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Outdoor Storage of Corn and Paddy Using Sealed-Stacks in the Philippines

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ABSTRACT

The applicability of using sealed stacks for modified atmosphere or gastight storage of paddy and corn stacked in the open in the Philippines was investigated. Heavy duty plastic was used to provide a solution to short and medium term preservation of dry paddy and corn at the farmer and farmer-cooperative level.

A series of experiments was carried out in Israel to develop the plastic structures. It included studies on permeabilities of plastic sheeting to oxygen and carbon dioxide, and resistance to insect and rodent penetration.

Investigations in the Philippines comprised storage under modified atmospheres (MA) using CO_2 *flushing of corn and biogeneration of MA using gastight storage of corn and paddy without gas replacement. Carbon dioxide flushing treatments proved effective for insect control but the low availability of* CO_2 *cylinders limits this approach at present. Moisture migration was observed in all the trials. The use of agricultural wastes provided insulation from diurnal temperature fluctuations and was effective in preventing moisture migration for up to 4 months storage under Philippine conditions. The trials showed that gastight storage provides an acceptable protection by maintaining the number of live insects below the threshold of economic damage without the need for pesticides.*

INTRODUCTION

Moisture content is the major factor in determining the storage behavior of grain (Pixton, 1982). Initial grain deterioration due to molds can be prevented if the moisture content is sufficiently low. However, the amount of moisture in dry grain bulks is sufficient to permit development of most stored grain insects (Howe, 1965). Therefore, periodic insect control measures are usually required to prevent loss of quality and quantity particularly in warm climates (Semple, 1985).

A method for preventing storage losses is sealed storage which is also called 'airtight storage', 'gastight storage,' or hermetic storage'(Hyde *et. al.*, 1973; De Lima, 1990). The intrinsic advantage of airtight storage of dry cereal grains lies in the generation, by the aerobic metabolism of insect pests and microorganisms, of an oxygen-depleted and carbon dioxide-enriched intergranular atmosphere of the storage ecosystem. By so doing, their development is arrested and storage damage is minimized.

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

Comparative data on the efficacy of aeration and the effect of insulation in preventing moisture migration in metal silos in the tropics is lacking.

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

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

The storage facilities used in this project were designed as gas-tight structures to provide affordable and user-friendly systems for grain conservation without the need for chemical pesticides. This report describes storage trials using corn and paddy in the Philippines, and relates storage conditions to quality conservation including moisture content, insect infestation and damage.

MATERIALS AND METHODS

Experimental Design

The experimental design was based on gathering the information required for developing a sealed grain storage technique within gastight plastic tarpaulins or plastic lined silos. Storage cubes (Volcani cubes) and silos manufactured from heavy duty plastic were used in order to provide a solution to preservation of dry corn and paddy (Navarro and Caliboso, 1996).

A series of preliminary trials using prototype plastic structures was carried out in Israel. Following this, a series of trials using paddy and corn was carried out in the Philippines. The Philippine investigations comprised both storage under modified atmosphere (MA) using carbon dioxide flushing of corn, and biogeneration of MA 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 detail in Israel. 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.

The field trials were accompanied by laboratory studies on the permeability of the plastic sheeting to gases (in Israel), resistance to insect penetration (in Israel and the Philippines), and resistance to rodent penetration (in Israel). Laboratory scale studies included: (a) the selection of a plastic sheeting by designing tests to identify plastic sheeting characteristics to determine permeability levels of atmospheric gases in particular; and (b) plastic sheeting integrity to investigate the influence of population density on both ingress and egress of insects through the liners and to test the influence of liner material to rodent penetration. The different stages of the experimental design are schematically presented in Fig. 1.

Site and Duration of Study

The corn trials were carried out on 10 Volcani cubes, one Volcani silo and two control stacks at the NFA Compound in Aglayan, Malaybalay; at the FX Foundation in Pangantukan, and at the Farmers Cooperative Incorporated (FCI) in Kisolon, Sumilao, all in Bukidnon, Central Mindanao.

