Donahaye J., Navarro S., Caliboso F., Sabio G., Mallo G. and Dator J.(1999) Prevention of Moisture Migration in Sealed Grain Stacks Stored in the Open in the Tropics Using Reflective Covers. Pp.316-323. In : Quality Assurance in Agricultural Produce. Johnson, G.I., To Le V.., Duc, N. D., and Webb, M. C. (eds.) **19th ASEAN Seminar on Postharvest Technology**, Ho Chi Min City, Vietnam 9-12 Nov 1999, ACIAR Proceedings No. 100.

Prevention of Moisture Migration in Sealed Grain Stacks Stored in the Open in the Tropics Using Reflective Covers

J. Donahaye*, S. Navarro*, F. Caliboso†, G. Sabio†, G. Mallo† and J. Dator†

Abstract

A sealed structure that provides protection of grain without the use of chemical pesticides and termed a 'Volcani Cube' was used in these experiments. A major advantage of the Volcani Cube is that it can be used to safely store grain outdoors when no suitable storage buildings are available. However, under tropical conditions, when grain is stored in the open with no shade, ambient diurnal temperature fluctuations can create temperature gradients within the stack that cause convection currents to carry moisture to the upper layers of the grain. To overcome this, an upper insulating layer of bags containing straw or husks was employed. Under Filipino conditions this solution enables safe storage of maize and paddy for periods of up to three months, while for more extended periods the top moistened layer of husks should be replaced with dry material. This method, although solving the problem, suffers from the inherent disadvantages of reduction in effective storage capacity, the necessity to procure and transport material to fill the bags, and the added expense of bags not used for storing grain.

In a search to develop an alternative, inexpensive and convenient method of insulating the stack from diurnal temperature fluctuations, the use of a shade screen placed above the cube was investigated. This material, described as a 'knitted thermal screen', is formed from aluminum-coated high-density polyethylene threads.

Trials in Israel and the Philippines showed that the reflective covers had a strong attenuating influence on temperature gradients and condensation at the top of the cubes on the condition that a space for the free movement of air was allowed between the cover and the plastic liner. For dry paddy, it was shown that after five months storage under a reflective cover, no perceptible increase in moisture content was found at the top of the stack and the grain remained in good condition.

TWO research and development projects carried out over the past nine years by The Bureau of Postharvest Research and Extension (BPRE) in the Philippines, with the cooperation and support of the Agricultural Research Organization (ARO) in Israel, have focused on the outdoor storage of grain inside hermetically sealed plastic liners termed 'Volcani Cubes' (Alvindia et al. 1994; Navarro et al. 1996, 1997; Caliboso et al. 1997; Donahaye et al. 1998, 1999; Navarro and Donahaye 1998). The practical outcome of the first project was to strengthen the present policy of the Filipino Government which is directed at providing farmer cooperatives with on-site storage units so as to decentralise 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 the flexible plastic outdoor storage cubes that were developed during the course of this project. In 1998, about 200 units were distributed to farmer cooperative recipients nationwide. Presently, Government orders have been placed to purchase additional units for distribution among farmer cooperatives. The second project was designed to provide a solution to the acute regional problem where paddy-rice is harvested at

* Department of Stored Products, Agricultural Research Organization, The Volcani Center, PO Box 6, Bet Dagan 50 250, Israel.

† Bureau of Postharvest Research and Extension, Muñoz, Philippines.

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 is 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 moulds. The technology being developed in the second project is intended to enable farmers to overcome the bottleneck that occurs at the second drying stage by providing them with a means of storing the intermediate MC paddy under tightly sealed conditions and thereby preventing spoilage for prolonged periods until drying by sun or machine is again an available option.

One significant finding of the first project was that, under Filipino conditions, for dry paddy or corn stored in cubes outdoors with no shade, the diurnal temperature fluctuations of the ambient atmosphere created temperature gradients within the cubes that caused convection currents to carry moisture to the top of the stack. To overcome this, an upper insulating layer of bags containing rice hulls or corn cobs 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 or corn cobs and fill the bags; and the added expense of bags not used for storing grain. It was shown that under Filipino conditions this method enables safe storage for periods of up to three months. For more extended time periods, the wet top layer of husks or corn cobs should be replaced (Navarro et al. 1995).

