Pakistan J. Sci. Ind. Res., Vol. 31, No. 2, February 1988

PROTECTION OF STORED FOOD GRAINS IN VILLAGES
Suitability of Different Grain Receptacles for Phosphine Fumigation

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(Received May 20, 1986; revised November 16, 1987)

Retention of phosphine gas in five different storage receptacles, commonly used in villages, was studied to assess their suitability for phosphine fumigation. Mud structures i.e. mud-bins, kuccha and pucca kothies did not retain phosphine gas for more than 24 hr. Metallic bins and plastic drums retained effective concentrations of phosphine over a period of 6 and more than 8 days respectively. The mud bins could be made gastight by applying an inner lining of polyethylene sheet.

Key words: Storage, Fumigation, Protection, Foodgrains, Receptacles.

INTRODUCTION

In Pakistan about 65 to 70 % of total grain production is presently retained in villages by the farmers for self-consumption, seed purposes and barter deals [6]. Since about 91 % farms in Pakistan are of the size less than 10 ha. [12], nearly 13.0 million tonnes of grain are stored at numerous small sized storages, scattered throughout the country. The mud built receptacles used for the storage of grain at villages are generally called "bharollas" and "kuccha kothies" whereas masonary structures are called "pucca kothies" and "pallies" when made of reeds only. Recently, the use of metallic bins, made of G.I. sheets, is also becoming popular. During storage, the activities of insects, rodents, birds and fungi cause heavy losses to grains, depending upon the length of storage, climatic conditions and type of storage receptacles.

Besides heavy quality losses, grains stored at village level also suffer weight loss due to insect activities, estimated to range from 2.5 to 5 % over a storage period of one year [1,6,3]. Under the general climatic conditions of Pakistan, grain at the time of harvest is normally dry and major cause of losses are insect pests [2].

Fumigation of stored grain with phosphine gas, if undertaken properly, is a safe and effective method for the control of insect pests of stored grain. Phosphine leaves no toxic residues in grains [5] and cause no harm to seed viability [14]. Moreover, its availability in solid form (AIP tablets which generate phosphine on exposure to moisture in air) also make it convenient to use it at village level. However, phosphine fumigation, although it is being practised at public sector storage, has found a very little application at village level grain storage. This is because of the lack of proper airtight granaries, since the success of phosphine fumigation depends upon achieving a level of its concentration (C), retained over a particular exposure time (T) or generally expressed as the product of C x T [11]. Studies were, therefore, undertaken to assess different grain receptacles for gastightness and thus, their suitability for phosphine fumigation. Experiments were also conducted to improve the gastightness of mud bins.

MATERIALS AND METHODS

Most of the work reported here was done in the laboratory. The "kuccha" and "pucca" kothies were studied in a farmer's house in a village near Nawabshah (Sind).

The mud bins used were oval shaped with an internal volume of about 0.45 m^3 and wall thickness of about 4.0 cm. These bins were comparatively smaller structures made of clay, finely chopped wheat straw and cow dung. The "kuccha kothies" were also made of similar materials but were rectangular in shape, built on raised platform of baked bricks. The dimensions of these kothies were 2m high from floor level, 1.66 m wide and 1.22 m deep with an internal volume of 4.05 m^3. The "pucca kothies" had shapes similar to "kuccha kothies", except that these were made of baked bricks using mortar cement for binding. The "pucca kothies" were not plastered and two units tested were slightly different from each other in size. Both types of kothies had circular openings at top for loading grain and a small outlet at floor level for discharging the grain. The "pucca kothies" had a window in the middle section, in addition to the openings for grain.

The metallic bins used were of cylindrical shape, having an internal dia. of 0.559 m. Each metallic drum had an internal volume of 0.25 m^3 and were provided with tightly fitted metallic lids. The bins were made of G.I. sheet of 22 gauge.

Plastic drums having tightly fitted lids and metallic clamps to gird it up and make it gastight were purchased from the local market. These cylindrical drums had an internal volume of 0.12 m^3 with a dia. of 0.4 m and height of 0.8 m.

Possible gas leakage sites of the mud bins, kothies and metallic drums were plugged and sealed using mud plaster. After a few hours' drying, cracks appeared on the plaster surface and were again filled with mud plaster.

