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Perfecting phosphine fumigations for food grain preservation and international trade in India

SOMIAHNADAR RAJENDRAN*

Central Food Technological Research Institute, Mysore, Karnataka 570 020, India

ABSTRACT

Bag-stack storage system along with favourable climatic conditions (25–35°C and 50–80% r.h.) contribute to high level insect-pest activity in stored grains in India. Consequently, the number of generations completed by pest insects in a year is relatively more than in countries with temperate climate. As mixing of residual insecticides with food grains is not permitted, there is a greater dependency on fumigation in preservation of food grains (estimated output for 2014-15, 257.07 million tonnes inclusive of 18.43 million tonnes of pulses). In this context, phosphine evolved from aluminium phosphide formulations has been playing a crucial role in food grain protection since 4 decades. Of late, its role in quarantine and pre-shipment (QPS) treatments is increasing owing to global restrictions on the use of methyl bromide, a familiar fumigant.

Deficiencies in current fumigation practice with phosphine have been examined and factors responsible for occasional failures to achieve 100% insect mortality in grain fumigations and incidence of insect resistance to the compound have been analyzed. To set right the situation, improvements with reference to storage practices for bagged-grains, selection of gas-proof sheets/covers, floor sealing, application rates appropriate for the type of cereal grain, insect-pest and its tolerance to phosphine and target terminal phosphine gas concentrations to be achieved are discussed. Significance of monitoring phosphine concentrations in all fumigations in order to ascertain the success of treatment has been emphasized. Responsibility of the grain storage as well as pest control agencies and regulatory bodies in implementing good phosphine treatment practices for effective grain protection as well as for pre-shipment consignments has been indicated.

Key words: Bag-stacks, Grain fumigation, Improved protocols, India, Phosphine, QPS applications

Insect pests are the major biotic depredating agents responsible for loss in quality and quantity of food grains and other stored products. Controlling insect pests is, therefore, important to ensure food security of the nation and to meet the quality demands of international market in trade. In this regard, fumigation is a key component of pest control measures applicable to food grains during storage. Similarly, international trade is largely dependent on fumigation by way of quarantine and pre-shipment (QPS) treatments for the supply of insect-free products. Phosphine evolved from aluminium phosphide tablet and powder formulations is the primary fumigant used for food grain preservation in India.

The present paper describes current grain storage and fumigation practices in India and examines the causative factors for occasional control failures and incidence of insect resistance to phosphine. Strategies have been put forth to perfect the fumigation practice for judicious exploitation of phosphine in stored grain protection as well as in QPS treatments.

CURRENT GRAIN STORAGE AND FUMIGATION PRACTICES

In India, nearly two-thirds of total cereal grains produced (238.99 million tonnes in 2014–15) is

*Corresponding author e-mail: *somiahr@gmail.com*

retained by farmers for own use. The balance, the marketable surplus, is largely handled by public sector comprising Food Corporation of India (FCI), Central Warehousing Corporation, State Warehousing Corporations, State Civil Supplies Corporations and Cooperative Sectors and to a limited extent by private sector such as National Bulk Handling Corporation Ltd, National Collateral Management Services Ltd, and Adani Agri Logistics Ltd. India exports about 6% (14.64 million tonnes excluding Basmati rice) of total grain produced and the quantity of cereal grain imported (0.55 million tonnes in 2014–15) is negligible.

Food grains held in central pool [primarily rice, (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) and limited quantity of coarse cereals] vary from 38 (April 2014) to 63 (June 2014) million tonnes, average being 48 million tonnes. Bag-stack storage system in conventional warehouses (covered godowns) of 5,000 metric tonnes storage capacity is the common practice. In addition to indoor storage, wheat and paddy in jute bags are held in open storage as cover and plinth (CAP) for 6 to 12 months to overcome shortage of storage space in covered godowns. Originally, bulk storage in concrete or metal silos by the FCI is very limited (0.46 million tonnes). In recent times, more warehouses have been built up to expand storage capacity to an extent of 12 million tonnes under new schemes such as Private Entrepreneurs Guarantee Scheme 2008. Furthermore, it has been planned to expand silo storage capacity up to 2 million tonnes in the near future. As storage loss is relatively high in labour-intensive CAP storage, the latter is discouraged; to a certain extent silo-bag storage of wheat has replaced CAP storage in Madhya Pradesh state.

