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Improved procedures for fumigating grain storages with phosphine in Indian warehouses

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ABSTRACT

An experiment was conducted jointly by a team of Central Warehousing Corporation (CWC) and Indian Institute of Crop Processing Technology (IICPT) in food-grain warehouses of CWC in 2 states, viz. Tamil Nadu and Andhra Pradesh, using Multi Layered Cross Laminated (MLCL) sheets and different methods of floor-sealing on the mortality of rusty grain beetle [*Cryptolestes ferrugineus* (Stephens)]. Survival of *C. ferrugineus* was noticed in treatment with 3 tablets for 7 days despite mean phosphine concentration up to 1,995 ppm at average temperature of 33ºC. This might be due to short exposure and also resistant population. However, complete mortality was recorded with 10-day exposure even with lesser concentration of phosphine. Hence 3 tablets with longer exposure are needed wherever *C. ferrugineus* population is abundant.

Key words: Fumigation, Grain storage, Mortality, PH_3, Rusty grain beetle

In India, the food grains are generally stored in jute bags. More than half a dozen pests are very common in storage. It is estimated that about 65% of the total produce is held by the farmers for food, feed and seed purpose, which is stored with unscientific method. The balance marketable surplus is supplied to central pool via procurement, which is held by public/private domain. Though major share of grain storage is with public sector, storage with private sector has also picked up momentum. Non-observance of proper handling and pest-control methods may result in considerable qualitative and quantitative losses. Various factors like type of storage structures, methods of application of prophylactic and curative treatments, biotic and abiotic factors contribute to maintain health of the stock. Large harvest, poor market demand, food security during and off-season processing are some of the factors that force farmers and traders to store grains and oilseeds (Alagusundaram, 2009).

Fumigation plays a major role in control of stored grain pests because of their unique characteristics and the great adaptability of the fumigation techniques. Fumigants can often provide effective, economical control where other forms of pest control are not feasible. Stored products require an ideal fumigant to be applied as a gas and achieve penetration within the grain mass. Effective fumigation requires that phosphine gas at lethal concentration is held in stacks long enough to kill all stages of the target pests. Loss of measurable phosphine gas results due to absorption by grain, penetration through fumigation sheets and leakages through holes and gaps. Control of insect population necessitates precise phosphine-fumigation control and accurate gas concentration measurements. The recent phase out of methyl bromide has left phosphine as the only economically and environmentally viable fumigant for the industry.

Aluminum phosphide has achieved a key status in the International market. India is entirely dependent on phosphine as the fumigant for disinfesting grain stacks, as it is low-priced, easy to apply and does not affect the quality even after repeated applications. Now-a-days, phosphine resistance is documented in every part of the world due to poor fumigation practices (Fitzapatrick and Brash, 2003).The resistance to phosphine occurs because of improper application of phosphine tablets, exposure of insect populations to sub-lethal dosages or due to poor fumigation covers, floor-sealing materials and also due to failure to monitor the gas concentration. To prevent the development of resistance, it is essential to avoid applications with sub-lethal doses (Fields

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and White, 2002) and use quality-fumigation covers (Rajendran, 2001). The factors that are responsible for unsatisfactory bag-stack fumigations include lack of training and management awareness, failure to monitor gas and poor fumigation techniques (Van Graver and Annis, 1992)

Of late, many relevant reports have been published on phosphine resistance of rusty grain beetle [*Cryptolestes ferrugineus* (Stephens)] (Jiang, 1995; Liu et al., 2003; Liu, 2004; Wang et al., 2004; Yan et al., 2004). The efficacy of phosphine is not satisfactory to keep *C. ferrugineus* under control in the high temperature and humidity conditions, where *C. ferrugineus* can survive at phosphine concentrations below 200 ppm (Lu et al., 2005). Some resistance strains could be killed effectively only, when phosphine concentration reaches 550 ppm for 45 days (Pang et al., 2002). Thus, it is essential to develop alternative methods for the control of this pest.

The recent development of very high resistance to phosphine in rusty grain beetle, *C. ferrugineus*, threatens the sustainability of phosphine — a key fumigant worldwide to disinfect stored grain (Nayak et al., 2013; Kaur and Nayak, 2014). The aim of the present study was to test the feasibility of retaining fumigant at a sufficient concentration for long enough to control known *C. ferrugineus* population with short- and long-exposure period, including resistant insects.

