Hermetic Storage of Grains in the Tropics

Filipinas M. Caliboso and G. C. Sabio*

Abstract

The history of hermetic storage of grains can be traced back to preneolithic times when man stored food in underground airtight structures to keep it free from insect infestation and likewise preserve its quality over a fairly long period of time. Man' s increasing reluctance to use pesticides however, has led to renewed interest and incentive in pursuing research and development in this area, particularly for large quantities of grains handled.

This paper briefly reviews the history of hermetic storage. It also presents the results of trials conducted in the Philippines that evaluated the applicability of the use of gastight flexible plastic sheeting developed in Israel for modified and gastight storage of dry paddy and corn stacked in the open. By using the method, the objective was to develop environmentally and user-friendly temporary or emergency grain storage facilities without the requirement of chemical pesticides, for use by farmers' organizations, cooperatives, grain processors and other intermediary parties where security reserve stocks must be maintained, yet permanent storage structures are lacking or inadequate.

The studies showed that gastight storage provides an adequate protection by maintaining the number of live insects and damaged kernels below the threshold of economic damage. Weight losses in both rice and corn stacks remained minimal while seed viability was preserved. No increase in the level of aflatoxin was noted in the hermetically sealed stacks of corn. The duration of storage ranged from 3 to 6 months.

Experiences in the commercialization of the technology in farmers' cooperatives are highlighted. Lastly, future prospects for further application of the technique are outlined.

Introduction

The provision of strategic food reserves has been a consistent policy of the Philippine government, the country being disaster-prone due to typhoons, lahar, etc. With dry grain, food and feed products, the onslaught of insect pests poses a serious threat occurring during storage. Man's increasing reluctance to the use of pesticides has led to a renewed interest and vigor in pursuing research and development work in the area of modified or controlled atmospheres, particularly for large quantities of grains held for long periods of time.

Airtight storage since ancient times has been shown to be the cheapest form of storage for long-term preservation of food grains. Once dubbed by the renowned French entomologist P. Vayssiere as "the process of the future for the protection of foodstuffs", hermetic storage offers the most viable non-pesticidal alternative for insect control.

This paper aims at reviewing the early and traditional forms of airtight structures, defining

* Bureau of Postharvest Research and Extension (BPRE), Department of Agriculture, Philippines

hermetic storage and the principles behind it. It further highlights the results of trials carried out in the Philippines using Volcani cubes and silo manufactured in Israel for rice and corn stored in the open. Insights gained from actual experience in the introduction and commercialization of the technology in farmer cooperatives are likewise shared. Finally, future prospects for further application of the technique are outlined.

Review of ancient and traditional airtight storage

The following discussion draws heavily on the paper of De Lima (1990). The earliest record of airtight storage dates back to the first century B.C. when the Roman writer Varro gave a detailed account of the construction techniques and the need for complete aeration of the pit before emptying. The pit was also tested with a burning lamp to ascertain safe entry, thus indicating a recognition of the importance of airtightness and oxygen depletion in successful grain preservation.

1 Underground structures

Unreinforced and reinforced pits and bins

In the preneolithic Middle East (9000 B.C.) and neolithic Europe (5000 B.C.), shallow (30 to 100 cm) underground pits were used which were similar to the shallow pits in use today in the drier parts of the Sudan. Pit storage has also been used in Egypt for at least 3,000-4,000 years and Attia (1948) suggested that the simplest pit found in Egypt today was used in ancient times. It resembles a ditch, lined with layers of straw or bamboo basket work and the grain covered with a layer of sand. Generally, these ditches hold just enough grain for the owner's domestic consumption but may hold up to 3 tons.

When iron tools became available, deeper underground structures were built with various shapes and designs, the most common being the "bottle", "pitcher" or "gourd" shapes, but conical and cylindrical designs are also popular. These are about 2 to 2.5 m deep and 3 to 3.5 m wide with a circular neck-like entrance hole of 60 to 80 cm in diameter. These underground structures were used in much of Europe including Britain, up to medieval times in northern Europe and up to the 18th century in Swaziland. Capacities range from 1 to 5 tons. Similar pits are often built in India up to 5 m deep holding 30 tons.

