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INTEGRATED PEST MANAGEMENT OF BAGGED GRAIN IN HOUSE-TYPE GODOWNS

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CONTENTS

Page

PREFACE iii

ABBREVIATIONS v

LIST OF TABLES vii

LIST OF FIGURES ix

EXECUTIVE SUMMARY xi

Section

I INTRODUCTION 1

II DISCUSSION 3

III CONCLUSIONS 11

IV RECOMMENDATIONS 13

V REFERENCES 17

APPENDIX I THE GSRL REPORT 19

CONTENTS 21

SUMMARY 23

Section

I INTRODUCTION 25

II DESCRIPTION OF EXPERIMENTS 27

III RESULTS AND DISCUSSION 31

Damage and Losses in Different Protocols 31
Changes in Insect Density During Storage 32
Phosphine Concentration Over Time. 33
Cost and Cost Effectiveness of the Protocols 34
Changes in Grain Weight Due to Moisture Transfer 35
Phosphine Resistance 36
Acknowledgements 55

PREFACE

The Food and Feed Grains Institute (FFGI) of Kansas State University (KSU) and the Grain Storage Research Laboratories (GSRL) of the Pakistan Agricultural Research Council (PARC) have been working together under the United States Agency for International Development (USAID) funded Storage Technology Development and Transfer (STDT)/Food Security Management (FSM) project to undertake applied research for the development of a suitable integrated pest management (IPM) protocol for bag storage of wheat in "house-type" godowns in Pakistan. The work was undertaken on a real life scale involving more than eight thousand tons of government wheat kept under experimental storage for 09 to 15 months in eight "house-type" godowns (Pakistan Agricultural Storage and Services Corporation (PASSCO) design) at Multan and Manga Mandi (near Lahore). The logistics and scientific inputs required for work of this magnitude were also tremendous. The studies, however, could cover only one storage season (1988-89) for want of time.

The GSRL has already issued two reports on this research. The first was a progress report issued in March 1989, and the second is their final report meant for general use issued in October 1990. There are still lots of data resulting from this work lying in GSRL waiting to be processed and scientifically analyzed.

After a perusal of the second GSRL report (appended herewith in full), it was felt that conclusions need to be stated separately and some recommendations, based on this research, also need to be formulated, for the benefit of field agencies. This is precisely the reason for writing this report.

Replication of the work for another storage season would have added to the authenticity of the results but the project was to originally end by June 1990. Though the project was later extended up to June 1991, its emphasis had shifted from bag to bulk storage and handling of wheat. This report, nevertheless, will be useful for PASSCO and the food departments who are likely to continue handling wheat in bags for quite some time before the inevitable changeover to the bulk system takes place.

ABBREVIATIONS USED

AlP = Aluminum Phosphide (tablets of this compound are used to generate phosphine gas in the field)

FD(s) = Food Department (s)

FFGI = Food and Feed Grains Institute

FSM = Food Security Management (Project name)

GASGA = Group for Assistance on Systems relating to Grain After-Harvest

gm = gram

GSRL = Grain Storage Research Laboratory

IPM = Integrated Pest Management

KSU = Kansas State University

MINFA = Ministry of Food, Agriculture, and Cooperatives

NRI = Natural Resources Institute (new name for ODNRI)

P1,P2 = Protocol-1, Protocol-2, etc.

PARC = Pakistan Agricultural Research Council

PASSCO= Pakistan Agricultural Storage and Services Corporation Limited

PEPF = Polyethylene Enclosure and Phosphine Fumigation

PFD = Punjab Food Department

STDT = Storage Technology Develop and Transfer Project (a component of the FSM project)

LIST OF TABLES

Table		Page
1	Grain Damage and Loss Produced by Insects During Storage in Bags at Multan, Pakistan Under Four Pest Management Protocols	37
2	Conversion Factors of Insect Damaged Grain to Weight Loss in Different Protocols	38
3	Grain Damage and Loss Produced by Insects During Storage in Bags in Four Test Management Protocols at Lahore	39
4	Density of Four Major Insect Pests (#/kg) and the Total Density at Arrival and Dispatch in the Four Protocols at Multan	40
5	Density of Four Major Insect Pests (#/kg) and the Total Density at Arrival and Dispatch in the Four Protocols at Lahore	41
6	Cost of Pest Control Inputs and the Value of Grain Lost Under the Four Storage Protocols for Bagged Grain in Multan Godowns	42
7	Cost of Pest Control Inputs and the Value of Grain Lost Under the Four Storage Protocols for Bagged Grain in Lahore Godowns	43
8	Changes in Weight and Value due to Moisture Transfer in One Metric Ton of Wheat Stored in Multan Godowns	44

LIST OF FIGURES

Figure		Page
2	Mean PH3 concentration in Protocol 1, Multan	45
3	Mean PH3 concentration in Protocol 2, Multan	46
4	Mean PH3 concentration in Protocol 3, Multan	47
5	Mean PH3 concentration in Protocol-1, Lahore	48
6	Mean PH3 concentration in Protocol-2, Lahore	49
7	Mean Phosphine concentration in Protocol-3, Lahore	50
8	*T. granarium*	51
9	*T. castaneum*	52
10	*R. dominica*	53

EXECUTIVE SUMMARY

The people of Pakistan derive a major portion (about 70%) of their daily requirements of calories and protein from food grains, particularly wheat. The government ensures availability of wheat at reasonable rates in the urban and production deficit areas by purchasing the farmer's surplus production (about four million tons) and also by arranging imports, if necessary. All this wheat is handled almost exclusively by the public sector where heavy losses are reported during the processes of its procurement, storage, and distribution in the country. The STDT project, a sub-component of the FSM project, is concerned mainly with the development of suitable technology to reduce storage losses. The main cause of storage losses is identified to be the development of insect infestation. Insect pests consume annually about 3.6% of public-sector wheat worth hundreds of millions of rupees (worth about Rs 430 millions in 1989-90). Nutritional deterioration, due to the insect infestation in stored wheat, impinges upon national health, but is difficult to quantify.

Storage losses in government owned wheat occur despite the best efforts of the public bodies responsible for its safety. In the research reported here, three safe IPM protocols have been investigated, including the one laid down for pest management in the code of practice of the Punjab Food Department (PFD), to find out the reasons for the failure of the current practices and to suggest improvements. The test protocols (P1, P2, etc.) have been compared in terms of their ability to provide minimum losses at the least cost and for the recommended protocol to be practicable in the real life operations. The protocol factually being followed in the field (as against that actually laid down in the books) was also considered as the fourth protocol for comparing the effectiveness of the ones under investigation. Phosphine fumigation was included in all the protocols as the main tool for insect control.

All the four protocols investigated here were found to be wanting in achieving complete control of insects for the reason that the insects have developed very high levels of resistance to the toxic action of phosphine gas. The main conclusion drawn from this research thus is that whole-godown fumigations can no more be undertaken in Pakistan without running the risk of further aggravating the resistance situation which has already reached alarming proportions. Of the three protocols compared, the one which provided for the under-sheet phosphine fumigation (P3) was considered to be comparatively most qualified to become the recommended protocol. However, for the proper IPM of bagged grains, which is still the predominant mode of wheat storage (about 70% of the total storage capacity) in the country, a more comprehensive protocol has been recommended. Designed in the light of the first-hand knowledge gained from these studies, the recommended protocol includes phosphine fumigation of bag stacks wrapped in a polyethylene sheet, the way it was done under P3 of the present experiments, but the period of exposure to phosphine gas has been extended by suggesting a fractionalized system of dose application instead of single application used in P3. The dose recommended is provisionally kept the same as used here in P3 which, it is hoped, will make resistance management possible for bagged grains at a cost of about Rs 9.00 per ton per year. Step-wise details of this protocol are given in the recommendation part of this report. For resistance management

in bulk grain, applied research on the scale undertaken here for bagged grain needs to be undertaken urgently.

The need has been identified for establishing an institute in the country which should be able to tackle the problems being faced by field agencies involved in grain handling and storage through research and training on a regular basis.

SECTION I

INTRODUCTION

A report covering research work on the development of the IPM protocols for the storage of bagged wheat in "house-type" godowns in Pakistan has recently been finalized (October 1990) by Mr. Mubarik Ahmed, GSRL, and Dr. S. Shahid Shaukat, FFGI. Presented here is essentially an addendum to that report which is referred to as **the GSRL report** throughout this addendum. The results presented in the GSRL report are subjected to further discussion so as to draw some conclusions. For this purpose, contents of the GSRL report were required to be referred to quite frequently. For the convenience of readers, therefore, GSRL report is appended herewith in full for ready reference. A progress report on this research issued earlier by GSRL (Ahmed M., 1989) provides some of the details of methodology, etc., not given in the final report being discussed here.

According to the approved "Plan of Work" for the STDT project research, the development of the IPM protocols for bagged storage (of wheat) had three main objectives (Anonymous, 1988). These were:

- to investigate (compare) three safe protocols (*) for maintenance of stored-grain quality;
- to recommend appropriate protocol which would provide for the minimum losses at the least cost; and
- to apply this recommended protocol to day-to-day operations of public-sector storage.

The main purpose here is to discuss the results contained in the GSRL report in relation to these objectives and to formulate suitable recommendations for the benefits of the end users of this research which are primarily the provincial food departments (FDs) and PASSCO.

(*) Protocol means a set of pest management operations referred to in the GSRL report by the symbol 'P'. The three safe protocols tested in these studies were:
P1 = Punjab FD's laid down procedures for pest management.(#)
P2 = Multiple dose whole-godown fumigation technique developed by Natural Resources Institute (NRI) of UK.
P3 = PEPF technique developed by GSRL for bag fumigation.
(#) P4 = Actual application of P1 by the Fds and PASSCO.

SECTION II

DISCUSSION

In the "Plan of Work" for the research on development of the IPM protocols, the first criterion set forth for success is the **maintenance of stored-grain quality** (Anonymous, 1988). For a rational comparison of the tested protocols, therefore, quality deteriorations under each protocol were required to be compared using the causative factors actually studied and reported in the GSRL report (see Appendix I). These factors are: the numbers of live (and dead) insects found in the wheat samples taken at the start (arrival) and termination (dispatch) of storage; weight loss due to the development of insect infestation in the wheat stored under different IPM protocols; increase in the number of "insect damaged grains" during storage; and the phosphine gas retention patterns achieved under each protocol for the control of insect pests. The relevance and reliability of these factors as indicators of comparative wheat quality deteriorations under different protocols need to be discussed.

Storage fungi being a minor problem under the dry climate of Pakistan, insects are the main agents causing deterioration in stored-grain quality (Ahmed et al., 1987). Absence of live insects in wheat samples at dispatch (termination of storage) would, therefore, seem to be a good indication of the effectiveness of the applied IPM protocol. In the research under discussion (the GSRL report), unfortunately, all the applied IPM protocols failed to eliminate the four major insect pest species found infesting the wheat under experiments both at Multan and Lahore. It will be seen from the data presented in Tables 4 and 5 (of the GSRL report) that live insects were always present in the samples taken at the time of dispatch (termination of storage), although the species which survived varied in various protocols. At Multan, live Rhizopertha dominica got eliminated as a result of the application of P1, P3, and P4, but not from P2. Similarly, Trogoderma granarium was eliminated from P1 and P2, but not from P3 and P4. Live Tribolium castaneum and Sitophilus oryzae were present in all the protocols at the time of dispatch (termination of storage), although Sitophilus oryzae was not even detected in any of the samples taken at the time of arrival (start of storage) of wheat in the godowns (Table 4). At Lahore (Table 5), Sitophilus oryzae disappeared from all dispatch samples under all protocols while Trogoderma granarium was eliminated from P1 and P3, but not from P2 and P4. Live Rhizopertha dominica and Tribolium castaneum were present in all the protocols at dispatch (Table 5). In the light of these findings, none of the applied protocols can, in fact, be termed as successful in the maintenance of stored-grain quality. A comparison between protocols would thus determine only the lesser failure. Even for such a comparison, variations in the number of live insects found in dispatch samples cannot be used as a criterion, because the levels of resistance to phosphine, in the species found infesting wheat under different protocols, clearly differed.

Insects convert the weight of grain into the weight of their own bodies through the processes of consumption and metabolism. Loss in the real weight of an infested commodity (on dry weight basis) is thus not only a sure sign of quality deterioration but also of the gross mismanagement in its storage. Can the weight

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loss figures, as given for each protocol in the GSRL report (Tables 1 and 2), be used as a criterion for a rational comparison of the protocols here?

Differences in weight loss in the wheat stored under different IPM protocols would seemingly suggest proportionate differences in the pest activity under these protocols as well. Laboratory determinations of weight losses in the wheat under test protocols at Multan (Table 1) indeed show a relationship with the total insect density (total load of live and dead insects) at dispatch (Table 4). At Lahore, such relationship is, however, not discernible (Tables 3 and 5). This is because the composition of infestations (extent, species, etc.) differed at Multan and Lahore and such differences can have different effects on the weight loss factor. We know that larvae (younger life stages) of some pest species, namely Rhizopertha dominica, Sitophilus oryzae and Sitotroga cerealella are internal feeders and live within the infested grain. They thus deteriorate quality and food value of the infested grain without causing much of a change in its weight. In cases where infestation is dominated by such species, a relationship between weight loss and insect numbers is difficult to establish as happened at Lahore (Tables 3 and 5). On the other hand, larvae of species such as Trogoderma granarium, Tribolium castaneum, and many more, which are external feeders, do cause proportionate weight loss in the infested commodity. Weight loss in grains infested dominantly by such species can, therefore, be related to their numbers as happened at Multan (Tables 1 and 4). At Multan, the position seems to differ between protocols as well. Conversion factors given in Table 2 of the GSRL report illustrate this point probably more clearly. It will be seen (Table 2) that the values of the conversion factor "during treatment (storage)" decreased from the "total" in the case of P1 and P2 (from 0.25 and 0.51 to 0.14 and 0.39 respectively), but increased in P3 and P4 (from 0.56 and 0.39 to 0.85 and 0.45 respectively). The reason for this could be seen in the data in Table 4 where it shown that Rhizopertha dominica (internal feeder) was the dominant species in P1 and P2 while Troqoderma granarium (external feeder) was dominant in P3 and P4. In the light of this discussion, it can be concluded that weight loss in stored-grains may not always be proportionate to quality deterioration. As such, in the context of the present studies (the GSRL report), weight loss in wheat under different protocols (Tables 1 and 3) is not considered to be a reliable criterion to compare the ability of these protocols to maintain stored-grain quality.

