14. INSECT PESTS OF STORED MAIZE AND THEIR CONTROL

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Maize is a food which is rich in nutrition for both human beings and insects. For example, you will feed any two groups of rice weevils under identical conditions, one with rice and the other with maize. You will then notice that the maize-fed weevils grow much bigger than the rice-fed one.

Farmers as well as agricultural experts are apt to overlook the harm done to their crops by insect pests after they are stored away although they are very sensitive to the control of insect pests in the field. More often than not the loss of their crops while they are in storage is regarded by the farmers as something beyond control. According to a Japanese survey, 5% of a cereal crop is normally lost because of insects while they are in storage and sometimes this loss amounts to as much as 10%. While in Thailand I was told that an about 10% of maize crop is eaten away monthly by insect pests swarming upon the grains while in storage. Of course, this information must be taken with some reservation. But there still is no doubt that the insect havoc on the maize crop in a tropical region where there is no marked seasonal rise or fall in temperature is much greater than in a temperate region.

For another thing, while growing crops are able to recover from injuries to some extent by its "compensatory ability", grains in storage are lacking in such ability and are left entirely at the mercy of insect pests one they are exposed to their attacks. Clear from all this is the fact that post-harvest control is economically important as the pre-harvest control.

Species and Behaviors of Insect Pests of Stored Maize

As many as 70 species of pests are reported in the world to infest stored maize. These are shown in the Table 1. But only 13 of these are considered as "Major pests" and two of the 13 breed only in the temperate zone. One of the two is the granary weevil whose habitat is in areas fit for wheat and barley farming and the other is the Mediterranean flour moth which is found only in some ill-equipped flour mills. Therefore, a total of 11 species constitute the major pests in temperate and tropical regions.

Table 1. The list of insect pests of stored maize in the world.

Acaridae

1. *Tyroglaphus dimidiatus* HERMANN
   - Common name: Common grain mite
   - Distribution: Cosmopolitan
   - Grade as pest: Minor pest

Trogiidae

2. *Trogium pulsatorium* LINNÉ
   - Common name: Flour booklouce

Distribution: Nearly cosmopolitan
Grade as pest: Minor pest

Tineidae

3. *Nemapogon granella* LINNÉ
   Common name: European grain moth
   Distribution: Europe, North Africa, Asia Minor, Japan, North America
   Grade as pest: Common pest
4. *Tinea misella* ZELLER
   Distribution: Europe, North America
   Grade as pest: Minor pest
5. *Tinea pallescentella* HAWORTH
   Distribution: Europe
   Grade as pest: Minor pest

Cosmopterygidae

6. *Pyroderces rileyi* WALSINGHAM
   Common name: Pink corn worm
   Distribution: Southern area of U.S.A., Mexico, Australia, Hawaii
   Grade as pest: Common pest

Oecophoridae

7. *Anchonoma xeraula* MEYRICK
   Common name: Grain worm
   Distribution: Japan
   Grade as pest: Minor pest
8. *Borkhausenia pseudospretella* STAINTON
   Common name: Seed moth
   Distribution: Europe, India, North America
   Grade as pest: Minor pest

Gelechiidae

9. *Sitotroga cerealella* OLIVIER
   Common name: Angoumois grain moth
   Distribution: Cosmopolitan
   Grade as pest: Major pest

Galleriidae

10. *Aphomia gularis* ZELLER
    Common name: Japanese grain moth
    Distribution: Europe, North America, China, Japan, India, Hawaii
    Grade as pest: Minor pest
11. *Corcyra cephalonica* STAINTON
    Common name: Rice moth
    Distribution: Cosmopolitan
    Grade as pest: Common pest

Phycitidae

12. *Anagasta kuehniella* ZELLER
    Common name: Mediterranean flour moth
    Distribution: Nearly cosmopolitan
    Grade as pest: Major pest
13. *Cadra cautella* WALKER
    Common name: Almond moth
    Distribution: Cosmopolitan
    Grade as pest: Common pest
14. *Ephestia figulilella* GREGSON