In Sudan, shallow pits in a trench with a rectangular shape or with sloping sides 10m wide, 2.5 m deep and 50 to 150 m long are found. In 1939, Australia built trenches and shallow pits to store wheat surpluses which were then covered with a waterproof sheet and a layer of earth.

The crops most often stored are corn, rice (and paddy), wheat, barley, beans and other pulses. The period of storage ranges generally from 2 to 3 years and can be as long as 10 years and yet losses are always reported to be small.

Where the surrounding soil structure was not self-supporting, early underground pits had wall reinforcement using clay/mud plastering and firing, or lining with brickwork, etc. Built more than a century ago, these structures are still in use today in the Middle East, China and India.

2 Semi-underground structures

In recent times, Argentina, Cyprus and Kenya used modern construction techniques to build huge semi-underground reinforced bins incorporating waterproof membranes into the designs to exclude groundwater. The bins in Argentina had a capacity of 2.5 million tons and were constructed by excavating the earth to form long semi-circular trenches approximately 4 m underground and 1.5 m aboveground with a base 5 m wide and a top 8 m wide. The trenches are divided into cells made of reinforced concrete holding 500 to 600 tons of grain.

The Cyprus and Kenya bins were similarly designed: 8 bins, each of 900-ton capacity were constructed in Nicosia, Cyprus in 1955 to 1956 and 70 bins each of 1500-ton capacity were built in Nakuru and Kitale in Kenya from 1967 to 1968.

3 Aboveground airtight storage

Conventional stores

Qianyu (1984) showed that the walls and floors of large bulk rectangular stores in China can be rendered airtight by painting with asphalt. Polyethylene sheeting is spread over the surface of the grain and sealed with wax in a trench on top of the wall. In another method, the bag stack is built on a ground sheet initially placed on the floor ; then the entire stack is covered with a 0.23-mm polyvinyl chloride (PVC) membrane and sealed to the floor sheet using a portable high-frequency welding machine.

Bulk silos and wet grain

Metal or concrete silos built above the ground have not been used for airtight storage. However in developed countries, notably Australia, these have been rendered airtight for purging with carbon dioxide or nitrogen mixtures to reduce the amount of oxygen present in the structures and thus arrest insect and microbial growth.

Because of the high energy costs involved in drying combine-harvested grain from 35 to 45% to 12 to 13%, the use of airtight silos for storage of wet grain for animal feed is gaining importance. The oxygen level rapidly drops to 0.5% after which a small amount of fermentation takes place. The grain is mycotoxin-free since mold growth is suppressed under anaerobic conditions.

The use of empty oil drums for seed storage is a traditional method applied by subsistence and small-scale farmers. However, these provide an incomplete hermetic seal unless treated with a sealing material. Also, to prevent the development of heavy infestations, the containers should be completely filled-up to minimize head space.

Definition of hermetic storage

Modified atmosphere (MA) is a general term that refers to a condition wherein the atmospheric gas composition in the storage container has been changed in order to create conditions favorable for the preservation of food. In hermetic storage, the atmosphere has been modified by sealing the container hermetically, so that a gas composition of low oxygen (or oxygen-free) and high carbon dioxide atmosphere is obtained. The alteration of atmosphere is achieved either biologically, through the respiration of organisms present in the foodstuffs stored or artificially by the use of catalytic or exothermic converters. It has been demonstrated that the major cause of death in insects was the lack of oxygen (Bailey, 1965).

This is in contrast to controlled atmosphere where the gas composition is modified artificially by purging the storage structure with inert gases such as carbon dioxide and nitrogen supplied from pressurized cylinders or otherwise.

