The fumigation of bag-stacks with phosphine under gas-proof sheets using techniques to avoid the development of insect resistance

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Abstract

The development of insect resistance to phosphine has been an increasing concern for the last decade. Until recently, it has been commonly assumed that, if resistance reached a level which made phosphine unusable, methyl bromide could, in many situations, be employed as an alternative. The listing of methyl bromide in 1992 as a depleter of ozone, suggests that this chemical may, eventually, be phased out for all but essential uses. With no other fumigants available, or likely to be introduced in the near future, the continued effectiveness of phosphine must now be considered imperative, and strategies introduced to avoid insect resistance.

The fumigation of bag-stacks, a common practice in developing countries, is often poorly carried out, leading to sub-lethal exposures to phosphine and potential insect resistance. Improvements in the methods employed, to ensure control of all stages of insect development, can be an important strategy in combating resistance. Trials with a technique of good quality fumigation of bag-stacks, under sheets, with particular attention paid to effective sealing at the floor level, demonstrated that 50% of the phosphine applied could be retained in stacks for at least five days. The introduction of routine fumigations of this standard could greatly assist in keeping the development of insect resistance to a minimum.

Introduction

In the last decade increasing concern has been expressed about the development of insect resistance to phosphine (Taylor 1989; Tyler et al. 1983; Winks 1986), and reports of several surveys of resistance have been published (Herron 1990; Sartori et al. 1990; Taylor 1989; White and Lambkin 1990; Zettler 1994). The recognition in 1992 (Watson et al. 1992) that methyl bromide could be an important contributor to depletion of the ozone layer has cast doubts on that chemical's continued availability as a fumigant. With no practical alternatives immediately available, the continued effectiveness of phosphine must now be regarded as imperative. The magnitude of phosphine resistance has generally been found to be greatest in developing countries, where standards of fumigation are often unsatisfactory and insects may be repeatedly exposed to low concentrations of fumigant (Mills 1983).

One of the commonest types of commodity fumigation in developing countries is the treatment of bag-stacks under gas-proof sheets and although, for such treatments, the original recommendation by phosphine manufacturers was a 72-hour exposure period, the advent of resistance has caused 5–7 day exposures to become standard practice in many countries. Winks (1987) has described increased exposure periods as the key to controlling phosphine-resistant insects, and has suggested that exposure periods of 10 days may be necessary in some circumstances. The effective disinfestation of bag-stacks depends not only on using fumigation sheeting materials that are relatively impermeable to phosphine, but particularly on the adequate sealing of sheets, at floor level and where they are joined, to prevent gas leakage. The extension of fumigation exposures beyond the original 72-hour period will be of little value in some developing countries where, because of leakage due to poor sealing, a lethal concentration cannot be maintained. The routine adoption of well-sealed enclosures for fumigation must be regarded as critical in management strategies for phosphine resistance.

Authors differ about the recommended minimum lethal phosphine concentration to be used for the fumigation of stored commodities. Friendship et al. (1986) suggest that for a fumigation to be considered satisfactory a minimum concentration of 0.2 mg/l (ca 150 ppm) phosphine should remain in the enclosure treated after five days. Van Graver and Annis (1994) recommend that a minimum phosphine concentration of 100 ppm be maintained for 7 days in well-conducted fumigations. monitoring of phosphine fumigations in developing countries has shown that gas retention in sheeted-stack fumigations frequently fails to meet either of the above recommendations. Figure 1 provides examples of phosphine gas retention in two fumigations of milled rice under sheets in Southeast Asia, and these are probably not atypical of many fumigations carried out in developing countries. Both treatments would probably fail the recommended regimes of gas retention indicated above.

Methods for Improving the Fumigation of Sheeted Stacks

The need arose recently to verify that the important beetle pest of maize, *Prostephanus truncatus* (Horn), could be effectively controlled by phosphine in sheeted-stack treatments in Africa. The ability to achieve complete control of the pest was considered particularly important since a related species, *Rhyzopertha dominica* (Fabricius), was one of the first insects to show resistance to phosphine in the field (Tyler et al. 1983). Also, because of the potential need to fumigate grain in Africa at high altitudes where low ambient temperatures may result in low grain temperatures, it was necessary to include one such location in the fumigation trial program.

