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INTEGRATED PEST MANAGEMENT IN HEXAGONAL BINS

(RESEARCH REPORT)

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PREFACE

One of the major assignment for STDT sub-component of the FSM project in Pakistan has been the undertaking of applied research, in collaboration with local research institute, particularly PARC, for the development of integrated pest management (IPM) technology for grain storage which would result in the minimum of losses and; at the least of costs. Elaborate research plans were prepared by the scientist of FFGI and PARC in this connection for studies covering all important type of storage structure and other conditions. The primary objective was to grain in-depth scientific understanding of public sector grain storage problems and, in the light of such first-hand information, conceive and field test possible improvement and practices.

This report is the culmination of STDT endeavors concerning pest management in Hex Bins. The problems discovered in the current fumigation practice were: uneven distribution, less downward diffusion and short period of retention of phosphine gas in the bins. It is heartening to note that by simply determining the suitable inserted position of the Aluminium Phosphide (AIP) tablets in wheat loaded bins, the desired improvements in their fumigation have been achieved. The problems have been solved and importantly, at no additional costs. It is hoped that the recommendations made in the report will be of great assistance to the Food Departments to save wheat stored in Hex Bins from insect damage. This will also help check and/or delay the onset of resistance to phosphine in storage pests which is feared to be spreading fast in this country due to the persistent in-adequate distribution and retention of phosphine gas in the stored wheat.

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October 23, 1990.

EXECUTIVE SUMMARY

Phosphine fumigation is the main pest management tool presently being used by the provincial Food Departments to protect stored wheat from insect damage. A critical examination of the fumigation carried out by the Punjab Food Department in Hex Bins at Badami Bagh has revealed that the operations were not fully successful. The main defect discovered was that critically essential concentration level of phosphine gas was not being achieved in the bottom parts of the bins as a result of which insects present there were not getting killed. The reason for this defect was detected to be wrong placement of Aluminum Phosphide (AlP) tablets on the grain top which resulted in quick gas release and unnecessary high build up of phosphine concentrations in the free space and the top grain layers from where it was obviously leaking out of the bins.

Diffusion of gas to reach a minimum concentration of about 200 ppm in all parts of the space being fumigated and its retention there for over a minimum period of seven days are the critical requirements for successful phosphine fumigation under Pakistan conditions. It is shown by experiments that these condition can be achieved in the Hex Bins by simply inserting the AlP tablets inside the grain instead of placing them on its surface as is presently being done. The 72 AlP tablets (per bin dosage rate presently being used by the Punjab Food Department), were divided into two portions and one portion (36 AlP tablets) was applied by burying it about one meter and the second about five meters deep in the grain mass with the help of a locally made applicator. The results showed that application of AlP tablets in this way achieved the critical requirement of gas diffusion and retention mentioned above for successful phosphine fumigation. This method is therefore, recommended for the application of AlP tablets in future for the fumigation of Hex Bins.

Improper phosphine fumigation result not only in higher management costs but also in the development of pest strains resistant to phosphine action. It is feared that continuation of such practices will ultimately lead to a situation when phosphine -- an ideal grain fumigant, will become useless as a pest management tool in this country. There is presently no other gas with properties as good as phosphine which could replace it. The alternative method of using grain protectants is also presently not feasible for use in Pakistan unless a change over to mechanical handling of grains takes place. It is imperative therefore, that the present practice of phosphine fumigation are improved.

Hex Bins are presently being used only sparingly because of labour extensive loading and ineffective insect control methods. Pest control methodology has now been improved. Induction of simple machines like the Grain Pump used in these experiments can make their loading easier and perhaps cheaper as well.

ACKNOWLEDGMENTS

Hex Bins as well as the wheat loaded therein were the property of Punjab Food Department. We wish to record our appreciation for the permission given to us to use these bins and wheat in the experiments reported here. We are particularly grateful to the following officers of the Department for their cooperation and help extended to us during the course of our work at badami bagh:

1- Mr. Kabeer Ahmed, Additional Director Food.

2- Mr. Mohammad Sharif, Deputy Secretary (Food), Govt. of Punjab.

3- Mr. Sheikh Ishtiaq Ahmad, Assistant Food Controller.

4- Mr. Khawaja Zaheer-u-din, Assistant Food Controller.

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7- Mr. Zawar Hussain Jaffri, Food Grain Inspector.

8- Mr. Shahid Ali Siddiqui, Food Grain Supervisor.

9- Mr. Rana Azim Ahmad, Food Grain Supervisor.

10- Mr. Shahid Mansoor, Food Grain Supervisor.

The insect Reldon 25 E.C. used in these studies was arranged from abroad by M/S Dow Chemicals, Karachi. We are grateful to Dr. Muhammad Afzal, Manager, R & D for his help in this connection. All requirements of AlP tablets used in fumigation experiments were met, free of cost, by the Punjab Food Department, Government of the Punjab.

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2- Mr. Zahid Nadeem, FFGI.
3- Mr. Shaukat Ali, FFGI.
4- Mr. Fayyaz Ahmad, FFGI.

ABBREVIATIONS USED

ai	=	*actual ingredient (of insecticide)*
AlP	=	*Aluminum Phosphide*
cm	=	*centimeter*
E.C.	=	*Emulsifiable Concentrate (of insecticides)*
FD(s)	=	*Food Department(s)*
FFGI	=	*Food and Feed Grain Institute*
g	=	*gram*
GSRL	=	*Grain Storage Research Laboratory*
KSU	=	*Kansas State University*
m	=	*meter*
mm	=	*millimeter*
NRI	=	*Natural Resources Institute*
PARC	=	*Pakistan Agricultural Research Council*
R.C.C.	=	*Reinforced Concrete Cement*
STDT	=	*Storage Technology Development and Transfer (a component of FSM project)*

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INTRODUCTION

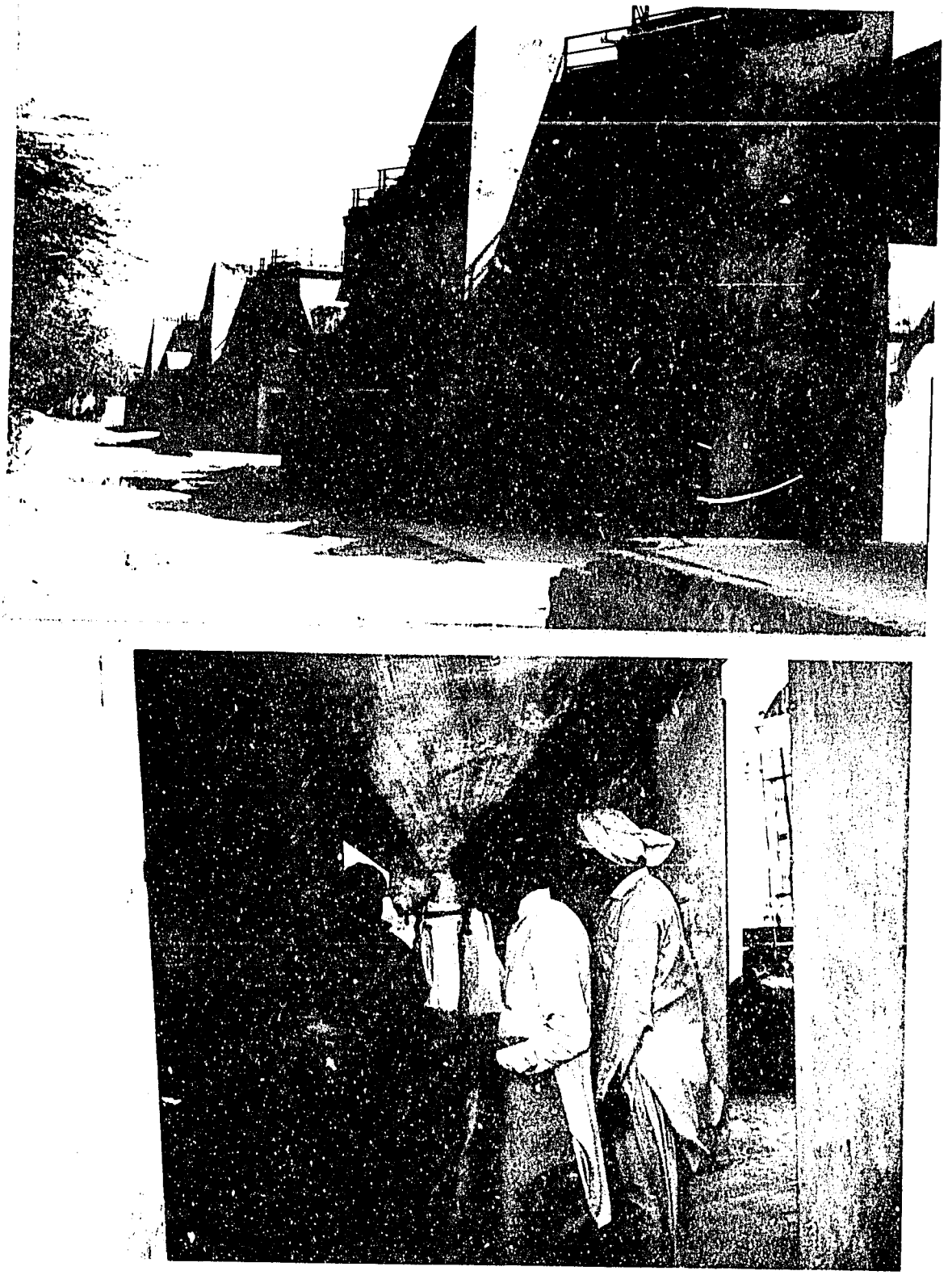
For the storage of wheat in bulk, provincial Food Departments (FDs) have a number of units of bee-hive shaped bins called 'Hexagonal' or 'Hex' Bins. Each Hex Bin can take a maximum of about 36.0 tones of wheat for storage. These bins were built in late 1940s and early 1950s in units varying in storage capacity from 500 to 3,000 tones at various places in the country. Total storage capacity of these bins in the country is for about 303,000 tones of wheat.