A series of paddy trials was undertaken on eight Volcani cubes, two Volcani silos and three control stacks at the NAPHIRE compound, Nueva Ecija, Philippines. The details of the field trials for corn and paddy are shown in Table 1.

Grain Supplies

Locally grown corn or paddy packed in 50-kg polypropylene bags were used in the field trials. Paddy of mixed varieties were obtained from the National Food Authority (NFA), Cabanatuan City and from the farmers in Muñoz, Nueva Ecija. The duration of storage was three to six months.

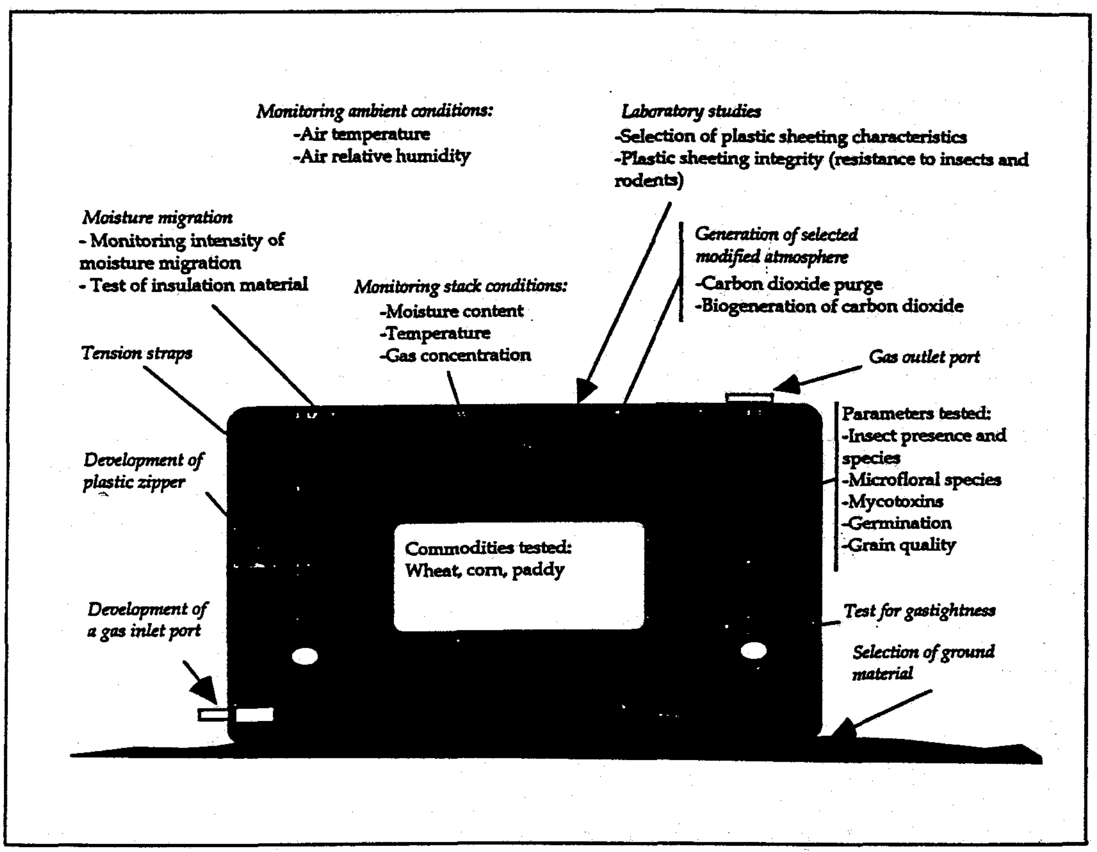


Figure 1. Schematic presentation of the Volcani cube and the different experimental steps and parameters used in the development of a technology for the prevention of losses in stored grain using modified atmosphere under gastight plastic covers.

Table 1. List of outdoor trials for corn and paddy carried out in the Philippines using the plastic Volcani cubes and silos.