The experimental program was carried out during the cooler months of August and September at three locations in Tanzania. The aim was to improve techniques of bag- stack fumigation in order to ensure maximum gas retention and minimise the opportunities for the selection of insects for resistance to phosphine. Duplicate 100 t stacks of maize were constructed on wooden pallets over good quality concrete floors in strategic grain reserve stores in Arusha, Dodoma and

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Dar es Salaam, locations which have ambient average minimum temperatures during the cooler months, of 8, 11 and 18°C, respectively. During stack construction, nylon capillary tubes were placed near the top, middle, and bottom of stacks, in a vertical central line, to enable monitoring of phosphine concentrations during fumigation. A fourth sampling position was located peripherally, at floor level, beneath stacks, and a fifth was situated on the vertical stack surface midway between the base and the top of the stack. Temperature sensors, and insect cages containing all stages of *P. truncatus*, were located adjacent to all fumigant monitoring positions.

Laminated PVC sheets, having a supporting nylon scrim, and weighing approximately 360 g/m^2, were used in all fumigations. In laying the sheets, which were checked initially for holes or tears, particular care was taken to ensure that, where joins were necessary, overlapping of at least 1 m was provided at the sheet edges so that when these were folded together a gastight seal was formed. Considerable care was also taken to ensure that any grain spillage was removed before the fumigation sheet was positioned, and that there was a minimum of 1 m of sheet margin on the floor, around stacks, which was pulled tight to the corners to remove folds and channels through which fumigant could escape. To provide a good seal between the fumigation sheet and the floor, much larger sandsnakes were used to replace the narrow type commonly employed, which are often made from discarded fire hosepipe. The larger sandsnakes were fabricated locally from lightweight canvas and had a diameter of approximately 15 cm, which provided at least twice the weight and contact area on the fumigation sheet as those made from fire hosepipe. In order to ensure that good sealing to the floor was achieved, two sandsnakes were used at stack corners and where sheets were joined.

Aluminium phosphide tablets producing 1 g of fumigant were used in all fumigations, and were placed either on trays or in cotton bags (Arusha), on the ground beneath stacks. At Arusha, an application rate of 3 g phosphine/t was used where, although the ambient average daily minimum temperature was 12°C, a light insect infestation in some parts of stack resulted in a grain temperature varying from 22 to 26°C. At Dodoma and Dar es Salaam, a phosphine application rate of 2 g/t was used; there was little infestation in the maize stacks, with grain temperatures in the range 20–22°C and 25–26°C, respectively. The extent of gas retention in stacks and the effectiveness of insect control were determined for both 5 and 7-day exposure periods. Phosphine concentrations were monitored in stacks by withdrawing samples at intervals through the nylon capillary tubing using a 50 mL gastight syringe, for direct injection into a Bedfont EC80 phosphine meter.

Results and Discussion

The average phosphine concentrations recorded in stacks, at the three locations, are given in Figures 2–4. The pattern of fumigant distribution within stacks over the first 24 hours was not identical, but phosphine became very evenly distributed in all stacks after approximately 40 hours and remained so until the end of the treatment periods. The distribution of phosphine in two of the fumigations is shown in the accompanying Tables 1 and 2 and is typical of all six stacks treated. The tables record the concentrations of gas at the different sampling positions during a 7-day fumigation at Dodoma (Table 1), and a 5-day fumigation at Arusha (Table 2). At Dodoma, the phosphine concentration at the end of the fumigation was slightly below 1.4 mg/L, having fallen from a maximum value of 2.0 mg/L during the preceding 5 days. Gas retention in all the stacks fumigated was sufficient to suggest that leakage between the fumigation sheets and the floor was minimal. Most of the leakage that occurred was probably through the fumigation sheets since the average fall in phosphine concentration, 7%/day, corresponded approximately to the known permeability of the type of sheet used.

A comparison of the maximum fumigant concentrations attained with the expected theoretical maximum values in stack treatments indicates the extremely good phosphine retention that occurred during the trials in Tanzania. At Dodoma, where a phosphine application rate of 2 g/t was used, and assuming a stowage factor for maize of 1.5 m^3/t, the theoretical maximum gas concentration with no allowance made for the volume occupied by the grain would have been of the order of 1.3 mg/L. However, allowing for the volume occupied by the grain, a maximum theoretical phosphine concentration of 2.0 mg/L or more was expected. The maximum concentration recorded was a little over 2 mg/L, and well within the expected range. At Arusha, where the application rate was 3 g phosphine/t, the evolution of fumigant was slower and the maximum concentration was not reached until 80

