Carbon Dioxide Treatment for Sealed Storage of Bag Stacks of Rice in Thailand

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Abstract

An evaluation was made of the use of carbon dioxide (CO_2) for controlling insects during long-term storage of rice. The first trial was carried out between 6 June and 3 December 1985. Three 72-tonne stacks of the rice varieties Na-sai, wet season rice, and Hom Mali were used. They were treated with CO_2 at 1.98, 2.03, and 1.97 kg/tonne of rice and opened for inspection after 2, 4, and 6 months, respectively. During the storage period, changes in temperature and relative humidity within the stacks were monitored. The moisture content, quality, and insect infestation of grain were investigated before and after storage. The treatment gave total insect control: no live insects were found in any of the treated stacks. There was no increase in percentage of fungal infection, except in the stack stored for 6 months. Aflatoxin was not detected and grain quality fell slightly at longer storage periods. In order to prove the effectiveness of CO_2 for control of insects during long-term storage, a second trial was conducted from 6 March 1986 to 6 March 1987. Three 63-tonne stacks of milled Na-sai rice were used. The stacks were treated with CO_2 at rates of 1.81, 2.11, and 2.41 kg/tonne of rice and were opened at 4, 8, and 12 months, respectively, after treatment. The results of this trial showed total protection from insects for up to 8 months, while some live insects were found in the third stack, opened at 12 months. There was no increase in the percentage of fungal infection, rather it decreased and aflatoxin was not detected in any stack. Rice quality was slightly changed, but all samples were acceptable.

This paper presents the results of both trials.

In Thailand milled rice is stored in warehouses in variable-sized stacks of jute bags. The warehouses are usually of the horizontal type ventilated to permit cooling of the grain through natural convection.

In this type of storage the grain is prone to insect attack and losses due to insect infestation are one of the basic problems of storing bagged rice. The main insect control procedure for bag storage in Thailand is fumigation. At present, only methyl bromide and phosphine are in use to fumigate bag stacks. However, if grain remains in storage for a substantial period after fumigation, it will be reinfested by insects sometime after removal of the fumigation sheets. There is therefore a need to develop a storage technique to guard against reinfestation. Apart from preventing losses during storage, there is also a need to develop a method to preserve the quality of grain for longer storage periods so as to meet the nutritional requirement of the consumers. The introduction of carbon dioxide to control insects and prolong safe storage of grain is a new technology that can achieve these aims.

Carbon dioxide (CO_2) is a fumigant that produces no harmful residues and is relatively safe to use (Annis and Graver 1985). It is effective in killing insects in all stages of their life cycles and could be used for long-term storage of milled rice (Annis et al. 1984; Suharno et al. 1984).

This paper describes the results of two trials on the use of carbon dioxide in the sealed storage of bag stacks of rice in Thailand.

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Materials and Methods

Trial I

The first trial was carried out at Mah Boonkrong Rice Mill Co. Ltd, Pathumthani Province, between 6 June and 3 December 1985. Three 72-tonne stacks of bagged milled rice of three different varieties—Na-sai, wet season, and Hom Mali—were used. After CO_2 had been added, the stacks were then uncovered sequentially at 2, 4, and 6 months for stacks 1, 2, and 3 respectively. The rice was then sampled for insect and fungal infestation, and for rice quality assessment. Further details of the trial stacks are given in Table 1.

Enclosure construction and testing

For each stack, a floor sheet (5 ×7 m) of PVC film with thickness 0.76 mm was laid on the concrete floor. The stack was then built on wooden pallets over the floor sheet. An enclosure (4.2 × 6.0 × 5.9 m) of 0.24 mm thickness plastic sheeting was fitted over the stack and the inner edge of the enclosure bonded to the floor sheet with sealant (Barrier adhesive). A domestic vacuum cleaner was used to create a small negative differential pressure within the enclosure. Leaks and imperfections in the seal were then detected by visual inspection and by the sound they made. After the leaks had been sealed, the degree of gastightness was determined by the steady-state pressure test method.

CO_2 introduction

Liquid CO_2 from 20 kg cylinders was introduced into the enclosure through a copper pipe (5 mm i.d.) connected to a PVC pipe (3 cm i.d.) and placed under the pallets. The amount delivered was determined from the loss of weight of the cylinders. An outlet vent of 30 cm diameter was made on the top of the enclosure to allow escape of displaced gases during CO_2 application. CO_2 was added until the concentration at the top was approximately 15% and that at the bottom over 60% (Table 2). The three stacks were thus treated with 1.98, 2.03, and 1.97 kg of CO_2 per tonne of rice. The introduction pipe was then removed and the outlet vent and introduction region sealed.

