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Self Regulated Atmospheres to Prevent Fungal Damage in Moist Paddy

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Appendix 2: Angelita M del Mundo and Angelina dR. Felix (1998) Sensory qualities of milled raw and cooked rices from a paddy stored with different moisture contents and under various storage durations. Final Contract Report, Institute of Human nutrition & Food, UPLB, Laguna, Philippines, 17 pp.

Appendix 3: Angelita M del Mundo and Angelina dR. Felix (1998) Sensory qualities of milled raw and cooked rices from wet paddy stored in a Volcani cube. . Final Contract Report, Institute of Human nutrition & Food, UPLB, Laguna, Philippines, 26 pp.

Appendix 4: Donahaye J.E., Navarro S., Filipinas Caliboso, Glory Sabio, Gemma Mallo and Dator J. (1999). Prevention of moisture migration in sealed stacks stored in the open in the tropics using reflective covers. 19th ASEAN Seminar on Postharvest Technology, Ho Chi Min City, Vietnam 9-12 Nov 1999 (accepted).

3. Executive Summary

The objective of this project was to provide a solution to the acute problem in far-eastern Asia where paddy-rice is harvested at high moisture contents (MCs) during the monsoon season. This paddy must then be dried rapidly to a safe MC in order to prevent it from molding and rotting. However, if the paddy is dried rapidly from about 30% to the required "safe" MC, the grains suffer stress resulting in cracking and breakage. To overcome this problem a two-stage drying procedure has been advocated where the paddy is initially dried to 18% (intermediate MC), at which stage yeast and bacterial activity are suppressed, followed by a second stage drying from 18 to 14% MC to prevent the development of storage molds. However, the drying problem is compounded by the fact that most farmers do not have flash dryers and are obliged to sell their grain directly to the traders. Even if flash dryers are available, insufficient capacity of second stage dryers creates a bottleneck at harvest time.

Our project was designed to develop a technology that would enable farmers to overcome this bottleneck at the second drying stage by providing them with a means of storing the intermediate MC paddy under tightly sealed conditions and thereby prevent spoilage for prolonged periods until drying by sun or machine is again an available option.

The present policy of the Filipino government is directed at providing small scale farmer cooperatives with on-site storage units so as to decentralize storage of the national grain reserve as well as provide rural communities with a higher level of food security. Implementation of this policy is under way, and already the concept of sealed storage to protect dry grain from insect infestation has been widely promoted together with the distribution of flexible plastic outdoor storage cubes that were developed by ARO and BPRE as the outcome of a previous CDR project (C7-053). In 1998, about 200 units of these storage structures were purchased and distributed to farmers' cooperative recipients nationwide. Recently, the government has purchased an additional 300 units for distribution among farmer cooperatives through soft-loans. This is being done as a mitigating measure in anticipation of "La Niña".

However, the problem of harvesting moist paddy in the rainy season still remains. Although both the previously developed storage technology, and the present one are based on the same principle of hermetic storage, the objective of the present project was to employ the principle of self-regulated atmospheres caused by aerobic metabolism in order to arrest fungal development and preserve grain quality in paddy of intermediate MC. Here, to prevent spoilage, oxygen depletion must be much greater and more rapid than that required to control insects, and it was anticipated that this would require a higher level of hermetic seal than that required for insect disinfestation.

The first two questions to be answered, before field trials could be initiated, were - do the rates of oxygen depletion obtainable by sealed storage of moist paddy prevent mold proliferation sufficiently in the damp grain; and, - can hermetic storage of intermediate MC grain, be carried out without having a deleterious influence on the aroma, taste and cooking qualities of the rice?

Both these aspects were studied during the first and second years with laboratory studies in the Philippines being undertaken on the effect of hermetically sealed "moist" paddy stored for different time periods on different quality parameters including milling and organoleptic characteristics; while in Israel, studies with the same paddy and also wheat were directed at evaluating rates of aerobic metabolism at different moisture contents and temperatures as a basis for determining rates of oxygen depletion within the storage structures.

In the first year a flexible storage structure of 10 tons capacity was manufactured from a plastic laminate chosen from a series of materials that were screened to test their permeability to oxygen and carbon dioxide. This structure was field-tested prior to shipping for paddy storage trials to be undertaken in the Philippines.

Although calculations indicated that the low permeability of the liner material would give a sufficient seal to reproduce laboratory conditions, an additional factor was anticipated to have an influence on the storage environment under field conditions. This was the development of air convection currents within the stack that carry moisture and deposit it at the top layer. These currents develop when temperature gradients are formed as a result of diurnal temperature fluctuations. This phenomenon was noted in the previous study when storage cubes were set-up in un-shaded sites. As a counter measure, an insulating layer of rice hulls was placed over the top layer of bags and this solution was adopted as standard procedure. However, for the storage of

intermediate MC grain the situation is much more critical since any rise in MC above 18% is liable to enable the anaerobic metabolism of bacteria and yeasts that have a strong influence on grain quality, particularly taste and aroma.

An improved solution developed during this project was the use of an external reflective shade cover placed over the storage cube in order to reduce temperature gradients within the grain and thereby minimize the moisture migration phenomenon. Initial trials that were carried out in both countries in the second year, were inconclusive. However, after modifications, further trials carried out during the third year in both countries gave positive results that have led to adoption of this concept for all outdoor storage in plastic liners, and inclusion of reflective covers in the standard commercial kits.

It was clearly demonstrated in the first year that the rates of oxygen depletion in hermetically sealed moist paddy could prevent mold proliferation, but the effects of hermetic storage upon paddy quality took longer to evaluate than planned, as this required repeat experiments to enable in-depth evaluations of cooking and acceptability parameters that were carried out by Prof. Del Mundo at the University of the Philippines, Los Baños after 1, 3 and 6 months of storage. The project findings indicated that after 1 month, quality of sealed paddy stored at up to 18%MC had not deteriorated. However, further evaluations made on paddy stored hermetically for 1, 3 and 6 months under both laboratory and field conditions confirmed that after the first month of storage the quality of moist paddy (16-18% MC) deteriorated progressively and the grain was no longer acceptable by the taste panels. These findings enable the following tentative recommendations to be made for paddy storage duration:

	For 18% MC	one (1) month
(not confirmed	For 17% MC	one (1) month
by	For 16% MC	can be extended to two (2) months
field trials)	For 15% MC	can be extended to three (3) months
	For 14% MC	still the recommended level for long term paddy storage

In conclusion, the present widespread implementation of the hermetic storage technology at the cooperative and village level throughout the Philippines has been backed up with BPRE initiated "on-the-spot" extension courses. Many aspects of this technology have not yet been explored especially field validation of the laboratory findings at 15 - 17% MC. However will we anticipate that this enterprise will serve as a starting point for the adoption of hermetic storage to protect paddy of intermediate MC until it can be dried.

4. Research Objectives

Rice is one of the most important food crops in the world and dependence upon its availability is a determining factor for food security of large sectors of the predominantly rural population, and also the urban poor. In Asia, rice is the major cereal crop, and in many countries national policy is towards self sufficiency and export. This has been achieved by the development of high yielding varieties with reduced growing seasons that have enabled farmers to produce larger harvests. However, the double cropping of early maturing varieties requires harvesting to take place during the monsoon season when the moist grains cannot be sun dried. Most of the rice is grown by small scale farmers who possess neither storage, nor artificial drying facilities. Consequently losses after harvest (before the grain can be sun-dried) due to mold development are high, or the grain has to be sold immediately to traders who have the facilities to dry it rapidly. Therefore the farmer is unable to control the price of his harvested paddy at the farm-gate and is obliged to sell at the moment of glut when prices are lowest. This problem of harvesting moist HYV paddy during the monsoon season has been recognized as THE major cause for losses by the small scale farmer (see FAO-IRRI/AED Rice Post-Harvest Conference summary by Dante de Padua, 20.10.97).

In the Philippines, more than half of the total annual local production of paddy-rice is harvested during the wet season (Philippine Agribusiness Fact Book and Directory, 1991-1992). Paddy is usually harvested at 20 to 21% MC during the dry season and 28 to 30% MC during the wet season (Mendoza et. al, 1984). In a survey conducted by Tolentino et. al (1992), the purchase of wet paddy by rice traders in Bulacan and Nueva Ecija provinces is about 53% of the total volume produced during the wet season and 13% of the total volume during the dry season. This indicates the high volume of wet paddy handled during the rainy season.

The use of mechanical dryers has been so far the recognized method of preventing deterioration of wet paddy during the rainy season. However, the high cost of investment, maintenance, and operation, are among the constraints limiting the adoption of this method especially in rural areas (Bermundo and Quiambao, 1984; Lorenzana, 1985). To this day, sun drying continues to be the most favored method of drying paddy. Thus during the rainy season, farmers and traders alike are forced to wait for the sun to shine.

A rapid change in the quality of paddy has been observed when drying is not carried out immediately after harvest. Rice yellowing (generally attributed to heating and microorganism activity), increases significantly after two weeks and one month delays in drying of paddy with an initial MC of 23-25% and 20-22%, respectively. Likewise, for paddy with an initial MC of 30%, yellowing increases significantly after 2 days delay in drying (Mendoza et. al, 1982). The increase in yellow kernels in milled rice creates an economic problem for producers and traders because yellow rice commands a low price in the market. Mendoza and Quitco (1984) provide computations of monetary losses due to yellowing. As a result of yellowing it has been estimated that up to 30% of the value of the country's total stocks is lost (Anon., 1988). Rice yellowing of moist paddy has also been investigated in Indonesia including isolation of associated fungi (Phillips et. al, 1989). Other evaluations of deterioration of moist paddy under aerobic conditions were used by Matsuda et. al (1974) including fat acidity and germination as qualitative indices and odor as a qualitative index.

The difficulty in adoption of mechanical dryers necessitates the examination of alternative solutions to the fungal deterioration of wet paddy. The use of chemicals (such as propionic acid) in the storage of wet paddy has been found effective in inhibiting deterioration due to fungi. However, this has posed some limitations due primarily to its prohibitive cost.

The use of airtight conditions or modified atmospheres for preventing deterioration of high moisture paddy during temporary storage until it can be dried, offers a novel possibility for farmers to maintain quality for prolonged periods. In rice, most storage fungi are inhibited by atmospheres with less than 1% O_2, (Richard-Molard et. al, 1986), whereas carbon dioxide (CO_2) concentrations in air of greater than 80% may be required to prevent fungal deterioration of high moisture commodities (Hocking, 1991).

