FUMIGATION OF BULK WHEAT IN CONCRETE SILOS IN BANGLADESH USING ALUMINIUM PHOSPHIDE PREPARATIONS

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Abstract: Trials were carried out to determine the distribution of phosphine and *Ct*-products achieved in concrete wheat storage cells when fumigated with aluminium phosphide preparations using various application patterns. With aluminium phosphide tablets added to the grain stream on loading in batches at half-hourly intervals, adequate *Ct*-products were achieved throughout the grain bulk after 7 days, but at some points no phosphine was observed until 1.5 days after application. With the total dosage of tablets ($\equiv 2gPH_3\ t^{-1}$) added to the grain surface when the bin was half-full, with the remainder of the load added after dosing, the gas evolved dispersed downward only, with no phosphine observed above the band of tablets. With the complete dosage added to the grain surface, the phosphine dispersed throughout the bulk but inadequate *Ct*-products for insect control were obtained after 6 days at 30 m depth and it appeared unlikely that a satisfactory *Ct*-product would be attained even after 10 days. In all of the trials substantial leakage of phosphine into adjacent bins was noted.

With the threat to phosphine fumigation posed by the resistant insect strains present in Bangladesh, it is important that fumigations be carried out effectively in silos. It is concluded from these trials that a dosage of $2gPH_3\ m^{-3}$ (i.e. 3 tablets per tonne) is satisfactory but a 7 day exposure period is required to ensure adequate gas distribution. The fumigant preparation should be added so that it is distributed at least at several levels in the bulk. Application as a single layer, either at the surface or in the bulk, is not a satisfactory method.

1. INTRODUCTION

The four Ministry of Food silo complexes were constructed under the first IDA Grain Storage Project during 1968-70. The complexes are of 100,000, 2 x 50,000 and 25,000 tonne capacity and are based on multiples of 750 tonne circular bins, 450 tonne star bins and 175 tonne semi-circular bins. The silos were constructed using the conventional slip-form technique. Recent reports from Australia (D. Ellis, personal communication) assert that concrete silos of similar vintage and identical construction in that country, particularly in coastal areas, have physically deteriorated to a considerable extent and can no longer be considered as suitable for fumigation processes.

The Bangladesh silos were equipped at the time of construction with automatic dispensers for aluminium phosphide pellets, but these were never used. Fumigation of imported wheat has, however, been carried out on a routine, if somewhat *ad hoc*, basis over the years using hand-dispensed aluminium phosphide tablets added to the grain stream. However these procedures do not appear to have been effective. Very high insect populations (in excess of 2,000 per kg) were present in residues from silo hopper bottoms in Chittagong and observations on wheat stocks issued from silos to other storage depots in many parts of the country suggested that infested wheat was not uncommonly being despatched from silos.

In view of the foregoing, it was decided to monitor a series of fumigations in order to assess the technical efficiency of the procedures recommended and to determine whether fumigation of grain in silo bins with phosphine was any longer an appropriate approach. The well-established phenomenon of phosphine resistence in Bangladesh would obviously have an influence on this determination. This paper gives details of five experiments undertaken to study the distribution and retention of phosphine in silos.

2. TRIALS

2.1 Trial 1

This trial was carried out to determine to what degree phosphine concentrations could be maintained in an empty concrete silo bin and to determine whether leakage into adjacent bins was significant.

2.1.1 *Methods:* A 750-tonne empty round bin at the Narayanganj silo complex, some 20 km south-east of Dhaka, was selected for this trial. The bin under test, No. 108, was situated at the extreme north-west corner of the complex which is aligned roughly on a N/S axis. This bin had some 60% of its external circumference permanently exposed to the elements and the moderate, prevailing NNW wind. The internal dimensions of the bin were: height 35 m, diameter 6 m, volume 1,000 m^3.

Grain could be loaded into the bin from a belt conveyor via a 65 x 65 cm hatch in the concrete floor over the bins and loaded out via a conventional steel hopper at the base of the silo, leading into a delivery chute with chain operated slide control. A 35 x 35 cm inspection and access hatch was cut into the bottom hopper. A cowl-type ventilator was present on the flat exposed cap of the bin. Two 20 x 20 cm ventilation ports led into the two adjoining star bins at the very top of the bin wall (Fig. 1).

