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COMPARATIVE EVALUATION OF ALUMINUM PHOSPHIDE FUMIGANT FORMULATIONS UNDER SEALED ENCLOSURE FUMIGATION STORAGE TECHNOLOGY (SEFUST)

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ABSTRACT

This research project was conducted with the primary purpose of searching for alternative fumigants that are cost effective and might be used by the agency in its nationwide adoption of the SEFUST method or CAST (controlled atmosphere storage technology) for the NFA's stock management operations. The project compared the performance of the fumigant formulation (Phostoxin) in present use by the agency against an alternative formulation (Quickphos) under the SEFUST method for a 6-month storage period. It focused its observations on the effect on the quality changes of milled rice such as percent damaged grains, percent discolored grains, percent moisture content, rice kernel whiteness, and insect-damaged kernels. Results revealed that SEFUST did not significantly affect the overall quality of the milled rice except for moisture content. Generation of the PH_3 concentration of the fumigant formulations was also measured and compared and showed that Phostoxin PH_3 generation is significantly higher than that of Quickphos. Furthermore, the PH_3 concentration at the top of the pile is not significantly different from the bottom of the pile for both fumigant formulations. The project also addressed the application cost of the two fumigant formulations under this method.

INTRODUCTION

The National Food Authority (NFA) of the Philippines as a government corporation is mandated to ensure food security for the nation by making food available, accessible, and affordable to the people at any given time of the year. And because of NFA's aspiration to realize this vital mandate, the agency, is now adopting as one of its implementing strategies, the Sealed Enclosure Fumigation Storage Technology or SEFUST. This technology has been shown through in-house research findings to be very suitable to the NFA storage system of operation. In fact, the agency further resolved that 70% of its milled rice stock inventory at any given time be devoted as food security stocks using this technology.

Since the agency has now adopted this fumigation technology, the need to search for alternative fumigant formulations that are comparable, if not more cost effective in performance to the present one used by NFA has become an urgent priority. This is because, of the current fumigants utilized worldwide, phosphine (PH_3) and methyl bromide (MB) are the only major fumigants labeled for food use in the U.S. (Wylie 1999), and MB is due to be phased out by the year 2005. It was further pointed out that currently there are no other viable chemical alternatives to PH_3 and even if manufacturers knew of a viable alternative, it would be five years or more before it could be on the market.

In pesticide evaluation, fumigant effectiveness is only one of the factors to be considered, and cost is no less important in this respect. Guided by this premise, this project was undertaken to test other phosphine-based formulations that could answer the above-cited concerns in the utilization of SEFUST.

MATERIALS AND METHODS

Experimental Design

The statistical design used for this project was the Two by Two Factorial Experiment in Randomized Complete Block Design (RCBD). The experimental stock consisted of 6 stacks of milled rice subjected to 2 main treatments using the fumigant formulations Quickphos and Phostoxin, both aluminum phosphide - based fumigants. Three untreated stacks served as controls. Each stack consisted of 6,000 bags totaling 300 tonnes. All stacks fumigated with Quickphos and Phostoxin, as well as control stacks, were opened after 6 months of storage.

Preliminary disinfestation of the warehouse

Prior to construction of the stacks, the warehouse, as well as the pallets were disinfested using residual sprays of permethrin at dosage and application rate recommended by the NFA. This measure was to prevent cross infestation of pests during the period when the trial stacks were being built.

Sampling for quality assessment

Before the stacks were covered, rice samples were withdrawn from the top portion and peripheries of the trial stacks, and these were examined for quality assessment. For improved accuracy, the rice bags where initial samples were taken were marked, and these same bags also served for sampling the stacks at the end of storage.

Preparation and installation of SEFUST materials

Initially, the materials and apparatus required for the SEFUST procedure were checked and prepared. Floor-sheets were laid down before the stacks were built. Also, the four corners of the experimental stacks (pallets) were lined with mats to avoid damage to the cover sheets during the pressure-decay test. During construction of each stack, gas-sampling lines of plastic tubing were installed in the top and bottom regions. Afterwards, the completed stack was covered with a plastic sheet. The sheets were then sealed together by gluing the cover sheet to the floor sheet using a solvent sealant. At the same time all holes in the liner were sealed using a mastic gun containing silicon sealant. The exposed ends of the gas sampling lines were also temporarily sealed. In order to check and ensure gas tightness of the enclosure, a pressure-decay test was conducted using an industrial vacuum cleaner attached to the gas port that sucked air from the enclosure until a negative pressure of 500 Pa was created. After ensuring that all the holes/leaks have been sealed, it was ascertained that the decay of pressure over time did not exceed 250 Pa or 2.5 cm of H_2O within 5 min thus ensuring an efficient tightness of the enclosure.