The present policy of BPRE (formerly NAPHIRE) advocates two stage drying, whereby high moisture paddy should be dried down to below 18% MC in the first stage to minimize rapid deterioration, followed later by drying of intermediate moisture paddy down to 14% MC (Andales, 1987). This project therefore aimed at finding an alternative to the second stage of drying or to delay the need to undertake the second drying stage beyond the presently acceptable holding period of 21 days (Quitco 1983).

The project's hypothesis is that at MCs below the level permitting bacterial growth, namely at water activity (a_w) <0.87, most storage fungi are fully inhibited in atmospheres containing less than 1% O_2. In addition, risks of mycotoxin production are nullified at reduced O_2 concentrations (Paster, 1987; Paster and Bullerman, 1988).

However, the influence of intrinsic and extrinsic factors governing microfloral activity of moist grain, and particularly paddy, under hermetic storage, requires further clarification in order to reveal the inter-relationships in the "grain-microflora" ecosystem. An important aspect of this research project which needs further elucidation, is the aerobic stability of paddy after opening the hermetic structures and prior to its utilization for human consumption (Diawara et. al, 1986.) This matter has not yet been clarified.

The storage of grain in gastight structures is a well known method to prevent insect activity in dry grains, and has been applied in practice including storage of grain in flexible plastic enclosures (Donahaye et. al, 1991; Navarro and Donahaye, 1988). Therefore it was postulated that the plastic industry is now capable of manufacturing durable, weather resistant liners to a degree of gas tightness that will restrict microfloral activity.

The objective of preventing losses using the aspects of microfloral and atmospheric gas composition interactions has not yet been addressed to problems encountered in tropical countries. The sparse literature on hermetic storage in the tropics has been based on the use of gastight metal structures. These tends to be susceptible to the establishment of temperature fluctuations that cause moisture migration and also encourage air infiltration caused by a pumping effect through leaks due to pressure differentials. Preliminary experiments using flexible liners in the tropics indicate that these problems can be significantly alleviated with encouraging results (Donahaye et. al 1991, Navarro and Donahaye 1985, Navarro and Donahaye 1988).

In the light of the above rationale, the objective of this project was to develop a storage solution for paddy at moisture contents above critical levels but below a_w 0.87 (equivalent to about 18% MC), by inhibiting fungal development. For this purpose, a flexible plastic structure was designed with a sufficiently tight hermetic seal that the self-generated metabolic activity of the paddy reduces oxygen concentrations to below 1%. This should enable the paddy to be stored without microbial damage until mechanical dryers become available, or sun-drying can be carried out at leisure, or in countries where parboiling or steam-boiling are practiced, the paddy can be processed.

The innovative aspect of this research is that it was the first attempt at providing a technologically sound alternative to two-stage drying, and at the same time providing the farmer with the means of delaying sale of his harvested grain until the price is right.

Present national policies are directed towards decentralizing storage reserves by increasing storage capacity in rural areas. Consequently, flexible sealed storage structures as developed in a previous CDR project (C7-053) are now being increasingly used in the Philippines at the cooperative level. Therefore this storage concept dovetails with existing policy trends.

5. Methods and Results

5.1 Laboratory studies on factors affecting grain conservation under gas-tight conditions (Israel).

The objective of the first laboratory studies, before field trials could be initiated, was to examine the rates of oxygen depletion obtainable by metabolic activity under sealed storage of moist paddy, and then verify how these rates would affect germination, and whether they could effectively prevent mold proliferation in the damp grain.

5.1.1 Metabolic activity:

Respiration studies were undertaken to evaluate paddy conservation under different combinations of water activity, and temperature. A parallel series of experiments was carried out on wheat, both for comparative purposes, and in order to provide data for preliminary field trials with experimental storage containers to be carried out in Israel, using wheat as a substitute for paddy.

i) Paddy

In order to determine the potential of paddy to generate self-regulated atmospheres under completely gas-tight conditions, controlled laboratory experiments were undertaken with five target levels of MC, namely, 14, 15, 16, 17 and 18% w.b approximately corresponding to the following water activities: a_w: 0.75, 0.80, 0.85, 0.88 & 0.90.

The experiments were undertaken at 25, 30° and 35°C, for three storage durations of 1, 3, and 6 months. A rice variety widely planted in the Philippines (IRRI 64) was used for the experiment. Paddy that arrived from the Philippines at an initial MC of 13.06% was moistened to the desired MCs before the start of the experiment. After moistening, glass jars were filled with paddy (370 g/jar). The jars were sealed hermetically with screw type metal covers equipped with septa for gas sampling, and transferred to thermostatically maintained chambers at the desired temperatures. The rates of respiratory metabolism as expressed by O_2 intake and CO_2 output were determined at regular graded intervals, by gas chromatography using a thermal conductivity detector. To evaluate metabolic activity inside the sealed system, the absolute weight of O_2 consumed by the grain was calculated. To do this, a manometric method using transducers was used to determine the interstitial space and headspace of the grain in the experimental jars. Paddy that arrived from the Philippines was derived from the same lots as those used by BPRE for their laboratory experiments (see Section 5.2). Two sets of experiments were carried out because the first consignment of paddy was later found to consist of rain damaged grain with an initial germination level of 23%. Therefore the laboratory trials in both the Philippines and Israel were repeated using high quality paddy with a germination rate of 91%.

The experiment was divided into two trials. The first was designed to record rates of change in gas composition under completely sealed conditions. The principal findings of this trial have been published (Donahaye et al. 1998) and are not reported in detail here. They can be summarized as follows: For good quality paddy, at all three temperatures, there was an approximate doubling (x 1.7) in respiration rate for every unit increase in MC over the range tested, and for rain damaged paddy, this ratio was slightly higher (up to x 1.9). Similarly, for every 5°C increase in temperature, the increase in respiration ranged from x 1.7 to x 2.2 for good quality paddy, and for rain damaged paddy from x 1.5 to x 1.95. A linear relationship was found between respiration rates expressed as log of oxygen consumption in mg O_2/100g/dry matter/ day plotted against paddy MC. For 18% MC at 35°C, respiration rate of high quality paddy was 20.36 mg O_2/100g dry matter/day, and for 14% MC paddy at 25°C it was 0.604 mg O_2/100g dry matter/day. For the same temperatures and MCs the low quality paddy gave values of 17.175 and 0.585 mg O_2/100g dry matter/day.

ii) Wheat

In order to prepare for the pilot-scale field trial to be carried out in Israel, where wheat is the only conveniently available cereal grain, an identical trial was carried out using wheat moistened from an initial 9.79% MC. to the same range of target MCs and held over the same range of temperatures. Rates of O_2 consumption and CO_2 output at the different MCs were measured and these are given at the 35°C level in Fig.1. The calculated metabolic activity of wheat inside the sealed jars under different temperatures is given in Fig. 2.

The Figures show that for wheat, the rates of self-regulation of atmospheres in gas-tight jars showed a similar dependence on MC and temperature but were consistently higher than those of paddy.

Fig. 1: Measured rates of oxygen consumption and carbon dioxide output of wheat held at

different moisture contents in gas tight containers at 35°C

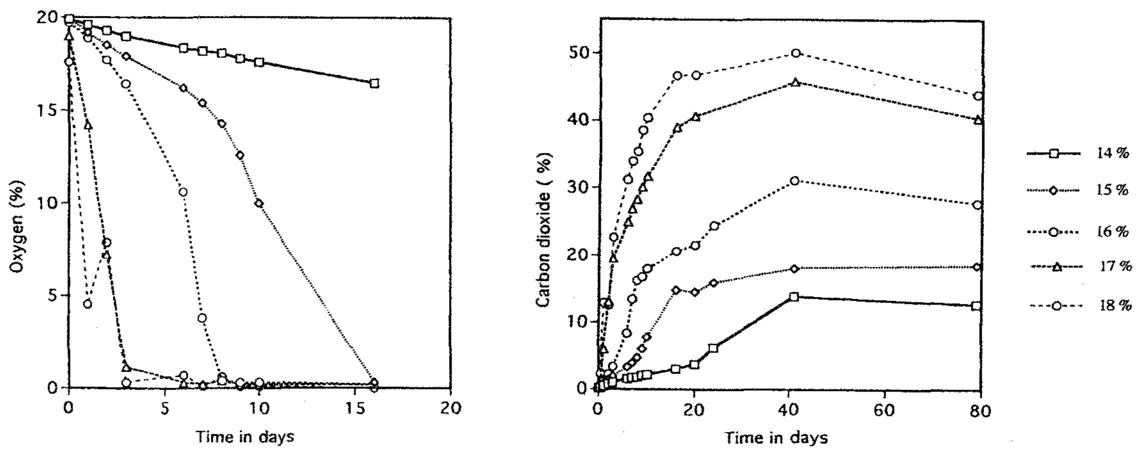
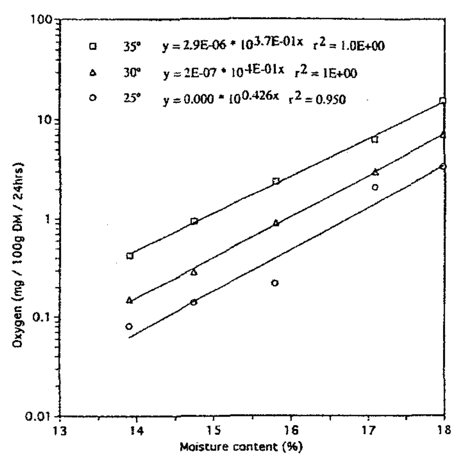


Fig. 2 Effect of moisture content and temperature on the metabolic activity of wheat in a gas-tight container



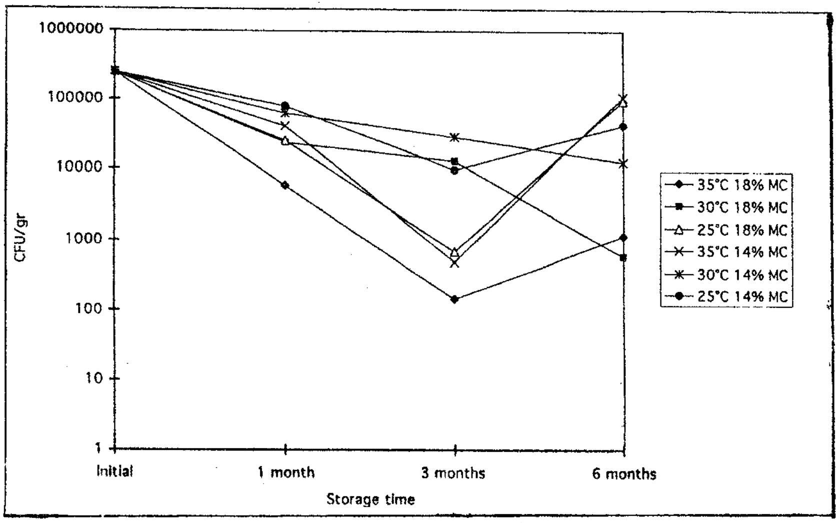
5.1.2 Effect of gas-tight conditions on fungal contamination

i) paddy

This trial, carried out both on rain damaged paddy and good quality paddy, was designed to evaluate the influence of the atmospheres so obtained on microfloral growth. Glass vials (100 ml) were filled with paddy moistened to the desired MCs. Contrary to the respiration trials, gas samples were only taken directly after sealing, and a day later to verify gas-tightness. Final gas samples were taken at the end of the trial, immediately prior to opening the vials for analysis of microflora. Final MC. determination of each sample was also measured at this stage.