Structure-wise, each bin is supported by columns of R.C.C. at a height of 2.6 m from ground level and has a conical hopper bottom of R.C.C. fitted with a 15 cm diameter spout provided with handle and locking mechanism for emptying operations. Walls of the bins are made of either R.C.C. or reinforced brick work. The roof has an R.C.C. flat slab with water-proofing on top. A manhole with iron lid is provided for each bin in the roof for its loading. Each set (cluster) of Hex Bins is provided with a 1.2 m wide stairs for the labor to carry bags of wheat to the roof for pouring into the bins (Picture-1).

To save wheat from insect damage, the current practice is to fumigate bins with phosphine gas using the standard Aluminum Phosphide (AlP) tablets (a standard tablet weighs 3.0 g and yields 1.0 g of phosphine gas) at the dose rate of two (2) tablets per ton by placing all the 72 tablets on the top of wheat surface. After placing AlP tablets in the bin, it is sealed by closing the manhole with its gasket laced iron lid. Sealing of bins for the purpose of fumigation is further supplemented by mud plastering around the top lid and the bottom spout opening. Insects however, re-appear in fumigated bins after some time requiring re-fumigations.

High labor requirements for their manual loading & not very effective phosphine fumigations make Hex Bins comparatively expensive for wheat storage. At Badami Bagh, it costs the Punjab FD roughly Rs. 30.00 per ton to load and unload wheat in Hex Bins whereas the cost of unloading from trucks, stacking in the godowns and reloading (for dispatch) of bagged wheat stored in conventional godowns is less than Rs. 10.00 per ton. Due to these reasons, Hex Bins are used only sparingly by the provincial FDs. Induction of machines for loading & unloading and improvements in the wheat protection methodology can reclaim these dormant facilities at much less cost than the construction of new godowns.

In the studies reported here, current practice of the Punjab FD for phosphine fumigation of Hex bins is critically examined and an improved method of application of AlP tablets is suggested which shall enhance the effectiveness of such fumigations without adding to the cost of the current practice.



Picture-1. Part of a set of Hex Bins showing stairs and the hopper bottom.

MATERIALS AND METHODS

A total of nineteen (19) bins loaded with about 684 tones of wheat of the Punjab Food Department (FD) were used in these experiments. These bins were part of a unit located at Badami Bagh near Lahore and were loaded in the last week of july, 1989 with wheat received from different places. Average moisture content of the wheat at the time of loading was 8.86 percent. Bins, in which insecticides were mixed with wheat, were loaded in the second week of October, 1989. The average moisture content of this wheat was 8.72 per cent. Most of the experimental bins were filled mechanically using a Grain Pump (Picture-2). All trials were terminated in mid March, 1990 when the Punjab FD wanted to issue the wheat for milling.

Five protocols involving fumigations and mixture of chemical protectant in wheat, were compared for their effectiveness to control insect infestation. In all cases, grain and/or air samples were drawn for monitoring of insect infestation and phosphine gas concentrations from three depths of wheat in the bins. These depth were 0.75, 3.00 and 5.50 meters from grain surface and are referred to in the text as top, middle and bottom sampling zones respectively. For drawing wheat samples, a pneumatic grain sampler (Cargill's Probe-A-Vac) was used (Picture-3). For air sampling, hard nylon pipes of about 2.00 mm internal diameter were installed at the three depths mentioned above, at the time of loading of the bins. One end of these pipes was taken out before sealing of the bins for fumigation through the narrow space near the hinges of the lid covers provided to close the bins from top. The pipes were labeled according to their position in the bin.

For the sealing of bins required for fumigation, iron lids laced with rubber gasket are provided to close the top manhole of each bin. These lids were used but the rubber gaskets were found to be generally damaged. The sealing of the bins was therefore, augmented by applying mud plaster around the closed lids and the bottom spouts.

Before loading wheat, all bins were cleaned by first sweeping manually, followed by insecticidal surface sprays. Other procedures varied for each protocols as detailed below:-

Protocol-1: In this protocol, phosphine fumigation procedures as prescribed by the Punjab FD were followed. Accordingly, before loading wheat, the experimental bins were thoroughly dusted from inside and its internal surface was sprayed with water solution of malathion 57 % E.C. at the dose rate of 2.0 g ai per square m of the surface. After loading wheat on July 27, 1989, the bins were fumigated on August 23, 1989 with phosphine by placing all the 72 AlP tablets (at the rate of two tablets per tone) on grain surface inside the bin (Figure-1 B).

Protocol-2: In this protocol, bins were cleaned as usual and their internal surface was sprayed with water solution of Actellic 50 % E.C. at the dosage rate of 0.5 g ai per square m of the surface. Successive dosing and higher dose rate of AlP tablets per bin were the main differences from Protocol-1. For first fumigation, a dose of three tablets per ton of wheat was used and all the 108 AlP tablets were placed on the grain surface before sealing the bin. After 48 hours of the first dosing, the bin was opened briefly and a second dose at the rate of two tablets per ton (total 72 tablets) was introduced into the bin as quickly as possible so that the gas already present in the bin would escape the least.

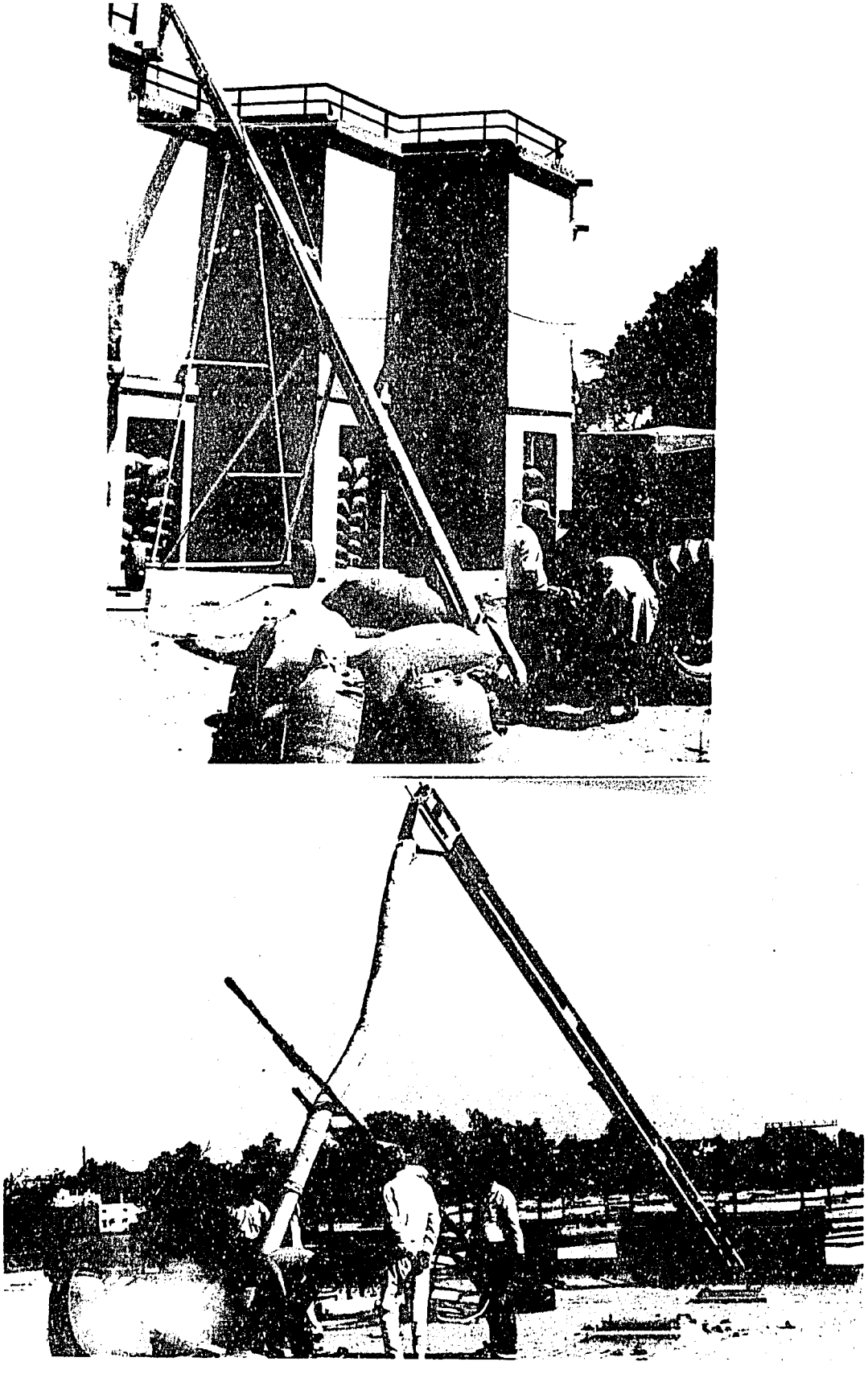
Protocol-3: It was the same as Protocol-1 except that the operations were carried out by the staff of the Punjab FD. Gas concentration in the bins under this protocol was not monitored but grain sampling before and after fumigation was undertaken for monitoring infestation levels.