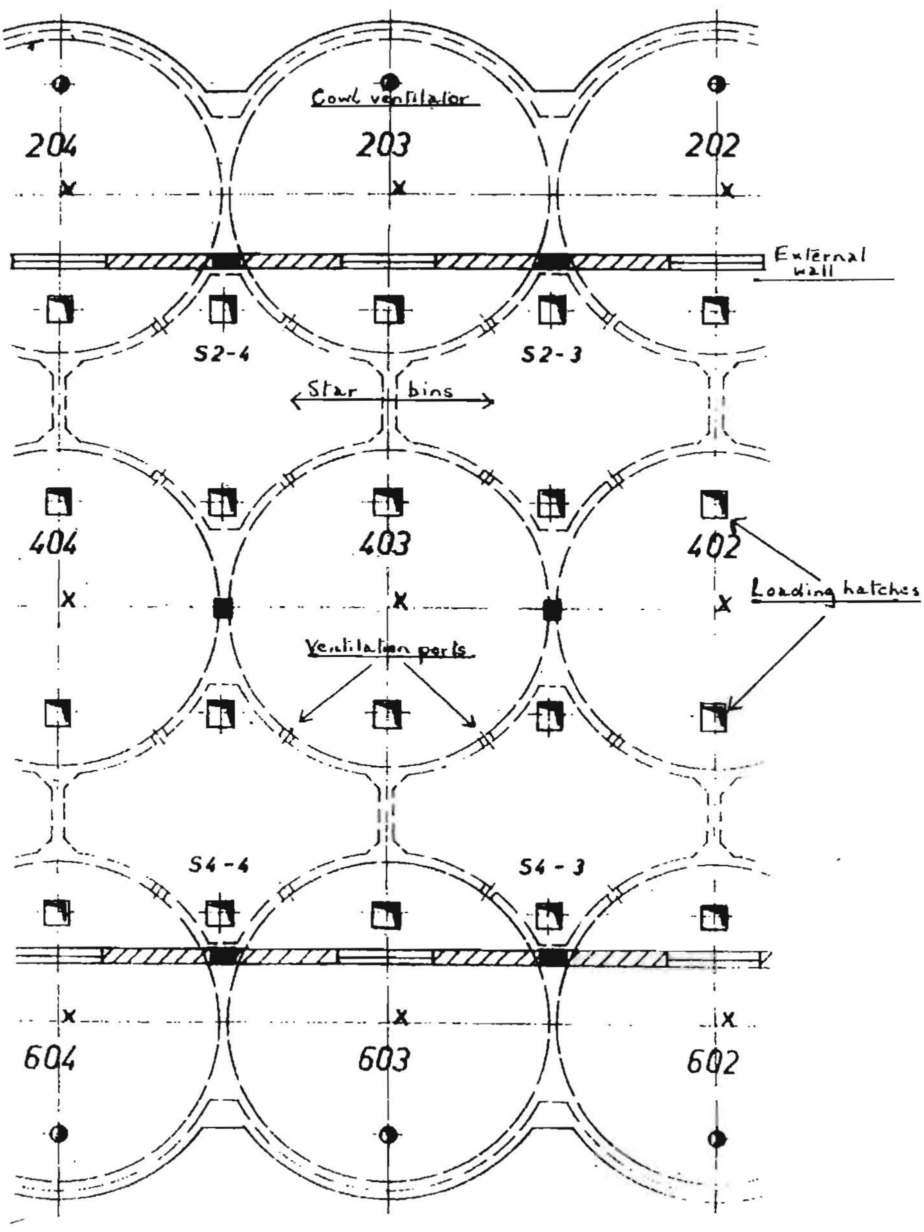

Fig. 1. Narayanganj silo complex - section of bin layout as seen from above.