Fungal contamination was evaluated using a standard plating method after 0, 1, 4, and 6 months of sealed storage. The data obtained on total fungi count clearly revealed that for both qualities of paddy, the fungistatic effect of the gas-tight conditions are well expressed even at low levels of water activity. Selected results of these analyses for the good quality paddy, are given in Fig. 3.

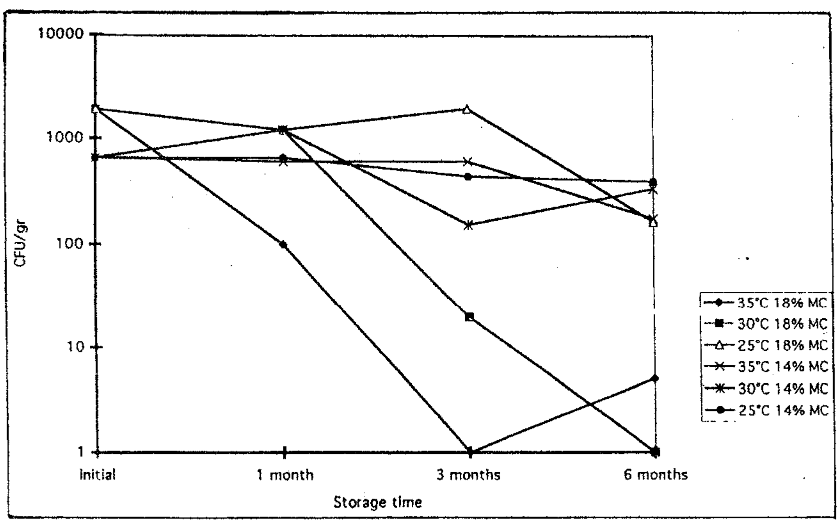
Fig 3: Fungal counts of good quality paddy taken before gas-tight sealed storage, and after one to six months of storage at 14 and 18% MC and three temperatures



ii) wheat

An identically designed trial to examine the effect of hermetic storage on the fungal count of wheat, gave similar trends in reduction of fungal count to that of paddy, though initial infection was in the order of 1,000 CFU/g (as against 100,000 CFU/g for paddy). Selected results are provided in Fig 4.

Fig. 4: Fungal counts of wheat taken before gas-tight sealed storage, and after one to six months of storage at 14 and 18% MC and three temperatures



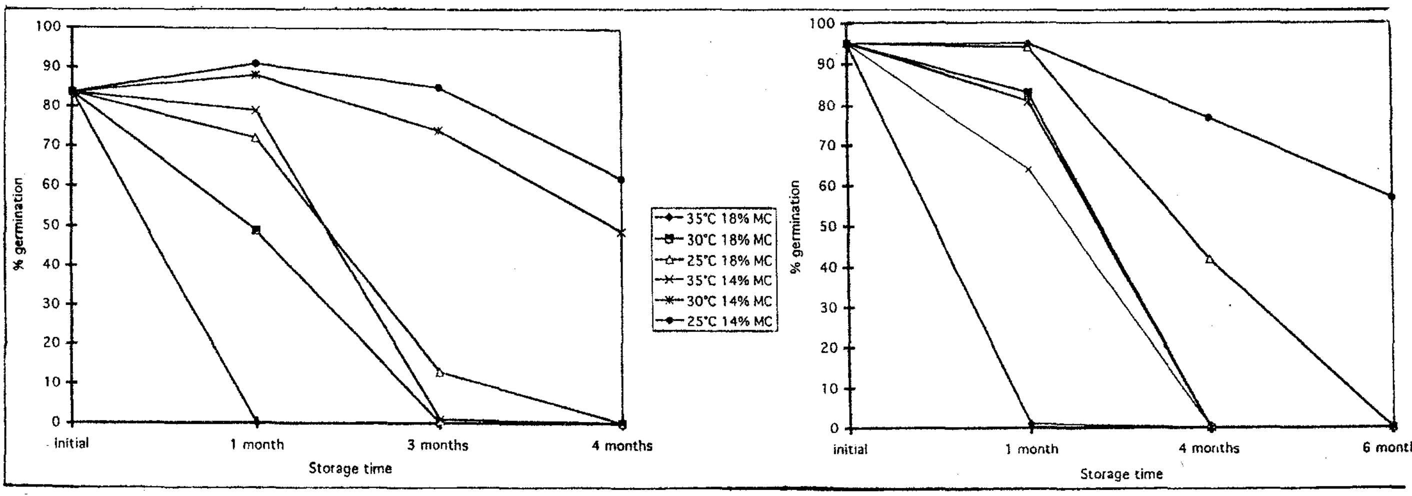
5.1.3 Germination

Although it has been shown by us that hermetically stored dry paddy retains its germination capacity well (Navarro et al. 1996), to the best of our knowledge the rates of decrease in germination of paddy at intermediate MCs have not been documented. Although such grain is not destined for seed, the germination index is of value in that it influences the potential of the grain for subsequent storage. The low levels of germination obtained for the first consignment of paddy received in Israel, served as a warning that this was poor quality rain-damaged grain that required the experiments to be repeated in the second year.

Results of germination of the good quality paddy and wheat during gas-tight sealed storage are given in Fig 5.

Fig 5: Effect of 4 month exposure under gas-tight seal at three temperatures on the germination of paddy (at 14 and 18% MC), and 6 months exposure on the germination of wheat (at 14 and 17% MC).

Paddy wheat



From the Figure it is clear that for both wheat and paddy there is a negative correlation between both MC and temperature, and germination. For paddy, at 18% MC and 35°C, germination fell to zero within one month, whereas at 14% MC and 25°C it was still high after 3 months. Intermediate MCs and temperatures (not shown in the figure) gave a graded decrease in seed viability. For wheat the capacity to retain germination was slightly greater, and for 17%MC wheat at 25°C, about 40% germination was retained after 4 months.

5.2 Laboratory studies on factors affecting paddy conservation under gas-tight conditions (Philippines).

Studies in the Philippines were devoted to evaluating the influence of hermetic storage on the quality conservation of paddy at different water activities. Poor quality paddy was used initially (not detailed in this report), followed by good quality paddy as in the Israeli trials, and the same methodology for adjusting the paddy to different MCs was employed.

5.2.1 Methodology

For the good quality paddy experiment, two trials were conducted. The first was undertaken for four weeks (Jan to Feb 1997), while the second trial was continued for six months (October 1997 to April 1998). The longer storage durations of the second trial was to test the limits of the system in protecting moist paddy from quality deterioration.

Experimental stock and set-up: The same five MC levels were used as in Israel. In addition, quality evaluations were carried out after five storage periods, namely: 0, 1, 2, 3, 4 weeks for the first trial and seven storage periods, namely 0, 1, 2, 3, 4, 5, 6 months for the second trial. The entire experiment was undertaken at ambient conditions.

A standard experimental procedure (not described here) was used to achieve homogeneity of test material, and to condition the paddy to the different MCs. The conditioned paddy at the target MCs was placed separately in 3.5L glass jars with screw on metal lid and gasket seal. To enable gas sampling, a hole was drilled in the lid and fitted with a plastic hose. Each jar contained 1.5 kg of paddy. In addition, one part of the paddy at 14% MC was kept in jars covered with filter paper, to serve as control under aerobic conditions. There were three replicates for each treatment. Codes given in the figures are as follows:

Treatments	**Code**	**Initial conditions**
Unsealed control	UC MC14	14% MC, not sealed, but with filter paper cover
Sealed control	SC MC14	14% MC, sealed
Treatment 1	MC 15	15% MC, sealed
Treatment 2	MC 16	16% MC, sealed
Treatment 3	MC 17	17% MC, sealed
Treatment 4	MC 18	18% MC, sealed

Parameters measured The physical parameters measured were CO_2 and O_2 concentrations, ambient temperature and relative humidity, MC and a_w. The effects of hermetic storage on the quality of stored paddy were assessed using the following parameters with analysis of samples that were taken at the start, and at the end of each storage period:

1. % yellow kernels
2. Minolta b* value
3. % milling recovery
4. % headrice recovery
5. Microfloral load
6. Sensory evaluation

For brevity, details of the methodology used in analysis of the first five parameters mentioned above, are not included here, but will be detailed in future publications.

Prof. M. Del Mundo, and Angelina Felix of the Institute of Human Nutrition and Food, University of the Philippines, Los Baños Laguna conducted the sensory evaluation. This consisted of an evaluation of the cooking and eating qualities of the rice milled from all the paddy samples taken at the end of each treatment. The objective was to relate MC and storage duration to cooking and sensory qualities of the corresponding cooked milled rice. Two kg freshly milled rice samples from each treatment were sent to UPLB after every sampling period.

Cooking trials to measure optimum cooking water and other parameters were conducted within the same day that the samples were received. Sensory evaluations employing the same consumer panel (n=50) were conducted the following day. Cooking and sensory assessments were conducted following the procedure of Del Mundo (1991).