'Insect damaged or weeviled grains' represent the proportionate development of pest infestation in stored commodities, be that infestation by an internal or external feeder of grains. Internal feeders are difficult to detect when in the larval (younger) stage, but on attaining adulthood they (pest) leave the infested grain through a small hole which is detectable. This is perhaps the reason that percentage of insect damaged (weeviled) grains used to be a measure of wheat quality and its pricing in trade circles in the sub-continent during the first half of this century (Anonymous, 1937). Fortunately, this aspect of wheat quality has also been studied and reported in the GSRL report (see Appendix I). The data on this account can, therefore, be used for comparing the efficiency of the protocols tested here.

Table 1 (of the GSRL report) shows that the percent increase (during storage) in the number of "insect damaged grain" in wheat stored at Multan for a period of one year was 0.93, 0.49, 0.40, and 3.67 for protocols 1, 2, 3, and 4, respective-

ly. This showed the superiority of P3 (PEPF) over all other protocols. P2 and P1 followed P3 in descending order while P4 was the worst (Table 1). At Lahore also, P3 was outstanding on this account as the percent increase in 'insect damaged grains' over a period of 13 months of storage of wheat under this protocol was only 0.113%, which was the lowest of all (Table 3). This (top) position of P3 at Lahore was despite the fact that wheat under this protocol was fumigated only once as against two times in protocols 1 and 2. P1 at Lahore cannot be compared because data for arrival (start of storage) for this protocol was not recorded (Table 3). P2 and P4 are also not directly comparable because storage under P4 was terminated after 9 months as against 14 months under P2 (see Table 7 of the GSRL report). Percent increase in 'insect damaged grains' was 0.133 in 9 months under P4 as against 0.620 in 14 months under P2. On the face of it, P4 would thus appear to be superior to P2 in preserving wheat quality. This, however, is not true. We know that insect populations increase in geometric progression and that most species can complete their life cycle in about four weeks under conditions of temperature and humidity as existed inside the godowns at Lahore. It can thus be estimated that had the wheat under P4 remained under storage for 14 months, the increase in the number of the 'insect damaged grains' would have reached a level of about 1.6%; i.e., more than double the level of such grains in this period under P2 (0.62)! This shows that, like Multan, P3 was 'the best' and P4 'the worst' protocols at Lahore as well.

The main tool used in all the protocols for the elimination of insects from the stored wheat was phosphine fumigation. We know that dosage in fumigants is the product of their concentration in the air and the time of exposure to that air. Bell (1986), while discussing factors governing the toxicity of phosphine to insects has, however, emphasized the importance of increase in the length of exposure time rather than using high concentrations for successful fumigations. In an earlier STDT research report on the "Integrated Pest Management in Hexagonal Bins", issued in October 1990, essential criteria were laid down for successful phosphine fumigation of wheat under Pakistan conditions. These were (a) the retention of at least 200 ppm air concentration of phosphine in all parts of the enclosure (a godown, a bin or under plastic sheets) for a period of at least 7 days, and (b) keeping of the enclosure sealed for at least 15 days to take advantage of the tailing down of this (200 ppm) concentration. In the research being discussed here (the GSRL report), the gas retention patterns achieved under protocols 1, 2, and 3 for both Multan and Lahore are shown in Figures 2 to 7. (For protocol 4, fumigation operations were not monitored at either site.) It will be seen that in all fumigations, the essential laid down criteria for success could not be achieved except in P3 (PEPF) at Lahore (Figure 7) and at Multan in the second fumigation carried out in December 1988 (Figure 4). In the first fumigation under P3 at Multan as carried out in August 1988, there seems to be some mistake involved. Either the polyethylene sheets used to make enclosures were of low quality and damaged, or most probably the number of AlP (Aluminum Phosphide) tablets needed for the generation of the required dose of phosphine gas were miscalculated. This is quite evident from the vast differences in the areas under the two curves representing the fumigations in August and December 1988, the small differences in the applied doses (1.0 gm and 1.14 gm phosphine per cubic meter of space, respectively) notwithstanding (see Figure 4 of the GSRL report). Considering these possibilities, the superiority of P3 (PEPF) is evident on this account as well, both at Multan as well as at Lahore.

The second criterion set forth in the 'Plan of Work' is for the recommending of a protocol **which would provide for the minimum losses at the least cost** (Anonymous, 1988). Here, the meanings of 'losses' could be the "weight loss" caused by insect infestation. Perhaps for this reason, 'weight loss' in the wheat during 'actual storage' under different protocols (Tables 1 and 3) was used as the criterion for calculating the 'net cost' of application for each protocol in the GSRL report (Tables 6 and 7). It will, however, be seen (Tables 6 and 7 of the GSRL report) that the 'least cost' protocol determined on this basis varied at Multan and Lahore. At Multan, P1 was the 'least cost' protocol costing Rs 0.96 per ton per month of storage period (Table 6), while at Lahore, it was P3 costing only Rs 0.51 per ton per month of storage period (Table 7). The variation is obviously due to the fact that, in the case of P1 at Multan, two phosphine fumigations were applied (Figure 2), while in the case of P3 at Lahore, only one fumigation was applied (Figure 7). P2 was expensive both at Multan (costing Rs 1.60 per ton per month) as well as at Lahore (costing Rs 2.11 per ton per month). P2 did not fare well in maintenance of stored-wheat quality either. It can, therefore, be concluded that P2 (multiple dose whole-godown fumigation) does not qualify to be the recommended protocol. This leaves the need for P1, P3, and P4 to be considered further.

For the purposes of comparison, the cost of a protocol to be considered should, in fact, be the actual expenditure which is incurred on its application. Unfortunately, the fumigation schedules under the protocols were varied according to the situation to avoid heavy losses in the stored wheat. This made the protocols uneven for straight comparison. It will be seen that two phosphine fumigations were applied at Multan within a period of 5 months (in August and December 1988) in P1 and P3 (Figures 2 and 4) but not in P2 where second fumigation was carried out after 7 months in February 1989 (Figure 3). At Lahore, a second fumigation was carried out in May 1989; i.e., after 9 months of the first one (September 1988) in P1 and P2 but not in P3 (Figures 5 to 7). Similarly, at Multan, the second fumigation in P2 was not a multiple dose one (Figure 3), while at Lahore it was (Figure 6). Such variations made the results in the GSRL report (see Appendix I) rather difficult to interpret. The simplest protocol in respect of expenditure is P4, which, according to the figures given in the GSRL report (Tables 6 and 7), is undoubtedly the 'least cost' one, because only Rs 4,000/= and 3,873/= were spent on its application at Multan and Lahore, respectively (Tables 6 and 7). However, because of its being 'the worst' protocol for the maintenance of stored-wheat quality (see discussion above), P4 also does not qualify to be the recommended protocol. This leaves only P1 and P3 to be considered further.

Although P4 is not being compared here, expenditure-wise P4 can be considered to represent a single fumigation P1 because theoretically, both protocols are the same except that P1 was applied by the research staff while P4 was applied by the public agencies concerned in their normal way (Ahmed M., 1989). On single fumigation basis, therefore, P1 (represented by P4) was about half as cheap as P3. At Lahore, P3 with single fumigation cost Rs 6403/= while single fumigation P1 (represented by P4) cost only Rs 3873/= (P4 cost given in Table 7). P1 with single fumigation, however, could not maintain stored-wheat quality (see discussion above). So, let us compare these two protocols (P1 and P3) on the basis of two fumigations under each.

If installed properly in the first instance, a second fumigation (and any number of subsequent fumigations) under P3 (PEPF) involves almost no further expenditure except the cost of AlP tablets required for the second (or more) fumigation. In the case of the whole-godown, fresh expenditure will have to be incurred for sealing the building for every fumigation. Besides, the requirements of AlP tablets for fumigation under P3 (PEPF) are much too less, compared to the whole-godown fumigation (P1) because of no head space. For these reasons, it will be seen that the cost of application of P3 at Multan was only slightly higher than P1 when two fumigations were applied in both cases (Table 6), whereas on the basis of single fumigation, P3 was almost twice as expensive as P1 (see discussion above). At Multan, P3 and P1 cost Rs 9089/and Rs 8397/=, respectively (Table 6). The expenditure on the application of P3 (PEPF) will go down still further with increase in the stack size because proportionately less polyethylene is required to wrap large sized stacks. Ahmed et al., (1986), have given the cost of PEPF (P3) application to bagged wheat as Rs 7.40 and Rs 8.77 per ton for stack sizes of 500 and 200 tons, respectively, with two phosphine fumigations applied in 9 months of storage period in both cases. It can thus be said that cost-wise, P1 and P3 are almost equivalent, while P3 was much better in the maintenance of stored-grain quality during storage (see above discussion).

The third objective of the IPM studies was **to apply this (the recommended) protocol to day-to-day operations of public-sector storage** (Anonymous, 1988). Ahmed et al., (1987), have already demonstrated the application of PEPF (P3) in the day-to-day operations of Sind (at Karachi) and Baluchistan (at Quetta) FDs involving a total of about 5,500 tons of bagged wheat in 21 stacks of various sizes. In the present studies (the GSRL report), P3 (PEPF) has now been demonstrated in experiments carried out on the real-life scale involving 2,000 tons of wheat in house-type godowns of the Punjab FD and PASSCO. All these trials and demonstrations constitute sufficient evidence to show PEPF, or P3, to be a practical protocol which can be, and in fact, has been applied to the day-to-day operations of public-sector storages at various places in the country.

In the light of the above discussion, it is concluded that P3 (PEPF) is the most qualified protocol to be recommended out of the three protocols tested in the present studies (the GSRL report) for use by public-sector for the IPM of bagged wheat stored in house-type godowns in Pakistan.

The discussion so far was in the context of the laid down objectives of the present IPM studies (the GSRL report). In the paragraphs below, other points which are also relevant to the conclusions reached here are discussed.

The results reported here (the GSRL report) highlight once again the importance of insect resistance in any IPM protocol for the safe storage of grains. In Pakistan, the problem seems to be escalating day-by-day, and as such, requires immediate attention of the public-sector agencies involved in food-grain storage (see also the earlier STDT report entitled "Integrated Pest Management in Hexagonal Bins," October 1990). Insect resistance was certainly responsible for the failure of all three protocols tested here in achieving the full control (see Tables 4 and 5 of the GSRL report). Champ and Dyte (1976) were the first to report the widespread occurrence of resistance to phosphine in insect pests of stored grains. The actual fumigation failure attributable to phosphine

resistance was first reported by Tyler et al., (1983), from Bangladesh. Alam et al., (1984), were the first to report phosphine fumigation failures in Pakistan but they attributed it to the insufficient gas tightness of the godowns. They (loc. cit.), therefore, recommended that the practice of whole-godown fumigation should be abandoned in favor of under sheet phosphine fumigation. Friendship et al., (1986), also proposed that "the simplest approach to ensuring that the commodities fumigated with phosphine in Bangladesh and Pakistan are given adequate exposure periods to lethal concentrations of gas is to replace the practice of whole-godown fumigation with that of fumigation under sheets."
The present studies (the GSRL report) are the first to show that even under sheet phosphine fumigations have failed to achieve complete control of insect pests of stored wheat in Pakistan (see Tables 4 and 5, the GSRL report). The failure of P3 (PEPF) in the present studies can only be attributed to the development of very high levels of resistance to phosphine in the pest species involved because adequate exposure periods to lethal concentrations were achieved (Figures 4 and 7). It will be seen that under P3 at Lahore, Rhizopertha dominica and Tribolium castaneum survived (Table 5) a concentration of more than 200 ppm of phosphine gas for over 12 days (Figure 7). Similarly, at Multan, Trogoderma granarium, Tribolium castaneum and Sitophilus oryzae survived (Table 4) a satisfactory concentration and time pattern achieved under P3 in December 1988, fumigation (Figure 4). Data presented in Tables 4 and 5 (of the GSRL report) also show how variations in the levels of resistance in the pest species involved under the four protocols (and perhaps in the four stacks of the same protocol) complicated the results. It caused not only significant variations in the total load of insects under different protocols but also in the pest status of the species under these protocols. At Lahore, the total load of live insects at arrival (start of storage) differed considerably between protocols but the dominant species in all cases was Rhizopertha dominica (Table 4). At Multan, however, not only the total load differed, but the dominant species also differed between protocols. In the case of P1 and P2, Rhizopertha dominica was the dominant species at the start (arrival) of storage, while in P3 and P4, it was Trogoderma granarium. In the face of these variations, it is difficult to determine the dominant pest species in the wheat stored at Multan and Lahore for these experiments (Tables 4 and 5).

Halliday et al., (1983), Taylor (1986), and Friendship et al., (1986), consider that resistance to phosphine develops (and progressively increases) due to the selection pressure caused by improper fumigation practices. The present results (the GSRL report) show that a single dose fumigation under polyethylene sheet (P3) can no more be considered 'proper' because of the survivals of insects (Tables 4 and 5). Adoption of P3 as such is thus likely to further aggravate the problem of phosphine resistance in Pakistan. As a provisional recommendation, therefore, it is proposed that PEPF (or P3) technology developed by GSRL (Ahmed et al., 1986 and 1987), be combined with multiple dose (or P2) technology developed by NRI (Friendhsip et al., 1986), for the management of phosphine resistant insect pests of stored grains in Pakistan. In other words, instead of applying the AlP tablets all at one time as was done here under P3 (the GSRL report), the total number of the required AlP tablets be divided in two equal lots and applied in two installments with an interval of 6 days in between. As already discussed above, this will not increase the cost of PEPF, or P3 (the GSRL report), very much but will increase the exposure period to lethal concentrations

of phosphine sufficiently long enough to kill all insects including, hopefully, the resistant strains as well.