Principles of airtight storage

1 Oxygen depletion and carbon dioxide production

Before an airtight structure is sealed, the oxygen level of the internal atmosphere is in equilibrium with the external atmosphere and will approximate 21%. The storage structure being airtight, the interchange of gases between the container and the atmosphere is discontinued, leading to a depletion of oxygen and the production of carbon dioxide. This is due to the aerobic respiration by the grain itself, the insects, microflora and other biological organisms through the breakdown of carbohydrates.

The lack of oxygen is the key factor in the suppression and mortality of insect populations as evidenced by the records of complete insect kill from exposures to atmospheres containing 2% oxygen (Bailey, 1965). In large-scale airtight storage, the decline in oxygen levels is slow and does not inhibit insect development when populations are low. Oxygen level drops mainly because of fungal development which is enhanced by the increase in moisture of the grain on the surface as a result of moisture condensation which in turn is triggered by diurnal temperature fluctuations.

The carbon dioxide is produced in small amounts and is readily absorbed by the grain and by the surface in underground pits and concrete structures and therefore the gas becomes insignificant and does not contribute to the arrest of insect and mold development.

2 Temperature gradients

Temperature is the only external variable to which the sealed container is exposed. The heat of radiation falls on the surface when the structure is below ground; in semi-underground bins, the whole of the external surface is exposed to atmospheric temperature and during the day, it is exposed to the direct heat of the sun. In aboveground structures, the full effects of temperature are felt over the entire structure. Diurnal temperature changes, which are high during the day and low at night, create temperature gradients within the grain. This results in convection currents in the internal atmosphere in the bin, giving rise to migration of moisture to the surface.

On the other hand, localized heating or "hot spots" occur within the grain mass due to heavy insect infestations and molding. Accumulation of dust and grain fragments along the central axis of a silo during filling is also a source of "hot spots". When this happens, the heat that accumulates cannot be dissipated through normal convection since the dust and small particles fill up the intergranular space giving rise to further heating. As temperature builds up, the grain, dust and small particles form a "cake" and burning takes place.

3 Moisture migration

The hot air during the day removes the moisture from the grain and carries it by convection to the surface. At night, the air deposits the excess moisture on the cool surface which is subsequently absorbed by the grain at the surface. This becomes a cycle that repeatedly occurs leading to elevated grain moisture levels above 16 to 17% which permit fungal growth. Some of the water that condensed also runs off along the sides of the silo. For grain with initial MC of 12%, this process may take 18 months to 2 years.

Development of hermetic storage in the Philippines

The breakthrough in the development of PVC liners that conform to prerequisite specifications of durability to climate, gas permeability and physical properties, enabled the design of three storage systems that are based on the hermetic principle i.e. bunker storage for conservation of huge stocks (10,000 to 15,000 tons), flexible silos supported by welded-wire mesh frame (50 to 1,000 tons) and liners for enclosing stacks of 5 to 50 tons. The last two facilities, developed in Israel, were the subject of a collaborative scientific investigation by the Agricultural Research Organization (The Volcani Center) of Israel and the Bureau of Postharvest Research and Extension of the Philippines. The research project was financed by a grant from the USAID-CDR Program.

A series of field trials for corn and paddy was conducted from April 1991 to May 1994. Corn trials were carried out in Bukidnon, Central Mindanao while the field experiments for paddy were conducted at the NAPHIRE Compound, Nueva Ecija in Central Luzon. A summary of the field trials for corn and paddy are given in Tables 1 and 2, respectively.

Table 1 Summary of storage trials for corn

Treatment	No.of structures observed*		Capacity (tons)		Storage duration (days)
	Cube**	Silo**	Cube	Silo	
CO_2	2		16.62−18.45		93− 97
Hermetic	8	1	15.02−19.25	38.73	93−184
Control	2		4.58− 4.75		93− 97

* 1 to 2 replicates per trial
** type of handling in bags

Table 2 Summary of storage trials for paddy

Treatment	No.of structures observed+		Capacity (tons)		Storage duration (days)
	Cube (bag)	Silo (bulk)	Cube	Silo	
Hermetic	8	1	13.43−15.06	31.86	78−183
Control	3		5.30− 5.56		78−117

+ 2 replicates per trial

1 Preparation of storage site

A level portion of ground was selected and cleared of sharp objects. A foundation composed of a 4 cm thick layer of rice hulls followed by a 2 cm deep layer of rice hull ash was laid down in an area corresponding to that upon which the cube or silo was erected. The foundation materials which are readily available waste materials in the Philippines were intended to protect the plastic sheeting from sharp objects, rodents and soil-borne insects.