Common name: Fig moth
Distribution: Cosmopolitan
Grade as pest: Minor pest

15. *Mussidia nigrivenella* RAGONOT
Distribution: Africa
Grade as pest: Minor pest

16. *Plodia interpunctella* HÜBNER
Common name: Indian meal moth
Distribution: Cosmopolitan
Grade as pest: Major pest

Pyralididae

17. *Aglossa dimidiata* HAWORTH
Common name: Black rice worm
Distribution: Japan, China, India
Grade as pest: Minor pest

18. *Pyralis farinalis* LINNÉ
Common name: Meal moth
Distribution: Cosmopolitan
Grade as pest: Common pest

19. *Pyralis manihotalis* GUENÉE
Distribution: U.S.A. (Florida), West Indian Ils., Central America, South America, India, Japan
Grade as pest: Minor pest

20. *Pyralis pictalis* CURTIS
Distribution: India, Thailand, Cambodia, Laos, Vietnam
Grade as pest: Minor pest

21. *Thagora figurana* WALKER
Distribution: Indonesia
Grade as pest: Minor pest

Dermestidae

22. *Trogoderma granarium* EVERTS
Common name: Khapra beetle
Distribution: Europe, Africa, Asia, Australia, U.S.A.
Grade as pest: Major pest

23. *Trogoderma ornata* SAY
Distribution: North America
Grade as pest: Minor pest

24. *Trogoderma versicolor* CREUTZER
Common name: Larger cabinet beetle
Distribution: Nearly cosmopolitan
Grade as pest: Common pest

Thorictidae

25. *Thorictodes heydeni* REITTER
Distribution: Europe, East Indian Ils., Guiana, Sudan
Grade as pest: Incidental pest

Trogositidae (*Temnochilidae*)

26. *Lophocateres pusillus* KLUG
Common name: Siamese grain beetle
Distribution: Tropics and subtropics in the world, Southern area of U.S.A.
Grade as pest: Minor pest

27. *Tenebroides corticalis* MELSH.

Distribution: U.S.A., Mexico
Grade as pest: Incidental pest

28. *Tenebroides mauritanicus* LINNÉ
Common name: Cadelle
Distribution: Cosmopolitan
Grade as pest: Common pest

Nitidulidae

29. *Carpophilus dimidiatus* FABRICIUS
Common name: Corn sap beetle
Distribution: Europe, Africa, South Asia, Japan, North America
Grade as pest: Minor pest

30. *Carpophilus hemipterus* LINNÉ
Common name: Died fruit beetle
Distribution: Europe, Asia, North America, Australia
Grade as pest: Incidental pest

31. *Urophorus humeralis* FABRICIUS
Distribution: Tropical Africa, South Asia, Europe, Southern area of U.S.A.
Grade as pest: Minor pest

Silvanidae

32. *Ahasverus advena* WALTL
Common name: Foreign grain beetle
Distribution: Cosmopolitan
Grade as pest: Common pest

33. *Cathartus quadricollis* GUÉRIN
Common name: Square-necked grain beetle
Distribution: Europe, Africa, North America, Central America, South America
Grade as pest: Common pest

34. *Crypotolestes minutus* OLIVIER
Common name: Flat grain beetle
Distribution: Cosmopolitan
Grade as pest: Common pest

35. *Cryptolestes turcicus* GROUVELLE
Distribution: Cosmopolitan
Grade as pest: Common pest

36. *Cryptolestes ferrugineus* STEPHENS
Distribution: Africa, South Asia, Newguinea, Formosa, Germany
Grade as pest: Common pest

37. *Oryzaephilus surinamensis* LINNE
Common name: Saw-toothed grain beetle
Distribution: Cosmopolitan
Grade as pest: Major pest

38. *Oryzaephilus mercator* FAUVEL
Common name: Merchant grain beetle
Distribution: Cosmopolitan
Grade as pest: Major pest

Cryptophagidae

39. *Pharoxonotha kirschi* REITTER
Common name: Mexican grain beetle
Distribution: Guatemara, Mexico, U.S.A. (Texas, Illinoi), Germany
Grade as pest: Minor pest

