Table 2.

Mice: The animals attacked both the CPE and PVC sheets exposed to mice in the folded position on the first day of exposure, and maximum damage was attained during the first week.

The presence of food in the cages did not prevent some animals from consuming partially or all the grain between the sheets.

In most cases (87%) the damage occurred in one side of the frame only, while the other side remained untouched.

In frames where the plastic sheets were in the tension position no damage by mice was observed over the whole exposure time (one month).

Table 2- Average damage levels* of the different plastic sheeting materials exposed in the two different positions to rats *(Rattus rattus)* and mice *(Mus musculus)* .

Rodent species	Plastic material	Position of sheeting	Replicates	Level of damage (after exposure) 1st day	1st week	2nd week	3rd week	4th week
Rattus rattus	CPE	Tension	4	0	1.25	1.25	1.25	1.25
		Folded	4	0	1.25	1.25	1.25	1.25
	PVC	Tension	4	0	0	0	0	0
		Folded	4	0	2.5	2.5	2.5	2.5
Mus musculus	CPE	Tension	4	0	0	0	0	0
		Folded	4	3.3	4.7	4.8	5	5
	PVC	Tension	4	0	0	0	0	0
		Folded	4	2	3.5	3.5	4.5	4.8

*Damage evaluation was recorded according to the following scale:

No damage -	0
Light superficial damage without penetration -	1
Penetration with 1 hole diameter up to 5 mm. -	2
Penetration with more than 1 hole diameter up 5 mm each -	3
Penetration with 1 hole diameter larger than 5 mm. -	4
Penetration with more than 1 hole diameter larger than 5mm.-	5

Rats: In contrast to exposure to mice, roof rats failed to respond to any position except in a special case where a rat was hungry due to absence of food in the cage, and damaged a folded PVC sheeting. It is interesting to note that the only recorded case of field damage were also by the house mouse though several species of field mice and rats were usually also present.

Restricted feeding: During the experiments with hungry rodents, one of each of the 4 replicates of both PVC and CPE sheeting presented under tension to hungry mice was heavily damaged and the grain inside partly consumed (Table 3). However the results obtained from presentation to hungry roof rats were similar to those made to replete rats; both plastic materials exposed in tension positions were attacked and all the grain inside consumed by the same individual rat that attacked the plastic sheeting in the previous experiment. It was concluded that this individual was particularly aggressive, damaging plastic sheeting even when fed under optimal conditions.

Table 3: Average damage levels* of the different plastic sheeting materials exposed in tension position to rats (*Rattus rattus*) and mice (*Mus musculus*) under restricted feeding.

Rodent species	Sheeting material	Replicates	Level of damage (after exposure) 1st day	1st week	2nd week	3rd week	4th week
Rattus rattus	CPE	4	0	1	1.25	1.25	1.25
	PVC	4	0	1	1.25	1.25	1.25
Mus musculus	CPE	4	0	1	1	1	1
	PVC	4	0	1	1	1	1.25

* According to the same damage scale as in Table 2.

Conclusions

The results show that mice and rats attacked plastic sheeting in the folded position even in the presence of another food source, but failed to attack plastic sheeting under tension. From this it is evident that the tension factor is important in preventing rodent damage in field situations. PVC sheeting material proved to be more resistant than CPE to attack by both rodents species. Mice and rats kept partially deprived of food were able to attack PVC plastic sheeting even under tension. Under abnormal conditions absence of sufficient food, although limited, rodents may cause damage to plastic sheeting. If this damage occurs it is extremely rare and it describes a very specific situation of food supply in the field. The laboratory findings strengthen the hypothesis that rodents in the field find difficulty in gaining a tooth-hold on the plastic material when it is under tension and without folds.

5.3.3.- **Development of a preliminary predictive model (Israel)**

(This section is part of a more detailed publication (Navarro *et al.*, 1994))

Materials and methods

In view of the complexity of the grain bulk ecosystem prevailing under gastight conditions, we proposed to use a simulation model to rapidly analyze numerous situations, and describe the critical limits of the different factors. The preliminary model was built to run numerical experiments to investigate the influence of degree of gas-tightness of the structure, expressed as the rate of O_2 permeation through the storage membrane, size of the grain mass, volume of the treated structure, number of initial insect/kg of grain, respiration rate of the mixed insect population, and birth and death rates of the species on changes in O_2 concentrations in the storage, changes in insect population, and amounts of grain consumed by the insect pests.

The preliminary version of the model was a first approximation of the system built to study the influence of the physical characteristics of the storage structure as well as effects of an initial insect infestation. The main state variables that defined the dynamics of the system were O_2 concentration, number of insects and loss in grain weight. The model was written using the modeling package STELLA (Pytte and Doyle, 1984) developed for Macintosh personal computers. Values of structural membrane permeabilities were based on laboratory measurements. Birth and death rates were estimated from field observations obtained from storages under aerobic and gastight conditions. At present the main assumptions of the preliminary version of the model are:

a) That oxygen is distributed uniformly throughout the grain mass and no gas stratification occurs;
b) The CO_2 effect on insects and CO_2 sorption by grain are ignored.
c) That the temperature of the grain mass is uniform, and therefore moisture migration due to temperature gradients is ignored;
d) That the influence of wind on the structure is negligible.
e) That influences of changes in temperature and barometric pressure are ignored.
f) That insect distribution is homogenous in the grain mass.
g) That the storage structure is cube shaped.
h) That no head-space volume exists. The volume of the structure is occupied by the grain mass with an interstitial air space of 45% and a bulk density of 750 kg/m^3.

Results

Calculated changes in oxygen concentration in gastight storages

Influence of different initial insect populations

For this exercise a fixed O_2 permeation 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 concentrations in response to different initial insect populations are illustrated in Fig. 3. Accordingly a cyclic change in concentrations is obtained as a result of O_2 permeation and the ability of insects to survive at low O_2 levels. These theoretical cyclic changes in O_2 concentrations were also observed in various 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 results indicated that there was a residual insect population even after an extended storage period of one year. This is shown by the continuing fluctuations in O_2 levels before a steady-state is reached (Fig. 3). This result was corroborated by field observations which showed that a residual population may remain when the grain is re-exposed to normal atmospheric air, though under the gastight conditions and restricted O_2 supply their reproductive capacity was limited (Burrell, 1980; Navarro *et al.*, 1993). There is only limited data in the literature regarding respiration of mixed population of insects (Birch, 1947; Calderwood, 1961; Carlson, 1966, 1968; Chaudhry and Kapoor, 1967; Keister and Buck, 1974; Park, 1936). Furthermore the respiration of these insect species under low O_2 tension has not been well documented (Donahaye, 1992; Navarro, 1974). To determine the changes in O_2 levels under different gastight conditions, more information is needed on the contribution of different species to O_2 consumption at low O_2 tensions.

Influence of membrane permeability levels

To clarify the importance of membrane permeability in a specific situation, the model was run with an initial infestation of two insects/kg at different levels of O_2 permeation rates for a 10 m^3 cube containing grain as above. Results obtained with O_2 permeation rates of 0.05, 0.12, and 0.24% O_2/day, at an initial infestation level of 2 insects/kg, are shown in Fig. 4. The calculated line for the 0.05%O_2/day permeation rate differs significantly from the lines with higher permeation rates. At the 0.05%O_2/day permeation rate, after a minimum O_2 level was reached the increase in O_2 concentration followed the O_2 permeation rate of a structure without insects. This exemplifies the importance of reducing the O_2 permeation rate levels below which the residual insect population can be eliminated from the grain.

Fig. 3: 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 permeation rate of 0.24%/day.

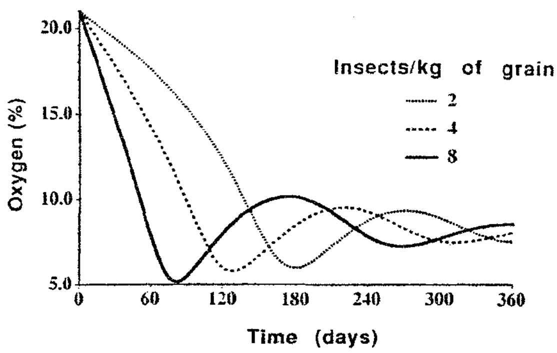
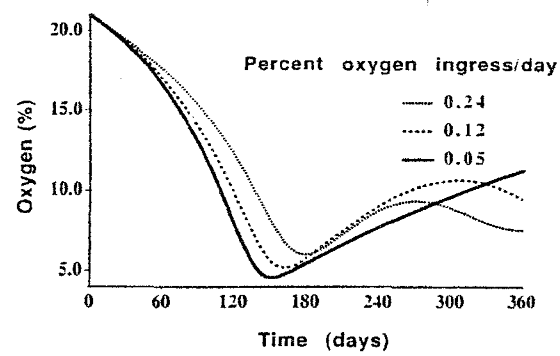


Fig. 4: Calculated oxygen concentrations in a 10 m^3 grain mass containing a fixed level of initial infestation of 2 insects/kg, having an oxygen intake of 157 µl/insect/day using a sealed liner at different oxygen permeation rates.



Calculated grain losses in gastight storages

Influence of different initial insect populations

In the model, the dry matter loss was calculated on the basis of O_2 required for oxidation of carbohydrates utilized in the process of insect metabolism. The model was run with the same parameters as used in Fig. 2, and the results are shown in Fig. 5. Calculated weight losses obtained with a gas permeation rate of 0.24%O_2/day at the three infestation levels indicated that losses over a one-year period ranged between 0.050 and 0.058% of initial weight. Observed weight loss (count and weight method) due to insect activity in a 15,500 tonnes capacity bulk storage held under sealed conditions over a 15 months period was 0.15% (Navarro *et al.*, 1984). The differences between field results and the model estimate may be partly derived from difficulties in obtaining accurate evaluation of the field trial.

Influence of membrane permeability levels

The model was run with an initial fixed infestation of two insects/kg at O_2 permeation rates of 0.05, 0.12, and 0.24% O_2/day for a 10 m3 cube containing grain. Results in Fig. 6 show that an O_2 permeation rate of 0.05%/day was sufficient to arrest the theoretical weight loss at a level of 0.018% over a one-year storage period, whereas for higher O_2 permeation rates, the weight loss continued to rise in proportion to the O_2 permeation rate. At a permeation rate of 0.05%O_2/day insect development was arrested and therefore the possibility of a residual surviving insect population is eliminated. This low O_2 permeation level, is difficult to obtain in rigid structures, but is achievable in practice using flexible tarps or liners. It could serve as a guideline for the sealing specifications of structures appropriate to the gastight storage method. With a permeability level of 81 ml O_2/m^2/day using a flexible liner 0.83 mm thick, a structure with a capacity of more than 10 m^3 would meet this requirement.

Fig. 5: Calculated weight-loss from 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 permeation rate of 0.24%/day.

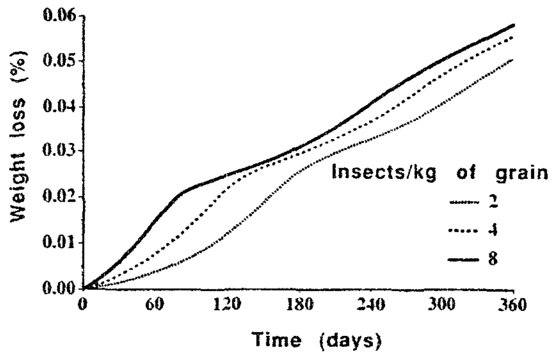
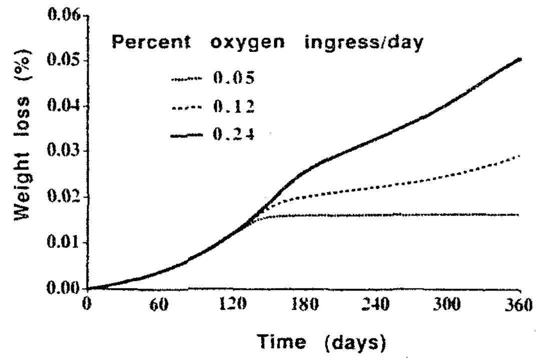


Fig. 6: Calculated weight-loss from a 10 m^3 grain mass containing a fixed level of initial infestation of 2 insects/kg, having an oxygen intake of 157 µl/insect/day using a sealed liner at different oxygen permeation rates.