Variation in terms of the cooking parameters (% height increase and cooking time), % acceptability and preference scores were obtained across MC's for the different storage periods. Cooked sensory qualities such as flavor, tenderness, cohesiveness and gloss were compared among the experimental samples.

5.2.2 Results and Discussion

i) Physical parameters:

Carbon dioxide and Oxygen concentration Rates of O_2 depletion and CO_2 build-up within the sealed jars were very similar to those recorded by the Israeli partners and are not detailed here. One aspect of the gas monitoring was to verify that the hermetic seal had not been broken so that samples for quality analysis truly reflected the target conditions.

Ambient temperature and relative humidity Average ambient temperature and relative humidity recorded during the first laboratory trial were 28.7°C (23.3 to 37.1°C) and 57.5 % RH (45.5 to 69.3% RH), respectively. During the second laboratory trial, the average ambient temperature and relative humidity recorded were 29.8°C (24.4 to 37.9°C) and 56.9% RH, (30.1 to 74.2% RH) respectively.

Moisture Content and water activity The paddy received from procurement and prior to conditioning for the first and second trials had average MCs of 11.4% and 11.0% and germination rates of 84% and 96%, respectively.

The average MCs and water activities of the different paddy treatments for both trials at the start of the experiments, are given in Table 1. Minor changes in MC were observed at various storage intervals throughout the duration of both trials in all treatments under hermetic storage. The MC of the untreated controls for both trials tended to decrease. This decrease in MC was anticipated because of the low ambient relative humidity, which triggered the drying effect. On the other hand, the paddy in sealed jars manifested slight increments in MC, this additional water being the product of respiration.

Table 1. Average initial MC and a_w of paddy.

	Trial I		Trial II	
Treatments	MC	a_w	MC	a_w
Unsealed C MC14	13.9%	0.79	14.1%	0.75
Sealed C MC14	13.9%	0.79	14.1%	0.75
MC15	15.1%	0.82	15.3%	0.80
MC16	15.9%	0.83	16.3%	0.85
MC17	16.9%	0.85	17.4%	0.88
MC18	18.0%	0.87	18.4%	0.91

ii) Grain quality parameters

Yellowing and b* value Changes in percent yellow kernels, as visually assessed, are shown in Fig 6. Both this and the changes in yellowness as measured by the Minolta Chroma meter, indicate an increasing trend in grain yellowing in all MC levels as storage progressed. Levels of yellowing in all treatments were still acceptable and under the 2% maximum yellowing limit set for Grade 1 milled rice by the National Food Authority (NFA) standards, except for paddy at 17% and 18% MC which were downgraded to Grade 2 (>2-4% maximum yellows) after 4 months storage at 17% MC and 5 months storage at 18%.

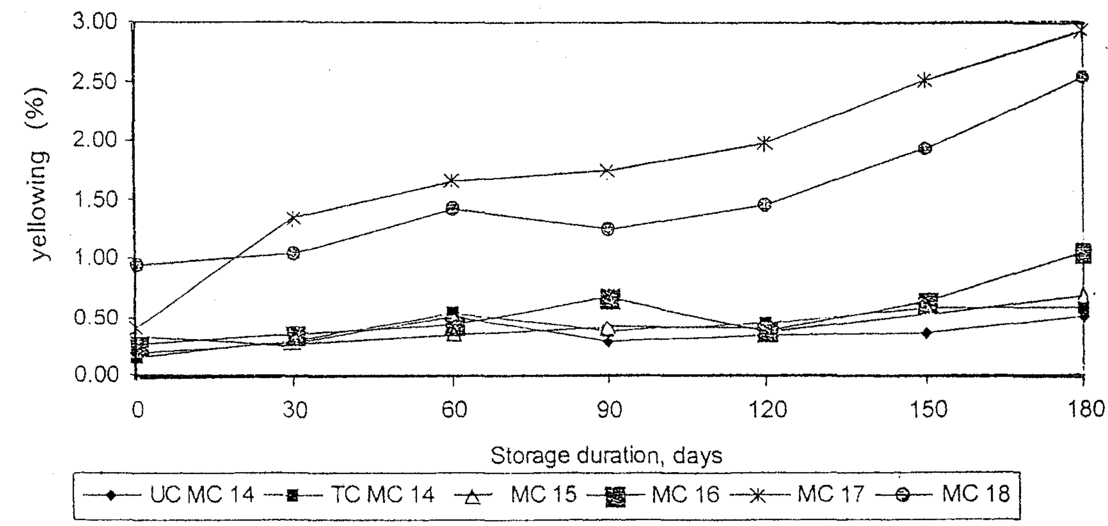


Fig 6: Changes in levels of yellow kernels in hermetically stored paddy at different MCs under laboratory conditions

Milling and headrice recovery It was noted that right from the start of the experiment, the milling and headrice recoveries were low. This condition could be brought about by grain conditioning which includes re-wetting and storage at very low temperature (2 ± 1°C). This process probably caused moisture stress leading to kernel fissuring and breakage.

Microfloral load The dominant fungal species observed from the samples prior to storage were *Aspergillus flavus* and *Fusarium oxysporum.* Other species observed but at low incidence were *Aspergillus fumigatus*, *Eurotium amstelodami*, *Fusarium poae* and *Syncephalastrum racemosum.* Fungal species such as *Eurotium chevalieri* and *Fusarium semitectum* were also isolated during the intermediate sampling periods.

The average initial total percent infection in the various treatments ranged from 21% to 26%. After 28 days of storage, changes in total percent infection varied with MC levels. Average total percent infection in paddy at the lower MCs (UCMC14, TCMC14, MC15, MC16) increased, whereas for paddy at 17% and 18%MC they decreased to 18% and 13%, respectively.

The paddy samples conditioned to 17 and 18% MC were observed to have high initial infections of *A. flavus* (90 - 100%) and *F. oxysporum* (96.7 - 100%). whereas, paddy conditioned at 14, 15 and 16% were also found infected by *A. flavus* (10 -70%), *A. fumigatus* (0 - 16.7%), *E. amstelodami* (0 - 6.7%), *F. poae* (0 - 6.7%), *F. oxysporum* (0 -

60%) and *S. racemosum* (0 - 3.3%).

At the end of the trial, fungal infection in sealed paddy samples at 17 - 18% MC were significantly reduced. Percent fungal infection with *A. flavus* was reduced to 3.3 - 30% and with *F. oxysporum* to 0%. Fungal infection in the sealed paddy samples at 14, 15 and 16% MC did not significantly change, perhaps because the O_2 remained at slightly higher levels during storage period.

Results of the microbial analysis in the second laboratory trial (6 month duration) showed that initially, nine fungal species were found infecting the paddy, the most common species at all MC levels being *A. flavus, E. chevalieri, E. amstelodami, Mucor circinelloides* and *F. oxysporum.* Other less frequent fungi were *Aspergillus niger, A. fumigatus, Curvularia lunata* and *Neosatorya fischeri..* During the first three months, *Eurotium* species and *N. fischeri* were noted to be infecting paddy at lower MCs (14%-16%). While *A. oryzae* and *Penicillium citreonigrum* prevailed in paddy at 15%-18% MC. For the 4^{th} and 5^{th} months, *Aspergillus ochraceous* was prevalent in paddy at 15%-17% MC, while *E. amstelodami* and *E. chevalieri* remained infecting paddy at the lower MCs (14% and 15%).

It was shown that *A. flavus* was present at all MCs throughout the storage time. However, after 6 months, growth of *Eurotium* sp. and *N. fischeri* were suppressed. Non suppression of *Byssochalmys nivea* and *Penicillium* was observed at 18% MC, implying that the modified atmosphere obtained by hermetic storage did not affect these species.

Bacterial populations rose sharply after a month of storage in paddy held at 18% MC, while in the paddy at 17% MC this occurred after 2 months of holding. As a result, a strong foul odor developed in these grains.

Sensory evaluation (This section is part of a full, detailed report provided by Prof. del Mundo and Ms .Felix, in 1998, see Appendix 2. Results of the preliminary trial using rain damaged paddy is not included here).

In the trial using good quality paddy, correlation analysis disclosed no significant differences in terms of cooking time across MCs and storage durations. Cooked rice aroma, taste, tenderness, cohesiveness, color and gloss were negatively correlated with MC and storage duration of stored paddy. These characteristics became inferior at higher MC level and longer storage period. Among these attributes, aroma and flavor had the strongest negative correlation with MC and storage duration. The poor acceptability and preference for cooked milled rice samples from paddy stored at 16% to 18% MC was primarily dictated by the presence of fermented smell in these samples. In the raw form, wholeness of grains and color were found to have a significant negative correlation with MC and storage duration. Milled rice samples from paddy stored at lower MCs had whiter shade of color and a higher proportion of whole grains compared to milled rice samples from paddy stored at higher MCs. As the lengths of paddy storage increased and at the higher MCs, color of the rice tended towards a creamy to grayish shade and broken grains became more evident.

5.3 Pilot scale studies on factors affecting grain conservation under gas-tight conditions

5.3.1 Permeability of liners to gases

Several plastic liner materials were especially developed for the project by Haogenplast. They were analyzed for permeability to oxygen and carbon dioxide. On the basis of these tests the most suitable material was chosen and a 15 m^3 storage structure was fabricated from the material.

The gas-tight seal of the structure was tested by inflation and measurement of pressure decay. This gave extremely good results. Permeability parameters of this storage cube were then examined under field conditions by inflation with carbon dioxide when loaded with dry wheat and then applying negative pressure for measurement of rate of pressure decay. These results may be compared with those of a 15m^3 Volcani cube used for dry grain storage (fig 7).

