RESIDUE PROBLEMS IN THE CONTROL OF INSECT PESTS IN PROCESSED FOOD COMMODITIES USING ALUMINIUM PHOSPHIDE

REMA DEVI, K.

THESIS
SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
(ENTOMOLOGY)
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF ENTOMOLOGY
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM

1984

D E C L A R A T I O N

I hereby declare that this thesis entitled "Residue problems in the control of insect pests in processed food commodities using aluminium phosphide" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

REMA DEVI, K.

Place: Vellayani

Date: 28-11-1984.

C E R T I F I C A T E

Certified that this thesis entitled "Residue problems in the control of insect pests in processed food commodities using aluminium phosphide" is a record of research work done independently by Smt. Rema Devi, K. under my guidance and supervision and that it has not previously formed the basis for award of any degree, fellowship or associateship to her.

Dr.(Mrs.) A.VISALAKSHI.
Chairman
Advisory Committee
Assoc. Professor of Entomology.

Place: Vellayani,
Date: 28-11-1984.

APPROVED BY:

CHAIRMAN

Dr.(Mrs.) A.Visalakshi.

MEMBERS: Dr. N.Mohan Das

Dr. R.S.Aiyer

28.1.85

Dr.(Mrs.) L.Prema

28-1.85

ACKNOWLEDGEMENT

It is as much my pleasant duty, as it is my privilege to express my sincere debt of gratitude to my guide and major adviser Dr.(Mrs.) A.Visalakshi, M.Sc.(Ag.), Ph.D., F.E.S.I., Associate Professor of Agricultural Entomology for the able guidance, inspiring criticism, valuable suggestions and enthusiastic encouragement she gave me throughout the course of this study and the preparation of thesis

I owe immense gratitude to Dr. N.Mohan Das, Professor and Head of the Department of Agricultural Entomology for serving in the Advisory Committee and helping me with valuable suggestions at every stage of this work.

I take this opportunity to extend my thanks to Dr. R.S.Aiyer, Professor and Head of the Department of Agricultural Chemistry for his expert advice and useful criticism.

I should specifically mention my thankfulness to Dr.(Mrs.) L.Prema, Associate Professor of Home Science, for her valuable and constructive suggestions.

I am greatly indebted to Smt. Vimala Devi, Assistant Professor of Home Science, for her ever willing help rendered in conducting the organoleptic studies.

I am grateful to Dr.(Mrs.) P.Saraswathy, Associate Professor of Agricultural Statistics for helping me in the statistical analysis of the data.

My thanks are also due to Dr. N.Sadanandan, Dean, College of Agriculture, Vellayani, for providing necessary facilities for this investigation.

I am thankful to Shri. Thomas Biju Mathew, Ph.D. Scholar for all the help rendered during the course of my work.

I express my thanks to Messrs. Excel Industries Limited, Bombay for the financial assistance made available to me for conducting this study.

I will be failing in my duty if I do not place on record my sincere respects to my husband for his constant encouragement and untiring inspiration, without which this work will not become a reality.

I express my thanks to each and every person who has helped me in different stages of the investigation.

REMA DEVI, K.

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INTRODUCTION

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In India, improper storage, rodents, insects and microorganisms account for 10 per cent wastage of food grains, a quantity good enough to feed atleast 50 million people. The loss is not merely in quantity but also in quality of the food grains. The qualitative loss is due to chemical changes in proteins, carbohydrate, amino acids, fatty acids and vitamins which affect the nutritive value of food grains (Pingale, 1976). The timely application of control measures against insect infestation is a method of preventing the huge post-harvest wastage of agricultural produce as well as of processed products. One of the most successful methods of controlling pests rapidly in stored food stuffs is fumigation. Amongst the various fumigants available in India, hydrogen phosphide is relatively inexpensive and a convenient fumigant for treatment of food grains stored in bulk or in smaller lots. The storage and transport cost of this fumigant is also relatively low.

An important problem faced in fumigation is that of the residues left behind in food stuffs after fumigation. The available information in India on the residues of phosphine in different stored materials include those in wheat (Bruce *et al*., 1962; Awasthi *et al*., 1971; Dhaliwal and Lal, 1974), in wheat flour, bengal gram and ground nut

(Dhaliwal and Lal, 1974), in turmeric (Kavadia *et al.*, 1978), in maize (Sinha *et al.*, 1979), in cowpea, moong and pea (Singh and Srivastava, 1980) and in paddy, rice, dried tapioca chips, sweet potato, cashewnut, turmeric and cowpea (Mohammed, 1982). Similar studies on many more food grains and processed food products remain to be done. Hence under the present programme, studies were undertaken to ascertain the extent of residues of phosphine in rice flour, wheat flour, semolina, maida, tea, coffee, cocoa powder, noodles, cattle feed, rice, dhal, green gram, soy beans, cumin, garlic and pepper when used as a fumigant to control the different pests infesting them under storage. Studies were also made on the bioefficacy of phosphine in controlling the different species of insects and the toxicity of phosphine to different stages of the insect pests reared on these commodities.

When food commodities are fumigated with fumigant, the organoleptic qualities of the products may be affected (Reynolds *et al.*, 1953). Therefore organoleptic studies were made to ascertain whether fumigation with phosphine affected the taste, colour, flavour, texture, etc. of the food products.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Bioefficacy of phosphine to storage pests

Experiments conducted by Lindgren *et al*. (1958) revealed that phosphine was effective as a fumigant against *Sitophilus granarius*, *Trogoderma granarium*, *Rhyzopertha dominica*, *Oryzaephilus surinamensis* and caused 100 per cent mortality of different species of insects when used at dosages of 4.4 mg/l to 9.8 mg/l with an exposure period of 24 to 96 hours at temperatures of 50 to 70^{o}F.

Coutinho *et al*. (1961) found that aluminium phosphide at rates of 15, 16 and 30 tablets per ton against *Araecerus fasciculatus* infesting stored coffee, *Pectinophora gossypiella* on stored cotton seeds, *Corcyra cephalonica* on stored groundnut respectively gave complete kill of all the stages of insects in 24 hours.

Trials conducted to compare the efficacy of EDCT and hydrogen phosphide at dosages of 2 lb/1000 cu.ft for two days and 2 tablets/ton for 7 days respectively against *Rhyzopertha dominica*, *Tribolium castaneum*, *Oryzaephilus surinamensis*, *Latheticus oryzae* and *Cadra cautella* in wheat stacks of 157 tonnes, under rubberized gas-proof covers revealed that hydrogen phosphide was more effective and gave hundred per cent mortality of all the stages of insects at all the levels of stacks whereas the maximum mortality produced by EDCT was only 52.9 per cent (Lallan Rai et al., 1964).

Puzzi et al. (1966) determined the effectiveness of phostoxin pellets in maize grains against Sitophilus oryzae and a reduction of 97.4 per cent was recorded with 1 pellet per 800 lb after 72 hours. Similarly 95.8 per cent reduction in insect population was recorded with 1 pellet per 1000 lb in 48 hours.

Zutzhi (1966) found that 3 g of aluminium phosphide per ton or 50 ft^3 (1.4 m^3) of wheat with 5 days exposure period was sufficient for effective control of insects in wheat and confirmed that the higher doses recommended by the manufacturers or employed elsewhere may be a wastage.

Qureshi (1967) studied the toxicity of phosphine against adults of Sitophilus zeamais, Tribolium castaneum and Araecerus fasciculatus in cacao in steel drum with a capacity of 44 gallons. Total mortality of adults of all species and also full fed larvae of Plodia interpunctella was obtained with 1 pellet (0.6 g each) for 24 hours. Total mortality of adults was also obtained with 1/2 a pellet per drum for 6 hours when gas was released naturally from 1/2 and 1/4 of a pellet respectively.

Rout and Mohanty (1967) found that hydrogen phosphide released at rates of 1.24 to 4.98 mg/l from phostoxin tablets, in a small bin containing rice gave complete mortality of adults of Sitophilus oryzae caged from the surface to a depth of 120 cm at temperatures of 28.8 to 32.2°C and moisture content of 10 per cent within 8 hours.

Anon. (1968) reported that fumigation of different stored agricultural commodities with aluminium phosphide @ 21 g/28 cu.m worth an exposure time of 7 days was found effective and resulted in 100 per cent mortality of different kinds of insect pests. It was also pointed out that phosphine penetrates evenly and rapidly in the commodity.

Puzzi et al. (1968) recommended that 1 pellet per 4 sacs of coffee with an exposure period of 72 hours at temperatures up to 27°C and 1 pellet per 4 sacs with an exposure period of 48 hours at temperatures above 27°C may be used for the control of Araecerus fasciculatus.

Experiments conducted by Esin (1968) on the possibility of using phostoxin tablets for the control of larvae and adults of Tribolium confusum feeding on wheat-flour revealed that total mortality was obtained from phosphine at 1 mg/l when small bags of flour containing insects were exposed for 3 days in air tight chambers.

Cornes and Adeyemi (1968) reported that an open top steel bin containing 40 tonnes of maize heavily infested with Sitophilus zeamais and Tribolium castaneum on fumigation with 160 phostoxin tablets, no live examples of the insects found either in the immediate post fumigation samples or in the incubated samples.

Phosphine concentrations of 1.16, 1.74, 2.33, 4.66 mg/l killed all the adults of Sitophilus oryzae placed at 0, 40, 80, 120 and 140 cm from the bottom of a steel bin containing rice in 24 hours. Tests against adults and eggs of Sitotroga cerealella placed at 0, 40, 80 and 120 cm from bottom of a column of rice with phosphine at concentrations of 2.33 and 3.49 mg/l revealed that all the adults were killed in 8 hours and eggs in 24 hours (Rout, Tripathy and Biswal, 1969).

Riley (1969) estimated the insect population in the stacks of cocoa before and after treatment with phostoxin at the rate of 2.86 tablet/ton. Reduction in insect population after treatment as indicated by sieving were 99.9 and 96.2 per cent after 2 and 48 days respectively as indicated trap catches were 93.9, 100 and 98.9 per cent after 2, 3.5 and 5 weeks respectively.

Adesuyi (1969) obtained complete mortality of different species of insects (Sitophilus zeamais, Tribolium castaneum, Carpophilus sp. etc.) in 10 tonnes of silo of maize fumigated with 5 phostoxin tablets per ton whereas the results obtained with 4 and 3 tablets/ton were not satisfactory.

Bitran et al. (1970) reported that in tests to determine the dose of phosphine to control Sitophilus zeamais in maize stored in very large concrete silos, it was found that complete control of all the stages was obtained by using tablets of 3 g at the rate of 0.8 to 1 / ton of maize or pellets weighing 0.6 g at the rate of 4 to 5 / ton. A rate of 0.6 tablet or 3 pellets / ton afforded 98.52 to 99.79 per cent control at a temperature of 28 to 31°C.

The effectiveness of phostoxin pellets was investigated by Ilie (1970). It was found that 5 to 6 pellets / ton killed all the stages of Sitophilus oryzae after an exposure period of 7 days.

Bitran et al. (1971) suggested a rate of 5 pellets of phostoxin / ton of maize stored in silos for the control of Sitophilus sp. and the silos to remain closed for 5 days.

Attempts made by Baskaran and Mookherjee (1971) on the effect of food on the susceptibility of Cadra cautella and Trogoderma granarium to phosphine revealed that the products rich in fats absorbed a great deal of the fumigant than those with a low fat content.

Kalkan and Tunca (1973) observed the effectiveness of phostoxin against various stages of Acanthoscelides obtectus, Sitophilus granarius and Tribolium confusum in bagged grain and flour in a fumigation chamber. Complete mortality of all the stages of the above insects was obtained at dosages of seven pellets per ton or five pellets per m^3 for 72 hours.

Fumigation of bagged flour with aluminium phosphide pellets by placing them inside or under the container at a rate of 160 per 1000 cu ft killed all the stages of all the insects within 48 and 72 hours respectively whereas 14 and 28 pellets per 1000 cu ft killed larvae, pupae and adults within 48 and 24 hours respectively, when the pellets were placed under the container (Vardell et al., 1973).

Yasan and Kiper (1973) suggested to fumigate the hazel nuts with phostoxin @ 2 tablets / m^3 for 72 hours for the control of Cadra cautella and Plodia interpunctella which causes economic losses.

Bitran (1974) obtained complete control of all the stages of Araecerus fasciculatus in coffee beans when the jute bags were fumigated for 48 or 72 hours with phosphine at 0.5 and 0.4 ai/m^3.

It was suggested to fumigate at a dose of 2 pellets of phostoxin per m^3 for the control of the adults of

Lasioderma serricorne and *Ephestia elutella* feeding on tobacco (Todorovski and Vasilev, 1975).

Currie (1975) recommended dosage of 30 tablets of phostoxin per 28 m^3 for the control of *Lasioderma serricorne* a pest of tobacco in store houses.

Barbera *et al.* (1976) studied the relative toxicity of phosphine to 13 different species of insects at concentrations ranging from 0.013 to 2.96 mg/l with exposure periods of 1 to 16 days. *Sitophilus species* proved to be the most tolerant among all species tested except *Trogoderma granarium* where the diapausing larvae were the most tolerant.

Based on the results obtained on the control of *Sitophilus zeamais* in stored maize it is recommended to fumigate with phosphine at the rate of 1 g ai / ton of grain for 5 days (Bitran and Campos, 1977).

Bitran (1979) found that phosphine at 1 g/m^3 with an exposure period of 72 hours effectively controlled all the stages of *Sitophilus zeamais* and *Sitotroga cerealella* feeding on maize under laboratory conditions.

Webley and Harris (1979) reported that storage pests of sorghum and maize viz. *Sitophilus oryzae* and *Tribolium castaneum* could be effectively controlled by fumigation with phosphine at the rate of 3 g/m^3 over 4 to 5 days exposure in well sealed stores.

Investigations with stored seeds of cowpea, phosphine at 1.6 g/m^3 killed all the stages in the life history of Callosobruchus chinensis (Chiang et al., 1980).

Mejule and Onyuike (1980) conducted space fumigation of a 9226 m^3 cocoa store with phosphine gas applied at the rate of 0.8 g/m^3. The store held 2 stacks of bagged cocoa beans each about 1250 tonnes. None of the living samples of Ahesverus advena, Cryptolestes sp., Necrobia rufipes, Lasioderma serricorne, Oryzaephilus mecator, Tribolium castaneum and Ephestia cautella were observed after 72 hours of fumigation.

Kashi, K.P. (1981) studied responses of 5 species of adult stored product insects (Tribolium castaneum (Hbst.), Tribolium confusum Duv., Rhizopertha dominica (F), Sitophilus oryzae (L) and Sitophilus granarius (L)) to various doses of phosphine in atmospheres of air or nitrogen and found that increasing the phosphine concentration resulted in increased mortalities of Tribolium castaneum, Tribolium confusum and Rhyzopertha dominica.

Laboratory experiments were carried out to determine the effectiveness of phosphine fumigation against been weevil

Acanthoscelides obtectus (Say) infesting bean seeds (Phaseolous). Application fumigation for 6 days at 0°C was recommended for the complete control of A. obtectus (Bogs, D., 1981).

Borah, B. and Mohan, B. (1981) reported that natural infestation of stored rice seeds by Sitotroga cerealella and Sitophilus oryzae could be effectively controlled by fumigation of the seeds with phosphine produced from aluminium phosphide (Celphos) at 56 g ai/28 m^3.