CO_2 temperature, and relative humidity measurement

Drager gas tubes were used to measure the

Table 1. Details of stack dimensions and loads in trial I.

	Stack 1 (2 months)	Stack 2 (4 months)	Stack 3 (6 months)
Height (m)	4.4	4.4	4.4
Width (m)	3.9	3.9	3.9
Length (m)	5.9	5.9	5.9
Mass of rice (tonnes)	72.0	72.0	72.0
Rice moisture content before treatment (%)	10.3	10.8	10.5
Rice moisture content after treatment (%)	11.8	11.7	10.7
Rice temperature (°C)	33.0(29.8–37.6)	32.4(29.8–40.4)	32.2(26.8–40.5)
Ambient temperature (°C)	29.5(27.7–31.1)	29.8(28.4–32.3)	29.8(27.7–31.1)
Relative humidity in stack (%)	65.4	65.0	62.6
Ambient relative humidity (%)	67.6	67.3	67.3

Table 2. Summary of CO_2 exposures for each test stack in trial I

Stack no.	CO_2 at end of gas addition		Average CO_2 after 24 hrs	CO_2 remaining after 10 days	Exposure time at > 35% CO_2	Time under cover after CO_2 treatment until opening stack	CO_2 present on uncovering stack			
	%		%	%	(days)	(days)	%			
	Top	Bottom					Top	Middle	Bottom	Average
1	>15	>60	> 60	60	31	60	17	18	15.5	16.8
2	>15	>60	> 60	60	25	120	3	5	4.5	4.2
3	>15	>60	> 60	60	40	180	-	-	-	-

relative humidity (RH) and CO_2 concentration within the stacks compared with the surrounding area. Temperatures within and outside the stacks were measured by hand held thermocouples and read from a LCD thermometer. CO_2 and water vapour concentrations were sampled from within each stack through semi-rigid nylon gas sampling lines (2 mm i.d.) placed in the stack during construction at three levels—top, middle, and bottom. Water vapour values were converted to relative humidities using the psychrometric chart. These measurements were recorded each day for the first 7 days and then once a week until the stack was uncovered.

Sampling for grain quality, fungal infection, and insect infestation was then carried out.

During construction of the stacks, 6 kg subsamples of 15 kg of rice per stack were taken to assess quality changes, mould damage, and insect infestation. When the stacks were uncovered, the grain was again sampled to determine any effects of CO_2 treatment. For this investigation, the rice was divided into three parts for assessment of grain quality, fungal infection, and insect infestation.

- Rice quality was assessed from physical, palatability, and chemical characteristics (Anon. 1975).
- Fungal infection was assessed by the blotter method (Anon. 1966).
- Insect infestation was determined by sampling for adults or free-living larvae from each stack before and after CO_2 treatment and by holding samples in the laboratory for 6 weeks to allow any hidden infestations to develop.

Trial II

A second trial (Table 3) was carried out between 6 March 1986 and 6 March 1987, in order to store rice up to 12 months.

Three stacks, each of 63 tonnes of milled rice, were treated with CO_2 at rates of 1.81, 2.11, and 2.41 kg/tonne of rice (Table 3) and the stacks opened at 4, 8, and 12 months after treatment (Table 4).

In this trial, milled rice was packed in 'jumbo' bags weighing 700 kg rather than 100 kg gunny sacks. Otherwise procedures were as for the first trial.

Table 3. Details of stack dimensions and loads in trial II.

	Stack 1 (4 months)	Stack2 (8 months)	Stack 3 (12 months)
Height (m)	5.0	5.0	5.0
Width (m)	3.5	3.5	3.5
Length (m)	6.0	6.0	6.0
Mass of rice (tonne)	63.0	63.0	63.0
Rice moisture content before treatment (%)	10.3	10.1	10.2
Rice moisture content after treatment (%)	10.4	10.3	10.3
Rice temperature (°C)	30.5 (29.0–33.8)	31.2 (28.8–35.4)	31.7 (27.9–36.5)
Ambient temperature (°C)	31.9 (29.4–35.0)	32.0 (29.4–35.0)	31.9 (29.0–35.0)
Relative humidity in stack (%)	66.2	59.3	63.9
Ambient relative humidity (%)	62.2	62.0	62.4

Table 4. Summary of CO_2 exposures for each test stack in trial II.

