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PHOSPHINE FUMIGATION OF BAGGED AND BULK PADDY IN SOUTHERN CHINA USING CONVENTIONAL AND SLOW RELEASE APPLICATION

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ABSTRACT

Phosphine fumigations of paddy rice in bagged-stacks and in bulk were undertaken at Xinzhao Panyu State Grain Depot, Guangzhou, China in 2002. Our aim was to develop and verify national standards for sheeted fumigations. Both the bulk and bagged paddy were stored protected from the weather in concrete warehouses and were sheeted on the bottom, top and four sides with clear polyvinyl chloride (PVC). Sheets were heat-sealed together and sealed to the floor by rubber tubes and plastics grooves. 7g m^{-3} AlP (producing 2.3 g m^{-3} PH_3) was applied to each storage by conventional application of tablets in plastics bags with a slow release technique. Twelve cages of mixed age cultures of resistant insect strains were placed into each fumigation. Insects used in the trials, included *Rhyzopertha dominica*, *Sitophilus oryzae, Tribolium castaneum, Oryzaephilus surinamensis* and *Cryptolestes ferrugineus.* Insects were removed from the fumigations at 14 days and 28 days. Mixed age cultures of resistant insects were completely controlled. In the bulk paddy warehouse, concentrations of phosphine remained above 375 ppm for the first 14 days. Use of conventional fumigation plus the slow release technique was successful in prolonging the period of effective concentration of phosphine sufficient to control all known resistant strains.

INTRODUCTION

Due to the combined advantages of low cost, ease of use and acceptance as a residue-free treatment, phosphine will remain the central component of insect pest management for the foreseeable future in the world (Taylor, 1989; Liang, 1989, 1994). However, the resistance in target pests threatens the continued viability of this fumigant (Champ *et al.*, 1976; Liang *et al.*, 1976, 1993; Tyler, *et al.*, 1983; Taylor, *et al.*, 1986, 1994; Zettler, *et al.*, 1989; Li, *et al.*, 1993,1994; Zeng, 1996). To protect and enhance the utility of phosphine as a fumigant for grain and to more fully integrate it into pest management in grain storage systems, there is a need to formulate national fumigation standards and to improve fumigation practice.

China is one of the world's largest producers of grain with a total production of about 495 Mt (million tonnes) per year. Phosphine as a fumigant controlling stored grain insects has been used for more than 40 years in China. Over 90% of the grain is fumigated with this fumigant. With a climate of high temperature and high humidity, the stored grain insects occur more seriously in Southern China than in other parts of China. Generally, the stored grain practices involve fumigation 3-4 times a year with 4-5 g/m^3 aluminium phosphide by slow release, or even employ 10 g/m^3 aluminium phosphide for 1-2 times a year in Southern China. Because of the continuous intensive use of phosphine over a long period, the frequency of occurrence of resistant strains has increased and resistance levels are becoming higher and higher. In addition to resistance, several other factors such as poor sealing, non-uniform distribution of phosphine, improper control of dosage and too short exposure times, contribute to control failures with phosphine (Zeng, 1998).

Using the experience and research results both in China and abroad, (Price *et al.*, 1988; White *et al.*, 1990; Winks *et al*, 1997; Collins, 1998; Daglish *et al.*, 1998; Collins *et al.*, 2002; Cao *et al*, 2003; Wang, 2003), and taking into consideration the situation of grain storage in Guangdong province, phosphine fumigations of paddy rice in bag-stacks and in bulk were undertaken at Xinzhao Panyu State Grain Depot, Guangzhou, China in 2002. The aim was to develop and verify national standards for sheeted fumigations and to improve fumigation practice.

MATERIALS AND METHODS

Warehouse

Two typical Guangdong grain warehouses were used in the trial. They had concrete board roofs or tile roofs, many windows and numerous columns inside, and were equipped with aeration fans. One warehouse contained bagged-stacks of paddy rice, the other held paddy rice in bulk.. The inside views of the two warehouses were as shown in Pictures 1 and 2.