In the second project, it was envisaged from the outset that when intermediate MC grain (circa 18% MC) is stored outdoors this phenomenon would also occur and would probably be even more critical, since any rise above 18% MC is liable to trigger the anaerobic metabolism of bacteria and yeasts that have a strong influence on grain quality, particularly taste and aroma.

In a search to find an alternative, inexpensive and convenient method of insulating the stack from diurnal temperature fluctuations, the use of a shade-providing awning consisting of 'Polysac-Aluminet' was investigated. This material is described by the manufacturer as a knitted shadecloth for use as a thermal screen and is formed from aluminum-coated high-density polyethylene threads. The trials described here were undertaken to study the effectiveness and applicability of these screens in protecting the grain stacks. The first trials were carried out in Israel using a 10 t capacity cube containing wheat, in order to obtain preliminary data and to finetune the method. Later trials were carried out both in Israel and the Philippines.

Trials in Israel

Materials and methods

The first trial in Israel was directed at simultaneously comparing the daytime temperature gradients at the top of a storage cube between unprotected and protected segments of the upper liner. Two densities of shade material were compared during daytime only, and the insulating effect of the two types was examined both when the cover was spread directly over the top of the liner (Figure 1A) and also when it was separated from the liner by a distance of 20 cm using spacers (Figure 1B).

The results of this first trial were inconclusive, even though they indicated a decrease in the temperature gradient of the stack when protected by the cover. Therefore a second trial was undertaken in which temperature measurements were recorded using temperature loggers ('Hobo', Onset Computer Corp.) to enable temperature gradients to be monitored at night-time, when condensation problems are more acute. However, in this case, an entire cover was used, and a 7-days on and 7-days off regime was employed. Here, the problem of fixing the cover above the cube became evident. To 'solve' this 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 (Figure 2). However, in this way the sides of the space above the cube were sealed by the cover. We believe that, although we recorded a small reduction in temperature gradient due to the cover, the absence of this gap between the top surface of the cube and around the borders of the stretched cover-screen may have resulted in trapping the heat between the cover and liner during the daytime. Later, this heat dissipated rapidly upwards through the screen as the air above it cooled towards dusk. Detailed results of this trial are not given here.

The third trial in Israel was designed to overcome this problem (Figure 3). In this trial the reflective cover was stretched over the top of the cube using 20 cm spacers, and care was taken to ensure that the cover

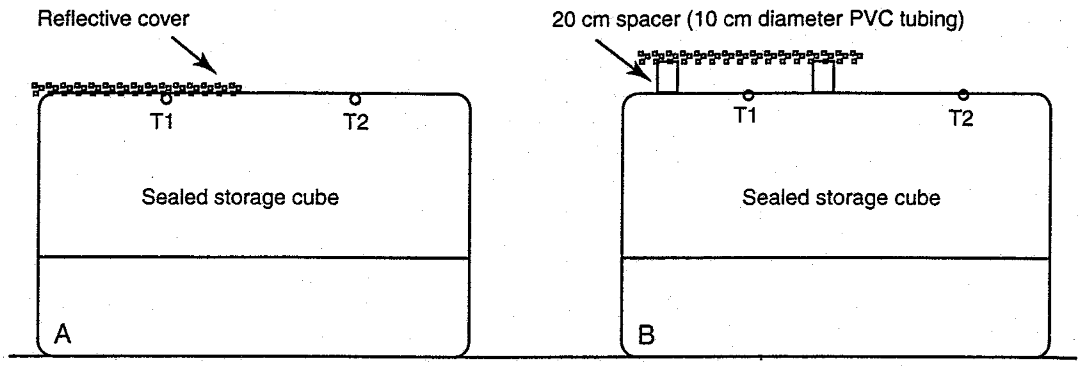

Figure 1. The set-up in first Israeli trial to compare daytime temperatures at (A) the upper liner, between shadecloth-covered and uncovered sections, and (B) between the shadecloth cover with and without spacers (T1 and T2 are thermocouple points which were connected to an electronic temperature recorder).