Mohammed (1982) reported that out of the ten insect pests infesting different stored commodities, none of them showed absolute control under the lowest dose of 1.5 g/m^3 of aluminium phosphide. At 3.0 g/m^3 there was no survival in Tribolium castaneum, Sitotroga cerealella, Corcyra cephalonica, Necrobia rufipes and Callosobruchus chinensis. But survivals were still in evidence under this dose with the insects Sitophilus oryzae, Rhyzopertha dominica, Araecerus fasciculatus, Lasioderma serricorne and Cylas formicarius reduction being 95.86 to 99.65 per cent. Among these five species there were no survivals under the highest dose of 4.5 g/m^3 of the fumigant with all the insects, excepting Cylas formicarius which still showed some survivals, the percentage reduction being 99.37 per cent only.

Susceptibility of different life stages of storage pests to phosphine.

Lallan Rai *et al.* (1963) fumigated bulk wheat stocks heavily infested by a wide variety of insect pests with hydrogen phosphide (Phostoxin) at dosage rates of 4, 3, 2 and 1 tablet / ton and reported that phosphine exerted a higher degree of toxicity on hidden infestation too.

Lindgren and Vincent (1966) determined the toxicity of phosphine to the different life stages of various species of storage insects and it was found that larvae of *Trogoderma granarium* were more resistant to phosphine than the larvae and adults of *Tribolium confusum*, *Sitophilus granarius* and *Sitophilus oryzae*.

Howe (1973) found that the different stages of *Sitophilus granarius* were not equally susceptible to phosphine fumigation. Concentration of 1 mg/l for 32 hours or 4 mg/l for 8 hours at 25°C killed all the stages of the insect except pupae.

Erakay *et al.* (1973) reported that fumigation of tobacco bales with phostoxin at the rate of 3 g/m^3 for 72 hours was completely effective against all stages of *Lasioderma serricorne* and larvae of *Ephestia elutella* and was 92.6 per cent effective against eggs of _E. elutella_.

Ozar (1974) conducted studies on the use of phostoxin for the control of _Callosobruchus maculatus_. The results showed that phostoxin at a rate of 0.3 g per 100 kg caused a mortality of 92.6 and 100 per cent of eggs and adults respectively. A dosage of 3.0 g/m^3 resulted in 97.7 and 100 per cent kill of eggs and adults respectively, whereas a dose of 4.5 to 6.0 g/m^3 gave complete mortality of all the stages.

Shayetch (1975) found that a mortality of 100 per cent, 97.4 per cent and 96 per cent for adults, larvae and pupae of _Sitophilus granarius_ respectively when phostoxin was used at the rate of 6 g per ton of wheat in an air tight store house.

Bell (1976) studied the tolerance of phosphine to different stages of _Ephestia elutella_, _Ephestia kuchniella_, _Ephestia cautella_ and _Plodia interpunctella_ and observed that eggs of all species were highly tolerant to the fumigant.

A study conducted by Mohammed (1982) revealed that the egg was found to be comparatively resistant in all the ten species of storage pests tested followed by pupae and larvae. The adult stage was the most susceptible showing 100 per cent mortality even at the lowest dosage of 1.5 g/m^3.

Residues of phosphine in the fumigated commodities.

Bruce *et al*. (1962) reported that residues in samples were 0.017 ppm which were reduced to 0.004 ppm after turning the grains when phostoxin tablets were used for the fumigation of wheat at the rate of 2 to 10 per ton.

Beratilief *et al*. (1965) fumigated wheat with 20 to 30 phostoxin tablets per m^3 and found that there was no detectable residue in any of the samples after 8 days.

Awasthi *et al*. (1971) reported that the residues of phosphine in wheat were below the detectable limit on 4th day of aeration in case of 2 and 4 tablets / ton and on 7th day of aeration in case of dosages of 6 and 8 tablets per ton.

The groundnut fumigated with phosphine at the rate of 2.08 mg/l did not contain any residues of phosphine when pellets were enclosed in paper envelopes (Proctor and Ashman, 1972).

Kalkan and Tunca (1973) found that the wheat flour fumigated with phostoxin pellets at the rate of 7 per ton or 5 per m^3 for 72 hours contain residues below the tolerance level.

Laboratory tests conducted by Vardell et al. (1973a) showed that little or no phosphine residues persisted on soy bean after fumigation with phosphine in chambers after an aeration period of 24 to 48 hours.

Vardell et al. (1973b) fumigated wheat flour in plywood containers with phostoxin at a rate of 160 pellets per 1000 ft^3 for 72 hours. Chemical analysis showed that flour fumigated seven times did not contain a high concentration of phosphine than flour fumigated once. The greatest concentration found was 0.0003 ppm.

Ozar (1974) reported that fumigation of stored leguminous seeds with 0.6 g to 3.0 g phostoxin per 100 kg for 72 hours left no residues of phosphine in the seeds.

Dhaliwal and Lal (1974) found that the residues of phosphine in the fumigated commodities resulting from treatments of 2, 4 and 8 tablets of 'Celphos' per ton for 5 days was found to reach the tolerance level of 0.01 ppm in 0.77, 0.29 and 1.45 days for wheat, 0.69, 0.77 and 1.66 days for wheat flour, 1.68, 2.02 and 3.69 days for grain and 1.93, 2.43 and 2.44 days for groundnut respectively.

The bagged turmeric in a store house fumigated with Celphos at a dosage of 140 tablets per 100 m^3 for 10 days was found to contain residues below detectable levels after one day of aeration (Kavadia et al., 1978).

Estimation of residues of phosphine in peanuts receiving a treatment dose of 1.12 mg/l showed that the residues were well below the tolerance level. The peanuts fumigated twice at the same dose contained a higher residue level of 11.3 ppb (0.0113 ppm) (Leesch, 1979).

Redlinger et al (1979) conducted in transit fumigation of wheat in ship with aluminium phosphide at the rate of 1.77 tablet per m^3 and found that residues were well below the established tolerance limit.

The phosphine residues in maize resulting from treatment dosages of 2 and 4 tablets of aluminium phosphide per ton were found to reach the same tolerance level of 0.01 ppm in 0.82 and 2.84 days respectively. The corresponding time for the residues to reach the level of detectability was 1.96 and 4.41 days (Sinha et al., 1979).

Singh and Srivastava (1980) reported that the residues of phosphine in fumigated moong, cowpea and pea reached below the tolerance limit of 0.01 ppm in 1.63, 2.19 and

2.51 days when celphos tablets were used at an exaggerated dosage of 8 tablets / ton. Half a minute washing of treated grain removed the residues below the tolerance level.

Mohammed (1982) found that in food commodities, treated with aluminium phosphide at 4.5 g/m^3 for a period of 5 days, the residues were below detectable levels after an aeration period of 12 hours excepting in cashew (0.0038 ppm) and dried ginger (0.003 ppm). When the dosage was increased to 12 g/m^3, except cashew (0.0129 ppm), ginger (0.0114 ppm) and sweet potato (0.010 ppm), in all the commodities phosphine got dissipated below the tolerance level after an aeration period of 12 hours.

Effect of different fumigants on the organoleptic qualities of treated food commodities.

Cotton (1943) reported that if chloropicrin is present in fumigated flour, it may have a bad effect on the baking quality but this effect disappears once the material is fully aerated.

Reynolds (1963) showed that the benzene hexachloride content of peanuts generally correlated positively with palatability scores and the quantity of insecticide applied.

Flour fumigated with EDB has normal baking properties and bread made from it had normal taste and odour (Plant and Zelebuch, 1953).

Trials conducted by Neizert (1953), Lindgren et al. (1958) showed that fumigation of wheat with phosphine under normal conditions has no adverse effect on the baking quality of flour made from it.

Majumder et al. (1961) reported that CS_2 affects the taste of coffee when used to fumigate monsooned (high moisture content) beans.

As reported by Monro (1980) bread made from flour fumigated with excessive dosages of methyl bromide may have a foreign odour and if the bread is toasted an unpleasant off-flavour may be produced.

MATERIALS AND METHODS

MATERIALS AND METHODS

Rearing of test insects:

The insects used for the study were *Tribolium castaneum* (Herbst), *Sitophilus oryzae* (Linnaeus), *Corcyra cephalonica* (Stainton), *Callosobruchus chinensis* (Linnaeus), *Araecerus fasciculatus* (De Geer) and *Lasioderma serricorne* (Fabricius). The stored products used in these studies were wheat flour, maida, rice flour, rice (husked), semolina (rava), noodles, cattle feed, gram flour, soy beans, green gram, dhal (broken pulses), coffee, tea, cocoa powder, garlic, pepper and cumin.

The products were purchased from the local market and were thoroughly cleaned to remove extraneous materials. Non-infested and fresh materials were procured for rearing the insects and for various experiments. *Tribolium castaneum* was reared on seven different commodities viz. wheat flour, semolina, maida, gram flour, noodles, cocoa powder and tea; *Sitophilus oryzae* on rice, cattle feed and dhal; *Araecerus fasciculatus* on coffee, garlic and pepper; *Callosobruchus chinensis* on green gram and soy beans; *Lasioderma serricorne* on cumin and *Corcyra cephalonica* on rice flour. Museum jars (20 x 20 x 12 cm) were half filled with the commodities and 50 insects were introduced into each jar. Each species of insect was introduced in separate jars and they were kept closed with muslin cloth held with rubber bands. Such settings were done once in ten days to obtain sufficient number of insects for the experiments.

Fumigant used for the experiment:

Aluminium phosphide in the form of pellets each weighing 0.6 g available under the trade name 'Celphos' supplied by M/s. Excel Industries, Bombay, was used for the studies. The chemical was used at three doses viz. 1.5, 3.0 and 4.5 g/m^3 with an exposure period of three days.

Fumigatorium:

A rectangular wooden fumigatorium was used for the studies. It had a capacity of 1.2m x 0.56m x 0.6m. The volume of the fumigatorium was 0.4 m^3. This box could be opened from the top portion. The upper lid could be held in position for closing the fumigatorium air-tight by the help of 12 screws with wing nuts.

Determination of bio-efficacy of aluminium phosphide on storage pests:

Infested commodities containing all the stages of insects were thoroughly mixed. They were then divided into six equal parts and transferred to six bags. They were tied and suitably labelled. From this three bags were fumigated in the fumigatorium. Required quantity of aluminium phosphide was placed in muslin cloth bag and introduced into the fumigatorium and closed air tight. The remaining three untreated bags arranged similarly in an air tight wooden box served as control. Fumigation was continued for 3 days.

After completion of fumigation, the bags were collected from the fumigatorium. The contents were aerated for 48 hours. Counts of all dead and living adults were taken and they were removed. For assessing the extent of surviving infestation, the fumigated materials were transferred to clean glass jars, closed with muslin cloth, held by rubber bands and incubated for a period of forty to sixty days. The adults emerging from the surviving immature stages in each treatments were recorded based on the length of the life-cycle (Table 1).

<u>Studies on the relative toxicity of aluminium phosphide to different stages of insects</u>:

For obtaining different stages of the insects viz. egg, larva, pupa and adults the following procedure was adopted.

<u>Egg stage</u>: One kilogram / 500 g of the host material was taken in clean glass jars of 20 x 15 cm diameter. Hundred insects (adults) of each species were collected randomly from

Table 1. Incubation of fumigated commodities for the surviving life stages to complete the development and emerge as adults.

Insect	Product	Period of incubation after fumigation (in days)		
		Egg	Larva	Pupa
T. castaneum	Wheat flour	40	1	10
	Semolina	42	1	10
	Cocoa	46	1	10
	Tea	47	1	10
	Noodles	46	1	9
	Gram flour	41	1	10
	Maida	40	1	9
S. oryzae	Rice	35	23	17
	Broken pulses	38	25	18
	Cattle feed	39	27	18
A. fasciculatus	Coffee	50	22	17
	Garlic	58	31	17
	Pepper	59	35	18
C. chinensis	Green gram	33	20	17
	Soy beans	37	24	17
L. serricorne	Cumin	57	30	17
C. cephalonica	Rice flour	50	1	18

the stock culture and released to the respective host materials. The jars were covered with muslin cloth and fixed with rubber bands. The insects were allowed to oviposit for a period of 3 days. After this period they were removed. Only in the case of *Tribolium castaneum* the eggs were removed by sieving, mixed with the commodities and then exposed to the fumigant.

Larvae and pupae: The commodities containing the egg stages were incubated for different days depending on the length of life cycle. The details are shown in Table 2. After incubation the commodities were transferred to clean muslin bags. In the case of *Tribolium castaneum* the fully developed larvae (4th instar) and the pupae and in *Corcyra cephalonica* the free living larvae (4th instar) were collected from the cultures and released into the host material in clean muslin bags. They were tied, labelled and fumigated.

Adult stage: The free living adults of different species of insects were collected separately from the cultures. They were introduced into the feeding medium in small cages of brass wire mesh (9 cm x 4 cm dia.) and ends covered with muslin cloth. The adults of *Corcyra cephalonica*, *Callosobruchus chinensis* and *Araecerus fasciculatus* were collected

Table 2. Incubation period for obtaining different life stages of insects for studying their susceptibility to phosphine.

Insect	Products	Period after oviposition (in days)	
		For larvae	For pupae
S. oryzae	Rice	13	19
	Cattle feed	16	22
	Broken pulses	15	20
A. fasciculatus	Coffee	23	34
	Garlic	25	31
	Pepper	28	39
C. chinensis	Green gram	10	15
	Soy beans	14	18
L. serricorne	Cumin	24	37
C. cephalonica	Rice flour	—	32

with an aspirator. Such cages with the insects were introduced into the respective host materials in clean muslin bags and tied, labelled and arranged in the fumigatorium.

The different stages were exposed to the fumigant as already mentioned. Then, after 48 hours of aeration, they were transferred to glass jars and kept closed with muslin cloth and incubated for varying periods for observing the adult emergence from the eggs, larvae and pupae from the fumigated samples. In the case of adults exposed to the fumigant the mortality counts were taken after the aeration period.

Assessment of results:

After incubation the total number of adults emerging from each replication was counted. Quick moving and swift flying insects were anathetized with ether and counted. From this percentage reduction of adult emergence was calculated by using the formula $P = \frac{MC - MT}{MC} \times 100$ where P = percentage reduction of adult emergence, MC = mean number of adult insects emerging from the untreated control and MT = mean number of adults emerging from the treated material.

ESTIMATION OF RESIDUES OF PHOSPHINE

The colorimetric method developed by Bruce *et al.* (1962) and recommended by Joint Committee of FAO and WHO on pesticide residues was used for the estimation of phosphine residues in the fumigated materials.

Preparation of standard curve and regression equation:

A standard solution (100 ppm) of phosphorus was prepared by dissolving potassium dihydrogen phosphate in clean distilled water. This served as the stock solution which was further diluted to get a 10 ppm solution. From this aliquots of 0.25, 0.5, 1.0, 2.0 and 4.0 ml were pipetted out into 25 ml volumetric flasks. To each of these solutions, 8 ml of 6 N sulphuric acid was added followed by 2 ml of 5 per cent ammonium molybdate and 2 ml of 0.15 per cent hydrazine sulphate. After the addition of each reagent, the contents of the volumetric flasks were well shaked and volumes made up. A reagent blank was similarly prepared. These flasks were placed in a boiling water bath for about 15 minutes. After that they were cooled to room temperature. The colour intensity of the phosphomolybdenum blue complex thus formed was measured by using spectrophotometer at 820 n.m against the reagent blank.

A regression equation was worked out with the help of O.D. values corresponding to each concentration. This equation was used for calculating the amount of phosphorus residues. From this phosphine equivalent was obtained by multiplying the phosphorus content by a factor 1.097.

