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Insects Infesting Stored Grain and Seeds

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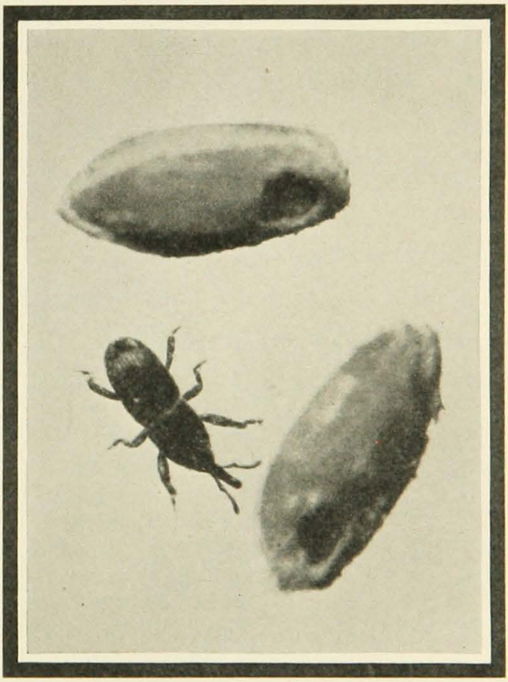

UNIVERSITY OF MINNESOTA
AGRICULTURAL EXPERIMENT STATION

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Insects Infesting Stored Grain and Seeds

Harold H. Shepard

INSECT PESTS became important in stored grain soon after man first learned to keep grain for seed and food purposes. The human race, in its explorations and migrations, usually carried these insects along. For instance, the remains of both granary and rice weevils have been washed from the interior of adobe bricks used about 1770 in building Spanish missions in Lower California.

As various sections of the world became the chief sources of grain supplies, grain was stored in larger quantities and shipped greater distances. Through the development of world trade, many of the most serious pests of stored grain have become cosmopolitan in distribubution. Nevertheless, the civilized world insists more and more on grain delivered free from insect infestation. Grain stored in a large quantity is usually cared for better than the same amount of grain in a number of smaller lots (as on farms). Even so, quantity storage involves many serious problems not affecting small storage. Experts have estimated the total annual loss of stored grain through the work of weevils in the United States to be about 50 million dollars; the estimated total annual insect damage in the United States is placed at about two billion dollars.

This bulletin gives information as to problems and methods in insect control and the specific pests involved, and is intended for growers and consumers of grain and seeds as well as the various intermediate agencies. The results of recent research on general problems in this field have been included, chiefly in tabular form. References to the original publications are given for the convenience of those who need further details.

INSECT PROBLEMS IN FARM STORAGE OF GRAIN AND SEEDS

Because the grower lacks space for storage, a large proportion of wheat and other grains is taken to the grain elevator as soon as possible after threshing. Unless the farmer in Minnesota holds grain over the second season or longer, he is not likely to have much trouble with grain insects. Even then, climatic conditions in this lati-

In 1921 the Minnesota Agricultural Experiment Station published Bulletin 198, "Insects Infesting Stored Grain and Seeds," by Royal N. Chapman. This bulletin was slightly revised in 1932 by the author of the present bulletin. Instead of again reprinting Bulletin 198, the subject matter has been largely rewritten and brought up to date where necessary. The author, however, has drawn heavily fom the original work of Doctor Chapman and wishes by this note to indicate his indebtedness for that assistance.

tude kill the more serious grain pests by freezing unless the grain is kept in large quantity or in a place where the temperature goes but little below freezing.

It is a good plan to provide a separate building for grain storage. The separate granary, of tight construction, can easily be kept clean and may be fumigated should it become necessary. When grain is stored in bins in the barn where fumigation is impossible or gives poor results, it is sometimes necessary to remove most of the insects by fanning the grain and then burning the insects. This process, however, does not remove kernels containing the larvae and eggs.

Grain and seeds are less likely to become infested if kept cool and dry. Seed corn stored in an upstairs room in the house over a period of years is almost certain to become infested, often with insects that migrate throughout the house wherever food is stored. Seed grain and shelled corn that is to be kept a second season or longer may be protected by fanning it each year and cleaning the storage room before the seed is put back.

The most common insect in Minnesota farm grain bins is probably the saw-toothed grain beetle. The Angoumois grain moth is common in corn, especially on the cob. Another common pest of stored seeds is the bean weevil. These pests and other less common varieties are described in this bulletin.