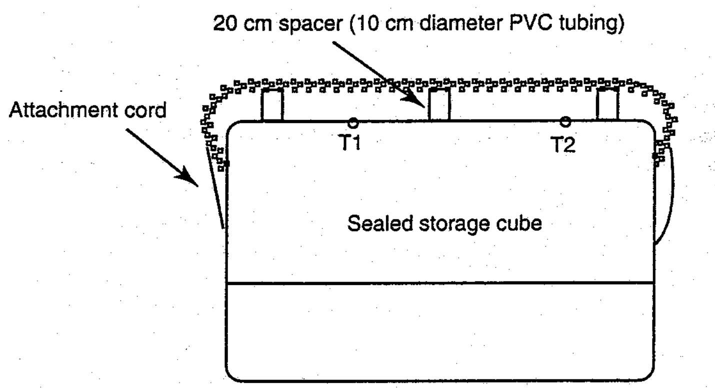

Figure 2. Trial using protective cover pulled down at sides and attached to tension straps (T1 and T2 are temperature loggers).

was not brought down at the sides, but remained with a gap to permit free air movement beneath the cover. At weekly intervals the cover was removed or replaced so that three alternating series of recordings (cover on, cover off) were obtained. Three temperature loggers, set to record the temperature at 1 h intervals, were placed at the centre of the cube—one above the liner, one below the liner, and one within the upper layer of bags at a depth of 10 cm. At the end of the trial the recordings were down-loaded into an Excel spreadsheet on a computer.

Results

A summary of the amassed data is provided in Table 1, which clearly reveals the attenuation in daily temperature fluctuations caused by the reflective cover. Over the course of the trial, the average daily temperature above the liner with the cover in place was about 7°C lower than without it, and this was particularly evident during the daytime (hours of sunlight) when there was a 10–15°C temperature difference.

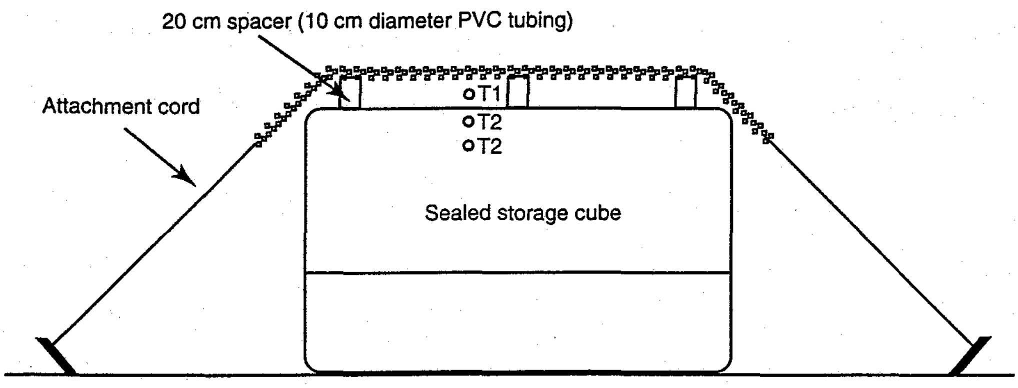

Figure 3. Trial in which air could freely move between the cover and the upper liner of the cube (T1, T2 and T3 are temperature loggers).

The temperature gradients shown in Table 1 reveal the conditions that generate a continuous rhythm of convection currents, when—during the night—moisture is transported to the surface layers, and—during the daytime—the surface layers lose moisture as they heat up. In the Israeli climate, we have shown (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, already it has been already shown that for outdoor storage of dry grain in the Philippines, there is a continuous, although gradual, process of moisture transfer to the surface due to the fact that the net moistening effect at night is greater than the net drying effect during the day. Therefore it was evident that trials would have to be carried out in the Philippines to verify whether this reflective liner could serve as a replacement for the insulating top layer of agricultural wastes as used in the present storage method for dry grain, or if it can effectively retard moisture migration during the storage of intermediate MC paddy under tropical conditions.

Table 1. Average weekly temperatures (°C) and temperature gradients recorded with and without a reflective cover placed above a 10 t capacity Volcani Cube at Bet Dagan, Israel (28 March to 10 June 1998).

