Protecting Stored Grains From Insects
Michigan State University
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Robert F. Ruppel, Extension Specialist
Kimberly A. Parker, Extension Intern
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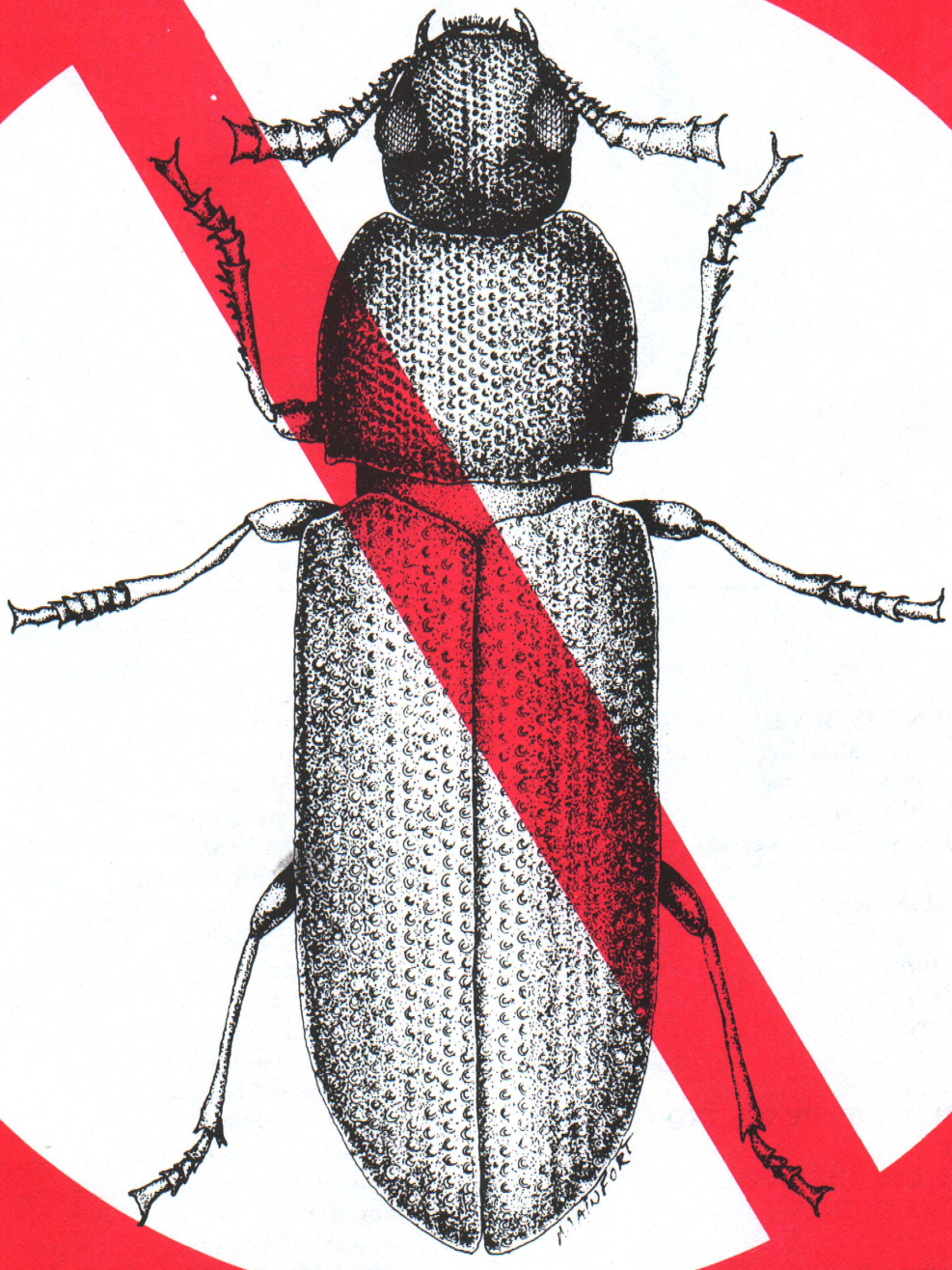

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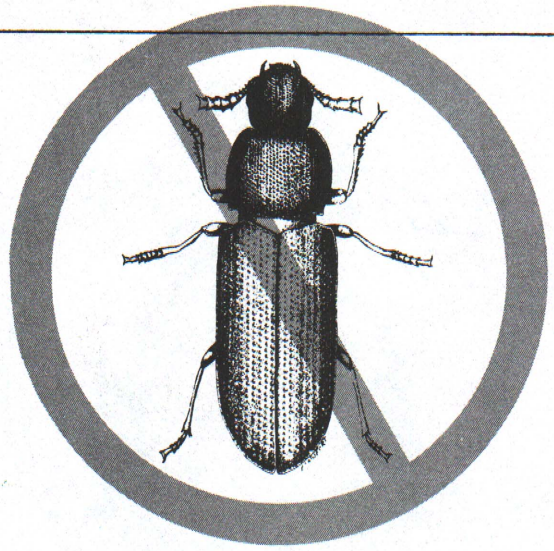
PROTECTING STORED GRAINS

FROM INSECTS



By Robert F. Ruppel and Kimberly A. Parker
Extension Specialist and Extension Intern

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Grain is sold on the basis of its quality. The presence of insects, dead or alive, and kernels damaged by them lowers the quality and the price of the grain. To avoid this loss, prevent insects from entering and damaging the grain. Stored grain insects are widely spread, abundant and small, and perfect protection can never be assured. The risks can be minimized, however, by following the precautions given in this bulletin. These precautions are most effective when they are part of a sound general management program to maintain quality of grains during storage.

The grain eaten by the insects lowers its test weight. The broken kernels and flour that they create are lost as screenings and further reduce the weight of the grain. The damaged grains and the presence of any insects, insect parts, cast skins, webbing, droppings and any odor or increased moisture that they cause could also lower the price received for the grain. The methods used to determine the cash amounts of the discounts are not uniform in the grain trade. An elevator that simply will not accept "weevily" grains at one time may make only a minimal discount for it at other times. The threat of the discounts, however, is always present as an incentive for protecting the grain from insects.

Insects are common in stored grains. A large-scale survey of farm-stored grains, primarily from the north central states, showed that 25 percent of the wheat, 56 percent of the oats and 80 percent of the corn samples examined had at least low numbers of insects in them. These are much higher proportions than expected, based on the relatively few reports of stored grain insects received by the Michigan Cooperative Extension Service, probably because the samples in the survey were thoroughly searched specifically for insects. Only a relatively few samples of the grains were from Michigan, but the Michigan samples were in line with those from the other states, so the results are probably representative of Michigan grains. There is no question that the insects are around and pose a threat to our grains that requires planning to avoid.

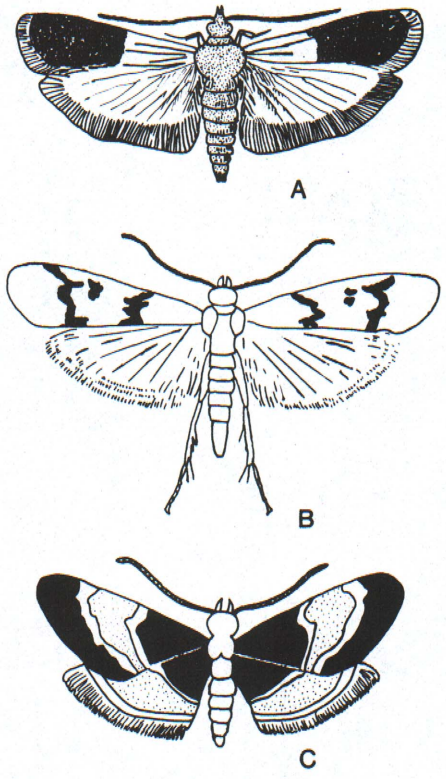

Fig. 1. Adult moths of some surface-feeding caterpillars of stored grains: A) Indian meal moth; B) Mediterranean flour moth; C) meal moth (redrawn from USDA publications).

Insects Found in Michigan Grains

Forty-six of the 80 species of stored grain insects known in the United States have been found damaging grain in Michigan. These include such insects as cockroaches, silverfish and sap beetles, which can feed only on grains that are out of condition and so are a sign, rather than a cause, of a grain problem. The stored grain insects are a diverse group. They can be divided into three general types based on their locations and their damage to the grains: caterpillars that feed on the surface of the grain mass; insects that feed from the outside of the kernels within the grain mass; and insects that feed inside the kernels. Some examples of each type of insect are presented here.