Mycetophagidae

40. *Litargus balteatus* LECONTE
    Distribution: Central and North America, Hawaii, Germany, Australia
    Grade as pest: Minor pest

Murmidiidae

41. *Murmidius ovalis* BECK
    Distribution: Europe, Japan, Indonesia, North America
    Grade as pest: Minor pest

Lathridiidae

42. *Cartodere filum* AUBE
    Distribution: Europe, Argentina, North America
    Grade as pest: Incidental pest

Tenebrionidae

43. *Alphitobius diaperinus* PANZER
    Common name: Lesser mealworm
    Distribution: Cosmopolitan
    Grade as pest: Common pest
44. *Alphitobius piceus* OLIVIER
    Common name: Black fungus beetle
    Distribution: Cosmopolitan
    Grade as pest: Minor pest
45. *Gnathocerus cornutus* FABRICIUS
    Common name: Broad-horned flour beetle
    Distribution: Cosmopolitan
    Grade as pest: Minor pest but sometimes major pest
46. *Gnathocerus maxillosus* FABRICIUS
    Common name: Slender-horned flour beetle
    Distribution: Tropics and Subtropics in the world
    Grade as pest: Minor pest
47. *Gnocephalum hoffmannseggi* STEPHENS
    Distribution: Indonesia
    Grade as pest: Incidental pest
48. *Latheticus oryzae* WATERHOUSE
    Common name: Long-headed flour beetle
    Distribution: Cosmopolitan
    Grade as pest: Common pest
49. *Palorus ratzeburgii* WISSMANN
    Common name: Small-eyed flour beetle
    Distribution: Cosmopolitan
    Grade as pest: Common pest
50. *Palorus subdepressus* WOLLASTON
    Common name: Depressed flour beetle
    Distribution: Cosmopolitan
    Grade as pest: Minor pest
51. *Tenebrio molitor* LINNÉ
    Common name: Yellow mealworm
    Distribution: Cosmopolitan
    Grade as pest: Common pest
52. *Tenebrio obscurus* FABRICIUS
    Common name: Dark mealworm
    Distribution: Cosmopolitan

Grade as pest: Common pest

53. *Neatus picipes* HERBST
Common name: Bload dark mealworm
Distribution: Cosmopolitan
Grade as pest: Minor pest

54. *Tribolium castaneum* HERBST
Common name: Rust-red flour beetle
Distribution: Cosmopolitan
Grade as pest: Major pest

55. *Tribolium confusum* JACQUELIN *du* VAL
Common name: Confused flour beetle
Distribution: Cosmopolitan particularly tropics and subtropics
Grade as pest: Major pest

Bostrychidae

56. *Dinoderus bifoveolatus* WOLLASTON
Distribution: Europe, Africa, Central and South America, West Indies Ils., New-guinea, Malaysia
Grade as pest: Incidental pest

57. *Prostephanus truncatus* HORN
Common name: Larger grain borer
Distribution: U.S.A., Mexico, Guatemera, Brazil
Grade as pest: Incidental pest

58. *Rhizopertha dominica* FABRICIUS
Common name: Lesser grain borer
Distribution: Cosmopolitan
Grade as pest: Major pest

Anobiidae

59. *Cartorama zeae* WATERHOUSE
Distribution: England, Barbados
Grade as pest: Minor pest

60. *Lasioderma serricorne* FABRICIUS
Common name: Cigarette beetle
Distribution: Cosmopolitan
Grade as pest: Minor pest

61. *Stegobium paniceum* LINNÉ
Common name: Drug-store beetle
Distribution: Cosmopolitan
Grade as pest: Minor pest

Curculionidae

62. *Caulophilus latinasus* SAY
Common name: Broad-nosed grain weevil
Distribution: Europe, U.S.A. (Southern areas), Mexico, Central America, West Indies Ils., Madila
Grade as pest: Minor pest

Rhynchophoridae

63. *Sitophilus granarius* LINNÉ
Common name: Granary weevil
Distribution: Cosmopolitan (except tropics and subtropics)
Grade as pest: Major pest