Week (1998)	Reflective cover	Above liner (A)	Below liner (B)	10 cm[a] (C)	Ambient temperature	Temperature gradient		
						(A–B)	(A–C)	(B–C)
(A) Weekly averages of 24-hour recordings								
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 daytime averages for sunlight hours (9 am to 6 pm)								
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 (7 pm to 8 am)								
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

[a] 10 cm = temperature recorded within the upper layer of bags at a depth of 10 cm.

Trial in the Philippines

Materials and methods

This trial was carried out in conjunction with a field trial for storage of intermediate MC (approximately 18% MC) paddy in order to evaluate quality conservation, using two 10 t capacity cubes, one for a 3-month, and one for a 6-month period. An additional cube containing dry paddy at 14% MC was set up for 5 months under a separate reflective cover but was not monitored for temperature gradients.

The cubes were set up at the Bureau of Postharvest Research and Extension (BPRE) (National Post-Harvest Institute for Research and Extension—NAPHIRE) compound in Muñoz using freshly harvested paddy (IR64) that was dried to approximately 18% MC from higher MCs using a fluidised bed dryer, and using paddy sun-dried to 14% MC. In this trial the 70% density reflective covers were suspended over the cubes using a series of poles and guy ropes to create a tent-shaped awning that also partially protected the sides. Temperatures were logged hourly above the liners, below the liners, 10 cm within the upper grain layer, and in the central core of the stacks at 18% MC. The set-ups were as shown in Figure 4. MCs of the different stack layers within the cubes were recorded at the beginning and end of both storage periods.

Results

A summary of temperature gradients recorded over a representative 16-day period during storage (November–December) is given in Table 2. For comparison, daytime temperature gradients recorded during a previous trial without a reflective cover (July–August) are also provided. Table 2 shows that with the reflective cover set up as an awning over the cubes, temperature gradients both at night and at daytime were small and compared favourably with those recorded in Israel.

Table 2. Summary of 16 days of recordings taken by temperature loggers in a Volcani Cube protected by a reflective cover at Muñoz, Philippines.

Temp. (°C)	Above liner	Beneath liner	10 cm deep	Temperature gradient		
	(A)	(B)	(C)	A–B	A–C	B–C
(A) Average daily						
Reflective cover (23 November–7 December)						
Average daily	28.4	27.6	28.0	0.8	0.4	–0.4
Average maximum	36.6	35.2	30.4	3.0	8.1	6.9
Average minimum	23.6	22.8	26.2	–1.2	–3.4	–3.8
(B) Average daytime						
Reflective cover (23 November–7 December)						
Average daily	33.3	31.8	28.6	1.6	4.8	3.5
Average maximum	37.0	35.1	30.3	3.1	8.3	6.9
Average minimum	29.1	27.0	26.1	–0.9	1.2	1.4
No cover (9 July–26 August)						
Average daily	39.88	33.15	30.98	6.73	8.89	2.17
Average maximum	50.88	39.43	33.41	14.23	19.84	6.41
Average minimum	30.12	29.69	28.36	0.73	–1.12	–2.43
(C) Average night-time						
Reflective cover (23 November–7 December)						
Average nightly	25.3	24.9	27.6	0.4	–2.8	–2.4
Average maximum	28.9	28.9	29.9	1.2	–1.0	–0.9
Average minimum	23.6	22.8	26.0	–0.4	–3.8	–3.4

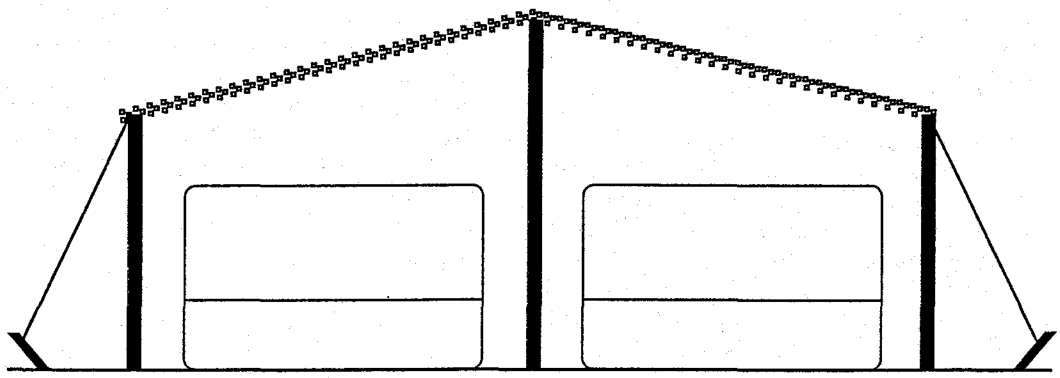

Figure 4. Experimental set-up of the reflective liner at Muñoz, Philippines.