Stack no.	CO_2 at end of gas addition		Average CO_2 after 24 hrs	CO_2 remaining after 10 days	Exposure time at > 35%	Time under cover after CO_2 treatment until opening stack	CO_2 present on uncovering stack			
	%		%	%	(days)	(days)	%			
	Top	Bottom					Top	Middle	Bottom	Mean
1	>15	>60	48.0	50	26	120	5	5	5	5
2	>15	>60	50.3	50	23	240	0	0	0	0
3	>15	>60	49.3	60	36	360	0	0	0	0

Results and Discussion

The results of the two trials were as follows:

Insect infestation

In both trials, insects were observed damaging bagged milled rice before and after treatment. Rice samples from all stacks contained a number of live and dead insects before treatment. Species represented included *Tribolium castaneum, Oryzaephilus surinamensis, Cryptolestes pusillus, Corcyra cephalonica,* and *Sitophilus* spp. The populations of some species increased after the 45 days of incubation undertaken to assess hidden infestation. No live insects were detected after uncovering the stacks in trial I, (maximum 6 months storage), but some dead insects were found. In trial II, no live insects were found in the stacks opened at 4 and 8 months. However, the third stack, opened after 12 months storage, contained live *Tribolium castaneum,* and *Oryzaephilus surinamensis* feeding on and damaging the milled rice (see Tables 5, 6, 7, and 8).

It was not clear why CO_2 had no effect on the populations of *Tribolium castaneum* and

Table 5. Insects present (numbers per 3 kg sample) in samples taken before and after treatment in trial I.

Species	Before treatment						After treatment					
	Stack 1		Stack 2		Stack 3		Stack 1 (2 months)		Stack 2 (4 months)		Stack 3 (6 months)	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Tribolium castaneum	2	0	2	1	4	2	0	3	0	6	0	3
Corcyra cephalonica	3	0	5	0	0	0	0	1	0	0	0	0
Oryzaephilus surinamensis	3	0	0	4	3	0	0	5	0	1	0	4
Sitophilus spp.	0	0	4	0	0	0	0	0	0	3	0	3

Table 6. Insects present (numbers per 3 kg sample) in samples taken before and after treatment in trial II.

Species	Before treatment						After treatment					
	Stack 1		Stack 2		Stack 3		Stack 1 (4 months)		Stack 2 (8 months)		Stack 3 (12 months)	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Tribolium castaneum	1	2	3	1	4	1	0	4	0	3	96	18
Oryzaephilus surinamensis	0	1	3	0	2	0	0	3	0	2	45	6
Sitophilus spp.	3	0	1	1	0	2	0	1	0	0	0	2

Table 7. Hidden infestation (numbers per 3 kg sample) in samples taken before and after treatment in trial I.

Species	Before treatment						After treatment					
	Stack 1		Stack 2		Stack 3		Stack 1 (2 months)		Stack 2 (4 months)		Stack 3 (6 months)	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Tribolium castaneum	14	0	8	0	11	0	0	0	0	0	0	0
Corcyra cephalonica	0	0	2	5	0	0	0	0	0	0	0	0
Oryzaephilus surinamensis	9	0	15	0	8	0	0	0	0	0	0	0
Sitophilus spp.	3	0	4	2	0	0	0	0	0	0	0	0
C. cephalonica (larvae)	0	0	46	0	0	0	0	0	0	0	0	0

Oryzaephilus surinamensis found after 12 months storage. The CO_2 had been added at a dosage of 2.4 kg/tonne of rice, which has been determined (Annis et al. 1984; Sukardi and Martono 1983) to be an optimal dosage. The enclosure was inspected regularly and no holes or tears were found in the sheeting. It may be that the 700 kg polypropylene woven jumbo bags used in the trial are less penetrable to the gas than are jute bags.

Fungal infection

Fungal species contaminating the grain were detected by collecting 400 grain samples and plating 25 grains per petri dish. The plated samples were then incubated on moist blotter at 23±2°C for 7 days, under alternating cycles of 12 hours Near Ultra Violet (NUV) light and 12 hours darkness. The results in trial I showed that the numbers and percentages of fungal species in the first two stacks had not increased as compared to pretreatment levels. However, in the third stack the percentage of fungal infection was slightly increased. Genera such as *Fusarium* and *Penicillium* were subsequently observed to be contaminating the grain (Table 9). It was found later that the sheet covering this stack had been torn during the last month of the trial, thereby permitting entry of outside air.