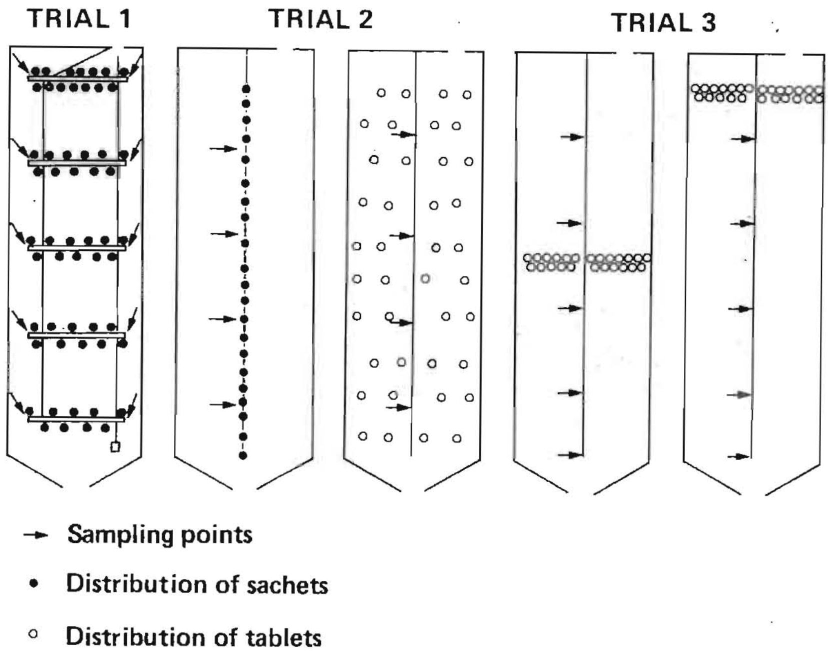

Fig. 2. Position of gas sampling lines and fumigation preparation in trials to investigate phosphine distribution in silo bins.

A rope and bamboo pole framework was assembled on the bin-deck floor. Polyethylene tubing (1.8 mm diam.) was taped to this framework to provide six pairs of gas sampling points at various depths in the bin (see Fig. 2). After assembly, sachets of an aluminium phosphide preparation (Detia Gas-Ex-B) were tied to the six bamboo poles at 30 sachets per pole (180 x 34 g sachets in total, equivalent to $2gPH_3$ m^{-3} in the bin). The framework was lowered into the bin through the loading hatch and was held in place by the use of weights and a combination of fine and coarse supporting ropes. The cowl ventilator was sealed with polythene sheet and both top and bottom hatches were sealed with tape. The bin atmosphere was at 23°C, 55% relative humidity at the start of the trial.

Gas sampling lines were also lowered to the centre of the empty adjoining round bin 107 and star bin S1-8.

2.1.2 *Gas concentration measurement:* All twelve lines were cleared, using a footpump, some eighteen hours after placement of the fumigant. Dräger Model 31 multi-gas detector pumps were used with CH 21201 PH_3 60/a detector tubes for normal readings. For trace readings in adjacent bins and hatch and hopper areas CH 31101 PH_3 0.1/a detector tubes were used. Throughout the trial, lines were cleared with a used detector tube prior to taking any reading and two separate readings were taken at all points. Readings were taken at roughly twelve-hourly intervals for the first three days and thereafter every twenty four hours.

2.1.3 *Results:* The mean concentration of phosphine observed in Bin 108 is shown in Fig. 3. Table 1 summarises the *Ct*-products achieved after various times. The phosphine concentration observed and *Ct*-products attained in adjacent bins is given in Table 2.

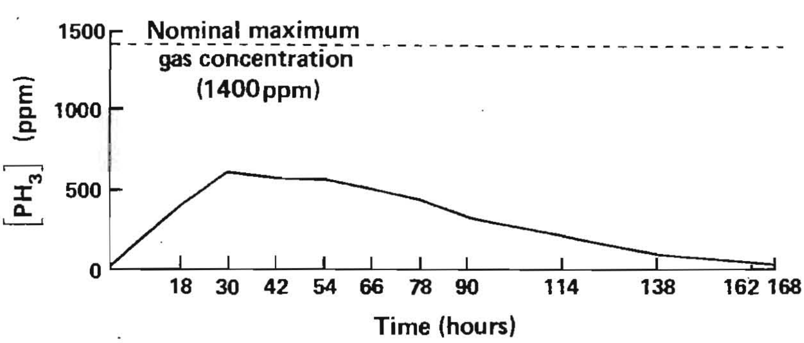

Fig. 3. Phosphine concentration (mean of 12 sampling points) observed in Trial 1 - Bin 108 treated empty at $2gPH_3\ m^{-1}$.

TABLE 1

Ct-products achieved in Bin 108 treated at $2gPH_3\ m^{-3}$ when empty (Trial 1).

Time after dosing (hours)	*Ct*-product achieved (g h m^{-3})		
	Mean of 12 points	Maximum	Minimum
72	48	51.3	45.2
96	59	62.8	54.5
120	65	69.8	60.1
144	69	77.2	63.4
168	70	79.1	64.8

2.1.4 *Discussion:* The evolution, build-up and dissipation of phosphine were extremely uniform throughout the bin. There was nothing to indicate that significant air movements were influencing gas concentrations nor were there any readings suggesting layering or

TABLE 2

Phosphine concentrations (ppm) and *Ct*-products (g h m^{-3}) in regions adjacent to Bin 108 during Trial 1.