Calculations based on average night temperature read-outs show that, since 18% MC paddy has an equivalent equilibrium relative humidity (ERH) 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 24.9°C, then at 100% RH it would contain 23.1g/m^3, i.e. there would be a condensation of 1.8 g for every cubic metre of air reaching the upper surface. Although the temperature logger records show that, for most of the night duration, air at 92% RH (=18% grain equilibrium MC) would become saturated when in contact with the upper plastic liner, the very small temperature gradient would produce only feeble convection currents. For a direct evaluation of the net effect of moistening of the surface layer at night-time and drying during the daytime, the MCs at the top of the stack were examined after 3 and 6 months. These findings are given in Tables 3 and 4.

Table 3. Average moisture contents (%) of intermediate moisture content paddy hermetically stored in a Volcani Cube in the Philippines for 3 months.

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

3-month storage of 18% MC paddy

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% (equilibrium RH = 92%) enable the development of yeasts and bacteria that can cause rotting and the development of unpleasant odours, the organoleptic characteristics of the paddy were also seriously affected.

Table 4. Average moisture contents (%) of intermediate moisture content paddy hermetically stored in a Volcani Cube for 6 months.

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

6-month storage of 18% MC paddy

Table 4 shows that the continued upward movement of moisture resulted in even higher MCs of the upper layers at the end of the 6-month storage period. However, here again the accumulation of moisture was only noted in the top two layers.

Dry grain storage

At the end of the 5-month storage period (7 December 1998 to 5 May 1999) the stack was opened and examined, and although a comprehensive examination of MCs by stack layer was not undertaken, the spot tests at the top of the cube revealed that there was no perceptible increase in MC, and the grain was dry throughout the stack.

Summary and Conclusions

The trials in Israel showed that the reflective covers had a strong attenuating influence on the development of temperature gradients and condensation at the top of the Volcani Cubes placed in the open, as long as a space for free movement of air was provided between the cover and the plastic liner. This was confirmed in the Philippines, but field trials with 18% MC paddy showed that this insulating effect was not sufficient to prevent a gradual build-up of moisture at the surface layer. However, for dry paddy, after 5 months of storage under a reflective cover, no perceptible increase in moisture content was found at the top of the stack and the grain remained in good condition.

As a result of these findings, a decision was taken to discontinue recommendations for inclusion of a protective layer of agricultural wastes at the top of the stack to be replaced every 3 months (Navarro et al. 1996). Instead, a suitably sized reflective cover would be included in the carrying bag of the storage kit, and instructions on setting up the cover would be added to the manual. Two additional configurations for positioning the reflective cover are illustrated in Figure 5.

Acknowledgment

This research was supported under Grant No. TA-MOU-94-C12-057 funded by the United States (US)–Israel Cooperative Development Research Program of the US Agency for International Development.

