Swamy SVSG, Wesley BJ, Vishnuvardhan S, Sandeep RD (2016) Effectiveness of phosphine fumigation in controlling insect pestsin a rice (*Oryza sativa*) storage warehouse. Pp. 425–428. In: Navarro S, Jayas DS, Alagusundaram K, (Eds.) Proceedings of the 10th International Conference on Controlled Atmosphere and Fumigation in Stored Products (CAF2016), CAF Permanent Committee Secretariat, Winninpeg, Canada.

Effectiveness of phosphine fumigation in controlling insect pests in a rice (*Oryza sativa*) storage warehouse

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ABSTRACT

Over-reliance on phosphine (PH_3) fumigant for control of storage insect pests has resulted in development of resistance in several insect species. An attempt was made to know the effectiveness of fumigation in controlling insect populations of raw rice stored in a warehouse in Machilipatnam, Andhra Pradesh. Insect populations were monitored using stack probes for about 16 months. Insect species, viz. *Tribolium castaneum* (Herbst) and *Cryptolestes* sp*.,* were noticed in raw rice. The storage facility is a rectangular compartment with reinforced cement concrete roof and fumigation of the total facility is common practice. A total of nine fumigation programmes were taken up between 45 and 60 days interval during the study period. Aluminium phosphide 56% (F) tablets were used at 11.95 kg sealing the compartment for about one week. However, the insects were found active throughout except for a little period immediately after fumigation. Presence of adult survivors immediately after aeration also indicated development of tolerance in the existing insect populations and the fumigant survivors are responsible for re-infestations with in short period. Rusty grain beetle [*Cryptolestes ferrugineus* (Stephens)] was found more tolerant than red flour beetle (*Tribolium castaneum).* To extend the effectiveness of phosphine, a strategy including regular sampling and resistance monitoring programmes, probably higher dosages for longer exposure periods ensuring effective sealing of the structure may be advocated.

Key words: Control, Insect, Pests, Phosphine fumigation, Rice, Warehouse

Phosphine (PH_3) as a fumigant has a history of nearly 85 years on which the world grain industry has been relied heavily for control of insect pests during storage for many years; because of its several attributes including cheaper price, versatility and ease in application and wider acceptance as a residue-free treatment.This over reliance has resulted in development of resistance in several stored product insect species including the lesser grain borer, *Rhyzopertha dominica* (Fabricius) (Collins et al., 2005), the red flour beetle, *Tribolium castaneum* (Herbst) (Emery et al., 2011) and the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Nayak et al., 2012).Though several alternatives such as ethyl formate, ethane dinitrile, carbonyl sulphide and sulfuryl fluoride have been developed, they cannot match the benefits offered by phosphine. Hence, the focus has been shifted to managing resistance to phosphine (PH_3) to ensure its future sustainability. Keeping this in view, an attempt was made to understand the effectiveness of fumigation in controlling insect pest populations of raw rice stored in bags in a warehouse maintained by Central Warehousing Corporation (CWC) at Machilipatnam, Krishna District, Andhra Pradesh.

MATERIALS AND METHODS

The storage facility selected for this study is a rectangular compartment of volume 3,320 m^3 with dimensions of 26.65 m× 23.73 m× 5.25 m (length × width × height) withrein forced cement concrete roof with total storage of 954 metric tonnes of raw rice procured and arranged in twelve stacks during March

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2014. The grain moisture ranged from 12 to 14% (wet weight basis) during the period. Insect populations were monitored using stack probes developed by Tamil Nadu Agricultural University for 16 months starting from November, 2014. Insect species, viz. *Tribolium castaneum* and *Cryptolestes ferrugineus,* were noticed to exist in raw rice. A total of four traps (one trap on each side) were installed in a stack at a height of 6 feet (1.8 m) and the number insects collected in the traps were recorded at fortnightly and presented as total number per four traps. Thus, observations were recorded for 16 months, i.e. 32 fortnights. Fumigation of total facility sealing the windows, ventilators and rolling shutters in doorways with the help of paper strips and starch pasteis the common practice being followed at this depot. Since March 2014, a total of 13 fumigation programmes (nine fumigations during the study period) were taken up with 45 to 60 days intervalby the end of March 2016. At each time of fumigation, Aluminium phosphide 56% (F) tablets (Manufactured by United Phosphorus Ltd., and supplied with the trade name; QuickPhos) were used at 11.95 kg sealing the compartment for about one week. Deltamethrin @ 120 g/100 m^2, malathion @ 30 ml/100 m^2 and dichlorvas @ 20 ml/100 m^2 were also used periodically as post fumigation surface treatments.