5.4.- FIELD STUDIES

5.4.1. Design, construction and testing of experimental stacks (Israel):

Plastic silos

The silos were made up of two units: an outer weldmesh cylindrical wall to provide the structural enclosure and an inside liner made of heavy duty PVC sheeting welded to form a continuous wall-floor unit into which the grain was placed. The lining came in two parts; the lower wall-floor unit and an upper liner forming a roof cone (Fig. 7). The roof cone was secured to the metal welded mesh walls by ropes. The enclosures were also provided with hooks to be fixed to the wire mesh. These liners when zipped together using a gastight zipper, provided the gastight seal for the storage container (Fig. 8). The silos were designed to enable bulk storage or bag storage, with mechanical loading and unloading, with the intention of providing a useful transition phase between bag and bulk handling. The silos used in these experiments had a storage volume of 53 and 90 m^3.

Storage cubes

Flexible cube-shaped envelopes 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. For this purpose a heavy-duty plastic tarpaulin, UV protected, and of food-grade quality, was manufactured in two sections. The lower section was laid on the ground and the bags of grain were placed directly on the tarp. Pallets were not required. 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 tarp was then placed over the stack to meet the lower section half way up the side. Both the "undersection" and "oversection" 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 do 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 tarpaulin tight around the curve of the sacks at floor level. This was done to prevent rodents from gaining a tootholdon the slippery surface and damaging the gastight seal. Cubes were fabricated in 10, and 20 ton capacity sizes. Cubes used in the trials were of all sections of PVC (Israel and the Philippine), all sections of CPE (Israel), and CPE top sections and PVC bottom sections (Philippines).

The 20 ton cubes measured 4.45x3.3.6x 2.00 m (l x W x h) with a maximum storage volume of about 30 m3 and weighed about 76 kg when empty. Dimensions of the 10 ton cubes were 3.36 x 2.95 x 1.5 m ((l x w x h) giving a maximum storage volume of 15 m^3 · Each cube was provided with a light carrying bag in which it is stored and protected from rodent attack when not in use.

The zipper: This consisted of a double or triple tongue and groove type zipper made of polyurethane. It had the advantage of being pliable over a wide range of temperatures and was resistant to deformation.

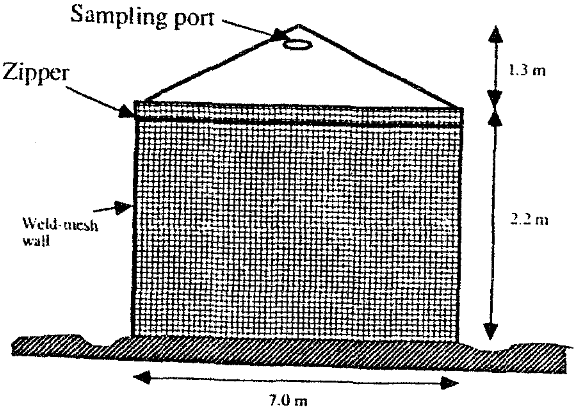


Fig. 7 - Schematic lateral view of a 90.4 m^3 capacity silo with weld-mesh wall.

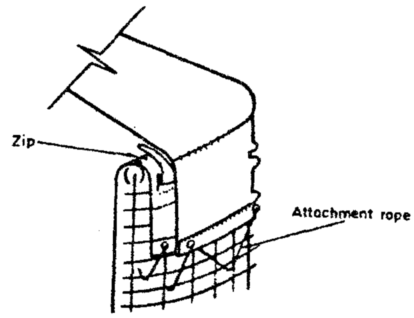


Fig. 8 - Method of securing roof-cone to floor-wall unit and weld-mesh walls in silos.

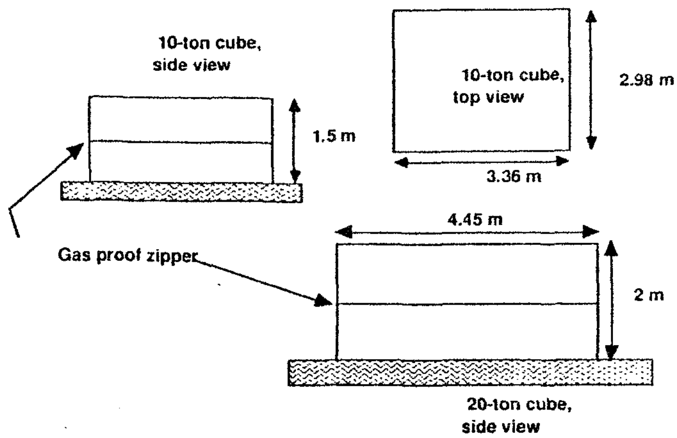


Figure 9 - Plan of 10 and 20-tonnes capacity cubes for bag storage of grain.

The gas applicator: This consisted of a ball-and-socket gas tap attached to an expansion chamber that passed through the plastic sheeting into the cube and was screwed with a gasket seal onto the tarp. The tap may be connected directly to the gas cylinder by tubing ending in snap-on connectors. The principle of adaptation of the cube for MA treatments is that the gas (preferably CO_2) can be supplied fairly rapidly (in liquid form) to flush through the stack so that the intergranular air is displaced and expelled through an upper screw-capped opening situated in the opposite corner of the oversection.

Integrity of the plastic tarps or liners and gastightness tests (inflated empty cubes).

The following tests were made on the empty cubes to evaluate the gastightness level.

i) Introduction of colored smoke from smoke-generators into the inflated cube;

ii) Daily measurement of decrease in height of the inflated cube;

iii) Carbon dioxide flushing followed by daily readings of CO_2 concentrations within the sealed cubes;

iv) Constant pressure test. Measurement of gas loss across the plastic by recording air-flow rates necessary to maintain constant pressure within the inflated cube.

The results of the above tests failed to reveal leaks in any of the tested cubes.

Gas tightness tests by carbon dioxide flushing of the filled cubes

A PVC storage cube was filled with 210 50kg sacks of wheat, flushed with 25kg CO_2 (app. 2.5kg CO_2/tonnes) using the single shot technique with liquid CO_2 applied by laying the cylinder horizontally, and CO_2 concentrations were monitored. Three repetitions of this procedure showed that the decrease from initial concentration of 84 - 91% CO_2 to below 30% took more than 30 days indicating that the tarp was satisfactory for the CO_2 flushing procedure (MA technique) in spite of the relatively high permeability to CO_2 (1.75 - 3.6%/day) (Fig. 10).

Two tests were carried out with cubes made of CPE tarp. The CO_2 flushing technique revealed that the daily decrease in CO_2 concentration ranged from ~3% at the higher levels, to less than 0.5%/day at 50 - 60% CO_2 (Fig. 11). After both flushing with CO_2, negative pressure was produced inside the tarps due to sorption of CO_2 by the grains. In the second case a negative pressure of up to 4 mm water was recorded for 6 days after flushing. These results showed that the lower CO_2 permeability rendered the CPE tarps more suitable for CO_2 flushing techniques. Grain was stored in the CPE tarp at the Bet Dagan site for 6 months, grain quality (moisture, germination) was monitored and it was on the basis of these findings that the first trial cubes to the Philippines consisted of a CPE oversection and PVC undersection.

Fig. 10: Carbon dioxide concentration and daily decay rate in a PVC cube containing 10-tonnes of wheat.

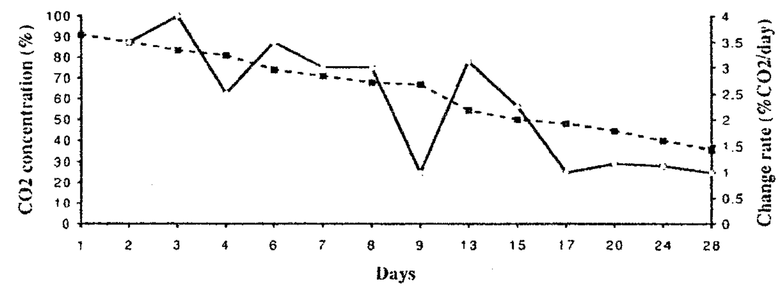
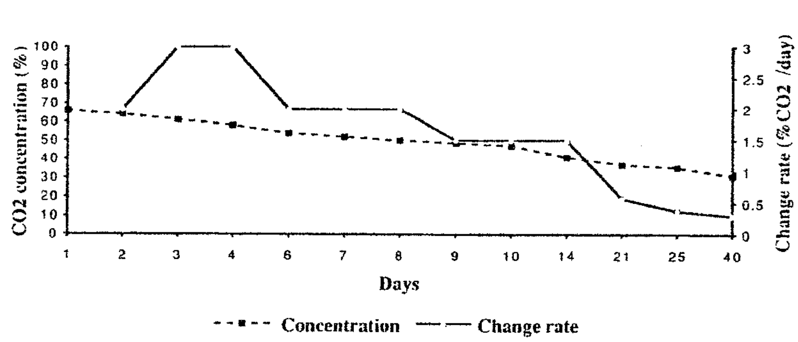


Fig. 11: Carbon dioxide concentration and daily decay rate in a CPE cube containing 10-tonnes of wheat.



Decay rate of CO_2 in cubes containing 10 tonnes of wheat ranged from 0.33 - 1.6% CO_2/day for the CPE tarps as against 1.75 - 3.6%/day for the PVC tarp.

5.4.2. **Performance of a 10 tons capacity cube containing wheat under gastight storage (Israel)**

Materials and methods

For temperature monitoring, 15 thermocouple cables were placed at different locations inside the PVC cube. To analyze gas composition, 3 plastic tubes was inserted inside the cube. The temperature and the atmospheric composition inside the cube were monitored weekly. Ambient temperatures and humidities were obtained from a meteorological station adjacent to the storage site.

Grain samples were taken at the time of loading and at the time of unloading from predetermined sites at the periphery and center of the top, middle and lower segments of the cube to evaluate insect infestations. The cube was unloaded after 11 months. The cube contained 10.17 tons of wheat stored in 198 bags. This wheat had remained in the open for one month before storage and consequently was exposed to infestation from the surroundings before storage began. No chemical treatments were given to the grain before or during storage.

Results and Discussion:

Infestation: At the beginning of the storage the infestation level was moderate (average of 6.5 live insects (LI)/kg of grain (Table 4). The live infestation consisted of *Tribolium castaneum, Rhyzopertha dominica, Oryzaephilus sp., Cryptolestes sp.,* and *Sitophilus oryzae.* At the end of storage no live insects were recorded from any of the sampling sites.

Gas composition: The CO_2 concentration increased rapidly over the first two weeks of storage to 14%, accompanied by a decrease in O_2 concentration to 2% due to insect respiration.

Subsequent mortality is attributed to these concentration changes (Fig. 12). However these gas concentrations were not maintained over the following storage period, and there was a gradual decrease in CO_2 and increase in O_2 concentrations over the following 8 weeks due to permeation of O_2 and CO_2 through the plastic tarp. During the subsequent 11 months of storage, there were 4 more cycles of sequential increases and decreases in CO_2 concentrations with corresponding decreases and increases in O_2 concentrations. These cycles indicate that there remained a small residual insect population whose development was not completely suppressed by the unfavorable atmospheric composition.

Temperature: The cube has a relatively small volume in proportion to surface area. Therefore the temperature of the grain was influenced strongly by the ambient conditions. Thus the inside temperature (average of 3 measurement points) during the summer months reached 30-35°C and in the winter months it fell to 10-12°C. There was no indication of spontaneous heating throughout the storage period.

Moisture content: The grain was received for storage at an average moisture content (MC) of 12.16%. At the end of the storage period the average MC was 12.28%. There was no indication of moisture migration as recorded from the samples taken from different sections of the grain bulk at the beginning and end of storage.