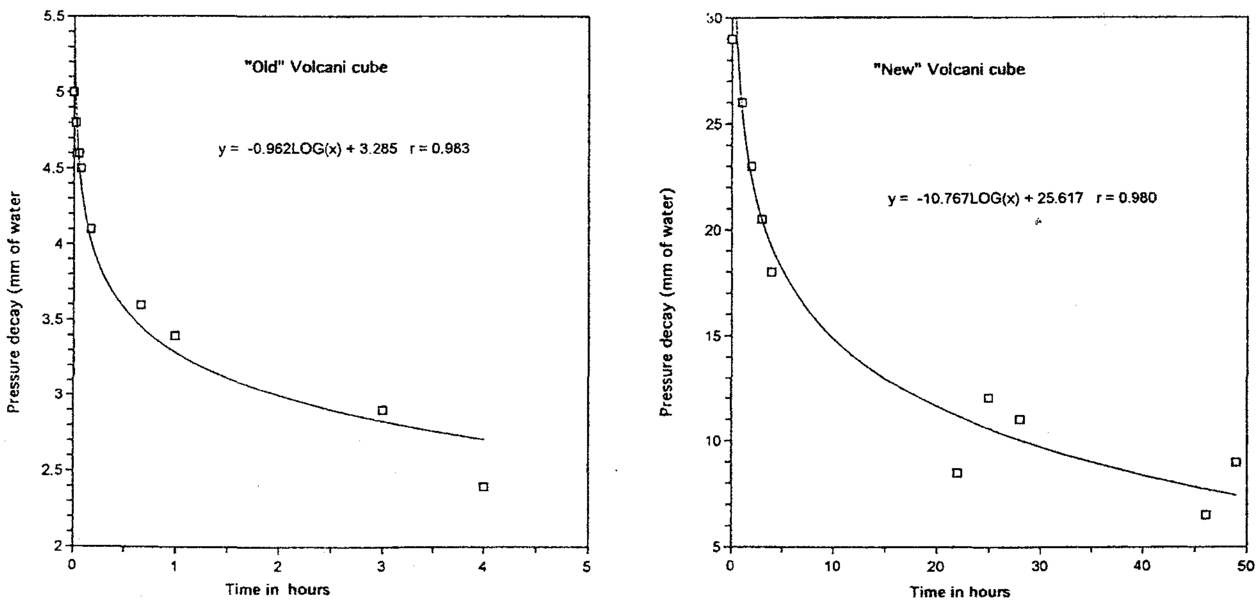


Fig 7: Pressure decay tests carried out on a standard Volcani cube and a laminated cube for evaluation of permeability indices

5.3.2 Field trial with moistened wheat

The structure was then loaded with app. 10 tons of bagged wheat, after the top layer of bags had been moistened. Calculations were made (based on the wheat respiration rates obtained in the laboratory) to determine the amount of wheat required to be moistened in order to obtain rapid reduction in O_2 levels as a simulation of conditions in the Philippines. The required amount of wheat in the upper layer of bags was subsequently moistened to approximately 18% MC and the liner sealed to test whether oxygen concentrations could be rapidly reduced to less than 1%. Although the trial was initiated under winter conditions with low ambient temperatures the results confirmed that intermediate MC grain is capable of rapidly reducing O_2 concentrations under field conditions, (see also Section 5.5.2.1).

This trial stimulated the speculation that if all the grain had been moistened to 18% MC, the oxygen depletion would have been so rapid as to enable the normal PVC based Volcani cube to be used for the same purpose. If this were true it would be extremely advantageous because of the large price differential between the two structures. It was decided on the basis of this trial to try to compare the "improved" and normal cube for the field trials in the Philippines.

5.4 Reflective covers (Israel and Philippines)

5.4.1 Introduction: One significant finding of the previous CDR project (Navarro et al. 1996), was that under Philippine conditions, for dry grain stored in cubes outdoors with no shade, the diurnal temperature fluctuations of the ambient created temperature gradients within the cubes that caused convection currents to carry moisture to the top of the grain stack. To overcome this, an upper insulating layer of bags containing rice hulls was advocated. This method effectively solved the problem but also suffered from several inherent disadvantages, namely: reduction in effective storage capacity of the cube, necessity to procure and transport the husks and fill the bags, and the added expense of bags not used for storing grain. Under Philippine conditions this method enables safe storage for periods of up to three months. For more extended time periods the wet top layer of husks should be replaced with dry husks.

In this project it was envisaged from the outset that when intermediate MC grain is stored outdoors in the field this phenomenon would also occur and would probably be even more acute.

In a search to find an alternative inexpensive and convenient method of insulating the stack from diurnal temperature fluctuations, the use of a knitted shade cloth as a thermal screen and formed from aluminium coated high density polyethylene threads named "Polysac - Aluminet" was investigated.

Initial trials in Israel were carried out during October-December of 1996, followed by further trials both in Israel and the Philippines during the summers of 1997 and 1998.

5.4.2 Methodology and Results (Israel)

A detailed description of these trials will be provided in a paper presented at the upcoming 19th ASEAN Seminar on Postharvest Technology to be held in Ho Chi Min City Vietnam in November 1999, (see appendix 3). A brief summary is as follows:

Several types of woven material were tested. The initial trial in Israel was directed at comparing the day-time temperature gradients at the top of storage cubes, between unprotected and protected segments of the cube. Two densities of material were compared and the insulating effect of the two types was examined both when the cover was spread directly over the top of the liner and also when it was separated from the liner by a distance of 10 cm using spacers. Results of this trial were inconclusive though they indicated a decrease in temperature gradient when protected by the cover. Therefore a follow-up was done in which temperature measurements were recorded using data-loggers specially purchased to enable temperature gradients to be monitored at night-time, when condensation problems are more acute. However, in this case, where entire covers were used using a 7-days on and 7-days off regime, the problem of fixing the cover above the cube became evident. To solve the problem, the edges of the cover (separated from the cube by spacers) were attached to cords that were drawn down and tied to the tension straps around the cube.

However, in this way the sides of the space above the cube were sealed by the cover. We believe that although there was a small reduction in temperature gradients, the absence of this gap between the top surface of the cube and around the borders of the stretched cover may have resulted in trapping the heat between the cover and liner. This prevented free air movement above the liner during the daytime, and may also have had a negative effect on reducing nighttime temperature gradients. The final trial in Israel was designed to overcome this problem (Fig. 8 c).

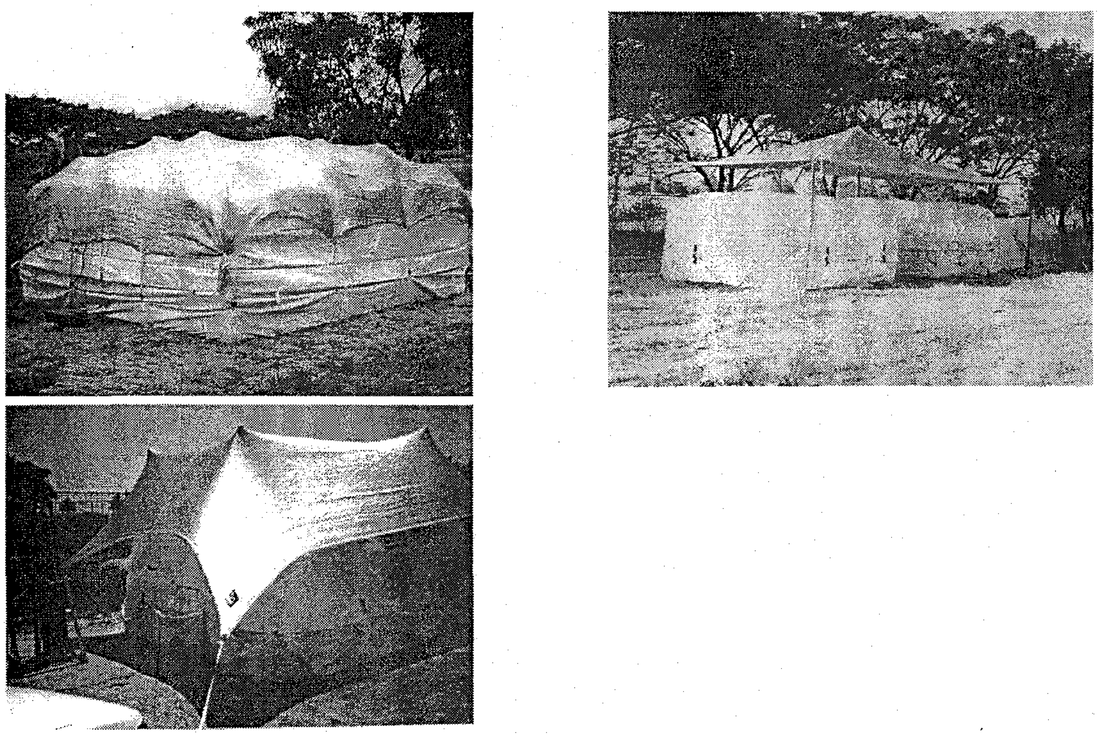


Fig 8: Reflective covers showing a) cover clamped over cube with spacers (Philippines); b) cover suspended above cube (Philippines); c) cover raised above cube with spacers (Israel).

In this trial the reflective cover was stretched over the top of the cube using 20cm spacers, and care was taken to ensure that the cover was not brought down at the periphery, but remained with a gap to permit free air movement beneath the cover. The cover was removed and replaced at weekly intervals so that three alternating series of recordings were obtained. A summary of the amassed data is provided in Table 2.

The Table clearly shows the attenuation in daily temperature fluctuations caused by the reflective cover. Over the course of the trial, the average daily temperature above the liner was about 7 degrees lower, with the cover in place, than without it and this was particularly evident during the day-time (hours of sunlight) when there was a 10 to 15 degree temperature difference.

Table 2: Average weekly temperatures and temperature gradients recorded with and without a reflective cover placed above a 10 ton capacity storage cube at Bet Dagan Israel (28th March to 10th June 1998)

a) Weekly averages of 24 hour recordings

Week (1998)	**reflective cover**	**above liner**	**below liner**	**10cm**	**Ambient temp**	**Temp gradient**	**Temp gradient**	**Temp gradient**
		(A)	**(B)**	**(C)**		**(A-B)**	**(A-C)**	**(B-C)**
Average	With	22.7	22.3	21.7	21.6	0.4	1.1	0.6
Average	Without	26.9	26.1	23.9	22.6	2.4	4.6	2.2

b) Weekly day-time averages of sunlight hours (9am to 6pm)

Week (1998)	**reflective cover**	**above liner**	**below liner**	**10cm**	**Ambient Temp**	**Temp gradient**	**Temp gradient**	**Temp gradient**
		(A)	**(B)**	**(C)**		**(A-B)**	**(A-C)**	**(B-C)**
Average	With	29.2	27.1	21.1	26.3	2.1	8.1	6.0
Average	Without	43.5	35.8	23.3	26.7	7.8	20.3	12.5

c) Weekly night-time averages (7pm to 8am)

Week (1998)	**reflective cover**	**above liner**	**below liner**	**10cm**	**Ambient Temp.**	**Temp. gradient**	**Temp. gradient**	**Temp. gradient**
		(A)	**(B)**	**(C)**		**(A-B)**	**(A-C)**	**(B-C)**
Average	With	18.1	18.9	22.0	18.3	-0.8	-3.9	-3.2
Average	Without	18.3	19.5	24.3	19.6	-1.2	-6.0	-4.8

The data obtained indicate that there is a continuous rhythm of convection currents due to temperature gradients, when, during the night, moisture is transported to the surface layers and during the day-time the surface layers lose moisture as they heat up. Under Israeli climatic conditions, we showed (Navarro et al., 1996) that throughout the year there is no marked net-moisture transfer to the surface in the storage cubes, and no special precautions need be taken. However, previous trials carried out in the Philippines showed that there was a continuous process of moisture transfer to the surface due to the fact that the net moistening effect at night was greater than the net drying effect during the day. Therefore it was evident that if this reflective liner is to meet the requirements for the storage of dry grain (as a replacement for the insulating top layer of agricultural wastes as a requisite in the present storage method), or for storage of intermediate moisture-content grain under tropical conditions, field trials had to be undertaken in the Philippines including an examination of grain moisture content at the top surface after storage.