A thin coat of asphalt in kerosene oil (in 1:5 ratio) was applied on the outer surface of the sealed mud-bins with a brush to improve gastightness of the bins. In another set of experiments, the inner surface of mud bins was lined with 0.1 mm thick polyethylene sheet for possible improvement in gastightness. For this purpose, a tube of polyethylene sheet having 4.25 m circumference and 2.5 m length was used for being shaped into a hollow bag by sealing one open end by tying it with a jute thread. The polyethylene bag was placed into the mud bin and filled with bulk wheat. This caused the sheet to be pressed with the walls of mud bin. The open end of polyethylene column was folded and similarly tied with jute thread after placing AIP tablets. The bins were finally closed from the top with circular lids made of mud and straw and sealed similarly using mud plaster.

Prior to the placing of aluminium phosphide tablets, nylon tubings (about 6.0 mm I.D.) were introduced, both at the top and bottom portions of each structure. These tubes were used to draw air samples from the fumigated structures to determine the concentration of phosphine gas after 24 hr. intervals, using the method described by Taylor [15].

Aluminium phosphide (AIP) tablets and pellets, each giving 1.0 and 0.2 g. of phosphine gas respectively were used to generate phosphine gas. The amount of phosphine gas applied in the receptacles tested, varied from 1.55 to 6.66 g./cu. m. of space.

Maximum theoretical concentrations of phosphine in air (ppm) for a particular application rate were calculated, assuming the system to be cent per cent gas-tight, by multiplying the amount of gas applied (g/m^3) in the known volume with a factor of 718[17]. The net free space in the structures holding grain were calculated by multiplying its volume with a correction factor of 0.40 for the air displaced by grain [9].

Grain samples collected before and after fumigation were analysed to record the mortality of insects. The samples were further incubated at 30 ± 1° and 55 % R.H. to check the emergence of insects, indicating the possible survival of eggs, larvae etc.

RESULTS

The results obtained by monitoring the concentration of phosphine gas in different storage receptacles are presented in Table 1. It will be seen that structures such as mud bins, kuccha and pucca kothies did not retain sufficient amounts of phosphine gas for more than 24 hr. The concentration of phosphine gas detected is also shown as percentage of its maximum theoretical concentration (Table 1), indicating a very poor degree of gastightness of these receptacles. After 24 hr. of the exposure of AIP tablets, only 4.37, 12.35 and 10.70 % of total phosphine gas was detected respectively in mud bins, kuccha and pucca kothies, which rapidly dropped to below detection limits within 36 hr. The average daily loss of phosphine gas from mud bins, kuccha and pucca kothies was worked out to be about 95, 87 and 89 % of the total gas generated respectively.

The plastic drums tested retained almost all the phosphine produced after 24 hr, which slowly dropped to 23.16 % of the calculated maximum after 8 days of the exposure of AIP tablets. The average daily loss of phosphine gas from plastic drums was worked out to be about 9.6 % of the theoretical maximum concentration. Metallic bins showed were more prove to bakage than plastic drums which retained 61.54 % of the total gas after 24 hr. The rate of decline in the concentration of phosphine gas from metallic bins was detected to be 15.37 % daily.

Table 2 shows the retention of phosphine gas in mud bins after applying three different methods of sealing. It will be seen that mud plastering or application of thin coat of asphalt on the outer surface of mud bins did not improve gastightness. The concentration of phosphine gas retained after 24 hr. of the start of fumigation was only 4.70 % of the total gas in asphalt coated mud bins and 4.23 % in mud bins sealed using mud plaster. The concentration of phosphine rapidly dropped in mud bins sealed either way and subsequently dropped below detection range within 36 hr. of the start up of fumigation. However, mud bins showed significant gastightness when the inner lining of polyethylene was applied, with an average of 61.98 % of total phosphine gas retained after 24 hr. The decline in concentration of phosphine gas was slowed down to an average leakage of 15.7 % daily as compared to about 95 % in mud bins without the application of inner lining.

Table 3 shows the mean number of insects recovered per sample of 200 g of wheat taken before and after fumigation in mud bins, lined with polyethylene sheet. It will be seen that no live insects were recovered from samples taken after such fumigation against an average of 51.0 live insects per sample recorded in unfumigated wheat.