Protocol-4: In this protocol, the normal dose of 72 AlP tablets per bin (two tablets per ton of wheat) was divided into two equal portions and buried into the grain instead of placing on the grain surface. One portion of (36 tablets) was deposited down at a depth of about five m while the other was buried only about one m deep in the grain mass (Figure-1 A) with the help of a special tablet applicator (Picture-4 & Figure-2). The bins were then sealed in the usual way for fumigation.

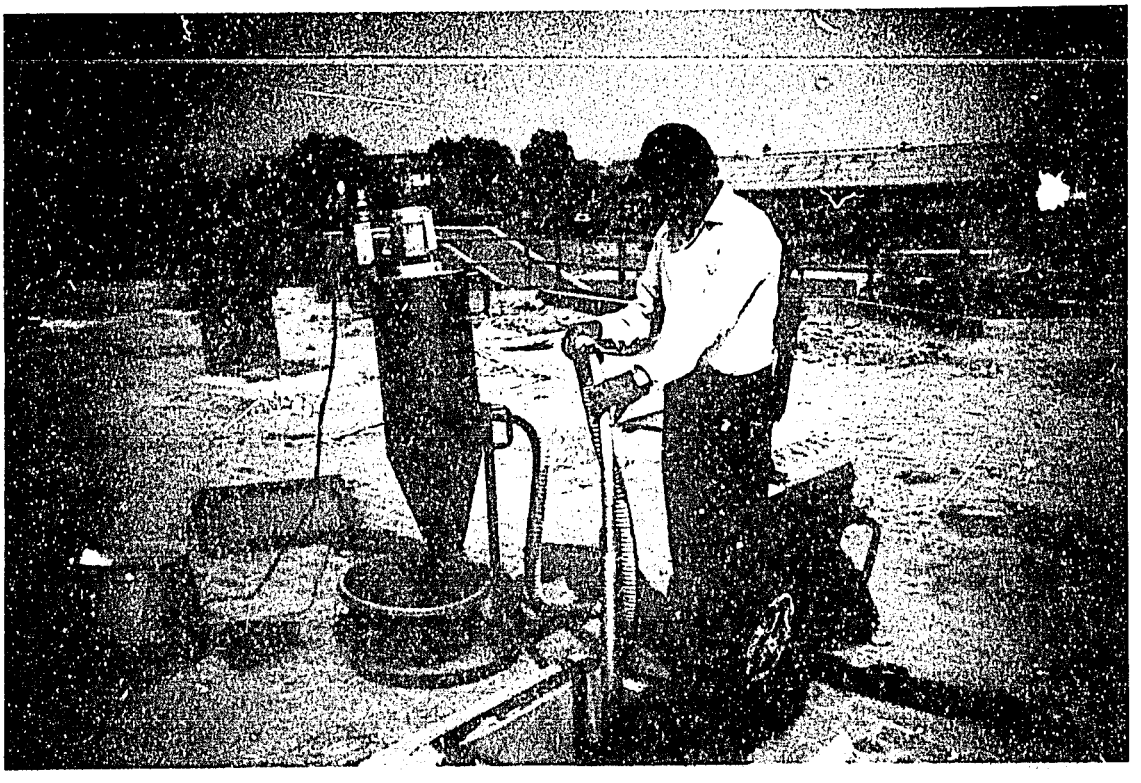
Protocol-5: In this protocol, the insecticide Reldan (Chlorpyriphos methyl) was mixed with wheat at a dose rate of 6.00 ppm and its effectiveness was compared with Actellic (Pirimiphos methyl) applied at the dose rate of 10.00 ppm. The formulations used were: Reldan 25 % E.C. and Actellic 50 % E.C. Dose rates for both the insecticides were according to the recommendations of their manufacturers. Both the insecticides were applied through a power sprayer while the bins were being loaded with the help of a Grain Pump. Water solution of the insecticides used in each case was about 0.8 liters per ton of wheat.

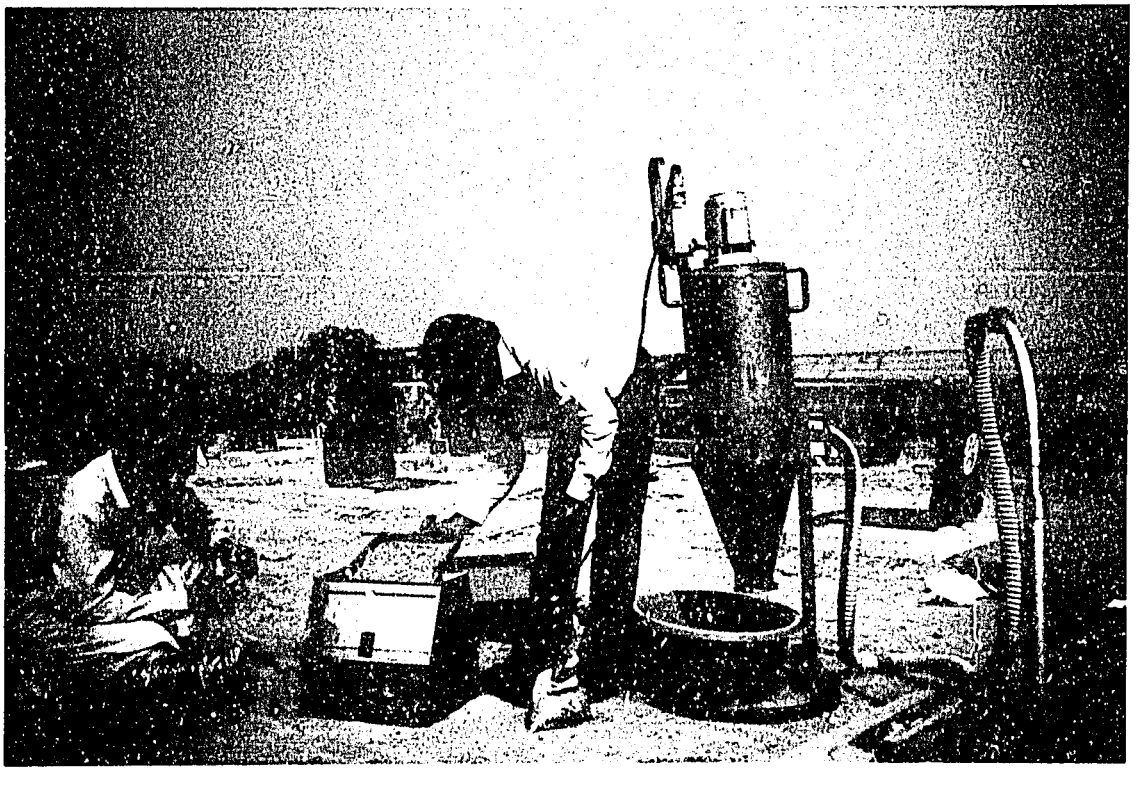
For monitoring of phosphine gas, a 'Cititox' meter was used in most cases (Picture-5). In some cases however, where concentration of phosphine exceeded 2,000 (two thousand) ppm, an other meter developed by NRI of UK [*commonly called as 'Harris Meter'*] was also used. For monitoring of the insects, the whole of the wheat sample (about one kg) was sieved (by dividing in four parts) using a set of four sieves. Insects were separated by sieves of 16 and 25 mesh. These were collected and counted to determine their numbers per kg of wheat sample.

Other experimental details are given with the results.



Picture-2: Loading of Hexbins with the help of a grain pump.





Picture-3. Probe-A-Vac being used to draw wheat samples from different depths of a Hex Bin.