Grain storage at farmer level is mostly in traditional storage structures, underground or above ground. Lately, food grains are stored by farmers in bins and in bags in small godowns.

Insect pest activity in food grains has been encountered from harvesting stage and thereafter, in all types of storages. Major beetle pests in stored food grains include the rust-red flour beetle, [*Tribolium castaneum* (Herbst)]; the rice weevil, *Sitophilus oryzae* (L.) and the lesser grain borer, *Rhyzopertha dominica* (Fabricius). The Khapra beetle, *Trogoderma granarium* Everts is confined to hot and dry climatic zones coupled with unhygienic storage conditions in North India.The germ eaters *Cryptolestes* spp are quite sensitive to dry conditions and hence, observed in local spots of caked grain and high moisture areas (e.g. bottom layers of grain stacks). Among moth pests, the almond moth/ Tropical warehouse moth, *Ephestia cautella* (Walker) is prevalent whilst the rice moth, *Corcyra cephalonica* (Stainton) is restricted to hot climatic regions. Severe infestation of psocids is noticed in the warehouses along the coastal region and in the North East with hot and high humid climate conditions. For India, there are many invasive pests of quarantine significance such as the larger grain borer, *Prostephanus truncates* (Horn), the bean weevil, *Acanthoscelides obtectus* (Say) and the Indian meal moth, *Plodia interpunctella* (Hübner) (Dev et al., 2005).

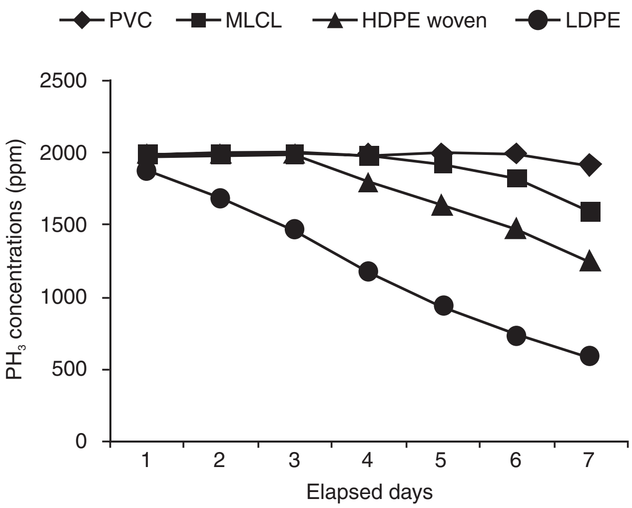

Fig. 1. Phosphine concentration profiles in wheat (m.c. 10-13%) stacks under previously (> 10 times) used gas-proof covers fumigated at 3 AlP tablets/tonne at 24–34°C (Explanations: Data are average of 3 (PVC), 30 (MLCL), 3 (HDPE woven) and 18 (LDPE) stacks/replicates;gas concentrations measured with Bedfont EC 80 or Porta Sens II phosphine monitor, (1–2,000 ppm measuring range)

Aluminium phosphide tablet formulation containing 56% active ingredient is routinely used for sheeted fumigation of grain bag-stacks; a few grain-storage agencies use powder (granular) formulation in sachet. Four brands of indigenous aluminium phosphide preparations are used. Food grains in metal silos by some of the private agencies are fumigated by on-site generation of phosphine from 77.5% aluminium phosphide granular formulation using indigenous phosphine generators.

Sheeted fumigation of individual grain stacks under tailor-made gas-proof cover by government-storage agencies or with appropriate size sheets by approved pest-control agencies is the standard practice. Earlier, low-density polyethylene (LDPE) sheets/covers were commonly used for grain stacks held indoors and outdoors. However, laboratory as well as field studies conducted by the Central Food Technological Research Institute (CFTRI), Mysore, revealed that low-priced LDPE are prone to develop pin-holes easily and/or damaged by repeated handling operations under warehouse conditions. In contrast, polyvinyl chloride (PVC) sheets and multilayered cross laminated film (MLCL) though expensive proved to be functionally better than other sheet types and noted to retain gas impervious property relatively for a longer period (Fig. 1).