RESULTS AND DISCUSSION

In spite of all these treatments, the insects found active throughout except for a little period immediately after fumigation as indicated by the trap collections (Table 1).The trap catches during the study period ranged from zero to the maximum of 744 *Tribolium sp.* and from 41 to 395 *Cryptolestes* sp. adult insects. Though insect catches were found reduced in numbers due to immediate effect of fumigation, they were never observed to be nil throughout the period except first and sixth fortnights only in case of *Tribolium* sp. The population fluctuations of both the insect species were mostly due to phosphine fumigation interventions rather than existing climatic factors. It was also observed that higher numbers of insects were collected in the traps while the rice stacks were under fumigation as the insects wander due to suffocation. Thus, during the first four months, the insect trap catches ranged from 0 to 47 of *Tribolium* sp. and 77 to 199 of *Cryptolestes* sp. adult insects. In the next four months, increased numbers of both the insects were found ranging from 26 to 644 and 67 to 395 respectively. In the third phase, the insect populations of both the insects fluctuated ranging from 22 to 744 and 41 to 224 respectively. Further, higher numbers were recorded in the last four months ranging from 70 to 392, and 95 to 253 respectively. Regular presence of insects in the traps indicated that apart from fumigant tolerant adults, the tolerant stages of these insects such as eggs and pupae, while during or after fumigation, continued to develop and emerge as adults. The emergence pattern of adult insects from the rice stacks after fumigation and subsequent aeration at five day

Table 1 Incidence of insect pests in stored rice as indicated by stack probe traps between December 2014 and March 2016

Period of observation		Total number of insects per 4 traps	
Month	Fortnight	*Tribolium* sp.	*Cryptolestes* sp.
14 Dec.	1st Fortnight	0	102
14 Dec.	2nd Fortnight	47	191
15 Jan.	1st Fortnight*	12	77
15 Jan.	2nd Fortnight	17	121
15 Feb.	1st Fortnight	28	199
15 Feb.	2nd Fortnight	0	109
15 Mar.	1st Fortnight*	3	102
15 Mar.	2nd Fortnight	14	103
15 Apr.	1st Fortnight	26	395
15 Apr.	2nd Fortnight	62	244
15 May	1st Fortnight*	46	174
15 May	2nd Fortnight	45	173
15 Jun.	1st Fortnight	87	102
15 Jun.	2nd Fortnight	244	67
15 Jul.	1st Fortnight*	644	175
15 Jul.	2nd Fortnight	93	87
15 Aug.	1st Fortnight	244	137
15 Aug.	2nd Fortnight	240	64
15 Sep.	1st Fortnight*	744	202
15 Sep.	2nd Fortnight	87	118
15 Oct.	1st Fortnight*	172	165
15 Oct.	2nd Fortnight	22	41
15 Nov.	1st Fortnight	91	107
15 Nov.	2nd Fortnight	76	224
15 Dec.	1st Fortnight*	392	245
15 Dec.	2nd Fortnight	115	208
16 Jan.	1st Fortnight	101	218
16 Jan	2nd Fortnight*	133	220
16 Feb.	1st Fortnight	70	253
16 Feb.	2nd Fortnight	75	145
16 Mar.	1st Fortnight*	95	126
16 Mar.	2nd Fortnight	134	95

*Indicates a fumigation was conducted, ended within one fortnight of the trap counts.

interval, revealed a good number of adult insects of both the species (from the 3rd day itself) in the traps and more numbers were found in case of *Cryptolestes* compared to *Tribolium* (Fig. 1). Observance of adult survivors immediately after aeration also suggested the presence of resistance in the existing insect populations and these fumigant survivors would then be responsible for re-infestations within short period. Moreover,there is a wide variation in susceptibility of life stages of different insects; adults are more susceptible than pre-adult stages. Similarly, Rusty grain beetle (*Crytolestes ferrugineus)* was found more tolerant than Red flour beetle (*Tribolium castaneum*).