In places where signs of termite presence were evident, soil poisoning was first conducted on the spot where the cube or silo would be erected.

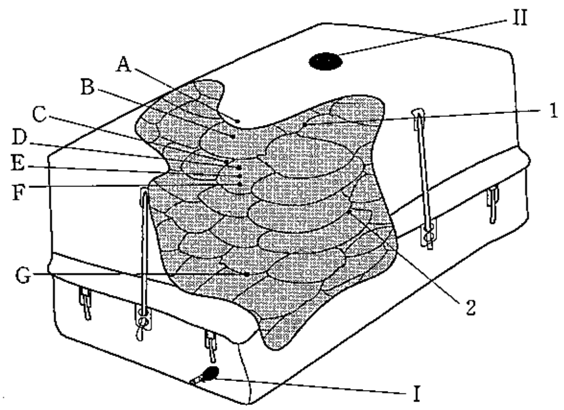
2 Construction of stack and insulation layer

The bottom section was spread out on the ground and the bagged or bulk grain was built or poured directly on the liner. Stacks were built in pyramid shape to allow rain water to run off immediately on the sides of the enclosure. After the stack had been built to the required height, the top layer was insulated with 2-3 layers of sacks containing dry rice hull. Thereafter, the top section was placed over the stack to meet the lower section halfway up the side and then zipped together. For the silo, the cone-shaped top surface was covered with a plastic sheet first before 1-2 layers of bagged rice hulls were laid over.

The rice hull insulation in both the cube and silo aimed at reducing the temperature gradients expected to build-up within the grain mass. The plastic sheet cover of the silo was designed to catch the water that would seep through the insulator and prevent the stored commodity from getting wet. The control stacks were built on pallets and stored in the open with an ordinary tarpaulin sheet cover.

3 Temperature and gas concentration monitoring

Seven thermocouple cables and two plastic tubings 3 mm in diameter were installed at

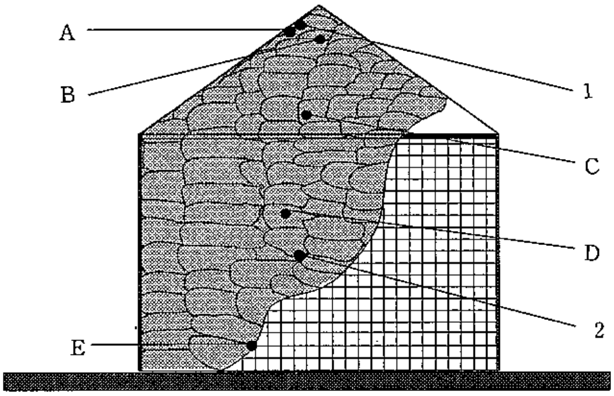


Temperature sensors are located at :
A upper tarp section
B lower tarp section
C below insulation
D 5 cm inside uppermost bag
E 10 cm inside uppermost bag
F 20 cm inside uppermost bag
G core of the stack.
Gas concentration tubes are located at :
1 lower tarp section
2 middle core
I gas applicator (for introduction of CO_2 or N_2).

Fig. 1 Diagram of experimental stack showing temperature and gas sampling points

different locations inside the cubes and silo (Figs. 1 & 2) to monitor grain temperature and gas concentration, respectively. Temperature sensors were manually monitored at regular intervals with an Anritsu type-T model HL 600.

Changes in the levels of CO_2 and O_2 inside the cube and silo were regularly measured using the GOW-MAC gas analyzer and Bachrach oxygen meter, respectively.