5.4.3 Methodology and Results (Philippines)

The first two trials in the Philippines also revealed the attenuating influence on temperature gradients due to the reflective covers when properly positioned, and these results are not reported here. This summary is confined to the third trial since it incorporated an examination of MCs at the top of the stacks at the beginning and end of storage. **(see also Section 5.5.)** This trial was carried out in conjunction with a field trial for storage of moist paddy using the low permeability cube (6 months) and the standard cube (3 months) to

evaluate quality. An additional cube containing dry paddy at 14% MC, (5 months) was set up under a reflective cover but was not monitored for temperature gradients.
In this trial a single layer reflective cover was erected over both cubes using a series of poles and guy ropes to create a tent shaped cover that also partially protected the sides (Fig 8b). Temperatures were logged hourly on a 24 h basis above the liners, below the liners, 10 cm within the upper grain layer, and in the central core of the stacks, thus permitting an evaluation to be made on the effect of the covers on temperature gradients during the night-time hours.
Calculations based on temperature read-outs show that if 18% MC paddy has an equivalent EMH of 92% RH the water content of the air at 10 cm depth, would be about 25.1g/m^3 at 27.6°C. If this air rises due to the night-time temperature gradient and cools at the surface below the liner to 25°C then at 100% RH it would contain 23.1g/m^3. Namely there would be a condensation of 1.8 gm for every cubic meter of air reaching the upper surface. However, this represents the worst-possible-scenario. Although the calculations show that for most of the night duration, air at 92% RH (=18% grain EMC) would become saturated when in contact with the upper plastic liner, the very small temperature gradient would produce only feeble convection currents. In order to evaluate the net effect of moistening of the surface layer at night-time and drying during the day-time, the MCs at the top of the stack were examined after 3 and 6 months These findings are given in Tables 3 and 4. A full report of this trial is given elsewhere.
Three months storage: From Table 3 it can be seen that after 3 months, moisture migration had caused an increase of 4% MC in the top layer and 2% MC in the second layer. Since MCs above 18% (EMH = 92%) enable the development of yeasts and bacteria that cause rotting and the development of unpleasant odors, the organoleptic characteristics of the paddy were also seriously affected (see field trial report by Prof. del Mundo: Appendix 3).

Table 3: Average moisture contents of intermediate moisture content paddy hermetically stored in a Volcani cube for 3 months.

Position	**Three composite samples**	**Beginning**	**3 months**	**Composite sample from all bags in each layer of stack**	**Average 3 readings**
	Average 6 readings	**22-Nov-98**	**23-Feb-99**	**23-Feb-99**	
Top (1)	1	18.0	19.3	1 (top)	22.0
	2	17.9	19.8	2	20.4
	3	18.0	20.1	3	18.0
				4	18.0
	1	18.0	17.2	5	18.3
Middle (4)	2	18.0	17.3	6	18.3
	3	18.2	17.5	7 (bottom)	18.0

Table 4: Average moisture contents of intermediate moisture content paddy hermetically stored in a Volcani cube for 6 months in the Philippines.

Position	Three Composite samples	Beginning	6 months	Composite sample from all bags in each layer of stack	Average 3 readings
	Average 6 readings	22-Nov-98	21-May-99	21-May-99	
Top (1)	1	18.3	24.8	1 (top)	28.5
	2	17.5	28.6	2	21.0
	3	17.6	21.4	3	18.2
				4	17.7
	1	18.0	18.3	5	17.0
Middle (4)	2	17.9	18.6	6	17.0
	3	17.6	18.4	7 (bottom)	16.7

Six months storage: Table 4 shows that convection currents caused an even greater increase in MC of the upper layers for the 6 month storage period. However, here again the accumulation of moisture was only noted in the top two layers. The acceptability parameters (very strong fermented odors) of the rice milled from this paddy were so low that analysis of the cooked rice was not deemed necessary (see del Mundo Report: Appendix 3).

Dry grain storage: This cube was only protected by the reflective cover, while the normally employed protective upper layer of bags containing rice husks was not used. At the end of the 5 month storage period, the stack was opened and examined, and although no detailed examination of moisture contents by stack layer was undertaken, the spot tests at the top of the cube revealed that no perceptible increase in moisture contents had occurred and the grain was dry throughout the stack.

5.5 Field Trials - Philippines

5.5.1 Materials and methods

Two outdoor trials were carried out at the BPRE, CLSU Compound, Muñoz, Nueva Ecija, both to test the flexible liner as an alternative storage system for preserving wet grain quality under Filipino conditions, and to determine the effect of reflective covers in reducing temperature fluctuations as reported in Section 5.4. Table 5 summarizes the initial field trial parameters.

Experimental stocks In the first trial, the paddy used was freshly harvested IR-64 variety certified seed from a single farm lot. The MC ranged from 20.6 % to 21.3%. A day after receipt, the stock was sun dried to 17.0 to 18.3%MC. The following day, two hundred and six bags were stacked in the Volcani Cube.

In the second trial five hundred bags of freshly harvested IR-64 variety certified seeds were purchased. The MC of the stock at procurement was 22.0% to 24.0%, and after mechanical drying ranged from 17.8% to 18.4%.

Table 5. List of field trials carried out to determine the storability of intermediate moisture paddy in hermetic storage in the Philippines climate conditions.

Field Trial #	Stack Code	Storage structure	Treatment		No. of Bags	Capacity (tonnes)	Initial MC Range (%)	Duration (days)
			Gastight	Control				
I	S1	Laminated Volcani cube	X		206	7.64	17.0 - 18.3	30
I	S2	Ordinary tarpaulin		X	20	0.88	13.6 - 14.5	30
I	S3	Ordinary tarpaulin		X	20	0.74	17.0 - 18.3	30
II	S4	Volcani cube	X		184	9.87	17.8 - 18.4	93
II	S5	Laminated Volcani cube	X		180	9.83	17.8 - 18.4	180
II	S6	Ordinary tarpaulin		X	20	0.96	17.8 - 18.4	180*
II	S7	Ordinary tarpaulin		X	20	0.95	13.8 - 14.4	180*

* - samples were taken on the 93rd day of storage at the top and along the periphery of the stack to serve as control for S4.

Preparation of storage site and construction of stacks This was carried out according to standard procedure developed earlier (see Navarro et al., 1996). The experimental paddy was bagged in 50-kg polypropylene sacks. For the first field trial, the paddy was stacked in a $15m^3$ laminated Volcani cube tailored from heavy-duty sheeting, UV-protected, of food-grade quality similar to the one pre-tested in Israel (S1). The laminated Volcani cube was further covered with a reflective awning (Fig. 8). In addition, two control stacks of 14% MC coded as S2 and 18% MC coded as S3 were piled on wooden pallets and covered with ordinary white tarpaulin sheets only.

For the second trial, a non-laminated (coded S4) and a laminated (coded S5) Volcani cube were used to store paddy at 17-18% MC. Two stacks of 18%MC (S6), and 14%MC (S7) served as controls. All the Volcani cubes whether laminated or not were covered with reflective awnings, whereas the control stacks were covered only with tarpaulins.

Temperature and gas concentration monitoring. Six thermocouple cables and two plastic tubes were installed at different locations inside the cubes to monitor grain temperatures and gas concentrations, respectively. Changes in CO_2 and O_2 concentrations were measured daily using a GOW-MAC gas analyzer and a David Bishop OxyChek 2, Oxygen meter respectively.

Sampling and parameters. Initial samples were collected during the building of the stacks and final samples were collected and analyzed to determine changes in the quality of stored paddy. The following physical and quality parameters were recorded:

1. % MC and a_w
2. % yellow kernels and Minolta b* values
3. % milling recovery and % head-rice recovery
4. Insect infestation
5. Microfloral load
6. Sensory evaluation (for cooked and uncooked milled rice)

The MCs of the paddy samples were monitored using a Dickey John Multi-Grain Tester. The a_w were measured using a Novasina MS1 Defensor. Percent yellow kernels were determined from the ratio of visually yellow kernels and the weight of milled rice. The Minolta b* value was measured with a Minolta Chroma Meter CR-110. For the assessment of milling recovery, wet paddy samples were dried first using the EUROTHERM Laboratory Mechanical Dryer and then milled using a Satake Grain Testing Mill.

The sensory evaluations of the field trials were conducted as in the laboratory evaluations by Prof. del Mundo and Ms. Felix, of UPLB (see Appendix 3). The evaluations were divided into two "activities":

Activity 1: A comparative analysis of cooking and sensory qualities of cooked and uncooked milled rice from wet paddy (18% MC) before storage and at the end of storage in the Volcani cubes ((S4, after 3 months and S5 after 6 months), and from control stacks under tarpaulins (S6, S7) at initial MCs of 14 and 18% respectively. Composite samples were obtained from the middle (4^{th}) layer of the Volcani cube stacks while for the controls, the samples were randomly obtained from the different sides of each of the stacks at the two sampling periods. The rice samples were milled at BPRE as described above and 2kg milled rice from each 3 kg paddy sample were then dispatched to UPLB.

Activity 2: An evaluation after three months (S4) and 6 months (S5) taken from the various stack levels/layers of the Volcani cubes in order to differentiate between layers using the same quality indices as in activity 1. In this case, composite samples from each layer were taken and dried down to 14% MC before milling. The topmost layer for both stacks was numbered as level 1 and the bottom layer as level 7.