64. *Sitophilus oryzae* LINNE
Common name: Small rice weevil

Distribution: Cosmopolitan
Grade as pest: Major pest

65. *Sitophilus zeamais* MOTSCHULSKY
Common name: Rice weevil
Distribution: Cosmopolitan
Grade as pest: Major pest

Anthribidae

66. *Araecerus fascicualatus* DEGEER
Common name: Coffee-bean weevil
Distribution: Cosmopolitan
Grade as pest: Minor pest, but in tropics, major pest

67. *Brachytarsus alternatus* SAY
Distribution: North America (East area)
Grade as pest: Minor pest

Scolytidae

68. *Pagiocerus frontalis* FABRICIUS
Distribution: Peru
Grade as pest: Minor pest

69. *Pagiocerus rimosus* EICHHOFF
Distribution: Mexico, Central and South America, Cuba
Grade as pest: Minor pest

70. *Pagiocerus zeae* EGGERS
Distribution: Colombia
Grade as pest: Minor pest

Insect pests of stored grains are roughly divided into the primary, the secondary and the tertiary categories. Defined as "primary pests" are those which directly attack intact grains in storage and eat the grain interior either from the outside or from the inside. Grouped as "secondary pests" are those which cannot infest intact grains until after the primary pests' invasion is well in progress or unless their feed are crushed, powdered or otherwise artificially processed. "Tertiary pests" are of the kind that feed on what remains, unfinished by primary and secondary pest. They also feed on the mold developing on the grains partially ingested by their "primary" and "secondary" brothers. Thus, there are three phases in the attack upon a heap of grains in storage. The first phase starts when "primary pests" launch their attack and the second phase is set when part of each grain's interior is eaten away to permit "secondary pests" to join in the attach. The third phase start both "primary" and "secondary" pests have done their part of the attack to let "tertiary pests" finish the grains along with scavengers which also feed on their bodies and excretions.

Angoumois grain moth has a nature to fly over to and oviposite, on a cereal crop about to be reaped or already heaped up to dry. The larval emerge from the eggs, bore into grains and live on until they pupate inside the grains. It can complete and further repeat its life cycle on the stored grains. It is easy to distinguish the infestation of this species from that of rice weevil or lesser grain borer, because the grains attacked by this insect are usually covered with what looks like a layer of fine dust and often strung together by twos and threes. The loss of maize caused by this pest is particularly damaging in Southeast Asia.

The Indian meal moth is also a pest no less important in that region. It severely damages not only maize but also rice crops. The larva of this insect makes it a habit to string several grains together and starts its attack with the grain's germ. It never ingests far into the grain core. At the time of pupation, the larva leaves the grains and forms a thin cocoon.

Of all the pests of maize crops in storage, the rice weevil and the small rice weevil are by far the most damaging. These two pests oviposite one at a time inside a grain by boring a tiny hole into the grains whenever laying an egg. In the cases of rice and wheat, the grains are normally large enough to permit only one larva to feed upon. But in the case of maize, one grain is large enough for three to four larvae to live on. Given an optimum temperature of 28°C to 29°C, the rice weevil completes its life cycle in a period of 23 to 30 days. As for the small rice weevil, the larva can complete its life cycle in 24 to 25 days provided that the temperature remains within the optimum 30°C to 35°C range. The life expectancy of the adults of both species is three months or longer. While the rice weevil can fly well, the small rice weevil rarely flies. The small rice weevil is gifted with a unique ability to develop heat by enhancing its population density whenever the temperature falls below the appropriate level. Both pests are in the habit of remaining in the dark part of the storage house for a while after their outbreak. Their route of invasion in the warehouse is upward from the bottom layer of the heap.

Among the insect pests of maize crops in the tropical regions, the lesser grain borer is second only to the rice weevil in terms of the capacity of working havoc. The adult deposites four to five eggs at a time among grains and the larva starts ingesting one as soon as it comes into being. The optimum temperature is 33 to 34°C and a period of about one month is needed for the larva to attain the stage of pupation. The pupa is formed while the larva is still inside its grain. As in the case of the small rice weevil, this insect has a tendency to produce heat at the height of its breeding period. The adult of this species flies well.