Temperature sensors are located at:
A below tarp section
B top one bag down
C top core
D middle core
E bottom core.
Gas concentration tubes are located at:
1 below tarp section
2 middle core.

Fig.2 Diagram of the plastic silo showing the temperature and gas sampling points

4 Gassing

Two (2) corn stacks in cubes were flushed with food grade CO_2 at a rate of 1.5kg per ton with a gas applicator. The applicator 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.

5 Sampling

Samples were collected at the onset and completion of storage to determine changes in the quality of stored paddy and corn. Three (3) composite samples of 1kg each were collected from all bags in each stack using a sampling spear. An additional 500g sample was obtained from each of the 15 individually marked bags which were distributed at different locations within the stack.

6 Parameters observed

Common parameters observed for both corn and paddy trials were moisture content, grain temperature, gas concentration, insect infestation, fungal infection, germinated kernels, seed viability and weight loss.

Additional parameters gathered for corn were aflatoxin contamination, moldy kernels and discolored kernels. For paddy, milling recovery, percentage of head rice recovery, percentage of broken rice and percentage of yellow kernels were added.

Moisture content determination was carried out by the oven-drying method (Anon., 1982). Insect density was determined by sieving live insects from composite and representative samples. These were sorted according to species.

Fungal enumeration and the extent of infection for corn were assessed 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).[1] Corn samples were first surface-sterilized with 0.5% sodium hypochlorite before plating and then those plated on AFPA were incubated for 48 h at 25℃ while those plated on other media were incubated for 7days at the same temperature.

Aflatoxin contamination was analyzed by two procedures, thin layer chromatography (TLC) and the rapid survey method using Target[R] AFLA Kits. The first procedure was based on two composite samples of about 20kg 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 procedure involved an initial rapid screening test using Target[R] AFLA Kits. Only corn grains with <20 ppb aflatoxin content were used in the experiment. At the end of the storage, composite samples of about 10kg each were collected from designated grids at the periphery of the stack (north, south, east, west and top), and from core (bottom and middle), then subjected to the same assay.

The calculation of quality parameters was determined by counting the number of insect-damaged, discolored or yellow kernels, moldy and germinated kernels in 1,000 kernel samples taken from the composite samples. Seed viability was measured by the rag-doll method. The actual weight loss was calculated as the difference in weight of corn or paddy at the start and completion of the storage period.

Data were statistically analyzed using the multi-factor analysis of variance (AVMF) and least square difference (LSD) tests.

Research findings

1 Corn

The moisture content of corn held under hermetic and CO_2-enriched atmospheres did not change significantly during storage. Moisture condensation was evident in cubes where storage periods exceeded 4 months but this obviously did not affect the moisture content of grains.

Grain temperature (Fig. 3), based on mean weekly daytime temperatures logged from observed stacks, was lower inside the storage structures than the ambient temperature. Temperatures recorded from the various points within the sealed stacks were also more uniform than in the control stacks. This could be the result of the insulation procedure by which the insulator prevented heat transfer from the top of the stack to the grain mass. In the uninsulated control stacks, fluctuations in grain temperature were limited to the top surface and 5 and 10 cm depth.

The effects of hermetic storage on oxygen and CO_2 concentrations and the retention of