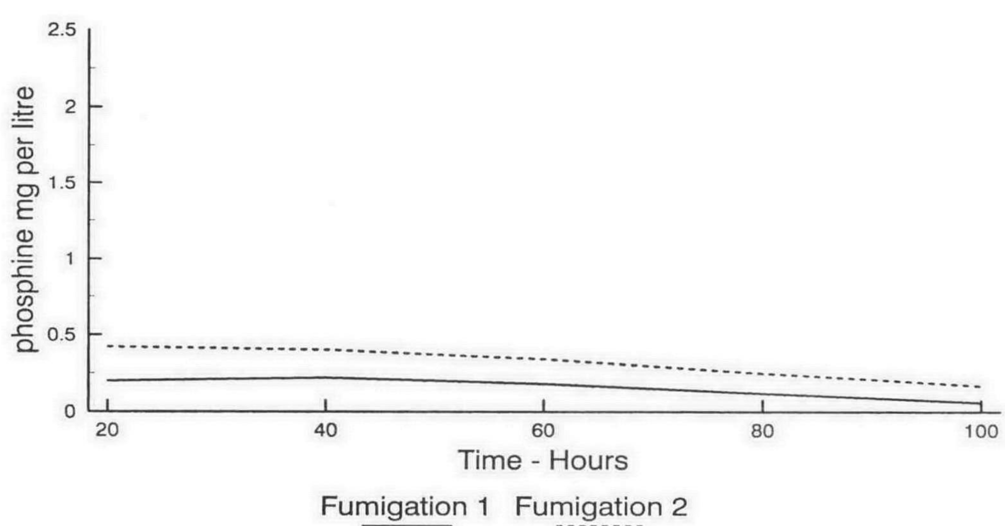

Fig. 1. Phosphine fumigations in Southeast Asia. The application rate is 2 g/ t of milled rice.

Table 1. Gas concentrations in mg/L recorded during a 7-day fumigation of maize at Dodoma, using phosphine applied at 2 g/t.

Sampling position	Time (hours)									
	18	25	42	49	66	74	90	114	138	162
Bottom centre stack	1.14	1.20	1.97	2.06	1.98	1.98	1.82	1.68	1.53	1.42
Middle centre stack	0.90	1.48	1.93	2.11	1.96	1.99	1.80	1.69	1.55	1.42
Top centre stack	1.30	1.54	2.02	2.11	1.95	2.01	1.83	1.69	1.57	1.45
Ground level under pallet	1.37	1.70	1.93	2.12	1.95	1.97	1.79	1.66	1.54	1.40
Stack surface midway – top of stack to floor	nd	1.88	2.05	2.17	1.99	2.01	1.84	1.70	1.58	1.46

nd= no data

Table 2. Gas concentrations in mg/L recorded during a 5-day fumigation of maize at Arusha, using phosphine applied at 3 g/t

Sampling position	Time (hours)								
	18	25	43	51	66	72	91	98	116
Bottom centre stack	0.70	1.03	1.66	1.83	2.15	2.29	2.33	2.40	2.33
Middle centre stack	0.67	0.99	1.65	1.86	2.15	2.29	2.33	2.40	2.33
Top centre stack	0.55	0.86	1.56	1.77	2.09	2.24	2.28	2.40	2.32
Ground level under pallet	0.67	1.01	1.64	1.88	2.17	2.39	2.34	2.40	2.33
Stack surface midway – top of stack to floor	0.75	1.09	1.64	1.91	2.18	2.37	2.34	2.40	2.35

hours. This may be attributed to the siting of the fumigant beneath the stack (in cotton bags) in direct contact with the concrete floor which was 1–2°C colder than the ambient store temperature, which fluctuated from 17 to 22°C. Retention of fumigant in stacks was particularly effective at Arusha, where only a small drop in phosphine concentration took place between the attainment of the maximum concentration and the end of the exposure period. All developmental stages of *P. truncatus* were effectively controlled in all the fumigations evaluated (Taylor and Harris 1994).

Using careful sheet placement and larger sandsnakes, the experimental program in Tanzania demonstrated that it is possible to retain at least 50% of the applied dose of phosphine in bag-stacks for 7 days or longer. This standard of fumigation was sufficiently good to suggest that, even at the lower ambient temperatures in Arusha (where grain stored for long periods might fall to 20°C), a phosphine application rate of 2 g/t would be expected to provide complete control of insect pests. Fumigations in which this level of gas retention is achieved should be attainable in routine practice at little extra cost, provided training and management inputs are properly applied. Monitoring of phosphine concentrations on a regular basis may, however, be necessary to ensure that gas retention is adequate in routine treatment programs. This measure would be fully justified as an aid to avoiding insect resistance to what could prove to be, in the future, the last remaining commodity fumigant.