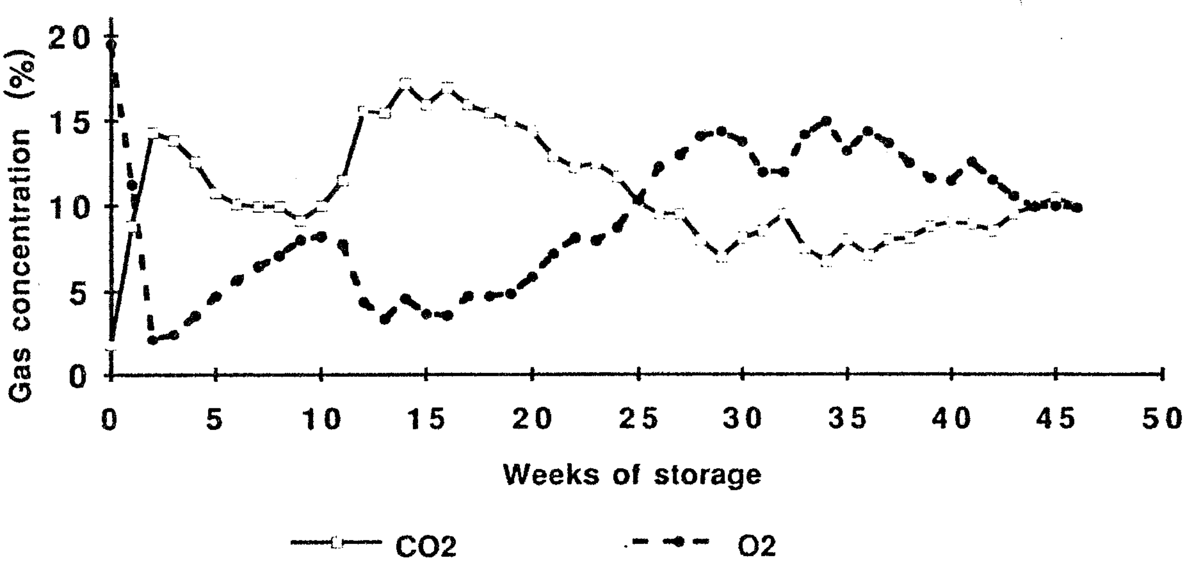


Fig. 12 - Gas concentrations measured in the gastight sealed cube containing 10 tonnes of wheat.

Table 4 - Grain quality data of the 10-tonne cube.

	At beginning of storage	At end of storage
Average live insects per kg	6.5	0.0
Average dead insects per kg	19.6	64.4
Average MC, %	12.16	12.28

5.4.3. Comparative study of different methods to protect the floor of plastic structures from underground rodent activity (Israel)

Materials and methods

This trial was conducted in conjunction and as part of the previously reported field trial using a PVC cube (Section 5.4.2.). The ground was leveled and cleared of sharp objects. A rectangle equal in dimensions to the floor of the cube was marked on the ground (length: 336 cm, width: 295 cm), and this was sub-divided into five smaller rectangles. Each rectangle was covered with a different protective material as follows:

Protective material A - 5 cm thick of sea-sand.
" B - 5 cm thick of gravel (particles size 8-13 mm).
" C - sheet metal (56 by 100 cm) (1 mm thickness).

" D - aluminum foil (80 by 180 cm)(0.04 mm thickness
Unprotected floor E - control (clay soil).

Results and Discussion:

During the trial rodents holes were noticed in the ground outside the cube opposite the area of unprotected floor (E).

The ground beneath the cube was examined after the storage period of 11 months, when the cube had been unloaded.

Protective material results after dismantling of the cube showed that:-

Protective material A - was found to be free of rodents and without any sign of such activity.

Protective material B - no rodent activity was noticed. However, due to the weight of the stack upon this layer, indentations into the liner by the gravel were noticed, but no damage was caused to the plastic material.

Protective material C - the sheet metal was in good condition. No rodent activity.

Protective material D - the aluminum foil was physically disintegrated and partly damaged. However, no rodent activity was noticed.

Unprotected floor (E) - rodent tunnels were noticed in the unprotected section of the ground. The rodents had dug the tunnels from the side of the cube underneath it, using the lower section of the tarp as a roof but without penetrating the cube itself.

The tarp was found to be in good condition, without damage to the floor or walls except for 5 holes of about <1 mm in diameter in the unprotected section of the floor, the origin of which was suspected to be rodents.

Sand provided efficient protection against rodent penetration and underground activity. This method is relatively cheap and easy to use where available. In areas without sand, we believe light soils or ash can provide similar protection.

Gravel also provided effective protection. However, it is relatively expensive and is not always available.

Sheet metal provided excellent protection, against rodent activity, but is still too expensive in most situations, and not common in many developing countries.

Aluminum foil was too delicate and not suitable for such use.

It appears that where feasible, a protective layer made from the cheapest local material available is most advisable. Where possible cubes should be placed on sandy or very light soils (e.g. "dior" or "loess"). Failing this, compacted or cemented surfaces should be considered (e.g. drying floors). Only as a last resort should the cubes be placed on heavy soils, and under these circumstances particular attention should be paid to the identification and control of rodent infestations.

In some areas of the Philippines the availability of ash, as a by-product of burnt rice hulls was observed. In those trials carried out in the Philippines ash was used successfully as a protectant against sharp objects and also against rodents and termites.

5.4.4. **Moisture migration within the storage cubes (Israel)**

Materials and methods

The cube: The storage structure is a brief description of the 10 ton cube used at Bet Dagan. The cube consisted of two sections of flexible CPE, an upper and lower section.

Loading: The cube was loaded with 50 kg sacks of wheat stacked cress-cross in eight layers within the lower section of the cube to a height of 1.5 m. The stack consisted of 4 layers of 26 sacks and 4 layers of 24 sacks plus a central row of 7 sacks giving a total capacity of 10,000 kg. After loading, the upper tarp was placed over the stack, the cube was sealed, and the tension straps were adjusted.

Temperature monitoring: Temperatures were monitored over several months by inserting T type thermocouples into the cube at progressive distances from the upper surface and recording readings at 20 minute intervals over a 24 hour period using a data logger.

Temperature measurement points were:

Point 1: Attached to the upper side of the plastic tarp at the top center of the cube.
Point 2: Attached to the jute fiber of the top of the sack beneath point 1.
Point 3: 5cm within the grain beneath point 2.
Point 4: 10 cm within the grain.
Point 5: 20 cm within the grain (at the bottom of the sack).
Point 6: At the center of the cube (at a depth of 40 cm beneath point 1).

Insulation with a felt layer: The efficacy of an insulating layer of "felt fiber" material placed over the upper layer of sacks directly beneath the top tarp was examined.

For comparison, the cube was opened, one half of the upper surface of the stack was covered with the insulating layer (1cm thick) and one half was left uncovered. The upper tarp section was replaced and the cube was zippered up. The temperatures in both sectors were monitored simultaneously. In this trial the insulating layer was placed over the southern sector of the cube.

Insulation with agricultural wastes: In these trials wheat straw was used instead of the felt layer. Sacks were filled with straw and laid over the top of the stack, each sack being c. 10 -15 cm thick. Initially the straw insulated sector was over the southern half of the cube to enable comparison between the straw and the felt layer (Fig. 13).

Tests on position of cube in relation to trajectory of the sun.: In this trial, the straw layer was removed from the southern sector of the cube and placed over the northern sector and temperatures were again monitored for 24 h periods.

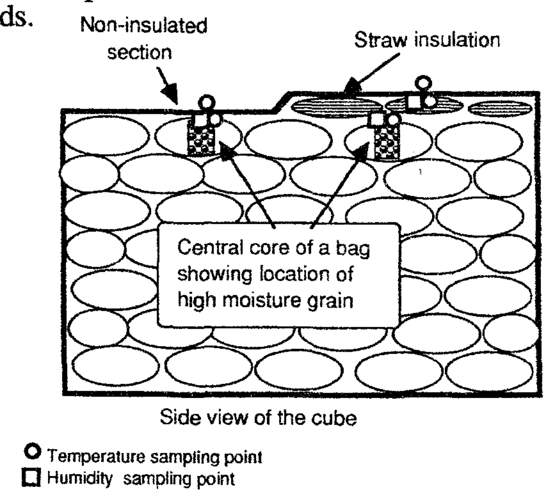


Fig. 13 - Sampling points in trials with straw insulation material.

Influence of grain moisture content on humidity fluctuations beneath the tarpaulin with and without straw insulation: In order to examine the influence of diurnal ambient temperature fluctuations on insulated and non-insulated storage cubes containing grain at different intermediate moisture contents, 6 storage trials were undertaken.

In each trial the northern sector was covered with an insulating layer of sacks containing straw. The southern sector was left exposed. At the top center of one sack in each sector, a 15cm diameter core of wheat was removed by pressing a section of rigid PVC piping into the sack from above to the bottom of the sack (c. 35-40 cm) and then removing the grain from within the pipe by hand. This grain was then replaced by grain that had been previously moistened to a pre-determined moisture content. A humidity sensor (NovaSina model EnPS-4 with capability of measuring up to 100%RH, with built-in heating to protect the sensor from saturation) was then placed together with a t-type thermocouple cable on top of the grain and linked to a data logger (Data Electronics, Australia "Model: Data-taker DT100F 54 channel field logger) together with thermocouples attached to the upper layer of the tarp (Fig. 13). The cube was then resealed and temperature and relative humidity were recorded sequentially from the insulated and non-insulated sectors of the cube over a 24 hour period.

The trials were run using wheat at 12%, 13%, 14%, 15%, 16%, and 17% MC respectively.

Results and Discussion:

Results of the trial are given in figs. 14 to 16. The results show that the temperature fluctuations below the felt insulating layer were only slightly less than those below the non-insulated tarp (Figs 14a and 14b). From this it may be concluded that the insulating properties of the felt layer had little effect on temperature fluctuations.

From Fig. 14c it can be seen that the straw layer provided better insulation than the felt layer. A range of 14oC was observed between the upper plastic tarp and beneath the straw layer over the 24h period, as opposed to 18.8oC between the upper section and beneath the felt layer, while the range between the upper layer and beneath the tarp were 21.1 and 21.6oC respectively .

The results show an even greater dampening effect on temperature fluctuations beneath the straw layer when this was placed over the northern section of the cube (a diurnal range of 6.4°C), and indicate that the position of the cube in relation to the sun trajectory also contributes to the temperature fluctuations beneath the tarp.

The results of trials using wheat at 13%MC are shown in Figs 15a and 15b. The recordings show that the reduction in temperature fluctuation at the top of the stack in the insulated sector resulted in a humidity fluctuation above the 13% MC wheat-core of 4.9% with a maximum of 69.5%RH. In contrast the humidity fluctuation below the non-insulated sector of the tarp was 52% with a maximum of 75% RH.

Further trials show that beneath the non-insulated sector of the tarp at the top of the stack, the diurnal temperature fluctuations remained high independent of the season, and ranged between 17.9 and 27.6°C. In contrast, for the insulated sector, diurnal temperature fluctuations ranged between 3.9 and 7.7°C (Figs 16a and 16b). The influence of temperature fluctuations on relative-humidity fluctuations at the different wheat MC was also investigated. For the non-insulated sector, the higher the grain moisture content the longer the air beneath the liner remained at very high relative humidities. However, no recordings of actual air saturation were logged, probably because air currents were mixing the air above the core of damp wheat with the air above the surrounding wheat of the sack.

Fig. 14a: Temperature fluctuations in the non-insulated sector of CPE cube.