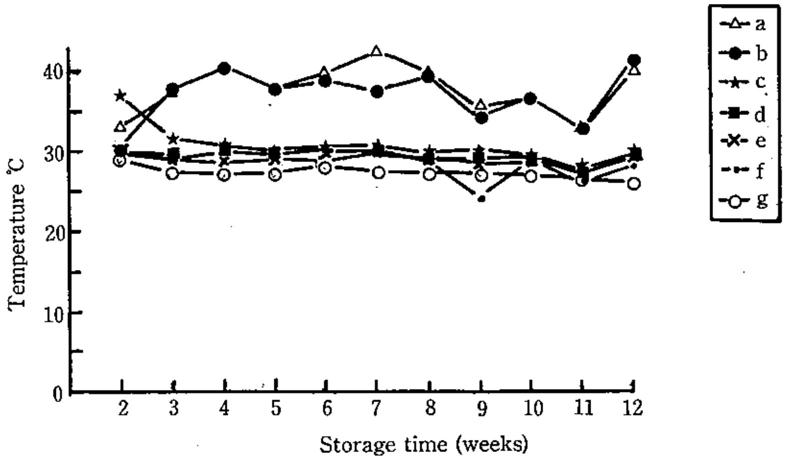


Fig.3 Temperature recorded from seven different points in the hermetically sealed corn stacks
a - above liner; b - above insulation; c - below insulation; d - 5 cm inside uppermost bag; e - 10 cm inside uppermost bag; f - 20 cm inside uppermost bag; g - core of the stack.

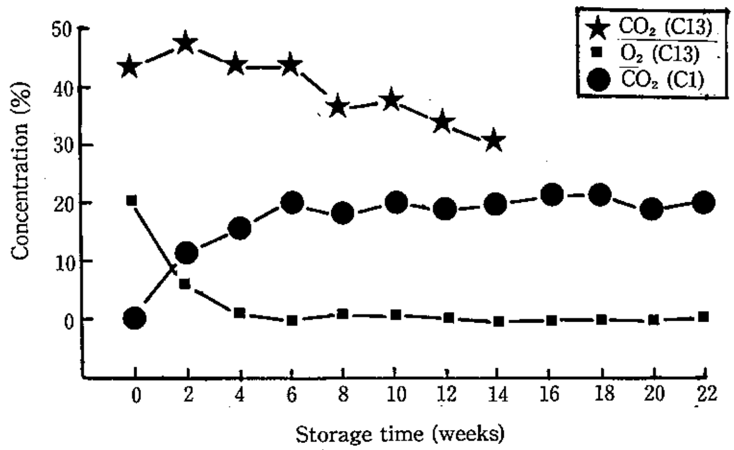


Fig.4 Carbon dioxide and oxygen concentrations recorded in the CO_2-enriched (C1) and hermetically sealed cube (C13) of corn

purged CO_2 within the storage cubes are presented in Fig.4. The oxygen level dropped below 2% within 3 to 4 weeks of storage while the CO_2 tension in most of the hermetic cubes rose to 12-16% and fluctuated within the range for most of the storage period. Some stacks that were stored for about 6 months showed even higher CO_2 concentrations (18-22%). The respiration of wet grains and molds could have contributed to the evolution of CO_2 and subsequent depletion of O_2. During the extended storage periods, the insulators became saturated with condensed water which seeped into and moistened the grain in the top layer and on the sides of the stack. The resulting modified atmosphere inside the enclosure proved to be lethal to insects, as evidenced by the high insect mortality.

In the CO_2-flushed stacks, the estimated decay rate of 0.21% CO_2 per day indicates that the CO_2 concentration exceeded the minimum recommended level of 35% and exposure period of 15 days to achieve complete disinfestation of the commodity.

The initial (i) and final (f) mean density of live insect population of 8 hermetic cubes and 2 CO_2-treated stacks did not significantly increase (1.87_i–0.95_f and 0.34_i–0.17_f, respectively) after storage but the mean density of live insects in 2 control stacks considerably increased (1.0_i–43_f). On the basis of insect infestation and in comparison with control stacks, hermetic and CO_2-treated stacks were considered to be superior.

The growth of fungi on grains kept under hermetic storage and CO_2-treated stacks seemed to be inhibited (Table 3). Stacks were predominantly infected with *Aspergillus flavus* and *Eurotium chevalieri*. The incidence of *A. fumigatus, A. niger, Penicillium citrinum* and *P. funiculum* was low. Hocking (1989) reported that atmospheres containing about 20% CO_2 generally inhibit mold growth.