The exact identification of stored grain insects is often difficult because each of the many different species has several life stages—egg, larva or nymph, pupa and adult—and there is considerable variation in appearance even among individuals of the same species in the same stage. The best general reference for identifying stored grain insects is "Stored Grain Insects," U.S. Department of Agriculture, Agriculture Research Service, Agricultural Handbook No. 500. This handbook is available for $1.50 from: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Surface-Feeding Caterpillars

These are the caterpillars (worms) that are seen feeding on the top, bottom or sides of the grain mass. They penetrate only a few inches into the grain. The caterpillars are cylindrical and have a definite head, six small legs just behind the head and a series of fleshy legs near their rear ends. They spin a silky, fine webbing as they feed, and their webbing, droppings and cast skins all add to the mess in the grain. The caterpillars make silky cocoons and change to a quiet stage, the pupae, when they finish feeding. The adults that emerge from the pupae are the small moths that are seen flying above the grain or roosting on the top or sides of the bin. The adults of three common surface-feeding caterpillars are shown in Fig. 1.

The meal moth and Mediterranean flour moth are most commonly found in grains high in moisture. (They can damage stored dry beans and soybeans as well as corn and small grains.) If these pests are present, suspect a moisture problem in the grain. The moisture may be caused by a leaky roof or snow blowing into the bin, but a more common cause is moisture migration within the grain because of poor aeration of the grain. This is a management problem. The decline of the meal moth as a stored grain pest indicates that management has improved greatly over the past few years.

The Indian meal moth can increase in grains of lower moisture, is more difficult to control than the meal moth, and has now become the most common pest of stored grain in Michigan. At rest, with its wings folded around its body, the adult moth is brown at both ends with a wide, white band across the middle.

Insects That Feed from the Outside of the Kernels

Most of our stored grain insects feed from the outside of the kernels. They range from the tiny (1/50 inch) grain mite (Fig. 2B; the mite is more closely related to spiders than insects) to mealworms (Fig. 2H) that are over ½ inch long; and from soft-bodied book lice (Fig. 2C) to hard-shelled adult beetles (Fig. 2 A, D and E). They occur in all stages from eggs, larvae (the young; Fig 2 F, G and H) to adult. They share the ability to penetrate into the grain mass to feed from the outside of the grain kernels. These insects are always around but have rarely been serious problems. The sawtoothed grain beetle (Fig. 2A) and the confused flour beetle (Fig. 2D), commonly called "bran bugs," have been most frequently found in our stored grains.

These insects feed on a wide variety of seeds, feeds, flour and grain debris. They are very rarely found in stored dry beans or soybeans and have never been a problem in beans. They feed primarily on broken kernels and fines in the grain. Some of them cannot increase in clean, whole grain and so are found only in grain in poor condition. There is nearly always enough cracked grain in farm storage to get them started. Once they build up in numbers, their activities cause increased moisture and temperature that can, in turn, result in increases in molds and the insects themselves.

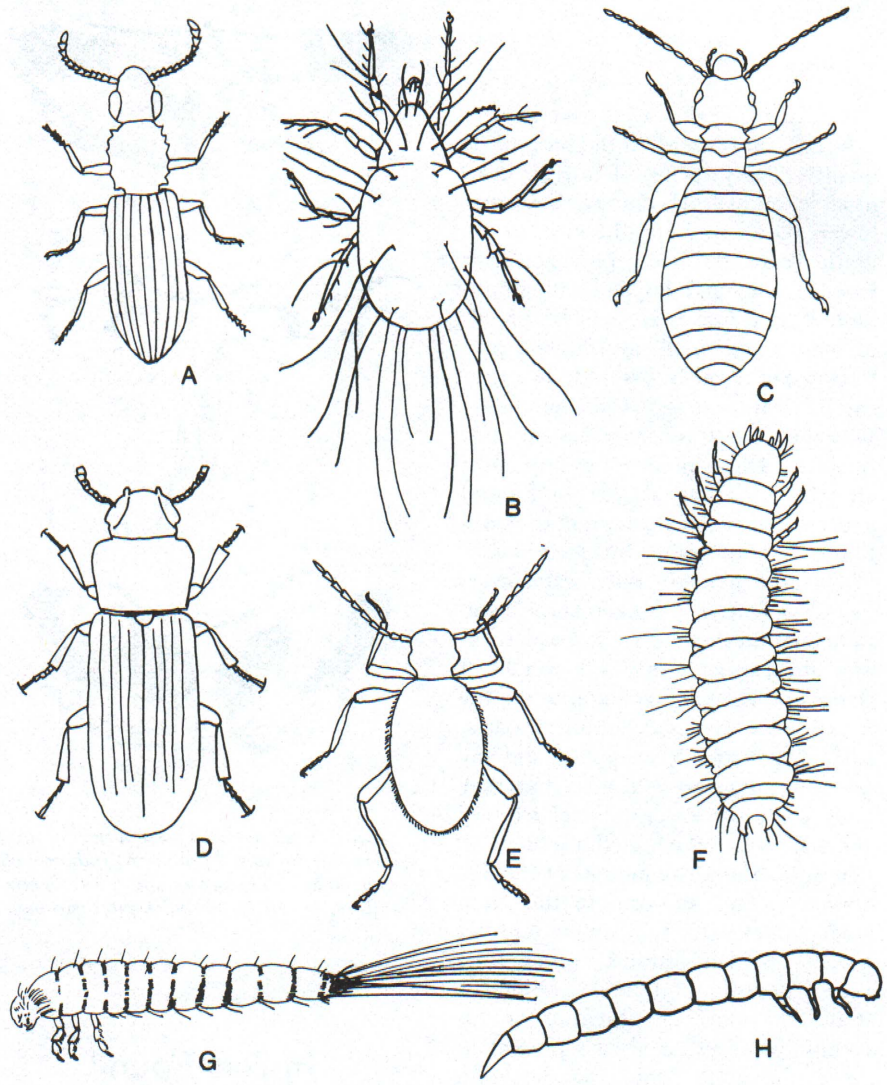

Fig. 2. Some insects that feed from the surface of kernels of stored grains: a) adult sawtoothed grain beetle; b) grain mite; c) booklouse (or psocid); d) adult confused flour beetle; e) adult spider beetle; f) larva of cadelle; g) larva of a carpet beetle; h) larva of a mealworm (redrawn from USDA publications).

Insects That Feed Inside Kernels

These insects lay their eggs on or in the kernels. The larvae that hatch from the eggs feed and pupate inside the kernels, where they cannot be seen. The adults chew small, round holes as they emerge from the kernels. The holes in the kernels and the adults on the grains are the only indications of their presence.

The Angoumois grain moth (Fig. 3B) has been found in corn and small grains in Michigan but not in any large numbers for years. The bean weevil (Fig. 3C) attacks dry beans and occasionally damages home-stored beans, but it very rarely has damaged large lots of beans. The granary weevil (Fig. 3A) is the best known and potentially most damaging of our stored corn and small grain insects. This is the weevil that gave the name to "weevily grain."

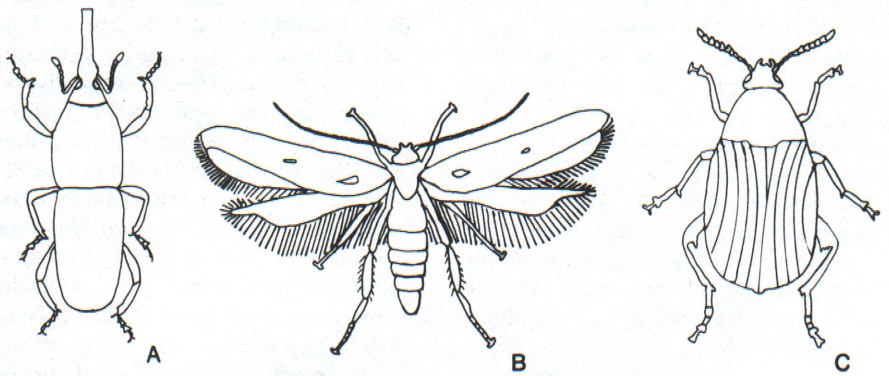

Fig. 3. Some insects that feed inside the kernels of stored grains: a) granary weevil adult; b) adult Angoumois grain moth; c) adult bean weevil (redrawn from USDA publications).

Its long snout and the round holes it leaves in the grain will identify the weevil. The weevil was found somewhere in all of the grain elevators examined during a survey of elevators in Michigan. The granary weevil is a threat but has rarely been numerous enough in recent years to cause damage in Michigan.

These insects increase most rapidly in warm, moist grain, but they can damage whole, dry grain. They may attack even the best managed grains. Granary weevils can penetrate deeply into the grain where they are very difficult to detect. They may go unnoticed until a "hot spot" forms. The presence of even a few adults or a few holes in the kernels means young are also present, inside the kernels where they cannot be seen. These insects are the most serious of all insect problems in stored grains, and anyone storing grain should be especially alert for any signs of them.

Sanitation

Source of Infestations

Some of the stored grain insects can fly and begin their infestation in maturing grains in the field. Though field infestation undoubtedly does occur in Michigan, it is a negligible source of infestation. The insects are everywhere and can easily be carried into the farm in infested lots of grain seed or feed or fly in from infested grains on adjacent farms.

Without doubt, the greatest source of infestation is old grain, seed, feed, spills, debris and accumulated grain dust in and around storage areas. A thorough survey for insects in and around Michigan elevators came up with insects in three-fourths of all samples taken. The samples included floor sweepings and dust from cracks and corners but did not include grains in the bins. Two or more species of insects were found in most of the samples. The least frequently infested samples were spills that were fully exposed to the weather. The shelter given by a loading dock, however, was sufficient for the insects to establish themselves in the spills.