The samples of grains fumigated in polyethylene lined mud bins showed no emergence of any insect species over 45 days' incubation, against an average of 203.75 insects per 200 g. of unfumigated (control) samples of wheat.

DISCUSSION

The results (Table 1) showed that the storage receptacles tested, either made of mud or bricks were not gastight enough to retain effective level of phosphine for more than 24 hr., against a minimum exposure of 5 to 7 days required for the complete disinfestation of grain [18,19]. With the major amount of fumigant (about 95 % daily) being lost through leakage, fumigation of grains in these porous walled receptacles would be ineffective and waste-

Table 1. Relative retention of phosphine gas in different storage receptacles after the placement of aluminium phosphide tablets (R.H.=60 %, average temperature = 22.5 ± 3 °C).

Storage receptacle tested	Approx. volume(m^3) of the receptacle	Amount of phosphine applied (g/m^3)	Concentration of phosphine gas in air shown in ppm and also as percentage of maximum calculated concentration (shown in brackets) after days of exposure of aluminium phosphide tablets in the receptacles.								Average daily leakage of phosphine
			1	2	3	4	5	6	7	8	(% of total gas)
Mud bin	0.45	6.66	209.0 (4.37)	–	–	–	–	–	–	–	95.6 %
Kuccha kothi	4.05	1.50	133.0 (12.35)	–	–	–	–	–	–	–	87.6 %
Pucca kothi	4.28	1.64	126.0 (10.70)	–	–	–	–	–	–	–	89.3 %
Metallic bin	0.25	1.60	707.0 (61.54)	498.0 (43.34)	272.0 (23.67)	212.0 (18.45)	157.0 (13.66)	96.0 (8.35)	–	–	15.4 %
Plastic drum	0.12	1.66	1413.0 (118.55)	1152.0 (96.65)	971.0 (81.46)	921.0 (77.27)	555.0 (46.56)	377 .0 (31.63)	310.0 (26.00)	276.0 (23.16)	9.6 %

Table 2. Relative retention of phosphine gas in different mud bins after applying three different sealing methods.
(i) R.H. = 68.0 %; (ii) Average temp. = 29.0 ± 4°; (iii) Average volume of mud bins = 0.45 cu. m.; (iv) Dose of phosphine = 1.77 g/cu.m. of free space.

Sealing methods used	Concentration of phosphine gas in air shown in ppm also as percentage of and maximum calculated concentration (shown in brackets) after days of exposure of aluminium phosphide tablets in mud bins							Average daily leakage of phosphine
	1	2	3	4	5	6	7	(% of total gas)
Mud bin sealed with mud plastering	135.0 (4.23)	–	–	–	–	–	–	95.8 %
Mud bins sealed with mud plastering and a thin coating of asphalt applied on outer surface	150.0 (4.70)	–	–	–	–	–	–	95.3 %
Mud bins sealed using inner linning of polyethylene sheet	1976 (61.98)	1288 (4040)	739 (23.18)	530 (16.62)	314 (9.85)	185 (5.80)	- –	15.7 %

Table 3. Average population of some insect pests recovered per sample (200 g) before and after fumigation of wheat in mud bins lined with 0.1 mm thick polyethylene sheet. Other conditions were.

(i) R.H. = 70.0 %; (ii) Average temperature = 27.0 ± 3.0°; (iii) Average volume of mud bins = 0.45 m^3.

Dose of phosphine (g/m^3)		Prefumigation insect population												Postfumigation insect population											
		T.castaneum			*T.granarium*			*R.dominica*			*S.oryzae*			*T.castaneum*			*T.granarium*			*R.dominica*			*S.oryzae*		
		A	L	P	A	L	P	A	L	P	A	L	P	A	L	P	A	L	P	A	L	P	A	L	P
1.77	(Alive)	5.50	0.75	0.25	–	–	–	13.50	–	–	16.25	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	(Dead)	9.40	1.50	–	23.5	–	–	31.50	–	–	15.75	–	–	9.50	–	–	17.75	–	–	29.75	–	–	15.25	–	–
Control	(Alive)	4.0	1.0	1.0	–	–	–	9.0	–	–	10.0	–	–	16.0	8.0	3.0	–	–	–	17.0	–	–	7.0	–	–
	(Dead)	8.0	–	–	13.0	–	–	18.0	–	–	12.0	–	–	12.0	–	–	15.0	–	–	28.0	–	–	19.0	–	–