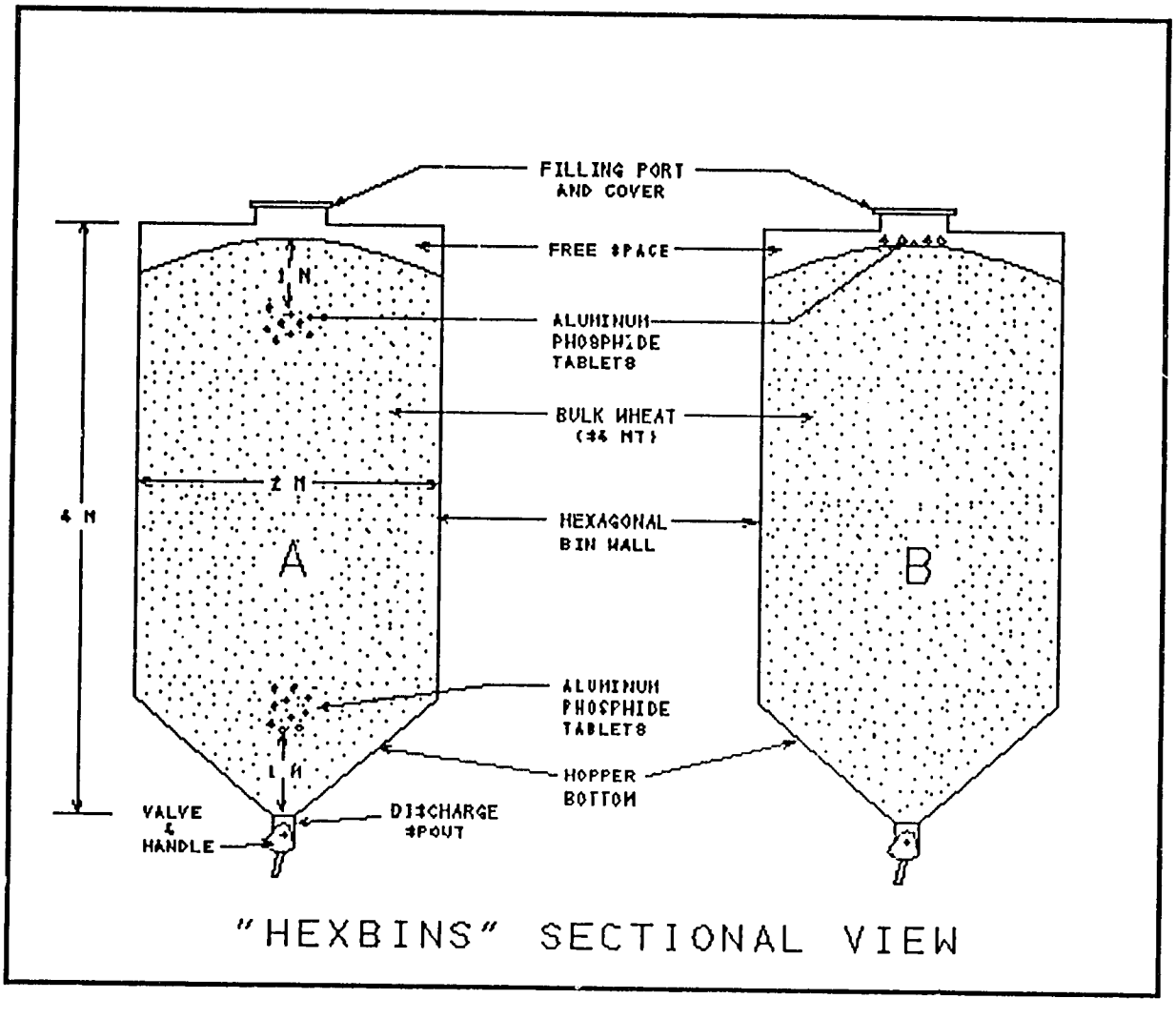


Figure-1. Longitudinal section of a Hex Bin showing the position of AlP tablets in the improved method of fumigation (A) as against the conventional method (B).

Picture-4. Showing how to load AlP tablets in the 'Chamber' of the 'Special AlP tablet Applicator' and the way these are inserted in the grain mass at the desired depths.

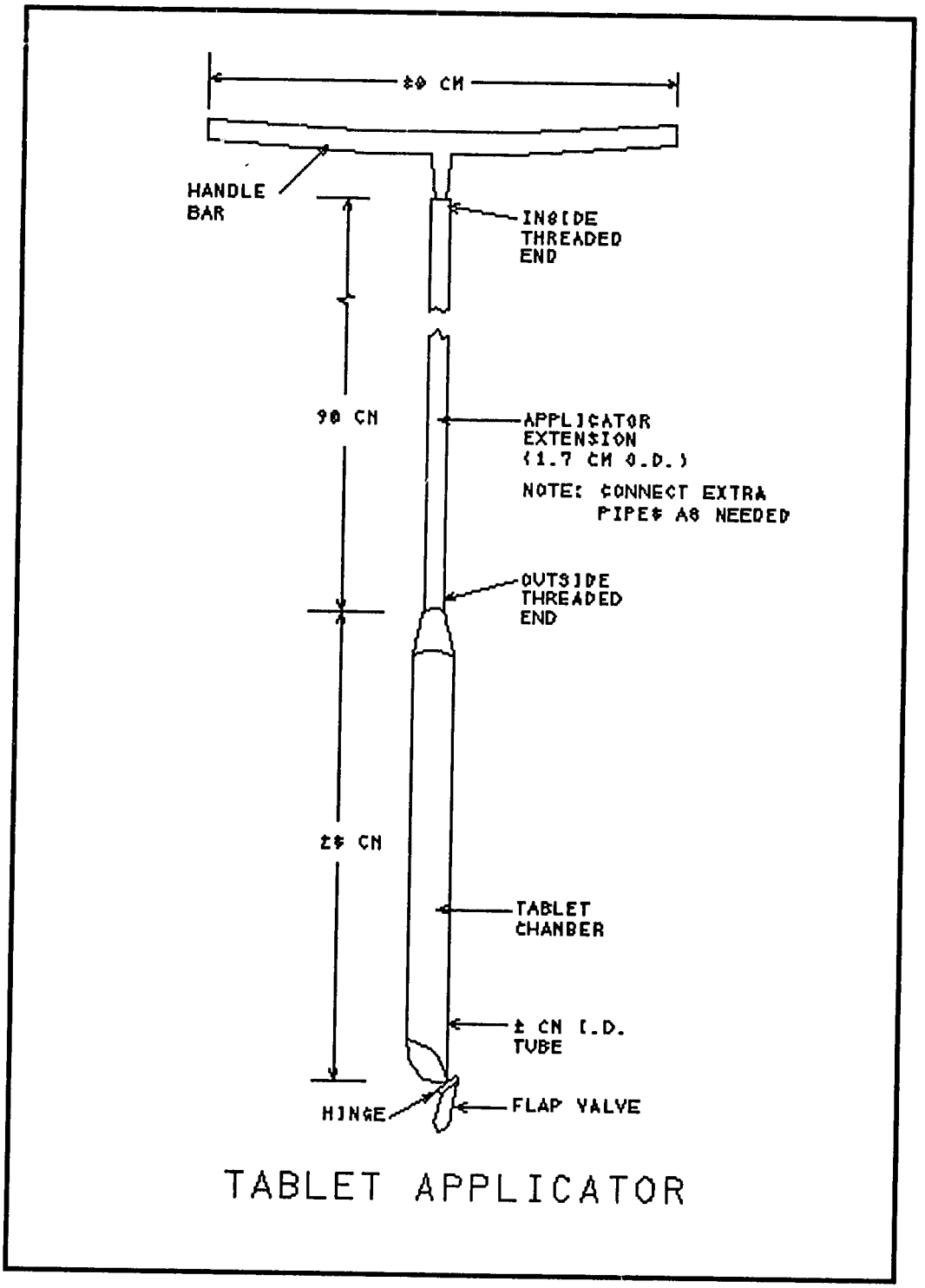
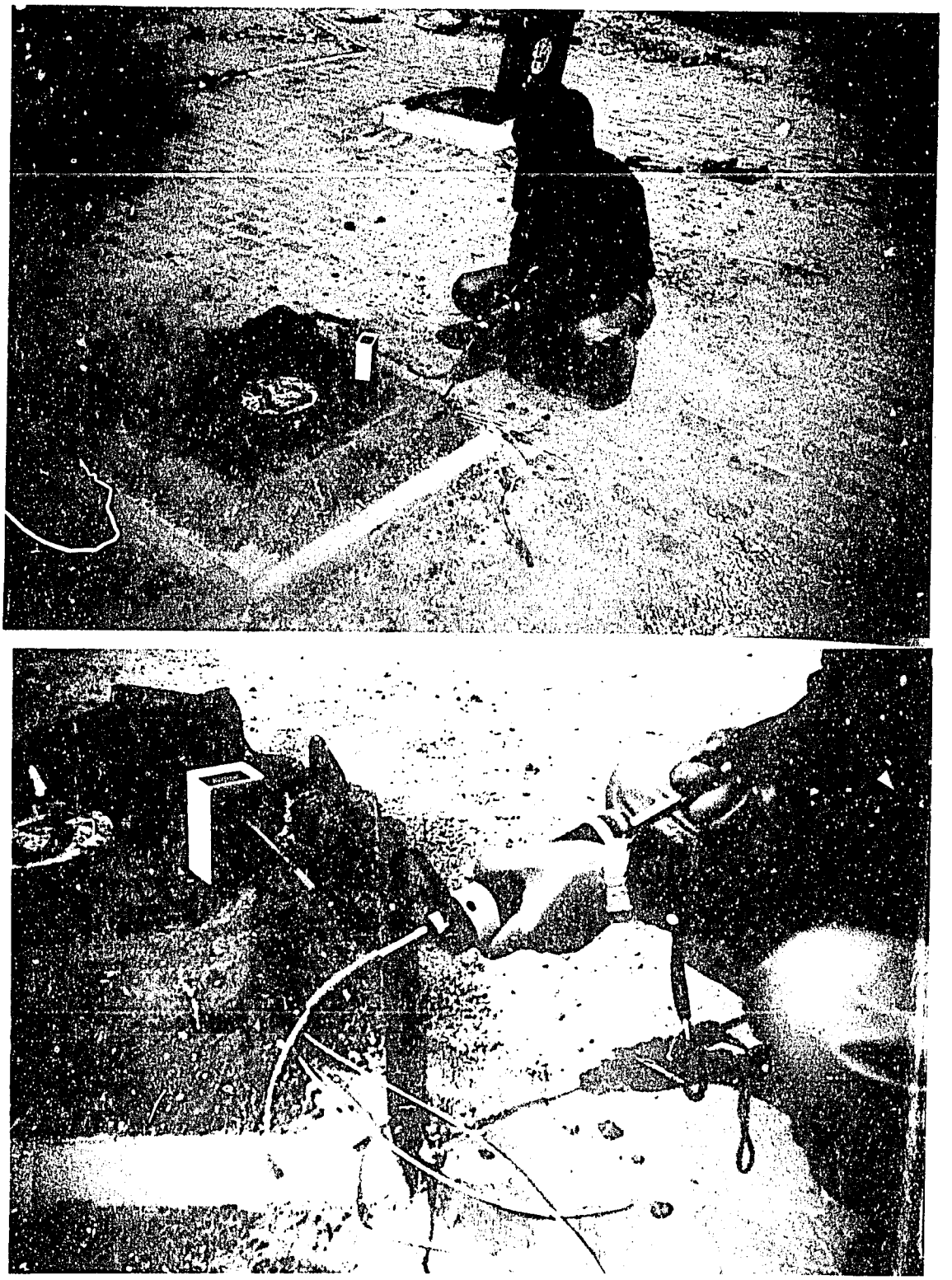


