The current status of phosphine fumigations in India

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Abstract

India uses about 80% of its total production of 2500 tonnes of aluminium phosphide formulations for the protection of stored products. Grain in bag-stacks are fumigated under cover with aluminium phosphide tablets, up to seven times depending on the storage period. Whole warehouses are fumigated only occasionally. Cured tobacco, in bales, is invariably treated with phosphine to control *Lasioderma serricorne*. Phosphine is also used to treat coffee seeds, especially monsooned arabicacherry coffee which is susceptible to *Araecerus fasciculatus*. Currently, dosage rates for various commodities vary from 3–6 tablets/t with a 5 day exposure period.

Field experiments revealed better gas retention by 0.15 mm PVC covers than the currently used 0.25 mm LDPE covers. For fumigation under prevailing storage conditions, 34 g aluminium phosphide pouches were found to be superior to tablet formulations. Field trials on fumigation of coffee seeds with aluminium phosphide tablets and tobacco bales with a magnesium phosphide bag formulation are reported. A survey on phosphine resistance indicated that *Tribolium castaneum* was commonly resistant, whereas *Sitophilus oryzae* was found to be occasionally so. Cases of control failures due to occurrence of resistant strains are documented. The steps taken to delay and/or to overcome the resistance problem including revised dosage schedules, according to ambient temperatures, and improvements in sealing methods are discussed.

Introduction

In India various stored products such as food grains, milled products, pulses, oilseeds, tobacco and animal products are disinfested by fumigating with phosphine evolved from aluminium phosphide tablet preparations. India is one of the leading manufacturers of metal phosphide formulations. The fumigant was introduced in this country during the 1960s. The first field trial on grains was reported by Lallan Rai et al. (1964). Phosphine, which is cheaper and easy to handle and use, replaced liquid fumigants such as ethylene dichloride — carbon tetrachloride mixture and mixtures containing ethylene dibromide. Of late there are reports criticising unsatisfactory fumigation practices involving phosphine in countries on the Indian subcontinent. They point out the spread of phosphine-resistant strains from such places (Taylor and Halliday 1986). Therefore it was intended to review the state of affairs of phosphine applications with regard to the protection of stored products in India. This paper outlines current fumigation practices involving phosphine, discusses resistance status and reports on recent field trials to improve application techniques.

Grain Fumigation

Wheat and rice, the two major staple food commodities, are stored and handled in jute bags (95 kg net weight). The bags containing the grains undergo at least 12 handlings from the start of procurement to reaching retail stores. Government agencies and the co-operatives keep the grain-stocks in their warehouses and the surplus stocks are stored in the open in CAP (cover and plinth) storages. Outdoor storage involves wheat and paddy only. Facilities are also available to store 4 lakh tonnes of paddy or wheat in metal and concrete silos (Shivanna 1990). The bag-stack grain storage system facilitates ventilation throughout the storage period and aids rapid distribution as well as dissipation of fumigants but at the same time it favours cross-infestation by crawling and flying insect pests. In many of the warehouses there is rapid turnover of stocks and the system of first-in first-out is not followed. The major pests encountered in grain stacks and storage premises are *Sitophilus oryzae* (L.), *Rhyzopertha dominica* (F.), *Tribolium castaneum* (Herbst), *Oryzaephilus surinamensis* (L.,) *Trogoderma granarium* Everts and *Ephestia cautella* (Walker).

Besides routine prophylactic treatment of bag-stacks and storage premises with malathion (0.15 g/m^2) and dichlorvos (0.2 g/m^2), the grain stocks are fumigated with phosphine under fumigation covers or sheets. Black low-density polyethylene (LDPE) covers of 0.25 mm thickness and, in a few places, rubberised fabric with aluminium finish on one side are used for fumigation of bag- stacks. The cover is weighted down to the floor with sandsnakes, mud, loose sand or merely gum tape or newspaper strips. The stacks are fumigated on more than one occasion at a dosage of 3 aluminium phosphide tablets per tonne with 5 days exposure period. The longer the stack remains in the storage depot the more it is fumigated. As many as seven fumigations with phosphine are permitted for stored grains.