Time after dosing (hours)	Location			
	Bin 107	Bin S1-8	Hatch Area	Hopper Area
12	16	28		
24	31	99	15	10
48	38	128	4	10
72	30 (3.2)[a]	50 (9.2)[a]	0	10
96	21 (3.9)	36 (10.7)	0	5
120	6 (4.2)	22 (11.5)	10	5
144	2.5 (8.6)	17 (12.1)	0.5	10
168	4.0 (8.7)	35 (13.1)	-	-

a *Ct*-products

sinking of gas even by the end of the seven-day trial period. It is evident that significant leakage either through the bin wall or the ventilation ports took place, since at no time at any sampling point did the phosphine concentration exceed 43% of the nominally available 1400 ppm (2.0 g m^{-3}) and readings as high as 190 ppm were achieved in the adjacent star bin (S1-8). Readings in the star bin were consistently higher than those in the round bin (Table 2), reflecting either the much greater area of common bin wall with Bin 109, the trial bin under fumigation, or the influence of the ventilation port leading directly into the star bin from Bin 108. There was no direct ventilation port connection between Bin 108 and the round bin (107) but there was a port connection between the star bin and the round bin (see Fig. 1).

The *Ct*-products recorded for the 3-7 day period (Table 1) indicate a barely adequate fumigation result for some susceptible species. The dosage rate of $2gPH_3$ m^{-3} is equivalent to 3 tablets per tonne of grain, the standard recommendation for a full bin.

2.2 Trial 2

Trial 2 was carried out to determine whether similar gas concentrations were achieved in a treated bin filled with wheat as were achieved in Trial 1 and to replicate the treatment both in a round bin with no external wall surface exposed to the elements and in a star bin with a greater relative surface area of bin wall.

2.2.1 *Methods:* In this trial three bins, Nos 108, 403 and S1-7, were treated at a rate equivalent to $2gPH_3\ m^{-3}$ with aluminium phosphide preparations. Gas sampling lines were attached to the central thermocouple cable at four depths in each bin; the gas sampling lines in the bins adjacent to Bin 108 from Trial 1 remaining in position. Brass gauze filters were fitted over the ends of the lines to prevent blockage by grain. Bin 108 was filled with 750 tonnes wheat (22°C, 12.2% moisture content) and fumigated using sachets (Gas-Ex-B) in order to duplicate the gas evolution pattern of Trial 1. The sachets (180 x 34 g each) were tied to the central thermocouple cable in groups of 10. Bin 403 was filled with 760 tonnes of wheat (21°C, 12.0% moisture content) and treated with 240 x 3 g aluminium phosphide tablets (Phostoxin) added in batches to the grain stream every half-hour over the four hour loading period. Bin 403 was a round bin in the central row of the complex without any exposed external wall surface, but with ventilation ports leading into all four ajoining star bins. Bin S1-7 was filled with 450 tonnes wheat (22°C, 12.4% moisture content) and treated with a total of 1,200 x 3 g aluminium phosphide tablets added to the grain stream in batches of half-hourly intervals during filling of the bin. After filling and treatment, the top and bottom hatches of each bin were sealed with tape.

2.2.2 *Readings:* Readings were taken as in Trial 1.

2.2.3 *Results and Discussion:* Phosphine concentrations observed for the four individual gas lines in Bins 403 and S1-7 are shown in Figs 4 and 5. No such presentation of results is possible for Bin 108. The initial, heavy concentrations of phosphine evolving in close proximity to the gas sampling points did not dissipate to the point at which meaningful readings (i.e. < 3000 ppm) could be obtained until after six days from the start of the trial (see Table 3). At day 12 there was still an average concentration of 755 ppm. Therefore, this fumigation told us little about actual concentrations achieved in a normal fumigation. Some movement and leakage of phosphine into adjacent bins through the bin walls and/ or ventilation ports took place (Table 3).

Table 4 shows the *Ct*-products acheived in Bins 403 and S1-7 for the 3-7 day fumigation period.

It can be seen that with this form of treatment phosphine

TABLE 3.

Phosphine concentrations (ppm), at four depths in Bin 108 after treatment when full with $2gPH_3\ m^{-3}$, with phosphine concentrations in the ajoining star and round bins (Trial 2, phosphine-releasing sachets close to the sampling points).