Figure-2. Measurements of the 'Special AIP tablet Applicator' drawn to help its local manufacturing.



Picture-5. The monitoring of phosphine concentrations at different depths using nylon tubing, a gastight syringe and the 'Cititox' meter.

RESULTS

Average distribution and retention pattern of phosphine gas in the bins as per Protocol-1 and 2 is presented in Table-1. Table-1 also compares the differences after applying a single dose of 72 AlP tablets and two successive doses (multiple dosing) of 108 and 72 tablets per bin (total dose 180 tablets per bin). It will be seen that the highest concentration of gas remained confined to the free space (space above grain surface in the bin) in both cases and despite a 2.5 fold increase in the number of tablets in the case of multiple dosing, gas concentrations in the bottom grain layers were almost identical in the two Protocols. There was some increase of gas in the top and middle grain layers in the case of multiple dosing but the difference was not proportionate to the increase (2.5 folds) in the number of tablets. In both cases, the critical requirements of at least 200 ppm gas in all parts of the bin over a period of seven days, could not be obtained in both cases.

Data in Table-2 shows the failure or only partial success of the two fumigation Protocols-1 and 3 because live insects were recorded in bins under these Protocols within a period of three months. Protocol-3 is a partial success because the population of *Rhizopertha dominica* which was quite high in the beginning, had gone down. Protocol-2 seemed to be successful as no live insects were recorded in these bins on November 13, 1989 (Table-2). In February and March, 1990 however, live insects were found in all the three Protocols with slightly higher numbers in Protocols 1 and 3 compared to Protocol-2.

For monitoring insects, wheat samples were drawn from top, middle and bottom layers of grain from all the nine experimental bins under fumigation Protocols. Samples were drawn at the time of loading of the bins and at intervals of three and six months after fumigation as well as at the time of termination of the experiments in March, 1990. To see if a particular pattern of vertical distribution of insects in the bins exist, the data from all these bins is average and presented in Table-3. The results showed no particular distribution pattern at the time of loading. This is what was expected because of disturbance of the grain in the process of loading. With the passage of time however, though insects remained present in all parts of the bins, the number of live insects belonging to the two major pest species namely *Rhizopertha dominica* and *Tribolium castaneum*, was invariably higher in the top grain layers compared with that of middle and bottom layers (Table-3).

From the results presented so far, two important facts of significance had emerged. First that the insect pests were present in all parts of the bins and second, that in all the fumigations, the critical level of 200 ppm of gas concentration was not achieved, even for a short time, in the bottom parts of the bins (Table-1). It was therefore, decided to try another Protocol in which the AlP tablets were buried in the grain (Figure-1 A) instead of placing on its top surface (Figure-1 B). This was the main feature of Protocol-4, the

results of which are presented in Table-4. It will be seen that more than 200 ppm of gas was present for over nine days in all parts of the bins - a gas retention and distribution pattern considered satisfactory for successful phosphine fumigation.

Results of the performance of chemical protectants are presented in Table-5. Both Reldan and Actellic failed to control *Rhizopertha dominica* which was the most important pest of wheat at Badami Bagh. The next most important pest namely *Tribolium castaneum* was controlled by Reldan only for about three months and by Actellic for the entire period of five months of the trial. Reldan provided full control against *Trogoderma granarium* for the trial period while Actellic provided protection against this pest only for about three months.

Table 1: Concentration of phosphine gas in the air monitored at four points in wheat loaded Hex Bins when 72 AlP tablets per bin were placed on the top rain surface as per practice of the Punjab Food Department as single dose compared with an experimental multiple dosing technique using 180 AlP tablets applied in the same way but in two instalments i.e. first dose of 108 tablets per bin followed by another dose of 72 tablets per bin after 48 hours.

METHOD	Days after initial dosing	Average conce. (ppm) of phosphine gas at four points			
		Free space*	Grain top*	Grain middle*	Grain bottom*
SINGLE DOSE	1	3362	690	142	Nil
	2	1338	838	370	80
	3	752	510	330	78
	4	470	365	207	58
	5	327	227	183	40
	6	213	160	125	37
	7	128	83	60	30
MULTIPLE DOSE	1	3720	1072	193	15
	2	2022	1120	507	63
	3	3032	1112	463	55
	4	1290	830	468	65
	5	562	458	305	35
	6	290	270	200	20
	7	133	113	90	30
	8	85	100	60	20

* Free space = Empty space in the bin above grain surface.
Grain top = About 0.75 metre deep from grain surface.
Grain middle = About 3.00 metres deep from grain surface.
Grain bottom = About 5.50 metres deep from grain surface.

Note:- Total depth of a bin from top to bottom spout is 6.10 metres.

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Table-2: Record of total insect load in wheat fumigated in Hex Bins with phosphine gas using the following three protocols:

Protocol-1: Fumigation operations actually carried out by research staff but using the method/procedure as well as the dose rate (72 AlP tablets per bin) prescribed by the Punjab FD. (Bin actually fumigated on August 23, 1989).

Protocol-2: Fumigation operations carried out by research staff using a method of multiple dosing and a dose rate of 180 AlP tablets per bin in two successive doses with 48 hours interval in between. (First dosing was carried out on August 23, 1989 using a dose rate of 108 AlP tablets per bin followed by a second fumigation in the same bin using a dose of 72 AlP tablets on August 25, 1989).

Protocol-3: Fumigation actually carried out by the staff of the Punjab FD using their normal procedures and dose rate of 72 AlP tablets per bin. (Bin actually fumigated on August 10, 1989).

