Trop. Sci. 1991, **31**, 109–121

Storage of paddy in hermetically sealed plastic liners in Sri Lanka

E. Donahaye, S. Navarro*, A. Ziv*, Yehudit Blauschild* and D. Weerasinghe†*

*Department of Stored Products, Agricultural Research Organization, The Volcani Center, P.O. Box 6, Bet Dagan, Israel and †Sarvodaya Economic Enterprise Development Services, Anuradhapura, Sri Lanka

Abstract *A trial was carried out in Sri Lanka on the outdoor storage for 6 months of locally grown paddy (type Nadu) in two hermetically sealed flexible liners termed 'storage cubes'. Insect infestations failed to develop in both cubes and TGM evaluations indicated a 0·33–0·64% loss in dry weight due to metabolic activity. In one of the cubes, which contained paddy at higher moisture contents, a moisture condensation effect was revealed on the under-side of the upper liner. Losses by mould development resulting from this effect were estimated at 1·24%. Means for obviating this occurrence are proposed.*

Keywords: paddy, rice, *Oryza sativa*, hermetic storage, plastic liners, storage in the tropics, loss-evaluation.

Introduction

The objective of this study was to provide information on the conservation of paddy in jute sacks when stored under tropical conditions, stacked in the open within a protective flexible PVC liner, termed a storage cube.

The storage cubes were designed for the hermetic storage of grain and other durable agricultural products in situations where permanent storage structures are not available or do not afford the necessary protection. They are intended to provide an inexpensive solution for medium- to long-term conservation of dry grain by protection from biological agents of deterioration and loss (insects, moulds and rodents) without the use of pesticides. Their capacities – 5, 10, 20 and 50 tons – are intended to provide solutions for communal storage by farmer cooperatives, or for storage at the small-scale commercial level.

In Sri Lanka, rice is stored from one harvest to the next as paddy, with the inherent advantages of physical protection from insect infestation afforded by the protective glumes (Breese 1963, Cogburn *et al.* 1983). The advantages in retaining surplus stocks of paddy for storage after harvest lie in strong fluctuations in market prices that peak shortly before the following harvest, particularly for the favoured 'Samba' varieties that are only grown in the major 'maha' season. Nevertheless, losses over a 6- to 12-month storage period are considerable unless preventive or control treatments are carried out.

Accepted 15 October 1990

A survey of eight different indigenous storage structures in 11 districts of Sri Lanka by Fernando *et al.* (1988) indicated losses of between 1% and 8% for storage periods ranging from 6 to 24 months. These structures were then evaluated in storage trials at Anuradhapura, including loss assessment using the thousand-grain mass (TGM) and count and weigh methods. Results revealed from 2·3% to 5·9% dry matter (d.m.) losses over 6 months. This was corroborated by our findings for 6 months' storage of 'Samba' type paddy (variety BG 11-11) without chemical protection in a warehouse in Anuradhapura. There we estimated by the TGM method, a loss of 5·8% d.m., with final infestation levels of *Rhyzopertha dominica* of up to 86 adults/kg (Donahaye *et al.* 1989). Since about 60% of the harvested grain is retained by the farmers for seed, home consumption and future sale (Fernando *et al.* 1988), it is clear that losses in this sector are large.

Storage of paddy outdoors, within flexible plastic structures, has been studied in the past in the tropics (Beeny *et al.* 1972). However, these systems were not adopted, one reason being the rapid decomposition of the liners due to UV radiation. More recently, the method of covering and sealing stacks inside warehouses with PVC liners for storage under carbon dioxide-enriched atmospheres has been developed by the CSIRO (Annis *et al.* 1984). It has been put into practice in a number of South East Asian countries under circumstances where advanced storage technology permits its application.