INSECT PROBLEMS OF SEEDSMEN

Seedsmen deal with a product that is to be grown rather than eaten. Any injury that prevents germination and growth of the seeds causes a total loss. Some insects destroy the entire seed, others only the germ; in either case the product is of no value as seed. In addition to this actual destruction, planters hesitate to deal with seedsmen who handle seed that is infested in even the slightest degree. In many cases, a few insects in the seed may mean a high percentage of infestation at the time of harvest. This is because some insects, such as the bean weevil, emerge from the seed in the field and later lay their eggs in the developing beans. The reputation of a seedsman, therefore, is at stake when there are insects in his establishment.

Infested beans and peas have caused much trouble to those who keep them in storage. The insects often leave the germ to be eaten last or avoid it altogether. Consequently, while the weevils are common and destructive, germination tests of seeds that have been treated as soon as the injury was discovered usually make a good showing. The seedlings, however, may be backward because the nourishment has been lost. In wheat and some other seeds the injury may not be apparent from a superficial examination, and the germination test must be relied upon in determining the extent of damage caused by insects.

As a rule only the insects that actually attack the seeds get into seedhouses; consequently, with few exceptions, those that attack seeds in the seedhouse live in these places rather than in the field. Those that attack other parts of the plants usually spend the winter in the field where the crop is grown. The rice weevil, the Angoumois grain moth, and a few others may be brought in from the field in seeds grown in the southern states. Careful inspection will reveal some of the insects, but others may be hidden in the center of the seed, only to come out later and move to other seeds.

The variety and number of insects that the seedsman should watch for when examining a shipment vary with the different seeds. He should be suspicious of all insects found in his seeds and tolerate none.

Temperature and moisture conditions of seedhouses are usually favorable to insects. Temperatures between 40° and 50° F. allow little development of the insects; lower temperatures practically stop development. However, if the seeds are later brought to a higher temperature, development will usually go on. Insects develop most rapidly at about 80° or 90° F. Normally few insects will develop at temperatures higher than 100°, most insects will die in a temperature of 120° in a few hours, and none can stand a temperature of 140° for even a very short time.

Moisture affects insects in much the same way that temperature does. Too much or too little prevents their development; ordinary amounts produce the most rapid development. The seedsman must try to keep the conditions of his seedhouse favorable to seeds but unfavorable to insects. A temperature below 40° F. makes it impossible for insects to develop and yet this temperature does not injure the seed.

The insects may be divided into two groups according to their method of feeding. Those of one group remain in the seeds until they reach the adult stage; those of the other group go from seed to seed and may eat only the germ. Some insects in the first group do not emerge until the seed has been planted. They do not increase in numbers while in storage. The pea weevil is an example. While the damage caused by these insects is not as noticeable as that caused by some others, it is often deceiving. Although they sometimes appear in the early spring and the infested seeds can be condemned or treated, very often their presence is not suspected and the seedsman sells infested seed without knowing it and his customer loses his crop as a result.

Insects that develop in the seedhouse increase in numbers under favorable conditions and cause a great deal of damage, which is evident if the seeds are inspected occasionally. Bean weevils are an example. They pass through generation after generation inside the seeds while in storage. An example of those that go from seed to seed eating only the germ is the Indian-meal moth.

The policy of keeping old seed must be decided by knowing what kind of insects they are likely to contain. When infested with insects that cannot pass a second generation in the storehouse, they may be kept until the second year; all the insects will have died by that time. These insects cannot spread to other lots of seed because they cannot start a new generation until they get out into the field. But if there are insects that produce new generations while in storage, it is unwise to keep the seed.

Fanning infested seeds or running them over a separator often removes a large proportion of the insects in cases of heavy infestation. Fanning is sometimes a good practice for removing insects from seed to be stored a second season or longer, for it reduces the danger of insect injury through longer storage.

INSECT PROBLEMS OF GRAIN ELEVATORS

Large storage elevators have power facilities for turning their grain, to cool and air it at the proper seasons. Insect problems are more difficult to cope with in the smaller country elevators, where such equipment is not available and cleanliness must be the chief safeguard against insects. This factor of cleanliness seems generally to receive too little consideration.

Cleanliness of a grain elevator involves the disposal of grain waste from around and beneath loading platforms, conveyor belts, loose wooden floors—anywhere that grain and grain products, dust, and chaff can accumulate, especially in places that are inclined to be warm and damp.