Commodity	Structure	No. of Trials	Treatment	Ave. Capacity	Duration of Storage (days)
Corn	Cube (sacks)	2	CO_2	17-19	93-97
		8	Gastight	15-19	93-183
		2	Control	5	93-97
	Silo (sacks)	1	Gastight	39	184
Paddy	Cube (sacks)	8	Gastight	13-15	78-117
		3	Control	5-6	78-117
	Silo (sacks)	1	Gastight	30	43
	Silo (bulk)	1	Gastight	32	183

The Storage Structures

Storage (Volcani) cubes

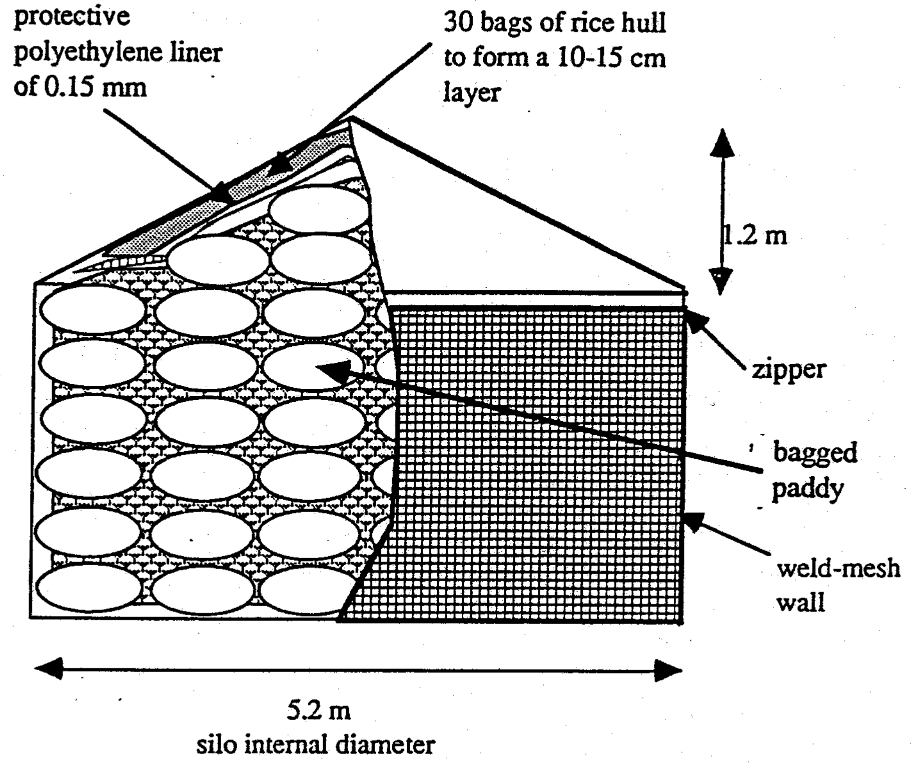
Flexible cube-shaped envelopes were designed for stack storage, the stack itself forming the rigid structure of the system (Fig. 1). The cube-shaped structures were planned for use on open ground and under rigorous field conditions. The Volcani cubes consisted of two sections: a lower floor-wall and an upper roof-wall. 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 built. After building the stack to the required height, the top tarp was placed over the stack to meet the lower section half way up the side. Both the 'undersection' and the 'oversection' were provided with a gas-tight multiple tongue and groove zipper to zip the sections together to form a continuous envelope. Made of polyurethane, it has the advantage of being pliable over a wide range of temperatures and is resistant to deformation.

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 liner tight around the curve of the sacks at floor level (Fig. 1). This was done to prevent rodents from gaining a tooth-hold on the slippery surface thereby preventing damage to the hermetic seal. Cubes used in the trials were all sections of the PVC, and CPE top sections and PVC bottom sections.

The '20-ton' cubes measured 4.45 x 3.36 x 2.00 m (1 x w x h) with maximum storage volume of about 30 m^3, and weight of about 76 kg when empty. Each cube was provided with a light carrying bag that is used to store and to protect it from rodent attack when not in use.