Recent evaluations on the role of post-harvest technology (PHT) systems in villages of India and Bangladesh (Lipton 1982) indicate that, in spite of previous wild exaggerations of PHT losses, as well as failed attempts in the past to introduce appropriate PHT activities, there is still a need to develop cost-effective, technically acceptable storage solutions to enable farmers to conserve grain safely without the use of insecticides. It was to fill this need that the storage structures reported on in this study, were developed and tested.

Materials and methods

Site and duration of storage

The storage trial was undertaken at the Samusala rice mill near Anuradhapura, between 12 April and 11 October 1989.

Grain supplies

Locally grown paddy in 65 kg jute sacks (long, bold grain varieties termed collectively 'Nadu') was purchased directly from farmers in the north-central region of Sri Lanka during the spring (Maha) harvest. The moisture content of the paddy at the farm gate was not uniform. One truck-load consisted of paddy at 17–19% moisture content (m.c.). However, most paddy within the mill and purchased over the preceding month, was generally drier; multiple sampling gave an average recording of slightly less than 14% m.c., although many samples were above 14% and several above 17% m.c.

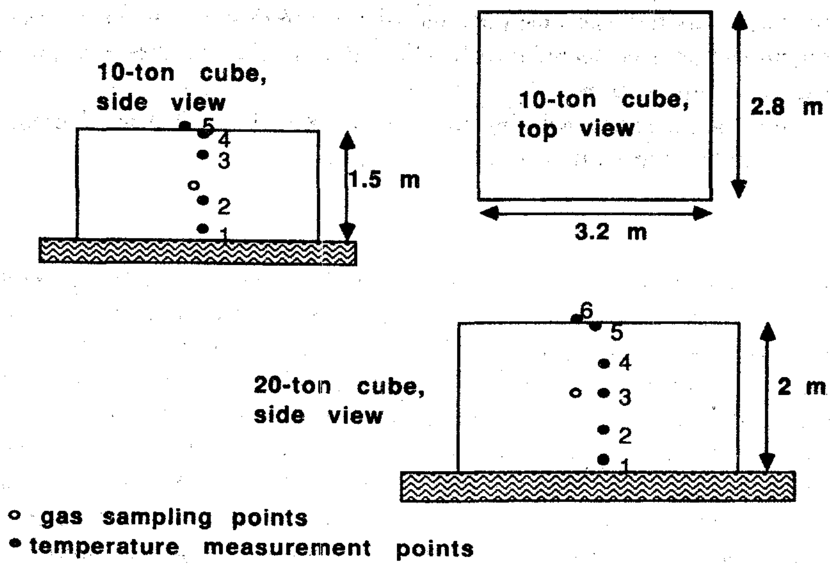

Figure 1. Plan of cube temperature monitoring and gas sampling points

Since the storage system is designed for storage of grain below the critical m.c., it was decided to dry the high-m.c. paddy before storage in the cubes. This was done on the drying floor of the mill in less than 4 hours (drying temperature 35°C, and 45–55% ambient relative humidity [r.h.]), and the paddy was then rebagged.

Storage structures

The trial was carried out using two cubes, one with a nominal capacity of 10 tons and the other, 20 tons. Both storage cubes consist of a lower floor-wall section of heat-welded flexible 0·83-mm-thick PVC sheeting which is laid on the ground and into which the sacks are stacked. When fully loaded, the upper roof-wall section is drawn over the stack and the two sections are hermetically sealed together using a gas-proof zipper. The zipper is covered by a protective over-flap. Dimensions of the 10-ton liner are 3200 × 2800 × 1500 mm (l × w × h) (Figure 1), giving a maximum storage volume of 13·4 m^3, and weighing 43 kg, when empty. Dimensions of the 20-ton liner are 4450 × 3360 × 2000 mm (l × w × h) with a maximum storage volume of 29·9 m^3, and a weight of 76 kg when empty.

Provision is made by means of tension straps and buckles attached to the liner, to keep the walls of the cubes under tension even if they are not filled to capacity. This is to ensure that there are no folds of material at points of contact around the floor level, thus affording a large measure of protection from rodent penetration (Navarro and Donahaye 1986).