Once grain becomes infested it should be kept separate from clean lots until it has been treated properly to free it of insects by fumigation or by exposure to low or high temperatures or low moisture conditions that kill the pests. It is well known that dry malt with a moisture content of about 3 per cent never becomes infested with weevils.

The species of insects that attack sound grain are relatively few and cannot do any appreciable amount of damage in milled products, but a number of insects follow after those that attack sound grain. These secondary insects feed upon the hulls left by the others and may cause the grain to heat. They also work in milled products and are a serious pest in mills.

Most insects found in elevators and granaries spend their lives in these places, living on refuse grain and in crevices of empty bins. When the bin is filled, the insects crawl into the grain and multiply. A few insects, as the Angoumois grain moth and rice weevil, enter the grain before it is threshed and are brought to the granary with it, but these are exceptions and this occurs only in the South. In Minnesota the grain insects are limited to the granary and the elevator, because of the low temperatures during the winter.

Modern concrete elevators are easily cleaned and may be kept free from insects with little effort. It is much more difficult to control insects in wooden buildings with cracks and crevices; they require careful cleaning before being refilled. Careful cleaning each season will reduce the trouble from insects as nothing else will. The little time spent for this each year may save having to spend a much longer time in freeing the place from insects that have become established, and it may prevent a heavy loss of grain.

When the temperature of the grain remains below 40° to 50° F. there is no danger of further damage, but if the temperature rises the insects become active in a short time. Grain that has been kept for some time and has not heated often has very little oxygen near the center of the mass and this lack of oxygen reduces the number of insects. For this reason it is not wise to take grain out of storage and air it when there is no evidence of its heating.

INSECT PROBLEMS OF TRANSPORTATION COMPANIES

Railroad boxcars in which grain and food products are shipped are often made with double walls having space between. Insects from an infested shipment may crawl between the walls, feeding there in accumulations of grain, and may enter later shipments that were originally free of pests. Cars should be thoroughly cleaned before reloading, as should also boats that carry such material. If it is impossible to clean them thoroughly, they may be fumigated as described on pages 26 to 29. The doors should be tightly closed and the gas allowed to act for 8 or 10 hours before airing.

The presence of moisture is an extra hazard in boat transportation because it increases the moisture content of grain or other food products enough to encourage insect pests that could not otherwise exist in them. Under boat conditions grain mites cause trouble more frequently than elsewhere and may become particularly serious when loaded grain boats are tied up at the docks over winter.

Often the carrier is blamed for the infestation of shipments in its care. In order to place the responsibility for such damage, it is necessary to determine the history of the shipment, the species of insect involved, and the stage in which it was when detected. Different species of insects have differing habits and require different lengths of time to develop at ordinary temperatures. An intimate knowledge of the details of the life history of insects is required in order to trace accurately the origin of an infestation. It is best in each case to seek the advice of an entomologist.

RELATION OF INSECTS TO GRAIN INJURY

Often the amount of grain actually eaten by the insects is not as important as the spoilage of the grain by factors secondary to the feeding of the insects and the potential danger to nearby grain through insect reproduction and spread.

Table 1. Respiration of Sound and Weevily Wheat at Different Moisture Contents; Temperature, 77° F.

Per cent moisture content	Milligrams carbon dioxide produced in 24 hours		
	100 grams sound wheat	100 grams wheat with 100 rice weevils	100 grams wheat with 70 granary weevils
8.7	trace	10.1	18.1
10.7	trace	20.0	25.6
14.0	0.67	26.7	25.0
15.2	1.00	27.4	25.6
17.4	13.2	27.3	27.7

Table 2. Respiration of Grain Weevils in Wheat at Different Temperatures

Temperature ° F.	Milligrams carbon dioxide produced per gram of insects in wheat	
	Rice weevil	Granary weevil
50	13.8	12.3
59	45.5	35.4
68	110.4	76.6
77	185.5	155.8
86	219.1	201.5
95	250.0	218.8
104	69.9	138.3

It is generally known that heating of grain is sometimes initiated by insects, but the end products of the use of the grain as food by the insects have only recently been shown responsible. These products are water, heat, and carbon dioxide. The first two are well known to be important factors in the spoilage of grain. The data in tables 1 and 2 give a good idea of the magnitude of insect activity in grain. They are taken from Minnesota Technical Bulletin 109 by David L. Lindgren, 1935, "The Respiration of Insects in Relation to the Heating and Fumigation of Grain."[1]

Grain that shows very much respiration is likely to heat and spoil. Table 1 shows that insects increase grain respiration tremendously. Moisture is given off by both weevils and grain in proportion to their carbon dioxide production. Hence the insects may even start the process of spoilage in grain that would otherwise be in good condition for storage. The lower the temperature, the less the danger from insect activity (table 2).