These studies (the GSRL report) also point out the need for further applied research on the management of resistant insect pests in Pakistan. For bagged grains, where phosphine gas can diffuse easily, application of PEPF (P3), coupled with multiple dosing technique as recommended here, needs to be explored and field tested for confirmation or modification of the dose rate proposed here on a provisional basis. For bulk grains, however, resistance management using phosphine fumigation seems to be a difficult proposition for Pakistan. Field trials in Pakistan of a new phosphine fumigation technique (SIROFLO) being developed in Australia (Winks et al., 1989), may prove useful. Alternatively, research on the use of grain protectants may be encouraged along with the present efforts to introduce bulk wheat handling and storage technology in Pakistan.

SECTION III

CONCLUSIONS

In the light of the discussion presented here and the results and discussion given in the GSRL report (see Appendix I), the following conclusions are drawn:

1. Resistance to phosphine in insects has reached serious proportions in Pakistan. Actual fumigation failures in the field must have been more common than were perhaps visualized by the planners of these studies. This is why all the three IPM protocols tested under these studies actually failed in achieving complete control of insects, both at Multan and Lahore.

2. In order to avoid heavy losses, fumigation schedules under the protocols were varied according to the situation; similarly, infestation composition in terms of dominant pest species as well as the levels of their resistance to phosphine varied under various protocols. This made straight comparison between the protocols rather difficult. However, considering the various relevant factors affecting losses and costs, it is concluded that P3 (PEPF) is the most appropriate protocol which, on the basis of the results of these studies, is recommended for use by public-sector agencies for the IPM of bagged wheat under storage in Pakistan.

3. Application of P3 (PEPF), the way it was tested here, is likely to further escalate the problem of phosphine resistance because P3 did not kill all insects. To avoid this, it is concluded that phosphine fumigation methodology under P3 protocol should be changed from single to multiple dose applications while keeping the dose rate, provisionally, the same as tested here. In other words, the total number of AlP tablets which were used for single fumigation under P3 in the present experiments should be divided in two equal portions and applied successively with 6 days interval in between. This, it is hoped, shall increase the exposure period sufficiently enough to kill all insect pests, including the resistant strains. This modification will not affect the cost of the recommended protocol (P3) which will be almost the same as for P3 at Multan (Table 6), i.e., Rs 2,275/= per stack of 250 tons.

4. Further applied research is needed urgently to discover ways and means for the management of resistant insect pests of stored food-grains in Pakistan. A concomitant program of training will ensure that full use will be made of the results of such research.

5. Four species of insects were found to be the major pests of stored wheat in the Multan and Lahore regions of the Punjab province. These were *Trogoderma granarium*, *Rhizopertha dominica*, *Sitophilus oryzae* and *Tribolium castaneum*. Due to variation in their resistance levels, it was difficult to determine the most dominant pest of wheat at these two sites. Another four species which were also

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found infesting wheat but were relatively less menacing were Sitotroga cerealella, Corcyra cephalonica, Cryptolestes ferrugineus and Oryzaephilus surinamensis.

6. Higher ambient temperatures (summer months) resulted in comparatively quicker decomposition of AlP tablets and generally higher leakage rates of the gas from godowns compared to lower temperatures (winter months). Thus, the gas concentration and retention pattern in godowns seemed to be generally better in winter months. What effect this factor will have on the factual control of infestation still needs to be determined.

7. The Punjab FDs laid down procedures for pest management when followed by the research staff (P1) yielded better results than when applied by the Department in their own way (P4). The need for improvements in the present pest management practices is therefore identified, which may be brought about through staff training on a regular, rather than periodical, basis.

SECTION IV

RECOMMENDATIONS

Based on the results of the IPM research presented in the GSRL report (see Appendix I) and, in the light of the discussion made thereon in this addendum, the following recommendations are made for the benefit of public-sector storage of grains in bags in Pakistan:

1. The present practice of whole-godown phosphine fumigation should immediately be abandoned. This is essential not only to arrest the alarming situation of insect resistance to phosphine which is growing fast due to these practices (of whole-godown fumigations) but also for the preservation of nutritional quality and physical quantity of wheat produced in the country during the essential phase of its storage through the year.

2. For safe storage of big quantities of bagged grains in house-type godowns or binishells in the public-sector or by the private entrepreneurs in Pakistan, adoption of the following IPM protocol is recommended.

   a. Before loading with the grains, all godowns (house-type or binishell) should first be emptied of all the junk or other stores which might have been placed there in a corner for some reason. The interior of the building should then be cleaned by sweeping the floor, walls, and ceiling, and the refuse thus collected should be taken out and buried or burned.

   b. All internal (swept) surfaces of the godowns should then be sprayed with a suitable power sprayer using 1.0% (actual ingredients) water solution of pirimiphos-methyl (Actellic) for application at the fate of 5 liters per 100 square meter surface area. Other suitable insecticides can also be used but not malathion, which has become ineffective due to the development of high levels of resistance to this compound in insect pests of stored grains. Necessary precautions should be taken to avoid inhaling the spray mist or the spray droplets falling on the naked parts of bodies of the workers.

   c. Plan maximum sized bag stacks of grain while avoiding the pillars, if any, in the godown building. Mark the base size of each stack on the floor of the godown. Calculate the quantity of transparent polyethylene sheet of low density and 0.2 millimeter thickness which will be required to wrap the bag stacks as planned.

   d. Arrange two plastic heat sealing machines for the welding together of polyethylene to make sheets of the

required sizes and shapes. One of these machines should be a continuous band sealing type (Doboy Power Heat Sealer Model HS-C or equivalent) while the other should be the ordinary pinching type. Make sure of a nearby power supply or arrange a small portable power generator to match the sealing machines.

e. Polyethylene sheet is manufactured in tubular form which is then pressed to make its two ply rolls for marketing. Use only single ply sheet by cutting it longitudinally. First, make sheets of the required sizes to be used as underlays, by joining smaller sheets using the continuous band heat sealing machine. The dimensions of these underlaid sheets should be about 1 meter extending on all sides from the base size of each stack marked on the floor.

f. At the time of loading the godowns, first of all, spread the polyethylene sheets prepared for use as underlays for the stacks onto the base areas marked on the floor for each stack. Then start constructing the stacks and raise them up to the maximum possible heights.

g. Tailor polyethylene covers for each stack using the sheet already procured for the purpose. These covers should be made to size to fit snugly on each stack. The covers can be made easily by welding together pieces of polyethylene sheets cut according to the measured requirements for each stack. Floor area where these covers are to be prepared should be very clean because the heat sealing machines do not weld strongly if the sheets are soiled. Each cover should be about 1 meter longer in depth than the height of the bag stack on all sides. When ready, place the covers onto each stack without unnecessary delay. The extending portions of the top cover and the underlaid sheet should then be held one upon the other, rolled together and kept pressed with the floor using the weight of the sand snakes or any other suitable weighty material. This shall make the stack gastight and ready for phosphine fumigation.

h. Fumigate the grain as soon as its wrapping in polyethylene sheet is completed. <u>Do not allow infestation to manifest</u>. For fumigation, calculate the total requirement of AlP tablets at the dose rate of 1.5 tablets per ton of grain (this equals roughly 1.0 tablet per cubic meter of the space under sheets). Divide the dose in two equal portions. Introduce one portion of the dose (AlP tablets) into the enclosure through two to four small slit openings (one in the center of each side of

the polyethylene cover) made with the help of a razor blade. Wearing surgical gloves, throw in by hand through these openings one portion of the dose (AlP tablets) in such a way that the tablets spread as sparsely as possible inside the polyethylene enclosure **(heaping of the tablets at one spot could be dangerous)**. Close the openings made in the polyethylene cover immediately after throwing in the AlP tablets with adhesive tapes. On the sixth day, remove the adhesive tapes and throw in the second portion of the dose (AlP tablets) in the same way as described above for the first portion. Again close the openings immediately with adhesive tapes. This shall complete the process of a single phosphine fumigation.

i. Do not remove polyethylene covers during the entire period of storage of grains under this protocol. This is essential to prevent a re-infestation. Arrange another fumigation after every 6 months of storage period or earlier in case infestation manifests itself.

j. Doors, ventilators, and windows of the godown building, if any, must be kept closed during the entire period of grain storage. This is essential to prevent entry of birds which may damage polyethylene sheet as well as to save phosphine gas, during the process of fumigation, from getting pumped out of the polyethylene enclosure due to the impact of wind entering the building through these openings.

k. Normally, house-type godowns and binishells in the public sector in Pakistan are constructed on raised platforms to make them rat-proof. Full use should be made of this feature of the godown buildings. In case a particular godown does not have rat-proof design, necessary anti-rat measures should be adopted to prevent entry of rats in the godowns. Rats, in a godown where grain is stored under PEPF, will play havoc with polyethylene wrapping and damage the grains as well.

l. Regular monthly inspection of the stored-grain should be considered an essential part of this protocol. Detection of live insects under polyethylene sheet should warrant an immediate action for phosphine fumigation.

3. An autonomous body should be established in the country with its headquarters at Lahore to undertake applied research in the real life problems encountered by the agencies involved in grains storage in the public and/or private sectors; and to organize regular training courses for various levels of management personnel running these agencies. This body may also be assigned the functions of A

GRAINS INSPECTION AGENCY in case standards and grades for various types of grains are introduced in the country.

SECTION V

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APPENDIX I

THE GSRL REPORT

CONTENTS

		Page
SUMMARY		21
Section		
I	INTRODUCTION	23
II	DESCRIPTION OF EXPERIMENTS	27
III	RESULTS AND DISCUSSION	31
	Damage and Losses in Different Protocols	31
	Changes in Insect Density During Storage	32
	Phosphine Concentration Over Time	33
	Cost and Cost Effectiveness of the Protocols	34
	Changes in Grain Weight Due to Moisture Transfer	35
	Phosphine Resistance	36
	Acknowledgements	55

SUMMARY

This investigation determines the effect of various integrated pest management practices in preserving the quality and quantity of bag-stored wheat and analyzes their cost/benefit. The experiments were conducted in PASSCO type godowns at Multan and Lahore. The pest management practices (protocols) included P1, the laid down practice of FD; P2, multiple dose fumigation and peripheral spraying of bags; P3, phosphine fumigation under polyethylene enclosure (PEPF); and P4, control or monitoring of actual agency routine practice that normally includes single phosphine fumigation.

In Multan the actual storage loss during treatment period was highest in control (P4), followed by PEPF (P3), multiple dose fumigation (P2), and recommended practice (P1). The total insect density at dispatch was highest in control (P4), followed by PEPF (P3), multiple dose fumigation (P2), and the recommended practice (P1). Thus storage loss was directly related to insect population development. The quantity lost and the value of loss was highest in control (P4), followed by PEPF (P3), multiple dose fumigation (P2), and recommended practice (P1). The cost of treatment (total expenditure) was highest for multiple dose fumigation (P2), followed by PEPF (P3), recommended practice (P1), and agency controlled godown (P4) in that order. Net cost (total expenditure plus value of loss) was highest for agency controlled (P4), followed by multiple dose fumigation (P2), PEPF (P3), and the recommended practice (P1) in that order. The calculated net cost per ton per month for P1, P2, P3, and P4 comes to rupees 0.96, 1.60, 1.40, and 3.99 respectively.

In Lahore, relatively less insect infestation was developed and lesser was the magnitude of loss. The highest storage loss was recorded in multiple dose fumigation (P2), followed by recommended practice (P1), control (P4), and PEPF (P3). The total insect density at dispatch was highest in the recommended practice (P1) followed by control (P4), multiple dose fumigation (P2) and PEPF (P3). However, the maximum percentage increase in number of insects at issue over arrival was found in control (P4), followed by multiple dose fumigation (P2), PEPF (P3), and the recommended practice (P1). Net cost (total expenditure plus value of loss) was highest in multiple dose fumigation (P2) followed by recommended practice (P1), control (P4), and PEPF (P3). Net cost per ton per month for P1, P2, P3, and P4 in Lahore was found to be rupees 0.99, 2.11, 0.51, and 0.81, respectively.

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SECTION I

INTRODUCTION

Background

Public-sector losses of wheat in Pakistan are reported to be as high as 3.6% which is worth about Rs 430/- millions at the 1989-90 price rate. The basic reasons for such high losses in the country are the improper storage practices. The major short-comings in this regard are lack of sanitary conditions, leaky and poorly maintained godowns, acceptance of substandard and infested wheat, inadequate and improper application of contact insecticides and fumigants, and lack of trained manpower. The substandard application of chemicals and improper grain protection practices have resulted in the development of highly resistant strains of insects and such populations are difficult to control. Despite this, insecticides remain important in preserving the quantity and quality of grain during storage. In fact, insecticides are generally the most effective management tools and in many instances are the only feasible method of controlling insect populations or holding them at an acceptable level.

The increasing limitations in insecticide applications have given rise to the concept of integrated pest control systems as an alternative. This involves efforts to develop compatible systems of insect management through chemical, physical, biological and other alternative methods applied singly or in combination to achieve the desired results.

Objectives of the Study

Major Objectives

To investigate the application, in bag storage, of three protocols (treatments) for maintenance of stored grain quantity and quality.

To evaluate the cost/benefit for the different protocols.

To demonstrate the applicability of the protocols in public-sector storage.

To establish a linkage of weather data information with suitable IPM program via design and implementation of a system that provides grain storage facility managers with a set of information on possible moisture movements and insect development under certain weather conditions.

Secondary Objectives

To observe the changes in the population of the stored grain insects in relation to several biotic and abiotic factors.