Fumigant application

Following the pressure test, the two fumigant formulations were applied using the recommended standard rate of 1 tablet/tonne. The Standard Operating Procedure (SOP) on SEFUST was observed throughout the whole operation.

Assessment of data gathered

Quality assessment of milled rice: The representative samples of milled rice from the experimental stacks were withdrawn at the start and at the end of the 6-month observation period. Quality was assessed using the following parameters: % damaged grains, % discolored kernels, % moisture content (m.c.), rice kernel whiteness and insect-bored kernels. Also, the presence of stored-product pests was assessed by visual observations and from samples gathered from the experimental stacks. The insects were identified down to species, and numbers of live and dead individuals were counted. Kernel whiteness was assessed using the KETT digital whiteness meter for rice (Model C-300-3) based on the principle of reflective index of the sampled surface.

Gas concentration monitoring: Gas concentrations were monitored on the 1st, 4th, and 7th day of fumigation. To monitor gas concentration, the sealant was first removed from the exposed end of the gas-line and this was then connected to a Dräger pump to which was attached a graduated phosphine indicator tube. When PH_3 is drawn through the pump the PH_3 concentration in ppm inside the stack is indicated by a color reaction, which takes place in the column of gas sensitive material packed inside the tube.

Cost benefit assessment

The total cost of storing bagged grains of milled rice under SEFUST was evaluated for the two aluminum phosphide-based formulations. The net costs of each fumigant formulation were determined and compared over a six-month observation period.

RESULTS AND DISCUSSION

Technical Analysis

Percent of damaged grains: Damaged grains of milled rice are defined as grains, whole or broken, which are distinctly damaged by insects, water, fungi, and/or any other means as based on the National Grades and Standards for Rice and Corn of the Philippines (Anon. 1997). Table 1 shows the results of grain damage for the initial and final samples gathered from the stacks. The Table shows that there were increments in damaged grains after 6 months of storage under SEFUST for the stacks treated by both fumigant formulations. When the percent change in damaged grains was further subjected to Analysis of Variance (ANOVA) to find out if differences in sampling points were significant, the results revealed no significance for all sources of variation considered.

TABLE 1
Mean percent of damaged rice grains before and after six months storage under SEFUST

Quality parameter	Sampling points	Fumigant			
		Quickphos		Phostoxin	
		Initial	Final	Initial	Final
Damaged grains	Top	2.56	3.09	1.71	2.04
	Peripheries	1.84	2.37	2.09	3.05

Percent of discolored grains: Table 2 shows the mean percent change in discolored grains after six months of storage. The Table appears to indicate that there were actual decrements in percentages of discolored grains at the sampling points except for one of the Phostoxin treatments, where the final peripheral samples gathered, showed an increase in discolored grains. Nevertheless, when these findings were subjected to ANOVA, results revealed that there were no significant increments or decrements in discolored rice grains, with the conclusion that SEFUST and the fumigations did not significantly affect this quality parameter.

TABLE 2
Mean percent of discolored rice grains before and after six months storage under SEFUST

Quality parameter	Sampling points	Fumigant			
		Quickphos		Phostoxin	
		Initial	Final	Initial	Final
% discolored grains	Top	1.76	1.33	1.65	0.68
	Peripheries	1.48	1.16	0.99	1.2

Percent moisture content: The initial mean m.c. of the experimental milled rice was 12.3% and well within the recommended m.c. for storage. Increments in m.c. of commodities stored under SEFUST have been commonly observed in previous studies and this project was no exception. Results showed that the milled rice exposed to the two fumigant formulations and sampled both at the top and peripheral portions of the stacks all exhibited a perceptible increase in m.c. after six months of storage as shown in Table 3. It was further revealed by ANOVA analysis that these were highly significant increments. A paper by Sukardi *et al.,* (1984) reported a significant increase in m.c. caused by condensation inside the enclosure that also occurred in the phosphine-treated stack of their experimental study. Furthermore, in another study, Muda *et al.,* (1987) found that rice after 3 months storage showed a significant increase in m.c. Whether this moisture condensed from the air or was desorbed from the rice was not revealed, though they did mention that perhaps it can be attributed to moisture desorption, their argument being based on the recorded m.c. of the rice before and after storage and the equally significant weight loss in the assessed bulk density of the rice. In our findings, Table 3 shows that there were considerable increments in m.c. at the two sampling points. The ANOVA results revealed that the changes in m.c. at the top region of the stack were significantly higher than the changes in m.c. at the periphery. This can be attributed to the fact that the top of the stack is close to the roof of the warehouse and it was precisely that part of the warehouse where the maximum fluctuations in temperature were experienced. Therefore, during this prolonged storage period, condensation within the enclosures occurred more at the top due to the above mentioned reason, and as a result of moisture migration, the rice grains readily absorbed the condensed water. It is also worth noting a statement by Delmenico (1989), that one of the primary factors influencing the rate of moisture migration is the presence of temperature gradients during storage. This is pertinent, since the experimental period covered the two climatic seasons experienced in this country.