Protocol Number	Average number of insects (*) recorded per kilogram of wheat sampled on the dates given below			
	July 27, 1989 (Bins loaded)	November 13, 1989	February 13, 1989	March 14, 1989
1	R.d. (L) = 0.60 (D) = 0.20 T.c. (L) = 1.84 (D) = 0.10 T.g. (a) (D) = 0.10	R.d. (L) = 0.07 (D) = 0.38 T.c. (L) = 0.39 (D) = 0.45	R.d. (L) = 8.98 (D) = 5.96 T.c. (L) = 4.34 (D) = 8.93 T.g. (a) (D) = 0.10	R.d. (L) = 7.33 (D) = 20.46 T.c. (L) = 2.10 (D) = 6.71 T.g. (a) (D) = 0.86
2	R.d. (L) = 0.95 (D) = 0.10 T.c. (L) = 0.17 (D) = 0.09 T.g. (a) (L) = 0.08	R.d. (D) = 0.08	R.d. (L) = 1.66 (D) = 1.93 T.c. (L) = 4.30 (D) = 6.55 T.g. (a) (D) = 0.31	R.d. (L) = 3.80 (D) = 4.64 T.c. (L) = 1.79 (D) = 4.91 T.g. (a) (D) = 0.40 (l) (L) = 0.09
3	R.d. (L) = 12.32 (D) = 1.13 T.c. (D) = 0.18 T.g. (a) (D) = 0.19	R.d. (L) = 0.50 (D) = 2.25 T.c. (L) = 1.90 (D) = 0.82	R.d. (L) = 3.47 (D) = 9.60 T.c. (L) = 4.09 (D) = 6.92 T.g. (a) (D) = 1.21 (l) (D) = 0.41	R.d. (L) = 4.41 (D) = 8.70 T.c. (L) = 5.99 (D) = 9.79 T.g. (a) (D) = 1.66

(*)Key to names of species:

R.d. = Rhizopertha dominica
T.g. = Trogoderma granarium
T.c. = Tribolium castaneum
(L) = Live
(D) = Dead
(a) = Adult stage
(l) = Larval stage

Note:

The data presented above is the average of three different bins used for each protocol.

Grain samples were drawn from top, middle and bottom parts of each bin. Insects found in these samples were added and averaged for numbers per kilogram of wheat sample.

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Table-3: Verticle distribution of insects in wheat loaded Hex Bins. The bins fumigated in the last week of July, 1989 with phosphine but the operations were not successful.

Sampling zone	Average number of insects (*) recorded per kilogram of wheat sampled on the dates given below			
	July 27, 1989 (Bins Loaded)	November 13, 1989	February 13, 1989	March 14, 1989
Top Layer of grain	R.d. (L) = 5.27 (D) = 1.39 T.c. (L) = 3.03 (D) = 0.36 T.g. (a) (D) = 0.34	R.d. (L) = 0.41 (D) = 0.32 T.c. (L) = 2.05 (D) = 0.85	R.d. (L) = 10.87 (D) = 9.22 T.c. (L) = 7.19 (D) = 8.63 T.g. (a) (D) = 0.82 (l) (D) = 0.41	R.d. (L) = 13.17 (D) = 18.21 T.c. (L) = 7.85 (D) = 7.56 T.g. (a) (D) = 1.95
Middle of the grain	R.d. (L) = 2.23 (D) = 0.49 T.c. (L) = Nil (D) = 0.09	R.d. (L) = 0.08 (D) = 0.55 T.c. (L) = 0.24 (D) = 0.13	R.d. (L) = 1.42 (D) = 2.62 T.c. (L) = 1.92 (D) = 3.46 T.g. (a) (D) = 0.50	R.d. (L) = 3.75 (D) = 13.42 T.c. (L) = 1.62 (D) = 6.11 T.g. (a) (D) = 0.38
Bottom layers of the grain	R.d. (L) = 6.90 (D) = 0.19 T.g. (a) (L) = 0.08	R.d. (L) = 0.07 (D) = 1.82 T.c. (L) = 0.07 (D) = 1.27	R.d. (L) = 1.80 (D) = 9.30 T.c. (L) = 3.63 (D) = 10.29 T.g. (a) (D) = 0.29	R.d. (L) = 4.50 (D) = 2.14 T.c. (L) = 2.61 (D) = 8.47 T.g. (a) (D) = 0.57 (l) (L) = 0.09

(*) Key to names of species:

R.d. = Rizopertha dominica
T.g. = Trogoderma granarium
T.c. = Tribolium castaneum
(L) = Live
(D) = Dead
(a) = Adult stage
(l) = Larval stage

Note:

Top grain sampling was from a depth of about 0.75m from the top grain surface while middle and bottom zone samples were drawn from depths of 3.0 & 5.5m respectively from top.

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Table-4: Concentration of phosphine gas in the air monitored at four points in wheat loaded Hex Bins during fumigation where the 72 AlP tablets per bin dose rate, as being used by the Punjab Food Department, was divided into two portions. One portion of 36 tablets was inserted about one metre deep in the grain while the second portion (36 tablets) was inserted about five metres deep in the wheat mass.

Days after initial dosing	Average conce	(ppm) of phosphine gas at four points		
	Free space*	Grain top*	Grain middle*	Grain bottom*
1	245	865	380	320
2	405	[illegible]	575	445
3	430	[illegible]	620	505
4	390	750	615	525
5	360	700	615	495
6	335	615	580	470
7	285	540	485	410
8	260	400	440	360
9	220	370	380	320
10	190	305	340	295
11	155	255	280	245
12	130	200	235	200
13	110	165	185	165
14	90	135	150	120

* Free space = Empty space in the bin bove grain surface.
Grain top = About 0.75 metre deep from grain top surface.
Grain middle = About 3.00 metres deep from grain top surface.
Grain bottom = About 5.50 metres deep from grain top surface.

Note:- Total depth of a bin from top to bottom spout is 6.10 metres.

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Table-5: Record of insects in wheat loaded in different Hex Bins after admixing insecticides as protectants (average of three replicated bins) compared with wheat which was loaded in the bin (data of only one bin) but received no treat men of insect cidal admixing.

Names (*) of insecticides & their dose rate in ppm	Average number of insects(**) recorded per kilogram of wheat sample		
	Just after treatment on October 10, 1989	After three months on January 11,1990	On emptying date on March 14,1990
Reldan six (6) ppm	R.d. (L) = 5.90 (D) = 1.06 T.c. (L) = 0.33 T.g. (a) (L) = 0.33	R.d. (L) = 16.50 (D) = 6.42 T.c. (L) = Nil	R.d. (L) = 23.30 (D) = 89.25 T.c. (L) = 2.28 T.g. (a) (D) = 0.81
Actellic ten(10) ppm	R.d. (L) = Nil (D) = 0.37 T.c. (L) = Nil (D) = 0.37 T.g. (a) (D) = 0.33 (l) (L) = 0.33	R.d. (L) = 10.15 (D) = 5.09 T.c. (L) = Nil (D) = 0.82 T.g. (a) (D) = 1.67 (l) (D) = 0.58	R.d. (L) = 0.54 (D) = 13.06 T.c. (L) = Nil (D) = 1.38 T.g. (a) (L) = 0.33 (D) = 17.63 (l) (L) = 1.22 (D) = 26.10
No insecticide used	Dated: Nov., 13, 89 R.d. (L) = 4.90 (D) = Nil T.c. (L) = 0.33 T.g. (a) (L) = 0.33 (D) = 0.33 S.o. (L) = 0.33		R.d. (L) = 5.91 (D) = 7.32 T.c. (L) = 8.82 (D) = 18.37 T.g. (a) (D) = 0.53 (l) (D) = 0.33 S.o. (L) = 0.80 (D) = 0.80

(**)Key to names of species:

R.d. = Rhizopertha dominica
T.g. = Trogoderma granarium
T.c. = Tribolium castaneum
S.o. = Sitophilus oryzae
(L) = Live
(D) = Dead
(a) = Adult stage
(l) = Larval stage

(*) Technical names of insecticides:

Reldan = Chlorpyrifos methyl

Actellic = Pirimiphos methyl

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DISCUSSION

In Pakistan, wheat is harvested in quite a dry state and grain moisture is rarely above 10 per cent at threshing time. Moulds are therefore, not a serious problem. Insect infestation in stored food grains is the main problem for the control of which, Hydrogen phosphide or phosphine gas is used as the main tool particularly for the management of large stocks in the public sector. Phosphine is an ideal grain fumigant because of many reasons - the convenience in its application by generating the gas on the spot from solid Aluminum (or Magnesium) Phosphide which is easy to transport in the form of tablets, pellets or sachets in airtight containers; its very good diffusion rate which makes it easy to penetrate the grain mass; its least sorption by the grain which allows long exposure to low concentrations of this gas without the risk of harmful residues or injury to the grain's germination capacity; its high toxicity to insects and finally; its low cost. One very important negative point of phosphine however, is that many species of insects can develop high tolerance to the toxic action of this gas. This is commonly referred to as the "acquired resistance" to phosphine. After the development of such resistance, higher doses of the gas and longer periods of exposure are required to control pests.