[1] Corrections should be made in Minnesota Technical Bulletin 109, page 18, second paragraph, to read:
" . . . . it would take 100 rice weevils or 70 granary weevils about five days at 25° C. to raise one kilogram of wheat one degree centigrade, ... One gram of uninfested wheat at a moisture content of 15.2 per cent will require from 6 to 15 days to be raised one degree Centigrade, or at a moisture content of 17.4 per cent it will require from 0.7 to 1.1 days, ..."

INSECTS THAT CAUSE DAMAGE TO STORED GRAIN AND SEEDS

Beetles and moths or their larval ("worm") stage are responsible for most of the losses to all classes of stored food products. A group of miscellaneous insects includes several that at times may be just as destructive as beetles or moths. Among these are mites, which are not insects at all, and book lice.

It should be kept in mind that insects attacking unmilled grains are, in general, quite distinct from those that attack milled products. One general exception is that insects attacking unmilled wheat will also attack macaroni, spaghetti, hard biscuits, and other hard products that in consistency resemble the wheat berry more than flour or meal. As a result, when flour is stored near wheat that is infested with weevils, a few weevils may enter the flour, but they cannot reproduce in it, hence they will cause little damage. But if macaroni is stored near the infested wheat, it will be seriously damaged. If wheat or macaroni is stored near flour that is infested with flour beetles, there is little danger of either the wheat or the macaroni being injured, for flour beetles have difficulty in attacking sound grain or hard cereal products. If the wheat has first been injured by weevils, it will consist of hollow berries that the flour beetles can attack in the same way as flour or meal.

There is a great deal of literature on the insects attacking grain and seeds. For descriptions, life histories, and habits, consult the references listed at the close of the bulletin.

LIFE HISTORY OF A TYPICAL INSECT

All insects hatch from eggs, with the exception of a few that are born alive. A typical life history of a beetle is as follows: The eggs, which may be only one fiftieth of an inch long or less, hatch in a week or two under summer conditions. The larvae or "worms" are very small when they first emerge from the eggs. As they eat and grow, they shed their skins periodically; their heads are larger after each successive molt. When they reach their full size, they feed for a time and again molt their skins. They then change from larvae to pupae. The pupa is inactive. It does not move about or feed. During this resting stage the larva is transformed into an adult beetle. During the last days of the pupal stage, which usually lasts about ten days, depending upon temperature and other conditions, the adult organs can be seen through the thin skin which is to be molted when the adult emerges. The larvae of most moths and of a few beetles form a cell or cocoon in which the pupal stage is spent.

All the growing of an insect is done in the larval stage. Adult beetles feed and may live for a year or more, during which time they crawl or fly about. Adult moths feed very little, if any, and live for only a few days or weeks. They mate and lay eggs but never grow.

The life cycle of these insects consists of four stages: adults, eggs, larvae, and pupae. With this in mind, no one should ever believe any of the stories about insects developing spontaneously from the germ of the wheat or from anything other than insect eggs.

DESCRIPTIONS OF THE PRINCIPAL INSECTS INFESTING STORED GRAIN AND SEEDS

Structure of a Typical Insect

To understand the descriptions of the insects herein discussed, it is necessary to know the general structure of an insect. The body of both the larva and the adult is divided into the head, thorax, and abdomen (see figure 1). The head bears the antennae (or feelers), the eyes, and the mouth parts. The thorax has three subdivisions, each bearing a pair of legs, and in the adult each of the last two subdivisions bears a pair of wings. In beetles the first pair of wings, the elytra, are hardened, forming a cover for the hind wings, which are folded underneath when at rest. In moths both pairs of wings are covered with dustlike scales. The abdomen of the adult has no appendages for locomotion.