Volcani plastic silos

The silos were made of two units, namely, a weld mesh circular wall formed from sections bolted together 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 (Fig. 2). The lining came in two parts: a lower wall-floor unit and an upper liner forming a roof cone. The roof cone was secured to the metal welded mesh walls by rope. 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. The silos were designed to allow bulk or bag storage, with mechanical loading or unloading, with the intention of providing a useful transition phase between bag and bulk handling. The dimensions of the silos were: diameter of 5.25 m, height of 2.2 m, storage volume of $52m^3$. and capacity of 35 to 40 tons.



Gas applicator

The Volcani cube was provided with a gas applicator that consisted of a ball and socket gas tap attached to the 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 to MA treatments is that 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 at the opposite corner of the oversection.

Control stacks

An ordinary tarpaulin sheet was used to cover the control stack stored in the open. The control stacks of sacks on pallets with a capacity of 5 tons were set up.

Preparation of Storage Site

A levelled portion of the 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 hull was laid down on the area where the cube was to be erected. The rice hull was meant to protect the plastic sheeting from puncturing by sharp objects, and the rice ash by rodents and to a limited extent, by termites. Rice hull and rice ash are agricultural wastes that are readily available in many parts of the Philippines.

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

Construction of Stack and Insulation

The bottom section was spread out straight on the ground prepared as above (preparation of storage site), and bulk grain or bags of grains were built directly on the liner. Pallets were not required. For the Volcani cubes, the top layer of the stack was insulated with two to three layers of sacks containing corn cobs (only during the first trial for corn) or rice hull. For the plastic silo, the cone-shaped top surface was covered with a plastic sheet. Then one to two layers of bagged rice hull were placed above the plastic sheet. The layers of rice hull aimed to reduce temperature gradients within the grain mass. The plastic sheet was designed to catch the water that could seep through the insulator and to prevent the grain bulk from getting wet.

After building the stack to the required height, the top section was placed over the stack, meeting the lower section halfway up the side, and then zipped together to form an envelope. The stacks formed a pyramid to allow rain water to run-off freely along the sides of the enclosure.

Temperature and Gas Concentration Monitoring

Seven thermocouple cables and two plastic tubings with diameter of 3 mm were installed at different locations inside the cubes and storage silo to monitor grain temperature and gas concentration, respectively. Readings on temperature sensors were manually monitored using the 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 levels of CO_2 and O_2 inside the gastight Volcani cubes and plastic silo for dry paddy were measured every two weeks using a Gow-Mac gas analyzer and Bacharach Oxygen meter, respectively.

Grain Sampling

Initial samples were collected during the building of stacks (cube and plastic silo). Final sampling was undertaken when the stacks were opened. Three composite samples of 1 kg each were collected from all bags in each stack using sampling spears. For the Volcani cubes, samples were obtained from the periphery (4 sides), top (uppermost layer) and core (middle and bottom).

For the plastic silo, additional samples were taken from the periphery (east and west), core (top, middle and bottom), and at the uppermost layer of the cone. Composite samples were taken to determine the general condition of the stack, and representative samples to assess grain quality at pre-determined points.

Purging CO_2-Treated Stacks

Corn stacks in cubes were flushed with food grade CO_2 at the rate of 1.5 kg per ton. The gas applicator used is as described previously.

Quality Evaluation

Moisture content was determined by drying grain samples for 1 hour in an oven (Anon., 1982).

Live and dead insects were sieved from the composite and representative samples. These were sorted according to group and species.

The actual weight loss was calculated as the difference in weight of grain at the start and at the end of each storage trial.

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

RESULTS AND DISCUSSION

Moisture Content

Corn - There was no increase in the average moisture content (mc) of corn held under gastight storage and CO_2-enriched atmosphere did not significantly change during storage (Table 2). Although condensation was evident in the cubes and in the silo where storage exceeded 4 months, the overall moisture content remained unaffected. These results imply that the problem of weight reduction in corn due to moisture loss during ordinary warehouse storage can be minimized by the storage methods employed within the plastic tarps or liners.