To evaluate different methods of sampling for their reliability.

SECTION II

DESCRIPTION OF EXPERIMENTS

The experimental procedure is given in Figure 1 and its detail is as under.

Godowns and Stacks. PASSCO type godowns with a rated storage capacity of 1110 tons in bags were selected for study at Lahore (Manga) and Multan (Thatta) sites. Each site had four godowns of similar maintenance condition, one for each of the four protocols (treatments). The internal size of the godowns was 30.5 x 18.9 x 5.6 m.

Four stacks were made in each godown. Each stack was approximately 14.26 m in length, and 8.42 m in width, and 14 bags in height. Each stack thus contained approximately 250 tons of wheat. Stack size and pattern were kept uniform at both the experimental sites.

Monitoring of Temperature. Thermocouples were placed in two of the stacks in each protocol at 2nd, 7th, and 12th bag height. Temperature in these layers was recorded on a bimonthly basis.

Monitoring of Phosphine Concentration. To monitor phosphine gas concentration, four nylon tubes were placed at the time of staking in the central portion at the top, middle and bottom of each of the stacks. One tube remained outside the stack.

Placement of Marked Bags

Thirty marked bags were placed in each of the stacks in all the protocols at 2nd, 7th, and 12th bag heights.

Treatment Procedure

The experiment consisted of the following four protocols (treatments).

Present System of Quality Maintenance As Laid Down by PFDs (P1). The godowns were cleaned and sprayed with Malathion 57% EC at the ratio of 1:25 before stacking on the walls, floor, and roof. Soon after stacking, the first fumigations were carried out in Multan and Lahore in August and September 1988, respectively, with aluminum phosphide (AlP) tablets at a dosage rate of 1 tablet/cu meter. In Multan, the second phosphine fumigation was carried out in December 1988, due to the development of insect infestation, whereas in Lahore, the second fumigation was conducted in May 1989.

Multiple Dose Fumigation and Peripheral Spraying of Bags With Actellic (P2). The godowns subjected to this treatment were made airtight (as far as possible) by mud plastering their doors, ventilators, and plugging the possible gas leakage points. The godowns were then fumigated with AlP tablets placed in fractionate doses; i.e., an initial dose of 1.5 tablet/cu meter followed by another dose of 1 tablet/cu meter on the third day of initial application. After the disappear-

ance of phosphine, the four stacks were sprayed on their exposed surfaces with Actellic 50% EC as per prescribed dose by the manufacturer. In Multan, first multiple dose fumigation and insecticide application were carried out in August 1988, which was followed by a single dose fumigation and insecticide application in February 1989. In Lahore, two multiple dose fumigations and insecticide applications were carried out, the first in September 1988, and second in May 1989.

Polyethylene Enclosure and Phosphine Fumigation (PEPF) (P3). The individual stacks were enclosed in polyethylene sheets (0.2 mm thick, low density, and transparent). Polyethylene underlays and caps were prepared according to the size of stacks by heat sealing the marked sheets. The cap and the bottom sheet were heat sealed together. This enclosure permits low dosage fumigation and also acts as a barrier in preventing cross infestation during the entire storage period.

For the purpose of fumigation, incision was given in the polyethylene sheet and aluminum phosphide (AlP) tablets at a rate of 1 tablet/cu meter were placed on top and periphery of stack. Gas concentration was monitored daily using Harris meter from the gas tubings. In Multan, two fumigations were carried out in the individual stacks in August and December 1988, whereas in Lahore, fumigation was conducted in September 1988, only and no additional fumigation was made as the stacks were found to be free from live insects in routine monthly sampling.

Methods of Sampling

Sampling at arrival. At arrival all the bags in each stack (except the marked bags) were sampled by means of a spear. For this purpose, a primary sample of about 250 g was obtained from each bag by probing at three different points to make up a separate composite sample for each of the stacks. The composite samples obtained from each stack were kept in a jute bag internally lined with polyethylene to prevent possible changes in moisture content and insect escape or entry. The composite sample of each stack was divided by Boerner type divider to obtain three laboratory samples. These arrival composite samples were analyzed in laboratory for insects and physical grain quality characteristics.

Sampling at issue. Sampling at issue was performed exactly in the same manner as at arrival.

Periodic sampling. Samples were drawn from peripheral layers of all the stacks in different experimental godowns at monthly intervals. For peripheral sampling 8 bag height was considered 'accessible height'. The number of bags in a stack up to accessible height were counted and the square root of total number of bags in accessible area was calculated. The square root indicated the number of groups to be made accessible area of each stack which was also equal to the number of bags in each group. From each group one bag was randomly selected. Such a bag was spear sampled from three different places to obtain 500 g of wheat. Thus a composite sample was obtained for each stack separately.

Placement of Marked Bags at Arrival. Thirty marked bags were weighed and placed in different horizontal and vertical layers of each of the stacks. For marking

a bag, a randomly selected bag was emptied in a produce flow sampler to obtain a "representative laboratory sample" of about 1-1.5 kg. The remaining grain was refilled in a bag which was sewn at its mouth, weighed, marked, and placed at different vertical and horizontal positions within a stack. The laboratory sample was analyzed for moisture content, insect infestation, and grain quality characteristics.

Recovery of Marked Bags. The marked bags were recovered at the time of issue. They were first weighed and then processed through the produce flow sampler to obtain a laboratory sample for analysis. The difference in weight and quality parameters indicated the actual weight loss and the level of deterioration in each bag.

Sample Analysis. All types of samples were brought in to the laboratory for determination of various physical quality characteristics. The samples were also subjected to different loss assessment methods.

SECTION III

RESULTS AND DISCUSSIONS

The results presented here only pertain to arrival and issue composite stack sampling and gravimetric method of loss assessment. The two methods are universally used for such studies though their accuracy has been questioned. Three sampling methods that include arrival and issue composite stack sampling, peripheral sampling and marked bags sampling (through produce flow sampler) and several loss assessment methods were simultaneously applied to test their reliability in this study. However, their results are under compilation and analysis and shall be produced at a later stage.

Damage and Loss in Different Protocols

Insect Damaged Grain. In Multan, at the time of storage in experimental godowns (arrival) the percentage of insect damaged grain was significantly higher ($p < 0.05$) in PEPF (P3) and control (P4) (Table 1). At issue there was a significant increase in damage percentage in control (P4) over the rest of the protocols (p at the most 0.001). The difference of arrival and issue, i.e., during storage period, was highest in control (P4) followed by the recommended practice (P1) multiple dose fumigation (P2) and PEPF (P3) in that order (Table 1). The difference between arrival and issue in the percentage damaged grain was significantly higher ($p < 0.001$) in control (P4) compared with all other protocols. However, there was no significant difference between multiple dose fumigation (P2) and PEPF (P3). The percentage increase of insect damaged grain during storage over arrival was highest in P1 followed by P4, P2, and P3 which indicates that the rate of insect damage was relatively slow in PEPF and multiple dose fumigation compared to recommended practice and control.

In Lahore, at arrival, the percentage of insect damaged grain was highest in control (P4), followed by PEPF (P3), and multiple dose fumigation (P2) (Table 3). The arrival data of the recommended practice (P1) could not be obtained. At issue highest numbers of insect damaged grains were recorded in control (P4), and multiple dose fumigation (P2), followed by recommended practice (P1), and PEPF (P3). The difference in arrival and issue was maximum in P2, succeeded by P4 and P3. There was an increase in percentage of insect damaged grains at dispatch over arrival of 3.65, 0.20, and 0.41 folds in P2, P4, and P3, respectively (Table 3).

Weight loss. Table 1 shows that in Multan the total weight loss in agency controlled godown (P4) was significantly higher than all the other protocols ($p < 0.001$). Interestingly, it was also found that the total weight loss in PEPF (P3) was significantly higher ($p < 0.05$) than multiple dose fumigation treatment (P2). However, this was due to the fact that the percent insect damaged grain at arrival in PEPF (P3) was substantially higher than that in multiple dose treatment (P2). The actual storage loss in different treatment during storage was highest in control (P4), followed by PEPF (P3), multiple dose fumigation (P2), and recommended practice (P1). The percentage increase in loss at issue over arrival was highest in P4, followed by P3, P2, and P1. These results,

though, contradict with the results of percentage of insect damaged grains in various protocols but it is presumably due to the fact that the relative abundance of different insect pest species varied considerably in the different protocols as well as within different stacks of the same protocol. Since different species have different feeding habits, viz. species like Tribolium castaneum infest germ part of wheat kernel or is a secondary feeder and thus damage greater numbers of grains with relatively lesser weight loss; whereas, Trogoderma granarium larvae infest relatively lesser numbers of grains but often consume the major portion of kernels.

Table 2 shows the conversion factors for insect damaged grain to weight loss in Multan. During the storage period under treatment, this factor is highest in PEPF (P3), followed by multiple dose fumigation (P2), control (P4), and recommended practice (P1), indicating that 85% of the infested kernel is consumed by the insects in PEPF (P3), while only 14% of the infested kernel is damaged in case of recommended practice (P1).

In Lahore weight loss was comparatively low due to better management and unfavorable environmental conditions for insect growth in all the treatments. Table 3 shows the weight loss and percentage of insect damaged grains in all the protocols. A scrutiny of Table 3 will reveal that the minimum weight loss and insect damage during treatment took place in protocol 3, whereas protocol 2 was the most affected treatment that registered a weight loss and insect damage of 0.44 and 0.62%, respectively.

Change in Insect Density During Storage

The insect infestation was higher in Multan than in Lahore (Manga). In both the places, in all eight species of stored grain insect pests were recorded that included Trogoderma granarium, Tribolium castaneum, Rhizopertha dominica, Sitophilus oryzae, Sitotroga cerealella, Corcyra cephalonica, Cryptolestis feurrugineus and Oryzaephilus surinamensis. Of these, the first four were common while the rest occurred very rarely. Table 4 shows the density of the four common insect pests at arrival and dispatch individually as well as the total insect density in four protocols of Multan.

In general, Rhizopertha dominica population density was higher, followed by Trogoderma granarium, Tribolium castaneum, and Sitophilus oryzae. However, different insect pests showed greater population development in different protocols. In protocol 1 (agency controlled) T. granarium and T. castaneum showed 9.37 and 3.49 fold increase at dispatch compared to arrival. In protocol 2 (multiple dose fumigation) R. dominica and S. oryzae showed a greater increase, whereas in protocol 3 (PEPF) T. castaneum and S. oryzae showed 23.16 and 88.12 fold increase, respectively, at dispatch compared to arrival. In protocol 4 (control), R. dominica and T. granarium exhibited 142.65 and 30.81 times increase respectively at dispatch to that of arrival. The total insect density at dispatch was highest in protocol 4 (control), followed by protocol 3 (PEPF), protocol 2 (multiple dose fumigation), and protocol 1 (agency controlled), in that order. In general, live insect density was lower than that of dead insects. This is presumably due to the natural mortality of insects as well as the mortality caused by insecticides. The reason why PEPF was unable to check insect

density as effectively as the agency controlled procedure is that the live insect density was higher at arrival in PEPF, compared to other protocols.

The insect density in the four protocols of Lahore is shown in Table 5. Rhizopertha dominica was the predominant species, followed by Trogoderma granarium, Tribolium castaneum and Sitophilus oryzae in that order. The maximum infestation at arrival was recorded in P1 followed by P2, P3, and P4. At issue, the insect density was highest in P1 followed by P4, P2, and P3. However, the percentage increase in number of insects at issue over arrival was found to be 1.05, 1.22, 1.10, and 1.63 for P1, P2, P3, and P4 respectively. This indicates that maximum increase in insect density took place in protocol 4.

In protocol 1, R. dominica showed 1.06 fold increase at dispatch over arrival. In protocol 2 all the first three above referred predominant species showed an increase over arrival at dispatch to range between 1.17 to 1.49 fold. In protocol 3 the increase was only recorded in case of T. granarium (2.72 fold), whereas, in the agency controlled godown (P4) the first three predominant species showed an increase ranging between 1.25 and 3.85 fold. In general, the total number of live insects at issue were less in all the protocols at Lahore except protocol 2. The lower insect density in all the protocols at Lahore as compared to Multan is probably due to relative better storage management of the entire complex and also unfavorable conditions for insect development.

Phosphine Concentration Over Time

First phosphine fumigations in Multan and Lahore were carried out in August and September 1988, respectively. Thereafter, in Multan, protocols 1 and 3 second fumigations were made in December 1988, and in protocol 2 in February 1989. In Lahore, the second fumigations were carried out in May 1989, in protocols 1 and 2, whereas protocol 3 was not fumigated as it was found free of infestation. The concentration of phosphine after fumigation in different protocols in Multan and Lahore are shown in Figures 2 to 7. To achieve an adequate control of insect population, a minimum phosphine concentration of 200 ppm should be maintained for a minimum period of 5 days. In cases where resistant populations exist, the exposure period should be at least 7 to 8 days in order to achieve a reasonable control. Since phosphine concentrations varied in Lahore and Multan, they are dealt with separately below.

Multan. In Multan as a result of fumigation carried out in protocol 1 in August 1988, the phosphine concentration of 200 ppm or more was maintained for only 2 1/2 days, which clearly implies that the fumigation was inadequate. This was presumably due to leakiness of the godown and higher temperature which permitted the escape of phosphine gas. Due to high insect attack in Multan, a second phosphine fumigation was carried out in the same protocol/godown in the first week of December 1988, when the temperature was relatively low. A higher dosage than 1 tablet/cu.m was used and this time lethal concentration (greater than or equal to 200 ppm) was maintained for 6 days (Figure 2). In multiple dose fumigation (protocol 2) carried out in August 1988, an initial dose of 1.5 tablet/cu.m was applied which was followed by a second dose of 1 tablet/cu. m on the third day of the initial dose. A peak concentration of 680 ppm was achieved within 24 hours after fumigation. Second dose resulted in another peak

concentration of 490 ppm. A phosphine concentration of 200 ppm or more was maintained for about 5 days. The second single dose fumigation was carried out in protocol 2 in February, 1989. The lethal concentration of more than 6 days was maintained at the dosage rate of about 1 tablet/cu.m (Figure 3). Due to higher retention of gas, presumably due to lower temperatures, multiple dosing was not considered cost economic. In polyethylene enclosure (protocol 3) first fumigation was carried out in August 1988. A lethal concentration of 200 ppm or more was maintained for about 6 days despite high ambient temperature. The second fumigation, carried out in February 1989, with same dose, retained the lethal phosphine gas concentration for more than 10 days (Figure 4).