Preparation of standard solution of phosphine in carbon disulphide to be mixed with commodities for recovery studies:

A standard solution of phosphine in carbon disulphide was prepared. For this aluminium phosphide pellet was placed in a 100 ml flask with 19/26 outer joint. Twenty five ml of distilled water was added to the flask. Then distilling type adapter with 19/26 inner joint containing a gas dispersion tube was quickly inserted into the flask. The other end of the dispersion tube was immersed in 100 ml of reagent grade carbon disulphide in a reagent bottle. The phosphine gas evolved from aluminium phosphide was allowed to dissolve in carbon disulphide for 2 hours. Then the evolving phosphine gas was oxidised with bromine; the resulting phosphoric acid was converted to its phosphomolybdenum blue complex. By measuring the colour intensity of this complex spectrophotometrically at 820 n.m. the intensity of phosphine in carbon disulphide was determined. The amount of phosphine in this carbon disulphide was calculated with reference to the regression equation obtained from potassium dihydrogen phosphate. A series of dilutions were then prepared from this concentrated solution of phosphine in carbon disulphide and used for further steps of recovery test.

$$y = (0.098x - 0.0145) \times 1.097$$

Procedure of recovery experiment:

The recovery procedure was as follows:- Five hundred gram each of the commodities was placed in a 5 litre round-bottomed flask with 24/40 cut joint. It had an i/c joint with an inlet and delivery tube and the delivery tube was attached to a series of scrubbers. The flask was kept in a water bath. A quantity of 1.5 litre of 10 per cent v/v sulphuric acid and 1 ml of carbon disulphide solution containing 1.0 µg of phosphine were added. The flask was immediately connected to the scrubbers each containing 7 ml of 0.2 N potassium permanganate and 3 ml of 5 per cent v/v sulphuric acid. Air was bubbled through the flask contents at the rate of 30 bubbles per minute for 30 minutes. After this, the contents of the flask were heated for 2 hours with the air-flow continuing. The scrubbers were then removed and 7 ml of 0.2 N oxalic acid added to each scrubber. Then the contents were pooled into a 100 ml volumetric flask and volume made up.

An aliquot of 10 ml was transferred to 25 ml volumetric flask; 8 ml of 6 N sulphuric acid was added to this followed by 2 ml of 5 per cent ammonium molybdate and 2 ml of 0.15 per cent hydrazine sulphate. After the addition of each reagent, the contents of the volumetric flasks were well shaked and made up to the volume. Control samples were also taken in the same way. Recovery percentage was then calculated referring to the regression equation (Appendix I).

Estimation of residues in the fumigated samples:

The residues of phosphine in all the fumigated commodities (wheat flour, maida, rice flour, rice, semolina, noodles, cattle feed, gram flour, soy beans, green gram, dhal, coffee, tea, cocoa powder, garlic, pepper and cumin) due to treatment dose of 4.5 g/m^3 for 3 days were estimated after 48 hours of aeration period. For this a quantity of 500 g of fumigated commodity was placed in the 5 litre capacity round bottom flask and phosphine content was estimated as done in recovery test.

ORGANOLEPTIC QUALITIES OF THE FUMIGATED COMMODITIES

Detailed investigations were carried out to study the effect of phosphine on the organoleptic qualities of different food products fumigated with aluminium phosphide and the details of the studies are given below:

Fumigation of food materials with phosphine:

The food materials treated with the fumigant were rice flour, wheat flour, maida, semolina, coffee, tea and cocoa powder. Lots of 250 g each of rice flour, wheat flour, maida and semolina and 100 g each of coffee, tea and cocoa powder were fumigated with 3.0 g/m^3 of aluminium phosphide in the fumigatorium for a period of 3 days. An equal amount each of the food materials placed in another wooden box similar to the one used as fumigatorium served as control. Both the fumigated and non-fumigated samples were aerated for 48 hours for the escape of any fumes present within the products and to bring out the off flavour of the treated samples, if any.

Assessment of organoleptic qualities of the selected food materials:

To find out whether the fumigation of the food materials affected the organoleptic characteristics, different preparations were made with them and were evaluated for their acceptability. As the method of cooking was one of the factors influencing the acceptability of foods, various cooking methods such as boiling, steaming and frying were employed to process the food materials. For coffee, tea and cocoa only boiling method was employed. The details regarding the method of cooking and the different preparations made using the various food materials are presented in Table 3.

Table 3. Details of different methods of cooking employed in processing the different food materials.

Food materials	Methods of cooking		
	Boiling	Steaming	Frying
Wheat flour	Infant food	--	Chappathi
Maida	--	Pudding	Pancake
Semolina	Porridge	--	Upma
Rice flour	--	Kozhu-katta & Pittu	--

Triplicate lots of 100 g of the treated and control samples were used to prepare the products. Only one preparation using one food material was prepared and presented for quality assessment by trained judges on each day, to avoid fatigue and to limit sample size. The preparations were served hot to avoid change in flavour and texture due to cooling. The testing was done in an ideal room condition in the morning between 10 and 11 A.M. being considered as ideal time for conducting organoleptic studies as reported by Swaminathan (1974).

Selection of judges:

The panel members for the organoleptic quality evaluation were selected from a group of young women. Only healthy women between the age of 20 and 50 were selected as recommended by Krum (1955). Sensitivity threshold test and triangle test were employed to select the judges.

Threshold test was employed to judge the ability of the members to recognise basic tastes and odours. Sodium chloride solutions of different molar concentrations (0.0526 - 2.9225) were used since most of the test products contained salt. Samples were coded and the judges were asked to write the code numbers of solutions in increasing order of concentration and also to express the result in the form of score given below.

0 = None or taste of pure water

? = Different from water

X = Threshold very weak (taste identifiable)

1 = Weak taste

2 = Medium

3 = Strong

4 = Very strong

5 = Extremely strong

King (1937) had suggested that the ability to identify the basic tastes at low concentration is valuable in selecting judges.

Conduct of triangle test:

In the triangle test, solutions of different concentrations were used. In the solutions supplied to the judges two were identical and they were asked to pick out the different sample.

Evaluation card for Triangle Test

Name of the product: Sugar solution

Note: Two of the three samples are identical. Identify the odd sample

Table 4

Serial No.	Code No.of samples	Code No.of identical samples	Code No.of odd sample

Boggs and Hanson (1949) has reported that the panel should be large enough to counteract unusual variability, or other factors which might interfere with day to day comparisons. However, small, highly sensitive panels would usually give more reliable results than large less sensitive groups. Thus from the forty eight members who participated in the initial primary threshold test, seventeen members were selected. They were again subjected to Triangle Test, and eight were finally selected as judges for the present study.

Conduct of the organoleptic qualities of fumigated and non-fumigated food samples:

The organoleptic evaluation of the fumigated and non-fumigated samples were done using the scoring method, since scoring tests were widely used for quality evaluation in research and industry (Swaminathan, 1974). Amerine et al. (1965) had also reported that the best use of scoring tests was to compare a control sample and an experimental sample.

A score card thus developed for the study is given in Table 5. Hence a 4 point scale for each of the main characteristics evaluated was prepared; separate score cards were prepared for different products, since the characteristics varied according to the test product. As indicated

Table 5. Score card for acceptability test of fumigated and non-fumigated food products

Quality attribute	Subdivision of attribute	Scores for each sub-division attributes	Score for sample I (Code No.) (fumi-gated)	Score for sample II (Code No.) (non-fumi-gated)
Appearance	Excellent	4		
	Very good	3		
	Good	2		
	Poor	1		
Taste	Excellent	4		
	Very good	3		
	Good	2		
	Poor	1		
Odour	Pleasant & familiar	4		
	Unpleasant & familiar	3		
	Unpleasant & unfamiliar	2		
	Not clear	1		
Colour	Normal cooked colour	4		
	Slight dis-colouration	3		
	High dis-colouration	2		
	Severe dis-colouration	1		
Texture	Very smooth	4		
	smooth	3		
	Rough	2		
	Very rough	1		

in the Table, appearance, taste, odour, colour and texture were the quality attributes assessed to study the organoleptic qualities of cereal products. Similarly for beverages, attributes such as flavour, colour, taste and clarity (body) were taken into consideration (Table 6).

Table 6. Score card for acceptability test of fumigated and non-fumigated beverages (coffee, tea and cocoa powder)

Quality attribute	Subdivision of attribute	Scores for each sub-division attributes	Score for sample I (Code No.) (fumigated)	Score for Sample II (Code No.) (non-fumigated)
Flavour	Fragrant	4		
	Pleasant	3		
	Bland	2		
	Stinking	1		
Colour	Amber red	4		
	Too dark	3		
	Dark	2		
	Light	1		
Taste	Very tasty	4		
	Tasty	3		
	Slightly astringent	2		
	Bitter	1		
Body	Very clear & sparkling	4		
	Clear with no film on the surface	3		
	Clear with film on the surface	2		
	Unclear	1		

The panel members were trained in the special techniques used in testing the odour and taste of foods; for e.g. panel members were trained to taste coffee and tea by slurping one teaspoonful of the liquid and smelling done by short, rapid sequence of short "sniffs".

Then the judges were requested to score the coded fumigated and non-fumigated samples of the same product, one after another, for each of its characteristics on the 4 rating points. The total score for each product and each sample was obtained by summing up the scores given for individual quality attributes.

RESULTS

RESULTS

I. Bio-efficacy of aluminium phosphide in controlling different species of insects infesting different food commodities.

Results of studies undertaken on the bio-efficacy of aluminium phosphide at different concentrations in controlling different species of insects reared on different food media are presented below:-

Control of *Tribolium castaneum* in infested products with aluminium phosphide.

The effect of aluminium phosphide in controlling *T. castaneum* reared on different food products at different concentrations of phosphine gas is presented in Table 7. At the lowest dosage of 1.5 g/m^3 the percentage reduction in survival of the insect in treated commodities as compared to untreated commodities varied from 92.49 to 100. In tea and cocoa powder there was cent per cent control of the infestation, followed by gram flour (95.17), noodles (94.71), semolina (94.14), maida (93.17) and wheat flour (92.49). When fumigated at a dose of 3.0 g/m^3 of phosphine, there was cent per cent control of the insect in all the commodities due to the treatment except in semolina (99.37%) wheat flour (98.60%) and maida (97.53%). At the highest dose of 4.5 g/m^3

Table 7. Effect of aluminium phosphide on control of *Tribolium castaneum* infesting different food commodities.

Dose	1.5 g/m^3			3.0 g/m^3			4.5 g/m^3		
Food products	Mean No. of adults		Per cent control	Mean No. of adults		Per cent control	Mean No. of adults		Per cent control
	Treated	Control		Treated	Control		Treated	Control	
Wheat flour	6.33	92.67	92.49	1.33	95.00	98.60	0.00	93.00	100.00
Semolina	6.00	102.33	94.14	0.66	104.66	99.37	0.00	103.00	100.00
Cocoa powder	0.00	65.00	100.00	0.00	66.00	100.00	0.00	66.33	100.00
Tea	0.00	62.33	100.00	0.00	64.00	100.00	0.00	63.33	100.00
Noodles	3.33	63.00	94.71	0.00	68.00	100.00	0.00	65.33	100.00
Gram flour	4.33	89.67	95.17	0.00	92.00	100.00	0.00	91.33	100.00
Maida	7.00	93.33	93.17	2.33	94.66	97.53	0.00	97.00	100.00

C.D. : Dose 0.699
Product 0.128

there was no survival of the insect in any of the stored products.

The statistical analysis of the data showed that the treatments were highly significant. There was significant difference among the three doses in the commodities in general except for tea and cocoa powder where all the three doses were on par. In noodles and gram flour the doses 3.0 g/m^3 and 4.5 g/m^3 were on par. The effect of phosphine on _T. castaneum_ reared on different food media was found to vary significantly. Thus at the dose of 1.5 g/m^3 the percentage reduction of adult population was significantly different in different commodities except in cocoa powder and tea, where the effect was on par giving a cent per cent reduction and were superior over the other products. At 3.0 g/m^3 there was significant difference between the different commodities giving the reduction in adult counts differently. At the highest dose of 4.5 g/m^3 all the commodities responded equally to the fumigant giving a cent per cent control of the insect.

Control of _Sitophilus oryzae_ in stored products with aluminium phosphide.

This weevil infesting three different food materials also showed differential response to phosphine gas (Table 8).

Table 8. Effect of aluminium phosphide on control of <u>Sitophilus oryzae</u> infesting different food products

Dose	1.5 g/m^3			3.0 g/m^3			4.5 g/m^3		
Products	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control
	Treated	Control		Treated	Control		Treated	Control	
Rice	10.00	144.67	93.09	1.00	149.33	99.33	0.00	142.33	100.00
Cattle feed	4.00	133.33	97.00	0.66	128.33	99.48	0.00	134.00	100.00
Dhal	4.00	100.67	96.03	1.00	100.83	99.00	0.00	98.00	100.00

C.D. : Dose 0.520

Product 0.520

Fig. 1 and 2 Effect of aluminium phosphide on control of storage pests infesting different food products when treated at different dosages:

Fig. 1 <u>Tribolium castaneum</u>

Fig. 2 <u>Sitophilus oryzae</u>

FIG. 1. TRIBOLIUM CASTANEUM

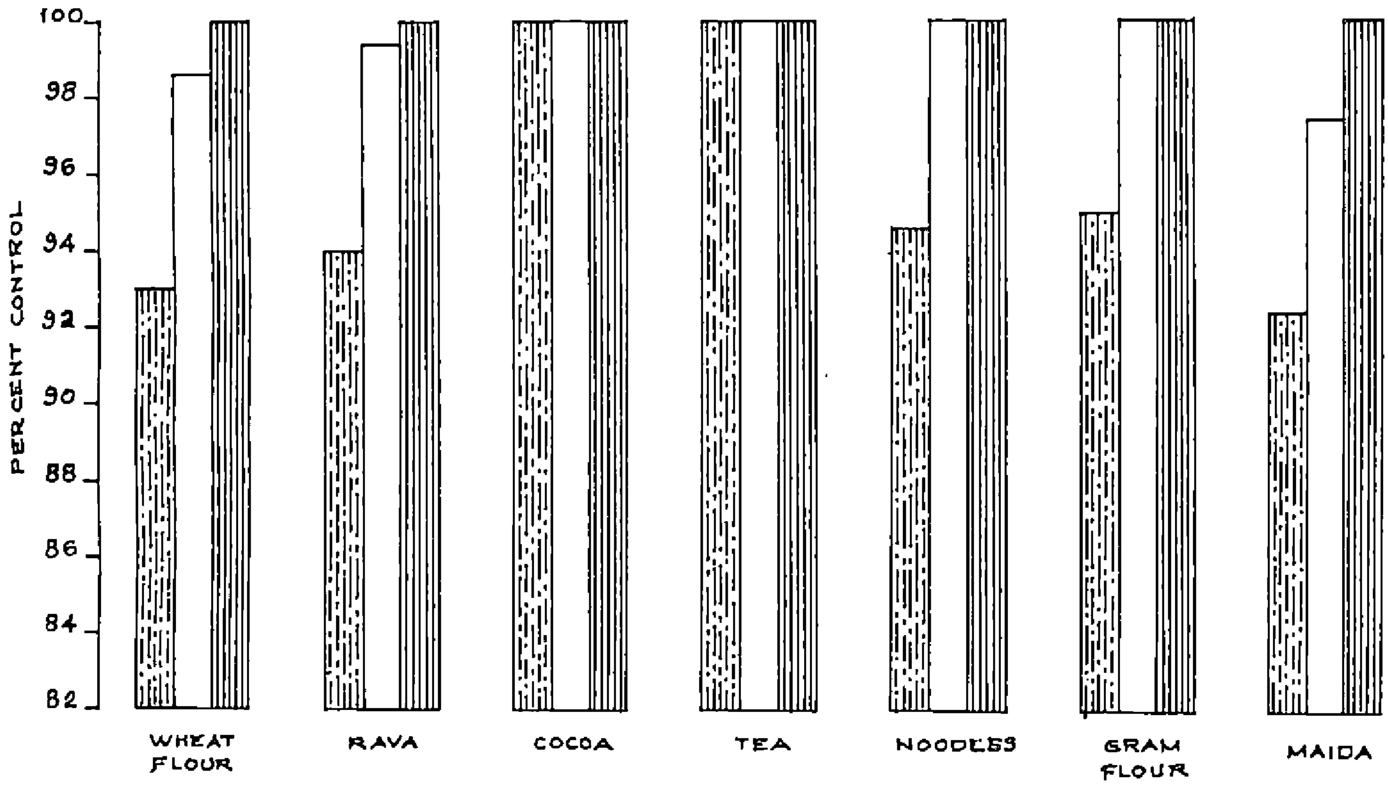
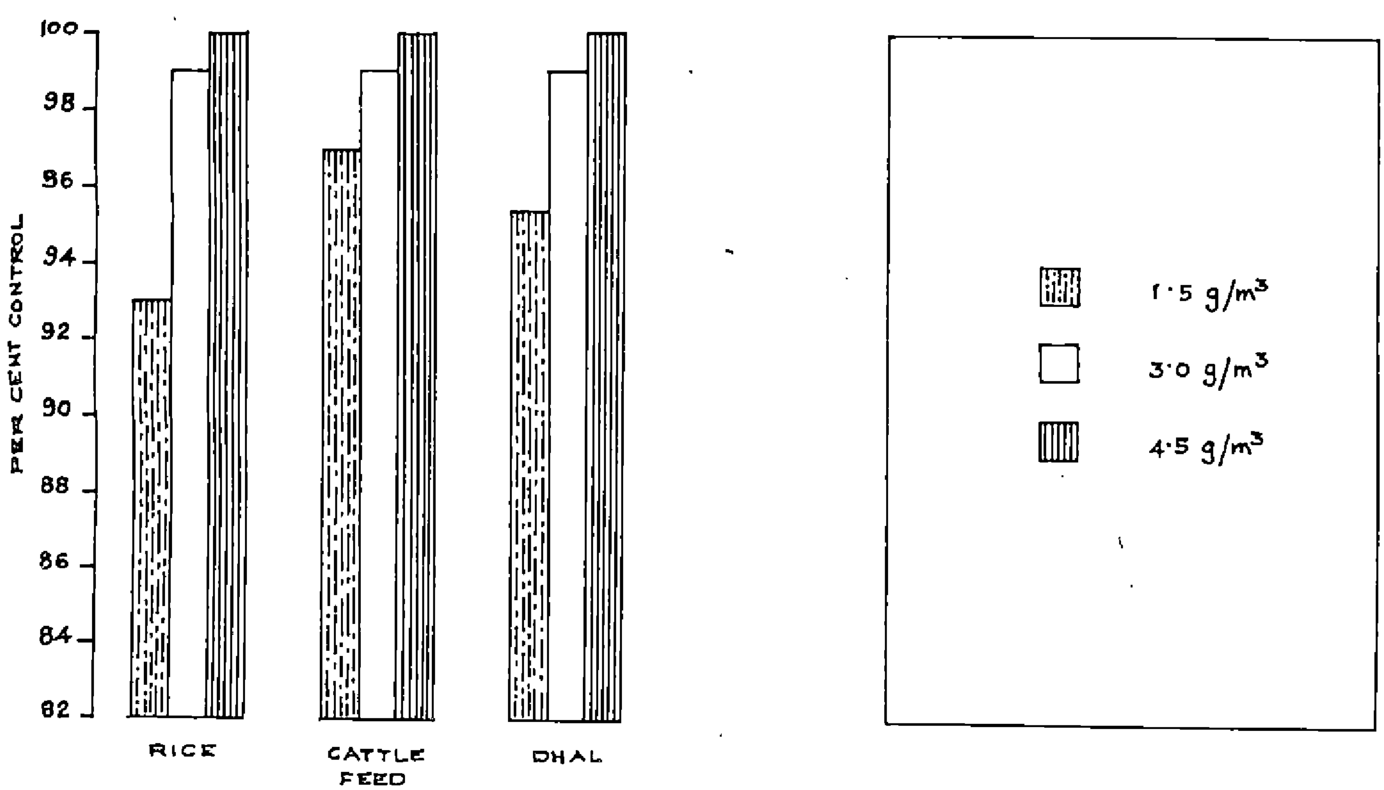


FIG. 2. SITOPHILUS ORYZAE



In rice, the percentage reduction in adult population was 93.09 compared to 97.00 per cent in cattle feed and 96.03 per cent in dhal at the lower dose of 1.5 g/m^3. At the medium dose of 3.0 g/m^3, the control percentages were 99.33, 99.48 and 99.00 respectively for the commodities. Cent per cent control was exhibited by the dose 4.5 g/m^3 in all the commodities. In the case of cattle feed, the dose 1.5 g/m^3 differed significantly from the next highest two doses. But the doses 3.0 g/m^3 and 4.5 g/m^3 were found to be on par in their effect. In dhal the insect showed differential response between the above doses giving the percentage reduction in adult population as 96.03, 99.00 and 100.00 respectively all of which were found to be significant. However, there was significant difference between the different commodities only at the lowest dose of 1.5 g/m^3. In the higher doses the response was on par.

Control of _Araecerus fasciculatus_ infesting different products with aluminium phosphide.

Table 9 shows that the percentage control of _A. fasciculatus_ with phosphine in different products ranged from 92.07 to 100.00. In pepper, the control was maximum (100.00) followed by garlic (95.03) and coffee (92.07) at the lowest dose. In coffee, percentage reduction

Table 9. Effect of aluminium phosphide on control of <u>Araecerus fasciculatus</u> infesting different food products

Dose	1.5 g/m^3			3.0 g/m^3			4.5 g/m^3		
Products	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control	Mean No,of adults		Per cent control
	Treated	Control		Treated	Control		Treated	Control	
Coffee	8.33	105.00	92.07	1.00	102.67	99.03	0.00	101.33	100.00
Garlic	5.00	100.67	95.03	1.33	100.00	98.67	0.00	99.00	100.00
Pepper	0.00	86.33	100.00	0.00	85.67	100.00	0.00	85.67	100.00

C.D. : Dose 0.365

Product 0.365

in adult population was 99.03, in garlic 98.67 and in pepper 100 per cent at the dose of 3.0 g/m^3. But cent per cent control of the pest was observed at the maximum dose (4.5 g/m^3) in all the commodities. From the analysis of the data, it was seen that all the three doses differed significantly in their effect in coffee. The same response was observed in garlic also. But in pepper the doses were on par giving absolute control. Comparing the different commodities at the lowest dose the response was found to be highly significant with 100 per cent control in pepper, followed by garlic (95.03) and coffee (92.07). At 3.0 g/m^3 there was significant difference between the percentage control in pepper compared to garlic and coffee but between the two commodities they were on par. At 4.5 g/m^3 all the three commodities behaved in the same way.

Control of *Callosobruchus chinensis* infesting different stored pulses by phosphine fumigation.

It could be seen from Table 10 that *C. chinensis* was under absolute control in green gram and soy beans at the highest dose (4.5 g/m^3). At the lowest dose of 1.5 g/m^3 the percentage control of the insect was to the tune of 98.09 and 94.94 per cent in green gram and soy beans respectively. Cent per cent reduction of the pest was

Table 10. Effect of aluminium phosphide on control of _Callosobruchus chinensis_ infesting different food products

Dose	$1.5\ g/m^3$			$3.0\ g/m^3$			$4.5\ g/m^3$		
Products	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control
	Treated	Control		Treated	Control		Treated	Control	
Green gram	18.33	362.67	94.94	4.00	366.00	98.91	0.00	365.00	100.00
Soy beans	3.33	174.67	98.09	0.00	173.66	100.00	0.00	173.66	100.00

C.D. : Dose 0.232
Product 0.189

in evidence in soy beans at 3.0 g/m^3 where as it was 98.91 in green gram.

Statistically green gram showed significant differential response between the three doses. For soy beans the lowest dose and the medium dose only differed significantly where the mean percentage reductions of adult population were 98.09 and 100.00 respectively. Comparing the significance in adult population in the two products, it was seen that at the lower two doses, they differed significantly whereas at the highest dose they were on par.

Control of *Lasioderma serricorne* infesting cumin with aluminium phosphide.

The response of *L. serricorne* reared on cumin to phosphine gas is given in Table 11. There was 89.44 per cent reduction in adult population at the dose 1.5 g/m^3. It became 92.24 per cent when the dose was increased to 3.0 g/m^3. Absolute control of the pest was obtained only at the highest dose of 4.5 g/m^3. The analysis of the data did not show any significance indicating thereby that all the doses were on par.

Control of *Corcyra cephalonica* in rice flour with aluminium phosphide.

Results of fumigating rice flour infested with *C. cephalonica* with phosphine is given in Table 12. It could

Table 11. Effect of aluminium phosphide on control of Lasioderma serricorne infesting cumin.

Dose	1.5 g/m^3			3.0 g/m^3			4.5 g/m^3		
Product	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control
	Treated	Control		Treated	Control		Treated	Control	
Cumin	18.33	173.67	89.44	1.33	176.33	92.24	0.00	174.33	100.00

Treatments : Non-significant

Table 12. Effect of aluminium phosphide on control of *Corcyra cephalonica* infesting rice flour.

Dose	1.5 g/m^3			3.0 g/m^3			4.5 g/m^3		
Product	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control	Mean No.of adults		Per cent control
	Treated	Control		Treated	Control		Treated	Control	
Rice flour	5.00	242.33	97.94	0.00	240.33	100.00	0.00	242.00	100.00

Treatments : Non-significant

Fig. 3 to 5 Effect of aluminium phosphide on control of storage pests infesting different food products when treated at different dosages:

Fig. 3 *Callosobruchus chinensis*

Fig. 4 *Lasioderma serricorne*

Fig. 5 *Corcyra cephalonica*

FIG. 3. Callosobruchus chinensis

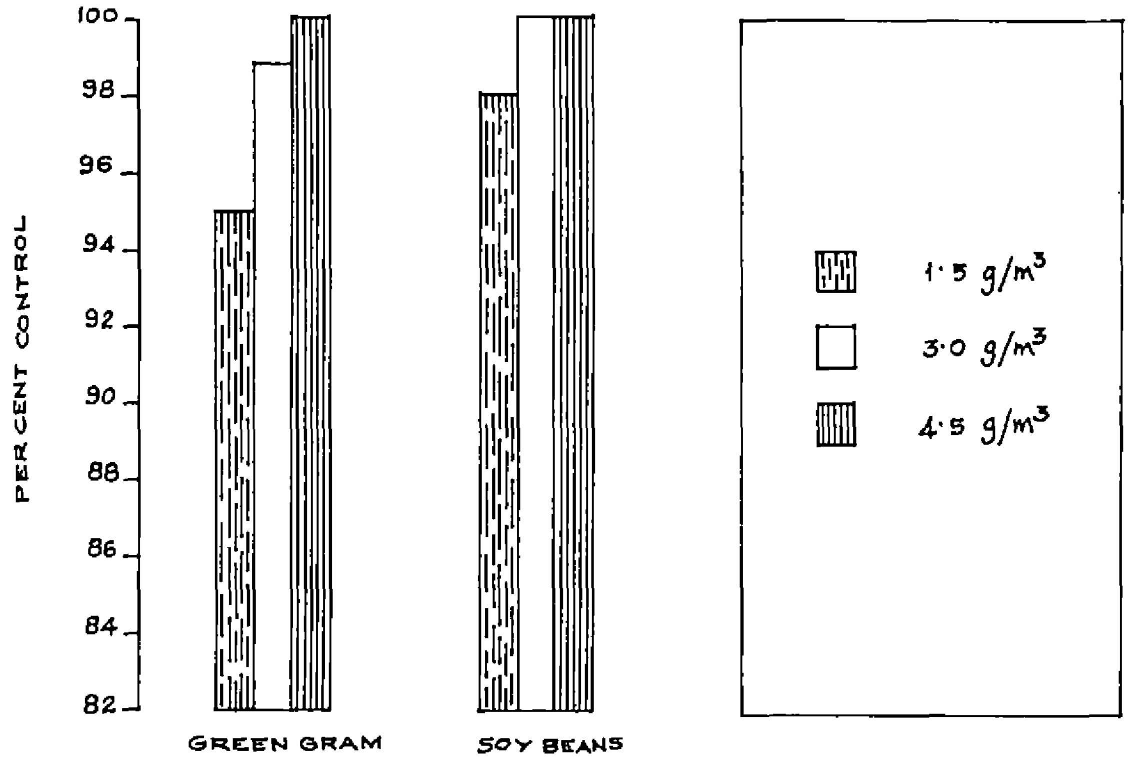


FIG. 4. Lasioderma serricorne

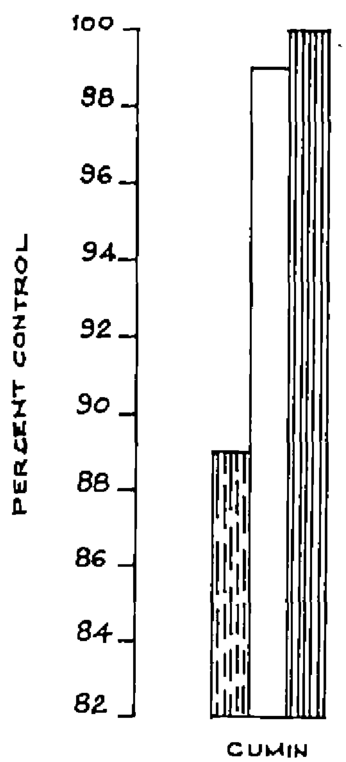
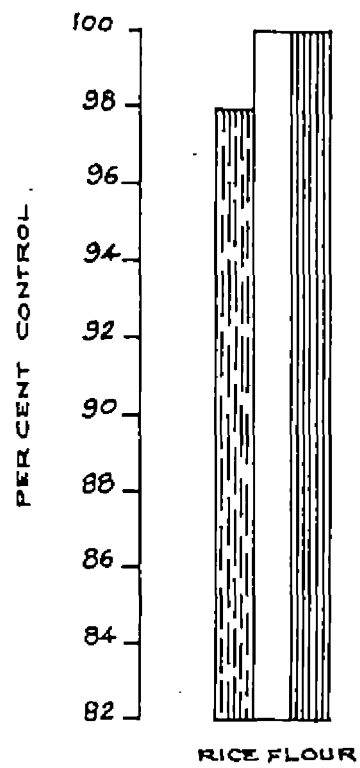


FIG. 5. Corcyra cephalonica



be seen that there was 97.94 per cent reduction in adult emergence at the lowest dose. Absolute control of the pest was observed when the dose was increased and the different doses were not showing any significance

II <u>Relative toxicity of aluminium phosphide on different stages of insects reared on different food commodities</u>.

Results of studies on the effect of aluminium phosphide on different life stages of the insects reared on different food products treated at different doses are presented below:-

<u>Control of *Tribolium castaneum* in different food products due to effect of phosphine on the different life stages</u>.

Tribolium castaneum reared on seven different products were exposed to phosphine and its effect on the various life stages are presented in Tables 13 to 15.