Paddy - The average mc of gastight sealed paddy in two stacks increased slightly from the beginning until the end of storage, whereas no increase was noted in the rest (Table 2). There was an increasing trend in mc in the two control stacks stored during the wet season, and a decreasing trend in the control stacks stored during the dry season. These differences manifest the importance of using gastight sheet to avoid moisture diffusion. Field trials showed that there was no critical moisture build up or localization in all the treatments including the control, except for one stack that exceeded the critical mc (14 percent) by 0.24 percent. The overall mc of bulk paddy stored under gastight conditions in the silo did not change significantly during the trial. This result suggests that bulk storage in the silo is technically feasible without adverse effect on the mc of paddy.

A significant reduction in the mc of wet paddy stored in sacks in silo was recorded from 18.21 to 14.87 percent after 43 days in storage. 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 hull forming the top insulation layer. This is evidenced by the fact that the average initial mc of the rice hull (7.97 percent) more than doubled at 18.58 percent at the end of the 43-day trial. A total of 92 bags of rice hull was used each weighing about 5 kg. The rest of the condensed water apparently was absorbed by the upper layer of the grain mass. 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 hull and any excess moisture that is not absorbed by the rice hull. This change in mc was not reflected by the grid samples.

Table 2. Moisture content of composite samples taken from corn and paddy stacks during outdoor trials using the plastic Volcani cubes and silos.

Commodity	Structure	Treatment	Ave. Initial mc	Ave. Final mc
Corn	Cube (sacks)	CO_2	12.30	11.94
		Gastight	13.97	13.08
		Control	12.62	12.03
	Silo (sacks)	Gastight	13.50	13.34
Paddy	Cube (sacks)	Gastight	11.55	11.96
		Control	11.39	11.69
	Silo (sacks)	Gastight	18.21	14.87
	Silo (bulk)	Gastight	10.75	10.63

Temperature

Corn - Records of weekly mean daytime temperature logged from the observed stacks revealed that temperatures inside the tarps (28°C) were much lower than those of the liner (35° to 42°C). 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 (28°C) was a result of the insulation procedure in which the insulation material prevented heat transfer from the top of the stack to the grain mass. The temperatures recorded at 10 cm below the insulation were in the range of 29° to 31°C. When the stacks were opened, it was observed that 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 at night time which were not monitored. In the uninsulated control stacks, fluctuations in grain temperature were limited to the top surface and in depths of 5 and 10 cm.

Paddy - A similar pattern of temperature levels was observed in paddy stacks as in the corn trials. The temperature recorded at various points inside the paddy stacks indicate that temperature fluctuations within the grain mass of gastight sealed paddy stacks and silos were reduced by the insulation layer and the insulation properties of the grain mass.

Gas Concentration

Corn - In the CO_2-treated cube the decay rate of CO_2 was 0.21 percent per day. The initial CO_2 concentration in the CO_2-flushed stack was 45 percent and it exceeded 35 percent after 11 weeks. The minimum recommended level of CO_2 to achieve complete disinfestation of the commodity is 35 percent 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.

In the gastight stacks, the CO_2 level rapidly increased to 12 percent while the O_2 concentration sharply declined to around 7 percent over the first 2 weeks of storage. Carbon dioxide tensions in most of the gastight stacks rose to 12 to 16 percent and fluctuated within that range for most of the storage period. In 2 stacks CO_2 concentrations were the highest reaching 18 percent and 22 percent. These high concentrations indicate that mold activity took place probably due to moisture condensation. Because of the extended period of storage in these stacks (6 months), the rice hull that also served as insulator became 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 oxygen and to the increased evolution of CO_2. This lethal atmosphere subsequently led to the mortality of the insects in the stacks.