Insect resistance to phosphine can be attributed to repeated exposure to sub-lethal concentrations probably due to failure in maintaining the concentrations of phosphine gas at levels that can cause lethality of all the stages of all the insects. The findings are in conformity with the observations of Rajendran (1999), and Pattanaik (2012). Rajendran (1999) surveyed India for resistance to phosphine fumigant in stored grain insect pests such as *T. castaneum, Sitophilus oryzae* (L.)*, Rhyzopertha dominica* (Fabricius)*, Oryzaephilus surinamensis* (L.) and *Cryptolestes* spp. and noticed the highest frequency of resistance in *T. castaneum* (100%). Likewise, Kabbashic et al. (2015) also reported that phosphine (PH_3) exposure for five days was unable to disinfest the flour from the red flour beetles. However, the same dose succeeded in disinfesting the test flour from larvae and adults when used for 6 and 7 days.

Besides, some practical difficulties were also observed at the site; that all the compartments are not fumigated at once, and re-infestation from the adjacent compartments is a common phenomenon. Furthermore, the sealing material (newspaper/ brown paper strips and starch paste) may not be strong enough to retain phosphine gas. Monkey menace was also one factor that influenced proper sealing. Keeping these difficulties in view, fumigation of individual stacks under cover with suitable polythene sheet may be preferred than fumigation of entire facility.

Although concentration and exposure time are the main factors that determine toxicity of the fumigant, the length of the exposure time is of greater importance. Phosphine (PH_3) is a slow acting poison that is absorbed slowly by some insects even at high concentrations. However, this problem cannot be circumvented by increased concentrations as extremely high concentrations may cause insects to go into a protective narcosis as reported in case of *Tribolium castaneum* (Bond, 1984). Susceptible adult insects get killed quickly, usually within a day, but immature eggs

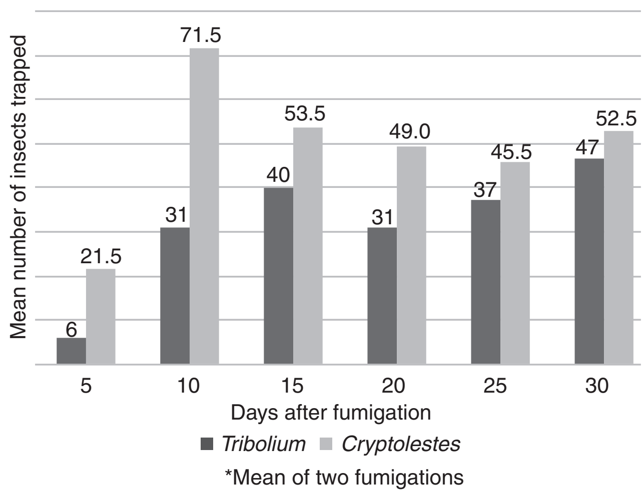

Fig. 1. Emergence trend of adult insects from rice stacks after fumigation and aeration

and pupal stages are tolerant to phosphine and can survive short exposures, even in high concentrations. Fumigation in an unsealed storehouse exposes the insects to a sub-lethal dose of phosphine and renders survival of resistant adult insects, eggs and pupae and continue breeding, passing on their resistance. To kill all stages of the insects' life cycles, the phosphine (PH_3) gas must be present in high enough concentrations for approximately 7 days. Rajendran (1992), reported that the primary cause of development of resistance is the use of substandard fumigation techniques particularly; dosages of phosphine and arresting gas leakages; which can be overcome by enclosing the grain stacks in polythene sheets. Tayler and Harris (1994) demonstrated a technique of good quality fumigation of bag stacks, under laminated PVC sheets weighing 360 g/m^2 with effective sealing at floor level by using larger sand snakes of 15 cm diameter and could retain at least 50% of the applied dose of phosphine (PH_3) for 7 days or longer. Hence, (PH_3) gas monitoring to check the levels of phosphine gas in grain stacks or in whole compartment under fumigations is to be made essential practice for a scientific and successful fumigation operation.

To extend the effectiveness of phosphine, a strategy including regular sampling and resistance monitoring programs, probably higher dosages for longer exposure periods ensuring effective sealing of the structure while limiting the number of fumigations should be adopted. Thorough studies are to be taken up on resistance development to phosphine fumigation with particular to the insect pests under report and other storage insect pests in general. However, present study suggested the immediate need of revising the dosage schedules and improving the standard of fumigations. Awareness and training on importance of effective fumigation should also be given not only to the warehouse managers but also to all the persons directly involve in this.

ACKNOWLEDGEMENTS

The authors thank the Central Warehousing Corporation, Machilipatnam, Andhra Pradesh for extending cooperation during the study. Thanks are also due to Mr T. Samatha Rao, Field Investigator for the technical assistance and Dr D. Bhaskara Rao, Dean (Ag. Engg.), ANGRAU for constant encouragement.

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