Time after dosing (hours)	Bin 108				Bin S1-8	Bin 107
	9 m	15 m	21 m	27 m		
24	> 3000	> 3000	2700	> 3000	1.0	0
48	> 3000	> 3000	> 3000	> 3000	10.0	10.0
72	> 3000	> 3000	> 3000	> 3000	8.0	8.5
96	> 3000	> 3000	> 3000	> 3000	5.0	5.0
120	> 3000	> 3000	> 3000	> 3000	6.5	6.5
144	3000	> 3000	2600	> 3000	4.0	4.0
168	2400	3000	1700	> 3000	3.0	4.0
192	1950	2500	1100	2700	3.0	3.0
216	1500	2000	850	1800	line cut	2.0
288	850	1200	170	800	-	1.0

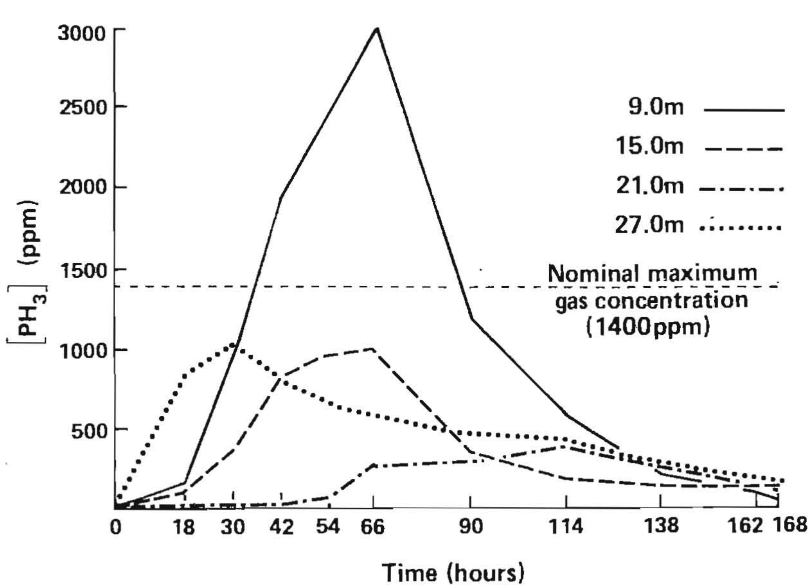

Fig. 4. Phosphine concentrations in 760 t wheat in Bin 403 treated with $2gPH_3\ m^{-3}$ added as tablets during loading - Trial 2.

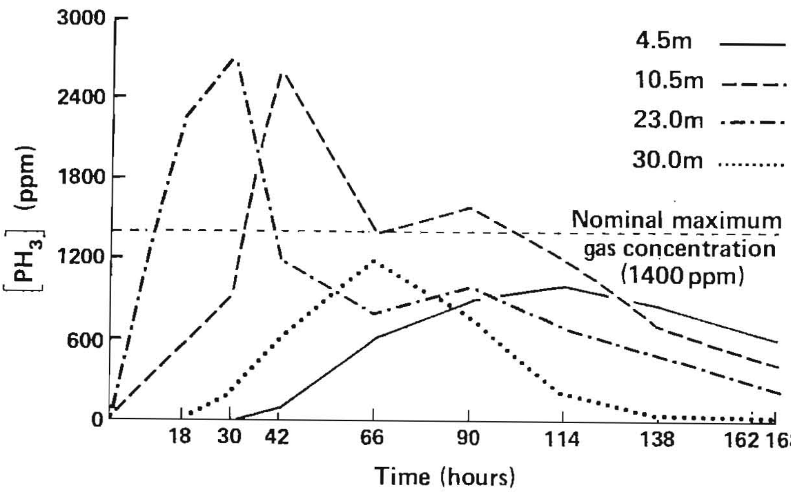

Fig. 5. Phosphine concentrations in 450 t wheat in star Bin S1-7 treated at 2gPH_3 m-3 added as tablets during loading - Trial 2.

TABLE 4

Ct-products (g h m^{-3}) achieved in Bins 403 and S1-7 fumigated when full at 2gPH_3 m^{-3} (Trial 2, phosphine-releasing tablets added to the grain stream at half-hourly intervals).