In trial II, during which the enclosures were completely sealed, the percentage of *Aspergillus spp.* and *Fusarium moniliforme* contaminating the grain before treatment decreased significantly after treatment. Only *Curvularia lunata* was found infecting the grain in the stack treated for 12 months (Table 10).

Aflatoxin analysis by thin layer chromatography (TLC) determined that the in both trials was completely free from aflatoxin contamination.

Rice quality

Na-sai and wet season rice are classified as intermediate amylose content (20–25%), having soft gel consistency (over 60 mm) with low and

Table 8. Hidden infestation (numbers per 3 kg sample) in samples taken before and after treatment in trial II.

Species	Before treatment						After treatment					
	Stack 1		Stack 2		Stack 3		Stack 1 (4 months)		Stack 2 (8 months)		Stack 3 (12 months)	
	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive	Dead
Tribolium castaneum	3	0	3	2	2	0	0	7	0	4	23	7
T.castaneum (larvae)	0	0	0	0	11	0	0	0	0	0	12	0
Oryzaephilus surinamensis	4	1	37	0	5	0	0	86	0	6	6	3
O.surinamensis (larvae)	0	0	20	0	0	0	0	0	0	0	0	0
Sitophilus spp.	2	0	0	0	0	1	0	0	0	0	0	0
Cryptolestes pusillus	0	0	0	0	0	1	0	0	0	1	0	0

Table 9. Fungal infection (percentage per 1 kg sample) in trial I.

Species	Before treatment			After treatment		
	Stack 1	Stack 2	Stack 3	Stack 1 (2 months)	Stack 2 (4 months)	Stack 3 (6 months)
	(%)	(%)	(%)	(%)	(%)	(%)
Aspergillus flavus	11	38	10	3	29	14
A.niger	0	3	1	0	0.5	6
A.glaucus	6	11	7	0	0	0
Penicillium citrinum	0	0	1	0	2	3
P.islandicum	0	0	0	0	0	3
Fusarium moniliforme	0	0	0	0	0	6

intermediate-to-low gelatinisation temperatures, respectively. They need about 17–18 minutes cooking to produce moderately tender rice. Hom Mali variety has a low amylose content (below 19%), soft gel consistency, and low gelatinisation temperature. All three varieties are aromatic and the aroma of all samples was detectable.

In trial I, the cooking and eating qualities before and after treatment were investigated. Amylose content, soluble amylose, elongation ratio, elongation index, cooking time, total solid suspended in excess cooking water, and water uptake ratio were not significantly different. The gel consistency was slightly decreased, however, and fat acidity and volume expansion tended to increase with storage period. Hom Mali (before treatment) had higher fat acidity than Na-sai and wet season rice. The fat acidity of Hom Mali after

Table 10. Fungal infection (percentage per 1 kg sample) in trial II.

Species	Before treatment			After treatment		
	Stack 1	Stack 2	Stack 3	Stack 1 (4 months)	Stack 2 (8 months)	Stack 3 (12 months)
	(%)	(%)	(%)	(%)	(%)	(%)
Fusarium moniliforme	5.5	0	0	2.5	0	0
Aspergillus flavus	5.0	3.0	0	5.0	1.0	0
A. niger	0.5	8.0	0	0	7.0	0
A.terrens	4.0	0	0	2.5	0	0
A.fumigatus	0	10.0	0	0	5.0	0
Cladosporium sp.	0	0	2.0	0	0	1.0
Curvularia lunata	0	0	0	0	0	3.0

Table 11. Rice chemical and cooking quality analysis in trial I.