The larva has no wings, and the abdomen is usually much longer than that of the adult. The thorax usually so much resembles the abdomen that it can be distinguished only by the legs. The larvae of moths usually have fleshy legs on the abdomen. These are called

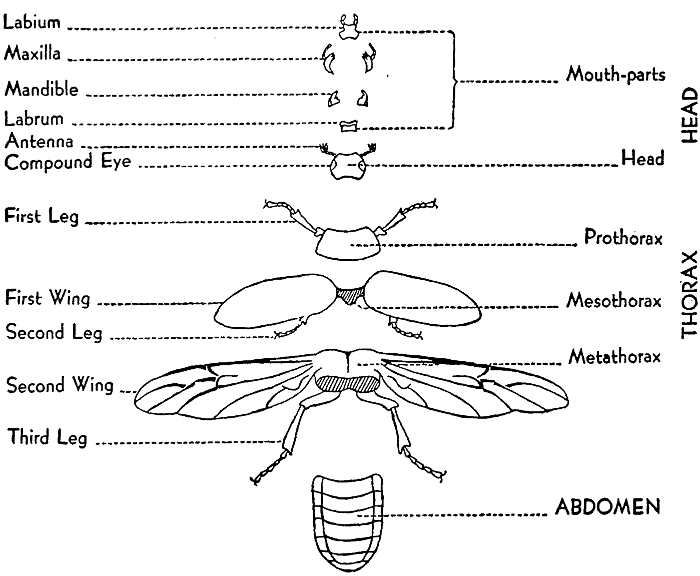


FIG. 1. Body of adult beetle separated to show parts (after Chapman)

prolegs to distinguish them from the true legs, which are found on the thorax. As larvae grow from the time they hatch until they are ready to transform to adults, it is not possible to give measurements that will be of any value in determining the species to which they belong. The larvae of some of the larger beetles become so much larger than those of the smaller beetles that they can easily be distinguished during the last part of their development, but when they are newly hatched they are small like the others.

Grain Weevils

Sitophilus granarius (L.) and *S. oryzae* (L.)

The term "weevil" is often applied to any small beetle occurring in a grain bin, in milled feeds, or in flour and other food products. Properly speaking, however, a weevil is a beetle that has a slender snout. Other kinds of beetles should be called simply flour beetles, tobacco beetles, etc.

Two species of true weevils affect grain in this region, namely, the granary weevil, *Sitophilus granarius* (L.), and the rice weevil, *S. oryzae* (L.). Both species are cosmopolitan in distribution, although damage by them is particularly serious in warm climates. The granary weevil prefers a somewhat cooler climate than the rice weevil. Minnesota winters, however, are too severe for survival even of the granary weevil, unless it is well protected, as, for instance, in grain stored in quantities large enough or locations warm enough to prevent adequate cooling of the center of the grain mass. Although the rice weevil sometimes overwinters here, it is less likely to than the granary weevil. Shipments of grain coming into the state contain the granary weevil more often than the rice weevil unless they come from some distant point to the south.

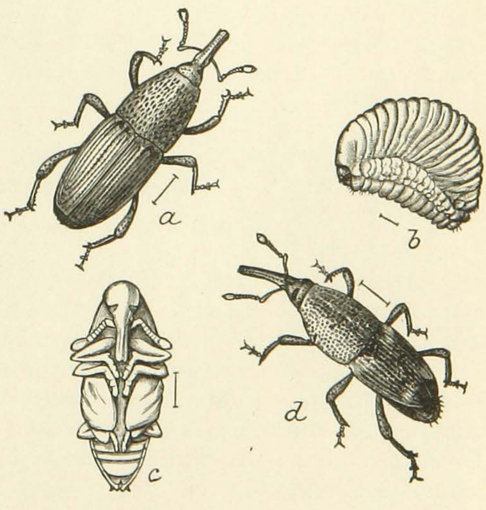


FIG. 2. Granary weevil, *Sitophilus granarius*, and rice weevil, *S. oryzae*

a, Granary weevil adult; *b*, larva; *c*, pupa; *d*, rice weevil adult (from Chittenden)

The granary weevil is a shiny, reddish-brown beetle about one sixth of an inch in length, and with a long "snout" or proboscis. The females make small holes in the wheat kernel in which the eggs are laid. The larvae hatch and spend their lives within the kernels as legless grubs and eat out the interior of the kernels. Only a shell remains when the insects reach maturity.

Development from the egg to the adult requires four weeks or more. The adult beetles as well as the larvae feed on wheat, or on corn, oats, barley, or rye. Macaroni and other hard products, such as pearled barley, are also infested by these beetles. However, they cannot survive and reproduce in milled products. The adults may feed upon such material for a short time, but the larvae require hard masses of food at least as large as a wheat kernel for the completion of their development. Adults may live a month or two without food, depending upon the temperature, and for seven or eight months under normal food conditions.