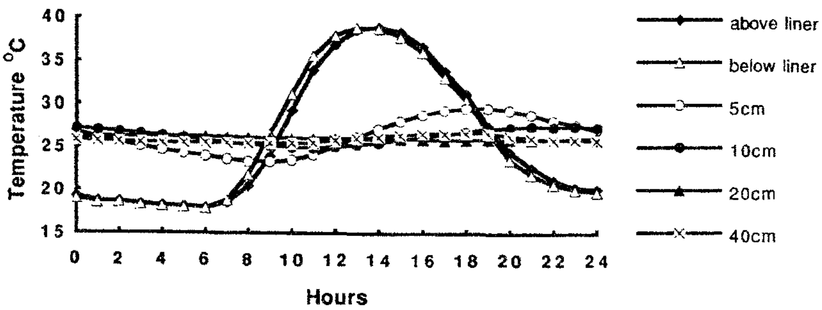


Fig. 14b: Temperature fluctuations in the blanket (felt-fiber) insulated sector of CPE cube.

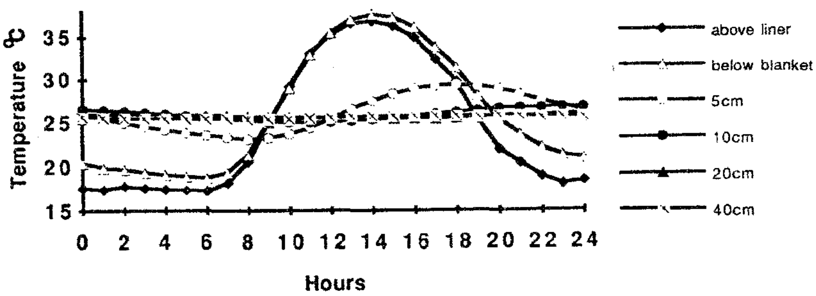


Fig. 14c: Temperature fluctuations in the straw insulated sector of CPE cube.

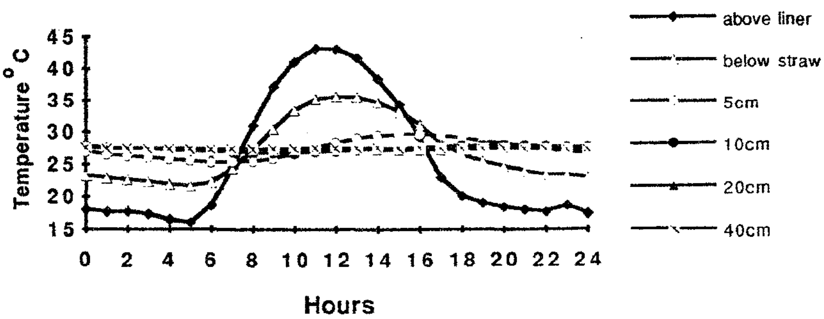
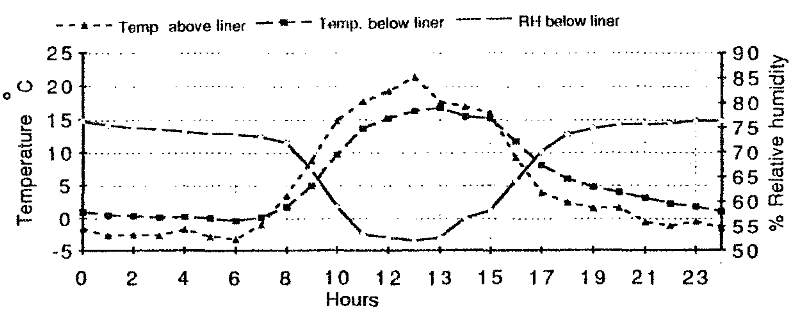


Fig. 15a: Temperature and relative humidity fluctuations in the non-insulated sector of CPE cube containing wheat at 13% moisture content.



In order to evaluate whether condensation would occur in a real-life situation, and whether the condensation at night, as the air cools, would have a greater influence than the drying effect as the air above the sacks warms up during the day, calculations were made to estimate the number of hours per 24-hours of saturated air at the top of the stack, for both the insulated and non-insulated sectors at the different grain moisture contents. Results showed that for the insulated sector, only at 17% MC would there be a period (2hrs) during which air at the top of the stack would be saturated (Table 5). However, for the non-insulated sector calculations show that for wheat at 12 to 15% MC, saturated air would be expected for 10 to 11 hours during the night time; while for 16 to 17% MC wheat the saturation period would be 15 hours. Clearly under the latter conditions the moistening effect at night would be greater than the drying effect during the day and the trend would be to an increase in moisture content of the surface layer of grain.

Fig. 15b: Temperature and relative humidity fluctuations in the straw insulated sector of CPE cube containing wheat at 13% moisture content.

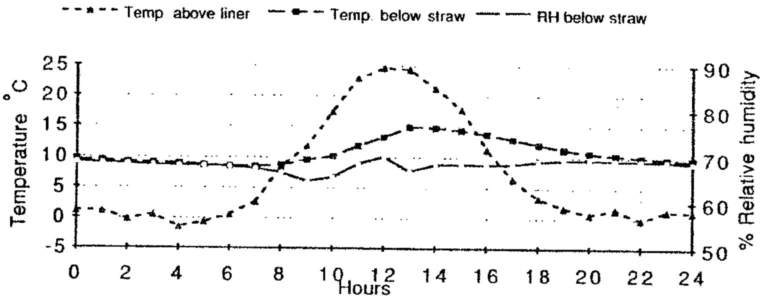


Fig. 16a: Temperature and relative humidity fluctuations in the non-insulated sector of CPE cube containing wheat at 17% moisture content.

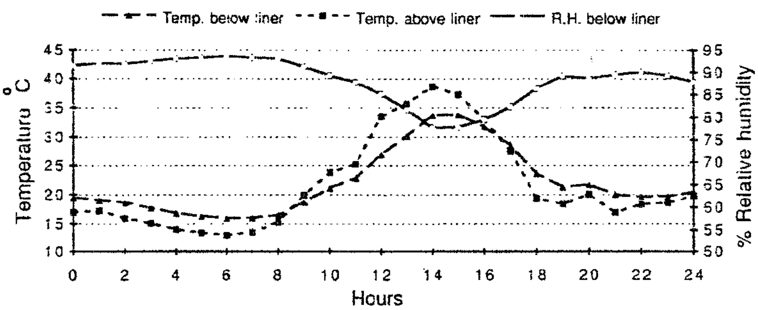


Fig. 16b: Temperature and relative humidity fluctuations in the straw insulated sector of CPE cube containing wheat at 17% moisture content.

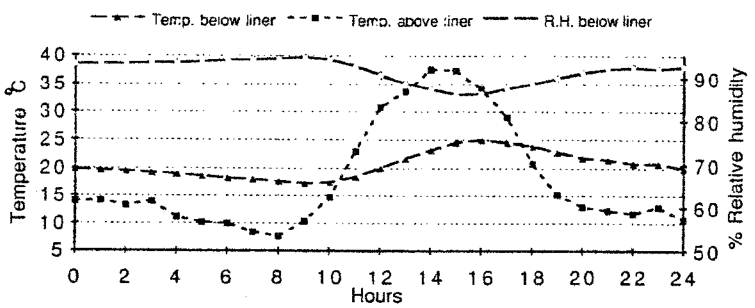


Table 5: Projected duration of saturation of air beneath the tarp for different grain moisture contents in CPE cube.

			insulated sector - *below insulation*					non-insulated sector -*below liner*				
Date	M.C. ***	ERH **	Max temp.	min. temp.	H_2O in air (g/m^3) at mean temp	ST*	hrs saturation	Max temp.	min. temp.	H_2O in air (g/m^3) at mean temp	ST*	hrs saturation
22 Apr. 92	12	62	24.4	18.2	11.4	13.0	0					
7 May 92	12	62						36.1	15.5	15.0	17.5	10
5 Jan. 92	13	68						16.8	-0.3	5.7	2.0	11
8 Jan 92	13	68	14.8	8.44	7.3	6.0	0					
28 Jun.92	14	73						42.6	21	23.4	25.0	10
30 Jun.92	14	73	32.3	28.4	22.6	24.5	0					
24 July 92	15	76						39.4	21.4	23.5	25.5	10
29-July 92	15	76	34.7	27.4	24.4	26.0	0					
20 Aug. 92	16	81	34.1	29.7	27.5	28.0	0					
27 Oct..92	16	81						39.1	11.5	18.7	21.5	15
4 Nov.92	17	82						33.8	15.9	18.9	21.2	15
12 Nov. 92	17	82	24.9	17.2	15.1	17.5	2					

* Saturation temperature; ** Recorded by Nova Sina; ***Measured by oven method

5.4.5. *Long term storage and moisture migration within a plastic silo containing wheat (Israel)*

Materials and methods

The silo was 7 m in diameter, formed by a structured wall consisting of four sections of weld-mesh to form a circumference of 22 m. The silo had a volume of 90 m^3 and was loaded by sucker-blower with 73 ton of locally grown wheat. To minimize damage to the liner the silo was erected on a layer of sea-sand 5-10 cm thick.

The grain temperature was recorded by nine thermocouple cables inserted into the silo. Thermocouples 1-5 were placed from ground level to the top of the silo along its central axis. Thermocouples 6-9 were placed at a height of one meter, across the silo from North to South. Temperatures were recorded periodically. A gas sampling tube was inserted to the center of the silo to measure the gas composition of the intergranular atmosphere. Periodical tests were carried out to determine the CO_2 and O_2 concentrations of the silo atmosphere.

An insulation sheet 3m by 1.5m, and 4mm thick consisting of synthetic flexible fibers, was spread over the top of the grain (Fig. 17).

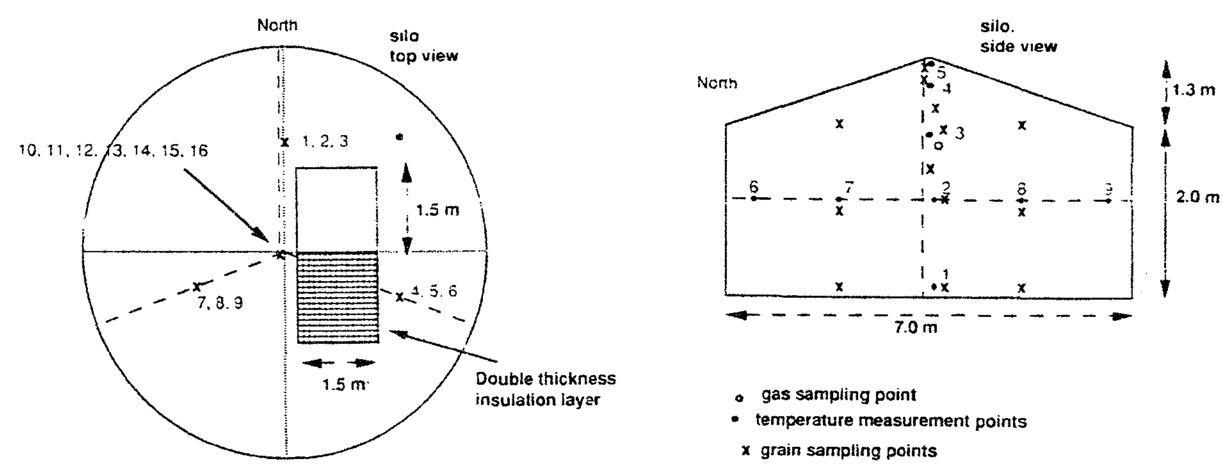
Grain samples, were taken through a sampling port equipped with a screw lid positioned at the center of the silo roof. Samples were obtained from the different depths using a "Graniscope" grain sampler. Every month 5 samples were taken and tested for moisture content and insect infestation. To prepare for evaluation of weight loss during the storage period using the thousand grain mass (TGM) method (Proctor and Rowley, 1983), 16 grain samples were taken at the time of loading, from different sites in the silo, and again from the same places at the time of unloading. Additional samples were taken from locations accessed through the sampling port on the roof of the silo. These samples were taken after 48 months storage at points 1 to 11, 13, 14, and 15 (Fig. 17).