The exposure period is rarely extended to 10 days or more which is necessary when the temperature is 20°C or less and when *Sitophilus* spp. or phosphine-resistant strains are present. Palliative treatments with higher application rates i.e., > 10 tablets/t and/or inadequate exposure periods i.e., less than 5 days are not ruled out. Most of the warehouses with gabled asbestos roofs are not suitable for whole-godown treatment. Nevertheless, occasionally fumigation of entire warehouse (shed-fumigation) with shell-type roof is carried out using aluminium phosphide tablets.

Reports supported by gas concentration data on whole godown treatments are, however, lacking. Detection and gas monitoring devices for phosphine are hard to come by and hence they are rarely used to assess the safety of the working environment when fumigation operations are under way. Phosphine concentrations as high as 2 ppm have been

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estimated in the workplace during grain fumigation. In the absence of suitable gas mask canisters, transient symptoms of occupational exposure in the workers involved in fumigation work have been noticed (Misra et al. 1988).

Quality checks are periodically made on aluminium phosphide tablet formulations supplied by the manufacturers as per the standards laid by the Bureau of Indian Standards (BIS 1980). Accordingly the tablet formulation should weigh 3 g, must contain not less than 56% aluminium phosphide by mass and the tablet should not decompose in 30 minutes to liberate phosphine in 100% humidified chamber. The aluminium phosphide content is determined by the reaction of phosphine carried by a stream of nitrogen with potassium permanganate. As the rate of nitrogen carrier gas flow has not been specified in the method of BIS (1980) chances of variable results exist, as pointed out by Rajen (1990). The optimum flow rate of nitrogen to carry phosphine to potassium permanganate is 15–25 mL/minute. Tablets manufactured in India were analysed at this institute for the user organisations in the last 10 years. Aluminium phosphide content ranged from 56 to 70%. Fumigation sheets/covers should also conform to the criteria stipulated in Indian standard (BIS 1991). There are various tests exemplified by fumigation retention test, tests for workmanship, strength of joints, tensile strength, ease of repair, blocking test, flex test, accelerated ageing test, etc.

During fumigation of bag-stacks with aluminium phosphide tablets, 50% of the tablets are distributed on the top and 50% all around the stack. It is known that the decomposition of the tablets is influenced by ambient humidity and temperature. Even in the presence of favourable conditions like 25°C and 75% r.h., it has been reported that undecomposed aluminium phosphide up to 5% persists in the spent dust (Friendship 1989). The latter is a source of contamination of grain. A 34 g aluminium phosphide bag formulation which releases 11 g phosphine, manufactured in India, has been recently cleared for use in the country. The authors conducted field trials in a storage depot at New Delhi and studied the comparative rate of evolution of phosphine from tablet and bag formulations. Bag-stacks of 11.7% moisture content of wheat, each of 135 t, were fumigated under 0.25 mm thick LDPE cover at 1.5 g phosphine/m^3 for 11 days at 17±2°C and 62±10% r.h.. Nylon tubes, 3 mm diameter, were positioned at the top, middle and bottom levels of the stacks to monitor the gas concentrations at regular intervals using a Miran 104 Gas Analyser. The rate of liberation of phosphine from the bag formulation was moderate and the trend is more acceptable from the point of achieving 100% insect kill (Fig. 1). The bag formulation is more convenient to use and dispose of than the tablet formulation and is preferable for use under the storage conditions in this country.

In an another experiment the performance of 0.15 mm plain polyvinylchloride (PVC) fumigation cover was compared with that of other covers currently used by government agencies i.e. 0.25 mm black LDPE and rubberised fabric with aluminium finish. All 3 covers tested were new and had not been used previously. The test fumigations were conducted on 135 t wheat stacks with a phosphine dosage of 1.5 g/m^3 at 17 ± 2°C and 62 ± 10% r.h. The PVC cover showed higher retention of the gas than LDPE or rubberised fabric covers (Table 1). Laboratory tests on permeability of phosphine through various films/fabrics revealed that PVC sheets were superior to LDPE sheets and rubberised fabrics (Kashi et al. 1977). In contrast, Banks (1984) while discussing the lack of data on permeability of fumigation sheets, quotes higher loss rates of phosphine through PVC than LDPE. Nevertheless PVC sheets have better functional qualities such as flexibility and durability. Plain and reinforced PVC sheets of various thicknesses are manufactured in India.