MATERIALS AND METHODS

Bag-stack fumigations of raw rice (*Oryza sativa* L.) stacks using aluminium phosphide tablets were undertaken. The experiment was conducted in warehouses situated in coastal belt of India comprising 2 states, Tamil Nadu (Thanjavur, Trichy) and Andhra Pradesh (Machlipatnam, Rajahmundry). A stack size of 30’×20’ was maintained for the study. New Multi Layered Cross Laminated covers of 200 GSM were used as a fumigation cover. Transparent hose of 0.5 cm (diameter) was suspended from top, middle and bottom layers up to the floor level for monitoring phosphine gas, and the terminal ends of the tubes were secured very tightly. The dosage of 3 tablets per tonnes of aluminium phosphide tablets was applied by placing the tablets in paper plates below the wooden dunnages and finally floor-sealing materials like sand snakes (three-fourths area was filled with sand) and surgical tape were used to prevent the leakage of gas. Raw rice with 3 replications each was used in all the stacks for fumigation. The PH_3 concentration was measured using UNIPHOS PH_3 monitor. *Cryptolestes ferrugineus* was used as a test insect. Known number of insects of mixed age group, were released in plastic vials with sufficient food materials (flour, broken rice and yeast). The vials were covered with a muslin cloth and secured with a rubber band. The vials were taken out after termination of fumigation and observed for mortality. The vials were kept for 3 months to note the emergence of adults. The treatment details are given in Table 1.

Table 1 Treatment details

Treatment	Particulars (Alp 3 g tablets)	Exposure period (days)	Method of sealing
T_1	3 tablets/MT	7	Sand snakes
T_2	3 tablets/MT	10	Sand snakes
T_3	3 tablets/MT	10	Surgical tape
T_4	Control	-	No fumigation

RESULTS AND DISCUSSION

The results from different study locations revealed that, PH_3 gas concentration was uniformly distributed in all the 3 layers in all treatments. The day-wise concentration at Thanjavur warehouse with different treatments ranged from 839 to 1,772 ppm (Fig. 1). The highest PH_3 concentration of 1,772 ppm was recorded with T_1,T_2 and T_3 on day 3. The mean concentration of phosphine in T_1, T_2, and T_3 was 1,544, 1,410 and 1,398 ppm, respectively. The terminal concentration in T_1 with 7 days exposure and T_2 with 10 days exposure and T_3 with 10 days exposure with application of surgical tape for sealing was 1,397, 942 and 839 ppm, respectively. This concentration was sufficient to cause complete mortality. In Thanjavur, complete mortality was observed in all the treatments except the control. At Thanjavur, the treatments T_1 and T_2 were also tried with 2 tablets per tonnes instead of normal

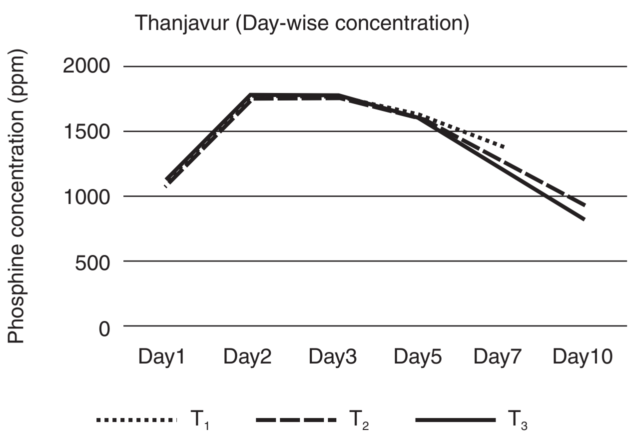

Fig. 1. Phosphine concentration profiles during fumigation of rice at Thanjavur. Details of treatment are given in Table 1.