Lahore (Manga). In Lahore (Manga), godowns first fumigations in all the protocols were carried out in September 1988. The temperature at the time of fumigation in Lahore was slightly lower than that at Multan. Therefore, the release of gas, in general, was slower and the gas was generally retained for a longer period. In the case of recommended practice (protocol 1), the lethal phosphine gas concentration was retained for 4 1/2 days (Figure 5). In multiple dose fumigation (protocol 2), the lethal concentration was maintained for 7 days (Figure 6), whereas in PEPF (protocol 3), the lethal concentration was retained for 11 days (Figure 7). The second fumigations were carried out only in protocol 1 and 2 during May 1989. Protocol 3 was not fumigated as it was found to be free of infestation. The retention of gas was more or less of similar duration as to first fumigation except that due to relatively higher temperatures the release of gas was much quicker (Figures 5 and 6). Thus, in Lahore, the fumigation was consistently more effective in all protocols compared to Multan godowns.

Effect of Temperature on Phosphine Gas Retention. In Lahore (Manga) godowns, in general, critical phosphine concentration (200 ppm or more) was retained for longer periods than in Multan godowns in all the protocols. The major reason for this is that the ambient temperature in Lahore (Manga) godowns, where fumigation was carried out in September 1988, was lower (30-34°C) compared to Multan (30-37°C) in August 1988. The relative lower temperature in Lahore was presumably responsible for slower release of phosphine. Besides this, probably Lahore godowns were less leaky compared to those of Multan. However, it was quite obvious in Multan that the same godowns when fumigated during winter (Temperature 14-18°C) were able to hold the lethal concentration of gas for longer durations (Figures 2 to 4). At the time of second fumigation in Lahore, the temperatures were slightly higher than prevailed at the time of first fumigation, which is reflected by a relative faster generation of gas and higher leakiness rate (Figures 5 and 6).

Cost and Cost-Effectiveness of the Protocols

The effect of inputs and the value of grain lost to insects in Multan is given in Table 6. The quantity lost and the value of loss was highest in agency controlled godown (P4), followed by PEPF (P3), multiple dose fumigation (P2), and recommended practice (P1), in that order. The cost of treatment (total expenditure) was highest for multiple dose fumigation (P2), followed by PEPF (P3), recommended practice (P1), and agency controlled (P4). Second fumigations were carried out in protocols 1, 2, and 3 due to the increased insect activity. The cost of treatment in protocol 1 includes the cost of malathion (for surface

spraying) and two fumigations with 3229 and 3664 AlP tablets in August and December 1988, respectively. The cost of treatment in protocol 2 includes the cost of Actellic as surface and bag spray and the cost of two fumigations with 8074 and 3665 AlP tablets in August 1988, and February 1989, respectively. The treatment cost for protocol 3 included two fumigations with 1512 and 1728 AlP tablets in August and December 1988, and the depreciated cost of 260 kg of polyethylene. The cost given for protocol 4 (agency controlled) is estimated. This protocol comprised of a single fumigation in October 1988.

Thus, in Multan the net cost (total expenditure + value of loss) was highest for agency controlled (P4), followed by multiple dose fumigation (P2), PEPF (P3), and recommended practice (P1). Thus, the net cost was lowest for the recommended practice because not only the expenditure was low but the quantity lost was also low presumably due to better quality of grain and relatively lower level of insect density both at the time of arrival as well as during storage period. On the basis of net cost per ton per month among the Multan protocols, recommended practice (P1) showed the lowest cost of Rs 0.96, followed by PEPF (P3) of Rs 1.44, multiple dose fumigation (P2) of Rs 1.60, and agency controlled (P4) of Rs 3.99.

In Lahore, cost of treatment in protocol 1 includes two surface sprays and two single dose fumigations (3024 tab. per fumigation) carried out in September 1988, and May 1989. In protocol 2, surface spray, peripheral spraying of bags, and multiple dose fumigation (each with 7,560 tablets) were carried out twice, one in September 1988, and the other in May 1989. In protocol 3, the cost of treatment includes depreciated cost of 240 kg polyethylene (polyethylene is resalable at one-third of initial cost) and the cost of one fumigation only, which was carried out in September 1988, with 1,336 tablets. Second fumigation was not carried out in protocol 3 as there were no signs of live insect infestation throughout entire storage period. The cost given for protocol 4 (agency controlled) is estimated and includes cost of one fumigation and cost of Actellic for surface and bag spraying. The fumigation and spraying in this protocol were carried out in October 1988.

In Lahore, the reliable weight loss data for protocol 1 at the time of arrival could not be recorded. However, basing on the assumption that at the time of arrival no weight loss or insect damage had occurred in this protocol, Table 7 has been prepared. The table summarizes the expenditures discussed earlier and some other features relating to this cost economic study. Thus, the net cost (total expenditure and value of loss) was highest in multiple dose fumigation (P2), followed by recommended practice (P1), agency controlled (P4), and PEPF (P3). The net cost, therefore, is lowest for PEPF, though its expenditure was higher than agency controlled (P4). The value of loss in P3 was Rs 288/- as opposed to Rs 4152/- in P4. The net cost per ton per month for PEPF (P3) was calculated as Rs 0.51, as compared to Rs 2.11 in multiple dose fumigation (P2), Rs 0.99 in recommended practice (P1), and Rs 0.89 in agency controlled (P4).

Changes In Grain Weight Due to Moisture Transfer

Table 8 shows changes in weight due to sorption or desorption of moisture in the peripheral layers of the stacks during various storage periods as determined by periodic sampling and also the per ton value of the grain. In general, the

moisture content increased from June 1988, to January 1989, and as a result the value of a ton of grain in June 1988, consistently increased up to January 1989. The figures of June are based on the average moisture content reading in June as determined in our grain quality survey.

Phosphine resistance

The warehouses in Multan have a history of at least 12 years of phosphine fumigation. Though sufficient information is not available, such a situation may be prevalent in other localities. The primary cause of development of resistance to phosphine is the use of substandard fumigation techniques, in particular the leakiness of the warehouses that leads to suboptimal concentrations. The resistance levels of various populations of stored grain insect pests in Pakistan are discussed below.

Trogoderma Granarium Full Grown Larvae (Khapra beetle). The level (range) of resistance to phosphine in the sample populations (strains) of Khapra beetle (*T. granarium*) in various parts of Pakistan is shown in Figure 8. In Karachi (Sindh), the resistance level ranges from 10 to 18 fold. Muzaffargarh strain showed higher level of resistance (35 fold).

Tribolium castaneum (rust-red flour beetle). The phosphine resistance level in various populations of rust-red flour beetle in Pakistan is shown in Figure 9. The resistance level in Karachi is higher (0-162). In Punjab, the level of resistance ranges from 4 to 14 fold.

In Peshawar the resistance level is zero, but in Mansehra (NWFP) the level ranges from 10-80 fold.

Rhizopertha dominica (lesser grain borer). The level of phosphine resistance in *R. dominica* populations in Pakistan is shown in Figure 10. In Karachi-Hyderabad (Sindh), the resistance ranges from 0-85 fold, whereas in Punjab, the level of phosphine resistance is relatively lower. However, in NWFP, the resistance is high. In Mansehra (NWFP), it ranges from 0-72 fold.

TABLE 1

GRAIN DAMAGE AND LOSS PRODUCED BY INSECTS DURING STORAGE IN BAGS AT MULTAN, PAKISTAN UNDER FOUR PEST MANAGEMENT PROTOCOLS

Treatments	Percent insect damaged grain			X-fold increase over arrival	Weight loss percentage			X-fold increase in loss over arrival
	Pre-treatment (Arrival)	Total (Dispatch)	Storage (Difference)		Pre-treatment (Arrival)	Total (Dispatch)	Actual storage loss (difference)	
Recommended practice (P1)	0.23 ±0.18	1.16 ±0.95	0.93	4.04	0.16 ±0.11	0.29 ±0.36	0.13	0.81
Multiple dose fumigation (P2)	0.26 ±0.28	0.75 ±0.89	0.49	1.88	0.19 ±0.20	0.38 ±0.35	0.19	0.99
PEPF (P3)	0.75 ±0.35	1.15 ±1.13	0.40	0.53	0.31 ±0.38	0.65 ±0.37	0.34	1.10
Agency Controlled (P4)	0.92 ±0.73	5.20 ±1.53	3.67	3.99	0.37 ±0.31	2.03 ±0.72	1.66	4.49

TABLE 2

CONVERSION FACTORS OF INSECT DAMAGED GRAIN TO WEIGHT LOSS IN DIFFERENT PROTOCOLS, MULTAN

Treatment	Conversion Factor	
	Total	During Treatment
Recommended Practice (P1)	0.25	0.14
Multiple Dose Fumigation (P2)	0.51	0.39
PEPF (P3)	0.56	0.85
Agency Controlled (P4)	0.39	0.45

TABLE 3

GRAIN DAMAGE AND LOSS PRODUCED BY INSECTS DURING STORAGE IN BAGS IN FOUR PEST MANAGEMENT PROTOCOLS AT LAHORE

Treatments	Percent insect damaged grain			X-fold increase over arrival	Weight loss percentage			X-fold increase in loss over arrival
	Pre-treatment (Arrival)	Total (Dispatch)	Storage (Difference)		Pre-treatment (Arrival)	Total (Dispatch)	Actual storage loss (difference)	
Recommended practice (P1)	*	0.520 ±0.094			*	0.310 ±0.054		
Multiple dose fumigation (P2)	0.170 ±0.150	0.790 ±0.604	0.620	3.647	0.280 ±0.362	0.720 ±0.457	0.440	1.571
PEPF (P3)	0.277 ±0.211	0.390 ±0.096	0.113	0.408	0.178 ±0.111	0.190 ±0.071	0.012	0.067
Agency Controlled (P4)	0.657 ±0.341	0.790 ±0.214	0.133	0.202	0.271 ±0.127	0.444 ±0.095	0.173	0.638

*Data not recorded

TABLE 4

DENSITY OF FOUR MAJOR INSECT PESTS (#/kg) AND THE TOTAL DENSITY AT ARRIVAL AND DISPATCH IN THE FOUR PROTOCOLS AT MULTAN

Treatment	Insect Species	Live A	Live D	X-fold increase (+) or decrease (-)	Dead A	Dead D	X-fold increase (+) or decrease (-)	Total A	Total D	X-fold increase (+) or decrease (-)
	R.d	3.04	0.00	$$	0.50	0.00	$$	3.54	0.00	$$
	T.g	0.48	0.00	$$	0.79	11.90	+15.06	1.27	11.90	+9.37
Protocol 1	T.c	0.73	3.86	+5.29	0.74	1.27	+1.72	1.47	5.13	+3.49
	S.o	0.00	0.32	$	0.00	0.00	0.00	0.00	0.32	$
Tot		4.25	4.18	-1.02	2.03	13.17	+6.49	6.28	17.35	+2.77
	R.d	0.73	2.01	+2.75	0.27	5.13	+19.00	1.00	7.14	+7.14
	T.g	0.54	0.00	$$	0.12	3.05	+25.42	0.66	3.05	+4.62
Protocol 2	T.c	0.38	9.78	+25.74	1.62	0.69	-2.35	2.00	10.47	+5.23
	S.o	0.00	1.12	$	0.15	0.00	$$	0.15	1.12	+7.47
Tot		1.64	12.91	+7.87	2.16	8.88	+4.11	3.80	21.79	+5.73
	R.d	0.32	0.00	$$	0.73	0.52	-1.40	1.06	0.52	-2.04
	T.g	16.05	2.50	-6.42	1.85	12.28	+6.64	17.90	14.78	-1.21
Protocol 3	T.c	0.09	160.23	+1780.33	6.98	3.54	-1.97	7.07	163.77	+23.16
	S.o	0.00	4.45	$	0.08	2.60	+32.50	0.08	7.05	+88.12
Tot		16.46	167.18	+10.16	9.64	18.93	+1.96	26.10	186.11	+7.13
	R.d	1.50	0.00	$$	1.55	435.08	+280.69	3.05	435.08	+142.65
	T.g	2.35	3.04	+1.29	3.96	191.40	+48.33	6.31	194.44	+30.81
Protocol 4	T.c	0.62	0.33	-1.88	105.01	0.69	-153.09	105.63	1.01	-104.58
	S.o	0.00	0.80	$	1.07	0.00	$$	1.07	0.80	-1.34
Tot		4.47	4.17	-1.07	111.59	627.16	+5.62	116.05	631.33	+5.44

A = Arrival, D = Dispatch, R.d = Rhizopertha dominica, T.g = Trigoderma granarium, R.c = Tribolium castaneum, S.o = Sitophilus oryzae, Tot = Total insects, $$ Places where insect density has decreased to zero level, $ = Places where insect density has increased over zero level