All samples from both activities were assessed in terms of cooking parameters and all samples of uncooked milled rice underwent sensory evaluation. For the cooked milled rice, only samples from three months storage were subjected to sensory evaluation. The strong unacceptable fermented odor during the determination of the cooking parameters of the samples from the six months storage stack led to the suspension of their sensory evaluation.

Cooking and sensory assessments were conducted according to the procedure of Del Mundo (1991). Optimum cooking water was established for each sample. Cooking parameters included % height increase and cooking time. Sensory qualities evaluated for the raw milled rice were % acceptability, preference score, aroma, color, gloss, wholeness of grains, brittleness of grains, and grain translucency. For the milled cooked rice, evaluations were for % acceptability, preference score, aroma, flavor, tenderness, cohesiveness, color and gloss.

5.5.2 Results and discussion

5.5.2.1 Physical parameters

<u>*Carbon dioxide and oxygen concentration*</u> During the first field trial, the O_2 level in the laminated Volcani cube S1 decreased to less than 1% two days after sealing. This level was retained until the stack was opened on the 30^{th} day. Meanwhile the CO_2 concentration reached a maximum of 26% after nine days.

For the second field trial, O_2 concentrations in the two sealed stacks also decreased to less than1% two days after sealing and this was retained until the cubes were opened for sampling. (After stack S4 was opened for MC sampling after 30 days, the O_2 level returned to less than 1% 3 days after sealing). Meanwhile, the highest CO_2 concentrations of 29% (S4) and 31% (S5 - see Fig 9) were attained after 71 and 48 days, respectively. **These findings clearly show that for paddy at 18%MC, the standard Volcani cube also enables paddy respiration to reduce and maintain O_2 concentrations to below 1% within 48 hours.**

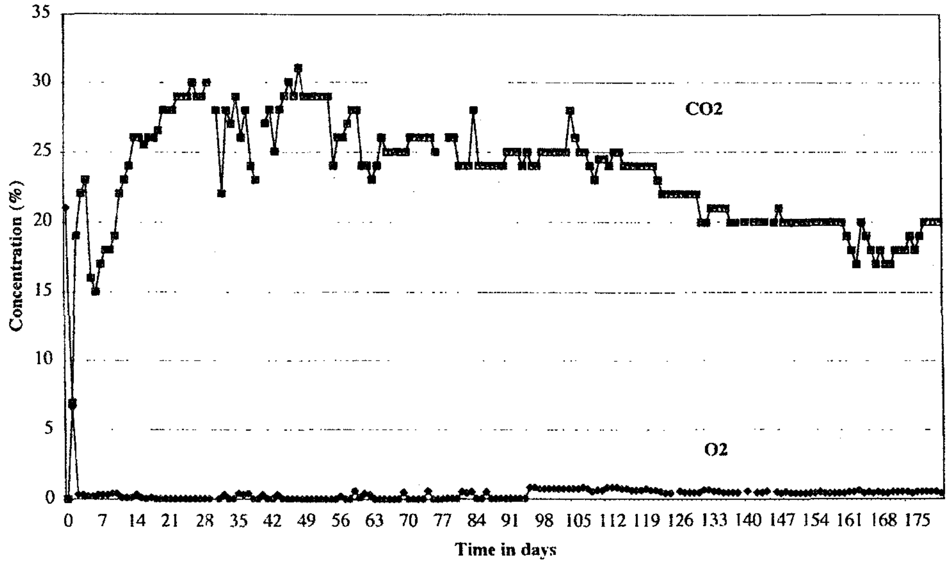


Fig 9: Gas concentrations within the sealed laminated cube (S5) during 6 months of storage

Temperature Grain temperatures recorded during the field trials revealed no indication of self heating. Observations also showed that during day-time, temperatures above and below the liner were consistently lower than that of the ambient, this being attributed to protective effect of the reflective cover by avoiding sorption of solar energy during the day.

Moisture content

Trial 1: The average MC in the laminated cube S1 had increased from 16.9% to 17.5% at the end of 31 days. This we attributed mainly to grain respiration. Also, there was evidence of moisture migration where 16 bags at the topmost layer of the stack were visibly wet and MC had increased to 18.5%. In contrast, the average MC of the control stack S2 decreased from 13.9 to 11.5% while that of S3 decreased from 16.7% to 13.4% after 31 days. (These reductions in MC may be attributed to the low ambient RH prevailing during the trial and the small size of the control stacks at 20 bags each, that facilitated natural ventilation. The large surface area to volume ratio of the small stack may also have facilitated this drying phenomenon).

Trial 2:

Initial MCs of the stacks are given in Table 5. When the Volcani cube S4 was opened after 93 days, clear evidence of condensed moisture was observed. On the average, the MC at the top layer had increased by 1.7%. The four faces of the stack (N, W, S, E) indicated signs of moisture migration and moisture condensation. However, the MC at the middle layer of the stack had decreased by an average of 0.8%. Again, the average MC of the control stacks S6 and S7 had decreased to 11.8% and 11.0%, respectively after 93 days, though, germinated seeds were observed in S6 in almost all the bags despite the eventual reduction in MC, (this probably resulting from strong condensation beneath the tarps).

After 6 months of sealed storage, the laminated Volcani cube S5 incurred heavy moisture condensation which damaged the top three layers and caused grain deterioration. The grains in the top layer increased in MC by 7.1%. Darkened, rotten and foul-smelling grains were found on the affected bags. At the sixth month sampling, both control stacks S6 and S7 encountered a further reduction in MC as an effect of natural drying due to high ambient temperatures.

5.5.2.2 Grain quality parameters

Yellowing and b value*

Trial 1: The average initial yellow kernels of sealed stack S1 and control stacks S2 and S3 were 0.13%, 0.09% and 0.06%, respectively. After 31 days of storage, yellow kernels in S1 significantly increased to 0.66%, the highest level being at the dampened topmost layer which increased to 1.26%. In the control stacks S2 and S3, the yellow kernels significantly increased to 0.33% and 0.49%, respectively. However, as in the lab experiments, the increase in yellow kernel levels did not exceed the 2% maximum limit set by NFA for Grade 1 milled rice. In the same manner, the average b* value of S1 increased from 9.6 to 10.6 the highest being at the dampened topmost layer which was 11.2. In S2 the b* value at 9.7 did not change, and in S3 it increased from 9.7 to 10.2.

Trial 2: The same trend was observed for sealed stack S4 where the average yellow kernels increased from 0.9% to 1.1% and the b* value from 9.6 to 10.8 after 93 days of storage. During the same period, yellow kernels and b* value in control stack S6 increased from 0.9% to 6.5% and from 9.7 to 11.2, respectively, while in S7, yellow kernel and b* value increased from 1.2% to 2.4% and from 9.5 to 10.2, respectively.

After 180 days of storage, sealed stack S5 was found to be heavily damaged with an increased average yellow kernel and b* value from 1.2% to 25.3% and from 9.8 to14.3, respectively at the top layer of the pile. Yellow kernel and b* value also increased from 1.0% to 14.4% and from 9.9 to 12.8, respectively at the middle layer of the pile. Yellowing and b* value in S6 and S7 increased further to 7.5% and 11.9 and 2.6 % and 11.2, respectively. The observations in both trials confirm the laboratory findings (Section 5.2.2).

Milling and head-rice recovery

Trial 1: The average milling recovery of S1 decreased from 65.1% to 59.7% while the control stacks S2 and S3 decreased from 65.2% to 60.0% and 65.7% to 60.1% respectively after 31 days of storage. Likewise, head-rice recovery of S1 decreased from an initial 80.7% to 65.9%, 62.4% and 38.8% at the bottom, middle and top layers, respectively while S2 and S3 decreased from 79.7% and 80.6% to 69.1% and 67.8%, respectively. The marked decrease at the top layer of S1 may be attributed to the increase in MC as a result of convection currents to the surface and condensation.

Trial 2: In contrast to trial 1, the average milling recovery of sealed stack S4 increased from

65.0% to 66.4% after 93 days of storage during the second trial, and the control stacks S6 increased from 64.7% to 67.3% and S7 from 66.1% to 67.7% during the same period. This may be attributed to biological aging which usually occurs after 1-3 months of storage After 180 days storage, the average milling recovery of Volcani cube S5 decreased from 65.6% to 59.8%, while head-rice recovery decreased from 80.2% to 79.1%. In contrast, milling and head-rice recovery of control stacks S6 and S7 increased to 65.6% and 90.2%, and 67.0% and 89.6%, respectively as a result of the drying phenomenon mentioned previously.

Insect infestation At the end of storage all control stacks in both trials were infested by the following species of stored product pests: *Rhyzopertha dominica, Sitophilus oryzae, Tribolium castaneum* and *Cryptolestes* sp. Ambient temperatures and relative humidities during the two trials favored development of these stored product insects. At the end of both trials, the sealed stacks in the Volcani cubes revealed no infestation.

Microfloral load

Trial 1: The initial total percent fungal infections in Volcani cube S1, and control stacks S2, and S3 were 12%, 12% and 10%, respectively. After 30 days, fungal infection in S1 decreased to 3% while the total percent fungal infection in S2 and S3 significantly increased to 15% and 20%, respectively.

Trial 2: In this trial, the stocks of paddy were initially found to be infected with *Aspergillus flavus, Curvularia lunata, Penicillium citrinum* and *Neosatorya fischeri.* Overall, the final results indicated that after three months of gas-tight storage, the percentage occurrence of the above fungi had significantly decreased while after 6 months storage, the atmosphere inside the cube was able to suppress totally the growth *of A. flavus, C. lunata, P. citrinum* and *N. fischeri.*

On the other hand, bacterial counts revealed a significant increase in the top layer of the paddy stored for 3 months. Visual observation showed that microbial growth was high especially in the peripheries and topmost layer of the bag. This was probably due to the increase in moisture as evidenced by moisture migration to the uppermost layer of the stack.

From the paddy stored for 6 months, it was noted that the population of bacteria had significantly decreased. Possibly the prolonged high CO_2 concentration was detrimental to the growth of bacteria since most food spoilage organisms appear to be sensitive to high levels of CO_2 (Pitt and Hocking, 1997). However, these findings did not correspond with those of the laboratory trials where bacterial counts were still high after 6 months (see section 5.2.2).