Time after dosing (hours)	Bin 403				Bin S1-7			
	9 m	15 m	21 m	27 m	9 m	15 m	21 m	27 m
72	161.1	60.3	N/R	74.4	N/R	138.4	146.9	N/R
96	204.4	73.7	N/R	90.6	53.0[b]	188.8	178.5	72.7[c]
120	224.9	80.3	31.7[a]	109.1	85.6	229.1	202.7	88.3
144	223.0	84.8	42.3	113.2	113.9	254.6	219.5	92.5
168	235.7	89.0	48.0	118.9	136.2	271.3	229.4	94.0

a Computation based on readings commencing at 48 hours.
b Computation based on readings commencing at 36 hours.
c Computation based on readings commencing at 24 hours.
N/R Not calculated, *Ct*-product zero or very low.

concentrations varied widely with the depth in the bins. No gas was recorded at all at the 21 m depth in Bin 403 for the first thirty six hours. Even after 7 days from dosing the *Ct*-product (Table 4) achieved there would have been inadequate for complete control of susceptible *Sitophilus oryzae* and resistant strains of *Rhyzopertha dominica*. However, the 120 hour *Ct*-product at 21 m (48 g h m^{-3}) may have been just adequate to achieve complete control of these species. At all other points in both bins a seven day exposure would have produced *Ct*-products (> 80 g h m^{-3}) which were probably quite adequate for complete control at these temperatures (Hole, 1981).

The high concentrations and *Ct*-produced recorded at other points indicate that leakage of gas is much reduced by the presence of the bulk wheat and that the increased surface area of wall in the star Bin S1-7 did not apparently give rise to reduced gas concentrations within the bin. Nor did the presence of four unsealed ventilation ports above the grain at the top of Bins 403 and S1-7 appear to exert any significant effect of gas levels within the bulk.

The distribution of the fumigant is important for short duration fumigations (Heseltine, 1973) but is not critical if sufficient time can be allowed to permit phosphine concentrations to equilibrate throughout the bin. Since instructions for application of fumigant even at half-hourly intervals will probably not be followed rigorously at the silo complexes in Bangladesh in practice, it remains to be seen whether the application can be yet further simplified without compromising the desired result.

2.3 <u>Trial 3</u>

This trial was carried out to determine to what degree and over what period of time phosphine, evolved from aluminium phosphide tablets, would penetrate a grain bulk in a silo from a central position in the grain bulk or when applied at the top of bin.

2.3.1 *Phosphine evolved from tablets placed half-way down a full wheat bin.*

2.3.1.1 *Methods:* Gas sampling lines were taped to the central thermocouple cable in round Bin 403 at 4.5 m, 10.5 m, 16.5 m, 23 m and 30 m depths, as previously described. 375 tonnes of wheat (24°C 14.5% m.c.) were loaded then into the bin. Aluminium phosphide tablets (1920 x 3 g, Phostoxin) were deposited onto the grain surface in one operation through both loading hatches. A further 375 tonnes of wheat from the same source were added to the bin. Both top hatches were then closed.

2.3.1.2 *Gas concentration measurements:* Readings, as described in Section 2.1.2, were taken daily at each point and the mean of two readings was recorded.

2.3.1.3 *Results and Discussion:* The variation in gas concentration at 16.5 m, 23.0 m and 30 m is shown in Fig. 6. No phosphine was recorded at 4.5 m and 10.5 m depths. *Ct*-products for the 3-8 days after dosing are given in Table 5.

TABLE 5

Ct-products achieved in Bin 403 treated with aluminium phosphide tablets applied at 2gPH_3 m^{-3} in a band half way down the grain bulk (Trial 3).

Time after dosing (hours)	Depth in bin [a]		
	16.5 m	23 m	30 m
72	53.8	156.0	N/R
96	63.4	256.5	N/R
120	66.7	350.6	26.0[b]
144	68.2	411.2	68.7
168	69.1	445.5	117.4
192	69.5	463.3	164.1

a No phosphine detected at sampling points at 4.5 and 10.5 m.
b Computation based on readings commencing at 48 hours.
N/R Not calculated, *Ct*-product zero or very low.

The phosphine evolved from tablets placed half-way down the silo passed rapidly, within 36 - 48 hours, down to the 23 m depth and thence down to the bottom of the bin in 96 - 120 hours. This penetration concurs with that recorded by Banks (1977). In our case, however, the gas dispersed downward through the bulk, not upwards as observed by Banks (1977). After eight days from treatment there was virtually no gas that the point of application but still 1300 ppm at the bottom of the bin. After ten days, this level had fallen to 400 ppm. As gas concentrations did not rise above the 'trace' level in the hopper free space below the bin and, as there was obviously no question in this trial of leakage through the