Characteristics	Before treatment			After treatment		
	Stack 1	Stack 2	Stack 3	Stack 1 (2 months)	Stack 2 (4 months)	Stack 3 (6 months)
Amylose (%)	24.31	22.87	13.71	23.70	23.0	15.20
Soluble amylose(%)	13.10	12.60	7.10	13.00	12.40	7.40
Alkali test						
spreading value	5.90	5.20	7.00	5.90	5.50	6.90
gelatinisation temp.	L	I/L	L	L	I/L	L
Elongation ratio	1.93	2.01	2.11	2.13	1.98	2.30
Gel consistency (mm)	89	95	93	69	93	66
Cooking time (min)	18	18	15	17	17	16
Total solids (g/8 g raw rice)	0.59	0.52	0.24	0.57	0.46	0.36
Volume expansion	3.60	3.72	3.46	4.00	4.20	5.01
Water uptake ratio	3.06	2.94	2.90	3.06	3.04	3.17
Fat acidity (mg %)	12.10	10.75	22.66	13.11	14.95	30.87
Brabender viscogram						
Gelatinisation temp.°C	70.5	72	58	71	72	70
Peak viscosity(B.U.)	750	740	880	800	700	880
Set back (B.U.)	+140	+160	-70	+260	+180	20
Consistency (B.U.)	350	420	310	500	400	340
Breakdown (B.U.)	200	260	380	240	220	320
Palatability						
Aroma	5.14	5.40	5.50	5.32	4.93	4.86
Tenderness	5.50	5.59	5.95	4.61	5.07	5.77
Cohesiveness	5.27	5.54	6.09	4.96	5.57	6.05
Whiteness	6.95	6.82	6.40	6.61	6.75	6.11
Glossiness	5.68	5.68	5.95	4.68	5.61	5.46

6 months storage increased by up to about 31% resulting in a distinguishable off-smell of the cooked rice.

Rheological changes in a viscous paste of 10% rice flour were assayed using a Brabender Visco/Amylograph. Results of the peak viscosity consistency and breakdown value showed no differences. The setback value showed an obvious increase in viscosity after treatment. Similarly, the cohesiveness of cooked rice and the palatability test score were decreased after treatment.

Investigation of the palatability of cooked rice showed that the score of all characters tended to decline after treatment. This indicated that the cooked rice had reduced aroma, tenderness, cohesiveness, whiteness, and glossiness as storage period increased. Moreover, the higher fat acidity after treatment resulted in a lower aroma score because the off odour of cooked rice could be distinguished (Table 11).

As regards physical quality, Na-sai variety showed a slight increase (from 10.29 to 11.48%) in moisture content after storage under CO_2 for 2 months. There were no yellow grains in either initial or stored samples, and the degree of whiteness of the milled rice was quite stable at between 47–48. In wet season rice held under CO_2 for 4 months, the grain moisture content and yellow grains were slightly increased, but the whiteness was unchanged. The Hom Mali variety showed a slight increase in grain moisture content, yellow grains, and degree of whiteness (Table 13).

In trial II, amylose content, elongation ratio,

Table 12 Rice chemical and cooking quality analysis in trial II

Characteristics	Before treatment	Storage period: 4 months control	4 months treated	8 months control	8 months treated	12 months control	12 months treated
Amylose (%)	25.76	26.53	26.24	27.17	26.38	26.70	27.06
Gel consistency (mm)	83	37	48	35	38	38	36
Elongation ratio	1.58	1.60	1.59	1.76	1.63	1.74	1.80
Free fatty acid (mg %)	11.62	29.69	25.88	46.63	35.63	51.00	49.00
Alkali test							
spreading value	6.2	5.5	5.6	5.4	5.7	5.2	5.2
gelatinisation temp.	L	I/L	I/L	I/L	I/L	I/L	I/L
Aroma of raw rice	0	0	0	0	0	0	0
Small scale cooking test							
volume expansion	3.92	3.66	3.83	3.50	3.67	3.84	4.08
total solids, (g/g raw rice)	0.79	0.74	0.81	0.66	0.63	0.51	0.53
water absorption	2.86	2.44	2.50	2.44	2.59	2.97	2.85
Brabender viscogram							
gelatinisation temp.°C	69.4	69	69.5	70	70	70.5	70
peak viscosity (B.U.)	570	565	630	960	930	920	920
setback (B.U.)	+145	+150	+130	+110	+140	+100	+140
consistency (B.U.)	370	410	410	520	545	500	540
breakdown (B.U.)	230	160	280	440	405	440	400
Palatability							
aroma	5.1	5.2	5.2	5.2	5.1	4.0	4.7
tenderness	5.2	5.3	5.0	5.0	4.8	4.5	4.9
cohesiveness	5.7	5.8	5.6	5.9	5.8	5.2	5.2
whiteness	7.2	7.0	7.0	6.9	6.9	6.4	6.2
glossiness	6.1	5.7	5.5	6.2	6.1	5.4	5.2

Gelatinisation temperature: L = Low, I/L = Intermediate–Low
Aroma (raw rice): 0 = none, + = scented, ++ = strongly scented

Palability	aroma	tenderness	cohesiveness	whiteness	glossiness
	9 = scented	9 = soft	9 = sticky	9 = white	9 = glossy
	1 = off-aroma	1 = hard	1 = fluffy	1 = light brown	1 = dull

and free fatty acid (FFA) levels were increased in both control and treated samples as storage period increased. Compared with the control, the amylose content of treated samples did not markedly change during storage, though it tended to increase slightly as storage period lengthened. The same pattern occurred with elongation ratio.