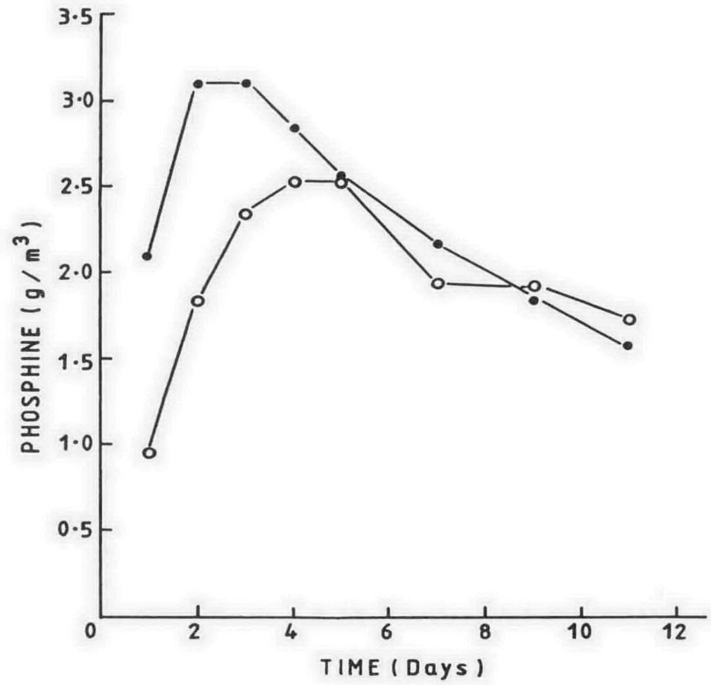

Fig. 1. Rate of liberation of phosphine from bag-stacks.

Detection and monitoring devices for phosphine are not commercially made in India. Phosphine indicator paper which can detect the presence of phosphine in the workplace at the hygienic level of 0.3 ppm was developed by Muthu et al. (1973) and improved by Kashi and Muthu (1975). Rajendran and Narasimhan (unpublished data) further improved the indicator paper for phosphine with rapid signalling action and longer shelf-life. The paper can be used for detection of leakage and to ascertain the safety of the working environment.

Fumigation at Rural Level

About 70–75% of grains produced in India are stored in the rural areas by the farmers (Sadana et al. 1988). Grains are stored indoors and outdoors in metal bins and in different types of traditional storage structures. Previously, only liquid fumigants, particularly ethylene dibromide, were used for grain protection. Recent surveys indicate that aluminium phosphide tablets are commonly used by the farmers although their traditional storage structures are not sufficiently gastight to retain phosphine a high vapour pressure fumigant, and the structures are often inside the living room (Thakre et al. 1988; Sadana et al. 1988). Lately, unit packages or capsules containing 3 aluminium phosphide tablets suitable for fumigation of one ton of grains and other food commodities have been introduced into the market in India (Banerjee and Deshmukh 1992).

Fumigation of tobacco

India is the fourth largest producer of tobacco in the world; annual production of flue-cured tobacco is about 120000 t. Tobacco plays an important place in the Indian economy (Rao 1992). Cured tobacco in bales is attacked by the cigarette beetle *Lasioderma serricorne* (F.) and the infestation problem is greater in the hot and humid coastal region in Andhra Pradesh which is the main production centre for tobacco. Tobacco bales, 100–180 kg net weight, are at present fumigated under cover with aluminium phosphide tablets at the recommended dosage of 1 g phosphine/ m^3 for 4 or 5 days

Table 1. Gas retention and other parameters of fumigation covers tested on 135 t wheat stacks dosed at 1.5 g PH_3/m^3 with 7 days exposure at 17±2°C and 62±10% r.h.