The coffee-bean weevil, as its name suggests, infests coffee-beans, but it is known as a serious menace to cacao crops in West Africa and as a major pest of nutmeg crops in India. It is also known as a pest of maize in the tropical areas. This insect deposits as many as 40 to 60 eggs at a time and the larva bores into a grain for habitation. The optimal growth temperature is 27°C. The greater the moisture content the grain is, the shorter is its life cycle, and a period of 50 days to 60 days is normally needed for the completion of life cycle in any tropical region.

Among the secondary pests of stored maize grains are the rust-red flour beetle and the confused flour beetle. The former frequently flies over a short distance but the latter never flies despite its well developed hind wing. Both species in their winged stage live for a rather long period of over a year. One female deposits eggs here and there and as many as 500 to 1,000 eggs, can be laid over the life time. The optimum temperature for the larval growth is 30°C and both species complete their life cycle in a period of about one moth. Both species are extremely omnivorous and feed not only on various cereal grains including maize but also on dried fruits and vegetables, copra and cacao nuts. Their adults have also a carnivorous nature.

Both the saw-toothed grain beetle and the merchant grain beetle enjoy a long life span in their adult. In one observation it was discovered that some adults of both species lived for as many as three years and three moths. The optimum temperature for their larval growth ranges from 27 to 30°C and their larval stage lasts for one to two months. The adults of both species deposite one egg at a place. Both species are of a highly omnivorous nature. They feed on cereals and cereal products, dried fruits and vegetables, cacao beans, leaf tobacco and sugar. They also prey on the young larvae of the rice weevil and the rust-red flour beetle as well as on each other.

The Khapra beetle has its origin in and around India. The optimum temperature for its larval growth varies from 32°C to 36°C. It has a range higher than that of any other insect pests of stored grains. In the optimal temperatures, the life cycle is about 50 days. In the unfavorable conditions, however, it requires over 200 days to complete its life. The larvae are extremely resistant to dry condition. It is reported that they could develop on malt and wheat grains of 2% moisture content. Further, its larvae were said to stay alive in fasted condition for several years, under low temperature. It is also well known that a marked rise occurs in the temperature of any portion of stored grains when infested with the larvae. The larvae, while young and unable to bore into a grain, be it maize or wheat, can only live on those grains which are previously infested with other insects or their seniors in and after the fourth instar. In case their grains lie in bulk, their thrust into that bulk rarely extends beyond the first 15 to 30 cm in depth and they tend to aggregate in a part near the floor. In India, this species is known as the most damaging pest to wheat crops although it plays havoc with maize and rice grains, as well. In Nigeria, Africa, it is a major pest to peanuts while in Europe and Australia where it does little damage to cereal grains, it causes extensive damage to malt in storage.

Pest Control Methods

No practical methods have yet been devised to secure stored grains against insect pests' infestation. For the time being, therefore, it is necessary to keep the storehouse in as unfavorable conditions as possible for their habitation. And for this purpose effective use of insecticides and a periodical series of fumigations are called for.

1. Preventive means

(1) Grains' moisture content: As Table 2 shows, most insect pests find a heap of grains habitable when their moisture content goes over 15%. The table also shows that the rate of propagation progressively decreases with every per cent after the moisture content breaks through the level of 12%. From this it follows that the first step to be taken to minimize insect damage to stored grains is to reduce their moisture content to the lowest possible degree as soon as they are reaped.

Table 2. Moisture content of rice grains versus propagation rates of rice weevils and small rice weevils. (Harada 1965)

Moisture Content (%)	10	11	12	13	14	15
Rice weevil	70	130	214	238	291	948
Small rice weevil	40	90	358	408	394	713

Remarks: The results above were obtained by comparing five pairs of insects left in their natural state of propagation.