A = Adult; L = Larva; P = Pupa.

ful. The effective level (above 200 ppm) of phosphine gas could not be maintained over the required period of 5-7 days in such porous receptacles, by simply increasing the dose of phosphine. The very high dose of phosphine, if applied to compensate leakage, would be uneconomical and a further wastage of the fumigant, whereas after shorter exposures to phosphine, the surviving insects or their tolerant stages would rapidly re-build their population, since no residual toxicity remains in the grain. Moreover, the mud and masonry structures are generally built within the dwellings at villages, a heavy leakage of toxic gas like phosphine may create hazards to human and animals.

The results (Table 1) show that metallic bins retain sufficient concentration of amounts of phosphine over 6 days' exposure and hence were gastight enough for carrying out effective fumigation of grain. The average CT product of 63.3 $g.hr/m^3$ achieved at a dose rate of 1.6 g/m^3, over 6 days' exposure, seems sufficient for the complete disinfestation of grain [19].

For small-scale storage of grain, plastic drums with airtight lid were found to be the best gastight receptacle (Table 1). At a dose rate of 1.66 g/m^3, a CT product of 195.5 $g.hr/m^3$ was achieved over 8 days' exposure. Drums from the chemical industry and from which chemicals have been drained could safely be used for the fumigation of upto 100 kg of foodgrains or seed. The exposure of one AlP pellet (generating 0.2 g phosphine) in such a drum will thus produce and retain phosphine gas in concentrations sufficient for complete disinfestation of grain.

The results of comparison of three different sealing methods applied on mud bins (Table 2) showed that the application of mud plaster or thin coat of asphalt on the external wall of the bins did not improve its gastightness. Leakage of phosphine was detected through small cracks appearing on the asphalt layer using silver nitrate impregnated filter paper strips. The cause of cracking of the asphalt layer was found to be due to its separation from mud wall after few hours of its drying. The results confirm the studies of Giles [7] who found that mud granaries could not be made airtight by the application of bitumen coatings.

The results (Table 2) also showed that mud bins could be made sufficiently gastight and thus suitable for phosphine fumigation by applying an inner lining of polyethylene sheet. The application of polyethylene bag in mud bins and its filling with bulk grain shapes it into the shape of a bin, where the internal pressure of the grain exerted on polyethylene sheet is balanced against mud walls. The grain filled in polyethylene could be fumigated inside the mud bins by placing AlP tablets in the bag before sealing its open end. Polyethylene sheet of 0.1 mm thickness is available in the market with a maximum circumference of 4.25 m. A single piece of such polyethylene tube could conveniently be used for the inner lining of mud bins of sizes commonly built at our villages. The length of the tube could be worked out according to the height of the bin with an extra length of about 1.5 meters to be used for folding and sealing open ends. The polyethylene tube may get damaged due to the movement of grain and hence be discarded after one season's storage. The findings confirm the studies of O'Dowd [13], who reported that mud granaries could be made airtight by applying an inner lining of polyethylene or PVC sheets.

The results presented in Table 3 show complete control of all the insects in grain samples after fumigation in mud bins, sealed by inner lining of polyethylene sheet. Since average CT products achieved over a period of 6 days were about 164 $g.hr/m^3$, eggs and larvae of insects which normally survive shorter exposures of phosphine due to their lower rate of respiration [8,10] were also controlled. This was further verified by incubating the fumigated grain over 45 days, showing no emergence of any insect species.

The penetration of phosphine gas through bulk grain has been worked out to be in a radius of 30 meters [4] and hence AlP tablets could safely be applied on top of grains stored in grain receptacles of commonly built sizes at our villages.

The airtight sealing of grain with high moisture content, especially under conditions of higher temperature, may lead to moisture accumulation and subsequently to fungal spoilage. Therefore, grain at the time of storage must always be dry (moisture content below 12 %) and in cool condition.

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