Particulars	PVC	LDPE	Rubberised
Particulars PVC LDPE Rubberised Price (size 9.7 m x 6.4 m x 5.2 m) in Rupees	6000	4000	10000
Weight (g/m2)	210	220	600
Thickness (µm)	150	250	–
Phosphine concentration on the final day (g/m^3)	3.0	2.2	1.3
Cumultative *CT* achieved	470	380	275
Handling characteristics	Very satisfactory	Satisfactory	Poor

(Philip Morris 1991). In addition to usual fumigation covers, use of an overlapping 0.05 mm polythene sheet has been recommended for improved gas retention during phosphine fumigations (ITC 1985).

In order to achieve effective gas concentrations quickly at all locales and also to avoid possible contamination by spent dust from aluminium phosphide tablets, fumigation tests were conducted with 34 g magnesium phosphide bag formulation. In a trial at Ghaziabad in Uttar Pradesh, 22.6 t of tobacco (11.6% moisture) in bales was successfully fumigated under a reinforced PVC cover of 0.15 mm thickness with magnesium phosphide bags at 16±3°C and 80±10% r.h. The dosage worked out to 2 g phosphine/m^3 with 10 days exposure period. The concentration profile as determined by the infrared gas analyser was satisfactorily high throughout the period (Table 2). Analysis of spent bag revealed a very low level of 0.5% magnesium phosphide, as against the initial level of 66%.

Table 2. Gas concentrations recorded during fumigation of tobacco bales with 34 gmagnesium phosphide bags at 2 g phosphine/m^3 dosage at 16±3°C and 80±10% r.h.

Experiment day	Average PH_3 concentration (g/m^3)	Remarks
0.5	0.96	Cumulative *Ct* = 410 g.hours/m^3
1.0	1.11	
1.5	1.64	100% kill of all stages of *L. serricorne* observed
2.0	1.75	
3.0	1.99	
4.0	2.13	
6.0	2.06	
8.0	1.98	
10.0	1.75	

Fumigation of green coffee

Coffee seeds especially monsooned ones stored in the hot and humid coastal regions are prone to infestation by the coffee bean weevil *Araecerus fasciculatus* (De Geer). Generally, coffee stocks are fumigated with methyl bromide. For the first time, a field fumigation trial with phosphine was carried out on a 20 t bag-stack of arabica-cherry-coffee in a storage depot at Mysore. Reinforced PVC cover of 0.15 mm thickness was used and the application rate was 1.5 g phosphine/m^3 (3.4 tablets/t) with 7 days exposure period. Average gas concentration at the time of termination was 0.8 g/m^3 and the estimated *CT* was 288 g hours/m^3. At the above effective dosage the quality of coffee was not impaired.

Resistance and Control Failures

Insects collected from grain storage depots located in different parts of the country were screened for resistance to phosphine and methyl bromide following the FAO method (1975). *T. castaneum* from all the eight places were found to be resistant to phosphine; the level of kill recorded at the discriminating dose was 0–20% only. In the case of *S. oryzae*, insects from 3 of 5 locations showed resistance and the kill ranged from 0–10% for the resistant strains. All the insects were susceptible to methyl bromide. Furthermore, *R. dominica* from wheat samples from a silo at Bombay was found to be resistant to phosphine by a factor of 380 at LD50. Wheat in the silo had been fumigated with phosphine on three occasions during a 1 year storage period. A similar case of field occurrence of high level phosphine resistance in the same species was reported earlier (Rajendran, 1989).