Results and Discussion:

Gas composition of the silo atmosphere:

The CO_2 concentration increased gradually up to about 10% at the twelfth week of storage and remained relatively high until the end of the observation period (Fig. 18). The occasional peaks in oxygen concentration and drop in carbon dioxide concentration during storage were attributed to air penetration of the roof unit to the wall-floor unit during grain sampling (for the deep layers a suction probe as described in the materials and methods, was used). The increase in CO_2 level was accompanied by a decrease in oxygen concentration to a minimum of about 5%, followed by a gradual increase over the following 48 months of storage (Fig. 18).

Fig. 17 - Temperature measurement points, grain and gas sampling points, and location of flexible insulation liner of the 90.4 m^3 capacity silo containing 73 tons of wheat.



Temperature:

The temperature inside the silo was influenced by the ambient temperature. This influence was apparent from measurements taken at the inner and outer regions of the bulk (Fig. 19). During the summer months average temperatures at the sampling points ranged from about 25 to 35°C and during the winter months they decreased to about 15 to 22°C. No indications of spontaneous heating were observed.

Grain Quality:

Grain moisture content: Average moisture contents of samples taken during loading and unloading of grain showed very little change ranging between 10.6 and 10.7%MC. As expected for gastight storage the average MC remained stable at this level over the first year During the second year there was an increase in moisture close to the peak of the silo where recordings in November registered 12.7 to 13%MC.

Germination: Germination was only slightly influenced and remained between 93 and 100% throughout the observation period (Table 6). Average germination of initial samples of wheat were 99.5% falling to 97% after 48 months of storage.

Weight loss measured by TGM: Samples taken after 43 months storage from the accessed sites did not show significantly different loss in weight values than those taken initially (Table 6).

Insect Infestation: An initial infestation principally by *Rhyzopertha dominica* was observed. Infestation levels as recorded by the number of live and dead insects per sample showed that at the beginning of the storage period, infestation was relatively low, with about 3 live insect/kg. After the first month, live infestation had decreased and during the first year of storage only a few dead insect were found.

Fig. 18 - Changes in gas concentration within the silo containing 73 tonnes of wheat during 48 months storage period.

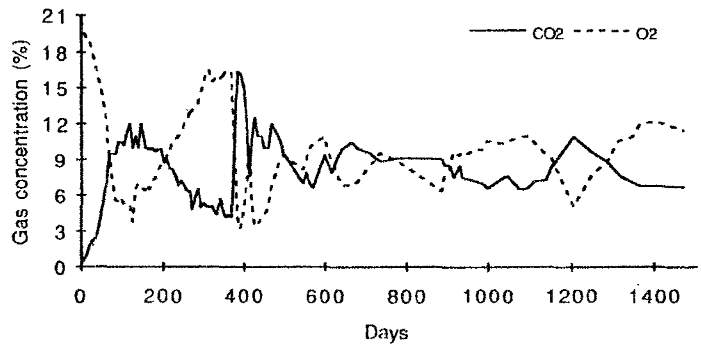


Fig. 19 - Changes in temperature of inner layers and outer layers of the grain within the silo containing 73 tons of wheat during 48 months storage period.

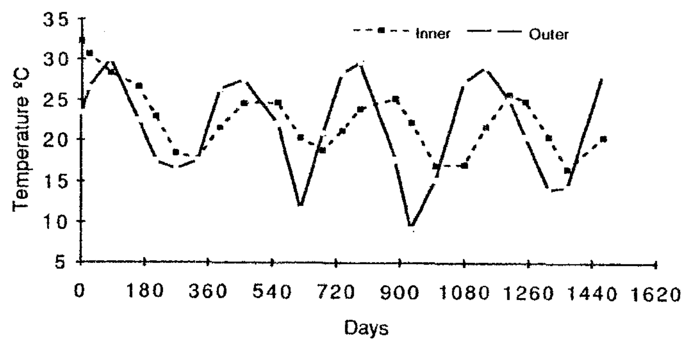


Fig. 20 - Changes in moisture content of the upper layers of the grain in the silo containing 73 tons of wheat during 48 months storage period.

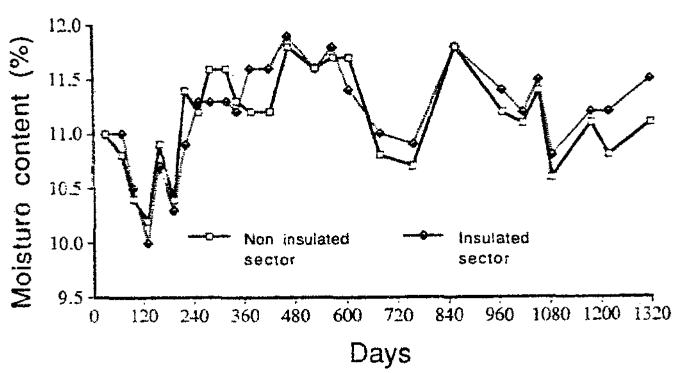


Table 6.- Data on moisture content, germination and weight loss based on samples of wheat taken at the beginning and after 48 months storage from 14 different depths of the silo.

	M.C. (%)		Germination (%)		TGM (gr)	
	Initial	Final	Initial	Final	Initial	Final
Average	10.63	10.71	99.50	96.93	33.65	34.35
S.D.	0.219	0.656	0.519	2.056	2.140	1.354

Although during the second year, there was an increase in the number of dead insects, it was only in July of the second year that significant numbers of live insects were again detected. This corresponded to an increase in CO_2 concentration and decrease in O_2 concentration (Fig. 18). Insect populations were markedly higher at the surface layer then in the deep layers of the bulk (Figs 21 and 22). Live insect populations at the surface of the bulk fluctuated between 0 and 8.6 insects/kg of grain throughout the storage period. The numbers of dead insects at the top layers of the bulk rose gradually during storage to a maximum and remained at an average of 63.7±20.3 (SD) dead insects/kg of grain. At the end of storage period no live insects were detectable in the deep layers of the bulk, while the average number of dead insects/kg was 3.7 (Fig. 22).

Fig. 21 - Infestation level of the upper layer of the silo containing 73 tons of wheat during 48 months storage period.

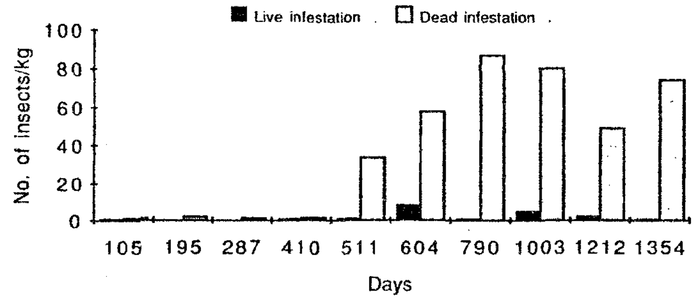
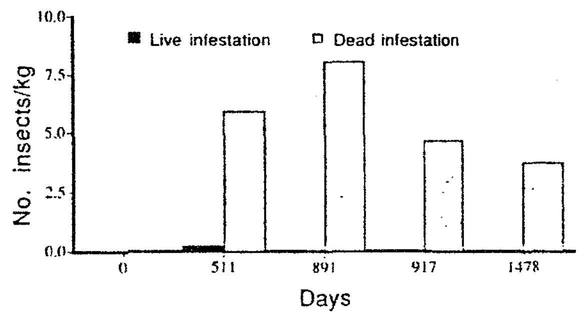


Fig. 22 - Infestation level of the deep layers of the silo containing 73 tons of wheat during 48 months storage period.



5.4.6. ***Corn storage trials (Philippines)***
(This section is part of a more detailed publication (Alvindia *et al.*, 1994))
Materials and methods

The corn trials were carried out at the NFA Compound in Aglayan, Malaybalay; at the FX Foundation in Pangantukan; and at Farmers Cooperative Incorporated (FCI) in Kisolon, Sumilao, all of which are in Bukidnon, Central Mindanao. Details of the field trials for corn are shown in Table 7.

Table 7- List of corn trials carried out in the Philippines.

		Structure		Treatment			Handling		
Trial #	Stack code	Cube	Silo	CO_2	Gastight	Control	Bags	Capacity (tonnes)	Duration of storage (days)
I-1	C1	x		x			x	18.45	93
I-2	C2	x			x		x	15.02	93
I-3	C3	x				x	x	4.75	93
II-1	C4	x			x		x	17.00	97
II-2	C5	x		x			x	16.62	97
II-3	C6	x				x	x	4.58	97
III-1	C7	x			x		x	19.25	112
III-2	C8	x			x		x	19.22	112
IV-1	C9	x			x		x	16.88	183
IV-2	C10	x			x		x	16.99	183
V-1	C11		x		x		x	38.73	184
VI-1	C12	x			x		x	16.77	148
VI-2	C13	x			x		x	16.77	148

Preparation of Storage Site A level portion of ground was selected and cleared of sharp objects. A 2 cm deep layer of rice hull ash followed by a 4 cm thick layer of rice hulls, was laid down in an area corresponding to that upon which the cube was to be erected. The rice ash and hulls were intended to protect the plastic sheeting from puncturing by sharp objects or rodents and to a limited extent, by termites. Rice hulls are an agricultural waste, readily available in many parts of the Philippines.

Experience in Bukidnon had shown that termites could damage the plastic sheeting. Therefore a standard practice was adopted to termite-proof the ground with chlordane before setting up a plastic cube or silo. A trench 1-foot deep was dug around the cube and flooded with a 2% solution of the insecticide at the rate of 1 gallon per linear foot. The floor area inside the trench was drenched with the same insecticide solution at the rate of one gallon per sq. ft.

Construction of Stack Insulation The bottom section was spread out on the ground and the bulk grain or bags of grains were built directly on the liner. Pallets were not required. After the stack had been built to the required height, the top section was then placed over the stack to meet the lower section halfway up the side and then zipped together to form the envelope. The stacks were built in a pyramid shape to allow rain water to run off immediately on the sides of the enclosure.

For cubes, the top layer of the stack was insulated with 2-3 layers of sacks containing corncobs (only during the first trial for corn) or rice hull. For silo, the cone shaped top surface was covered with a plastic sheet. Then 1-2 layers of bagged rice hulls were placed above the plastic sheet (Fig. 24). The layers of rice hulls or corn cobs aimed to reduce temperature gradients within the grain mass while the plastic sheet was designed to catch the water that would seep through the insulator and prevent the grain bulk from getting wet.

Control stacks were also set up consisting of stacks stored in the open on pallets, protected by ordinary tarpaulins.

Temperature and gas concentration monitoring Seven thermocouple cables and two plastic tubing with a diameter of 3 mm were installed at different locations inside the cubes (Fig. 23) and storage silo to monitor grain temperatures and gas concentrations, respectively. Temperature sensors were manually monitored with an Anritsu type-T model HL 600.

Temperature measuring points were located along the central axis of the silo below the liner top and below the insulation layer. Changes in the level of CO_2 and O_2 inside the cubes were measured every two weeks using the GOW-MAC gas analyzer and Bachrach Oxygen meter, respectively.

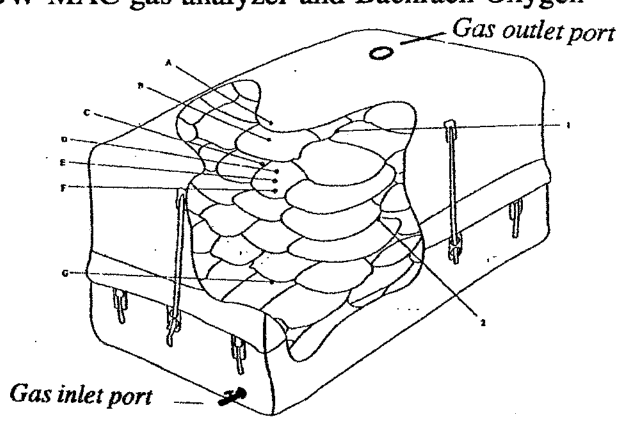


Fig. 23: Diagram of experimental stack, showing temperature and sampling points. Temperature sensors are located at sites : A- over tarp section; B- lower tarp section; C- below insulation; D- 5 cm inside uppermost bag; E- 10 cm inside uppermost bag; F- 20 cm inside uppermost bag; G- core of the stack. Gas concentration tubes are located at 1- lower tarp section; 2- middle core.