Sensory evaluation

Activity 1: **Cooking parameters.** Initial samples from all stacks showed that the optimum rice to water ratio was 1:1.25 (80 g milled rice to 100 ml water). This ratio did not change during storage. There was no significant difference in percent height increase of the cooked rice (used to indicate volume expansion) among samples during each storage period. Percent height increase ranged from 146.9% to 221.4%. Cooking time ranged from 15.4 to

18.4 minutes revealing an insignificant increasing trend in cooking time as paddy storage was prolonged.

The cooked and uncooked qualities of the rice samples at 14% and 18% MC taken initially from the control stacks under tarpaulins (S6, S7) and the18% MC paddy from the sealed Volcani cubes (S4, S5), were similar. After three months of storage, the tenderness and cohesiveness of the cooked rice from the different set-ups remained similar. There were also no significant differences in uncooked milled rice qualities such as wholeness of grains, grain translucency and grain brittleness across storage set-ups and duration. Samples taken from the Volcani cube (S4) however had become inferior in terms of the other characteristics. There was a decrease in the overall rating for cooked rice flavor, color and gloss from initial time to third month of paddy storage. Similarly, the rating for uncooked milled rice color and gloss consistently declined after three and six months for the paddy stored in the Volcani cubes.

The characteristics most highly affected were aroma, percent acceptability and preference scores of the cooked and uncooked milled rice samples.

After 3 months, **aroma** of the sample from the Volcani cube (S4) was significantly inferior to the control samples (which had rapidly dried due to ambient ventilation as explained previously). Off odor, specifically a fermented smell was perceptible in both the cooked and uncooked milled rice. After six months storage, the milled cooked rice of samples taken from the Volcani cube (S5), were no longer presented for sensory evaluation due to a highly distinct fermented smell recorded during the cooking trials.

Acceptability as judged by two sensory panels (one from UPLB and one from a farming community) gave a mean of 35% acceptability for the cooked rice, and 51.6% for the milled uncooked rice derived from samples taken from Volcani cube S4 after three months storage. These percentages were significantly lower than the acceptability of controls S6 and S7. The sample from S7 originally at 14%MC had a mean acceptability of 95% in the cooked form and 91.7% when uncooked. The sample from S6, originally at 18%MC, had a mean acceptability of 90.0% and 84.7% in cooked and uncooked forms, respectively. After six months of storage, only three judges from the panels indicated acceptability for the raw sample of wet paddy stored in S5.

For **Preference scores** which rank the choice levels, a positive number indicates generally-accepted, and a negative number indicates generally-rejected. Samples S4 and S5 from the cubes received a consistent negative score in the cooked form as opposed to the control samples S6 and S7. Similarly, there was a notable decrease in preference score of uncooked milled rice in S4 and S5 from the initial test to three months and to six months of storage. Although samples from S6 and S7 were generally similar in terms of the different cooked and uncooked rice qualities, in terms of overall acceptability and preference scores, S7 (originally at 14%MC) was better than S6 (originally at 18%MC) after three and six months storage.

Scores **for color, gloss, flavor, tenderness, cohesiveness, wholeness, brittleness,** and **translucency** of the samples were also made, but although of value in themselves, they are not presented here as they are subservient to the scores for acceptability and preference.

Activity 2: (Comparative analysis of the seven layers in the sealed Volcani cubes S4, S5).

Cooking parameters. Optimum cooking water was the same for the seven samples during the two storage periods. A rice to water ratio of 1 : 1.25 (80 g milled rice to 100 ml water) was established for all samples at both 3 and 6 months storage. Percent height increase and cooking time were similar across samples during each storage period though a diminishing trend in height increase and an increasing trend in cooking time were noted as storage was extended from three to six months.

A difference in **acceptability** scores was registered by the two groups of consumer panels particularly in terms of milled cooked rice quality. The samples from all layers were rated as unacceptable by one panel (UPLB staff) while the other panelists accepted the cooked rice from S4 except those from the two topmost layers. In the uncooked form, both sets of consumer panelists indicated acceptability for samples coming from layers 3, 4 and 7 during the third month. Both sets of panelists also rated the uncooked samples from all layers as unacceptable during the sixth month (S5).

With regard to **preference,** panelists unanimously rated the samples from layer 3 to 7 as the best of the seven layers. The rating was both for cooked and uncooked milled rice samples stored for 3 months. The milled rice sample from layer 7 was rated as the best sample in both cooked and uncooked forms. After six months of paddy storage, the samples were no longer presented for sensory evaluation in the cooked form. The samples had distinct off odor and the laboratory staff already refused to taste the samples presented to them during the optimum cooking water determination. Only the uncooked milled rice from seven layers were presented to the panelists and all were rated unacceptable.

Aroma: The major drawback of the samples from the top layers during months 3 and 6 was their off odor/fermented smell. During month 3, fermented smell was distinct in samples from layers 1 and 2. Off odor of lesser intensity was noted for all other samples. Between cooked and uncooked milled rice forms, the intensity of the fermented smell was stronger in the cooked form. After six months, the off odor/fermented smell became highly perceptible in all samples including those in the uncooked form.

A slight variation across samples in terms of uncooked rice characteristics like **color, gloss, wholeness** of grains, **brittleness** of grains and grain **translucency** were noted during month 3, as was the case for month 6. Color of the uncooked milled rice grains however notably changed from creamish white to yellowish after six months for samples from layers 3 to 7and the yellowish color of the samples from layers 1 and 2 during month 3 were further intensified during month 6.

Overall, among the samples from the seven layers, the scores and descriptions for the sensory attributes were higher and/or better for samples in the lower layers. The sample from the lowest layer of the three months storage (S4) was still acceptable in both cooked and raw forms to the panel comprising a rice farming community. However, regardless of layer, a duration of six months was deemed inappropriate for hermetic storage of paddy at 18%MC.

5.6. Summary and Conclusion

From the above laboratory and field trials, it was agreed among the project investigators that the following storage durations can be recommended for intermediate MC storage of paddy in hermetically sealed Volcani cubes:

For 18% and 17%MC paddy storage can be prolonged for one month. Perception of a fermented smell was very evident in cooked form after 2 months. Other cooked qualities such as flavor, color and gloss as well as the raw qualities like color, wholeness of grains and translucency became inferior beyond one month of paddy storage.

For 16% MC paddy - storage can be extended to two months. Significant negative changes in cooked rice aroma as well as in such qualities as color and gloss in both cooked and raw forms were observed at above two months of paddy storage. Other sensory qualities slightly changed after more than two months of storage.

For 15% MC paddy - storage can be extended to three months. Slight changes in sensory qualities with an off-odor slightly perceptible in the cooked form were noted after three months of storage.

Paddy at 14% MC showed remarkably good sensory attributes even at three months which is still the recommended duration for paddy storage. In fact in a study by del Mundo (1995) it was shown that IR64 paddy stored for one year at 12%-14% MC at ambient conditions had comparable sensory qualities to paddy stored for three and six months.

The hermetic storage under hypoxic conditions of about 1% O_2 or less, needed to arrest mold development, can be obtained using a well sealed standard Volcani cube. The moisture migration phenomenon experienced in outdoor storage, which is exacerbated at intermediate MCs, can be strongly reduced using reflective covers, provided they are correctly placed over the cubes.

6. Impact, Relevance and Technology Transfer:

A previous joint CDR project (C7-053) has facilitated implementation of the present policy of the Philippine government which is directed at providing small scale farmer cooperatives with on-site storage units so as to decentralize storage of the national grain reserve as well as provide rural communities with a higher level of food security. In 1998, about 200 units of these storage structures were purchased and distributed to farmers' cooperatives nationwide. Presently, 300 additional storage units have been purchased by the government to mitigate the effect of La Niña. To date this concept of sealed storage to protect dry grain from insect infestation has been widely promoted by BPRE and Fumitechniks through an intensive training program of on-the-spot demonstrations and courses. It is anticipated therefore that the findings of this project can be translated into practice by dove-tailing this technology into the recently developed concept of storage in flexible liners. Policy decisions may have to be made in the light of these findings, but should the concept of storage of intermediate MC grain be adopted, even a one-month delay after harvest, before paddy must be dried or consumed should have a revolutionary effect on harvest losses, farmer income and food security

The project has had a stimulating effect on the activities of BPRE whose central role in postharvest activities of the Philippines cannot be over-emphasized. Funding has enabled the purchase of equipment essential for carrying out research into hermetic and controlled atmosphere (CA) storage. At present a member of BPRE (Ms Glory Sabio) is undertaking

PhD studies in the Department of Stored Products at the Volcani Center as a direct outcome of this cooperation. Lastly, it was only through the CDR funded projects that cooperation reached a level where ARO was chosen by BPRE for special citation - "in recognition of ARO's contribution in hastening the development of the country's postharvest industry by supporting research and development activities responsive to the needs of the agricultural sector".

7. Project Activities/Outputs:

Investigators of the project attended and presented relevant papers at the following conferences.

1) International Conference on Controlled Atmospheres and Fumigation, held in Cyprus, April 1996
2) 18th ASEAN seminar on grains postharvest technology held in Manila, March 1997.
3) 7th International working Conference on Stored-product Protection, Beijing, China Oct. 1998.

Project meetings/visits

1) 1995 Drs Donahaye & Navarro to BPRE (during grain storage course funded by Israeli government) followed by National Seminar on Grain Storage Technology and Food Security.
2) 1996 Ms Caliboso to ARO
3) 1997 Dr. Donahaye (private funding) and Dr. Navarro to BPRE and UPLB
14) 1999 Dr. Andales to ARO (September)

8. Project Productivity:

A considerable amount of the early experimental work needed to be repeated both in the Philippines and Israel, due to the purchase of paddy which later was revealed to be of sub-standard quality. However the project did cover the major objectives and included the development of reflective covers which did not form part of the original work plan but emerged as an essential addition. The development of the descriptive model could not be completed in time but a Stella language simulation model has been set up and the experimental data required to verify the model has been largely gathered.

9. Future Work:

The outcome of this study will depend largely on decisions by policy makers and in-depth extension activities. We believe that much remains to be done in the introduction of environmentally friendly storage solutions to developing countries, and that hermetic storage at the cooperative and small farmer level is one of the most promising courses of action for providing food security in the 21st Century.

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