The most important step in preventing insects from infesting stored grains is clearing them out of the storage area before bringing in the new grain. The insects are small and can live in the tiniest cracks, so assume that insects are present even if you don't see them.

Cleanup

A thorough cleanup of the bin and the area around it is the first essential step in protecting stored grains. The best times for cleanups are a month or so before new grain is brought in and again immediately after the bins are filled.

The first decision is what to do with old grain stocks on hand. The best decision is to get them away from new grain that is intended for long storage by selling, feeding or at least isolating them in a separate bin. The old grain should be thoroughly checked for insects (as described later) before the new grains are harvested. Stocks of old grain found to be infested should be fumigated, and clean grains should receive a surface spray and/or have "Pest Strips" hung over them before the new grain is brought in. A grain protectant can be added to old grain if it is moved to a different bin. (Fumigation and the other operations are described later.) Putting new grain on top of old grain is asking for trouble unless the grain will definitely be fed or sold very quickly.

Stored grain insects can feed on any grain substance. Any seed, feed, spills or accumulations of remnants should be removed from inside and around the bins. Feed, bury, burn or spread the debris as far from the bins as possible. The space under the subflooring in some bins is a special problem because it is a trap for broken grains and grain dust and is often not accessible for cleaning. Hollow walls, ducts, enclosures for machinery and other inaccessible areas within the bin also present special cleaning problems. Remove as much debris from these spaces as possible. (Special precautions to clean up these spaces are given later.) Grain dust around feed mills and other machinery was the most heavily infested in the survey of elevators noted earlier. Grain debris is also common in harvesting, hauling and handling machinery. Farmers have even found insects in ducts used to move grain or feed. Give special attention to cleaning in and around all grain machinery, as well as in and around the bin itself.

Make a thorough cleaning about a month before the new grain is harvested. Clean up grain handling equipment and any spills and grain remnants around the bin as soon as possible after you bring the new grains in. This cleaning will prevent any insect increase in the debris before the next harvest.

Sealing the Bin

Insects, and moisture that assists their increase, can enter even the smallest opening in the bin. Seal every opening in the roof and sides of the bin as tightly as possible. Give special attention to openings under the eaves and around ports and doors. Provide for sealing or covering auger and fan ports when they are not in use. When you seal the bin, keep in mind the need for inlet or exhaust of air during aeration of the grain. Do not seal the bin in a way that will prevent aeration when it is needed later. Be sure to reseal the bin after each aeration.

Fumigant gases will escape through wood, concrete and most other building materials except metal or glass. Polyethylene sheeting will hold the fumigants, and we recommend covering the bottom and sides of all but steel bins with polyethylene sheets. Tape the edges of the plastic to assure the tightest possible closure. The plastic will also serve as a barrier to any water soaking through the floor or walls. Because many insects can easily chew through the sheeting, apply a sanitary spray (described later) before the sheeting is put on. The sealing and sheeting of flat storage bins can be extremely difficult, so plan carefully. The large surface area exposed in flat storage makes all insect control operations difficult, and we strongly recommend that flat storage be used only for short-term storage.

Rats, birds and other animals can also foul stored grain. Make every effort to keep them out of grains. Wooden and older bins with established nests of rats and bins near roosting areas for birds may require a trapping or baiting program to rid them of the vermin. Killing birds requires a special permit from the Michigan Department of Natural Resources. Check with the local DNR office before killing birds.

Control in Bins

Sanitary Sprays

Stored grain insects are small and require very little space and food. No cleaning, no matter how thorough, can be sure to remove all insects, so apply a sanitary spray as soon as the bin and equipment are cleaned and readied for the new harvest. A compressed-air garden sprayer or a small pressure sprayer can be used. Make a special effort to get the spray into cracks and corners where insects could be hidden. Apply the spray in coarse droplets that will run into openings, even screw holes and cracks in wood, and apply it as high up the inside walls of the bin as you can reach. Make a special effort to spray the area under the subflooring and areas in and around the bin and equipment that you can't clean.

The insecticides recommended as sanitary sprays are listed below. Not all formulations of these insecticides are meant to be used around stored grains. Formulations meant only for use in the fields may leave an odor or stain in the grains. Read the label on any insecticide to be sure that it is intended for use in stored grains before you buy it.

—malathion (5 lb./gal. liquid formulation): 5 1/8 fl. oz. of formulation in 1 gal. water applied to 500 sq. ft. of surface. (Calculations of square feet are given in the Appendix.)

—Pyrenone (Pyrenone Crop Spray, a liquid formulation containing 60 percent piperonyl butoxide and 6 percent pyrethrins): 2 1/6 fl. oz. of formulation in 1 gal. water applied to 750 sq. ft. of surface. Pyrenone is especially recommended where Indian meal moth is seen in the bin or where it has been a problem in the bin in the past.

—methoxychlor (2 lb./gal. liquid formulation): 12 4/5 fl. oz. of formulation in 1 gal. water applied to 500 sq. ft. of surface.

Pest Strips

Resin strips impregnated with the insecticide dichlorvos (DDVP, Vapona) are sold under several brand names, the best known of which is "Pest Strips." The insecticide is released slowly and diffuses through the air when the strip is hung. The fumes will kill flying insects and insects on the surface of the bin and grain in which the strip is hung. The strips are effective only in enclosed areas with limited air movement. The fumes will not penetrate the grain and are effective only on the surface. These strips can be hung in empty bins at one strip per 1,000 cu. ft. of bin space to help keep the bin clear of insects after cleaning. (How to calculate the cubic feet in a bin is explained in the Appendix.) The strips can be used in place of a sanitary spray in newer tight, well cleaned bins. They should be used in addition to the spray, however, in older bins or in bins that have had insect infestations in the past. The strips can also be placed under the subflooring of bins when that space can not be properly cleaned and sprayed.

Fumigation

Some bins are simply impossible to clean and spray properly. These include older bins and bins that have hollow walls, false floors, ducts and enclosures for machinery that can not be thoroughly cleaned. These bins give us our greatest problems. Clean such bins as thoroughly as possible. You can then fumigate the empty bin to kill hidden insects before you fill the bin. We recommend, however, a fumigation shortly after filling to kill any insects that may be in the grain as well as in the bin.

Factors That Influence Insects and Control

Most of the stored grain insects can feed on such a wide range of grains and grain products that food is not a limitation. Insects can not control their body temperature, so the critical factor in their speed of development is the surrounding *temperature.* One or more stages—eggs, larvae, pupae or adults—of our stored grain insects can survive periods of subfreezing temperature and overwinter in an inactive state in Michigan. Insect activity starts, but is extremely slow, at about 50°F. (Average monthly air temperature exceeds 50°F only from May through October in south central Michigan [see Fig. 4].) Activity increases at temperatures of 60 to 70°F, and the insects will increase rather slowly in numbers at these temperatures. The reason that we have limited problems with insects in Michigan, even though we have a large

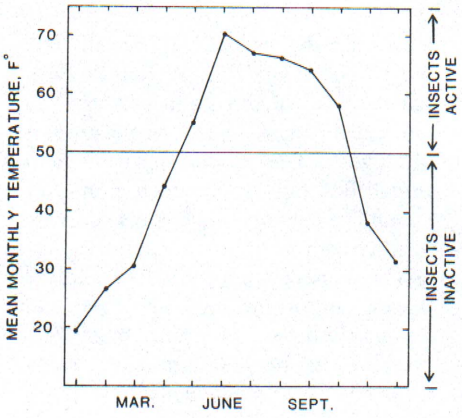

Fig. 4. Mean monthly temperatures at Lansing, Mich. Insects become nearly inactive below 50°F. Insects are inactive from Oct. through Apr. in Michigan (data from Mich. Weather Service).

variety of stored grain insects, is that our grain temperatures are too low to allow the pests to increase rapidly. Development and increase occur most rapidly at temperatures of about 80 to 85°F. Grains are good insulators and these high temperatures normally never occur in grains in Michigan except at the top surface or sides of the bin. Where moisture pockets appear in the grain, "hot spots" can develop from the increased physiological activity of the moist grain. The moisture and temperature in turn accelerate development of molds and insects, which further add to the moisture and temperature. If not detected, hot spots can cause severe damage.

Some insects can live only in grains that are high in moisture, and all stored grain insects increase more rapidly as grain moisture increases. Therefore, insect infestation increases with each increase in grain moisture (see Fig. 5). Molds are more sensitive to moisture than insects and usually do not increase when grain moisture is less than about 12 percent. Molds can increase rapidly in wet, warm grain and are even more of a threat to grain quality than insects as moisture levels rise. The formation of hot spots accelerates mold growth as well as insect development.