TABLE 5

DENSITY OF FOUR MAJOR INSECT PESTS (#/kg) AND THE TOTAL DENSITY AT ARRIVAL AND ISSUE IN THE FOUR PROTOCOLS AT LAHORE

Treatment	Insect Species	Live A	Live D	X-fold increase (+) or decrease (-)	Dead A	Dead D	X-fold increase (+) or decrease (-)	Total A	Total D	X-fold increase (+) or decrease (-)
Protocol 1	R.d	54.20	5.67	-9.56	17.57	13.45	-1.31	71.78	76.48	+1.06
	T.g	0.88	0.00	$$	0.86	0.37	-2.32	1.24	0.37	-3.35
	T.c	4.59	0.38	-12.08	2.74	3.93	+1.43	7.35	4.32	-1.70
	S.o	0.91	0.00	$$	0.42	0.23	-1.83	1.33	0.23	-5.78
	Tot	60.58	6.05	-10.01	21.59	17.98	-1.20	77.70	81.40	+1.05
Protocol 2	R.d	14.37	23.21	+1.61	12.18	8.52	-1.43	26.72	31.72	+1.19
	T.g	0.31	0.12	-2.58	1.01	1.42	+1.40	1.32	1.54	+1.17
	T.c	1.15	4.75	+4.13	3.41	2.06	-1.65	4.56	6.80	+1.49
	S.o	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	$$
	Tot	15.83	28.08	+1.77	16.60	12.00	-1.38	32.72	40.07	+1.22
Protocol 3	R.d	7.20	8.86	+1.23	6.71	6.67	-1.00	21.05	15.54	-1.35
	T.g	1.35	0.00	$$	4.42	15.58	+3.52	5.77	15.72	+2.72
	T.c	0.00	0.20	$	7.80	7.07	-1.10	7.80	6.93	-1.12
	S.o	0.00	0.00	0.00	0.11	0.00	$$	0.11	0.00	$$
	Tot	8.55	9.06	+1.06	19.04	29.32	+1.54	34.73	38.19	+1.10
Protocol 4	R.d	9.97	0.69	-14.45	4.70	17.71	+3.77	14.69	18.41	+1.25
	T.g	2.40	0.13	-18.46	12.03	29.48	+2.45	14.44	26.87	+1.86
	T.c	0.00	0.46	$	1.17	4.09	+3.49	1.17	4.50	+3.85
	S.o	0.00	0.00	0.00	0.25	0.00	0.00	0.25	0.00	0.00
	Tot	12.37	1.28	-9.66	18.15	51.28	+2.82	30.55	49.78	+1.63

A = Arrival, D = Dispatch, R.d = Rhizopertha dominica, T.g = Trigoderma granarium, R.c = Tribolium castaneum, S.o = Sitophilus oryzae, Tot = Total insects, $$ Places where insect density has decreased to zero level, $ = Places where insect density has increased over zero level

TABLE 6

COST OF PEST CONTROL INPUTS AND THE VALUE OF GRAIN LOST UNDER THE FOUR STORAGE PROTOCOLS FOR BAGGED GRAIN IN MULTAN GODOWNS

Parameters	Protocols			
	P1	P2	P3	P4
Quantity stored (tons)	1000	1000	1000	500
Storage period (months)	12	12	12	12
Weight loss %	0.13	0.19	0.34	1.66
Quantity lost (tons)	1.3	1.9	3.4	8.3
Value of loss (Rs)	3120.00	4560.00	8160.00	19920.00
Total expenditure (Rs)	8397.00	14599.00	9089.00	4000.00
Net cost (Rs)	11517.00	19159.00	17249.00	23920.00
Net cost/ton/year (Rs)	11.52	19.16	17.25	47.84
Net cost/ton/month (Rs)	0.96	1.60	1.44	3.99

TABLE 7

COST OF PEST CONTROL INPUTS AND THE VALUE OF GRAIN LOST UNDER THE FOUR STORAGE PROTOCOLS FOR BAGGED GRAIN IN LAHORE GODOWNS

Parameters	Protocols			
	P1	P2	P3	P4
Quantity stored (tons)	1000	1000	1000	1000
Storage period (months)	15	14	13	9
Weight loss %	0.31*	0.440	0.012	0.173
Quantity lost (tons)	3.1	4.4	0.12	1.73
Value of loss (Rs)	7440	10560	288	4152
Total expenditure (Rs)	7383	18927	6403	3873
Net cost (Rs)	14828	29487	6691	8025
Net cost/ton/year (Rs)	11.86	25.27	6.18	10.70
Net cost/ton/month (Rs)	0.99	2.11	0.51	0.89

*Figure based on the assumption that the grain at the time of arrival in protocol 1 was of insect damage.

TABLE 8

CHANGES IN WEIGHT AND VALUE DUE TO MOISTURE TRANSFER
IN ONE METRIC TON OF WHEAT STORED IN MULTAN GODOWNS

Protocol	June		September		November		January		April	
	Weight (kg)	Value (Rs)	Weight (kg)	Value (Rs)	Weight (kg)	Value (Rs)	Weight (kg)	Value (Rs)	Weight (kg)	Value (Rs)
Recommended practice (P1)	1000	2400	1017.48	2441.96	1015.12	2436.30	1021.55	2451.72	1003.06	2407.34
Multiple dose fumigation (P2)	1000	2400	1024.63	2459.12	1018.42	2444.20	1026.34	2463.22	1009.51	2422.84
PEPF (P3)	1000	2400	1015.24	2436.59	2436.59	1016.26	1016.26	2429.03	1004.62	2411.10
Agency Controlled (P4)	1000	2400	1013.84	2433.23	1007.26	2417.43	1012.50	2429.99	997.16	2393.20
Average of All Stacks	1000	2400	1017.79	2442.70	1014.01	2433.62	1019.16	2445.99	1003.58	2408.62

INTEGRATED PEST MANAGEMENT STUDIES

AT ARRIVAL

SPEAR SAMPLING OF ENTIRE LOT.

1. Grain quality
2. Incidence of insects.

SAMPLING AND WEIGHMENT OF INDIVIDUALLY MARKED BAGS.

1. Weight and grain quality of marked individual bags placed in different zones of stack.
2. Incidence of insects in individual bags

STORAGE

a. MONITORING OF INSECTS IN
   - PERIPHERAL SAMPLING.

b. MONITRING THE PHYSICAL FACTORS.
   - GODOWN TEMPERATURE
   - GODOWN HUMIDITY
   - GRAIN TEMPERATURE
   - GRAIN MOISTURE

c. MONITORING THE METHODS AND EFFECTIVENESS OF TREATMENTS
   INSECT INFESTATION
   - GRAIN QUALITY.
   - TREATMENT COSTS.

d. MONITORING THE GRAIN QUALITY IN PERIPHERY

AT ISSUE

1. Grain quality.
2. Incidence of insects.

1. Weight and grain quality of individually marked bags placed in different stack zones.
2. Incidence of insects in individual bags.

RESULTS

- Overall deterioration during storage.
- Overall increase in number of stored grain insect pests.
- Weight loss by various loss assessment methods.
- Possible relationship between various biotic and abiotic factors responsible for losses during storage.
- Effectiveness of treatments with its cost economics.

- Actual weight loss and quality deterioration in individual bags placed in different zones of stacks.
- Relationship between actual weight loss. loss assesment methods and the factors contributing to losses.
- Relationship between whole stack, spear, peripheral spear and marked bag sampling for determination of relative incidence of insects as determined by various methods, grain quality and the physical and biological factors responsible for losses.
- Effect of atmospheric conditions on grain moisture, moisture movement, insect population movement in various zones of stack, etc.

FIG.2

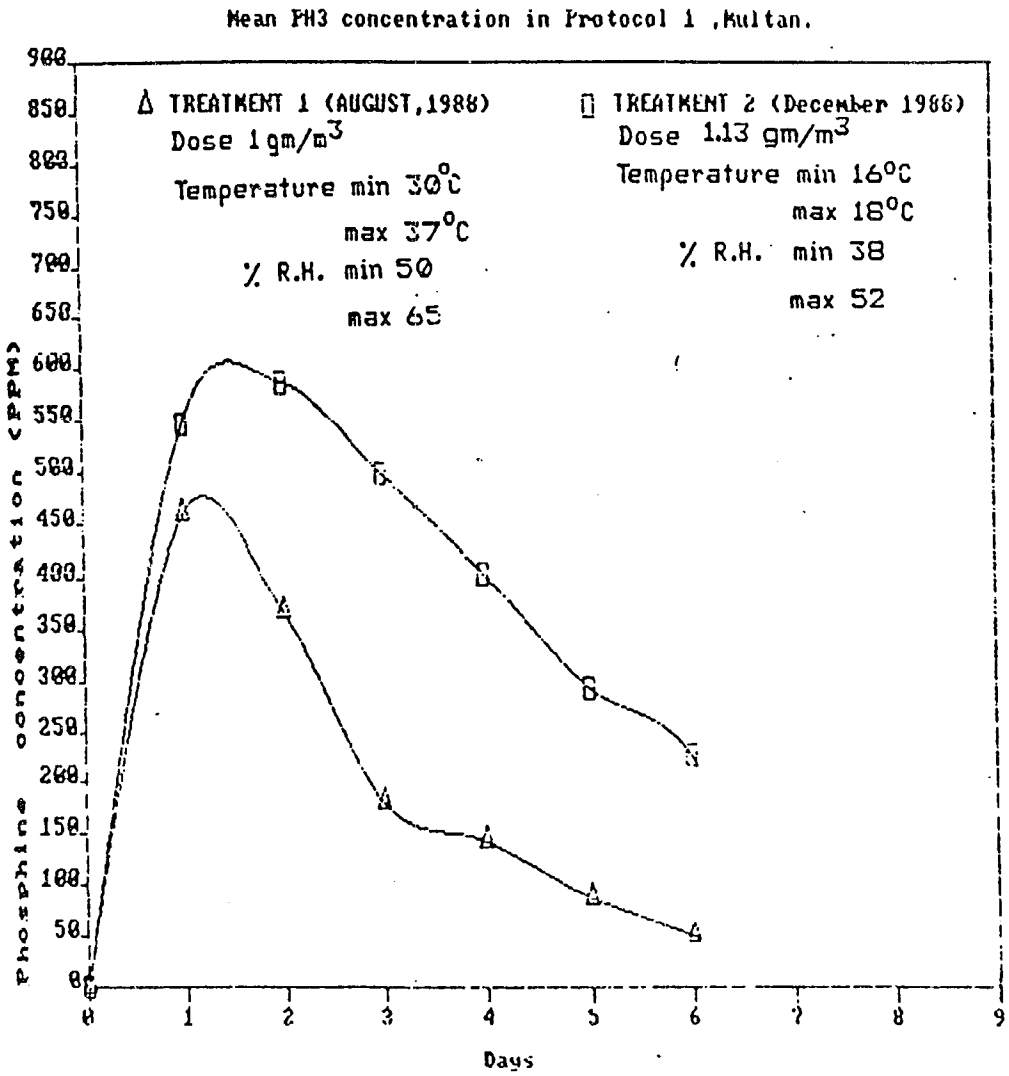

Mean PH3 concentration in Protocol 1 ,Multan.
Δ TREATMENT 1 (AUGUST,1988)
Dose 1gm/m3
Temperature min 30°C
max 37°C
% R.H. min 50
max 65
□ TREATMENT 2 (December 1988)
Dose 1.13 gm/m3
Temperature min 16°C
max 18°C
% R.H. min 38
max 52
Phosphine concentration (PPM)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
Days

FIG. 3

Mean PH3 concentration in Protocol 2, Multan.