Sand snakes of different sizes are generally used for floor sealing of stacks during sheeted fumigations. Occasionally sand directly, mud and paper strips are used by a few storage agencies.

In stack treatments, phosphine dosage is calculated in a simple way based on tonnage of the stack rather than volume of the enclosure basis by all grain-storage agencies. Furthermore, differences in recommended phosphine application rates and exposure period between organizations, i.e. manufacturers of aluminium phosphide formulations, users (central and state grain-storage agencies) and regulatory bodies were noted.

Grain storage in bag-form in jute sacks favours spillage and cross-infestation. In addition, hot and humid climatic conditions promote rapid insect multiplication that the numbers of generations completed by stored grain insect-pests in a year are more necessitating repetitive phosphine fumigations. The frequency of fumigation of grain stacks with phosphine depends on the need or the level of infestation observed but it is known to be once in 3 months, on an average, for a stack during storage.

For grain fumigation by farmers in their traditional storage structures, use of 10 g pouch has been recommended. However, detailed studies on functional deficiencies of the rural storage structures for phosphine fumigation and ways to improve their gas tightness are lacking.

There are national regulations with respect to fumigant formulations (*The Insecticide Rules, 1971 and the Insecticides (Amendment) Rules, 2015 issued under the Insecticide Act, 1968*) and their application (*NSPM 22*) (Anon. 2011), dosage schedules for quarantine treatments (*The Plant Quarantine (Regulation of Import into India) Order, 2003*) and tolerance limits in food grains (*Food Safety and Standards (Contaminants, Toxins and Residues) Regulations, 2011 under the Food Safety and Standards Act, 2006*). As per the latter, no phosphine residues are permitted in food grains when issued for human consumption. This is in contrast with Codex Alimentarius (of FAO/WHO) limit of 0.1 ppm phosphine in whole grains.

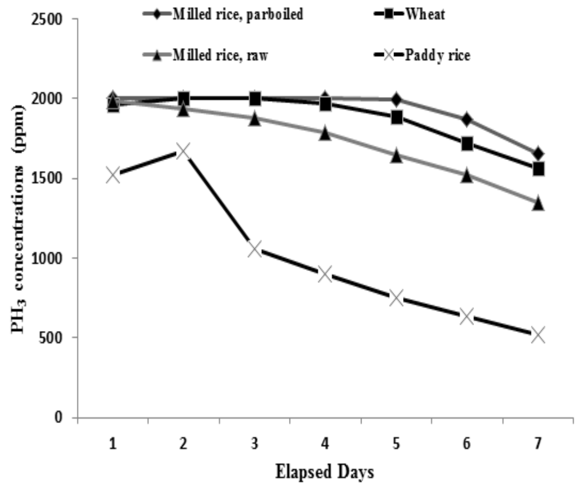

Fig. 2. Variations in phosphine concentration profiles due to sorption factor in food grain stacks under new LDPE covers treated at 3 AlP tablets/tonne at 24–34°C (Explanations: Data are average of 4 for milled rice, parboiled; 17 for wheat; 3 for milled rice, raw and 1 for paddy rice stacks/replicates (m.c. of the grains ranged from 10–13.5%); gas concentrations measured with Bedfont EC 80 or Porta Sens II phosphine monitor (1-2,000 ppm measuring range)

Table 1 Suggested phosphine dosages and target terminal concentrations for effective grain fumigation

Food grain	Pest type	Temperature (°C)	Dosage (g phosphine/m^3)	Minimum exposure period (days)	Target end concentration of phosphine (ppm)
All cereals except paddy rice	All insects except Khapra beetle, *T. granarium*	≥ 25	3	7	500
		10–24	3	10	500
	Phosphine-resistant insects and *T. granarium*	≥ 25	6	10	1,000
		10–24	6	14	1,000
Paddy rice	All insects except Khapra beetle, *T. granarium*	≥ 25	4-8	7	500
		10–24	4-8	10	500
	Phosphine-resistant insects and *T. granarium*	≥ 25	4-8	10	1,000
		10–24	4-8	14	1,000

IMPROVED FUMIGATION PRACTICES

Phosphine is a cost-effective low dosage (≤ 10 g/m^3) fumigant with least effect on the quality of fumigated grains. Consequently, in spite of the deficiencies in the current storage and fumigation practices, phosphine fumigant has helped preservation of food grains economically. Nevertheless, there has been increasing concern among grain storage agencies and regulatory authorities on occasional control failures either due to improper fumigations or occurrence of phosphine-resistant insects. Hence the necessity has arisen to adopt improved strategies in phosphine fumigations, so as to retain its effectiveness in food grain protection and to expand its role in QPS treatments.