(2) Packing materials in use: The kind of material used to pack grains for storage is no small factor for prevention of insect damage to them. Grains contained in a paper bag are far less susceptible to insect attack than those contained in a jute bag.

(3) Warehouse conditions: The warehouse must be kept as cool and as dry as possible and its structure must also be of an unsuitable design for insect pests to inhabit. It is also necessary to keep every inch of the interior clean so as to lessen the chance of insect in habitation.

(4) Preventive use of insecticides: Since no insecticide can produce its effect without its physical contact with the pest at the outset of its attack against stored grains,

it is of little help in case the grains are already under attack.

(i) Pyrethrins, Piperonyl butoxide

This insecticide, developed in the United States in 1946, is commercially known as PGP—short for Pyrenone Grain Protectant—and available in both emulsified and powdered forms. The emulsified PGP is sprayed at the concentration of 1: 20–40 dilution. The PGP is entirely harmless to man and animals and can be directly sprayed over the grains. As such, this chemical is widely in use in Japan. The optimum per square meter dose is about 100 ml. In term of the 1:20 solution, the emulsified PGP has the residual effect over 6 months and in terms of the 1:40 solution, for half that length. The PGP powder, when mixed with grains, is effective for a much longer period of about one year but, when spread over the grains, its preventive effect against insect attack does not last as long as emulsified PGP. When mixing with grains, 0.2% in weight of PGP powder is sufficient and when dusting the floor, five to ten grams per one square meter is the standard use.

(ii) Fume Lindane

When vaporized together with a pyrogen, lindane or lindane-DDT mixture serves as a powerful fumigant. This fumigant has a more far-reaching effect than that of spraying or dusting because it permits the chemical to penetrate into every nook and corner of the storehouse including small chinks on the wall and tiny cracks in the pillar. Every one of the bags stored in a heap there can also be thoroughly disinfested on the surface although the chemical is not penetrating enough to exterminate the pests already inhabiting deep inside the grains. Select a smoke candle specially designed for warehouse fumigation and burn lindane at a rate of 0.5 g per cubic meter. Then you can expect its effect to last for three to four months. While smoking, the candle generates much heat and, therefore, must be treated with every possible precaution against a fire.

2. Combative means

Preventive means such as outlined above should of course take precedence over combative means. But once any insect pest damage is done to stored grains, some combative means outlined below must be pursued to minimize it. Since stored grains are for human or livestock consumption, every possible care must be used not to leave any poisoning possibility behind in case any poisonous chemical is used for exterminative purposes. Such means must at the same time be inexpensive and of the kind that will not cause any deterioration of the grains in storage even when employed in a huge granary with a large stockpile.

Among the physical exterminative means conceivable are heat treatment and cold treatment, but the former is impracticable in view of its adverse effect upon the quality of the grains and the latter is too expensive if not technically infeasible. Also technically feasible is the use of a high-frequency wave radiator and radioactives, but those methods, too, is too expensive to be of practical use at present.

Thus, the only practicable, economical means we find applicable for pest control today is fumigation. Since carbon desulfide was first used as a fumigant by Doyeer of France in 1853 a wide variety of insecticides for fumigation have been developed. Listed in Table 3 are the fumigants widely employed today and their chemical and physical characteristics.

(1) Carbon disulfide: In view of its inflammable, explosive nature and its tendency to reduce its insecticidal efficacy at a temperature below 20°C, this chemical is not suitable as a cereal fumigant.

(2) Ethylene oxide: Mixed with carbon dioxide gas, this chemical is in use as

Table 3. Main fumigants and their characteristics.

Kind	Chemical formula	Molecular weight	Boiling point (°C)	Specific gravity	Gasometic reading	Melting point (°C)
Hydrogen phosphide	PH_3	34.04	−87.4	0.746	1.183	−133.8
Carbon disulfide	CS_2	76.13	46.3	1.263	2.63	−111.6
Chloropicrine	CCl_3NO_2	164.38	112.0	1.651	5.69	− 64.0
Ethylene dicromide	$CH_2Br \cdot CH_2Br$	187.86	131.6	2.17	6.50	10.0
Ethylene oxide	$(CH)_2O$	44.05	10.7	0.887	1.52	10.7
Hydrogen cyanide	HCN	27.03	26.5	0.688	0.94	− 14.0
Methyl bromide	CH_3Br	94.95	4.5	1.732	3.29	− 9.3

a fumigant for cereal pest control in the United States and some other countries. But in view of its extremely wide explosible range, Japan is not using it for safety reasons.