Gassing: Corn stacks in cubes were flushed with food grade CO_2 at a rate of 1.5 kg per ton (stack code C1 and C5). The gas applicator was as described previously (Section 5.4.1.).

Sampling: Initial samples were collected during the building of the stacks (cube and silo) and final sampling was undertaken to determine changes in the quality of the stored paddy and corn. Three composite samples of 1 kg each were collected from all bags in each stack using sampling spears. An additional 500 g sample was obtained from each of 15 individually marked bags which were distributed in different locations within the stack as it was built.

Quality evaluation: Moisture content determinations were carried out by drying grain samples for one hour in an oven (Anon., 1982). Live insects were sieved from the composite and representative samples. These were sorted according to group and species. The enumeration of fungal species on grains and the extent of fungal infection was determined by plating 10 seeds randomly taken from composite samples into each media of Aspergillus-Flavus-

Parasiticus Agar (Pitt et al., 1983); Diglycerol Glucose Agar (Hocking and Pitt, 1980); Dichloran Rose Bengal Chloramphenicol Agar (King et al., 1979) and Dichloran Chloramphenicol Agar (Nash and Snyder, 1962). Corn samples were first surface sterilized with 0.5% sodium hypochlorite before plating and then those plated on AFPA were incubated for 48 hours at 25^{0}C while those plated on other media were incubated for 7 days under the same temperature.

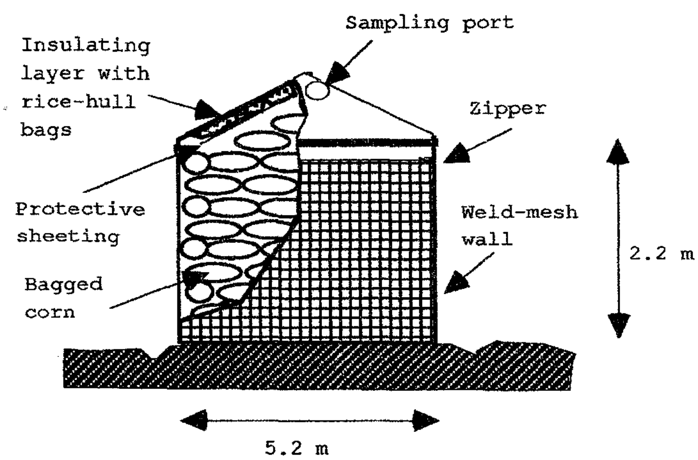
Two sampling procedures were adopted for the aflatoxin analysis using thin layer chromatography (TLC). The first procedure was based on two composite samples of about 20 kg collected randomly from all the bags that went into the stack. Each composite sample was then mixed well, after which three sub-samples were taken for analysis.

The second sampling procedure involved an initial aflatoxin test of the Rapid Screening Method using TARGET^R AFLA kits. Only corn grains with $\leq$20 p.p.b. aflatoxin content were used in the experiment. At the end of the storage, composite samples of about 10 kg each were collected from designated grids at the periphery of he stacks (North, South, East West and Top), and from core (Bottom and Middle).

The calculation of quality parameters was determined by hand counting the number of insect damaged, discolored, moldy and germinated kernels in 1000 kernel samples taken from composite samples. Viability tests were done by the rag-doll method. The actual weight loss was calculated as the difference in weight of bagged maize at the start and at the end of the storage trial.

Data were statistically analyzed using the Multi-Factor Analysis of Variance (AVMF) and Least Square Difference (LSD) tests.

Fig. 24: Diagram showing vertical cross section of experimental silo of 52 m^3 capacity containing bagged corn.



Results and discussion

Moisture content Except for a slight and non-significant increase in trial C9 the moisture content of corn held under gastight storage and CO_2-enriched atmospheres did not significantly change during storage (Table 8). Although condensation was evident in cubes and the silo where storage exceeded four months, the overall moisture content remained unaffected. These results also imply that the problem of weight reduction of corn due to moisture loss during ordinary warehouse storage can be minimized by the storage methods employed within the plastic tarps or liners.

Grain temperature Recordings of mean weekly daytime temperatures logged from the observed stacks revealed that temperatures inside the tarps were much lower than those of the ambient. The temperatures recorded from the various points within the sealed stacks were also more uniform than those in the control stacks. The uniform temperature observed inside the sealed stacks was a result of the insulation procedure, by which the insulation material prevented heat transfer from the top of the stack to the grain mass. These typical temperatures as recorded during the trial for gastight stored corn (stack code C4) are shown in Fig. 25. Observations made during the opening of the stacks, moisture condensation was apparent below the liner, especially on stacks stored for more than 4 months. This moisture condensation could have been due to low temperatures prevealing at night time, which were not monitored. In the uninsulated control stacks (C3 and C6), fluctuations in grain temperature were limited to the top surface, and depths of 5 and 10 cm.

Table 8- Moisture content of stored corn during the trials.

Trial #	Stack code	Treatment	Moisture content	
			Initial	Final
I-1	C1	CO_2-treated	13.16 a	12.16 a
I-2	C2	Gastight	12.56 a	12.55 a
I-3	C3	Control	13.26 a	12.23 a
II-1	C4	Gastight	11.59 a	11.93 a
II-2	C5	CO_2-treated	11.44 a	11.72 a
II-3	C6	Control	11.98 a	11.82 a
III-1	C7	Gastight	13.49 a	13.15 a
III-2	C8	Gastight	12.86 a	12.74 a
IV-1	C9	Gastight	13.25 a	14.25 a
IV-2	C10	Gastight	13.39 a	13.63 a
V-1	C11	Gastight Silo	13.50 a	13.34 a
VI-1	C12	Gastight	13.02 a	13.61 a
VI-2	C13	Gastight	13.56 a	12.77 a

In a row, means followed by the same letter are not significantly different at 5% level using LSD test.

Gas concentration The effect of gastight storage on CO_2 concentrations and the retention of CO_2 within the storage cubes is presented in Fig. 26. In the CO_2 treated cube (stack code C1) the decay rate of CO_2 was 0.21%CO_2/day. The CO_2 concentration in the CO_2-flushed stack exceeded 35% for more than 11 weeks. The minimum recommended level of CO_2 to achieve complete disinfestation of the commodity is 35% for 15 days of exposure. This demonstrates the high degree of gastightness and integrity of the cube making it a material suitable for storage of grain under modified atmosphere.

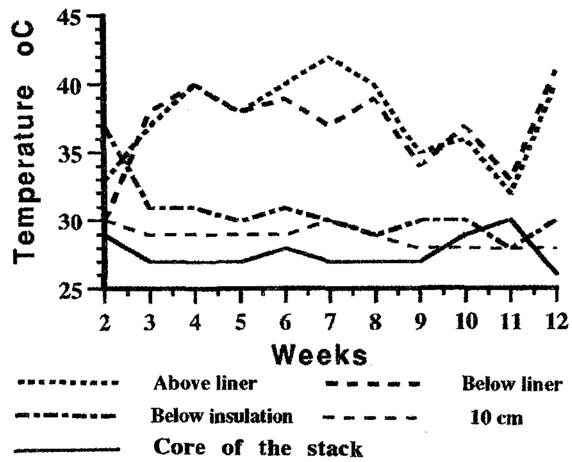


Fig. 25: Typical temperatures recorded from seven different points in the insulated and gastight stored corn (stack code C4).

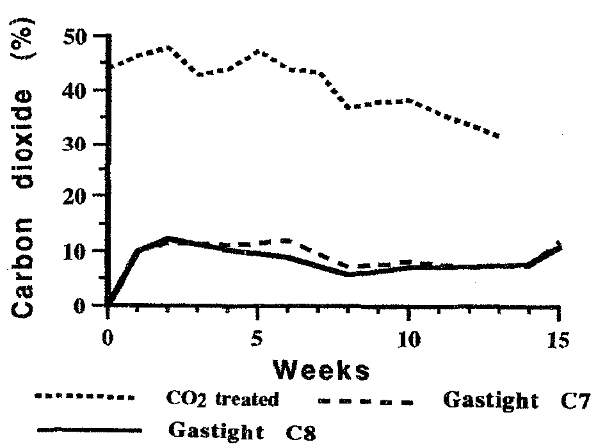


Fig. 26: Typical carbon dioxide concentrations recorded in the carbon dioxide treated (stack code C1) and gastight stored corn (stack codes C7 and C8).

In the gastight stacks, the CO_2 level rapidly increased to 12% while the O_2 concentration sharply declined over the first two weeks of storage to around 7% (C7 and C8). Carbon dioxide tensions in the most of the gastight piles rose to 12-16% and fluctuated within that range for most of the storage period. In trial IV the highest CO_2 concentration in stack code C9 was 22% and in stack code C10 it was 18%. These high concentrations indicate that some mold activity took place due probably to high moisture condensation. Because of the extended period of storage in these stacks (6 months), the rice hulls that also served as insulator were observed to be saturated leading to wetting of the top layer and sides of the stacks. The respiration of the wet grain and molds 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 stacks.

Insect infestation The insects found in corn were *Sitophilus zeamais, Rhyzopertha dominica, Oryzaephilus surinamensis, Latheticus oryzae, Lophocateres pusillus, Carpophilus spp., Tribolium castaneum, Cryptolestes spp., Typhaea stercorea,* species of ants, crickets and cockroaches. The changes in density of insect populations in the corn stacks from beginning to end of storage are shown in Table 9. No significant increase in population density of insects was noted in the gastight sealed corn stacks, whereas the population in the control stacks increased considerably. Live initial insect population was recorded in the stacks. This population was suppressed in the gastight stacks in comparison with populations that developed in the control stacks. The CO_2 treated stack C1 provided an adequate insect control. On the basis of insect infestations and in comparison with control stacks, all the trial treatments were considered successful.

Fungal infection. Corn stacks were predominantly infected with *Aspergillus flavus* and *Eurotium chevalieri* while the incidence of other *Aspergillus* spp. *(A. fumigatus and A. niger),* and *Penicillium citrinum* and *P. funiculosum* was low (Table 10). Following three to six months of gastight storage, in cubes and silos most fungi generally did not develop. In CO_2 - treated stacks, while there was a significant reduction in the occurrence of the above species, the proliferation of *Fusarium moniliforme* was noted at the periphery and bottom of the cubes and at the top of the silo which may have been enhanced by moisture condensation. Similar occurrence was noted at the top of the gastight silo.

The inhibition of the growth of fungi may be attributed to the effect of modified atmosphere. An atmosphere containing about 20% CO_2 generally inhibits mold growth (Hocking, 1989). However, high moisture favors the growth of *F. moniliforme* which can tolerate an atmosphere of 14-15% CO_2 and 0.5-1% O_2 (Wilson, 1975).

As noted above the suppression of fungal growth, and especially of the toxigenic A. *flavus* in gastight stored corn is very significant. However, the proliferation of *F. moniliforme* requires further investigation, since this species may produce the mycotoxin fumonisin.

Aflatoxin contamination. The aflatoxin level in corn before and after storage under gastight conditions is presented in Table 11. The low level of aflatoxin after 148 days of storage indicates that the incidence of such contamination in dry corn stored under gastight conditions is minimal.

Table 9- Density of insects per kg in corn trials.

Trial #	Stack code	Treatment	Initial		Final	
			Live	Dead	Live	Dead
I-1	C1	CO_2-treated	0.00	ND†	0.00	ND†
I-2	C2	Gastight	0.00	ND†	0.00	ND†
I-3	C3	Control	1.71	ND†	68.66	ND†
II-1	C4	Gastight	1.33	ND†	1.00	ND†
II-2	C5	CO_2-treated	0.67	ND†	0.33	ND†
II-3	C6	Control	0.30	ND†	17.33	ND†
III-1	C7	Gastight	2.00	0.00	0.33	2.67
III-2	C8	Gastight	3.00	0.00	0.33	9.00
IV-1	C9	Gastight	2.33	0.00	1.00	2.00
IV-2	C10	Gastight	0.67	0.33	3.30	1.00
V-1	C11	Gastight Silo	3.00	0.00	0.67	2.67
VI-1	C-12	Gastight	2.33	0.00	1.00	2.00
VI-2	C-13	Gastight	3.30	0.00	0.67	1.00

ND†-not determined

Table 10- Mean percentage fungal infection in all corn stacks kept at various atmospheres.