Only a few of the stored grain insects will increase in thoroughly clean, whole grain. Most of them require cracked grain, fines or flour before they can get established in grain. Once established, many of the insects' activities will increase heat and moisture that

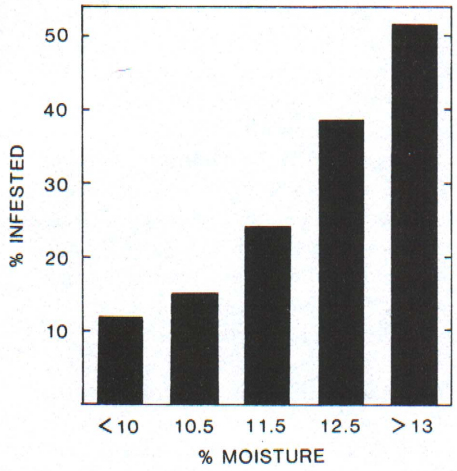

Fig. 5. Percentages of farm-stored wheat samples of various moisture contents infested by insects. Note that infestation increases as moisture increases (data from USDA).

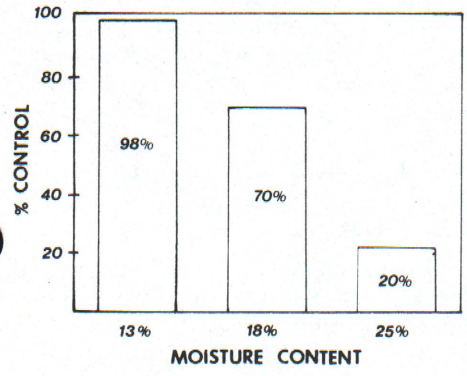

Fig. 6. Percent mortality of the rice weevil using malathion as a grain protectant in corn of various moisture content levels. Mortality decreases as moisture increases (data from a research report by Dr. A. Saldarriaga, 1958).

break the grain and allow the insect numbers to soar. Once again, those hot spots can be a problem. Unfortunately, there is no practical way to handle and clean dry grain without causing some cracks that will give the insects at least an opportunity to live in the grains.

The same factors that influence insect numbers—temperatures, moisture and the presence of fines—also influence the control of the pests. The movement of fumigant gases through the grain strongly depends on temperature. Low temperatures, generally below 50°F, impede the movement of fumigants so that higher dosages are required for control. High moisture will reduce the effectiveness of insecticides as grain protectants (see Fig. 6), and moist grain will impede the movement of the fumigants. Fines will also interfere with fumigation. The biggest problem with fines, however, is that they also impede air movement during regular aeration of the grains. Poor aeration is the primary cause of moist grain at the surface and of moist pockets of grain in the bins that promote insect infestations and formation of hot spots.

Management is the Key

Good management is as essential to protecting stored grains from insects as it is to all other aspects of maintaining grain quality during storage. Many of our "insect problems" are actually management problems that cause the grain to go out of condition and allow insects to build up in the poor grain. The low temperatures during much of the year in Michigan minimize the threat of insects in our grain (see Fig. 4). A good sanitation program and well planned management are all that are generally needed to assure top quality of stored grains in Michigan for a year or more. The basics of good management are presented in Extension bulletin E-1431, "Stored Grain Management." This bulletin is available at your county Extension office.

Management practices enable us to manipulate the factors that influence insects—temperature, moisture and fines. Start reducing cracked grains by adjusting and operating harvest machinery to deliver sound grains into the hopper. Loading, handling, cleaning and drying equipment should also be operated to minimize damage to the grain. Loads with high proportions of cracked grain should be set aside for early sale or feeding whenever possible, especially if the remainder of the grain is intended for long-term storage (more than one year). Clean the grain of cracks and debris before it is stored. Clean it especially thoroughly if it's intended for long-term storage. Remove the screenings from the storage area and sell, feed, bury, burn or spread them as soon as possible after the bins are filled.

High moisture is the greatest threat to general grain quality, as well as a contributor to insect problems. To reduce insects, grains should be held at no more than 12 percent moisture content. This is simply not practical, however, because the cost of drying most grains to this level is prohibitive and the super-dry grains would crack excessively during handling. The moisture content must be a compromise among cost, cracks and risk of insects and molds. "Stored Grain Management" recommends that grains intended for long storage contain 1 to 2 percent less moisture than grains for short-term storage. This is a good practice to reduce the threat of insects.

The management bulletin also recommends holding grains within 10°F of the average air temperature, or at the lowest temperature that good practice permits. Careful aeration of this grain will both adjust the temperature and prevent moisture pockets, and eventually hot spots, from forming in the grain.

The fines tend to concentrate in the central core of some bins (see Fig. 7), where they interfere with aeration and provide a starting point for some insects. Taking a load or two out of the bin just after filling will reduce this core of fines.

A peak at the top of the grain is also undesirable because it increases exposure at the surface and interferes with aeration and fumigation. Taking a load or two out of the bin will also help to reduce this peak.

The most common problem with stored grain insects has been surface infestations that appear when the grain is improperly aerated and moisture condenses on the surface. The insects signify an aeration problem that must

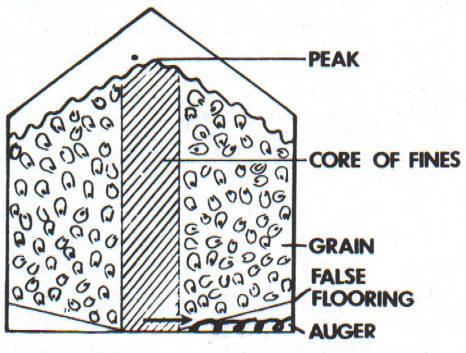

Fig. 7. A diagram showing the peak and central core of fines that are often left on grain storage bins. Much of the core of fines can be removed and the peak leveled by taking out a load or two after filling the bin.

be corrected. Trying to maintain quality grains in bins without equipment for aeration is extremely difficult. We strongly recommend that such bins be used only for temporary storage and that they be checked frequently for any signs of problems. Old-fashioned "turning"—moving the grain from one bin to another—may be the only way to break up moist spots that may form in bins that have no aeration facilities.

Surface Treatments

Insect infestations can begin with insects that are already in the new grain as it is put into the bin, though this is not likely in Michigan. Generally, infestations are hidden in cracks and corners of the bin before the new grain is brought in. A good sanitation program and the use of a sanitary spray greatly reduce this threat. Insects can enter the grain easily by flying or crawling into the upper or lower surfaces of the grains. The application of a grain protectant (described later) as the grain is going into the bin will give some protection to the grain surface. Cleaning and spraying and placing "Pest Strips" in the space under the subflooring are all that can be done to protect the bottom surface of the grains from infestation.

Surface treatment with insecticides can reduce the chances that insects will enter through the upper surface of the binned grains. You can reduce the amount of exposed surface by leveling the top of the grain. This will also make the surface treatment more effective. The very broad surface exposed in flat storage presents a special problem. Leveling the surface as much as possible and using a surface treatment are very strongly recommended in flat storages.

Pest Strips

Hanging "Pest Strips" above the grain will help deter insects from invading stored grains. The strips are effective only in enclosed areas with limited air movement. They should be applied after the bin is filled at one strip per 1,000 cu. ft. of space above the grain and changed at intervals indicated on the label (the calculations of cubic feet are given in the Appendix). The strips are effective only in warm weather, when insects are active. New strips should be hung above grains already in storage in May and replaced as needed during the season.

Surface Treatments

Sprays or dusts of the insecticides malathion and, where Indian meal moth is a problem, Pyrenone or Bt can be applied over the surface of the grain to kill insects as they are entering the grain. Not all formulations of these insecticides are intended for use in stored grains and some formulations may leave undesirable stains or odors in the grains. Read the label on the insecticide to be sure that the product is intended for use in stored grains before you buy it.

Malathion (Cythion is a well known brand name) is available as a liquid emulsifiable concentrate and as a dust formulation for surface treatment of grains. The emulsifiable concentrates (EC) are mixed with water and applied as sprays, while the dusts (D) are applied directly without mixing with water. Malathion can be used in corn and small grains but not in dry beans or soybeans. Level any peak at the top of the grain before treating the surface. The amounts of the various formulations of malathion to be applied per 1,000 square feet are:

—malathion 5 lb./gal. EC at ½ pint of formulation in 1 to 2 gal. of water.

—malathion 2 percent D at 15 lb.

—malathion 6 percent D at 5 lb.

(Calculations of square feet are given in the Appendix).

Malathion will not control Indian meal moth (Fig. 1A). A surface spray of Pyrenone, Alleviate or Bt should be used in bins where Indian meal moth has been a problem or moths are seen in the bin. Special liquid formulations of mixtures of piperonyl butoxide with pyrethrins (some Pyrenone formulations) or allethrin (some Alleviate formulations) are available for surface sprays. These special formulations vary in concentration of the insecticides. Follow the instructions on the labels when using these special formulations. The same Pyrenone formulations used as a sanitary spray can also be used as a surface spray to control Indian meal moth and to protect corn and small grains, but not dry beans or soybeans, from other surface-feeding insects:

—Pyrenone (Pyrenone Crop Spray, a liquid formulation containing 60 percent piperonyl butoxide and 6 percent pyrethrins) at 2⅓ fl. oz. formulation in 1 gal. water applied per 1,000 sq. ft. of grain surface and raked into the upper surface of the grain.