Paddy - The average CO_2 concentration recorded in the cubes of paddy were in the range of 10 to 15 percent. Lower CO_2 concentration (6-7 percent) reported in 3 stacks were due to leaks caused by mechanical damage in the plastic sheeting. After 6 weeks of storage, it was discovered that the zipper in 1 stack was unlocked. In the bulk silo trial, there was heavy infestation by the lesser grain borer. The silo remained unsealed for several days, thus, enabling the insects to attack the liner. After the damage in the liner was detected, the bulk was fumigated with phosphine at the rate of 6 g/ton.

The high CO_2 concentration (18 percent and 19 percent) recorded in two stacks indicate that the initial moisture content of the commodity also caused intensive biogeneration of CO_2 by microorganisms.

Insect Infestation

Corn - 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 the beginning until the end of storage are shown in Table 3. No significant increase in population density of insects was noted in the gastight sealed corn stacks, while the population in the control stacks increased considerably. Initial live 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 provided adequate insect control. On the basis of insect infestation findings compared with control stacks, all the trial treatments were considered successful.

Marked and significant increases in insect-damaged kernels were noted in the control stacks. Although significant, only a very slight increase in insect damage was recorded in only two gastight trials.

Paddy - Initial and final counts of live insects revealed no population increase in the gastight sealed paddy stacks (Table 3). In contrast, there was a marked increase in insect density in the control stacks, 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 before storage were 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 a large number 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 3). These results indicate that gastight conditions were not achieved in the silo. Although insect development was inhibited, residual insect population could remain due to insufficient level of gastightness.

Table 3. Density of insects, average per kg of grain taken from corn and paddy stacks during the outdoor trials using the plastic Volcani cubes and silos.

Commodity	Structure	Treatment	Initial Live	Final Live	Initial Dead	Final Dead
Corn	Cube (sacks)	CO_2	0.34	0.17	ND†	ND
		Gastight	1.87	0.95	0.06	2.95
		Control	1.01	43.00	ND	ND
	Silo (sacks)	Gastight	3.00	0.67	0.00	2.67
Paddy	Cube (sacks)	Gastight	5.87	3.71	5.00	42.67
	Control	15.17	43.17	0	91	
	Silo (sacks)	Gastight	10.33	1.33	0	1.00
	Silo (bulk)	Gastight	24.67	15.00	18.67	261.67

ND†-not determined

Weight Loss

Corn - 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, which were significantly much higher than in the treated stacks (Table 4). The control stacks, in addition to insect infestation, suffered from mold infection and rodent and bird attack.

Paddy - The weight losses observed during the field trials are shown in Table 4. The magnitude of losses recorded from the gastight sealed paddy stacks was about 18 times lower than in the control stacks. Said losses resulted in weight loss of 0.231 percent for the gastight cubes and 4.307 percent for the control stacks.

Table 4. Change in actual weight (kg) of corn and paddy stacks during the outdoor trials using the plastic Volcani cubes and silos.

Commodity	Structure	Treatment	Initial Weight	Final Weight	% Weight loss
Corn	Cube (sacks)	CO_2	17,535	17,490	0.259
		Gastight	17,605	17,524	0.460
		Control	4,665	4,416	5.338
	Silo (sacks)	Gastight	38,730	38,587	0.369
Paddy	Cube (sacks)	Gastight	14,280	14,247	0.231
		Control	5,387	5,155	4.307
	Silo (sacks)	Gastight	30,380	30,340	0.130
	Silo (bulk)	Gastight	31.860	31,777	0.260

CONCLUSIONS

1. Moisture migration was observed in dry corn and paddy stored in sealed plastic enclosures and located outdoors in the Philippines. This was effectively prevented by insulating the upper layer with bags containing rice husk. The gas-tight storage trials provided acceptable protection by reducing live insect populations below the threshold of economic damage.
2. Analysis of quality parameters showed that gas-tight storage in plastic enclosures is safe and technically feasible for outdoor storage of corn and paddy. Under Philippine climatic conditions, the safe storage period did not exceed four months. The technology has strong potential for adoption by farmers and cooperatives.

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