References

Friendship, C.A.R., Halliday, D. and Harris, A.H. 1986. Factors causing development of resistance to phosphine by insect pests of stored produce. In: Howe, V., ed., GASGA Seminar on Fumigation Technology in Developing Countries, TDRI, Slough, England, March 1986, 141–149.

Herron, G.A. 1990. Resistance to grain protectants and phosphine in coleopterous pests of grain stored on farms in New South Wales. Journal of the Australian Entomological Society, 29, 183–189.

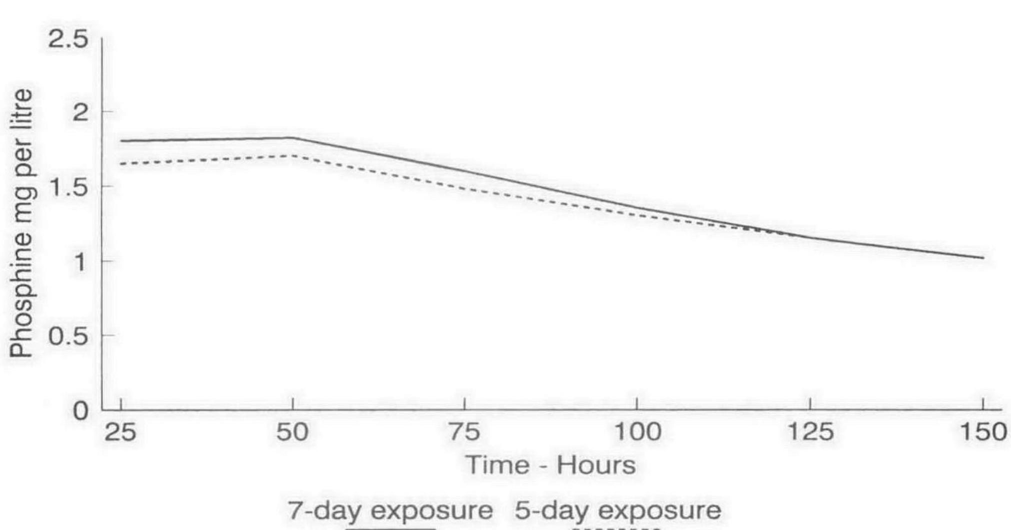

Fig. 2. Phosphine fumigation in Dar es Salaam. The application rate is 2 g/t of maize.

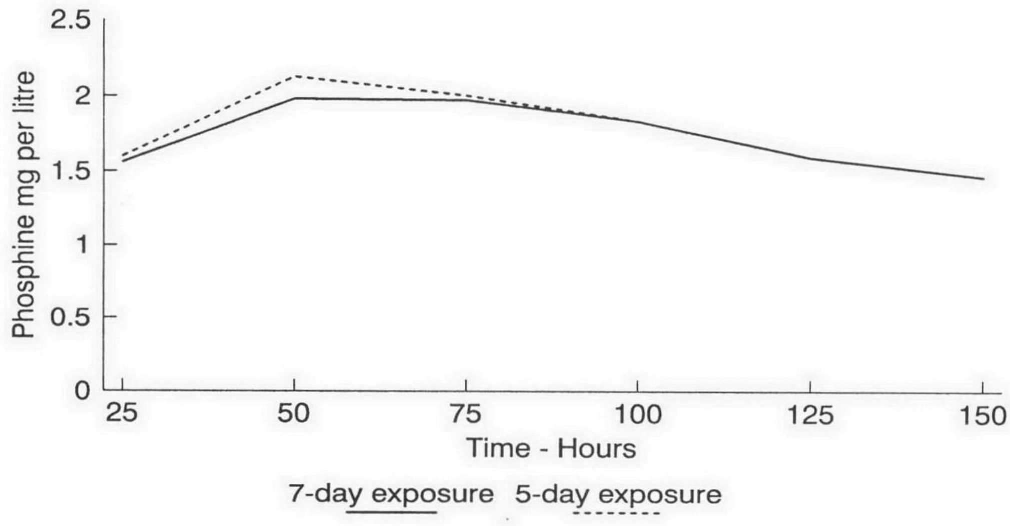

Fig. 3. Phosphine fumigation in Dodoma. The application rate is 2 g/t of maize.