<u>Egg stage</u>: At the lowest dose of 1.5 g/m^3, the percentage reduction in adult emergence from the treated commodities compared to untreated commodities varied from 78.29 to 99.29. The highest percentage reduction was in cocoa powder (99.29) followed by tea (98.09), noodles (97.98), gram flour (97.02), semolina (79.40), maida (78.62) and wheat flour (78.29). When the dose was increased to 3.0 g/m^3, the percentage reduction in adult emergence varied from 97.65 to 100. At this dosage in

Table 13. Effect of different food products on susceptibility of the egg stage of *Tribolium castaneum* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No.of adults emerging from		Percentage reduction of adult emergence	Mean No.of adults emerging from		Percentage reduction of adult emergence	Mean No.of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Wheat flour	26.33	123.33	78.29 (62.240)	2.33	109.66	97.87 (81.522)	0.00	110.33	100.00 (90.000)
Semolina	29.66	144.00	79.40 (63.030)	0.00	124.66	100.00 (90.000)	0.00	132.33	100.00 (90.000)
Cocoa powder	0.33	46.66	99.29 (85.408)	0.00	36.00	100.00 (90.000)	0.00	43.00	100.00 (90.000)
Tea	0.66	34.66	98.09 (81.876)	0.00	37.66	100.00 (90.000)	0.00	37.66	100.00 (90.000)
Noodles	1.33	66.00	97.98 (81.658)	0.00	62.33	100.00 (90.000)	0.00	64.00	100.00 (90.000)
Gram flour	3.33	112.00	97.00 (80.030)	0.00	110.66	100.00 (90.000)	0.00	114.66	100.00 (90.000)
Maida	28.00	131.00	78.62 (62.450)	4.00	170.33	97.65 (81.134)	0.00	146.33	100.00 (90.000)

C.D. : Dose 1.0942
Product 1.6714

(Figures within parentheses are angular values)

Table 14. Effect of different food products on susceptibility of the larval stage of Tribolium castaneum to phosphine fumigation.

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction in adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Wheat flour	2.33	97.00	97.59 (81.134)	0.00	113.00	100.00 (90.000)	0.00	108.00	100.00 (90.000)
Semolina	2.33	131.33	98.22 (82.348)	0.00	102.33	100.00 (90.000)	0.00	120.66	100.00 (90.000)
Cocoa powder	0.00	39.33	100.00 (90.000)	0.00	42.66	100.00 (90.000)	0.00	36.66	100.00 (90.000)
Tea	0.00	32.33	100.00 (90.000)	0.00	32.66	100.00 (90.000)	0.00	32.66	100.00 (90.000)
Noodles	0.00	61.00	100.00 (90.000)	0.00	56.33	100.00 (90.000)	0.00	55.33	100.00 (90.000)
Gram flour	0.66	104.66	99.36 (85.412)	0.00	105.66	100.00 (90.000)	0.00	104.33	100.00 (90.000)
Maida	2.33	140.66	98.34 (82.587)	0.00	131.33	100.00 (90.000)	0.00	127.33	100.00 (90.000)

C.D. : Dose 0.8398
Product 0.0898

(Figures within parentheses are angular values)

semolina, cocoa powder, tea, noodles and gram flour cent per cent reduction was seen followed by wheat flour (97.87) and maida (97.65). At the highest dosage of 4.5 g/m^3 cent per cent reduction in adult emergence was seen in all the commodities.

The statistical analysis of the data revealed that the treatments were highly significant. Variation in adult emergence for different products was prominent at the dose of 1.5 g/m^3. There was significant difference in the adult emergence in the different products. Wheat flour (78.29), semolina (79.40) and maida (78.62) were showing minimum reduction in adult emergence and were on par. Cocoa powder, gram flour, noodles and tea were also found to be on par in their effect. At the dose of 3.0 g/m^3 the products wheat flour and maida were on par in their effect differing significantly from the other products which showed cent per cent reduction in adult emergence. The three doses (1.5, 3.0 and 4.5 g/m^3) also differed significantly in wheat flour and maida. In the case of semolina, tea, gram flour and noodles the treatment 3.0 g/m^3 was found to be significantly superior over the lowest dose of 1.5 g/m^3. But all the treatments were on par for cocoa powder.

Larval stage: It could be seen from the Table 14 that the percentage reduction in adult emergence at the lowest

Table 15. Effect of different food products on susceptibility of the pupal stage of *Tribolium castaneum* to phosphine fumigation.

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Wheat flour	6.00	97.00	93.81 (75.588)	1.33	109.00	98.77 (83.543)	0.00	110.66	100.00 (90.000)
Semolina	4.33	90.66	95.22 (77.670)	0.00	98.66	100.00 (90.000)	0.00	87.33	100.00 (90.000)
Cocoa powder	0.00	43.00	100.00 (90.000)	0.00	41.66	100.00 (90.000)	0.00	42.66	100.00 (90.000)
Tea	0.00	33.00	100.00 (90.000)	0.00	36.33	100.00 (90.000)	0.00	35.33	100.00 (90.000)
Noodles	0.33	62.66	99.47 (86.556)	0.00	61.66	100.00 (90.000)	0.00	61.00	100.00 (90.000)
Gram flour	1.33	105.00	98.73 (83.543)	0.00	104.66	100.00 (90.000)	0.00	111.33	100.00 (90.000)
Maida	10.33	154.00	93.29 (75.820)	3.33	162.66	97.95 (81.686)	0.00	159.33	100.00 (90.000)

C.D. : Dose 0.3469
Product 0.9179

(Figures within parentheses are angular values)

dose 1.5 g/m^3 ranged from 97.59 to 100. In cocoa powder, tea and noodles the larvae showed cent per cent mortality. In gram flour the percentage reduction was 99.36 followed by maida (98.34), semolina (98.22) and wheat flour (97.59). Absolute control of the larval stages of the pest in all the products was seen at the doses 3.0 and 4.5 g/m^3.

Statistical analysis of the data showed that at 1.5 g/m^3 there was significant difference between wheat flour (97.59), semolina (98.22), maida (98.34) and gram flour (99.36). In the case of cocoa powder, tea and noodles they were on par in their effect at all the three doses showing cent per cent mortality in larval stage. The doses 3.0 and 4.5 g/m^3 were found to be on par in their effect for all the products with cent per cent reduction in adult emergence.

Pupal stage: In the case of pupal stage of *T. castaneum* (Table 15), the percentage reduction in adult emergence varied from 93.29 to 100 at different doses. At the lowest dose of 1.5 g/m^3 there was cent per cent mortality for cocoa powder and tea followed by noodles (99.47), gram flour (98.73), semolina (95.22), wheat flour (93.81) and maida (93.29). When the dose was increased to 3.0 g/m^3 there was cent per cent mortality for semolina, cocoa powder, tea, noodles and gram flour. But for wheat flour and maida, the percentage

Table 16. Effect of different food products on susceptibility of the egg stage of *Sitophilus oryzae* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Rice	36.00	139.33	73.93 (58.285)	9.33	136.33	93.16 (74.776)	0.00	130.33	100.00 (90.000)
Cattle feed	33.33	132.33	74.81 (59.868)	6.33	125.66	94.96 (76.864)	0.00	123.33	100.00 (90.000)
Dhal	27.33	103.33	73.55 (59.015)	2.33	104.33	97.76 (81.318)	0.00	102.33	100.00 (90.000)

C.D. : Dose 0.4632
Product 0.4632

(Figures within parentheses are angular values)

reductions were 98.77 and 97.95 respectively. At the highest dose cent per cent reduction was obtained.

At the lowest dose 1.5 g/m^3 except for cocoa powder and tea (100 per cent) all the other products significantly differed from each other. The dosage 3.0 g/m^3 was found to be statistically superior to 1.5 g/m^3 for wheat flour and maida. For all the other products the 2 doses (1.5 and 3.0 g/m^3) were on par in their effect.

Adults: The adults reared on the different commodities were found to be highly susceptible to the fumigant, producing a cent per cent mortality even at the lowest dose of 1.5 g/m^3.

Control of *Sitophilus oryzae* in different food products due to effect of phosphine on the different life stages.

Effect of phosphine on the life stages of *S. oryzae* reared on the food commodities (viz. rice, cattle food and dhal) is presented in Tables 16 to 18.

Egg stage: It could be observed from Table 16 that the percentage reduction in adult emergence of *S. oryzae* ranged from 73.55 to 74.81 at the lowest dose (1.5 g/m^3). Comparing the different products cattle feed showed higher percentage reduction (74.81) followed by rice (73.93) and dhal (73.55).

Table 17. Effect of different food products on susceptibility of the larval stage of <u>Sitophilus oryzae</u> to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Rice	23.00	154.00	85.06 (67.210)	1.33	119.66	98.89 (83.782)	0.00	137.66	100.00 (90.000)
Cattle feed	17.33	130.33	86.70 (68.472)	1.33	121.66	98.90 (84.021)	0.00	111.33	100.00 (90.000)
Dhal	15.66	120.33	86.98 (68.644)	0.66	111.00	99.40 (86.556)	0.00	106.00	100.00 (90.000)

C.D. : Dose 19.76
Product - Treatments non-significant

(Figures within parentheses are angular values)

Table 18. Effect of different food products on susceptibility of the pupal stage of *Sitophilus oryzae* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Rice	36.00	164.00	78.05 (62.030)	3.66	109.67	96.66 (81.134)	0.00	153.00	100.00 (90.000)
Cattle feed	31.00	152.33	77.68 (61.754)	3.33	110.00	96.97 (81.686)	0.00	123.33	100.00 (90.000)
Dhal	30.33	125.00	76.00 (61.340)	1.66	109.66	98.46 (82.826)	0.00	107.66	100.00 (90.000)

C.D. : Dose 11.97
Product - Treatments non-significant

(Figures within parentheses are angular values)

Fig. 6 and 7 Effect of aluminium phosphide on the life stages of storage pests when treated at a dosage of 1.5 g/m^3

Fig. 6 *Tribolium castaneum*

Fig. 7 *Sitophilus oryzae*

FIG. 6. TRIBOLIUM CASTANEUM

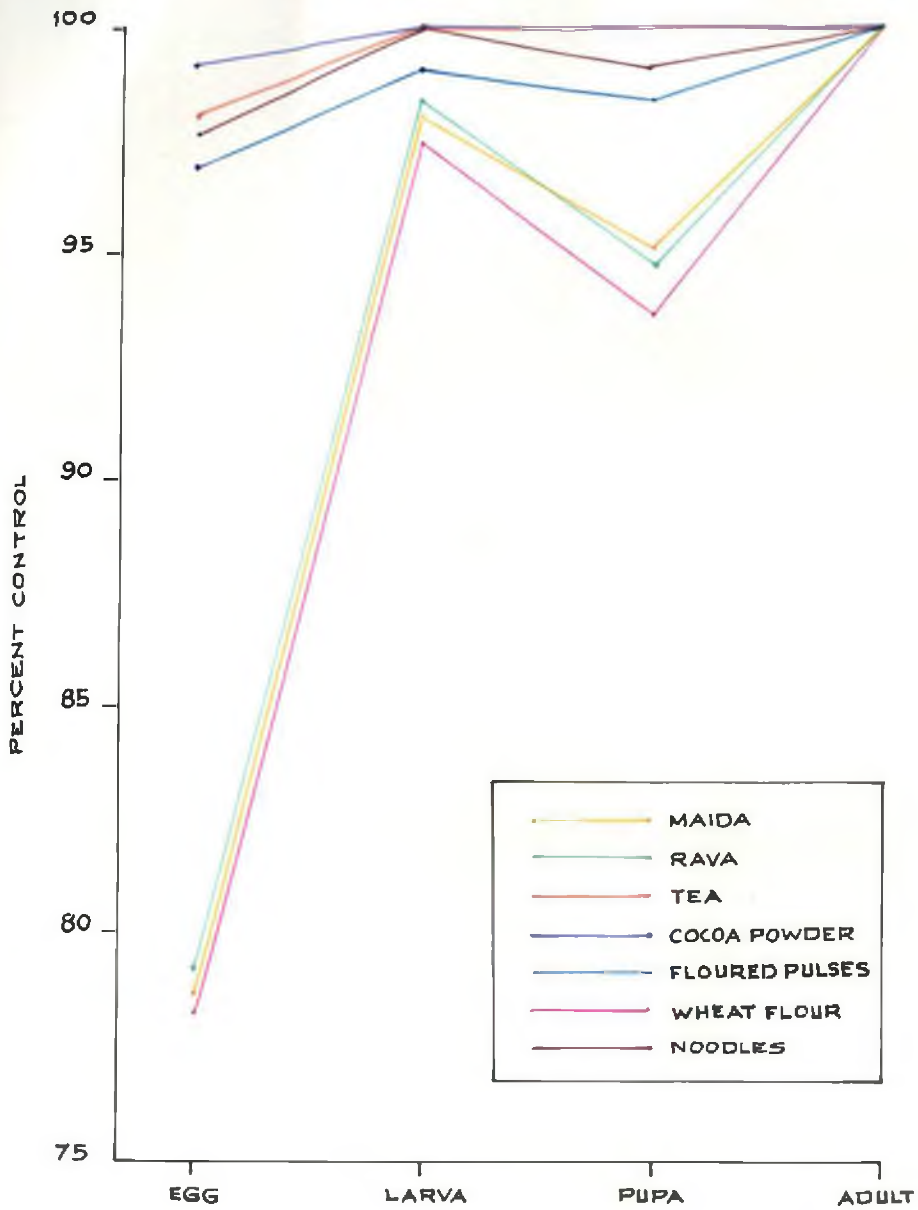
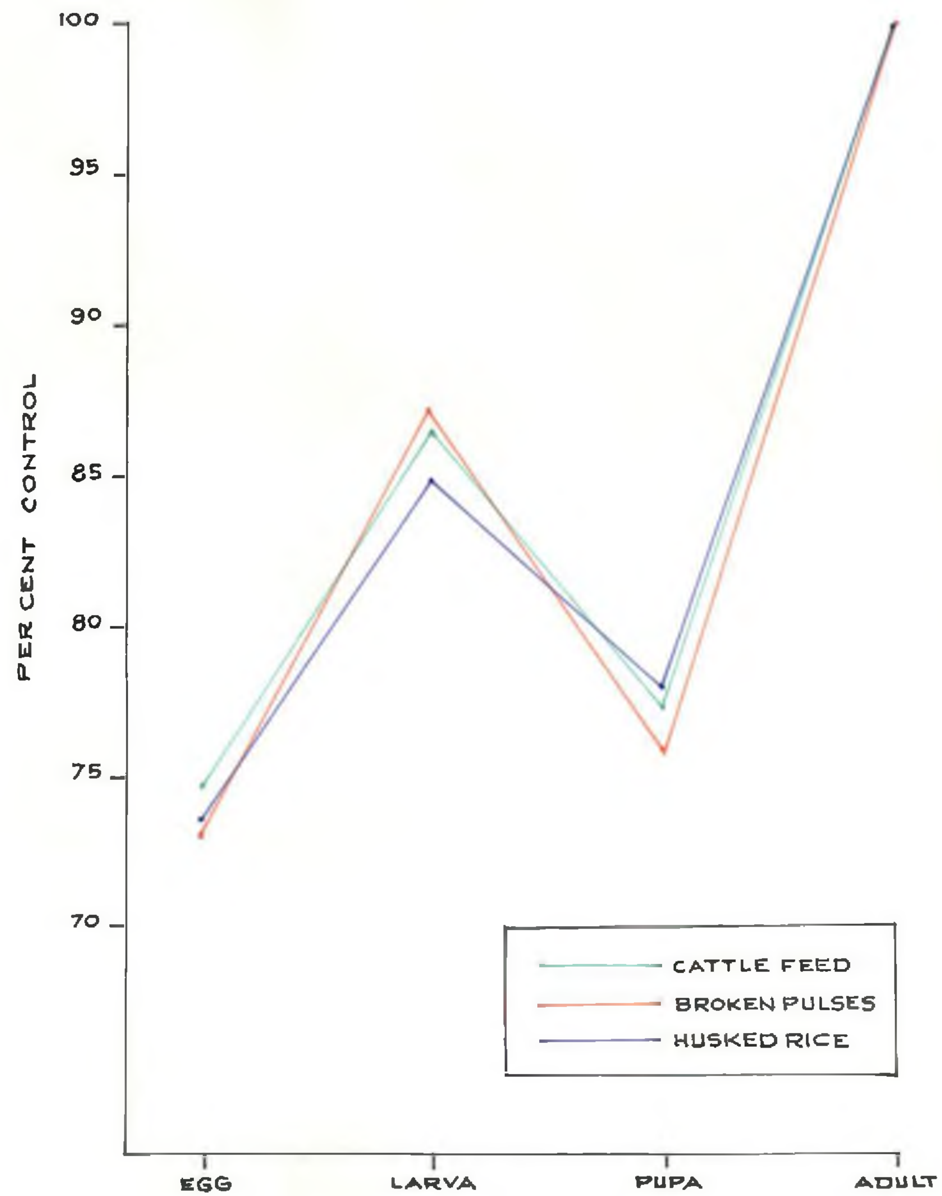


FIG. 7. SITOPHILUS ORYZAE



At 3.0 g/m^3 the percentage reduction for rice, cattle feed and dhal were 93.16, 94.96 and 97.76 respectively. Cent per cent reduction in adult emergence was observed for all the products at the highest dose of 4.5 g/m^3.