The liner material specifications include: freedom from toxic chemicals (food quality); protection from degradation by UV radiation; fire-retardant protection and zero permeability to liquid water.

The cube was set up on the drying floor (a soft cement base which was previously swept clean to remove all projecting stones, grit, grain, etc.).

Loading

Paddy for the 10-ton cube was obtained from grain bagged on the drying floor immediately after redrying. It was therefore hot when loaded into the cube. This cube was loaded manually with 148 sacks, giving a total weight of approximately 9620 kg. Loading was criss-cross with 25 sacks per layer, and in six layers, to give a height of 1·6 m. The 6th layer consisted of 19 sacks and four sacks along the centre formed the 7th layer.

Paddy for the 20-ton cube was obtained from recently harvested grain held prior to storage in the rice mill. Loading was criss-cross with 35 sacks (5 × 7) per layer and seven layers to a height of 1·9 m. The eighth layer consisted of six sacks only. As a result there was some slack in the walls after the cube sections had been zipped together; this was pulled up using the tension straps. Total load was 16 315 kg (although a further layer of 35 sacks = 2275 kg could easily have been added).

Monitoring of grain during loading and unloading

Grain samples were taken from the loading-line at a rate of one sample (approx. 1 kg) for every 15 sacks. The initial sample taken into a polyethylene bag was immediately subdivided into two sub-samples, one sub-sample being transferred to a numbered cotton bag (170 × 250 mm) which was loosely clamped with staples and placed next to the bag stacked in the silo. This sub-sample was removed at the end of the storage period for analysis. The other sub-sample was used immediately:

1. To measure initial moisture content using a Dickey John moisture meter specially calibrated for Sri Lankan Nadu-type paddy against the standard oven method for measuring moisture content (Anon. 1966).
2. Initial infestation. The sub-sample was sieved through a 10-mesh sieve and inspected for free-living insects. Recordings were adjusted to give the number of insects per kg.
3. TGM (Proctor and Rowley 1983). Due to the large numbers of samples being measured, grain counting was limited to approx. 300 grains per sample taken at random.

The above analyses were carried out again at the end of storage on the sub-sample stored within the structures during the storage period.

Quality analysis

Most rice for local consumption is steam-boiled before milling. Therefore, for further evaluation of the influence of storage on quality, the paddy was weighed after removal from the cubes. It was then sieved to remove stones and dockage, and placed in soaking tanks for 48 hours. The water was then drained off and the paddy was transferred to the boilers. After steam boiling (5 minutes), redrying and milling, the milled rice was re-weighed to calculate yield. Clearly this is less accurate than determination of milling yield by laboratory analysis, but is the method practiced in commerce and provided a valuable index. (Characteristic of Nadu-type paddy is a yield of about 65%, with about 25% husks and 10% dockage, light and empty grains removed from the surface of the soaking tanks, and brokens.) Other quality evaluations undertaken by the miller were colour (whiteness and yellow grains), brokens, smell, and taste after cooking.

Installations for periodic monitoring during storage

Both cubes were installed with T-type thermocouple cables and 4-mm-diam plastic tubing for monitoring of temperatures and gas compositions during the storage period. The cables and tubes were prepared ahead of time, and were threaded through a rubber gasket which was inserted into the liner at a point beneath the protective flap. All cables and tubes, which were positioned at different heights along the central axes of the cubes (Figure 1), were placed in position progressively as the layers of sacks were stacked into the liner. Temperatures were measured using an Anritsu model T 1534 portable temperature meter, and gas composition was recorded using a Bacharach portable gas concentration analyser and a portable Teledyne oxygen analyser model 355.

Temperature and gas sampling was carried out upon completion of loading and after the cubes had been sealed, and was continued on a once-weekly basis until the end of storage.