Phosphine dosage though appears to be simple, in reality, it is intricate by commodity sorption, pest type and temperature factors. For example, paddy rice is exceptionally sorptive (due to physical sorption by the husk) to phosphine as revealed by gas-concentration profiles in field experiments and requires increased phosphine dosage (Fig. 2). Dosages not adjusted to these factors, shorter exposure periods, use of substandard fumigation sheets/covers and poor floor sealing over the years have lead to repeated exposure of insect pests to sub-lethal phosphine concentrations. Poor maintenance of gas concentrations during routine phosphine treatments in some of the grain-storage centres has been reported (Rajendran, 2007). Evidently, there has been continued selection pressure on stored grain insect pests when exposed to sub-optimal phosphine concentrations in routine grain-stacks treatments to develop resistance to the fumigant. Unfortunately, any control failure in routine fumigations is not diagnosed since cross-infestation is regular under the existing storage system.

Based on extensive laboratory and field experiments, revised phosphine dosages along with target terminal concentration to be achieved for controlling normal susceptible and phosphine-resistant insects in India have been arrived. The recommended target end concentration for controlling normal insect-pests is 500 ppm minimum; when there is occurrence of phosphine-resistant insects the target terminal concentration must be ≥1,000 ppm (Table 1). It may be noted that European and Mediterranean Plant Protection Organization (EPPO) has lately revised phosphine dosages for the control of various stored product insect pests (EPPO, 2012a, b). To establish whether phosphine concentration inside the enclosure is at the target level or not, it is necessary to use phosphine gas monitors (1–2,000 ppm measuring range). There is a need for all major grain storage depots in India to equip with phosphine-monitoring devices to enable technical staff to ascertain whether fumigations conducted in their warehouses reach the required standards or not, i.e. retention of target gas concentration till the end of exposure period.

It is unfortunate that the introductory or old recommendation of 3-day exposure period is still considered in fumigations using aluminium phosphide formulations and practiced in some situations and by a few agencies. It has been well established that it takes 24 to 72 h for aluminium phosphide tablets or pouches

Table 2 Approved phosphine dosages for QPS treatment of food commodities

Commodity	Country	Dosage	Exposure period	Major target pests
		Export from India (pre-shipment fumigation)		
Barley, maize	Iran	2 g phosphine/m^3	7 days at >15°C	*Araecerus fasciculatus* Deg Geer, Coffee-bean weevil
Rice		3AlP tablets/tonne	3 days	*T. granarium*
Maize, soybean	Malaysia	5 g phosphine/m^3	5 days	*T. granarium*
Sorghum bicolor (L.) Moench (for feed)	New Zealand	2 g phosphine/m^3	5 days at 25-29°C; 4 days at ≥30°C	*T. granarium, Alphitobius laevigatus* (Fabricius), Black fungus beetle, *Latheticus oryzae* Waterhouse, Longheaded flour beetle, *Corcyra cephalonica* (Stainton), Rice moth
Peanuts	Vietnam	4 g phosphine/m^3	10 days	*T. granarium, Caryedon serratus* (Olivier), Peanut bruchid
Cumin	Ecuador	3 AlP tablets/tonne	Not specified	*T. granarium*
		Import (quarantine fumigation)		
Almonds	USA	40 g phosphine/1000 ft^3 (1.4 g/m^3)	7 days	*Ephestia kuehniella* Zeller, Mediterranean flour moth

[1]*http://phytosanitarysolutions.com* (Accessed12 April 2016)

to liberate maximum level (>80%) of phosphine depending on r.h. (primarily) and temperature (Rajashekar et al., 2006; Xiancheng, 1994). Obviously, fumigation period of 3 days is inadequate as phosphine liberation from tablets/powder formulation will be under progress, and achievement of insecticidal gas concentration throughout the enclosure is yet to take place. In such a situation, tolerant egg and pupal stages will survive and eventually, the resultant insect population will be selected as phosphine-resistant ones. An exposure period of 7 days or more is insisted to ensure 100% mortality of all life stages of stored grain insect-pests.