Table 2 Mean and terminal phosphine concentration (ppm) and mortality (%) at different locations

Treatment no.	Thanjavur			Trichy			Rajahmundry			Machlipatnam		
	Mean	Terminal	Mortality	Mean	Terminal	Mortality	Mean	Terminal	Mortality	Mean	Terminal	Mortality
T_1	1,544	1,397	100	1,458	1,250	74.71	1,995	1,976	56.18	554	139	73.4
T_2	1,410	942	100	1,753	1,217	100	1,901	1,419	100	471	183	100
T_3	1,398	839	100	1,684	1,116	100	1,792	1,161	100	733	191	100
T_4	0	0	09	0	0	07	0	0	04	0	0	06

Details of treatments are given in Table 1

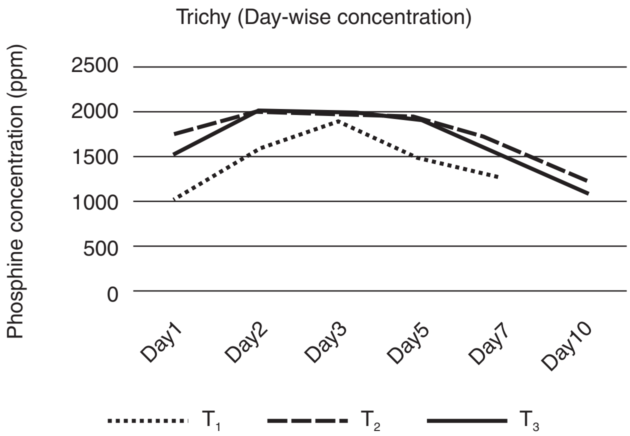

Fig. 2. Phosphine concentration profiles during fumigation of rice at Trichy. Details of treatment are given in Table 1.

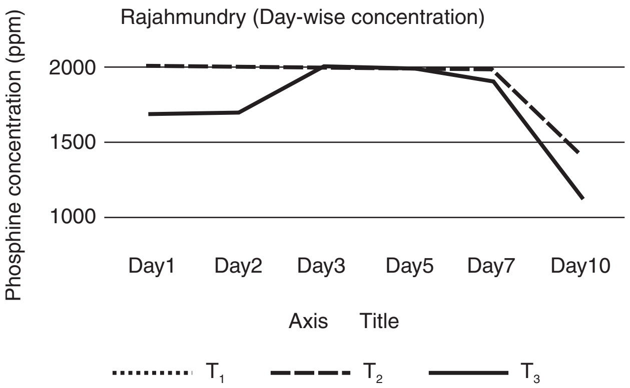

Fig. 3. Phosphine concentration profiles during fumigation of rice at Rajahmundry. Details of treatment are given in Table 1.

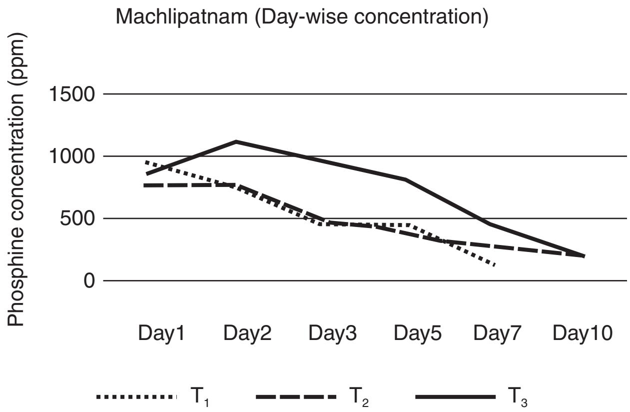

Fig. 4. Phosphine concentration profiles during fumigation of rice at Machlipatnam. Details of treatment are given in Table 1.

3 tablets. Phosphine concentration in these treatments was between 755 and 1,328 ppm which also caused complete mortality.

The mortality of *C. ferrugineus* with different exposure periods in Trichy warehouse showed that the highest mortality was observed in T_2 and T_3 but in T_1 treatment the mean mortality was 74.7% despite mean and terminal PH_3 concentration of 1,458 and 1,250 ppm. The day-wise concentration with different treatments (Fig 2) ranged from 1,067 to 2,000 ppm.