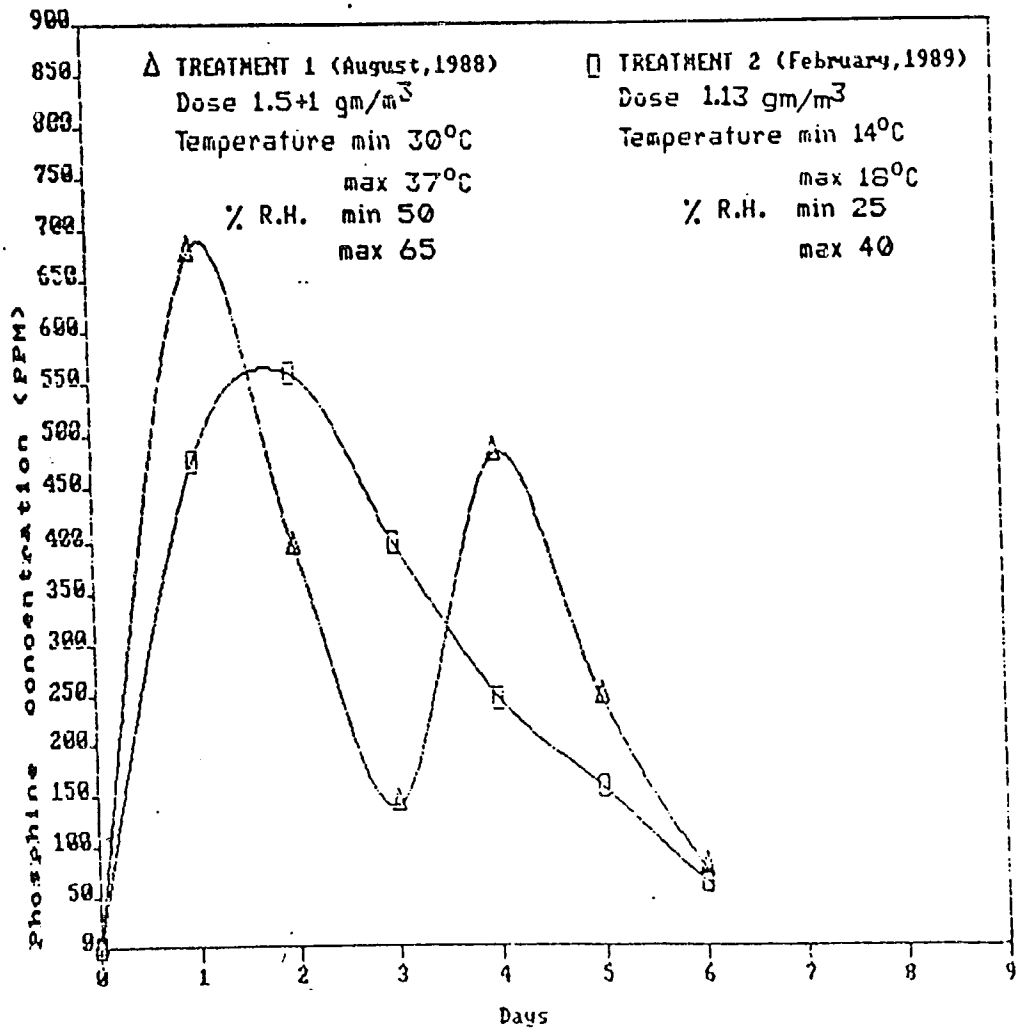


FIG. 4

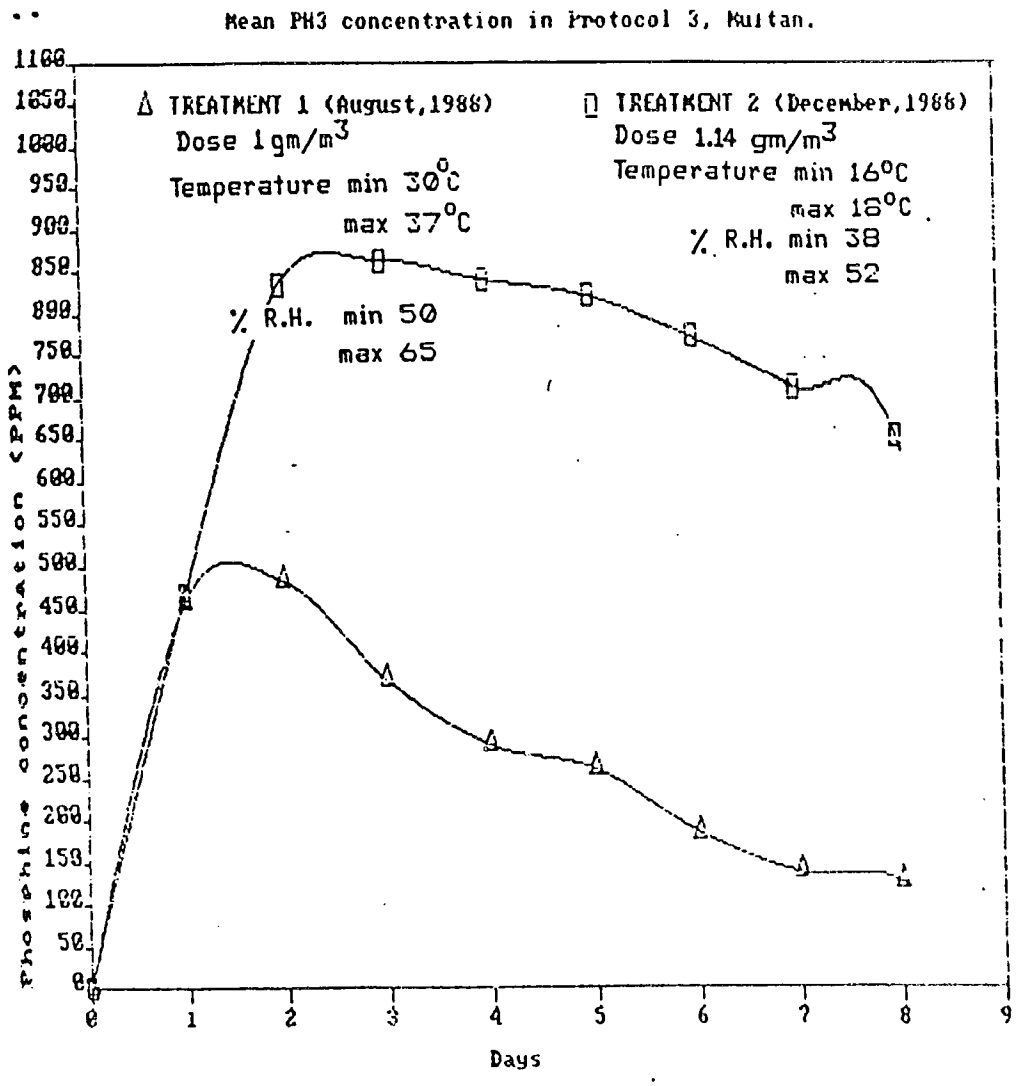

Mean PH3 concentration in Protocol 3, Multan.
TREATMENT 1 (August,1988)
Dose 1 gm/m3
Temperature min 30°C
max 37°C
% R.H. min 50
max 65
TREATMENT 2 (December,1988)
Dose 1.14 gm/m3
Temperature min 16°C
max 18°C
% R.H. min 38
max 52
Phosphine concentration (PPM)
Days
0
1
2
3
4
5
6
7
8
9
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000
1050
1100

FIG.5

Mean PH3 concentration in Protocol-1, Lahore.

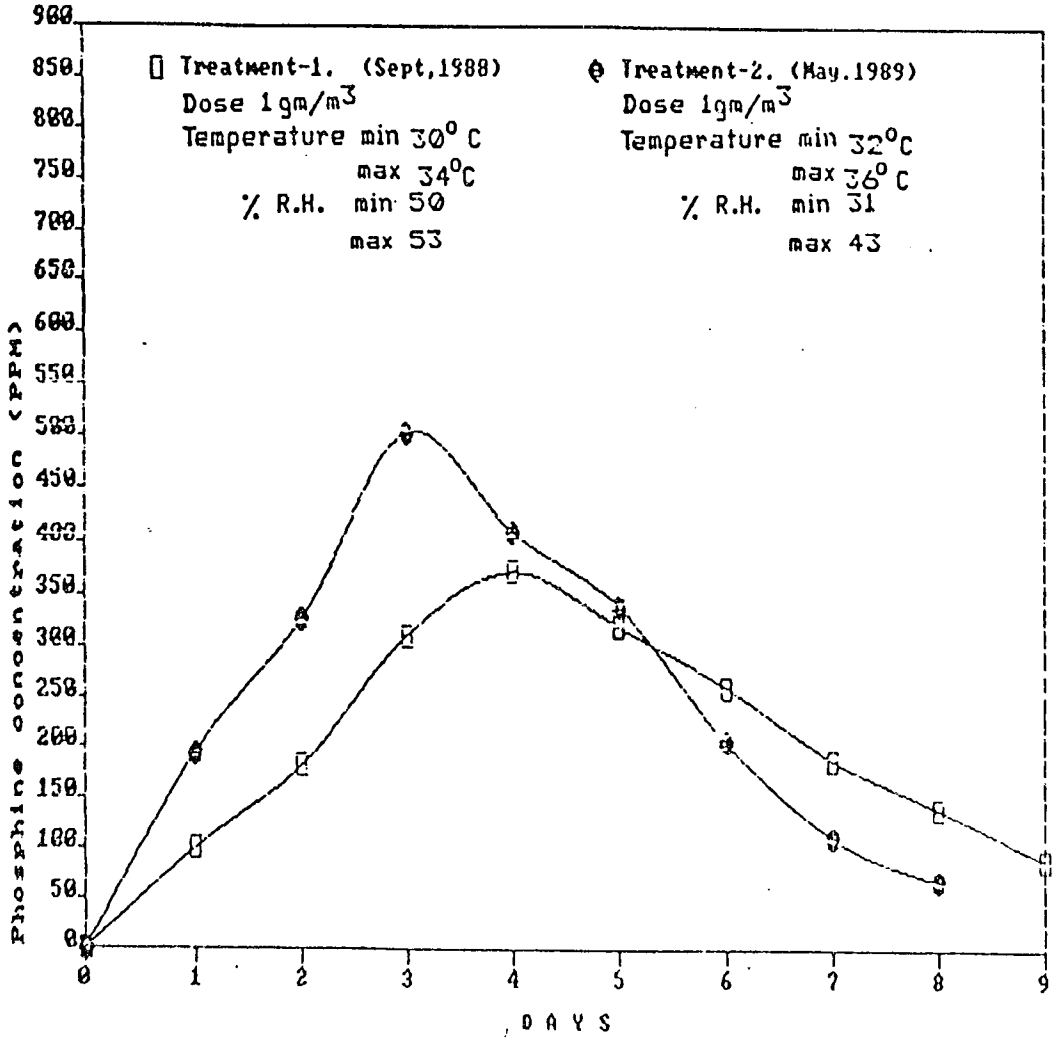


FIG. 6

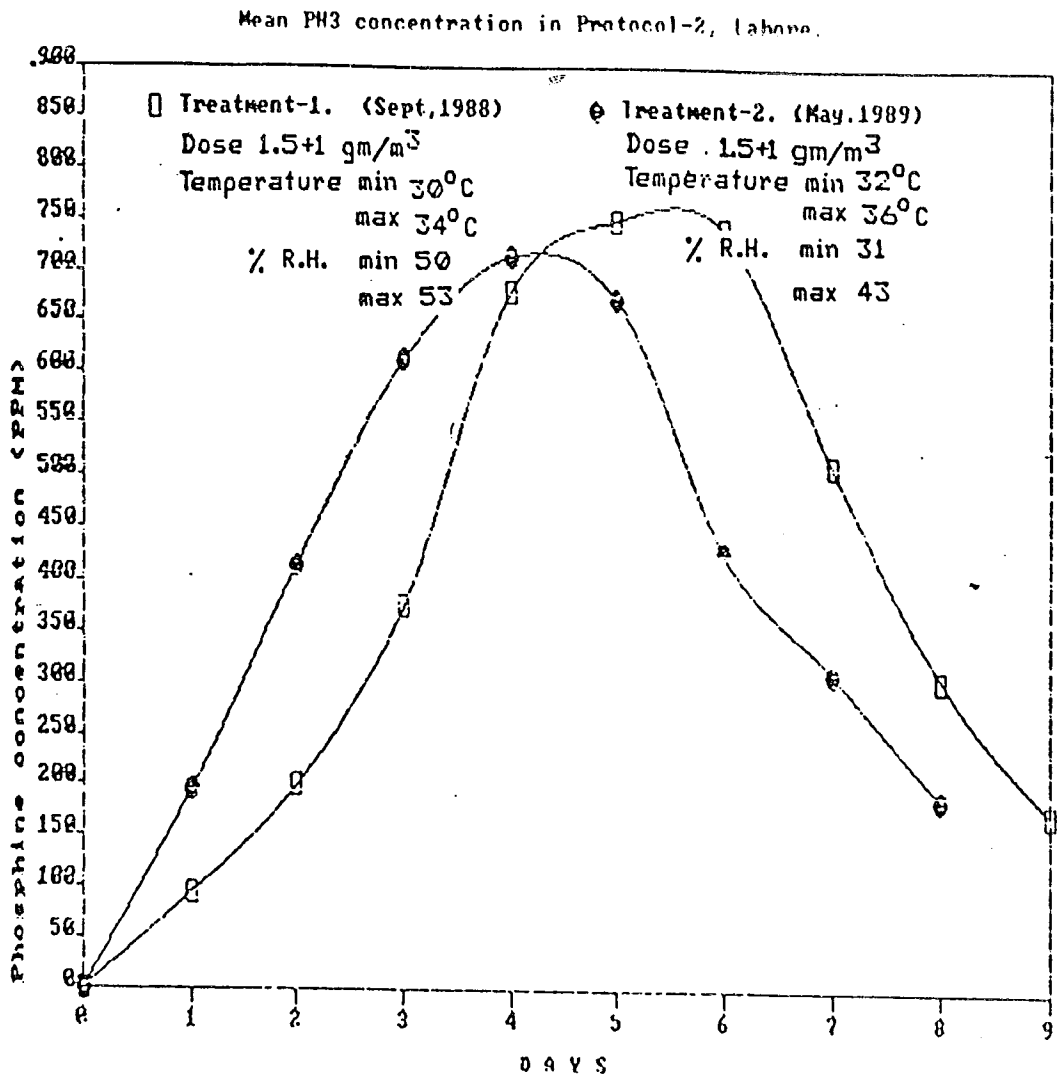

Mean PH3 concentration in Protocol-2, Lahore.
Treatment-1. (Sept,1988)
Dose 1.5+1 gm/m3
Temperature min 30°C
max 34°C
% R.H. min 50
max 53
Treatment-2. (May.1989)
Dose 1.5+1 gm/m3
Temperature min 32°C
max 36°C
% R.H. min 31
max 43
Phosphine concentration (PPM)
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0
1
2
3
4
5
6
7
8
9
DAYS

FIG. 7

Mean Phosphine concentration in protocol-3 Lahore.