Dimensions of the warehouse holding bagged-stacks were approximately 25.6 m L x 17.5m W x 5.5m H with a volume of 2464 m^3. The height of the stacks was 5.2~5.5 m, and total weight was 1141 t. Dimensions of the bulk warehouse were approximately 50.0 m L x 19.6 m W x 5.0m H with a volume of 4900 m^3. The height of the grain bulk reached 4.1~4.5 m, and weighed 2326 t.

Grain

Grain used for the trials was paddy rice.

Paddy rice in the bag-stacked warehouse was produced in Hunang Province, China, had been in storage since April 2002. The moisture content was 12.8%. The initial density of insects at the time of the trials were 2 *Rhyzopertha dominica and 9 Sitophilus oryzae* per kg grain.

Paddy rice in the bulk stored warehouse was produced in Jiangxi Province, China, had been in storage since March 2002. The moisture content was 13.2%. The initial density of insects at the time of the trials 8 *Rhyzopertha dominica* and 6 *Cryptolestes ferrugineus* per kg grain.

The grain temperature during the trial was tested at several points inside the grain mass using an electronic system of temperature monitors.

Sealing

Both the bulk and bagged paddy stored in the warehouses were sheeted on the bottom, top and four sides with clear 140 μm polyvinyl chloride (PVC) sheets. Sheets were heat-sealed together and sealed to the wall by rubber tubes and plastic grooves. The objective of this is to greatly minimise if not prevent phosphine gas from leaking out of the warehouse and from ambient air entry into the warehouse. Any phosphine gas leak or air entry will dilute the concentration of phosphine inside the warehouse and will eventually lead to pest survival, particularly of the eggs and the pupae, thus resulting in a fumigation failure.

Pressure testing

Before the sealed warehouses in PVC sheets can be used for fumigation, they have to undergo pressure testing and achieve a pressure decay half life of at least 5 min (e.g. 500 Pa to 250 Pa in 5 min or more). The practical way is to use a heavy-duty vacuum cleaner that is connected to a sealed pipe to create a vacuum pressure of about 500 Pa. An U-tube manometer capable of reading up to 4 inches of water (1000 Pa) should be attached to the accessible part of the PVC sheets, as shown in Picture 3.

Insects

Insects used for the trials were as follows:

Rice weevil (*Sitophilus oryzae*), Maize weevil (*Sitophilus zeamais*), Lesser grain borer (*Rhyzopertha dominica*), Red flour Beetle (*Tribolium castaneum*), and the Rusty grain beetle (*Cryptolestes ferrugineus*.

Twelve strains of test-insects, comprising the above 5 species, were supplied by Zhengzhou Grains College (ZZGC), Chengdu Grain Storage Research Institute (CGSRI) and Guangdong Institute for Cereal Science Research (GICSR). With five test insect species for each warehouse, the insect cages with feed mixture were inserted at different locations at different depths below the grain surface. All tested insects were mixed-aged and mixed-resistance. Mortality was assessed after 14 days and 28 days exposure for each warehouse.

Phosphine

Conventional application of tablets in plastics bags with a slow release technique, 7 g/m^3 aluminium phosphide 56% tablets were applied to each warehouse.

In the bag-stacked warehouse, all tablets were put in 30 µm plastic sheet bags with a slow release technique. In the bulk warehouse, a dosage of 4.2 g/m^3 aluminium phosphide tablets was applied by conventional application in cotton-cloth bags; the rest consisting of 2.8 g/m^3 tablets were packaged in 30 µm plastic sheet-bags with a slow release technique.

Concentration monitoring

For monitoring the phosphine concentration, 3 to 5 special plastic tubes with about 1.5 cm internal diameter were inserted into the grain mass at different depths and locations for each warehouse. The phosphine concentrations during the trial were monitored daily at the several points inside the grain mass and in the aeration ducts using a Bedfont EC80 phosphine monitor.

RESULTS AND DISCUSSION

The trials were undertaken at the Xinzhao Panyu State Grain Depot, Guangzhou, China from April to September, 2002. During the trials, the temperature of the grain mass was 21.8~33.3°C. The changes of phosphine concentration in early months are given in Figure 1.