Results and discussion

Storage and ambient temperatures during the trial

10-ton cube

Initial high temperatures of grain entering the cube, particularly at the bottom, which was taken directly from the drying floor (41°C), dropped rapidly to about 34°C (Figure 2), which represents the average ambient temperature over the 24-hour period. Point 5, which measured the temperature of the upper liner, showed great fluctuations due to differences in time of day and cloudy or sunny conditions. The temperature range of between 24 and 56°C indicates that very considerable changes in r.h. of the air directly below the liner were taking place. However the stable temperatures within the cube indicate that temperature gradients likely to cause moisture migration up through the bulk were not present, and no heating phenomenon was detected within the bulk.

20-ton cube

A very similar pattern of temperature fluctuations was observed (Figure 3) to those recorded in the 10-ton cube. No indications of internal hot spots were evident from any of the sampling points, including those not depicted in the graph.

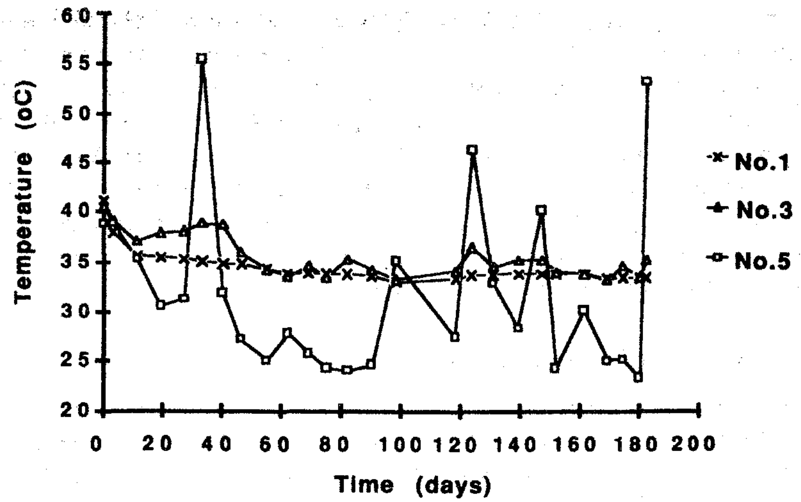

Figure 2. Temperature during the storage period (12 April–11 October 1989) at three points in the 10-ton cube

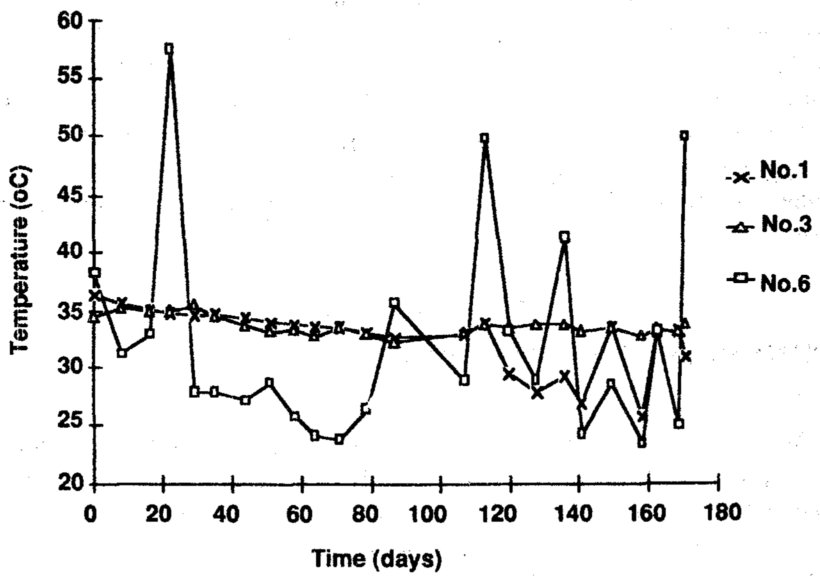

Figure 3. Temperature during the storage period (12 April–11 October 1989) at three points in the 20-ton cube

Ambient temperatures and relative humidities

Meteorological data from the Anuradhapura area indicate for the April–October season average temperature fluctuation within a 24-hour range from 23°C to 25°C, and range of r.h. from 62% to 80%.