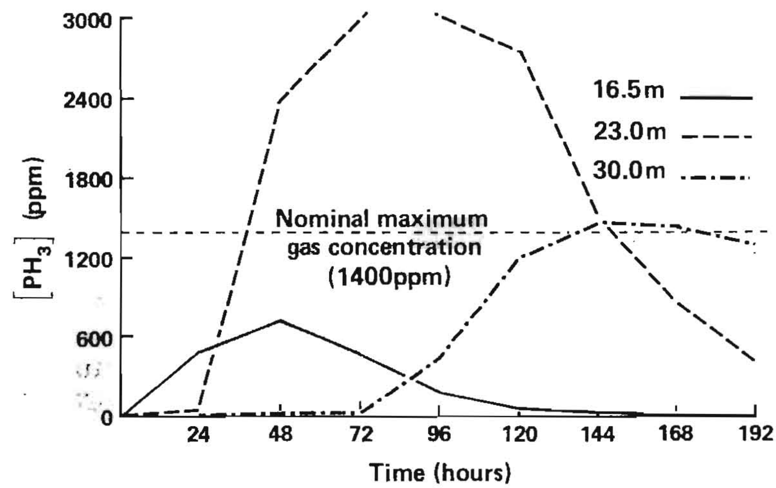

Fig. 6. Phosphine concentrations in 750 t wheat in Bin 403 treated at a rate of $2gPH_3\ m^{-3}$ with tablets added in a layer after half-filling the bin - Trial 3.

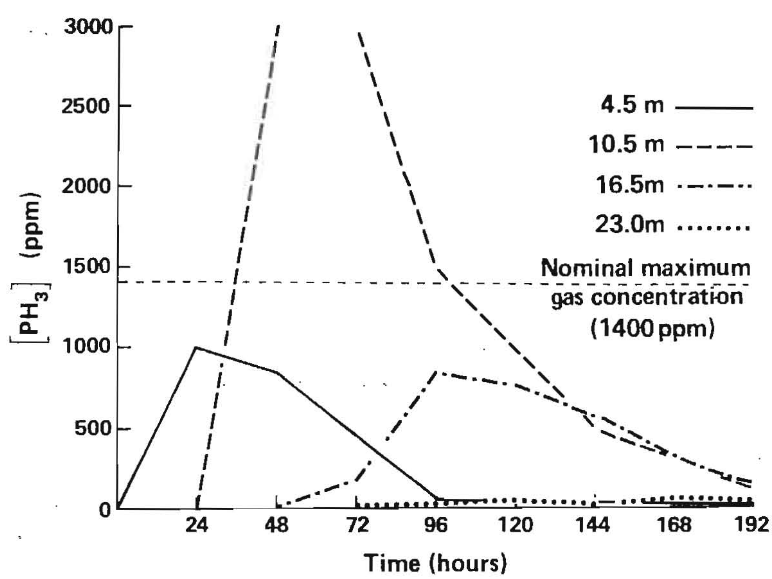

Fig. 7. Phosphine concentrations at 760 t of wheat in Bin 403 treated at a rate of $2gPH_3\ m^{-3}$ with tablets added to the grain surface after filling.

ventilation ports at the top of the bin, it must be concluded that leakage through the bin wall is the most important gas loss factor in a normal fumigation.

Ct-products achieved were more than adequate for insect control at 23 and 30 m and possibly just adequate at 16.5 m depth. A six or seven day exposure period would be required for effective results, but gas levels at the bottom of the bin would still be possibly undesirably high to permit grain movement immediately.

2.3.2 *Phosphine evolved from tablets placed at the top of a full wheat bin.*

2.3.2.1 *Methods:* After an interval of five days to allow remaining phosphine to dissipate, Bin 403, with wheat and gas lines intact, was again treated. Tablets of aluminium phosphide (1920 x 3 g in total, Phostoxin) were tipped onto the surface of the grain through both loading hatches. Ten tonnes of wheat were loaded into the bin to cover the tablets.

Gas sampling lines were suspended at a depth of 15 m in all four adjacent star bins sharing a common wall and ventilation ports with Bin 403. Top and bottom hatches of the empty star bins were closed but not sealed. Temperatures in the star bins were 26-28°C with relative humidities of 55-64%.

2.3.2.2 *Results and Discussions:* The phosphine concentrations observed at 4.5 m, 10.5 m, 16.5 m and 23 m depths are shown in Fig. 7. Readings were not sufficiently high at the 30 m point to permit a similar presentation but are given, together with *Ct*-products achieved at all points between 3 and 8 days after closing, in Table 6. Gas concentrations observed in the adjacent star bins are given in Table 7.