Resistance to phosphine develops due to the selection pressure caused by improper fumigation practices (Halliday et al., 1983; Friendship et al., 1986). High resistance to phosphine in the two species involved in the present study namely *Rhizopertha dominica* and *Tribolium castaneum*, has already been reported from Pakistan (Taylor, 1986; Taylor and Halliday, 1986). The results reported here show that the problem is being further aggravated. The method of fumigation of Hex bins presently being followed by the Punjab FD (Tables-1 and 2) is only partially effective and as such, causes a selection pressure on the pest species involved. The insects surviving such operations can only be those which have relatively higher natural tolerance to phosphine. The survivors of further such operations will thus be even more tolerant and such "selection" will ultimately result in the development of strains which may have hundreds of times more tolerance to this gas than their ancestors. It may be emphasized that "selection" is a heredity based natural phenomenon which helps evolution and continuation of life on this planet. Application of insecticides results in the acceleration of this phenomenon. The development of resistant strains is much faster in insects because of their short life span (weeks) compared to higher animals (having life spans spread over decades). The first implication of the appearance of resistant pest strains is that it increases the cost of pest management by necessitating higher dosage rates of pesticides to control such pests. An even more serious implication in the context of phosphine is that improper fumigation practices will ultimately lead to a situation when it will become useless as a pest management tool while there will be no available substitute with the same desirable properties. While there are alternate compounds in the case of almost all other pesticides, scientists have not so far been able to discover a substitute of phosphine.

Fumigants act in a gaseous state. The dosage necessary to kill an insect is achieved progressively by way of respiration of insects in an atmosphere where fumigant is present. Dosage is thus a function of the amount of fumigant present in the atmosphere (concentration in the air) and the period (time) of exposure to that atmosphere. As such, dosage of fumigants is generally expressed in terms of the product of concentration (C) and time (T) or CT. Toxicity of phosphine however, does not follow a linear relationship with its CT product (Monro et al., 1972; Bell, 1979; Winks, 1984). Some life stages of insects, such as eggs, require comparatively longer time of exposure to acquire a lethal dose than the adult or larval stages which are more active. Similarly, resistant strains of insects are not killed at short exposure time. Besides, higher concentrations of phosphine, may cause narcosis in insects (Winks, 1985), which may lead to their survival if shorter exposures are used. In view of all these factors, maintenance of lethal levels of phosphine gas in the fumigated space over at least seven (7) days is considered essential to control most of the stored products insect pests, including the resistant ones (Mills, 1986). For Pakistan however, in view of its peculiar conditions (Ahmed, et al., 1987) it is considered essential that a concentration of at least 200 ppm be maintained in all part of the fumigated space for at least seven days and the enclosure be not opened for at least 15 days to take advantage of the tailing down of this concentration. These criteria of success are met only by following Protocol-4 in the experiments reported here (Figure-3). Data in Table-4 shows that keeping the dosage rate (of 72 AlP tablets per bin) same as in Protocol-1, more than 200 ppm of gas could be retained in all parts of the bins for upto nine days which is more than satisfactory. Fumigation of bins will thus be perfect if AlP tablets are buried in the grain in equal numbers at two depths of one and five m instead of placing them on the grain surface (Figure-1 A). The reasons for the apparently higher retention of gas were not investigated but the gas seems to get trapped in the grain mass or probably, the rate of generation of gas from the AlP tablets slows down when these tablets are buried in the dry wheat having moisture content of less than 9.0 per cent.

Data of insect load in bins under Protocol-3 (Table-2) shows that the failure of fumigation operations at Badami Bagh was not due to any deficiency on the part of management but a fault of the Protocol because the outcome was almost the same when the prescribed Protocol was applied by the researchers themselves (Table-2, Protocol-1). The results improved a little when the rate of application of AlP tablets was increased from 72 to 180 per bin and applied in two successive doses (Table-2, Protocol-2). Even this Protocol (Protocol-2) was not satisfactory because the critical conditions of 200 ppm phosphine in all parts of the bins could not be achieved (Table-1). The data suggest that the gas was leaking out of the bins rather rapidly. Day time thermal expansion of the atmosphere in the headspace (free space) could be the major cause of this leakage. Data in Tables-1 and 4 further suggest that such leakage of gas was taking place from the top of the bins. The gas did diffuse to the bottom parts of bins within 24 to 48 hours of its production at the top (Table-1) but perhaps because of the negative pressure due to leakage from the top, it was not building up to the desired concentration levels at the

bottom despite the very high concentrations at the top (Table-1).

Data in Table-4 also shows this tendency of gas movement. Although AlP tablets were buried in the grain at depths of one and five m from the top grain surface, phosphine concentration in the freespace was quite high (average 245 ppm) within 24 hours of dosing (Table-4).

One of the advantage in phosphine fumigation mentioned above is that it leaves no toxic residues in the grain. This however, is a disadvantage as well because it provides no protection against reinfestation. Surface spray of grain stacks with suitable contact insecticides is undertaken to provide a barrier against reinfestation but its cost effectiveness is rather doubtful (Hodges, et al., 1990). A better recommendation is the use of "Polyethylene Enclosure and Phosphine Fumigation" or PEPF technique for bagged grains (Ahmed, et al., 1987) but it (PEFF) has the disadvantage of being difficult to apply to bulk grain. For the protection of bulk grain, admixture of insecticide(s) is commonly undertaken to disinfest as well as to provide protection against reinfestation (McFarlane, 1989). Special formulations of insecticides of low mammalian toxicity are marketed and registered under local laws in many countries for use as grain protectants. So long as the protectant stays unchanged, its residue in grain has positive value as protectant. Residual persistence however, varies according to the chemical composition of the insecticide and also due to the ambient conditions of grain temperature and its moisture content.

The use of grain protectants has, at present, a limited application in Pakistan because of the predominantly manual grain handling in the public sector. However, a trail was undertaken making use of the Grain Pump employed for loading Hex Bins in the present studies. Only 'Reldan' is registered as grain protectant in Pakistan and was therefore, tested here. 'Actellic' was used only for comparison of effectiveness. Results in Table-5 show that *Rhizopertha dominica* is already resistant to the action of both the insecticides. This however, is not an acquired resistance because both insecticides have no history of use as grain protectant in this country. Both insecticides however, belong to the organophosphorus group of compounds which are known to be ineffective against this species (McFarlane, 1989). Higher population of *Rhizopertha dominica* in the treated bins (Table-5) compared with the control (no insecticide treatment) bins could be due to slight addition of moisture in the wheat resulting from the spray treatment. Both insecticides however, provided protection against the other two species for about three month. Thereafter, Reldan failed to control *Tribolium castaneum* while Actellic failed against *Trogoderma granarium* (Table-5).

Contrary to the general impression that insect breed mostly in the top layers of grain, data in Table-3 shows that they can live as deep as 5.50 m inside the grain. Live as well as dead insects were present in all parts of Hex Bins upto a depth of 5.50 m (Table-3). The top grain layers however, had higher population (Figure-4). A similar pattern of

vertical distribution is reported in *Cryptolestes ferrugineus* by Hagstrum (1989). The data in Table-3 thus emphasizes the necessity of the distribution of phosphine gas in all parts of the bins for successful fumigation. Data used for the construction of Figure-2 was the average of all bins fumigated by placing the AlP tablets on the grain surface where phosphine was not reaching the bottom of the bins in sufficient concentrations (Table-1). All bins were loaded in July and fumigated in August, 1989. Figure-4 shows that population of insects had gone down after fumigation in August, 1989 but started rising again after November, 1989. This also confirms that the fumigations carried out by placing AlP tablets on grain top were not successful and that even an increase of dosage rate (from 72 AlP per bin tablets to 180) did not improve the results.

Data in Tables-2, 3 and 5 and Figure-2 show that the Lesser Grain Borer, *Rhizopertha dominica* was the most dominant of the pest species encountered followed by the Red Flour Beetle, *Tribolium castaneum* and the Khapra Beetle, *Trogoderma granarium* in descending order.