To achieve the target concentrations, besides dosage, the quality of gas-proof sheet/cover deployed and proper floor sealing are significant. MLCL or PVC sheets/covers are preferred over other types. Although quality-conscious grain storage agencies have already discontinued the use of LDPE sheets, several other agencies are yet to switch over to PVC or MLCL sheets for phosphine fumigations. During fumigation of bag-stacks, it is recommended to use always standard size (15-20 cm diameter and 1- 1.2 m length) sand-snakes for effective floor sealing.

Hygienic conditions and level of housekeeping influence the extent of insect infestation in grain stacks as well as storage premises and hence, dictating the need for repeated phosphine treatments. Repetitive fumigations with exposure of insect pests to sub-optimal phosphine concentrations mean more and more selection pressure on insect population favouring development of resistance. Housekeeping is important in pest management that it could curtail the resident insect population and hence, restrict the infestation pressure for repeated fumigation.

Phosphine is a high vapour pressure (29,260 mm of Hg at 25°C) fumigant and grain treatment under leaky conditions in traditional rural storages could easily lead to resistance development. Unless the storage structures have a polyethylene liner to retain phosphine, successful disinfestation cannot be guaranteed.

PHOSPHINE IN QPS TREATMENTS

Khapra beetle, *T. granarium* is an important quarantine pest for several countries and hence, there is a particular concern about the presence of Khapra larvae in export consignments in international trade. There have been occasional restrictions on certain food and feed commodities from India (e.g. maize (*Zea mays* L.) by Vietnam, peanuts (*Arachis hypogaea* L.) by Russia, rice by China, Russia and the USA) by importing countries due to interception of Khapra larvae at destination ports. Khapra larvae especially at the diapausing stage are tolerant to any chemical control measure and consequently, higher fumigant doses are recommended to control the pest (EPPO, 2012b). For pre-shipment fumigation of Indian consignments, phosphine doses and exposure period vary as dictated by the regulatory body of importing country (Table 2). For instance,Vietnam recommends a dose of 4 g phosphine/m^3 for 10 days for cereals, pulses, and oilseeds from India and Malaysia recommends 5 g phosphine/m^3 for 5 days for maize and soybean [*Glycine max* (L.) Merr.] consignments. Generally for onshore quarantine treatments, methyl bromide is recommended as per the Plant Quarantine (Regulation of Import into India) Order, 2003. Nevertheless, for almonds [*Prunus dulcis* (Mill) D. A. Webb] from the USA, quarantine treatment with phosphine is allowed upon arrival at an Indian port. Phosphine is likely to play a significant role in QPS treatments in India in view of increasing restrictions on the use of methyl bromide in international trade and owing to non-availability of any registered alternative fumigant such as sulfuryl fluoride.

CONCLUSION

Notable changes in fumigation technology have been observed globally for the past two decades. In contrast to the static system as in conventional fumigation of bag-stacks and whole warehouses with aluminium phosphide formulations, direct supply of phosphine using on-site phosphine generators, and continuous flow and recirculation systems with phosphine delivered from cylinder sources have been developed. Moreover, cyliderized ethyl formate formulations have come up as methyl bromide substitutes for specific treatments (Ryan and De Lima, 2014).

In India, as grain in bag form continues to be the primary storage system, no significant changes in fumigation practice with phosphine have taken place. It is time to revamp the current practice adequately to meet the challenges such as insect resistance and higher market demands (zero tolerance for insects) in international trade. Way forward, occasional control failure and phosphine-resistance issues can be tackled by: (*i*) adopting revised application rates of aluminium phosphide tablets/sachets and exposure periods, so as to achieve desired target terminal concentrations, (*ii*) pursuing good storage and fumigation practices, so that the number of phosphine treatments to the same bagged grain is reduced to a minimum to avoid selection pressure, and (*iii*) occasionally using an alternate fumigant (e.g. sulfuryl fluoride or ethyl formate) if available/permitted to break resistance. It is a joint responsibility of the grain storage agencies, commercial pest control operators and regulatory bodies to implement good fumigation practice for sustained effective use of phosphine for grain protection and QPS treatments.

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