Table 3 Mean percentage fungal infection in all corn stacks kept at various atmospheres

Fungal species	CO_2-treated		Hermetic		Control	
	Initial	Final	Initial	Final	Initial	Final
Aspergillus flavus	23.00	0	10.50	11.00	21.00	11.00
other *Aspergillus* spp.	0	14.00	0	4.00	0	5.50
Eurotium chevalieri	40.00	1.00	12.75	29.50	3.00	71.00
Cladosporium cladosporoids	0	14.00	0	0	0	7.00
Penicillium funiculosum	0	0	0	0	0	11.00
Peniciliun citrinum	2.00	0	0	0	2.00	6.00
Fusarium moniliforme	2.00	15.00	0	0	0	55.00

However, there was a proliferation of *Fusarium moniliforme* on wet grains at the periphery and bottom of stacks and on top of the silo. Wilson (1975) reported that high moisture favors the growth of *F. moniliforme* which can tolerate an atmosphere of 14-15% CO_2 and 0.5-1% O_2. Since this species may produce the mycotoxin fumonisin, the proliferation of this fungus needs further investigation.

Aflatoxin level in 4 stacks kept under hermetic conditions for about six (6) months remained low with no significant increases. Initial level ranged from <1ppb to 12.77 (±2.88) while final level reached values of 1.12 (±1.76) to 13.71 (±4.72), indicating that hermetic storage protects corn from aflatoxin contamination.

Discolored kernels which may be caused by heat damage or mold activity did not significantly change in both hermetic and CO_2-treated stacks. Mean initial and final values of discolored kernels were 7.29-7.97% in 8 hermetic stacks and 3.48-3.9% in 2 CO_2-treated stacks. Control stacks showed severe kernel discoloration, from an initial level of 4.56 to a final level of 9.52% during storage.

Percentage of germinated kernels did not show any significant increase in both hermetic and CO_2-treated stacks. Seed viability of corn stored for about 3 months under the gastight structures did not change significantly and not even during relatively long storage periods (about 6 months), suggesting that seeds can be kept and preserved utilizing the gastight storage technology.

Weight loss in corn may be effectively prevented through hermetic and CO_2-flushed atmospheres. Mean percentage weight loss recorded in 2 stacks each of hermetic and CO_2-treated structures after 3 months was very low at 0.30% and 0.26%, respectively, while in the control stacks, mean percentage weight loss of 2 stacks was very high, 5.34%. Percentage weight loss in hermetic stacks ranged from 0.25% to 1.1% after about 6 months of storage.

2 Paddy

No significant increase in the average MC of gastight paddy stacks was noted except in 2 stacks where a slight increase occurred. There was a real trend towards an increase in MC in the 2 control stacks stored during the wet season and a decrease in MC of the control stack stored in the dry season. These differences indicate the importance of having gastight sheets to avoid moisture diffusion. The field trials show that there was no critical moisture build-up or localization in all the treatments and the control except for 1 stack that exceeded the critical MC of 14% by 0.24%. Likewise, the overall MC of paddy bulk-stored under gastight conditions in the silo did not change significantly during the trial, suggesting that bulk storage of dry paddy in hermetic plastic silo is feasible without adverse effects on the MC of paddy.

Grain temperature levels observed in paddy showed similar patterns to those in corn. The insulation procedure obviously, had likewise reduced temperature build-up within the grain mass.

CO_2 readings generated from 4 paddy stacks with MC ranging from 11.68-13.46% that were stored under hermetic cubes ranged from 10-18%. The level of CO_2 generated was lower in paddy with lower MC and higher in paddy with higher MC.

Initial and final counts of live insects (Table 4) in paddy stored under hermetic conditions did not reveal any significant population increases. The density of live insects in these stacks at the end of storage however was much lower when compared with the control stacks. The control stacks showed marked increases in the density of live insects. Results indicate that since the liner was not completely impermeable to oxygen and CO_2, residual insect population may remain but at extremely low levels.

The milling yield and yellow kernels in paddy stored in hermetic structures did not change significantly. The levels of head rice and broken kernels were maintained in 8 out of 12 stacks, which may be due to the biological aging phenomenon, resulting from 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 increased and the increased hardness was translated into a greater resistance to milling and higher total and head rice yield.