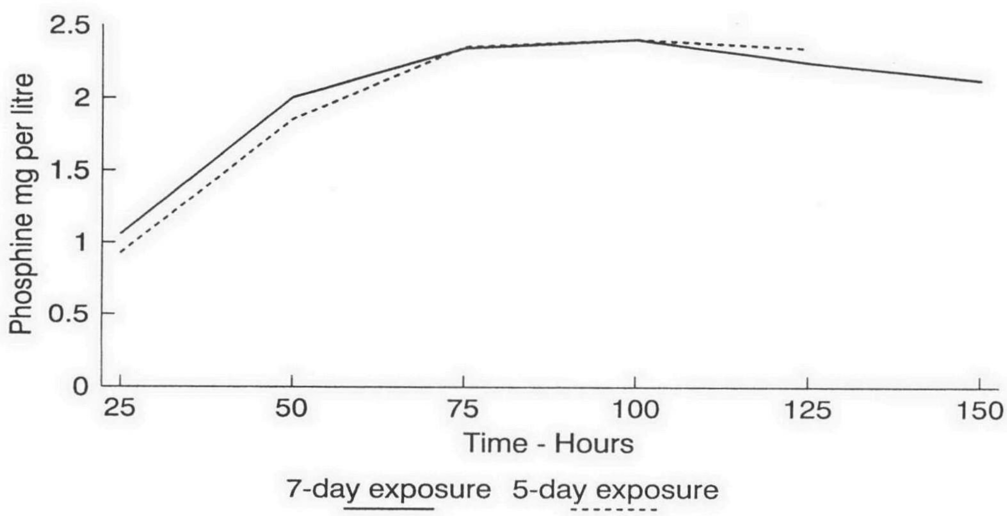

Fig. 4. Phosphine fumigation in Arusha. The application rate is 3 g/t of maize.

Mills, K. A. 1983. Resistance to the fumigant hydrogen phosphide in some stored product species associated with repeated inadequate treatments. Mitteilung-Deutschen Gesellschaft Fur Allgemeine Und Angewandte Entomolgie, 4, 98–101.

Sartori, M.R., Pacheco, I.A., and Vilar, R.M.G. 1990. Resistance to phosphine in stored grain insects in Brazil. In: Fleurat Lessard, F. and Ducom, P., ed., Proceedings of the Fifth International Working Conference on Stored-product Protection, Bordeaux, France, September 1990, II, 1041–1049.

Taylor, R.W.D. 1989. Phosphine a major grain fumigant at risk. International Pest Control, 31 (1), pp, 10–14.

Taylor, R.W.D. and Harris, A.H. 1994. Control of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), in bagged maize by fumigation under gas proof sheets. FAO Plant Protection Bulletin, in press.

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

van S Graver, J. and Annis, P. 1994. Suggested recommendations for the fumigation of grain in the ASEAN region. Part 3. Phosphine fumigation of bag-stacks sealed in plastic enclosures: an operations manual. Kuala Lumpur, ASEAN Food Handling Bureau/ Canberra, Australian Centre for International Agricultural Research, 52.

Watson, R.T., Albritton, D.L., Anderson. S.O. and Lee- Bapty, S. 1992. Methyl bromide: its atmospheric science, technology, and economics. Synthesis report of the interim assessments of methyl bromide science, and technology and economics. UNEP, Ozone Secretariat, Nairobi, Kenya, June 1992.

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 Entomology, 83 (5), 1738–1744.

Winks, R.G. 1986. The effect of phosphine on resistant strains. In: Howe, V., ed., GASGA Seminar on Fumigation Technology in Developing Countries, TDRI, Slough, England, March 1986, pp. 105–118.

Winks, R. G. 1987. Strategies for effective use of phosphine as a grain fumigant and the implication of resistance. In: Donahaye, E., and Navarro, S., ed., Proceedings of the Fourth International Conference on Stored-product Protection, Tel Aviv, Israel 1986, 335–334.

Zettler, J. L. 1994. Phosphine resistance in stored product insects. In: Navarro, S. and Donahaye, E., ed., Proceedings of an International Conference on Controlled Atmosphere and Fumigation in Grain Storage, Winnipeg, Canada, June 1992.