Atmospheric composition within the cubes

During the storage period, the CO_2 analyser ceased to function. Therefore, a continuous record of gas compositions is not available (recorded as dotted lines in Figures 4 and 5).

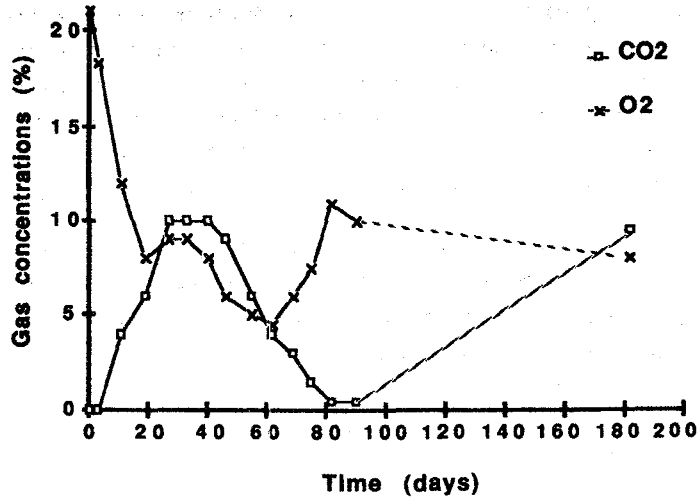

Figure 4. Carbon dioxide and oxygen concentrations within the 10-ton cube during the storage period (12 April–11 October 1989)

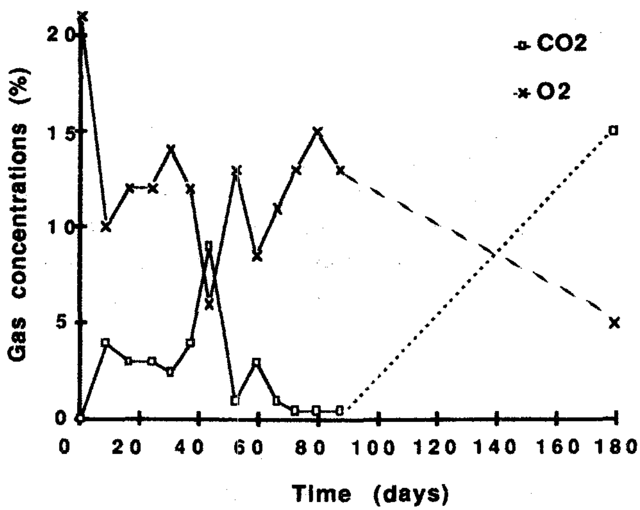

Figure 5. Carbon dioxide and oxygen concentrations within the 20-ton cube during the storage period (12 April–11 October 1989)

However, reliable recordings of O_2 and CO_2 before the hermetic seals were broken prior to unloading, indicate that there had been continuous, high levels of CO_2 and low levels of O_2 in the 20-ton cube, possibly due to activity of microflora; this is based on the assumption that if there had been complete kill of insects, a gradual reversal of gas concentrations would have occurred, with relatively low levels of CO_2 and high levels of O_2, as were recorded in the 10-ton cube.

For the 10-ton cube there appears to have been an initial development of insects from very low population levels, causing a gradual increase in CO_2 and decrease in O_2 concentrations until May/June. This was followed by a reversal in these trends due to incomplete insect kill, as evidenced by a very slow build-up of CO_2 towards the end of the storage period. This was corroborated by observations of live *Tribolium castaneum* adults on some sacks during unloading, although only one infested sample was recorded, also by *T. castaneum*.

Figure 5 shows a more rapid initial drop in O_2 and rise in CO_2, indicating higher initial infestation, and this is reflected in the sample analysis for infestation. The reason for intermediate fluctuations in concentration is not clear and may be due in part to recording errors, but the final recording of 15% CO_2 is indicative of fungal activity and was clearly due to the condensation effect at the surface layer revealed during unloading.