(3) Hydrogen cyanide: Because of its low phytotoxicity, this chemical is widely used to fumigate seedlings, fruits, vegetables and other green products. However, this gas is not very effective in controlling such pests as the rice weevil which inhabits deep inside a grain because of its limited penetrability.

(4) Ethylene dibromide: This fumigant has a high boiling point and, as such, heat must be applied for its vaporization. The chemical is widely used against fruitflies because they are particularly susceptible to its gas. It commends itself highly as a powerful fumigant for stored grain because of its excellent penetrability but is too expensive to serve this purpose fully.

(5) Chloropicrine: W. Moore established the efficacy of this chemical as an insecticidal fumigant in 1917. It is not inflammable and highly penetrative. Besides, it has no adverse effects on the quality of stored grains as a fumigant. Thus, the chemical has come into wide use as a substitute for carbon disulfide against insect pests of stored grains. By virtue of its high sterilization effect, the chemical is also used to prevent the degeneration of soft rice. But it cannot be used for any live crops on account of its toxic effects. The fatal density of this gas is 2 mg per liter and even a small dose is extremely irritable to the ocular and nasal mucose membrane—a considerable impediment to the progress of fumigation. But because of this same characeristic, one can sense the presence of this gas readily. This chemical has a drawback in its corrosive nature against metals, especially iron, and has a higher boiling point. Thus, the fumigation at lower temperature is not recommendable with this chemical.

(6) Methyl bromide: The efficacy of this compound as a fumigant was proved by De Coupils of France in 1932. Then, thanks to the studies by Shepard and his associates of the United States in and after 1937, it has come into such an extensive use that it has largely taken the place of chloropicrine. This substance is easily vaporized because of its low boiling point and therefore usable for fumigation even if the atmospheric temperature is low. Its gas possesses a high degree of penetrability and is capable of putting under control even such tenacious pests as the rice weevil. Another merit of this fumigant is that it has a relatively low degree of "sorption"—a physical and chemical process of any gas holding on to the fumigated object. This means that the gas once absorbed is easy to pass away. This chemical is also preferable over other fumigants in that its solubility in water is

limited to a negligible 1.44 g/100 g (25°C) and that the gas density necessary for the fumigation has no possibility of causing combustion whatever.

As for its toxicity, the human body has a maximum tolerance of 20 ppm as the fatal dose ranges from 10 to 20 mg per liter. Since the gas is practically odorless while its density is low, it is imperative on the fumigator to wear a gas mask while at work. The presence of methyl bromide gas ranging from 40 to 800 ppm in density can be detected with a gas detector lamp—an appliance of the flame reaction theory. The yellow flame of this lamp burning a copper wire varies its color from green to indigo blue as the density rises. In order to obtain an accurate reading of gas density we must turn to a color reaction tube or a gauge designed to measure it by means of the interferometer-type gas analysor.

(7) Hydrogen phosphide: Originally developed in Germany after the war and now known by its trade name of "Phostoxin", this fumigant is a solid substance having a variety of characteristics which other fumigants do not possess.

Hydrogen phosphide accounts for as much as 1.54 g out of a 3 g tablet of this substance. The remaining 1.46 g are made up of such additives as a plasticizer, expander, explosion deterrent and an odorizer. The carbide smell given forth by this substance in the form of tablets is harmless if sniffed at upon opening the can. Each tablet generates one gram of hydrogen phosphate when it absorbs the moisture in the air. Three to four hours are normally needed for the tablet to begin its vaporization process and for one to two days to complete that process although the time required varies according to the prevailing humidity. The hydrogen phosphate gas is highly poisonous and the human body is constituted to tolerate only up to 0.05 ppm of it. No harm will be done to man and animals unless the tablet is accidentally moistured. At least a period of 72 hours should be set aside for a fumigation process in view of the rather low display of its insecticidal effects.