TABLE 3

Mean moisture contents before and after 6 months storage under SEFUST

Quality parameter	Sampling points	Fumigant			
		Quickphos		Phostoxin	
		Initial	Final	Initial	Final
Moisture content	Top	12.10	12.80	12.17	12.67
	Peripheries	12.53	12.80	12.67	12.77

Rice kernel whiteness: Results of the final samples gathered after 6 months of storage (Table 4) revealed that there were increments in kernel whiteness in those at the top portion of the stacks compared to the ones at the peripheries, which showed a decrease in whiteness. However, when these differences were subjected to ANOVA analysis these differences were found to be insignificant. Also, consideration of the other factors involved namely, treatment and fumigant formulation, and the interaction between the two, also revealed insignificant results indicating that these factors did not affect the overall physical appearance of the rice kernels. This result has some parallel with the study by Muda *et al.,* (1987) on the sealed storage of milled rice using carbon dioxide, where it was stated that the CO_2 treatment did not cause significant changes in grain color in terms of whiteness using the same storage system as that used here.

TABLE 4

Mean values for rice kernel whiteness before and after 6 months storage under SEFUST

Quality parameter	Sampling points	Fumigant			
		Quickphos		Phostoxin	
		Initial	Final	Initial	Final
Kernel whiteness	Top	52.43	52.57	51.40	51.47
	Peripheries	53.03	52.80	52.80	52.63

Insect - bored kernels: The effectiveness of the treatment can also be measured in terms of the visible damage inflicted by insects on the rice kernels. Such damage manifested by insect-bored kernels is shown in Table 5, where it can be seen that regardless of the fumigant formulations and the sampling points, there were increments in the number of insect-bored kernels after a six-month storage period. However, again, when the data were subjected to ANOVA, it was found that these increments were not significant for all the factors considered. (This signifies that the effectiveness of the two aluminum phosphide based fumigants, Quickphos and Phostoxin, was further enhanced by the well-sealed enclosure, thereby, arresting the development of insects further inside the sealed stacks thus, maintaining the quality of the milled rice).

TABLE 5

Mean numbers of insect bored kernels before and after 6 months storage under SEFUST

Quality parameter	Sampling points	Fumigant			
		Quickphos		Phostoxin	
		Initial	Final	Initial	Final
Insect Bored Kernels	Top	5	12	4	11
	Peripheries	6	11	6	11

Phosphine gas concentration

A comparison between the two fumigant formulations applied at the same dosage rates, showed that the Phostoxin formulation gave the fastest generation of gas on the first day with 300 and 200 ppm for the top and bottom sampling points respectively (Table 6). This may be compared with the gas generated by Quickphos on the same day for which, only 33 and 42 ppm were recorded from the same sampling points. Moreover, on the seventh day, Phostoxin again registered the highest concentrations at 900 and 808 ppm as compared with Quickphos at 677 and 683 ppm for the top and bottom sampling points. Similar observations were reported by NFA researchers Donceras *et al.* (1992), and Andrada *et al.* (1999) on these fumigants using the conventional fumigation procedure. Also, it is important to mention that the enclosures were indeed gas-tight as evidenced by the recorded gas concentrations, which for both fumigant formulations were way above the minimum requirement of 100 ppm for 7 days exposure.

The ANOVA statistics carried out on these results indicate that the difference between the two fumigant formulations was highly significant at the 1% level in terms of release of gas. The higher gas concentrations generated by Phostoxin as compared to Quickphos both for the top and bottom sampling points are illustrated in Fig. 1. The increase in PH_3 concentration of the two commercial formulations over the seven-day exposure period is shown in Fig. 2. Statistical analysis using Duncan's multiple range test revealed that on the 7th day gas generation from Phostoxin was not significantly different from the gas generated by Quickphos, even though for the first day and the 4th day gas evolution from the Quickphos formulation was significantly lower. This may be due to the fact that the two formulations have different inherent behavior in their release of PH_3 in relation to time.