In the bag-stacked warehouse, the phosphine concentration rose slowly, since all tablets were put in 30 µm plastics sheet bags with a slow release technique. From the 5^{th} day after application of aluminium phosphide, the phosphine concentration had reached over 100 ppm where it remained for about a month, the peak concentration being 334 ppm.

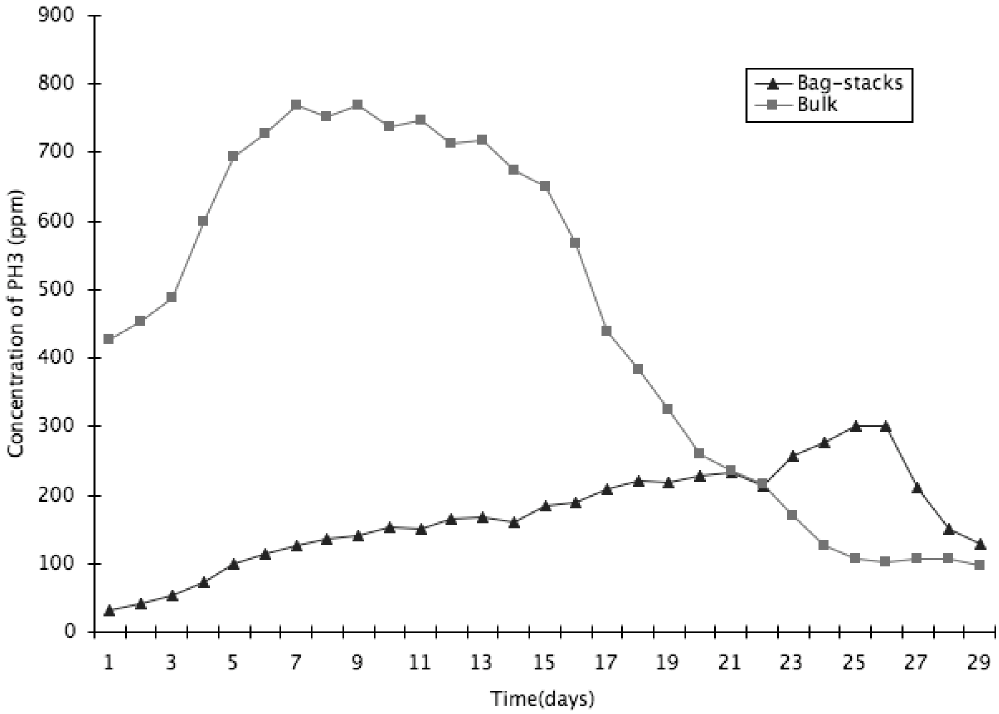

Figure 1. Concentrationn of phosphine (ppm) in the grain bulks over 29 days fumigation

In the bulk warehouse, the phosphine concentration rose more quickly than in the bagged stacks since a dosage of 4.2 g/m^3 aluminium phosphide tablets was applied by conventional application of cotton cloth bags, while the rest at a dosage of 2.8 g/m^3 in tablets was packaged in 30 μm plastic sheet bags with a slow release technique. In the first month after application of aluminium phosphide, the peak phosphine concentration was over 987 ppm, and the phosphine concentration remained at over 300 ppm for 14days.

The bio-assays of tested insects was assessed after 14days and 28 days exposure for each warehouse. The resistance factors of the test-insects used in the trials are shown in Table 1. Insects in all cages were killed, and no live insects were detected in the grain mass for at least five months.