At Rajahmundry, complete mortality was observed in T_2 and T_3, but in T_1 the mean mortality of 56.18% was noticed despite mean and terminal PH_3 concentration of 1,995 and 1,976 ppm. The day-wise PH_3 concentration with different treatments (Fig. 3) indicated the range from 1,161 to 2,000 ppm. The trend of complete mortality in T_2 and T_3 was similar at Machilipatnam warehouse as recorded at other locations despite low mean and terminal concentration. The day-wise PH_3 concentration with different treatments (Fig. 4) indicated the range from 183 to 1,120 ppm. The average mortality in T_1 was just 73.4% even at mean and terminal PH_3 concentration of 554 and 73.4 ppm, respectively. No significant variation in mortality was noticed in top as well as bottom layers in any of the treatments, indicating uniform distribution of PH_3 in the stack. The mortality in control (T_4) was 4–9%, probably because the temperature in all locations ranged from 30º to 35ºC and humidity was 55–70%.

When phosphine was introduced as a fumigant, it was considered that an exposure period of 72 h was adequate. Subsequent studies, however, revealed that if the fumigant is to be effective against resistant as well as susceptible insects, a longer exposure period (>5 days) is required (Rajendran, 2007).

The retention of gas was found satisfactory at all the places and it is sufficient to kill the insects; however, it was surprising to get overall low phosphine concentration at Machilipatnam, probably due to leakage of gas through the enclosure. Quality Multi Layered Cross Laminated fumigation covers along with air-tight floor sealing (sand snakes and surgical tapes) was found efficient in managing the pests. The lack of ideal air-tight conditions for fumigation in leaky structures increases the frequency of phosphine fumigation (Lorini et al., 2007).

Bengston et al. (1997) demonstrated sources of ineffective phosphine treatments of bag-stacks of milled rice in woven polypropylene bags. The authors showed that poor results could occur when sealing and other operating procedures are not up to the standard. Poor fumigation practice include use of sheets having holes, and two or more sheets placed by simple overlap, rather than rolling together up to a meter length, leading to rapid loss of phosphine.

Mills (1986) observed that the EPPO recommendations on exposure period as well as concentration may not be adequate for the control of resistant population of *Rhyzopertha dominica* (Fabricius), *C. ferrugineus* (Stephens), *Tribolium castaneum* (Herbst) and *Oryzaephilus surinamensis* (L.). The author suggested that application of sequential dosing and slow-release formulation may be effective against resistant insects. In tests against resistant *C. ferrugineus,* Bell et al. (1990) observed that insect mortality was more with rising phosphine concentration than with falling concentration. Alice et al. (2014) reported that complete mortality of insects *Sitophilus* sp. and *R. dominica* was observed with 2 or 3 tablets and/short or longer exposure periods. However, few populations of *C. ferrugineus* survived in treatment with 3 tablets for 7 days. Control failure due to occurrence of high-level phosphine resistance in milled rice stack against insect populations including *Cryptolestes* spp., was also reported (Rajendran and Narasimhan, 1994; Rajendran and Muralidharan, 2000). Nayak et al. (2000) determined that a target phosphine concentration of 1,450 ppm with 6 days exposure or 720 ppm with 11 days exposure is necessary for controlling phosphine-resistant psocids.

At Trichy, Machlipatnam and Rajahmundry survival of *C. ferrugineus* were noticed in T_1, i.e. treatment with 3 tablets for 7 days despite higher mean concentration upto 1,995 ppm at temperature ranging from 30º to 35ºC.This indicates that *C. ferrugineus* is a difficult pest to be controlled under normal conditions with 7 days of exposure. This could be because of presence of resistant strains. Under similar conditions at Thanjavur, complete mortality was recorded with a mean PH_3 concentration of 1,544 (T_1) and 1,048 ppm (T_1 with 2 tablets). This indicates availability of suspetible strains at Thanjvur. However, complete mortality was recorded in all locations in treatments T_2 and T_3 after 10 days exposure. Thus, it is evident that it is not only the concentration but longer exposure period that is also necessary to control resistant populations of *C. ferrugineus*. Application of quality fumigation covers and effective sealing are important in successful fumigation.

The treated insect vials were kept under observation for further emergence of adults. The data revealed that there were no emergence of insects in the treated vials collected from different locations even after 6 months of storage, whereas insects emerged from the untreated control.

CONCLUSION

Three tablets with longer exposure (10 days) are needed wherever *C. ferrugineus* population was abundant. Quality multi layered cross laminated fumigation covers along with air-tight floor sealing (sand snakes and tape sealing) was found to be efficient in managing the pests. However, tape sealing was found to be suitable to maintain the warehouse in hygienic condition irrespective of its cost.

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