Bt — spores of the bacterium *Bacillus thuringiensis* formulated as an insecticide and sold under such brand names as Bactospine, Dipel, SOK-Bt and Thuricide — will also control Indian meal moth and other surface-feeding caterpillars in stored grains. Bt will control only caterpillars — it will not control any other types of insects or the adult moths of these caterpillars. Bt kills very slowly and it may take a week to kill all of the caterpillars. Bt can be applied to dry beans and soybeans as well as corn and small grains. Bt is available as liquid or wettable powder formulations that vary in the concentration of Bt. Follow the instructions on the label. Some formulations of Bt can be added to the top layer of grain as the grain goes into the bin (the section on grain protectants explains how to do this).

Grain Protectants

The Insecticides

Good sanitation and rigorous management will greatly reduce the threat of stored grain insects in Michigan. The application of a grain protectant to grain that is intended for more than one year of storage will further reduce the risk.

Grain protectants are insecticides that are mixed with the grain as it is going into the bin. The protectants will continue to kill any insects in the grain or insects that enter the grain for as long as a year. The insecticides and the rates at which they are used were selected to protect the grain effectively without leaving an objectionable or hazardous residue in the grain. The protectants are much less hazardous, easier to apply and less expensive than fumigants and protect the grain long after they are applied. For preventive treatments, we strongly recommend grain protectants instead of fumigants, except for special problem bins that can not be properly cleaned and must be treated to control established infestations.

Grain protectants can be used in corn and small grains but are not registered for use in dry beans and soybeans. High

moisture in the grain reduces their effectiveness (see Fig. 6), and they are not reliable in controlling established infestations of insects. They are intended for use only in clean, dry grain — either new grain going into the bin or lightly infested, older grain as it is being turned. (Roughly speaking, lightly infested grain contains insects that can be found only through diligent searching.) Heat reduces residual effectiveness of the protectants, so a protectant should be applied only after the grain has been through the heat of the dryer and has cooled to 90°F or less.

Malathion and Pyrenone are the only insecticides that can be used as grain protectants in stored grains at present. Malathion does not control Indian meal moth (Fig. 1A), so Pyrenone or a special application of Bt should be used where the Indian meal moth has been a problem or is seen in the bin. There are many formulations of malathion and Pyrenone that are intended for field use only and that may leave an odor or stain in the grain. Read the label on the insecticide to be sure that it is intended for use in stored grain before buying it. Malathion (Cythion is one well known brand name) is available as a liquid emulsifiable concentrate and as dust formulations. Pyrenone is available as a liquid emulsifiable concentrate containing 60 percent piperonyl butoxide and 6 percent pyrethrins (Pyrenone Crop Spray is a well known formulation). The dust formulations (D) are added directly to the grain without mixing with water. The liquid emulsifiable concentrates (EC) are mixed with water for application. The amounts of these insecticides to apply per 1,000 bushels of grain are:

—malathion 5 lb./gal. EC at 1 pint formulation in 2 to 5 gal. water.

—malathion 2 percent D at 30 lb.

—malathion 6 percent D at 10 lb.

—Pyrenone EC at 22 fl. oz. formulation in 5 gal. water. (Pyrenone is especially recommended where Indian meal moth has been a problem or when the moth is seen in the bin.)

Bt (spores of the bacterium *Bacillus thuringiensis* formulated as an insecticide) can be added as a grain protectant to the first and last foot or so of grain as it is going into the bin to protect it against surface-feeding caterpillars of the Indian meal moth and other moths. Bt will not kill the adult moths nor insects other than caterpillars. Bt is available in several formulations of varying concentrations. Follow label instructions for proper use as a surface protectant.

Application

The dust formulations are simply metered in the grain from some convenient location as the grain is moving into the bin. You may be able to make some device to meter the dust into the grain or obtain the metering equipment from your insecticide dealer. A special rig for metering grain protectant dust into grain is the "W.H.B. Jr." auger applicator model AA 468, available from the WHB Co., 1126 26th St., Greeley, CO 80631.

The liquid formulations are also applied to the grain as it flows into the bin. A small pressure sprayer with the nozzle directed into the grain stream at the base of the auger or leg can be used. Service the sprayer frequently to be sure that it is operating properly. Simply dripping the liquid into the grain streams is as effective as spraying, and a drip applicator requires less servicing and maintenance. You can make a simple drip applicator by adding a needle valve to meter the protectant into the grain through the bottom of the container. The flow rate of the liquid will vary with the depth of the liquid in the container. A more uniform flow can be obtained by using a float valve in a second container to keep the liquid level constant above the needle valve (Fig. 8). Special drip applicators are also available:

—"Auger Jet Applicator" from Acme Brass and Machine Works, 609 E. 17th St. Kansas City, MO 64108

—"Reddick Flo Meter" from Reddick Fumigation, P.O. Box 71, Williamston, NC 27892

Equipment Calibration

Application equipment must be calibrated to apply the proper amount of grain protectant. The liquid emulsifiable concentrate formulations are mixed with water before they are sprayed or dripped into the grain. Calibrations should be based on the gallons of mixed protectant and water recommended per 1,000 bu. of grain. Malathion can be applied in 2 to 5 gal. of water per 1,000 bu. We have found no advantage in the use of the higher rates and recommend that malathion be used at the 2 gal. per 1,000 bu. rate. Steps to calibrate applicators are:

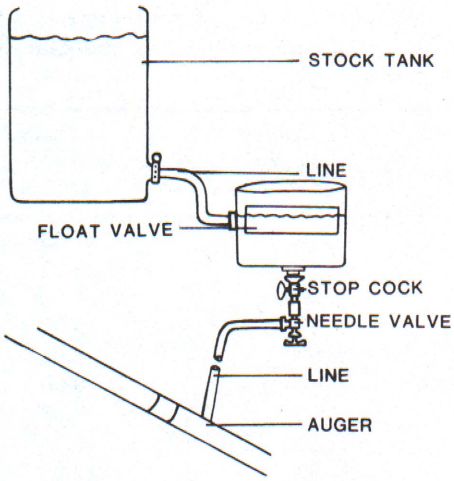

Fig. 8. A diagram of a simple drip applicator for grain protectants. The needle valve is used to meter the protectant into the grain stream. The float valve is used to keep a constant level of liquid over the needle valve (developed by A. P. Love, MSU).

—Check the equipment manual or run a test to determine the capacity of the auger or leg, in bushels of grain per hour, that will be used.

—Fill up the dust, spray or drip applicator that will be used and adjust it so that it is operating properly.

—Start the applicator and collect the dust or spray that it puts out in five minutes. Collect the dust in a bag or bottle and weigh it in ounces on a reliable scale. Collect the spray or drips in a bottle that is marked in fluid (liquid) ounces and measure the amount delivered. Scales or bottles with metric measures can be used—grams for the dusts and milliliters (or cubic centimeters) for the liquids. (Transformation of metric to English units is given in Tables 1 and 2.)

—Compare the ounces or fluid ounces delivered during the five-minute test period with the ounces of dust in Table 1 or the fluid ounces of liquids in Table 2 for the desired amounts per 1,000 bu. at the capacity of the auger or leg used. The ounces or fluid ounces given in the table can be interpolated for intermediate amounts of grain protectant desired or for intermediate auger or leg capacities. (The general equations are given in Table 1 and 2 for more exact calculations.)

—Adjust the equipment to increase or decrease the flow of the protectant and repeat the test until the required

Table 1. Ounces of grain protectant DUSTS needed per 5 minutes with augers or legs of various capacities to obtain the desired pounds of dust per 1,000 bu. of grain.[a]

Capacity of auger or leg, bu./hr.	*Desired pound of protectant dust per 1,000 bu.*			
	10	*15*	*30*	*60*
100	1.33	2.00	4.00	8.00
200	2.67	4.00	8.00	16.0
300	4.00	6.00	12.0	24.0
400	5.33	8.00	16.0	32.0
500	6.67	10.0	20.0	40.0
600	8.00	12.0	24.0	48.0
700	9.33	14.0	28.0	56.0
800	10.7	16.0	32.0	64.0
900	12.0	18.0	36.0	72.0
1000	13.3	20.0	40.0	80.0

[a]*Multiply the tabular values by 28.35 if the dust was weighed in grams instead of ounces during calibration. For example, the first entry — 1.33 ounces — would be 37.71 grams.*

The basic equation for calibration is:

$F = 0.001333 \times R \times C$

when F = ounces of dust per 5 minutes, R = desired pounds of dust per 1,000 bu. of grain, and C = capacity of the auger or leg in bu./hr. For example, if 10 lb. of dust per 1,000 bu. were desired (R = 10), and the auger capacity were 450 bu./hr. (C = 450),

$F = 0.001333 \times 10 \times 450 = 5.999$ oz. dust/5 min.