The phosphine did reach the 30 m depth of the grain bulk within 4 - 5 days but not in a sufficient amount to give an effective *Ct*-product at this depth.

The *Ct*-producs achieved after 8 days from dosing at 23 and 30 m were quite inadequate, even for control of the most susceptible species. By prolonging the exposure to ten days it is difficult to see how the results at these depths could have been significantly improved. Concentrations would not have risen appreciably due to falling gas as little gas remained at higher levels.

It is clear that neither of these two simplified forms of fumigant application will give adequate concentrations of phosphine throughout the grain bulk for sufficient periods of time to offer

TABLE 6

Ct-products achieved in Bin 403 treated with aluminium phosphide tablets applied at $2 gPH_3\ m^{-3}$ to the grain surface (Trial 3). Gas concentrations achieved at 30 m depth also shown.

Time after dosing (hours)	Depth in grain 4.5 m	10.5 m	16.5 m	23 m	30 m	Phosphine concentration (ppm) at 30 m
72	73.7	165.2	N/R	N/R	N/R	0
96	78.7	218.1	N/R	N/R	N/R	5.0
120	80.2	255.2	40.8[a]	N/R	N/R	5.0
144	81.5	276.0	64.8	3.3[b]	0.83[b]	20
168	82.4	287.4	82.1	5.3	2.00	40
192	83.3	293.6	90.9	7.0	3.5	45

a Computation based on readings commencing at 48 hours.
b Computation based on readings commencing at 84 hours.
N/R Not calculated, *Ct*-product zero or very low.

TABLE 7

Phosphine concentrations (ppm) observed in the four star bins ajoining Bin 403 while under fumigation (Trial 3, surface fumigation).

Time after dosing (hours)	Bin No. S2-3	S2-4	S4-3	S4-4
12	75	5	20	8.5
24	15	10	40	17
48	15	10	50	30
72	11	1.0	30	15
96	1.0	1.0	35	20
120	0.2	0.2	18	10
144	trace	trace	16.5	11
168	0	0	4.0	5.0
192	0	0	1.0	1.0

an acceptable prospect of elimination of all of our target species whether susceptible or otherwise.

3. CONCLUSIONS

To date we have no evidence to show that insect populations in the Bangladesh silo system have developed resistance to phosphine. We do, however, have a considerable amount of data to show that resistance to phosphine has been developed in the godown system where only bagged grain is handled (Tyler *et al.*, 1983). Tests conducted so far show that *Tribolium castaneum*, *Rhyzopertha dominica*, *Cryptolestes ferrugineus* and *Oryzaephilus surinamensis* have all developed levels of resistance to phosphine that are of practical significance (C.E. Dyte, personal communication).

It could be argued that in the absence of evidence of resistance from silos we should adopt the most economic form of fumigation and simplify the application method where possible as we have attempted to do in these trials. It would however, be most unwise to assume that phosphine resistance is or will remain absent from silo insect populations. Therefore we should promote fumigation techniques which prevent the exposure of grain insects to possibly sub-lethal or marginal doses of phosphine. As bin temperatures during the winter months will drop to the 20 - 23°C range, as they were during the earlier part of these trials, and this will adversely effect the level of control which can be expected at low concentrations, this reinforces the conclusion that placing the fumigant formulation on top of the bulk grain should not be encouraged as a fumigation technique.

It seems quite clear that substantial gas loss does occur through the concrete bin walls, but it is also clear that quite satisfactory phosphine levels can be achieved and maintained in a silo complex of this age and type at the economically acceptable rate of $2gPH_3\ m^{-3}$.

There was no indication that the presence of the small ventilation ports above the grain surface at the top of the bins detracts in any significant way from the fumigation results. Normal closing of the bin hatch covers on the bin deck floor and hopper hatches at the bases of the bins, without any additional sealing measures, would seem to be adequate for a normal treatment. Concentrations measured in the bin hatch and hopper areas during fumigations showed no dangerous levels of phosphine and ventilation of these areas was adequate.

Future recommendations for a fumigation technique at these silos should aim at ensuring that the fumigant is dispensed at several levels throughout the grain bulk either by a simple manual application during the filling process or by bringing into commission the automatic pellet dispensers. The dosage rate should remain at $2gPH_3\ m^{-3}$ (equivalent to 3 tablets per tonne of grain for a full bin) and the fumigation period should be 7 days to ensure even and adequate distribution of gas at all levels.

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