TABLE 6
Phosphine gas concentration generation for Quickphos and Phostoxin

Fumigant	Sampling Point	Monitoring Time (days)	Mean (ppm)
Quickphos	Top	1	33
		4	400
		7	677
	Bottom	1	42
		4	350
		7	683
Phostoxin	Top	1	300
		4	850
		7	900
	Bottom	1	200
		4	833
		7	808

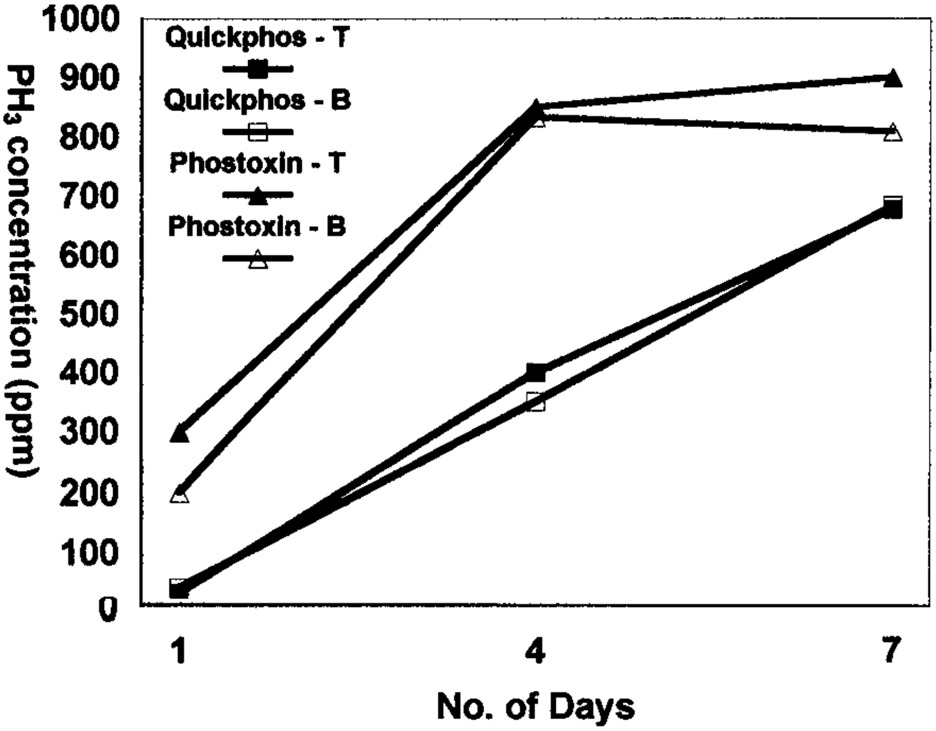

Fig. 1. Phosphine concentrations during fumigation with Quickphos and Phostoxin under SEFUST

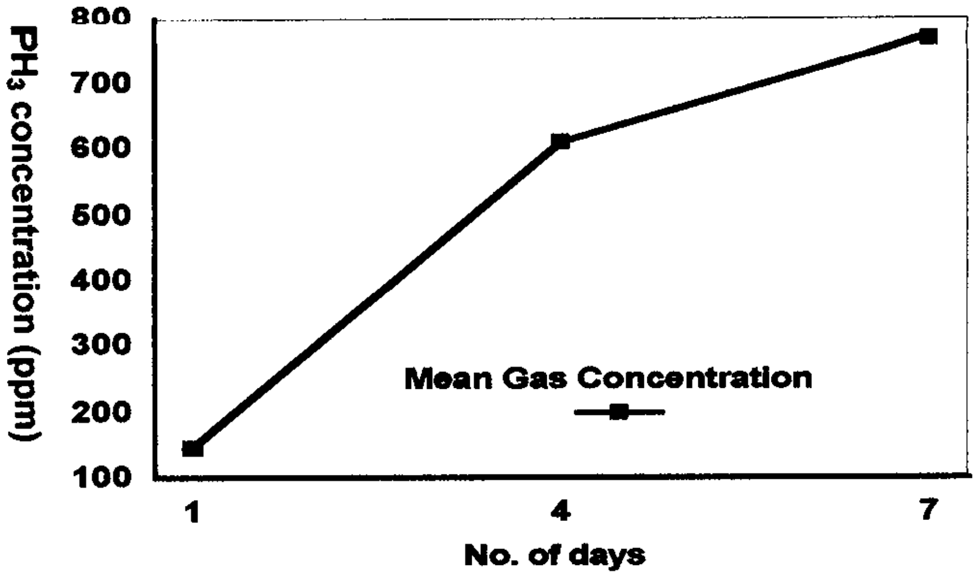

Fig. 2. Peak phosphine concentration regardless of brand of fumigant under SEFUST