TABLE 1
The resistance levels of the test-insects

Species	Strain	Resistance factors (FAO method)
Sitophilus oryzae	LS2	0.0088
	CDSO	183
	GDSO	148
Sitophilus zeamais	GDHz	0.0058
Rhyzopertha dominica	QQ14	0.0042
	CDRD	184
	RD7	327
	RD15	186.7
Tribolium castaneum	CDTC	8
	XIEJI	212
	QIHE	449
Cryptolestes ferrugineus	CF20	73.9

Before the sealed warehouse could be used for fumigation, the pressure testing was done in the bagged warehouse. Because of the large grain mass, the use of a heavy-duty vacuum cleaner was not sufficient to create a vacuum pressure of about 500 Pa and we were able to achieve a pressure decay half-life of 84.5 s from 120 Pa to 60 Pa in duplicate testing. We regarded this as a good level of sealing. The pressure testing was not done in bulk warehouse, because the grain mass was too large. However, on the basis of practical experience, the sealing in the bulk warehouse would be better than in the bag-stacked warehouse.

CONCLUSIONS

Both the bulk and bagged paddy, sheeted on the bottom, top and four sides with 140 μm PVC film supplied a good sealing condition for fumigation. Phosphine fumigations using a total dose of 7 g m^{-3} AlP by conventional application with a slow release technique completely controlled all known resistant insects and by successfully prolonging the period of effective concentration of phosphine, the grain remained for at least 5 months with no reinfestation,. This method could be recommended for grain storage practice in Southern China.

Picture 1. Inside view of the bag-stacked warehouse

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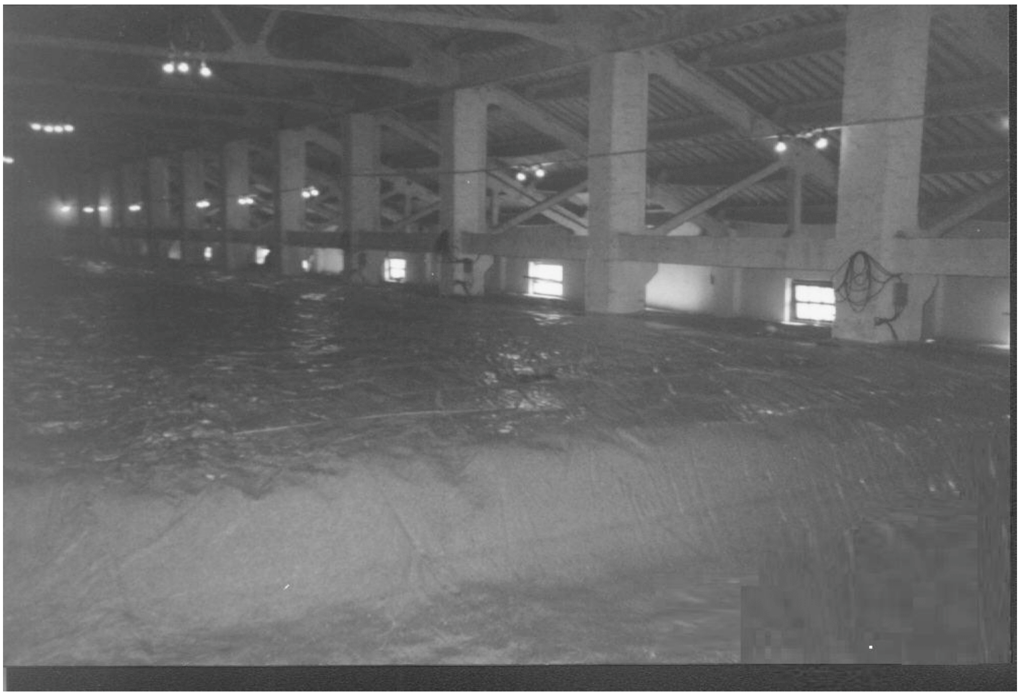
Picture 2. Inside view of the bulk warehouse



Picture 3. Pressure testing

Champ, B.R., and Dyte, C.E. (1976) Report on the FAO global survey of pesticide susceptibility of stored grain pests. FAO Plant Protection and Production Services No. 5, FAO Rome, 1976, P297.

Collins, P. J. (1998) Resistance to grain protectants and fumigants in insect pests of stored products in Australia. In: *Proceedings of the Australian Postharvest Technical Conference*, (Edited by: H. J. Banks, E. J. Wright and K. A. Damcevski). 26-29 May 1998, Canberra, Australia. P 43-45.