Three distinct cases of control failures in field fumigations owing to the occurrence of phosphine-resistant strains have been recorded (Table 3). In a warehouse at New Delhi a bag-stack of wheat was fumigated under 0.25 mm LDPE cover with aluminium phosphide tablets at 1.5 g phosphine/m^3 for 11 days at 15–19°C and 50–72% r.h. Despite the high concentration of 1.6 g/m^3 (analysed by MIRAN 104 Gas Analyser) on the final day, active adults of *T. castaneum* and *S. oryzae* were noticed. Inspection of post-fumigation samples revealed that other life stages were also alive. Fumigation with phosphine alone at 3 tablets/t and 5 days of exposure had been the practice in the warehouse for many years. In an another instance, survival of adults of *Liposcelis* spp. was observed after fumigation of milled rice under cover at 1.5 g phosphine/m^3 for 7 days.

In the last case, survival of all stages of *L. serricorne* was observed after fumigation of the tobacco bales at 1.25 g phosphine/m^3 (5 tablets/t) for 7 days at 27–33°C and 65–90% r.h. The recommended dosage for the control of cigarette beetle in tobacco bales is 1 g/m^3 (EPPO 1982; Philip Morris 1991). At 25°C, phosphine concentration exceeding 0.3 g/m^3 throughout the exposure period of 96 hours has been claimed to be sufficient for all the stages of *L. serricorne* (Hole et al. 1976). In the present case, gas concentration on the 4th day was 0.4 g/m^3 which declined to 0.2 g/m^3 on the 7th day. Repeated applications under less-retentive fumigation covers had probably resulted in high-level resistance to phosphine. Further trials in the warehouse revealed that a dosage of 2 g phosphine/m^3 for not less than 10 days was effective against the resistant strain.

Conclusions

The climatic conditions in India allow rapid multiplication of insects in short durations and the current grain storage system permits quick reinfestation of fumigated commodities. Hence,

Table 3 Instances of control failures during wheat (at New Delhi), rice (Mysore) and tobacco bale (Ongole) fumigations with phosphine

	Commodity		
	Wheat (Case 1)	Rice (Case 2)	Tobacco (Case 3)
Moisture content (%)	11.7	13.3	12.1
Quantity (t)	135	180	18.5
Volume (m^3)	190	243	71
Fumigation cover	LDPE, 0.25 mm	LDPE, 0.25 mm	HDPE woven laminated with polyethylene
Phosphine dosage (g/m^3)	1.5	1.5	1.25
Exposure period (days)	11	7	7
Temperature range (°C)	15–19	25–28	27–33
Relative humidity (%)	50–72	70–80	65–90
Final concentration (g/m^3)	1.6	1.5	0.2
Cumulative *CT* ($g.hour/m^3$)	550	260	85
Survivors	*S. oryzae*, *T. castaneum* (all stages)	*Liposcelis* sp.	*L. serricorne* (all stages)

fumigants and insecticides are repeatedly applied. Intentional and/or ignorant palliative treatments which occur both in commercial treatments and at central/state storages need to be discouraged. It is recommended to give phosphine dosages preferably on volume basis at 1.5 g/m^3 for grains (3–4 g/m^3 for paddy) and coffee seeds and 2 g/m^3 for tobacco bales with a minimum of 7 days exposure period at and above 25°C and 10 days and above at lower temperatures. More than 15 days exposure period will be necessary when *Sitophilus* spp. and *T. granarium* or phosphine-resistant strains are present. Low phosphine dosages of less than 1 g/m^3 with still longer exposures are suggested for the buffer stocks of bagged grains and grains in silos. Such long-term phosphine treatment techniques have been attempted and proved effective in Thailand and China (Sukprakarn et al. 1986; Liang Quan 1990). It is unlikely that any major changes in the grain storage system will take place in the near future in India. Therefore, phosphine application techniques have to be improved to avoid repetitive treatments. Sealing materials and methods for cover fumigations need to be evaluated. For instance, at the Indian Grain Storage Institute, Hapur (Sone Lal, personal communication 1993) experiments are in progress on securing the fumigation sheet with rubber piping against a plastic trough embedded all around the bag-stack, as practised in China for improved gastightness during sheeted fumigations (Liang Quan 1990). Technical personnel involved in the preservation of stored products need to be informed/ instructed about the slow action of phosphine on insects, the importance of extended exposure periods and the resistance problem.

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