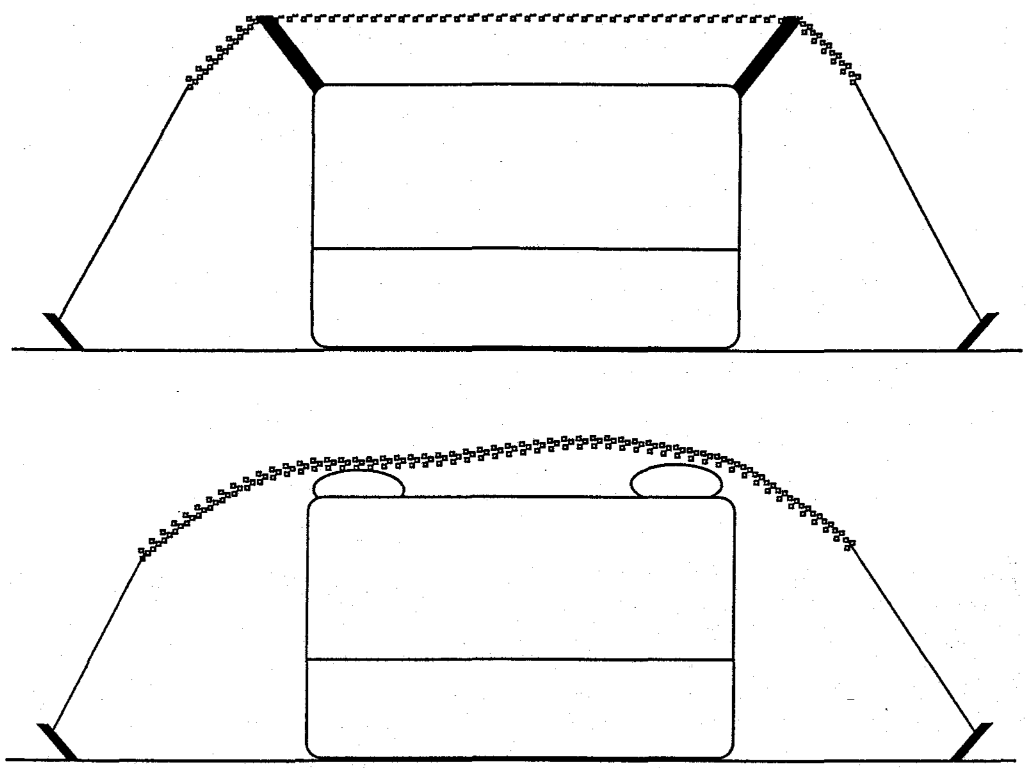

Figure 5. Additional configurations for positioning the reflective cover above the storage cube.

References

Alvindia, D.G., Caliboso, F.M., Sabio, G.C. and Regpala, A.R. 1994. Modified atmosphere storage of bagged maize outdoors using flexible liners: a preliminary report. In: Highley, E., Wright, E.J., Banks, H.J. and Champ, B.R., ed., Proceedings of the 6th International Working Conference on Stored-product Protection, 17–23 April 1994, Canberra, Australia, Volume 1. Wallingford, CAB International, 22–26.

Caliboso, F.M., Navarro, S., Alvindia, D.G., Donahaye, E.J., Sabio, G.C. and dela Cruz, M.T. 1997. Effect of gastight storage on growth of fungi in paddy stored outdoors. In: Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Grain Storages, 21–26 April 1996, Nicosia, Cyprus. Nicosia, Printco Ltd, 135–144.

Donahaye, E.J., Andales, S.C., Chernoguz, D., Navarro, S., Azrieli, A. and Rindner, M. 1998. Respiration rates of paddy at different temperatures and moisture contents. In: Proceedings of the 18th ASEAN Seminar on Grains Postharvest Technology, 11–13 March 1997, Manila, Philippines, 145–152.

Donahaye, E.J., Andales, S.C., Navarro, S. and Caliboso, F. 1999. Self regulated atmospheres to prevent fungal damage in moist paddy. Final report of Project Number TA-MOU-94-C12-057 submitted to the United States Agency for International Development (USAID), 32p.

Navarro, S., Donahaye, E., Caliboso, F.M. and Sabio, G.C. 1996. Application of modified atmospheres under plastic covers for prevention of losses in stored grain. Final Report submitted to United States Agency for International Development (USAID), CDR Project No. C7-053, August 1990–November 1995, 32p.

Navarro, S., Caliboso, F.M., Sabio, G.C. and Donahaye, E.J. 1997. Quality conservation of paddy stored under gas-tight seal outdoors in the Philippines. In: Proceedings of the International Conference on Controlled Atmosphere and Fumigation in Grain Storages, 21–26 April 1996, Nicosia, Cyprus. Nicosia, Printco Ltd, 159–168.

Navarro, S. and Donahaye, E.J. 1998. Outdoor storage of corn and paddy using sealed-stacks in the Philippines. In: Proceedings of the 18th ASEAN Seminar on Grains Postharvest Technology, 11–13 March 1997, Manila, Philippines, 225–236.