Statistical analysis of the data showed that at the lowest dose of 1.5 g/m^3 cattle feed significantly differed from rice and dhal. But all of them differed significantly at the dose 3.0 g/m^3. The dose 4.5 g/m^3 was found to be significantly superior to the other two doses.

Larval stage: Table 17 revealed that at the dose 1.5 g/m^3 dhal showed highest percentage reduction (86.98), followed by cattle feed (86.70) and rice (85.06). The percentage reduction in rice, cattle feed and dhal were 98.89, 98.90 and 99.40 respectively at the dose of 3.0 g/m^3. At 4.5 g/m^3 100 per cent reduction in adult emergence was seen.

Pupal stage: Increasing trend of mortality was observed in the case of pupal stages for all the three products when the dose was increased from 1.5 to 4.5 g/m^3 (Table 18). At the lowest dose rice showed highest percentage reduction (78.05) followed by cattle feed (77.68) and dhal (76.00). At the medium dose, the percentage reduction ranged from 96.66 to 98.46. Cent per cent mortality of pupal stage was obtained for all the products at 4.5 g/m^3.

Adult stage: There was cent per cent mortality of *S. oryzae* in all the three doses in all the three commodities.

Control of *Araecerus fasciculatus* in different food products due to effect of phosphine on the different life stages.

Effect of different commodities viz. coffee, garlic and pepper on the survival of different stages of *A. fasciculatus* subjected to fumigation with phosphine was studied, the details of which are presented from Tables 19 to 21.

Egg stage: At 1.5 g/m^3 dose, the mortalities observed in pepper was 99.61 per cent, followed by garlic (96.54%) and coffee (72.67%). Cent per cent reduction in adult emergence was observed for garlic and pepper at 3.0 g/m^3 dose and for coffee it was 90.90. Absolute reduction in adult emergence was seen at 4.5 g/m^3 dose.

Garlic and pepper were found to be on par in their effect at the doses of 1.5 and 3.0 g/m^3 which differed significantly from coffee. For coffee, the dose 3.0 g/m^3 was found to be significantly superior to 1.5 g/m^3 dose in the effect.

Larval stage: Garlic and pepper showed cent per cent mortality at 1.5 g/m^3, followed by coffee (92.86). At the higher doses cent per cent reduction was observed in all the

Table 19. Effect of different food products on susceptibility of the egg stage of *Araecerus fasciculatus* to phosphine fumigation.

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Coffee	26.33	96.33	72.67 (58.434)	9.00	99.00	90.90 (72.443)	0.00	99.00	100.00 (90.000)
Garlic	3.33	96.33	96.54 (80.950)	0.00	103.00	100.00 (90.000)	0.00	108.00	100.00 (90.000)
Pepper	1.33	86.66	99.61 (86.324)	0.00	90.33	100.00 (90.000)	0.00	88.33	100.00 (90.000)

C.D. : Dose 5.297
Product 5.297

(Figures within parentheses are angular values)

Table 20. Effect of different food products on susceptibility of the larval stage of *Araecerus fasciculatus* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Coffee	7.33	102.66	92.86 (74.442)	0.00	99.00	100.00 (90.000)	0.00	95.33	100.00 (90.000)
Garlic	0.00	103.33	100.00 (90.000)	0.00	104.66	100.00 (90.000)	0.00	103.00	100.00 (90.000)
Pepper	0.00	96.66	100.00 (90.000)	0.00	97.00	100.00 (90.000)	0.00	95.66	100.00 (90.000)

C.D. : Dose 0.2404
Product 0.2404

(Figures within parentheses are angular values)

Table 21. Effect of different food products on susceptibility of the pupal stage of *Araecerus fasciculatus* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Coffee	12.33	93.33	86.79 (81.250)	0.00	93.33	100.00 (90.000)	0.00	97.33	100.00 (90.000)
Garlic	1.66	105.33	98.42 (83.426)	0.00	99.66	100.00 (90.000)	0.00	97.33	100.00 (90.000)
Pepper	0.00	96.66	100.00 (90.000)	0.00	97.00	100.00 (90.000)	0.00	95.66	100.00 (90.000)

C.D. : Dose 0.476
Product 0.476

(Figures within parentheses are angular values)

three products. At the lowest dose coffee differed significantly from the other two products.

Pupal stage: The percentage reduction in adult emergence from the pupal stage varied from 86.79 to 100 (Table 21). Pepper gave cent per cent reduction followed by garlic (98.42) and coffee (86.79). At the increased doses 3.0 and 4.5 g/m^3 there was cent per cent reduction in adult emergence.

Adult stage: Cent per cent reduction in adult survival was obtained for all the products at all the doses.

Control of *Callosobruchus chinensis* in different food materials due to effect of phosphine on the different life stages.

Different life stages of the pest reared on green gram and soy beans responded differently to the fumigant.

Egg stage: The percentage reduction in adult emergence at the lowest dose of 1.5 g/m^3 for green gram and soy beans (Table 22) were 72.76 and 79.38; at 3.0 g/m^3 the percentage reductions became 90.85 and 100.00 per cent respectively. At the highest dose of 4.5 g/m^3, cent per cent mortality was obtained for both the products. There was significant difference between the products at the doses 1.5 and 3.0 g/m^3.

Table 22. Effect of different food products on the susceptibility of the egg stage of *Callosobruchus chinensis* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No.of adults emerging from: Treated material	Control	Percentage reduction of adult emergence	Mean No.of adults emerging from: Treated material	Control	Percentage reduction of adult emergence	Mean No.of adults emerging from: Treated material	Control	Percentage reduction of adult emergence
Green gram	27.33	100.33	72.76 (58.518)	9.00	98.33	90.85 (72.366)	0.00	101.33	100.00 (90.000)
Soy beans	22.33	108.33	79.38 (62.940)	0.00	132.33	100.00 (90.000)	0.00	111.00	100.00 (90.000)

C.D. : Dose 0.5934
Product 0.4345

(Figures within parentheses are angular values)

Table 23. Effect of different food products on susceptibility of the larval stage of *Callosobruchus chinensis* to phosphine fumigation.

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Green gram	6.33	135.33	95.32 (77.695)	0.00	131.00	100.00 (90.000)	0.00	120.66	100.00 (90.000)
Soy beans	1.66	122.33	98.64 (83.904)	0.00	132.33	100.00 (90.000)	0.00	111.00	100.00 (90.000)

C.D. : Dose 1.219
Product 0.006

(Figures within parentheses are angular values)

Table 24. Effect of different food products on susceptibility of the pupal stage of *Callosobruchus chinensis* to phosphine fumigation

Dose (g/m^3)	1.5			3.0			4.5		
Products	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Green gram	12.33	142.66	91.36 (72.849)	0.00	139.66	100.00 (90.000)	0.00	130.66	100.00 (90.000)
Soy beans	5.66	130.33	95.65 (78.750)	0.00	130.00	100.00 (90.000)	0.00	127.00	100.00 (90.000)

C.D. : Dose 0.3928
Product 0.3207

(Figures within parentheses are angular values)

Fig. 8 and 9 Effect of aluminium phosphide on the life stages of storage pest when treated at a dosage of 1.5 g/m^3

Fig. 8 Araecerus fasciculatus

Fig. 9 Callosobruchus chinensis

FIG. 8. Aracerus fasciculatus

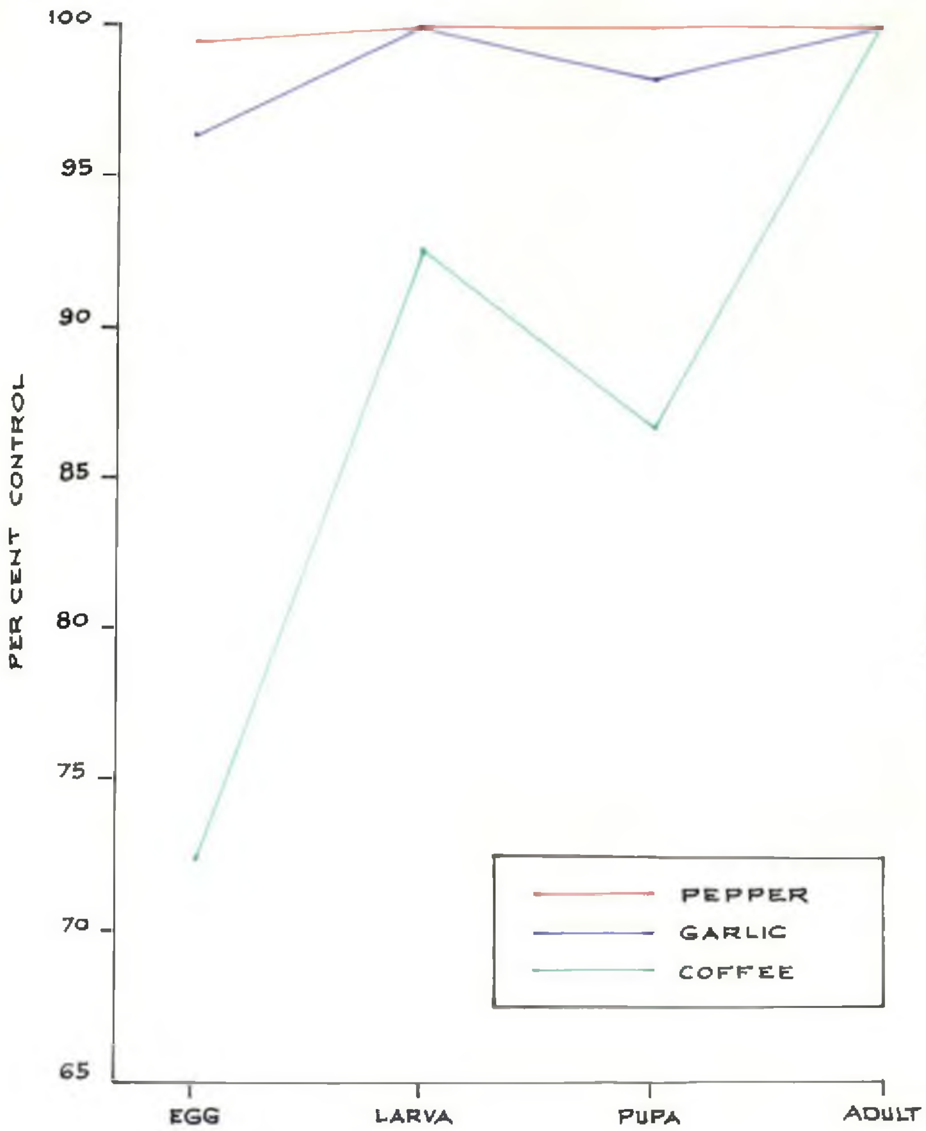
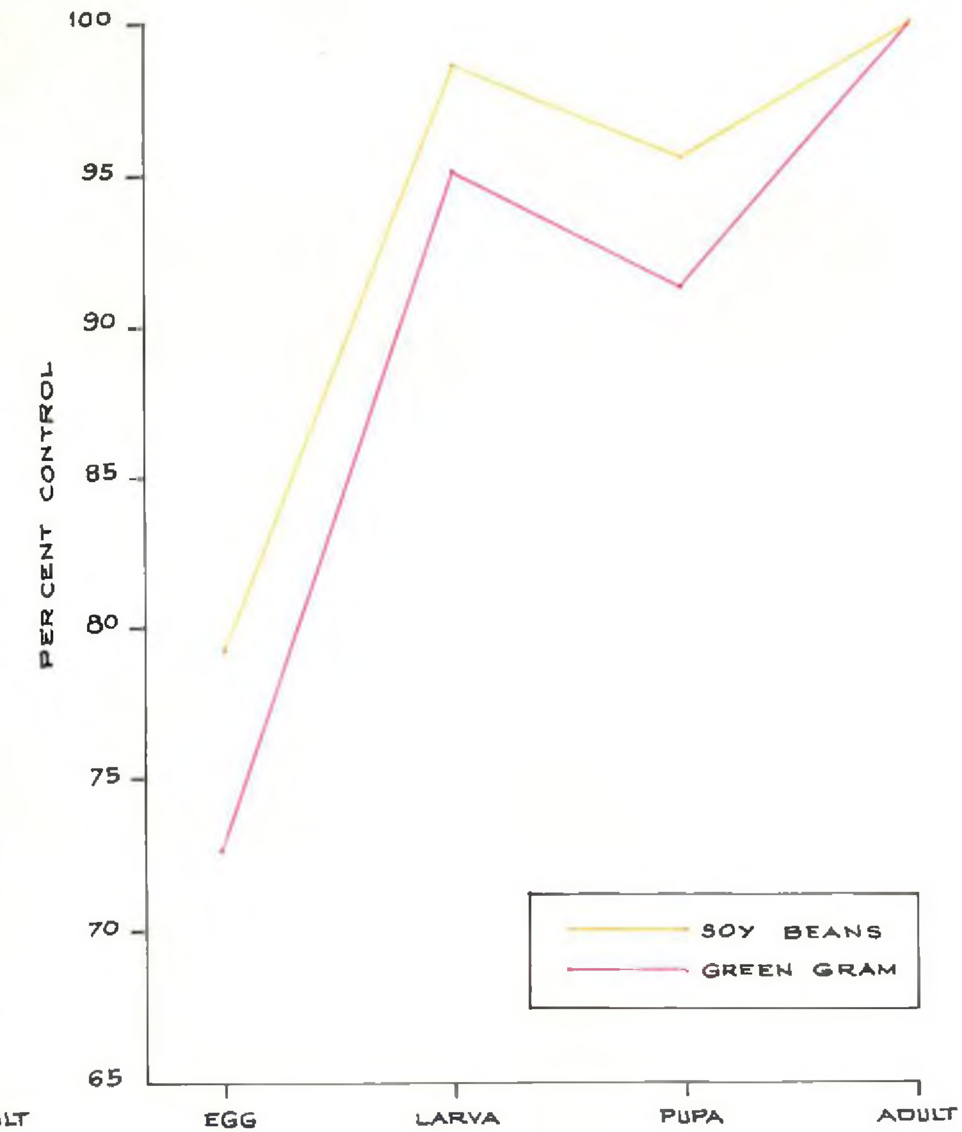


FIG. 9. Callosobruchus chinensis



Larval stage: Though there was variation in percentage reduction (95.32 to 98.64%) of larval stage of C. chinensis (Table 23) to the fumigant in green gram and soy beans, at the lowest dose, no variation could be seen at the higher doses of 3.0 and 4.5 g/m^3, where cent per cent reduction in adult emergence was seen. There was significant difference between the products and the doses 1.5 and 3.0 g/m^3. The doses 3.0 and 4.5 g/m^3 were found to be on par.