Table 2. Fluid ounces of grain protectant LIQUIDS needed per 5 minutes with augers or legs of various capacities to obtain the desired gallons of liquids per 1,000 bu. of grain.[a]

Capacity of auger or leg, bu./hr.	*Desired gallons of mixed protectant per 1,000 bu.*			
	2	*3*	*4*	*5*
100	2.13	3.20	4.27	5.34
200	4.27	6.40	8.54	10.7
300	6.40	9.60	12.8	16.0
400	8.54	12.8	17.1	21.3
500	10.7	16.0	21.3	26.7
600	12.8	19.2	25.6	32.0
700	14.9	22.4	29.9	37.4
800	17.1	25.6	34.2	42.7
900	19.2	28.8	38.4	48.0
1000	21.3	32.0	42.7	53.4

[a]*Multiply the tabular values by 29.57 if the liquid was measured in milliliters instead of fluid ounces during calibration. For example, the first entry — 2.13 fl. oz. — would be 62.98 ml.*

The basic equation for calibration is:

$F = 0.01067 \times R \times C$

where F = fluid ounces of liquid per 5 minutes, R = desired gallons of liquid per 1,000 bushels of grian, and C = capacity of the auger or leg in bushels per hour. For example, if 2 gal. of liquid per 1,000 bu. were desired (R = 2), and the auger capacity was 450 bu./hr. (C = 450),

$F = 0.01067 \times 2 \times 450 = 9.603$ fl. oz. liquid/5 min.

ounces or fluid ounces are delivered by the application equipment.

—Record the equipment settings and the amount required per five minutes and check the equipment occasionally as the bin is being filled.

Using a grain protectant on grain going into long-term storage will provide additional protection from insects. Treated grains should still be checked for insect problems as thoroughly as untreated grains; however, the main problems will probably appear at the upper and lower surfaces of the grains, where the protectants break down most rapidly. This can be prevented by applying a double amount of protectant to the lower and upper few feet of grain going into the bin. The extra protectant applied to that limited amount of grain will not leave an unacceptable residue in the grain.

Insect Dusts and Oils

Fine, dusty materials such as silica, road dust and lime have been used in the past to protect stored grains from insects. Some brands of diatomaceous earth (a fine, hard powder) are still available for use in seed and ground feed but not as a protectant in food or feed grains. The use of insect dusts in place of chemical protectants has been promoted by health food groups that do not want artificial chemicals in food. This practice cannot be condoned even for home lots of grains because of naturally occurring high levels of arsenic, lead and fluorine present in some diatomaceous earths. Oils, especially white mineral oil, have also been used as surface sprays and grain protectants. The oils, too, cannot be recommended, both because their effectiveness is questionable and because applying them may lower grain quality.

Check for Insects

Stored grain insects are widespread, numerous and very small, and they can show up even in the cleanest, best managed bins. You must check bins frequently to be sure of detecting pests before they do much damage. We strongly recommend checking bins twice a month from May through October, the months when insects will probably be active (see Fig. 4), and at least monthly from November through

April. It is difficult to detect small numbers of insects in a bin, but checks should be as thorough as time allows. Unfortunately, bin designers haven't made provisions for easy periodic checking of grains. Temperature cables hung at various levels in the bin are recommended to detect pockets of high temperature that could develop into hot spots later on. Instructions on inspecting grain and a table for diagnosing common stored grain problems are presented in "Stored Grain Management," (Extension bulletin E-1431). Make the special checks for insects along with the regular inspections for grain quality.

It's easy to check the top surface of the grain. A grain sieve that will hold the grain while dropping the fines and any insects into a pan under the sieve is very helpful for examining grains. A grain probe for taking a core of grains from the upper layer is also very helpful. If a probe and sieve are not available, you can use some kind of a scoop to take the sample and a pan or piece of plastic to spread it on for examination. When checking grain:

—Be alert for heat, moisture or off-odors that indicate a problem as you enter the bin.

—Look for living or dead insects on the roof or sides of the bin or on the surface of the grain.

—Examine the surface of the grain for any signs of mold and webbing, droppings,cast skins and kernels showing insect damage.

—Take several samples of grain with the probe or scoop. We recommend that you take about 1 pint samples of grain from each of six or more areas of the surface. Examine the samples carefully for any signs of insects or their damage. Be especially alert for round holes in the kernels that indicate the presence of insects that feed inside the kernels.

—If you find insects, save them for identification, dig into the grain (a probe is a definite help here) to determine how deeply they have penetrated into the grain mass, and try to get an idea of their abundance.

Checking for insects in the grain mass itself is next to impossible. Checking the bottom surface of the bin is difficult and a thorough check is next to impossible in many bins. Do the best you can:

—Try to check the space under the subflooring, if there is one, for any evidence of water, mold or signs of insects. You will have to use a flashlight and take samples or look through the fan or auger port for this.

—Run out some grain through the auger and check it thoroughly, as noted earlier, for insects and any signs of their presence. Check the grain, too, for temperature, moisture and off-odors that indicate problems.

Decide on Control

The presence of insects or their damage in stored grain represents some loss in value of the grain. The first decision to make when you find insects is whether the grain is worth treating. Remember that the damaged grain, odor, mess and dead insects will remain even after the insects are killed. Some estimate of the value of the grain after treatment and the cost of control must be made. The best decision may be to immediately sell the grain at a discount or to feed it as soon as possible. The insects in the grain are a threat to newly stored grains, so fumigation of the infested grain (described later) is recommended if other good grain is nearby and the infested grain must be kept. Insects are often a result, not the primary cause, of grains going out of condition. Check grain thoroughly for problems using the diagnostic table in "Stored Grain Management" and correct the problem for the future.

The type of insects found in the bin strongly affects the type of control used. Indian meal moth (Fig 1A) can be controlled only by Pyrenone and Bt, for example, and insects that feed within the kernels (Fig. 3) are especially threatening. You can identify the insects using "Stored Grain Insects," USDA Agricultural Handbook No. 500, or by taking the insects to your county Extension office. Include some damaged grain and as many of the insects as you can collect in the sample that you turn in so that a positive identification can be made. The location of the insects in the grain — on the surface or in the grain mass — must be known, too, to select the proper control. You also need some idea of the numbers of insects present. Heavy infestations of insects are obvious, but there is no reliable general rule of what constitutes a light infestation. As a very rough rule, an infestation should be considered light if you find the insects or their damage only by diligent searching.

Crusting and high moisture and fines very often accompany insect infestations. The crust will interfere with aeration and fumigation and even with surface treatments, so it must be removed to assure good control of the insects. High moisture will reduce the effectiveness of surface treatments and grain protectants, and high levels of either moisture or fines will interfere with fumigation. Test levels of moisture and fines before attempting control. It may be necessary to reclean and redry the grain before treating.

Surface Infestations

Infestation at the top surface of the grain, usually by the surface-feeding caterpillars (Fig. 1), has been our most common insect problem. These infestations are usually aided by moisture condensation caused by improper aeration of the grain or by leaks in the roof or eaves, and they are often accompanied by crusting. Remove the crust before treating and correct the moisture problem as soon as possible. Apply a surface treatment of insecticide, using the insecticides Pyrenone or Bt if only caterpillars are found. Use Pyrenone if other types of insects are also present. Check the control obtained about a week after application. Bt is slow to kill, but control should be complete within the week. Control of Indian meal moth (Fig. 1A) has been a problem in a few bins. Please notify your county Extension agent if control of this pest is poor. Hanging "Pest Strips" over the grain (as noted in the section on surface treatments) will help control surface infestations.

Infestations on the bottom surface of the grain are very difficult to control. Hanging "Pest Strips" and spraying with malathion or Pyrenone though the auger or fan port will help control a light infestation in a bin with a subflooring. Fumigation (described later) is recommended when there is an established infestation at the bottom of the bin.

Grain Protectants

Grain protectants can be used if light infestations of insects are found in the

grain mass but are not reliable against heavy infestations. The grain can be treated as it is being turned (moved from one bin to another). This involves the cost of moving the grain, as well as the cost of the grain protectant and the risk of increased cracks and fines because of the extra handling. Most importantly, it requires a spare bin or other space to hold the grain during treatment. These costs and problems should be balanced against the cost of fumigation in deciding whether you should use a grain protectant. After applying the grain protectant, use a surface treatment and "Pest Strips" as additional assurance against the reappearance of the insects.

Fumigation

Fumigation (described later) is recommended to control heavy infestations. Costs and problems are associated with the use of fumigants, but they are more reliable than grain protectants in stopping an insect infestation.

Fumigation

Fumigants are restricted-use pesticides that can only be bought by, and used under the supervision of, persons holding special pesticide applicator certificates in grain fumigation. Information on those certificates can be obtained from representatives of the Michigan Department of Agriculture or from county Extension agents. Basic information on grain fumigation is presented in Extension bulletin E-1025A, "Grain Fumigation," available at county Extension offices.