Fungal species	CO_2-treated		Gastight		Control	
	Initial	Final	Initial	Final	Initial	Final
Aspergilluss flavus	23	0	10	11	21	11
other Aspergillus spp.	0	14	0	4	0	5
Eurotium. chevalieri	40	1	13	29	3	71
Cladosporium cladosporoides	0	14	0	0	0	7
Penicillium funiculosum	0	0	0	0	0	11
Penicillium citrinum	2	0	0	0	2	6
Fusarium moniliforme	2	15	0	0	0	55

Table 11- Extent of aflatoxin contamination (ppb) in gastight stored corn in cubes.

Stack Code	Initial	Final
C7	7.90	6.55
C8	12.77 (± 2.88)	13.71(± 4.72)
C 12	< 1 ppb	1.21 (± 0.75)
C 13	< 1 ppb	1.12 (± 1.76)

Corn quality. Changes in the quality of corn is presented in Table 12.
Discolored kernels: Discoloration is a common parameter to indicate the corn quality. It express heat damage or mold activity. The gastight or CO_2 treated stacks did not show significant increase in discolored kernels except in one trial where the storage period was extended for 148 days. The control stacks suffered severe kernel discoloration.
Insect damaged kernels: Marked and significant increase in insect damaged kernels were noted in the control stacks. Although significant but only a very slight increase in insect damage was recorded only in two gastight trials.
Moldy kernels: A decrease in the percentage of moldy kernels occurred in the CO_2 -purged stacks. In two of the gastight trials moldy kernels were significantly and markedly increased. However it should be noted that no significant change in moisture content occurred and similarly fungal infection was generally inhibited. Fungal infection shown in the Table 10 does not necessarily correlate with moldy kernels shown in the Table 12, because the mold presence was determined by visual inspection; whereas test on fungal infection determined the presence of seedborn fungi after sterilization of their surface and plating the kernels on suitable media.

The moisture readings were based on composite samples collected from every bag of the stack. Therefore, it does not reflect the presence of relatively wetter bags that were observed on the top and sides of the stacks.

Although a lot of rice hull was provided as a insulator, these were not enough to absorb the moisture that formed underneath the plastic during the entire duration of the prolonged storage (148-184 days). At some point in time, the hulls became saturated such that the excess water dripped, wetting some portions of the stack. This was very evident upon opening of the stack stored for prolonged time wherein visual examination revealed moldy bags particularly on the top layer immediately below the insulator and on the sides. Water also accumulated on the plastic film placed beneath the insulator above the first layer of of corn in silo.
Germinated kernels: No significant increase in germinated kernels were observed except in two gastight stacks (C2 and C7) where the increase was very slight.

Viability: The germination of corn stored in the gastight sealed and CO_2 treated trials did not change significantly during storage (Table 13). Under gastight conditions the viability of corn kernels was maintained for relatively long storage periods. The germination in C7-C-10 was very low initially due to a high mechanical drying temperature of 120^0 C and a prolonged drying time exceeding recommendations. The results showed that seeds can be kept and preserved utilizing the gastight storage technique.

Table 12- Comparison of quality parameters in corn expressed as means at beginning and end of trials.

Stack code	Treatment	% discolored kernels		% insect damaged kernels		% moldy kernels		% germinated kernels	
		initial	final	initial	final	initial	final	initial	final
C1	CO_2-treated	4.33	3.68 ns	0.05	0.00 ns	0.59	0.00 **	0.20	0.31 ns
C2	Gastight	14.00	15.35 ns	0.07	0.04 ns	0 .00	0.13 *	0.69	1.11 *
C3	Control	7.49	14.91**	0.79	5.51**	0 .93	1.45 ns	0.93	1.45 ns
C4	Gastight	4.54	4.52 ns	0.30	0.37 ns	0.03	0.02 ns	0.04	0.04 ns
C5	CO_2-treated	2.62	4.12 *	0.30	0.37 ns	0.01	0.00 ns	0.20	0.01 ns
C6	Control	1.62	4.13 *	0.35	2.24 **	0.00	0.01 ns	0.00	0.01 ns
C7	Gastight	6.61	6.73 ns	0.39	0.67 ns	0.00	0.17 ns	0.11	0.27 *
C8	Gastight	6.02	4.93 ns	0.19	0.51 **	0.00	0.50 *	0.24	0.34 ns
C9	Gastight	6.73	6.61 ns	4.24	4.28 ns	4.67	1.87 ns	0.64	0.80 ns
C10	Gastight	6.20	4.93 ns	0.43	0.48 ns	0.79	2.88 *	0.87	0.80 ns
C11	Gastight silo	6.21	6.35 ns	0.13	0.69 **	0.00	4.07 **	0.99	0.75 ns
C12	Gastight	6.26	11.17 **	0.31	0.32 ns	0.00	1.04 **	0.67	0.79 ns
C13	Gastight	7.98	9.53 ns	0.36	0.31 ns	0.00	1.10 **	0.19	0.44 ns

ns= $P>0.050$; *= $P<0.050$; **= $P<0.010$

Table 13- Changes in the viability expressed by % germination of corn.

Trial #	Stack code	Treatment	Initial	Final
I-1	C1	CO_2-treated	88.67[a]	87.00[a]
I-2	C2	Gastight	88.33[a]	87.33[a]
I-3	C3	Control	88.00[a]	86.67[a]
II-1	C4	Gastight	86.00[a]	87.00[a]
II-2	C5	CO_2-treated	87.67[a]	88.00[a]
II-3	C6	Control	86.00[a]	86.00[a]
III-1	C7	Gastight	80.00[a]	80.00[a]
III-2	C8	Gastight	66.00[a]	66.33[a]
IV-1	C9	Gastight	64.67[a]	65.33[a]
IV-2	C10	Gastight	79.67[a]	65.33[a]
V-1	C11	Gastight Silo	87.00[a]	87.33[a]
VI-1	C-12	Gastight	93.66[a]	92.00[a]
VI-2	C-13	Gastight	89.33[a]	87.33[a]

In a row, means followed by the same letter are not significantly different at 5 % level using LSD test.

Weight loss The results indicate that weight loss in corn may be effectively reduced through gastight sealed or CO_2-treated storage. The control stacks suffered serious insect attack and consequently loss in weight was significantly much higher than the treated stacks (Table 14). The control stacks, in addition to insect infestation suffered from mold infection and from rodent and bird attack.

Table 14. Change in actual weight(kg) in corn stored under various conditions.

Trial #	Stack code	Treatment	Initial weight	Final weight	% weight loss
I-1	C1	CO_2-treated	18450	18401	0.265
I-2	C2	Gastight	15020	14963	0.379
I-3	C3	Control	4750	4509	5.073
II-1	C4	Gastight	17000	16961	0.229
II-2	C5	CO_2-treated	16620	16578	0.252
II-3	C6	Control	4580	4323	5.611
III-1	C7	Gastight	19200	19152	0.250
III-2	C8	Gastight	19220	19158	0.320
IV-1	C9	Gastight	18430	18227	1.100
IV-2	C10	Gastight	18430	18347	0.450
V-1	C11	Gastight silo	38730	38587	0.370
VI-1	C12	Gastight	16770	16695	0.450
VI-2	C13	Gastight	16770	16690	0.400

5.4.7. *Paddy storage trials (Philippines)*

Materials and methods

The paddy trials were conducted at the NAPHIRE compound, Nueva Ecija. A summary of the field trials for paddy is given in Table 15.

The parameters observed on moisture content, temperature, gas concentration, insect infestation and fungal infection during cube and silo storage trials for paddy were the same as for the corn trials. In the paddy trials, the quality parameters measured were milling recovery, percent head rice recovery, percent broken and percent yellow grains.

Table 15- List of paddy trials carried out in the Philippines.

		Structure		Treatment		Handling			
Trial #	Stack code	Cube	Silo	Gastight	Control	Sacks	Bulk	Capacity (tonnes)	Duration of storage (days)
I-1	P1	x		x		x		14.00	94
I-2	P2	x		x		x		13.43	94
I-3	P3	x			x	x		5.30	94
II-1	P4	x		x		x		13.63	117
II-2	P5	x		x		x		13.84	117
II-3	P6	x			x	x		5.30	117
III-1	P7	x		x		x		14.77	78
III-2	P8	x		x		x		15.06	78
III-3	P9	x			x	x		5.56	78
IV-1	P10	x		x		x		14.78	97
IV-2	P11	x		x		x		14.73	97
V-1	P12		x	x			x	31.86	183
VI-1	P13		x	x		x		30.38	43

Results and Discussion

Moisture content The average MC of gastight sealed paddy in stack code P2, and P11 increased slightly but significantly from the beginning to end of storage, whereas no significant increase was noted in the rest (Table 16). There was a real trend towards increase in MC in the two control stacks stored during the wet season (P3 and P6) and a decrease in MC of the control stacks stored in the dry season (P9). These differences indicate the importance of having gastight sheet to avoid moisture diffusion. Field trials show that there was no critical moisture build up or localization in all the treatments and the control except for P11 that exceeded the critical MC of 14% by 0.24%. The overall MC of paddy in bulk stored under gastight conditions in the silo did not change significantly during the trial (P12). This result suggests that bulk storage in the silo is feasible without adverse effect on MC of paddy.

A significant reduction in MC of the wet paddy in silo was recorded (P13) from 18.21% 14.87% after storage of 43 days. This reduction may be explained by the thermal gradients that caused the mass transfer of moisture. Air movement induced by diurnal temperature difference and moisture diffusion in the process of moisture equilibrium between the grain and the air resulted in the air picking up moisture from the wet paddy leading to the formation of dew under the liner in the cool period of the evening. Water that condensed below the liner was initially absorbed by the rice hulls. This is evidenced by the fact that the MC of the rice hull which initially had an average of 7.97% was more than doubled at 18.58% at the end of the 43-day trial. A total of 92 bags of rice hull were used; each of about 5 kg. The rest of the condensed water apparently was absorbed by the upper layer of the grain mass and some water also accumulated on the thin plastic film placed between the rice hull and the paddy bags. The film was provided to catch water that may drip between the sacks of rice hulls and also catch any excess moisture that is not absorbed by the rice hull. This change in MC was not reflected by the grid samples. Since the moisture translocation may have been confined at the upper layer. The evidence that the weight of grain changed only very slightly indicates that excess water remained within the stack and silos.

Table 16- Moisture content of composite samples taken from paddy stacks during the trials.

Trial #	Stack code	Treatment	Moisture content	
			Initial	Final
I-1	P1	Gastight	10.30 [a]	10.56 [a]
I-2	P2	Gastight	9.87 [a]	10.83 [b]
I-3	P3	Control	9.67 [a]	11.60 [b]
II-1	P4	Gastight	11.68 [a]	12.37 [b]
II-2	P5	Gastight	12.07 [a]	12.28 [a]
II-3	P6	Control	12.15 [a]	12.80 [b]
III-1	P7	Gastight	11.16 [a]	11.27 [a]
III-2	P8	Gastight	11.61 [a]	11.07 [b]
III-3	P9	Control	12.34 [a]	10.67 [b]
IV-1	P10	Gastight	12.23 [a]	13.08 [a]
IV-2	P11	Gastight	13.46 [a]	14.24 [b]
V-1	P12	Gastight silo	10.75 [a]	10.63 [b]
VI-1	P13	Gastight silo	18.21 [a]	14.87 [b]

In a row, means followed by the same letter are not significantly different at 5% level using LSD test.