Pupal stage: It could be observed from Table 24 that the percentage reductions on pupal stage of C. chinensis in green gram and soy beans at the dose 1.5 g/m^3 were 91.36 and 95.65 respectively. The products at the higher two doses showed cent per cent mortality. Statistical analysis of the data revealed that the dose 1.5 g/m^3 was significantly inferior to 3.0 g/m^3 for the products and there was significant difference between the products also at 1.5 g/m^3.

Adult stage: All the three doses produced cent per cent mortality of the adults of C. chinensis in green gram and soy beans.

Control of Lasioderma serricorne in cumin due to effect of phosphine on different life stages.

L. serricorne was reared on cumin and the response of the fumigant on the life stages of the insect was studied.

Table 25. Effect of aluminium phosphide on the life stages of *Lasioderma serricorne* reared on cumin

Dose (g/m^3)	1.5			3.0			4.5		
Life stages of the insect	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence	Mean No. of adults emerging from		Percentage reduction of adult emergence
	Treated material	Control		Treated material	Control		Treated material	Control	
Egg	34.33	133.33	74.25 (59.472)	0.33	130.00	92.05 (73.570)	0.00	137.00	100.00 (90.000)
Larva	16.00	135.33	88.18 (69.820)	0.00	110.33	100.00 (90.000)	0.00	127.33	100.00 (90.000)
Pupa	21.33	122.00	82.51 (65.275)	0.00	123.00	100.00 (90.000)	0.00	123.66	100.00 (90.000)
Adult	0.00	100.00	100.00 (90.000)	0.00	100.00	100.00 (90.000)	0.00	100.00	100.00 (90.000)

C.D. : Egg, Larva, Pupa, Adult } 2.008

(Figures within parentheses are angular values

Egg stage: From Table 25 it could be seen that the percentage reduction in adult emergence varied from 74.25 to 100.00 at the 3 doses. The highest percentage reduction was at the dose 4.5 g/m^3 showing 100 per cent mortality. At 1.5 and 3.0 g/m^3 the percentage reductions were 74.25 and 92.05 respectively. The three doses were found to be significantly different from each other in their effect on the percentage reduction in adult emergence from the egg stage.

Larval stage: It could be observed that the percentage reduction in adult emergence at 1.5 g/m^3 was 88.18. But at 3.0 and 4.5 g/m^3 cent per cent mortality was observed. The higher doses were on par which varied significantly from the lowest dose of 1.5 g/m^3.

Pupal stage: Percentage reduction in pupal stage of *L. serricorne* at the lowest dose of 1.5 g/m^3 was 82.51. Cent per cent mortality was obtained at the higher doses of 3.0 and 4.5 g/m^3. The dose of 1.5 g/m^3 was found to be significantly inferior to the higher doses.

Adult stage: Absolute reduction was observed at the three doses of 1.5, 3.0 and 4.5 g/m^3 when the adults were exposed to phosphine.

Control of *Corcyra cephalonica* in rice flour due to effect of phosphine on different life stages.

The insect reared on rice flour was used for studying the effect of the fumigant on different life stages of the insect (Table 26).

Table 26. Effect of aluminium phosphide on the life stages of *Corcyra cephalonica* reared on rice flour.

Dose (g/m^3)	1.5			3.0			4.5		
Life stages of the insect	Mean No. of adults emerging from: Treated material	Control	Percentage reduction of adult emergence	Mean No. of adults emerging from: Treated material	Control	Percentage reduction of adult emergence	Mean No. of adults emerging from: Treated material	Control	Percentage reduction of adult emergence
Egg	16.00	140.33	88.59 (70.180)	2.33	139.00	98.32 (82.587)	0.00	139.66	100.00 (90.000)
Larva	0.00	86.00	100.00 (90.000)	0.00	84.66	100.00 (90.000)	0.00	121.66	100.00 (90.000)
Pupa	14.33	144.66	90.09 (71.570)	0.00	110.33	100.00 (90.000)	0.00	111.66	100.00 (90.000)
Adult	0.00	80.00	100.00 (90.000)	0.00	80.00	100.00 (90.000)	0.00	80.00	100.00 (90.000)

C.D. : Egg, Larva, Pupa, Adult 0.417

(Figures within parenthesis are angular values)

Egg stage: The percentage reduction in the adult emergence of *C. cephalonica* at the lowest dosage of 1.5 g/m^3 was 88.59. It became 98.32 when the dose was increased to 3.0 g/m^3. Cent per cent reduction was obtained at the highest dose of 4.5 g/m^3.

Larval stage: For the larval stage, all the three doses of 1.5, 3.0 and 4.5 g/m^3 were found to be on par showing cent per cent mortality.

Pupal stage: It could be observed that the percentage reduction at the dose of 1.5 g/m^3 was 90.09 with a cent per cent reduction in 3.0 and 4.5 g/m^3 which differed significantly from the lowest dose in their response.

Adult stage: Cent per cent mortality was observed for the adults of *C. cephalonica* at all the three doses.

III Residues of phosphine in different food commodities fumigated with aluminium phosphide.

Phosphine residues were estimated in the commodities fumigated with aluminium phosphide at the highest dose of 4.5 g/m^3 exposed for 3 days and aerated for 48 hours. The amount of residues in the commodities were estimated from the regression equation $y = (0.098x - 0.0145) \times 1.097$. The sensitivity of the minimum level of detectability of phosphine was found to be 0.0017 ppm. The data presented in Table 27 reveal that in semolina and noodles, the residues were below detectable levels. In wheat flour, maida and rice flour the residues of phosphine were 0.0031, 0.0026 and 0.0029 ppm.

Table 27. Residues of phosphine in different food commodities fumigated with aluminium phosphide @ 4.5 g/m^3 for a period of 3 days and aerated for 48 hours

Commodity	Phosphine residue (ppm)
Semolina	BDL
Noodles	BDL
Maida	0.0026
Rice flour	0.0029
Wheat flour	0.0031
Cattle feed	0.0032
Rice	0.0034
Dhal	0.0042
Green gram	0.0049
Gram flour	0.0053
Soy bean	0.0059
Tea	0.0072
Coffee	0.0079
Cocoa powder	0.0081
Cumin	0.0082
Garlic	0.0089
Pepper	0.0091

The residues to the extent of 0.0032 ppm in cattle feed and 0.0034 in rice could be tetected. Higher residues could be recorded on soy bean (0.0059 ppm), gram flour (0.0053 ppm), green gram (0.0049 ppm) and dhal (0.0042 ppm). In the beverages cocoa powder, tea and coffee a slightly higher residues could be detected viz. 0.0081, 0.0072 and 0.0079 ppm respectively. But the maximum residues were seen on the spices, pepper (0.0091 ppm), garlic (0.0089 ppm) and cumin (0.0082 ppm).

IV <u>Effect of phosphine fumigation on organoleptic qualities of food products</u>.

The general acceptability of the different food materials fumigated with aluminium phosphide in comparison to non-fumigated materials are given in Tables 28 to 32.

Table 28. General acceptability of the preparations of wheat flour under fumigated and non-fumigated conditions

Methods of processing	Acceptability score	
	Fumigated	Non-fumigated
Boiling (Infant food)	83.0	84.5
Frying (Chappathi)	93.0	94.5

In the case of wheat flour, (Table 28) in the boiled preparation (infant food) the variation in acceptability score was 83.0 for fumigated and 84.5 for non-fumigated; for the fried preparation it was 93.0 and 94.5 respectively.

Table 29. General acceptability of the preparations of semolina under fumigated and non-fumigated conditions.

Methods of processing	Acceptability score	
	Fumigated	Non-fumigated
Boiling (Porridge)	100.0	100.5
Frying (Upma)	108.5	110.0

For semolina (Table 29) in boiled preparation the scores were 100.0 and 100.5 for fumigated and non-fumigated samples and in the fried preparation the scores for fumigated and non-fumigated were 108.5 and 110.0 respectively.

Table 30. General acceptability of the preparations of rice flour under fumigated and non-fumigated conditions

Methods of processing	Acceptability score	
	Fumigated	Non-fumigated
Steaming (Puttu)	99.5	97.0
Steaming (Kozhukkatta)	106.5	107.5

In the case of rice flour the acceptability scores for the steamed products (Puttu and Kozhukkatta) were 99.5 and 106.5 for the fumigated and 97.0 and 107.5 for non-fumigated ones respectively (Table 30).

Table 31. General acceptability of the preparations of maida under fumigated and non-fumigated conditions

Methods of processing	Acceptability score	
	Fumigated	Non-fumigated
Steaming (Pudding)	91.0	91.5
Frying (Pancake)	111.0	111.5

In maida the score for the fumigated steamed product viz. pudding was 91.0 whereas it was 91.5 for non-fumigated product; in the fried preparation (pancake) the scores were 111.0 and 111.5 for the fumigated and non-fumigated products respectively (Table 31).

Table 32. General acceptability of beverages under fumigated and non-fumigated conditions

Method of processing	Acceptability score	
	Fumigated	Non-fumigated
<u>Boiling</u>		
Coffee	94.0	95.0
Tea	94.0	97.0
Cocoa powder	87.0	88.0

The acceptability score for the beverages viz. coffee, tea and cocoa powder given in Table 32 revealed that for fumigated coffee it was 94.0 and for non-fumigated 95.0. In tea and cocoa powder the acceptability scores for the fumigated products were 94.0 and 87.0 and for non-fumigated products they were 97.0 and 88.0 respectively.

DISCUSSION

DISCUSSION

Fumigation with phosphine using aluminium phosphide has been recognized as a safe and easy method in the storage, for controlling insects not only of agricultural products like cereals, pulses and spices but also of the various processed products. Before recommending phosphine fumigation it is necessary to examine the method from the various relevent angles. The present work has such a theme and covers various stored products and their insect pests. The factors studied were bio-efficacy of the fumigant in controlling the pests in various food products, the relative susceptibility of the different stages of the insects reared in different commodities to toxicity of the fumigant, residues left in the products after fumigation and effect of fumigation on the organoleptic qualities of the materials.

As regards the bio-efficacy of the fumigant in controlling the infestation in the different products, a dose of 3.0 g/m^3 was found sufficient for getting effective control of the pests. The efficacy of the fumigant to the insect in different products showed variations. Mortality of T. castaneum at the dose of 3.0 g/m^3 varied from 97.53 to 100.00 per cent in the seven products tried, of S. oryzae from 99.00 to 99.48 per cent in three products of A. fasciculatus from 98.67 to 100.00 per cent in three products and of *C. chinensis* from 98.91 to 100.00 per cent in two commodities. In *C. cephalonica* also 100 per cent mortality was observed at 3 g/m^3 but in *L. serricorne* reared on cumin only 92.24 per cent mortality was observed at this dose.

A comparative assessment of the percentage control of the different species of insects showed that the toxicity was to a great extent depending upon the food media in which the insects were reared and also on the dosage of the fumigant. The variation in the degree of susceptibility of the different species could be due to the nutritional status of the different media on which they were reared. That the susceptibility of insects to insecticide toxicity is substantially influenced by variations in their food, has been reported by various workers like Devaraj Urs and Mookherjee (1967), Rattan Lal and Attri (1967), Baskaran and Mookherjee (1971) and Murthy and Srivastava (1971).

Results of the studies have also indicated that the different stages of the insects responded differently to the toxicity of the fumigant, the adults invariably being the most susceptible in all the species under study, this being so even at the lowest dose of 1.5 g/m^3 of the fumigant. The other life stages viz. egg, larva and pupa were less susceptible, the eggs being least susceptible, the larvae being most susceptible and pupae were of intermediate susceptibility. Varying susceptibility of different life stages of insects might be due to variation in the uptake of the fumigant as suggested by Bond (1980). He observed that mature larvae and adults absorbed 2 to 3 times as much phosphine as pupae at all concentrations tested and mortalities were appreciably higher in the former stages. Sun (1947) reported that insects in inactive stages were relatively resistant to the effect of the fumigant because of the reduction in the respiratory activity. Vincent and Lindgren (1972), Barbera et al. (1976) and Bell (1976) also reported similar findings.

With a view to understanding how the susceptibility of the life stages of the insects to phosphine is related to the overall control of insect infestation in the different food media a comparison of the relevant data at the dose 1.5 g/m^3 was made. The lowest dose of 1.5 g/m^3 was selected for this comparative study since the effect of different products as well as of different stages of the insects was clearly differentiated at this dose only.

In the case of T. castaneum least control of the pest was in evidence in wheat flour and maida (Table 7). Correspondingly low toxicity of the fumigant was seen in egg, larvae and pupae reared on these two commodities. On the highest level of bio-efficacy also the similar relations were observed. Thus when control of the insect infestation was absolute in cocoa powder and tea, the mortalities of the eggs, larvae and pupae also were highest in these products, the overall picture in this case was that as the control of T. castaneum infesting seven products varied from 92.49 to 100 per cent, the mortality of the eggs varied from 78.29 to 99.29, of larvae from 97.59 to 100.00 and of pupae from 93.29 to 100.00 per cent (Tables 13 to 15).

Reduced mortality observed in wheat flour and maida may be related to such factors as high fat / water or higher surface area which favour adsorption of phosphine by the fumigated food stuffs as mentioned by Kroller (1968). In the case of the two beverages, cocoa powder and tea, cent per cent control was observed even at the lowest dose of 1.5 g/m^3 which was in accordance with the results obtained by Qureshi (1967) and Mejule and Onyuike (1980) who observed 100 per cent mortality of the insects even at a lower dose of 0.6 g/m^3. The intermediary control of T. castaneum in semolina and noodles may be due to the reduced surface area of the commodities and easy penetration of the gas resulting in more mortality of the insects. In the case of gram flour the binding of phosphine by the protein content of the commodity may be the reason for not getting 100 per cent mortality as reported by Dhaliwal and Rattan Lal (1974).

With _S. oryzae_ similar relations as observed with _T. castaneum_ in different products were seen. Thus, as control of the infestation by the insect in the three products varied from 93.09 to 97.00 per cent (Table 8) there was corresponding variation of 73.55 to 74.81 per cent mortality in eggs (Table 16), 85.06 to 86.98 per cent mortality in larvae (Table 17) and 76.00 to 78.05 per cent in pupae. In the case of pupae, however, the highest mortality (78.05%) was seen in rice in which the infestation control was the least (93.09%) (Table 18).

The control of infestation by _A. fasciculatus_ in three was positively correlated with susceptibility of the life stages of phosphine fumigation. Thus as infestation control varied from 92.07 to 100.00 per cent in three materials (Table 9) the corresponding variation in susceptibility to the fumigant were 72.67 to 99.61 per cent in egg, 92.86 to 100.00 per cent in larvae and 86.79 to 100.00 per cent in pupae (Tables 19 to 21). Similar positive correlations were in evidence with _C. chinensis_ also on two pulses (Table 10).