FFA levels increased noticeably as the storage period lengthened. The control showed higher FFAs than the treated samples, particularly for the 8 months storage period. However, as the storage period extended to 12 months, the difference in FFA levels between control and treated samples became insignificant. This suggested that the reduction of CO_2 concentration might cause the rapid increase of FFA levels in treated samples. On the other hand, the increased FFA at 12 months storage was accompanied by off-odours in the cooked rice. However, no off odour could be detected from raw rice soaking in 10% sodium chloride solution. Also, as the storage period extended, the alkali spreading value gradually decreased. Na-sai needed a somewhat longer cooking time after than before treatment. The gel consistency of the starch slurry rapidly decreased after storage, indicating an increase in hardness of rice following storage.

In small scale cooking tests, total solids suspended in excess cooking water appeared to decrease. Volume expansion and water absorption also appeared to fall during 8 months storage, and showed no recovery in the rest period. Although the elongation ratio of the grain increased during cooking, the volume expansion of cooked rice did not show the same effect.

Determination of rheological properties of the viscous paste showed changes in gelatinisation temperature, peak viscosity, setback, consistency, and breakdown value. The gelatinisation temperature, peak viscosity, consistency and breakdown value clearly increased during storage. The setback value of treated samples remained unchanged, but appeared to fall in untreated stored samples. Increasing infestation of the controls was observed during storage, possibly contributing to the decrease in setback value. Although the setback value of the control samples was decreased, gel consistency measurements indicated that the rice was harder following storage.

As regards the palatability of cooked rice, the score of all characters tended to decrease as storage period increased. Storage tended to cause reduction in aroma, tenderness, cohesiveness, whiteness, and glossiness, as has been reported before. Eight months storage under carbon dioxide did not affect aroma and cohesiveness. However, lower scores were obtained following longer storage periods. The cooked rice became less sticky and had an unpleasant smell when cooked. The tenderness, whiteness, and glossiness all gradually decreased during storage. Nevertheless, although these changes in palatability occurred, the product was still acceptable to consumers after 8 months storage (Table 12).

Rice moisture content increased slightly in all stacks. There was no significant change in the degree of whiteness and no yellow grain was

Table 13. Rice physical analysis in trial I

	Before treatment			After treatment		
	Stack 1	Stack 2	Stack 3	Stack 1 (2 months)	Stack 2 (4 months)	Stack 3 (6 months)
Yellow grain (g)	0.0	0.02	0.06	0.0	0.11	0.60
Degree of whiteness	47.0	46.5	40.0	48.0	47.0	42.3

Table 14. Rice physical analysis in trial II

	Before treatment			After treatment		
	Stack 1	Stack 2	Stack 3 (4 months)	Stack 1 (8 months)	Stack 2 (12 months)	Stack 3
Yellow grain (g)	0.03	0.0	0.02	0.0	0.0	0.0
Degree of whiteness	50.1	50.6	50.8	48.0	50.0	49.3

found in the treated stacks (Table 14). This suggests that sealed storage following CO_2 treatment can preserve rice quality for up to 12 months.

Conclusion

The results of trial I, in which milled rice was stored for up to 6 months in sealed plastic enclosures following CO_2 treatment, were satisfactory in terms of control of insect infestation and prevention of reinfestation. No live insects were observed in any treatments. Aflatoxin was not detected, despite the fact that the percentage and numbers of some fungal species increased, particularly in the stack stored for 6 months. Although rice quality changed little during storage, it did tend to decrease with increase in storage period.

In trial II, rice quality assessments gave results similar to those from trial I. However, the percentage incidence of most fungal species decreased, with an increase in only one minor species. CO_2 was effective in controlling insects in the stacks opened at 4 and 8 months, but not in the stack sealed for 12 months.

It is concluded that the CO_2 treatment method is effective in controlling insect pests and mould growth, and will preserve milled rice during long-term storage, provided the enclosure remains sealed.

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