Fumigants are gases that can penetrate the grain mass and even the kernels to kill insects. The term "fumigation" is sometimes used for smokes, mists or aerosols and even the fumes from "Pest Strips." These are fine solid or liquid particles that are suspended in the air but, unlike the true fumigant gases, they cannot penetrate surfaces. It is the ability to penetrate that gives fumigants their big advantage in controling stored grain insects. This same ability creates the greatest problems with their use: bins must be sealed tightly enough to hold a toxic concentration of the gas for the time that it takes to kill the insects, and the gases that escape from the bin during fumigations are lethal to humans, livestock and other animals. Every step in the use of fumigants must be done properly if the fumigation is to be effective and safe.

The Fumigants

Fumigants are sold as compressed (liquefied) gases, solid packets or tablets, or liquids (called "pour-ons") that change to gases after they have been applied. The common fumigants are summarized in Table 3.

Compressed gas. Methyl bromide is sold as a liquefied gas in cylinders of various sizes. The liquid changes to gas as it is released from the cylinder and can be piped over the top of the grains. It can be used in corn and small grains, for one application only in dry beans, but not in soybeans. Methyl bromide penetrates and kills quickly. Methyl bromide gas is relatively heavy and can be recirculated (described later). It must be used in tightly sealed bins, either tightly caulked steel bins or bins of other materials that are lined with polyethylene sheeting. Methyl bromide is effective at relatively low dosages and is probably the least expensive of the fumigants. It will leave a small residue of bromide in the grain, so avoid making repeated applications. Methyl bromide is highly toxic and must be handled with care.

Solids. Phosphine is sold as packets or tablets of aluminum or magnesium phosphide, which reacts with the moisture in the air to evolve phosphine gas. The phosphine gas does not begin to be generated until some time, generally several hours, after application. Like methyl bromide, phosphine penetrates and kills quickly and must be used in tightly sealed bins. The solid state of the phosphine formulation makes it the easiest of all fumigants to apply. Phosphine is highly toxic and must be handled with care. The gas is relatively light and the packets or tablets should be injected (described later) or pushed into the grain to avoid excessive loss from the surface. Phosphine should not be recirculated. It leaves little residue in the grain when it is properly used. Phosphine can be used in dry beans and soybeans, as well as corn and small grains.

Table 3. Some Common Fumigants Used in Stored Grains.

Fumigant	*State*	*Trade names*	*Common Uses*
carbon disulfide	liquid	80/20	General grain fumigant; sold in mixture with carbon tetrachloride.
carbon tetrachloride	liquid	—	Weak fumigant; mixed with other fumigants to reduce fire hazard.
chloropicrin	liquid	Larvacide	Grains; safe with seeds; highly irritating; used as a warning gas.
ethylene dibromide	liquid	EDB	Grains. (The use of EDB was being curtailed as this paper was being written.)
ethylene dichloride	liquid	EDC	Grains and seeds, sold in mixture with carbon tetrachloride.
methyl bromide	compressed gas	Meth-O-Gas	General fumigant; low-moisture seeds.
phosphine	solid	PhosToxin	Grains and seeds.
sulfur dioxide	liquid	—	Used as warning gas.

Pour-ons. The liquid fumigants are usually composed of carbon disulfide and/or ethylene dichloride in various mixtures with carbon tetrachloride to reduce the fire risk and small amounts of other fumigants as warning gases (they either have a recognizable odor or irritate the skin) or for some special uses. The pour-ons penetrate and kill more slowly than methyl bromide or phosphine. As evidenced by the recent disclosures of ethylene dibromide residues in grain products, the pour-on may leave a small amount of residue in the grain, so repeated applications are not recommended. The advantages of the pour-ons are that they are relatively less toxic than the others and they can be used in bins that are relatively less tightly sealed. They are usually applied by pouring or spraying them over the top of the grains. Some of them can be injected or recirculated, as noted on their labels. The pour-ons can be used on corn or small grains, but not in dry beans or soybeans.

Safety Precautions

Fumigants are special hazards because they are toxic gases that can penetrate nearly everything except metal, glass and some plastics. Some of them are also flammable or will corrode or damage certain materials. A general discussion of safety with fumigants is given in Extension bulletin 1025A, "Grain Fumigation." Specific precautions on the safe use of the products are given on the labels of the fumigant containers. Read these instructions carefully before you buy a product to be sure that you can use it effectively and safely. One fundamental precaution to follow with all these products is to apply them in two-person teams, with each person always in sight of the other during all steps of fumigation.

Labels and Labeling

A fumigant will be effective only if it remains at a high enough concentration for sufficient time to kill the insects. The uniform diffusion of the fumigant through the grain is affected by many factors, including the permeability of the bin, the type and levels of moisture and fines in the grain, the depth of the grain, the grain surface area, temperature and wind. The fumigants also vary in their effects on the grain; some can be used for stored seed and others can not. Fumigants also have special uses, such as fumigating bagged seed under tarpaulins or grain on trucks. The information on the container of the fumigant—the *label*—assumes that the user is knowledgeable about the use of the product, and the label instructions are often very general. More detailed information on the use of the product, including its use in special situations, is usually available in pamphlets and the like from the manufacturer of the fumigant. These printed materials are called *labeling*. The labeling should be available from your dealer. Get it and study it to get the most out of the specific product that you will use.

Selecting a Fumigant

Only methyl bromide and phosphine can be used in dry beans, and only phosphine can be used in soybeans. The choice of fumigants in corn and small grains is broader. Sealed bins are necessary for all fumigants. Methyl bromide and phosphine require tight sealing and are intended for use in wood, cement or brick bins only if these bins are carefully lined with impermeable plastic sheeting. The pour-ons are better for use in the latter types of bins, but the bins must be tightly caulked for even a pour-on to be effective. The large surface area and usually poor sealing of flat storage makes their fumigation extremely difficult. Flat storage should be caulked as tightly as possible before a pour-on is applied and covered with an impermeable cover afterward.

Consider the availability of appropriate safety and application equipment for the various fumigants when selecting a fumigant. The depth of the grain in the bin needs to be considered, too, because the fumigants vary in their ability to penetrate the grain mass. Injecting or recirculating (described later) is possible with some fumigants. Recirculation requires additional equipment but can increase the effectiveness of the fumigants. Consider also the relative toxicity of the fumigants. Methyl bromide and phosphine are highly toxic and must be handled with extreme precautions because a mistake could be quickly fatal. The pour-ons are relatively — but only relatively — less toxic. They are less rapid in their effect than the other two, but they are safe only if used with full precautions. The prices for fumigants vary, and you should shop for them as you shop for any other supply.

Dosages and Applications

The amount of fumigant to be used will vary with the fumigant, its types of application, the grain, the bin and other factors. Gases are more active at higher temperatures, and grain temperatures of 50°F or more are usually needed for effectiveness. Dosages can be adjusted for temperatures. High levels of moisture or fines in the grain will also impede diffusion of the fumigant. Once again, some adjustment in dosage may be made for these conditions, but grain may need recleaning and redrying before a fumigant is used. The fumigant will drop rapidly through the conical peaks of grains that are sometimes left in bins. Level such peaks before fumigating.

Much of the fumigant loss from a reasonably tight bin is from the surface of the grains. A covering of impermeable plastic or a specially treated tarpaulin placed over the grain immediately after applying the fumigant will reduce the loss. The cover should be used in all flat storages, in upright bins that are less than about half full, and in all bins when winds are expected to be high during fumigation. Increased dosage may be an alternative to a cover. Compare the costs of the additional dosage and the cover before deciding on one or the other.

Fumigants are usually applied to the surface of the grains and left to diffuse down through the grain mass (Fig. 9). Pour-ons can be sprayed over the grain surface using a pressure sprayer that applies a solid stream (not fine spray droplets) of the pour-on. Sealed containers of the pour-on can also be placed at intervals over the grain and then unsealed and poured by hand over the grain surface. Use the required safety equipment and move from the back of the bin to the front while applying the pour-ons. Some pour-ons can be injected or recirculated (as noted later) to aid their effectiveness.

Phosphine packets or tablets are usually applied by pushing them just below the surface of the grains. The covering grain will help reduce the loss of fumigant from the grain surface. They can also be mixed in the grain

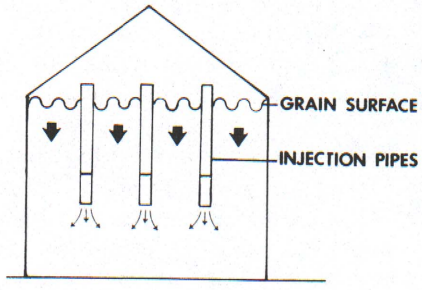

Fig. 9. Fumigant gases are relatively heavier than air and will diffuse downward through the grain when released at the grain surface. Injecting the fumigant — applying it through pipes pushed into the grain — will enhance penetration and prevent loss of the gas at the surface.

flow as the bin is being filled. This is an advantage when infested grain is being turned or a bin could not be properly cleaned and sprayed before filling. Phosphine and some pour-ons can also be injected — dropped down pipes inserted at various depths in the grain (Fig. 9) — for deep penetration into the grain mass. Injection costs include the cost of the pipe and some effort, but it assures good penetration of the gas into deep bins.