3. How to use methyl bromide as a fumigant

(1) Leakage prevention: All the chinks and crevices that could permit the gas out of the warehouse or the silo subject to fumigation must be detected and filled up beforehand. Leakage detection is usually made by means of smoke candles in case warehouse and by test fumugation in case of silos.

(2) Stacking arrangement: Since the methyl bromide gas is heavier than the air, it tends to sink to a lower level and stagnate there unless the air is stirred up with a fan. Usually 10 to 15 hours are necessary for the gas to fill up the fumigated warehouse with an even measure of density at all levels of its interior. When a storehouse with a stockpile of grains is subjected to fumigation, the bales' pile should be divided into separate heaps of an equal volume with the lowest possible height, each bale spaced at least one meter away from any other and none closer to the nearest wall than 20 or 30 cm.

(3) Fumigation under vinyl covering: In case a heap of grains is fumigated out in the open, vinyl sheets are used to cover the heap. But such a fumigation usually requires more than ordinary dosage. Preferably, therefore, such a tent should be set up in the warehouse in a shape similar to that of a four-sided Japanese mosquito net with a long-trailing skirt. When such a tent is used indoors, make sure not to let gas out while fumigating either through any crack on the floor or through the rim of its skirt. Sand bags lined up in a row may serve well as a "weight" to keep the skirt rim pressed down. It is also advisable to disinfest the whole of the warehouse interior before dosing the fumigant inside the tent.

(4) Dosage and exposure: Among the pests of stored maize, khapra beetle is, by

far, the most resistant to methyl bromide followed by rust-red flour beetle and confused flour beetle. Namely, khapra beetle is three times as resistant as rice weevil. and rust-red flour beetle and confused flur beetle are twice as resistant as rice weevil. However, khapra beetle is only occassionally found on stored maize, while rust-red flour beetle and confused flour beetle are quite common insects. Therefore, unless you find khapra beetle on the maize you want to fumigate, you can use the dosage which is necessary to kill rust-red flour beetle or confused flour beetle. This dosage will also be sufficient to control rice weevil, lesser grain borer and other common insects.

When the temperature is higher than 20°C, a dose of 16 g per cubic meter is considered necessary for complete extermination of the pest when this particular fumigant is used in a warehouse well secured against leakage and that of 24.5 g per cubic meter, when it is used the fumigation is done outdoors or when the warehouse is not well secured against leakage. When this fumigant is used only to check the further spread of insect damage, a dose of 10 g per cubic meter should be sufficient. And if this fumigant is used inside any silo not equipped with a gas circulatory device as much as 42 g per cubic meter will be needed for complete extermination of the pest, since it is difficult to fill the silo's interior with a gas of even density. But silos equipped with a gas circulator, as much as 33 g per cubic meter will be enough. The time needed for this fumigant to produce its full effect is 48 hours.

(5) Safety precautions: Worker is required to wear a gas mask specially designed for methyl bromide and it is advisable to operate the dosing from outside the warehouse. At the completion of fumigation, he must examine the presence of gas inside the warehouse by the gas detector and keep the warehouse off limits until the gas diffuse away completely.

Discussion

A. Senanarong, Thailand: Could the method of methyl bromide fumigation as you explained be applied to seed corn? Does it have some effect on seed germination or seed viability?

Answer: Seed corn is not injured on the germination and viability by the fumigation of methyl bromide at all. Therefore, I advise rather that seed corn should be fumigated before storing.

P. Phit, Thailand: In Table 3, is the boiling point expressed in centigrade or in Farenheit?

Answer: It is expressed in centigrade.

T. Mizukami, Japan: Is there any relationship between air humidity and gas effects?

Answer: In the case of methyl bromide, there are not particularly relationship between air humidity and gas effects. However the quantity of sorption increases when temperature goes down.