The residue data (Table 27) of phosphine estimated from the different food commodities fumigated with aluminium phosphide at 4.5 g/m^3 for a period of 3 days revealed that the residues were below the tolerance limit of 0.01 ppm in all the commodities. The residues were below detectable limit in semolina and noodles. The lowest range of residues were seen in maida, rice flour and wheat flour (0.0026 - 0.0031 ppm) followed by cattle feed and rice (0.0032 and 0.0034 ppm). Similar results were obtained by Kalkan and Tunca (1973) and Vardell et al. (1973) for wheat flour. In soya bean, gram flour, green gram and dhal, the residue level was slightly higher to the tune of 0.0042 to 0.0059 ppm. The reason for the more residues in these commodities might be due to the protein content of the commodity as the substrates rich in protein are known to have greater affinity for phosphine than those low in protein content as explained by Dhaliwal and Rattan Lal (1974).

In the beverages the residues were found to vary from 0.0072 to 0.0081 ppm. Similar findings are reported by Sullivan and Murphy (1966) for cocoa and coffee beans and Mohammed (1982) for tea.

Maximum residues were detected in the spices to the tune of 0.0082 to 0.0091 ppm. This may be due to the presence of oleoresins and similar components in these spices.

In general the differential level of residues of phosphine in these commodities may be attributed to the chemical composition of the commodities like protein (grams), oleoresins (spices), alkaloids (beverages) and fat. The adsorption of phosphine with protein and mineral components of the substrates have been investigated by Berck (1968) and adsorption by moisture and fat contents in the food materials by Kroller (1968).

The effect of fumigation with phosphine on the organoleptic qualities of the food products was assessed by testing the general acceptability of the different food materials fumigated in comparison to non-fumigated. As evidenced by the acceptability score, there was no perceptible difference among the boiled and fried preparations of wheat flour and semolina, fumigated or non-fumigated (Tables 28 and 29). Similarly in the case of rice flour the preparations made by steaming and in maida by steaming and frying, the difference in the acceptability score was quite negligible. Even in the case of all beverages a similar trend was seen. Observations made by Neizert (1953) and Lindgren <u>et al</u>.(1958) showed that fumigation of wheat with phosphine under normal conditions had no adverse effect on the baking quality of the flour made from it. Thus it can be concluded that under the recommended doses phosphine does not affect the organoleptic qualities of the food commodities.

Thus it can be conclusively stated that aluminium phosphide which has gained worldwide acceptance as a source of phosphine for effective fumigation of cereals, grains, pulses and other agricultural commodities can be safely recommended for fumigation against the storage pests. The results uniformly indicating negligible residues below the tolerant limit of 0.01 ppm in the fumigated materials indicate the suitability of phosphine as a fumigant for control of pests of processed foods and feeds as well as in raw agricultural commodities.

SUMMARY

SUMMARY

The bio-efficacy of aluminium phosphide in controlling the different species of insects infesting stored wheat flour, maida, rice flour, rice, semolina, noodles, cattle feed, gram flour, soy beans, green gram, dhal, coffee, tea, cocoa powder, garlic, pepper and cumin was determined when used at 3 doses of 1.5, 3.0 and 4.5 g/m^3. After fumigation for 3 days the treated commodities were incubated for periods depending upon the life cycle of the various insects. Out of the three doses tried the middle dose of 3.0 g/m^3 was found to be adequate for the effective control of the pests. It was found that toxicity of the fumigant was to a certain extent affected by the food media in which the insects were reared.

The relative susceptibility of different stages of insects to aluminium phosphide in different commodities at doses of 1.5, 3.0 and 4.5 g/m^3 with an exposure period of 3 days was also studied. Results of the studies have revealed that the different stages of the insects responded differently to the toxicity of the fumigant. The adults of all the species of insects in all the products were highly susceptible and there was cent per cent mortality even at the lowest dose of 1.5 g/m^3 of the fumigant.

The other life stages, egg, larva and pupa showed lower susceptibility than the adults, the egg showing the least susceptibility followed by pupae and larvae in that order. Depending upon the stage, the dose required for the complete control of the pests was also found to vary. The high dose was necessary for the elimination of the egg stage and at these higher doses the other life stages of the insects in all the commodities had shown complete mortality. The percentage control of T. castaneum infesting seven food commodities varied from 92.49 to 100.00; the mortality of the egg ranged from 78.29 to 99.29 per cent, of larvae from 97.59 to 100.00 and of pupae from 93.29 to 100.00 per cent at the dose of 1.5 g/m^3. Same response was observed for S. oryzae in three different products; the control of infestation of the insect in three products ranged from 93.09 to 97.00 per cent. In egg stage, the variation in mortality was from 73.55 to 74.81 per cent, for larvae 85.06 to 86.98 per cent and for pupae from 76.00 to 78.05 per cent at the lowest dose of 1.5 g/m^3. Similar results were obtained for A. fasciculatus in three products in which the percentage control varied from 92.07 to 100.00 per cent at the dose of 1.5 g/m^3. In Callosobruchus chinensis in pulses, Corcyra cephalonica in rice flour and Lasioderma serricorne in cumin also egg stage was the most resistant.

The residues of phosphine in the commodities due to fumigation with aluminium phosphide at the dose of 4.5 g/m^3 with an exposure period of 3 days were estimated after an aeration period of 48 hours, by colorimetric method. The residues were below detectable level in semolina and noodles. The residues of phosphine in wheat flour, maida and rice flour were 0.0031, 0.0026 and 0.0029 ppm respectively. In cattle feed and rice the residues were 0.0032 and 0.0034 ppm. Higher residues could be observed in soy bean (0.0059 ppm), gram flour (0.0053 ppm), green gram (0.0049 ppm) and dhal (0.0042 ppm). In the beverages coffee, tea and cocoa the residues were 0.0079, 0.0072 and 0.0081 ppm respectively. The highest residues were in the spices, pepper (0.0091 ppm), garlic (0.0089 ppm) and cumin (0.0082 ppm).

Organoleptic studies were made to find out whether fumigation with phosphine affected the taste, colour, appearance, texture, flavour, etc. of the food products. Based on acceptability score, it was concluded that there was no perceptible difference among the boiled and fried preparations of wheat flour and semolina between fumigated and non-fumigated materials. In rice flour (steaming), maida (steaming and frying) and beverages (boiling) also similar results were obtained.

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(* Original not seen.)

APPENDICES

Appendix I.

Recovery percentage of fortified samples of different commodities treated with aluminium phosphide.

Sample	Recovery %
Semolina	83.71
Noodles	81.45
Maida	83.72
Rice flour	86.20
Wheat flour	83.71
Cattle feed	76.24
Rice	83.64
Dhal	81.45
Green gram	78.29
Gram flour	79.62
Soy bean	76.35
Tea	78.08
Coffee	71.74
Cocoa powder	74.08
Cumin	78.62
Garlic	73.53
Pepper	74.08

APPENDIX II

Abstracts of the analysis of variance on the effect of aluminium phosphide on control of storage pests infesting different food products (Tables 7 to 12).

Table 7. Effect of aluminium phosphide on the control of *Tribolium castaneum*

Source	df	Mean SS
Dose	2	112.040*
Product	6	14.718**
D x P	12	8.351
Error	42	1.247

Table 8. Effect of aluminium phosphide on the control of *Sitophilus oryzae*

Source	df	Mean SS
Dose	2	55.630**
Product	2	4.230*
D x P	4	4.201
Error	18	0.276

Table 9. Effect of aluminium phosphide on the control of *Araecerus fasciculatus*

Source	df	Mean SS
Dose	2	46.750*
Product	2	17.025*
D x P	4	11.185
Error	18	0.5994

Table 10. Effect of aluminium phosphide on the control of *Callosobruchus chinensis*

Source	df	Mean SS
Dose	2	21.030**
Product	1	8.990**
D x P	2	3.840**
Error	12	0.0339

APPENDIX II (Contd.)

Table 11. Effect of aluminium phosphide on the control of *Lasioderma serricorne* on cumin

Source	df	Mean SS
Dose	2	0.156
Error	6	34.718

Table 12. Effect of aluminium phosphide on the control of *Corcyra cephalonica* on rice flour

Source	df	Mean SS
Dose	2	0.056
Error	6	1.456

* Significant at 5% level

** Significant at 1% level

APPENDIX III

Abstracts of analysis of variance on the effect of different food products on susceptibility of different stages of *Tribolium castaneum* to phosphine fumigation (Tables 13 to 15).

Table 13. Effect on the susceptibility of the egg stage

Source	df	Mean SS
Dose	2	1499.140**
Product	6	229.535**
D x P	12	113.009**
Error	42	3.143

Table 14. Effect on the susceptibility of the larval stage

Source	df	Mean SS
Dose	2	132.245*
Product	6	14.143*
D x P	12	14.147
Error	42	157.470

Table 15. Effect on the susceptibility of the pupal stage

Source	df	Mean SS
Dose	2	263.845**
Product	6	100.588*
D x P	12	43.405**
Error	42	0.316

* Significant at 5% level

** Significant at 1% level

APPENDIX IV

Abstracts of analysis of variance on the effect of different food products on susceptibility of different stages of Sitophilus oryzae to phosphine fumigation (Table 16 to 18).

Table 16. Effect on the susceptibility of the egg stage

Source	df	Mean SS
Dose	2	2129.150**
Product	2	97.550*
D x P	4	12.750
Error	18	0.219

Table 17. Effect on the susceptibility of the larval stage

Source	df	Mean SS
Dose	2	1159.870**
Product	2	4.055
D x P	4	1.910
Error	18	398.460

Table 18. Effect on the susceptibility of the pupal stage

Source	df	Mean SS
Dose	2	1942.520**
Product	2	23.400
D x P	4	28.670
Error	18	146.270

* Significant at 5% level

** Significant at 1% level

APPENDIX V

Abstracts of analysis of variance on the effect of different food products on the susceptibility of different stages of *Araecerus fasciculatus* to phosphine fumigation (Table 19 to 21).

Table 19. Effect on the susceptibility of the egg stage

Source	df	Mean SS
Dose	2	652.17**
Product	2	530.17**
D x P	4	733.23**
Error	18	31.57

Table 20. Effect on the susceptibility of the larval stage

Source	df	Mean SS
Dose	2	80.320*
Product	2	80.320*
D x P	4	80.245*
Error	18	0.059

Table 21. Effect on the susceptibility of the pupal stage

Source	df	Mean SS
Dose	2	261.455**
Product	2	112.150*
D x P	4	112.150**
Error	18	0.232

* Significant at 5% level

** Significant at 1% level

APPENDIX VI

Abstracts of analysis of variance on the effect of different food products on the susceptibility of different stages of *Callosobruchus chinensis* to phosphine fumigation (Tables 22 to 24).

Table 22. Effect on the susceptibility of the egg stage

Source	df	Mean SS
Dose	2	1334.415**
Product	1	236.320**
D x P	2	127.220**
Error	12	0.2225

Table 23. Effect on the susceptibility of the larval stage

Source	df	Mean SS
Dose	2	1691.49**
Product	1	8.53*
D x P	2	8.525
Error	12	1386.89

Table 24. Effect on the susceptibility of the pupal stage

Source	df	Mean SS
Dose	2	424.18**
Product	1	13.075*
D x P	2	13.075*
Error	12	0.0975

* Significant at 5% level

** Significant at 1% level

APPENDIX VII

Abstract of analysis of variance on the effect of aluminium phosphide on the life stages of Lasioderma serricorne reared on cumin

Table 25. Effect on the life stages of Lasioderma serricorne

Source	df	Mean SS
Egg	3	112.036**
Larva	3	131.918**
Pupa	3	127.750**
Adult	3	122.826**
Stages	3	12.003*
Error	56	6.051

* Significant at 5% level

** Significant at 1% level

APPENDIX VIII

Abstract of analysis of variance on the effect of aluminium phosphide on the life stages of Corcyra cephalonica reared on rice flour

Table 26. Effect on the life stages of Corcyra cephalonica

Source	df	Mean SS
Egg	3	139.186**
Larva	3	120.631**
Pupa	3	135.051**
Adult	3	104.583**
Stages	3	12.246
Error	56	0.499

* Significant at 5% level

** Significant at 1% level

RESIDUE PROBLEMS IN THE CONTROL OF INSECT PESTS IN PROCESSED FOOD COMMODITIES USING ALUMINIUM PHOSPHIDE

REMA DEVI, K.

ABSTRACT OF A THESIS
SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN AGRICULTURE
(ENTOMOLOGY)
FACULTY OF AGRICULTURE
KERALA AGRICULTURAL UNIVERSITY

DEPARTMENT OF ENTOMOLOGY
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM

1984

ABSTRACT

Investigations were carried out to determine the bio-efficacy of fumigation with aluminium phosphide in controlling different species of insects feeding on stored wheat flour, maida, rice flour, rice, semolina, noodles, cattle feed, gram flour, soy beans, green gram, dhal, coffee, tea, cocoa powder, garlic, pepper and cumin under laboratory conditions at the doses 1.5, 3.0 and 4.5 g/m^3 with an exposure period of 3 days. Studies revealed that the dose of 3.0 g/m^3 was suitable for effective control of the pests and that the toxicity of the fumigant depended upon the media in which the insects were reared.

Studies conducted on the relative susceptibility of different stages of insects feeding on different food commodities at the 3 doses revealed that adult stage was highly susceptible showing cent per cent mortality even at the lowest dose of 1.5 g/m^3. The egg stage of all the species in all the commodities was relatively resistant to the fumigant followed by pupae, larvae and adults in that descending order. The dose required for the elimination of the different life stages of different insects in different commodities varied depending upon the stage. Thus the percentage control of *T. castaneum* infesting

seven food commodities varied from 92.49 to 100.00 per cent; the percentage mortality of the egg ranged from 78.29 to 99.29, of larvae from 97.59 to 100.00 and of pupae from 93.29 to 100.00 per cent at the lowest dose of 1.5 g/m^3. S. oryzae also, in three different products showed the same response where the percentage control varied from 93.09 to 97.00. In egg stage the variation in mortality was from 73.55 to 74.81 per cent, in larvae 85.06 to 86.98 per cent and in pupae the variation was from 76.00 to 78.05 per cent at the dose of 1.5 g/m^3. Similar results were obtained for A. fasciculatus in three products, C. chinensis on pulses, C. cephalonica on rice flour and L. serricorne on cumin.

The residues of phosphine resulting from a treatment dose of 4.5 g/m^3 of aluminium phosphide in different food commodities were far below the tolerance level of 0.01 ppm after an aeration period of 48 hours. The residues were below detectable level in semolina and noodles, followed by maida (0.0026 ppm), rice flour (0.0029 ppm), wheat flour (0.0031 ppm), cattle feed (0.0032 ppm), rice (0.0034 ppm), dhal (0.0042 ppm), green gram (0.0049 ppm), gram flour (0.0053 ppm), soy bean (0.0059 ppm), tea (0.0072 ppm), coffee (0.0079 ppm) and cocoa powder (0.0081 ppm). The highest residues were for spices, cumin (0.0082 ppm), garlic (0.0089 ppm) and pepper (0.0091 ppm).

The effect of fumigation with phosphine on the organoleptic qualities of the food products was assessed by testing the general acceptability of the different food materials fumigated in comparison to non-fumigated. As evidenced by the acceptability score, the difference between the fumigated and non-fumigated products was quite negligible.

It is concluded that phosphine can be used as a fumigant to control insect infestation in the stored products under study without risk of toxic residues and loss of organoleptic qualities.