Methyl bromide is usually released under a cover placed over the grain surface. The cover should be held off the grain surface by crates or other objects to allow space for the gas to circulate evenly over the grain surface. The edges of the cover should be weighted down to reduce loss of gas. Methyl bromide and some pour-ons can be recirculated to assure better penetration and even distribution throughout the grain. The fumigant can be recirculated by fitting a duct from the fan to below the cover over the surface of the grain (Fig. 10) and running the fans long enough to move the air several times through the grains. Costs of recirculation include the cost of the ducts and fittings and some additional effort, but it assures a more even distribution of the gas and, in some cases, allows a lower dosage of fumigant to be used.

Applying the Fumigant

Fumigation must be done as a single, complete operation without interruptions. If any problem occurs during the fumigation, the operation should be shut down and completely redone later.

Fumigants are toxic gases and you should make every effort to reduce the time you are exposed to them. Spend some time planning the operation to be sure that the fumigation will be made safely, quickly and completely. Follow these steps:

—Recheck the sealing of the bin.

—Reconfirm grain temperature and levels of fines and moisture.

—Level any peak on the grain and remove any crusting.

—Put the cover in place, if it is needed during fumigation, or arrange it so that it can quickly be put in place immediately after the fumigant has been applied.

—Recheck all calculations (some useful equations are included in the Appendix).

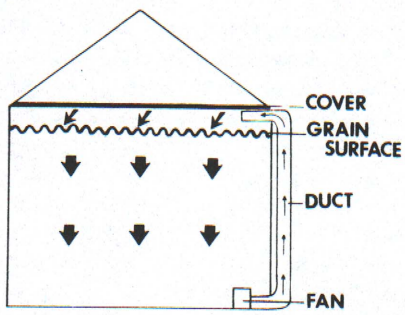

Fig. 10. Some fumigants can be recirculated to aid in their penetration and even distribution. The fan pulls the gas through a duct to the space under the cover at the top of the grain.

—Be sure that you have the right fumigant and safety equipment at hand.

—Lay out the equipment and fumigant so that you can carry out the operation smoothly in as short a time as safety permits ("judicious haste").

—Be sure that two knowledgeable people with the required safety equipment will keep each other in sight during the operation.

—Apply the fumigant on a warm day with minimal winds. Keep alert for problems and shut down the operation if there is some question.

—Post warning placards and put up barriers, if necessary, to keep people and livestock away from the treated bin.

Aeration

The fumigant needs to remain in the grain long enough to assure that the insects are dead. Prolonged exposure to some fumigants will reduce the germination of some seeds, however, and any residual fumigant left in the grain poses a risk, especially if the grain is moved. Therefore, aerate the grain to remove the fumigant as soon as the required fumigation period is complete. Two people wearing the required safety equipment, each keeping the other in sight at all times, should work together on this. Remove any cover and open all vents that were sealed for the fumigation. Then run the fan to exhaust several complete changes of air in the bin. The cover, crates, weights, cans and other equipment in the bin should be removed and barriers and warning placards taken down when aeration is complete. Fumigant gases will dissipate from even the tightest sealed bins in time. If a bin cannot be aerated, it should be opened and the cover and the equipment removed as soon as the fumigation time has passed. The barrier and placards should be kept up and the area around the bin avoided, however, until the gas has all disappeared. This will take a minimum of one week in warm weather to as long as a month in cool weather.

Important Warnings

Fumigated bins should be checked for insects especially carefully. Fumigation is expected to kill all of the insects in the bin, but some may survive to cause a problem later. Stay alert for any signs of insect activity.

Recent notices of residues of the fumigant ethylene dibromide (EDB) in whole and processed grains should alert us to take the following precautions to avoid further residues:

—Avoid repeated fumigations, especially with methyl bromide.

—Apply only the required amounts of fumigant.

—Dry and clean grains with high levels of moisture or fines—which are most likely to absorb the fumigants—before fumigation.

—Aerate the grain thoroughly and avoid moving it until the fumigant has dissipated.

APPENDIX

Some Useful Conversions and Equations

Liquid measure:

1 fluid ounce = 29.57 milliliters (ml, also called cubic centimeters, cc)
16 fluid ounces = 1 pint
2 pints = 32 fluid ounces = 1 quart
4 quarts = 128 fluid ounces = 1 gallon

Weight:

1 ounce = 28.35 grams
16 ounces = 1 pound
2,000 pounds = 1 ton

Standard test weight, in pounds, of one bushel of some grains:

barley — 48	rye — 56
corn, pop — 56	sorghum — 56
corn, shelled — 56	soybeans — 60
dry beans — 60	speltz — 40
oats — 32	wheat — 60

Dry measure:

1 bushel = 1.2445 cubic feet
1 cubic foot = 0.8035 bushels

To change volume, V, in cu. ft. to bu., B:

$B = V \times 0.8035$

For example, a bin with a volume of 4,712.4 cu. ft. (V = 4,712.4) would hold $B = 4{,}712.4 \times 0.8035 = 3{,}786.5809$ bu.

To change bu., B, to cu. ft., V:

$V = B \times 1.2445$

For example, a bin with 1,500 bu. of grain (B = 1,500) would have a grain volume

$V = 1{,}500 \times 1.2445 = 1{,}866.75$ cu. ft.

Calculations of surface area, volume of grain and volume of air space are needed to determine the proper amounts of insecticides to use in stored grains. Some of the common calculations are presented here. The equations were set to be used with a pocket calculator. The measurements represented by the letters in the equations are shown in Fig. 11.

To determine the area, A, of the surface of the grain:

(a) in a rectangular bin:

$A = L \times W$

For example, a bin 20 feet long (L = 20) and 8 feet wide (W = 8) would have a surface area

$A = 20 \times 8 = 160$ sq. ft.

(b) in a circular bin:

$A = 0.7854 \times D^2$.

For example, a bin 23 feet in diameter (D = 23) would have a surface area

$A = 0.7854 \times 23 \times 23 = 415.4766$ sq. ft.

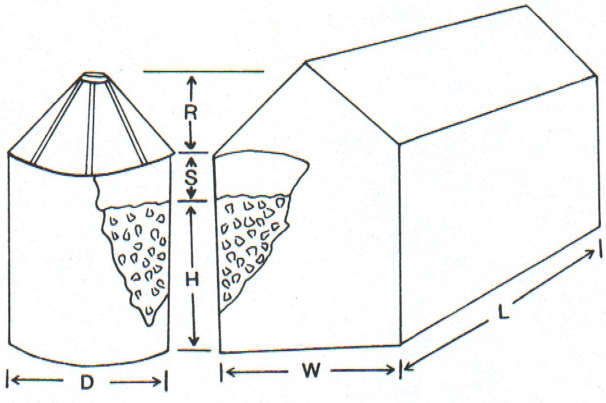

Fig 11. The following symbols are used in the equations for calculating areas and volumes:
D = diameter of a circular bin
D^2 = diameter squared (the diameter multiplied by itself [D × D]
0.7854 = 3.1416 ÷ 4; a constant to permit the use of the diameter, rather than the radius, in the equations
W = width and L = length of a rectangular bin
H = height of grain in bin
S = height of space from grain surface to the eave or rim of the bin
R = height from eave or rim to the peak of the bin

To determine the volume, V, of grain

(a) in a rectangular bin:

$V = L \times W \times H$.

For example, a bin 15 feet long (L = 15) and 10 feet wide (W = 10) filled with grain to a depth of 7 feet (H = 7) would have a grain volume of

$V = 15 \times 10 \times 7 = 1{,}050$ cu. ft.

(b) in a circular bin:

$V = 0.7854 \times D^2 \times H$.

For example: a bin 20 feet in diameter (D = 20) filled with grain to a depth of 15 feet (H = 15) would have a grain volume of

$V = 0.7854 \times 20 \times 20 \times 15 = 4{,}712.4$ cu. ft.

To determine the volume of air space, V, above the grain:

(a) and the peak of a gabled roof on a rectangular bin:

$V = [(0.5 \times R) + S] \times L \times W$

For example, a bin 35 feet long (L = 35) and 18 feet wide (W = 18) filled with grain to 2 feet from the eaves (S = 2) and with a roof peak 6 feet above the eaves (R = 6) would have an air space of

$V = [(0.5 \times 6) \div 2] \times 35 \times 18$
$= (3 + 2] \times 35 \times 8$
$= 5 \times 35 \times 18 = 3{,}150$ cu. ft.

(b) and the cone-shaped roof of a circular bin:

$V = [R \div 3) + S] \times 0.7854 \times D^2$

For example: a bin with a diameter of 30 feet (D = 30) filled with grain to 3 feet of the rim (S = 3) and the cone-shaped roof peak 5 feet above the rim of the bin (R = 5) would have an air space of

$V = [(5 \div 3) + 3] \times 0.7854 \times 30 \times 30$
$= [1.6667 + 3] \times 0.7854 \times 30 \times 30$
$= 4.6667 \times 0.7854 \times 30 \times 30 = 3{,}298.5621$ cu. ft.

MICHIGAN STATE UNIVERSITY

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