Grain temperature A similar pattern of temperature levels were observed in paddy stacks as in the corn trials. The temperature recorded at various points inside the paddy stacks during field trials indicate that temperature fluctuations within the grain mass of gastight sealed paddy stacks and silos could be reduced by insulation.

Gas Concentration The maximum CO_2 concentrations recorded in the gastight silos and cubes of paddy is shown in Table 17. The maximum CO_2 concentration reached 19%. Lower CO_2 concentrations reported in P1, P2 and P12, were due to leaks in the plastic sheeting caused by insects or mechanical damage. In stack P1, after six weeks of storage, it was discovered that the zipper was unlocked. In the first silo trial P12 there was a heavy infestation by the lesser grain borer. The silo remained unsealrd for several days which enable the insects to attack the liner. After damage to the liner was detected, it was decided to fumigate the bulk with phosphine at a dosage of 6 g/ton.

The high CO_2 concentration recorded in P11 and P13 indicate that the initial moisture content of the commodity caused intensive biogeneration of CO_2 by microorganisms also.

Table 17- Maximum CO_2 concentrations generated in storage cubes of gastight stored paddy and their initial moisture content.

Trial No.	Stack code	Percent CO2	Initial moisture content
I-1	P1	6	10.30
I-2	P2	7	9.87
II-1	P4	13	11.68
II-2	P5	10	12.07
IV-1	P10	15	12.23
IV-2	P11	18	13.46
V-1	P12	5	10.75
VI-1	P13	19	18.21

Insect infestation Initial and final counts of live insects revealed no significant population increase in the gastight sealed paddy stacks (Table 18), whereas in the control stacks (P3, P6 and P9) there was a marked increases 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 stacks was not achieved. In spite of the presence of few live insects at the end of storage, all treatments in the trials were successful. This is matched by a much lower percentage weight loss in the treated stacks compared with the control stacks.

The different insect species found in the silo trial of bulk paddy (P12) before storage, consisted of live *Rhyzopertha dominica, Sitophilus oryzae, Lophocateres pusillus, Oryzaephilus surinamensis* and *Carpophilus dimidiatus* and a few dead *Tribolium castaneum.* During unloading, live *R. dominica, L. pusillus, O. surinamensis* and large numbers of dead insects of various species were retrieved. The density of live insects at the end of the trial was reduced, while an increase was noted in the density of dead insects (Table 18). These results indicate that gastight conditions inside the silo inhibited insect development but could leave a residual insect population. Initial flushing with CO_2 however, could be used to control initial infestations.

Fungal Infection The prevalent species associated with the gastight silo containing wet paddy stacks were *A. flavus, P. citrinum, E.chevalieri,* and *F. moniliforme* (Table 17). After 43 days of storage, infection by *A. flavus* increased while infection with *P. citrinum, E.chevalieri,* and *F. moniliforme* decreased markedly. The decrease in the incidence of infection by the *P. citrinum* and *E.chevalieri* may be attributed by the modified atmosphere while the decrease in the occurrence of *F. moniliforme* may by the effect of the significant reduction of MC of paddy from 18.21 to 14.87% since the *F. moniliforme* thrives better in high moisture grains. It is evident that the population of *A. flavus* was not affected by the modified atmosphere. An atmosphere containing about 20% of CO_2 was not attained inside the silo to inhibit the growth of *A. flavus.*

Table 18- Average density of insects per kg of sample in paddy trials.

Trial #	Stack code	Treatment	Insects density		Significance level
			Initial	Final	
I-1	P1	Gastight	5.33 (-)	8.00 (-)	ns (-)
I-2	P2	Gastight	9.67 (-)	1.67 (-)	*(-)
I-3	P3	Control	13.67 (-)	35.33 (-)	ns(-)
II-1	P4	Gastight	8.67 (0)	0.33 (36.33)	** (**)
II-2	P5	Gastight	17.00 (0)	2.33 (63)	*(**)
II-3	P6	Control	16.67 (0)	51.00 (91.00)	ns (**)
III-1	P7	Gastight	0 (18.00)	4.33 (122.67)	**(**)
III-2	P8	Gastight	0 (11.33)	6.67 (26.67)	* (ns)
III-3	P9	Control	0 (12.33)	47.33 (89.33)	**(ns)
IV-1	P10	Gastight	3.33 (0.33)	6.33 (2.67)	ns(ns)
IV-2	P11	Gastight	3.00 (0.33)	0 (4.67)	ns(*)
V-1	P12	Gastight silo	24.67 (18.67)	15.00 (261.67)	ns (**)
VI-1	P13	Gastight silo	10.33 (0)	1.33 (1.00)	(**) (ns)

ns=not significant; * =significant at 5% level; **=significant at 1% level
The number represents live insects per kg. of sample while the number in brackets represent the number of dead insects.

Table 19- Percentage fungal infection of gastight silo with paddy of intermediate MC

Fungal species	Initial	Final
Aspergillus flavus	74	80
Aspergillus citrinum	57	1
Eurotium chevalieri	18	15
Fusarium moniliforme	14	12

Paddy qualities Changes in the percent milling recovery, head rice, broken and yellow grains in dry paddy is presented in Table 20. The milling yield and the level of the yellowing grain in the gastight paddy stacks were not significantly altered.

In general gastight storage preserved grain quality by maintaining the level of head rice. The level of head rice and brokens were preserved in 8 out of 13 stacks except in P1 and P4 which showed a rise in percent of head rice. This could be explained by the biological aging phenomenon which occurs in paddy during the first 3 to 4 months of storage. It is theorized that the aging phenomenon may be the result of a sol-gel transformation of colloidal starch and protein deposited during ripening and transformation into a more stable, water-insoluble physical form during storage. Tensile strength of the grain increases and the increased hardness is translated into a greater resistance to milling and higher total and head rice yields.

Expectedly, the two control stacks P3 and P6 showed a decrease of head rice and increase in brokens. Because the trial was conducted during the dry season and in view of the short duration of storage, the control stacks for trial P9 did not exhibit severe quality deterioration. Rice yellowing however, was also very pronounced in the untreated control stack of P3. Although yellowing increased in the wet paddy stack (P13), the final level remained low.

The above data suggest that gastight storage of dried bagged and bulk paddy has no adverse effect on milling yield, grain yellowing and other quality parameters.

Viability The germination of paddy stored under gastight sealed conditions did not change significantly during the trials (Table 21).

Weight loss The weight losses observed during the field trials are shown in Table 22. The magnitude of loss recorded from the gastight sealed paddy stacks was about 18 times lower than in the control stacks resulting in 3.75 to 4.85% weight loss.

Table 20- Comparison of quality parameters in paddy expressed as mean at the beginning and end of storage.

Stack code	Treatment	% milling recovery		% head rice		% yellow kernels		% broken kernels	
		initial	final	initial	final	initial	final	initial	final
P1	Gastight	68.71	69.67**	75.47	77.27*	0.32	0.26ns	25.43	22.73 *
P2	Gastight	69.66	70.16ns	83.20	82.53ns	0.16	0.23ns	16.80	17.46ns
P3	Control	70.33	70.31ns	82.80	78.33*	0.16	4.67**	17.20	21.67*
P4	Gastight	66.12	67.61*	73.60	77.33**	0.27	0.23ns	26.07	22.67ns
P5	Gastight	66.47	65.35ns	72.47	72.47ns	0.33	0.34ns	27.53	26.30ns
P6	Control	66.89	67.00ns	77.73	70.90**	0.33	0.22ns	22.07	20.10ns
P7	Gastight	64.62	63.90ns	76.55	77.71ns	1.00	0.69ns	23.45	22.56ns
P8	Gastight	64.37	64.68ns	81.32	81.81ns	0.08	0.05ns	18.68	18.19ns
P9	Control	64.26	65.57ns	82.61	82.85ns	0.23	0.13ns	17.39	17.19ns
P10	Gastight	64.09	63.15ns	82.24	74.64*	0.07	0.16ns	17.76	24.70*
P11	Gastight	62.96	61.85ns	81.74	77.24ns	0.02	0.06ns	18.24	22.76ns
P12	Gastight silo	65.27	65.06ns	87.32	79.47*	0.13	0.12ns	12.68	19.88**
P13	Gastight silo	65.60	65.67ns	84.66	79.88ns	1.83	2.52*	10.88	15.11**

ns=not significant; * =significant at 5% level; **=significant at 1% level

Table 21- Percent germination of paddy during field trials.

Trial No	Stack Code	Treatment	Initial	Final
II	P4	Gastight	98.67 a	89.33 b
	P5	Gastight	97.67 a	100.00 a
	P6	Control	97.67 a	98.33 a
III	P7	Gastight	95.67 a	93.33 b
	P8	Gastight	88.33 a	86.00 a
	P9	Control	95.00 a	91.67 a
IV	P10	Gastight	86.00 a	89.33 a
	P11	Gastight	83.67 a	83.00 a
V	P12	Gastight silo	93.67 a	93.00 a
VI	P13	Gastight silo	95.33 a	94.77 a

In a row, means followed by the same letter are not significantly different at 5% level using LSD test.

Table 22- Percentage weight loss in paddy stacks during the trials.

Trial number	Stack code	Treatment	Percent weight loss
II	P4	Gastight	0.32
	P5	Gastight	0.21
	P6	Control	4.85
III	P7	Gastight	0.29
	P8	Gastight	0.27
	P9	Control	3.75
IV	P10	Gastight	0.19
	P11	Gastight	0.10
V	P12	Gastight silo	0.26
VI	P13	Gastight silo	0.13

6. Impact, Relevance and Technology Transfer:

The gastight storage technology developed has a strong potential for adoption in the Philippines by the farmers cooperatives and the non-government organizations which process and market their own produce. At present inadequate storage space has prevented these entities from expanding their business resulting to the loss of business opportunities.

Financial analysis of investing in gastight cubes of 5-ton capacity for outdoor storage of grains showed a net profit of about US$100/ton for paddy and US$80/ton for corn.

The collaborating scientists have developed expertise in modified atmosphere storage systems. Their research techniques and methods have been improved. They also have opportunities for scientific interactions with other ARO scientists.

The Philippines has now prepared an intensive training program on gastight storage for trainers and potential users such as warehouse managers, farmers cooperatives, and private merchants and processors. Other communication support systems have been developed too to transfer this technology to intended users. A series of seminars will also be conducted to develop consciousness of this technology among policy makers for integration in their area development plans.

7. Project Activities/Outputs:

The investigators of the current project attended the following International Conferences:

1. International Conference on Controlled Atmosphere and Fumigation in Grain Storages. Winnipeg, Canada June, 1992.
2. 6th International Working Conference on Stored Products Protection, Canberra, Australia, April 1994

Project Meetings/ Visits:

1. Mrs. F. Caliboso to Israel, May, 1991.
2. Dr. J. Donahaye to Philippines, November, 1991.
3. Dr. S. Navarro to Philippines, April-May, 1993.
4. Mrs. F. Caliboso and Mr. G.Sabio to Israel, October-November, 1995

Publications:

1. Alvindia, D.G., Caliboso, F.M., Sabio, G.C. and Regpala, A.R. 1994, Modified atmosphere storage of bagged maize outdoors using flexible liners: a preliminary report. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R. (Eds.) Proc. 6th Intern.Work. Conf. Stored-prod. Protection, CAB International, University Press, Cambridge, Vol. I: 22-26.
2. Navarro, S., Donahaye, J.E. and Fishman, S. 1994. The future of hermetic storage of dry grains in tropical and subtropical climates. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R. (Eds.) Proc. 6th Intern.Work. Conf. Stored-prod. Protection, CAB International, University Press, Cambridge, Vol. I: 130-138.

8. Project Productivity:

The project substantially accomplished all the proposed goals.

9. Future Work:

The handling of wet paddy and corn have been one of the difficulties in the postharvest operations in the Philippines. This is due to the inability to dry the produce during the main cropping season which falls during the rainy months. Thus, it was proposed to continue the development of gastight storage for temporary holding of wet paddy.

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