The structures

At the end of the 6-month storage period, both cubes were in good condition. No tears were found and no indications of rodent damage were observed, either before or after unloading. No breaks or openings in the zipper seals were found. This corroborated the evidence provided by the gas measurements that both structures remained hermetically sealed throughout the storage period.

Unloading

10-ton cube

No indications of moisture migration were observed in this cube which, in contrast to the 20-ton cube, did not contain paddy at above critical moisture content. Individual live adults of *T. castaneum* were observed on the outside of a few sacks, indicating that metabolic activity within the cube had been insufficient to control the initial low infestation.

20-ton cube

Removal of the upper liner revealed about ten sacks on the upper layer that were visibly infected with mould. Examination of the sacks revealed that mouldy grains were limited in depth to the surface grains and mould on the sacks appeared to be limited to actual points of contact between the PVC liner and the sacks. These findings indicate a condensation situation on the under surface of the liner at night, followed by run-off into the sacks where these were in contact with the liner. All other sacks in the cube appeared in excellent condition and no live insects were observed.

Evaluations of conservation within the structures

Moisture content, infestation levels, and TGM evaluation of the paddy samples at the beginning and end of storage are given in Tables 1 and 2.

Table 1. Sample results at beginning and end of storage in the 10-ton cube

Sample No.	12 April 1989 Inloading data			18 October 1989 Outloading data		
	MC	Insects*	TGM	MC	Insects*	TGM
1	13·8	0	22·15	12·3	T 9	22·08
2	11·2	0	20·36	10·1	0	20·02
3	10·8	0	20·78	11·2	0	21·28
4	11·2	0	20·96	11·6	R (2)†, Cr (2)	20·72
5	18·3	0	20·10	12·5	0	21·00
6	14·0	0	21·61	11·2	0	20·10
7	13·3	0	20·78	10·5	T (2)	21·47
8	9·0	0	21·69	9·0	T (2)	21·69
9	9·8	0	21·83	9·5	0	22·20
10	9·4	0	21·69	9·8	0	22·18
11	9·8	0	23·12	12·3	0	21·55
Average	11·87		21·37	10·91		21·30
s.e.	0·835		0·263	0·364		0·232

*Number/kg, R = *Rhyzopertha dominica*, T = *Tribolium castaneum*, Cr = *Cryptolestes* sp.
†Dead insects are recorded in brackets

Table 2. Sample results at the beginning and end of storage in the 20-ton cube

Sample No.	16 April 1989 Inloading data			13 October 1989 Outloading data		
	MC	Insects*	TGM	MC	Insects*	TGM
1	12·6	0	24·01	ND	ND	ND
2	18·5	S 2	21·84	13·4	0	22·06
3	11·2	0	29·84	12·6	R (2)†	25·67
4	12·2	0	27·06	12·6	0	27·09
5	12·4	0	24·64	12·7	0	25·85
6	10·6	0	28·22	9·4	0	17·18
7	14·8	0	24·96	13·0	0	24·34
8	11·4	0	23·72	12·3	T (4)	24·38
9	11·9	T 2	26·49	13·0	0	27·04
10	14·3	0	24·28	12·3	T (2)	26·61
11	14·6	0	23·51	12·3	0	24·57
12	14·3	0	25·40	13·3	0	26·91
13	11·5	R 2	25·25	10·5	0	26·58
14	13·7	Ty 2	23·31	21·5	0	22·7
15	13·3	0	20·46	ND	ND	ND
Average	13·15		24·87	12·99		24·69
s.e.	0·516		0·614	0·774		0·773

*Number/kg, R = *Rhyzopertha dominica*, S = *Sitophilus oryzae*, T = *Tribolium castaneum*, Ty = *Typhaea stercorea*
†Dead insects are recorded in brackets
ND = no data

Moisture Content

10-ton cubes In this cube the average initial m.c. was 11·87±0·835% s.e. (standard error), the relatively low m.c. being due to the fact that this paddy was redried at the mill. Clearly since the liner was hermetically sealed with very low permeability to water vapour, any radical change in m.c. would indicate moisture migration. This had not occurred. Final moisture contents averaged 10·91±0·364% s.e., these low levels being probably responsible for the fact that no condensation effect or moulding was experienced at the top of the cube.