Collins, P.J., Daglish G.J., Bengston M., Lambkin T.M. and Pavic H. (2002) Genetics of resistance to phosphine in *Rhyzopertha dominica* H. (F.) (Coleoptera: Bostrichidae). *Journal of Economic Entomolgy*, **95**, 862-868.

Daglish, G. J. and Collins, P. J. (1998) Improving the relevance of assays for phosphine resistance. *In*: *Proceedings of the 7th International Working Conference on Stored-Product Protection.* P584-593.

Price, L.A. and Mills, K.A. (1988) The toxicity of phosphine to the immature stages of resistant and susceptible strains of some common stored product beetles and implications for their control. *Journal of Stored Products Research* **24,** 51–59.

Liang, Q. *et al.* (1976) Resistance to phosphine in four major species of stored grain pests in Guangdong, China. Sichuan Liangyou Keji 4,1-11 (in Chinese).

Liang, Q. (1989) The current status of fumigation and controlled atmosphere storage technologies in China. *Proceedings of an International Conference on Fumigation and Controlled Atmosphere Storage of Grain*, P162-173.

Liang, Q., Wu Z. and Zeng L.. (1993) Survey of resistance to phosphine in stored grain pests in Guangdong province. *Proceedings of the 3rd academic exchanges, Storage Specialty Branch of Chinese Cereals and Oils Association*, Chengdu, China, 220-225.

Liang, Q. (1994) Meet the challenge of insect resistance to phosphine. *Grain Storage* **23(4),** 3-9.

Li, Y. (1993) The phosphine resistance of stored grain pests and control countermeasures. *Proceedings of the 3rd academic exchanges, Storage Specialty Branch of Chinese Cereals and Oils Association*, Chengdu , China, 400-408.

Li Y. and Li W. (1994) Inheritance of phosphine resistance in *Sitophilus oryzae* (L.) Coleoptera: Curculionidae. *Proceedings of the Sixth International Working Conference on Stored-Product Protection.* **1,** 113-115.

Taylor, R.W.D. and Halliday, D. (1986) The geographical spread of resistance to phosphine by coleopterous pests of stored products. *Proceedings of the British Crop Protection Conference, Pests and Diseases*, 607–613.

Taylor, R.W.D. (1989) Phosphine --- a major grain fumigation at risk. *International Pest Control* **31,** 10-114.

Taylor, R.W.D. and Harris, A.H. (1994) The fumigation of bag-stacks with phosphine under gas-proof sheeting using techniques to avoid the development of insect resistance. *Proceedings of the 6th International Working Conference on Stored-Product Protection.* **1,** 210-213.

Tyler, P.S., Taylor, R.W., and Rees, D.P. (1983) Insect resistance to phosphine fumigation in food warehouses in Bangladesh. *International Pest Control***.** **25**: 10-13.

Wang D. (2003) The technical expectation on phosphine recirculation fumigation. *Grain Storage* **32(2),** 29-32.

White, G.G. and Lambkin, T.A. (1990) Baseline responses to phosphine and resistance status of stored-grain beetle pests in Queensland, Australia. *Journal of Economic. Entomolgy.* **83,** 1738-1744.

Winks, R.G., and Hyne, E.A. (1996) The use of mixed-age cultures in the measurement of response to phosphine. *Proceedings of an International Conference on Controlled Atmosphere and Fumigation in Stored-products*, 3-15.

Zeng, L. (1996) The advance of phosphine resistance in stored grain insects. *Natural Enemies of Insects* **18, 4,** 37-42.

Zeng, L (1998) Development and countermeasures of phosphine resistance in stored grain insects in Guangdong Province, China. *In. Proceedings 7th International Working Conference on Stored-product Protection.*

Zettler, J.L., Halliday, W.R. and Arthur, F.H. (1989) Phosphine resistance in insects infesting stored peanuts in the Southeastern United States. *Journal of Economic. Entomolgy.* **82,** 1508-1511.