Other observations

In the visual inspections and analyses of the stored-product pests present on the experimental stacks and samples, the number of insects found were insufficient to cause severe damage except in Stack 4 treated with Quickphos. Large numbers of live saw-toothed grain beetle adults (*Oryzaephilus surinamensis*) were found in the peripheral regions of the stack. Some individuals were hiding in the seams of bags. They were distributed over the surface of the stack particularly in the lower portion and in one of the four corners. This observation, led to a consideration of the relative orientation of the stacks inside the warehouse. Stack 4 under Quickphos treatment was located nearest to the door leading to another warehouse that could possibly have been the source of cross infestation. Entrance into the stacks could have been via the junction between the over-liner and floor liner. This glued junction may have weakened over time enabling entry of the pests. Immature and adult psocids were found in replicates 2 and 3 of Quickphos (20++). It is also worth noting that based on the visual inspection conducted after the stacks were opened, a few live spiders and ants were found at the periphery of the stacks, beneath the pallets, or on the floor sheeting respectively. This only serves to emphasize the need for a high standard of maintenance on hygiene and sanitation as well as the need to conduct routine inspection of the plastic enclosures in order to take maximum advantage of the fumigations and the technology in general.

Cost Analysis

The total operating cost of using Quickphos for one stack of milled rice (approximately 6,000 bags of 50 kg) for six months of storage was found to be cheaper at PhP 37,924 (US$ 1≈ PhP 50) compared to Phostoxin at PhP 38,095. Likewise, when the cost of application per tonne was determined, Quickphos was still cheaper by PhP 0.57/tonne over Phostoxin. For the detailed assumption and cost computation see Table 7.

TABLE 7

Comparative cost analysis of aluminum phosphide based fumigants Quickphos and Phostoxin under SEFUST over a 6 month period

Item	QUICKPHOS	PHOSTOXIN
I. Direct Cost*		
A. Fixed Cost		
1. Depreciation	16,650.00	16,650.00
2. Repair/Maintenance	6,960.00	6,960.00
Sub-Total	23,610.00	23,610.00
B. Variable Cost		
1. Cost of Chemicals**	1,431.00	1,602.00
2. Labor Cost	1,323.40	1,323.40
3. Supplies and Material	5,560.00	5,560.00
4. Handling Cost	6,000.00	6,000.00
Sub-Total	14,314.40	14,485.40
Total Operating Cost	PhP 37,924.40	PhP 38,095.40
Cost of Application/tonne	PhP 126.41	PhP 126.98

*Assumptions:

1. Volume of milled rice = 6,000 bags (300 tonnes)
2. Dimension of stack (meters): 11 x 7.32 x 5
3. Duration of storage: 6 months
4. Rate of Application: 1 tablet/MT
5. Set - up of stack (No. of days): 2
6. One set of cover material (floor & cover sheets) to serve 1 stack at a time

** Based on the costing report as of December 31, 1999 by the Pest control Section of the Quality Assurance Division (QAD), TRDD.

CONCLUSION

The quality parameters of the milled rice (% damaged grains, % discolored grains, rice kernel whiteness, and insect-bored kernels) were found to be maintained during storage and were not significantly affected by the SEFUST technology, with initial PH_3 fumigation.

There was a significant increase in m.c. of the rice stored under SEFUST technology after 6 months of storage, the m.c. at the top portion of the stack being significantly higher than at the periphery.

It was concluded that for storage of milled rice under the SEFUST technology, the cost of fumigation per tonne for Quickphos was cheaper by PhP 0.57 compared to Phostoxin.

RECOMMENDATION

Based on the findings of the study, it is therefore recommended that Quickphos be used as an alternative fumigant formulation for the SEFUST technology in the

NFA food protection storage system of operation. Also it is considered most important to employ a high standard of hygiene and sanitation, plus a strict routine inspection be conducted by our field pest control applicators in order to ensure optimum benefit from the technology and the application of chemical fumigants.

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