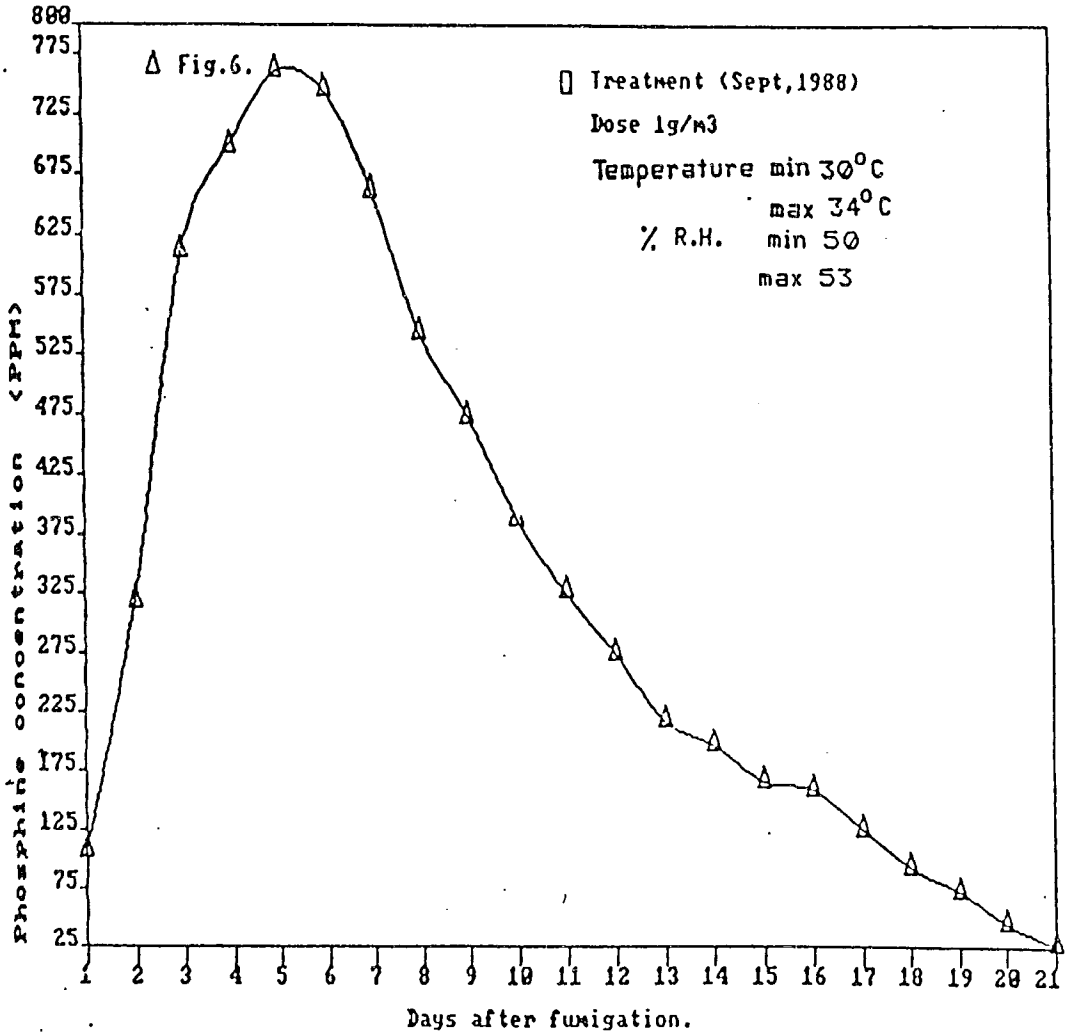


FIG. 8

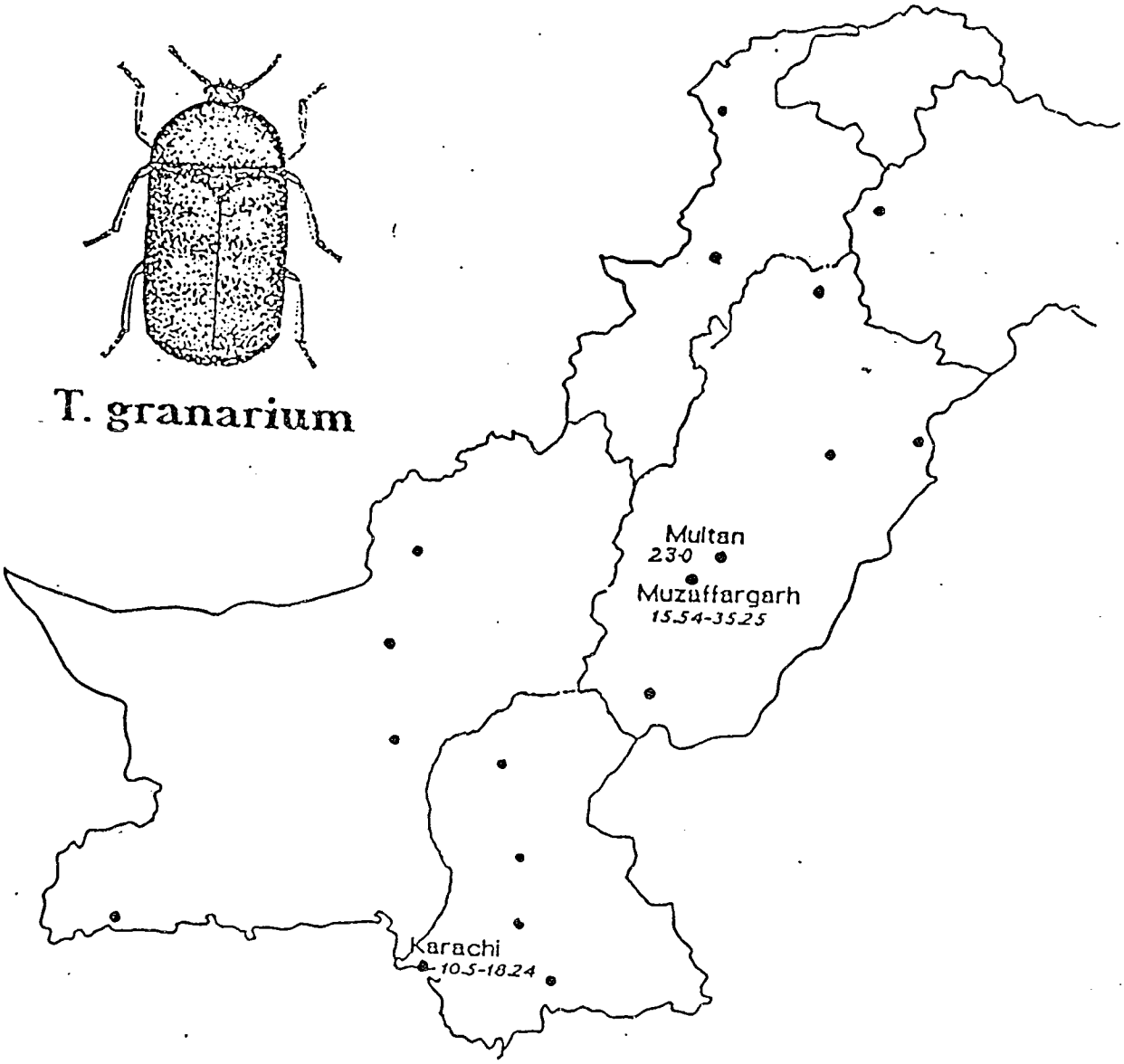

T. granarium
Multan
23·0
Muzaffargarh
15.54-35.25
Karachi
10.5-18.24

FIG. 9

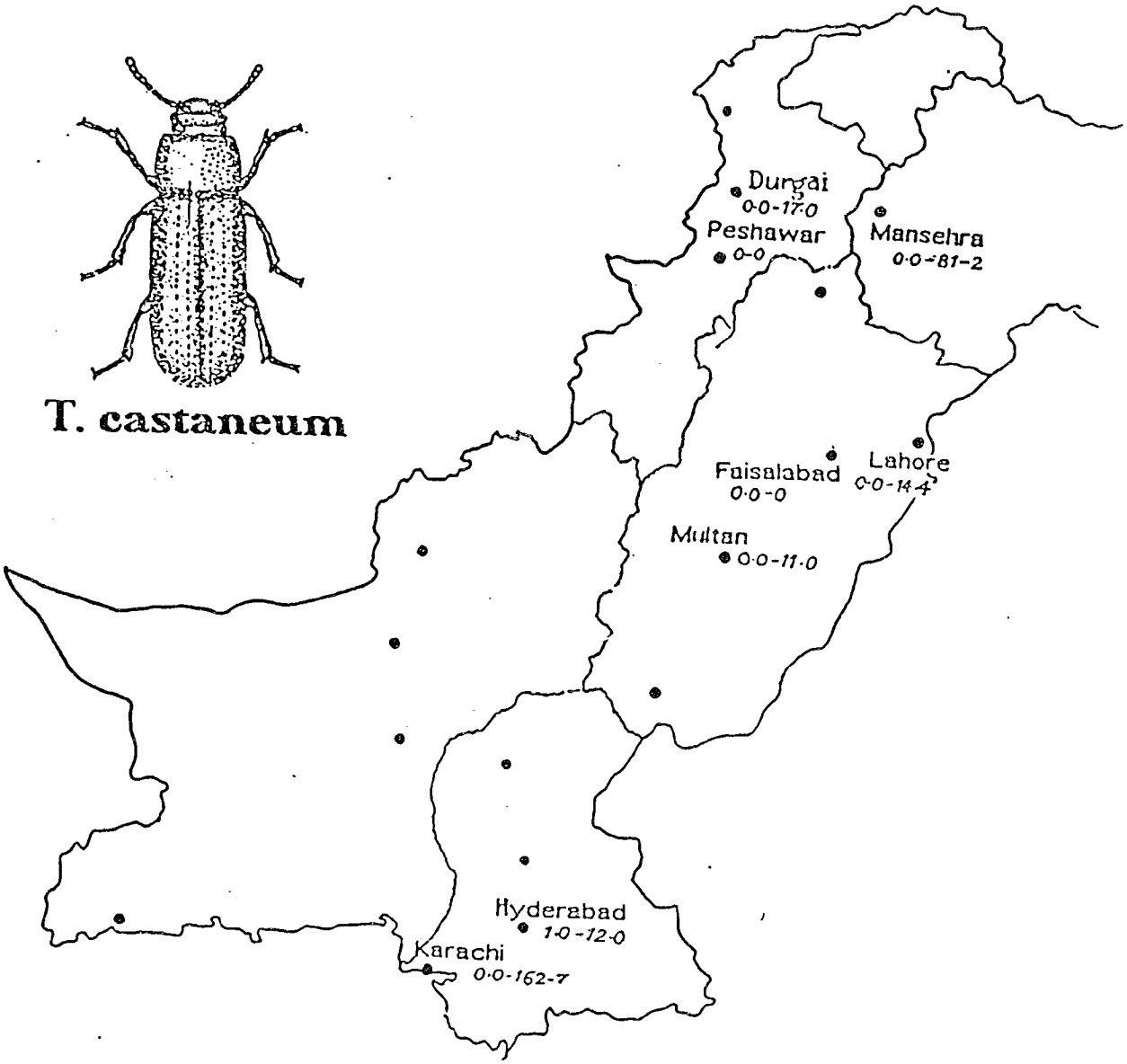
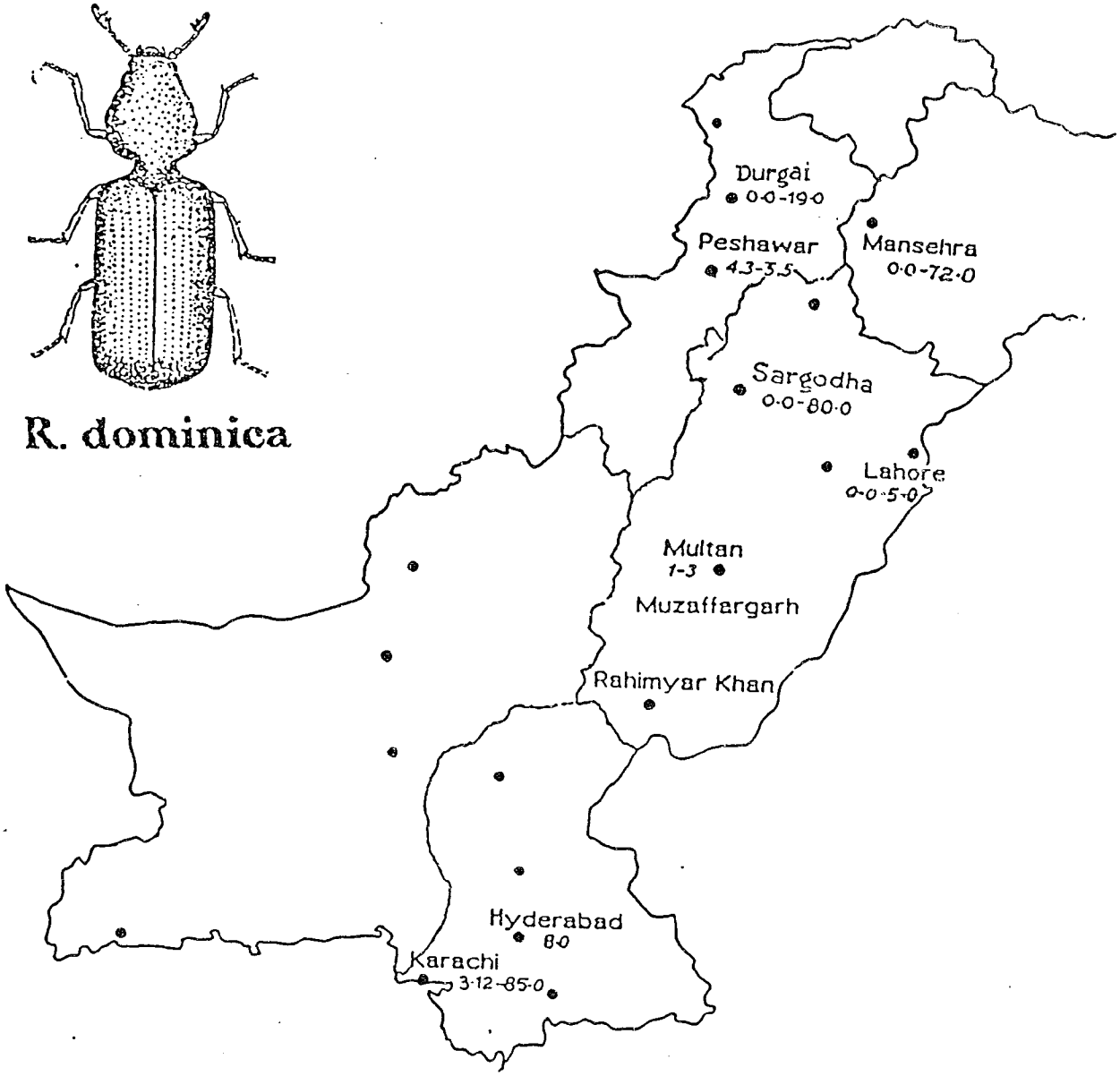

T. castaneum
Dungai
0·0-17·0
Peshawar
0-0
Mansehra
0·0-81-2
Faisalabad
0·0-0
Lahore
0-0-14·4
Multan
0·0-11·0
Hyderabad
1·0-12·0
Karachi
0·0-162-7

FIG. 10

R. dominica



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