20-ton cube The initial m.c. of the samples in this cube averaged 13·15±0·516% s.e. at entry and 12·99±0·774% s.e. at removal. A high initial m.c. of 18·5% recorded from one sample was the chief cause for concern that possibly some of the paddy was well above the critical moisture content level.

Insect infestations

Low levels of live infestation by adult insects were recorded initially in the 20-ton cube, including all the major pests of paddy in storage (*Rhyzopertha dominica, Sitophilus oryzae, Tribolium castaneum*, and *Typhaea stercorea*). At the end of storage, no live insects were recorded.

In the 10-ton cube, no insects were recorded initially, probably because the grain was collected directly from the drying floor, temperatures were very high, and any free living adults had the opportunity of seeking shelter. At the end of storage, no live insects were recorded from the samples except for one, which contained nine live *Tribolium* adults. *Tribolium* adults were also observed on the surface of sacks in the 10-ton cube as described above. Dead insects recorded in the final samples were mainly *R. dominica, T. castaneum*, and *Cryptolestes* sp.

Of the 26 samples examined at the beginning and end of storage from both cubes, four were infested with live insects initially, whilst six contained dead insects; one contained live insects at the end of storage.

TGMs

The TGMs recorded at the beginning and end of storage showed a 0·33% loss in dry weight in the 10-ton cube, and a 0·64% loss in the 20-ton cube. These calculated losses are attributed to metabolic activity of the grain, insects and microorganisms.

Milling Yields

Although mould was visible on only about ten sacks, 20 sacks from the upper layer of the 20-ton cube were removed separately, weighed, steam-boiled, milled, and reweighed to calculate output. An additional two groups of grain were taken from the main bulk of

Table 3. Milling yields of rice from paddy taken from different sections of the 20-ton cube

	Paddy (input) (kg)	Rice (output) (kg)	Yield (%)	Rice loss (kg)
20 surface sacks (mouldy)	1300	720·2	55·4	131·3
231 sacks of main bulk	15 015	9834·8	65·5	0
Total	16 315	10 554·8		131·3

Table 4. Quality evaluation of rice milled from paddy stored in different sections of the 20-ton cube

	Colour	Smell	Grade	Taste	Remarks
Surface sacks (mouldy)	changed (yellow)	good	2	good	30% breakage
Main bulk, group 1	good	good	1	good	ND
Main bulk, group 2	good	good	1	good	ND

ND = no data

stored grain and processed to determine output; the average output was 65·5%. This was used as the base-line for determining loss in output of the surface sacks. For comparison, the usual output of rice from 'Nadu' type paddy at the Samusala rice mill is 65–67%. Table 3 summarizes losses due to mould as calculated from output recorded at the mill. The figures represent a loss of 1·24% due to mould in the 20-ton cube.

In milling practice, differences between moisture content of the paddy and milled rice resulting from soaking, steam-boiling and drying, are not taken into account for calculating outputs.

Quality Evaluations

Table 4 indicates quality evaluation as carried out by the rice miller on samples taken from different sections of the 20-ton cube. The change in colour was responsible for the lower grade assigned to this rice by the miller. Rice samples for taste evaluation were cooked at the mill. No differences were detectable on samples taken from different sections of the 20-ton cube.

Conclusion

Storage for 6 months in both cubes prevented development of insect infestations, although some live insects were recorded from the 10-ton cube. Calculated losses of 0·33%

and 0·64% should be compared with loss evaluations of up to 5% in normal storage practice. Also, there is a need for longer storage of the higher priced short round rice varieties termed 'Samba' which are grown principally during the main (Maha) growing season. For this grain the potential for insect infestation losses rises steeply for storage beyond the 6-month period.