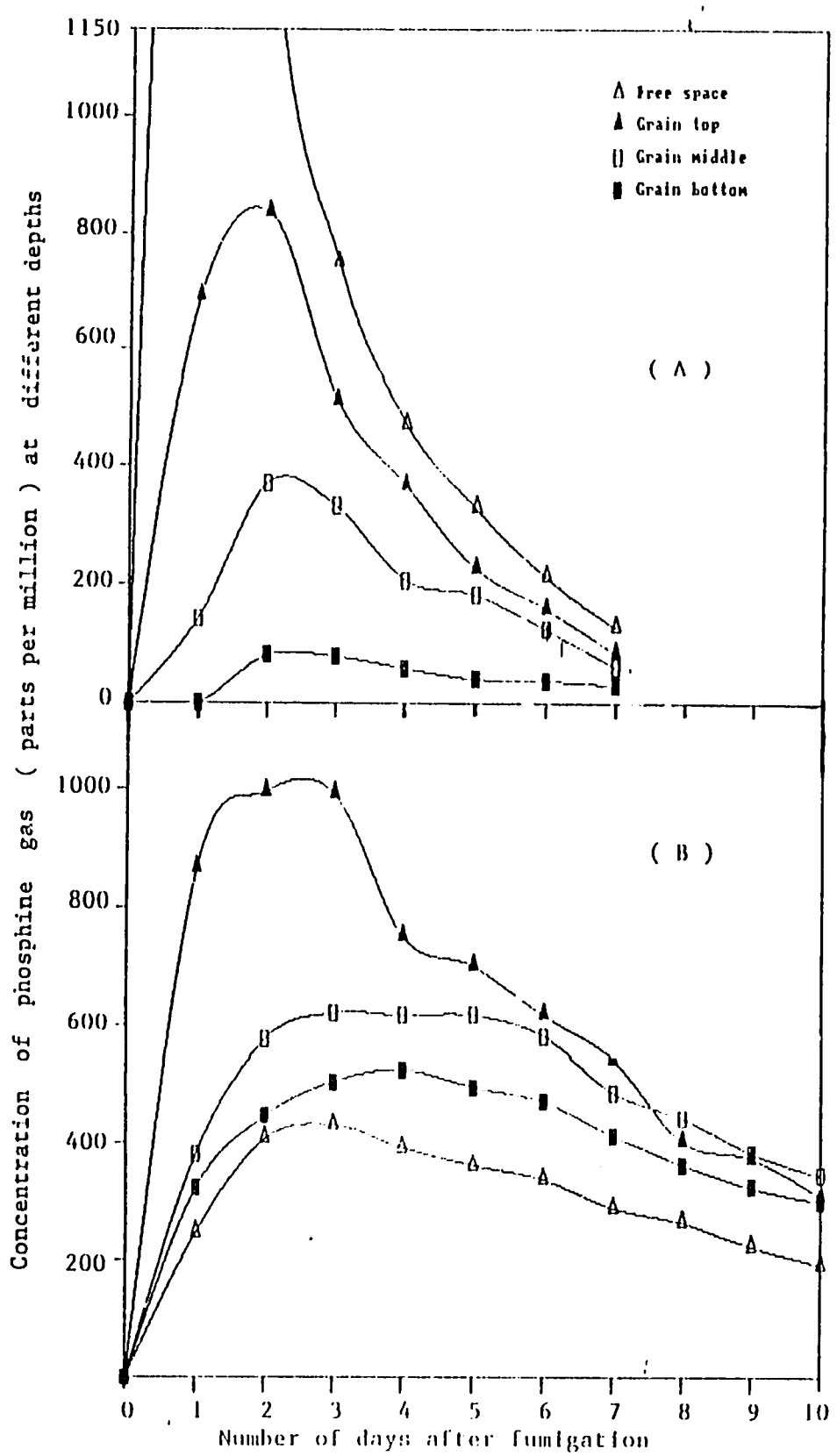

Figure-3. Difference in the gas distribution and retention pattern when 72 AlP tablets are buried (A) at depths of 1 and 5 m (36 tablets at each site) in the grain mass compared with their placement on the surface (B) of wheat in a Hex Bin.

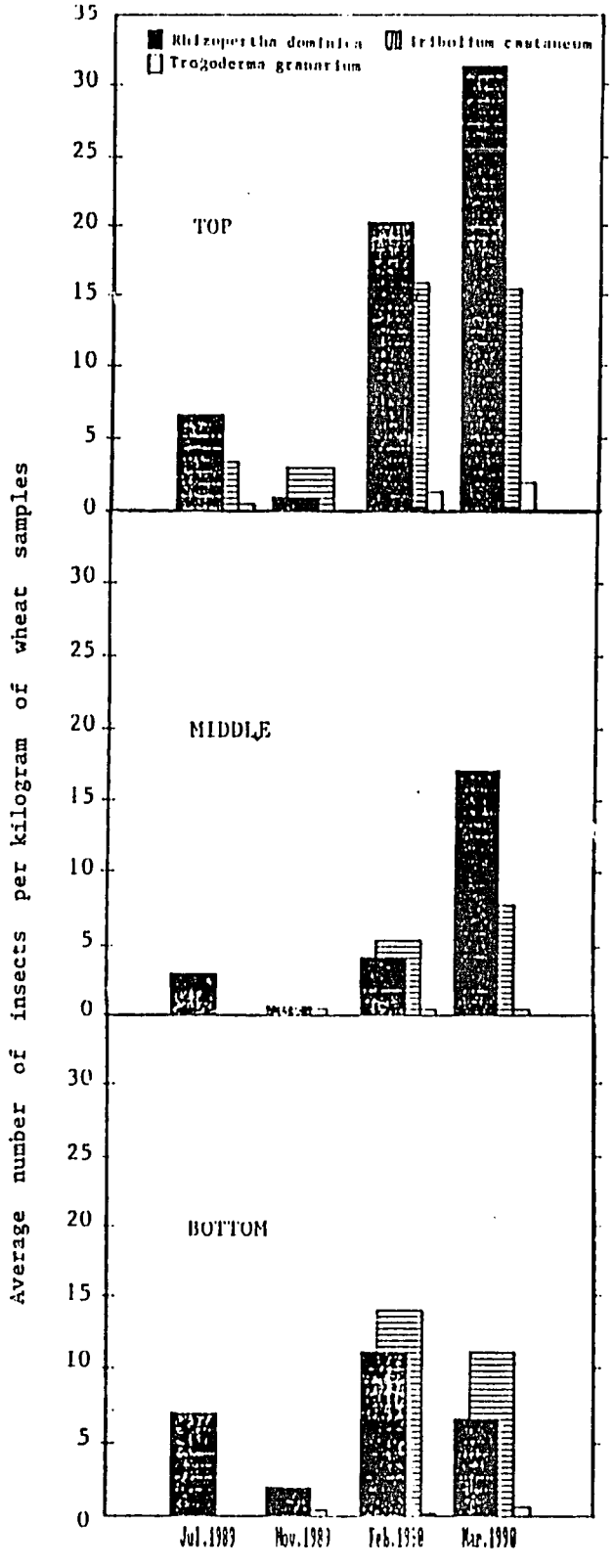

Figure-4.Vertical distribution of insects in Hex Bins full of wheat. Bins were loaded with wheat in July and fumigated with phosphine in August, 1989.

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CONCLUSIONS

The following conclusions are drawn from the studies reported here:-

1- The Protocol prescribed by the Punjab Food Department for fumigation of Hex Bins results in only partial disinfestation of wheat. Such improper phosphine fumigations result in the development of insect strains resistant to the toxic action of phosphine.

2- The placing of AlP tablets on the grain surface, as per the Punjab FD's currently followed Protocol, results in the quick release of phosphine gas from the tablets causing accumulation of very high concentrations of gas in the top parts of bins. Apparently due to leakage from there, critical levels of phosphine concentration do not form in the bottom parts of the bins which results in the survival of some (tolerant) insects present there. This flaw can however, be removed by simply burying the AlP tablets inside the grain at recommended depths (Figure-1 A) instead of placing them on the grain surface (Figure-1 B).

3- Higher populations of insects live in the top grain layers in Hex Bins though live as well as dead insect belonging to all the three main species are found dispersed in other parts of the bins as well.

4- The Lesser Grain Borer, *Rhizopertha dominica* was the most dominant pest infesting wheat in Hex Bins at Badami Bagh followed by the Red Flour Beetle, *Tribolium castaneum* and the Khapra Beetle, *Trogoderma granarium* in descending order.

5- Insecticides 'Reldan' and 'Actellic' failed to control the main pest namely, *Rhizopertha dominica* but provided protection to wheat against the other two species only upto about three months of their admixture with wheat at the company recommended doses.

RECOMMENDATIONS

1- For the management of insect infestations in wheat stored in Hex Bins, fumigation with phosphine gas is the best strategy to follow under the present manual system of loading grain in these bins.

2- Before loading wheat, the bins should be cleaned by dusting if found necessary on inspection. No surface spraying of insecticides is required inside the bins.

3- For phosphine fumigation, the currently adopted dosage rate of 72 AlP tablets per Hex Bin is adequate. This number of the tablets should not however, be reduced even if a bin is not loaded to its full capacity of about 36 tones of wheat.

4- AlP tablets should be applied by burying them in the grain and not by just placing them on the grain surface. The proper way of applying the total dosage of 72 tablets (per bin) is to insert 36 tablets to a depth of about five meters and the remaining 36 tablets to a depth of one mere inside the grain with the help a 'Special AlP tablet Applicator' (Figure-2). After inserting all the tablets in the grain, the mouth of the bin should immediately be closed using its iron lid. The bins should then be sealed by plastering mud around its closed top mouth and the bottom spout.

5- The bins under fumigation should not be opened for at least fifteen (15) days after sealing. However, inspection of top grain layers should be undertaken for live insects every month. In case no live insects are found, the bins should immediately be re-sealed after inspection to prevent reinfestation. In the event of presence of live insects, a re-fumigation should urgently be arranged except when wheat is to be issued for consumption in the immediate future.

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