The two control stacks stored during the dry season showed a decrease in head rice and increase in broken kernels. The stacks did not show any severe quality deterioration but the control stacks observed during the rainy season displayed pronounced yellowing.

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

Table 4 Average density of insects per kg of sample in paddy trials

Trial No.	Stack code	Treatment	Insect density		Significance level
			Initial	Final	
I − 1	P 1	Hermetic	5.33 (-)	8.00 (-)	ns (-)
I − 2	P 2	Hermetic	9.67 (-)	1.67 (-)	* (-)
I − 3	P 3	Control	13.67 (-)	35.33 (-)	ns (-)
II − 1	P 4	Hermetic	8.67 (0)	0.33 (36.33)	** (**)
II − 2	P 5	Hermetic	17.00 (0)	2.33 (63)	* (**)
II − 3	P 6	Control	16.67 (0)	51.00 (91)	ns (**)
III − 1	P 7	Hermetic	0 (18.00)	4.33 (122.67)	** (**)
III − 2	P 8	Hermetic	0 (11.33)	6.67 (26.67)	* (ns)
III − 3	P 9	Control	0 (12.33)	47.33 (89.33)	** (ns)
IV − 1	P10	Hermetic	3.33 (0.33)	6.33 (2.67)	ns (ns)
IV − 2	P11	Hermetic	3 (0.33)	0 (4.67)	ns (*)
V − 1	P12	Hermetic silo	24.67 (18.67)	15.00 (261.67)	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 represents the number of dead insects.

Germination of paddy stored under hermetic conditions did not change significantly during the trials, suggesting a high potential for seed preservation.

The magnitude of losses recorded from the hermetic stacks (0.10-0.32%) was about 18 times lower than that of losses in the control stacks (3.75-4.85%).

Results of field trials on hermetic storage of both paddy and corn indicated that this storage technology is applicable under Philippine conditions. It is recommended for outdoor as well as for indoor storage of dry paddy and corn. The target beneficiaries are big farmers, farmer groups or farmer cooperatives and small-scale traders.

For outdoor storage, safe use of the hermetic storage system developed as an alternative storage structure is recommended for about 3 months only. If the storage period is to be extended, the rice hull insulators should be replaced with dry ones or the rice hull re-dried before re-sealing the structure. For indoor storage, safe use of hermetic storage structures for dry paddy and corn can be longer for the following reason. Since the temperature inside the building is more or less uniform, moisture migration can be eliminated and grain wetting can be prevented.

Commercialization of hermetic storage

Commercialization of hermetic storage in the Philippines began in 1997 and was adopted mainly by farmer cooperatives. A total of 162 units of hermetic cubes called "Volcani Cubes" with a 10-ton capacity have been distributed to various cooperatives nationwide. Of this number, only 12 units so far have been used.

Initial feedback gathered from some farmer cooperatives who have used or are presently using the cubes is very encouraging. Most underscored the importance of the storage structure in keeping their produce safe from insects, rodents, birds and from adverse weather conditions while speculating for better prices.

Conclusion and recommendations

Hermetic structures using gastight plastic liners can be a safe and viable alternative to permanent structures for storage of grain. They enable to preserve the quality of dry paddy and corn and minimize weight loss. Flexibility, transportability, ease of erection, simplicity of operation and maintenance, and durability are distinct advantages. Their availability in different sizes and capacities can suit a wide range of requirements to fit several levels of operations. They are particularly valuable for emergency storage of food aid in times of calamities.

The gastight structures can also be used with CO_2 to disinfest organically grown cereals. The preservation of processed raw materials as well as spices which require non-pesticidal preservation techniques is a possible application. Experiments are underway too for their use in disinfesting dried fruits and controlling wax moth in honeycombs. The cube can also serve as a mobile fumigation chamber.

In addition, hermetic storage provides a possible alternative to cold storage for seed preservation. Finally, its application for other non-food products such as tobacco, furniture, museum artifacts, etc. is another strong prospect.

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