Moisture condensation was experienced at the top of the 20-ton cube. This was probably due to the high moisture contents of part of the paddy stored in this cube and the extremely steep temperature gradients caused by direct sunlight on the upper PVC liner during the day, followed by rapid cooling at night, with the sacks underneath maintaining the high temperatures. The amount of mouldy rice was relatively small and resulted in a reduction in milling yield of 10·1% for the top 1·3 ton of grain, or a net loss of 131 kg of milled rice from the total of 16 315 kg paddy stored in the cube.

The quality of the rice from all the stored paddy was excellent except that the sections of the paddy taken from the upper portion of the 20-ton cube were designated as second-grade.

Our results show that the storage technology described herein does provide a non-chemical solution for storage of paddy in Sri Lanka for farming communities, cooperative enterprises, and those which do not have access to storage structures. Many farmers and traders are unable to measure the moisture content of their paddy, and are aware of the constraints against excessive drying (particularly loss in weight in commerce and also cracking of the kernels). Therefore, if this method were to be adopted, some cubes would probably be filled with paddy at above 14% m.c. For this reason it is important that an insulating layer be placed above the top layer of sacks to reduce the daily temperature fluctuations. It is suggested that each cube be supplied with an insulating layer with the proper dimensions needed to cover the top layer of sacks. This would form part of the standard kit contained within the carrying bag of the cube.

Acknowledgements

The authors thank the staff of the Samusala Rice Mill, Srawisthipura, for their cooperation throughout the storage trials. This research was funded in part by the American Jewish World Service, with additional funding from the Moriah Foundation. Logistical support and facilities were provided by the Sarvodaya Shramadana Movement of Sri Lanka.

References

Anon. (1966) Determination of moisture content. International rules for seed testing. *Proceedings of the International Seed Testing Association* **31**, 128–134.

Annis P. C., Banks H. J. and Sukardi (1984) Insect control in stacks of bagged rice using carbon dioxide treatment and experimental PVC-membrane enclosure. *Division of Entomology Technical Paper No.* **22**, CSIRO, Australia, 38 pp.

Beeny J. M., Jensen L. A., Varghese G. and Sanusi Bin Jangi M. (1972) Use of butyl rubber silos for paddy storage in the tropics. *Tropical Agriculture (Trinidad)* **49**(2), 151–160.

Breese M. R. (1963) Studies on the oviposition of *Rhyzopertha dominica* (F.) in rice and paddy. *Bulletin of Entomological Research* **53**, 621–627.

Cogburn R. R., Bollich C. N. and Meola S. (1983) Factors that affect the relative resistance of rough rice to Angoumois grain moths and lesser grain borers. *Environmental Entomology* **12**, 936–942.

Donahaye E., Blauschild Y., Ziv A., Navarro S. and Weerasinghe D. (1989) *ARO-AJWS-SARVODAYA Grain Storage Project in Sri Lanka*. Final Technical Report, 31 pp.

Fernando M. D., Palipane K. B. and Adhikarinayake T. B. (1988) Improvements of farm level grain storage methods in Sri Lanka. *Tropical Post Harvest Technologist* **1**(1), 47–67.

Lipton M. (1982) Post-harvest technology and reduction of hunger. In: *Feeding the Hungry: a Role for Post-harvest Technology?* Institute of Development Studies, Sussex, Bulletin, Vol. **13**(1), 4–11.

Navarro S. and Donahaye R. (1986) Plastic structures for temporary storage of grain. In: *Proceedings of the Eighth ASEAN Technical Seminar on Post-Harvest Technology, Manila, Philippines*. pp. 189–194.

Proctor D. L. and Rowley J. Q. (1983) The thousand grain mass (TGM) method. A basis for better assessment of weight losses in stored grain. *Tropical Stored Products Information* **45**, 19–25.