The rice weevil is similar to the granary weevil in appearance, habits, and development. It differs, however, in being smaller, not as flat, and is dull dark brown with four indistinct light spots on the wings, whereas the granary weevil is shiny chestnut brown without spots. The rice weevil is a more active insect than the granary weevil. The latter cannot fly since it lacks functional wings; the rice weevil is a vigorous flier. In fact, in the South as far north as Kansas the rice weevil may infest shocked and stacked grain outdoors. In Minnesota it must depend upon transportation of its food as a means of spread. This species is said to be the most important insect pest of stored grain in the United States.

The higher the temperature and the moisture content of grain, the better able are weevils to gain a foothold in it, building up a population to the point where the grain may go out of condition very rapidly. Weevil development and injury are relatively slow either at temperatures much below 70° F. or at grain moisture contents of much under 13 per cent. Above these figures, development and injury increase rapidly.

Lesser Grain Borer

Rhizopertha dominica (Fabr.)

Although the lesser grain borer is seldom found in grain reaching Minnesota, it is a serious pest of whole grain in most of the large grain centers farther south. It has been common in the Gulf States for many years. Its presence in large numbers in midwestern cities, however, seems to date from the time of World War I when large supplies of infested wheat came into the country from Australia; hence the name "Australian wheat weevil" by which many grain dealers know it.

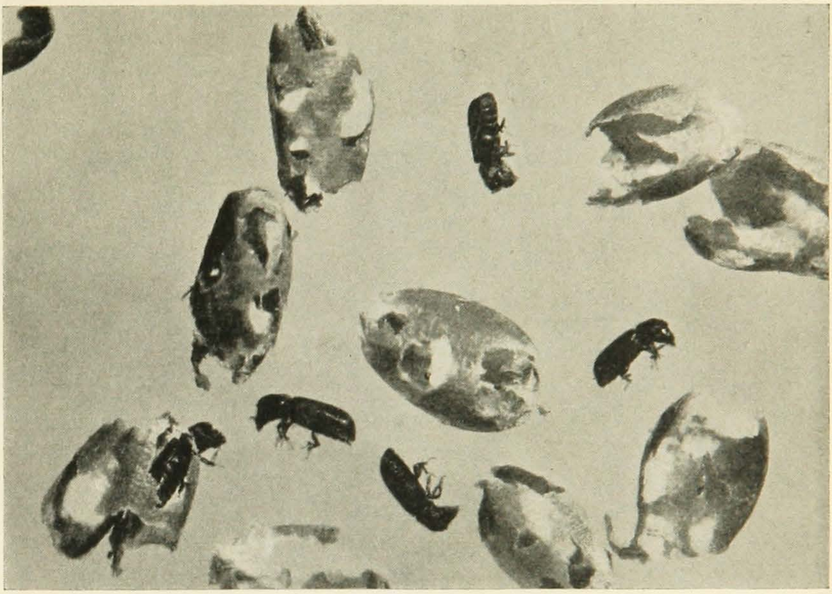


FIG. 3. Lesser grain borers and their work in wheat kernels

The lesser grain borer is of smaller size than the grain weevils, of a cylindrical form with the head turned under the thorax and armed with powerful jaws to bore into grain. It flies freely. Continuous feeding by this insect will eventually reduce grain to a mere handful of bran. Since the grain borer can develop successfully in grain containing only about 10 per cent moisture, considerably below the requirement for the grain weevil, rather dry grain may be damaged provided the grain is warm enough.

The eggs are dropped singly in accumulations of grain particles or are attached in bunches to the grain kernels. The whitish grubs crawl on the grain, feeding on flour particles or damaged kernels, then bore into the kernels to complete their development. Development requires about the same time as for weevils, that is, about a month from the egg to the adult stage under summer temperature conditions. The species apparently is even more dependent upon warmth than is the rice weevil for successful development.

Angoumois Grain Moth
Sitotroga cerealella (Oliv.)

The Angoumois grain moth, a serious pest of unmilled grain, is second only to the grain weevils in destructiveness and is especially troublesome in corn, both shelled and in the ear.

The adult moth is small, with a wing expanse of about half an inch, and is buff or light grayish-brown with a satiny luster. It may

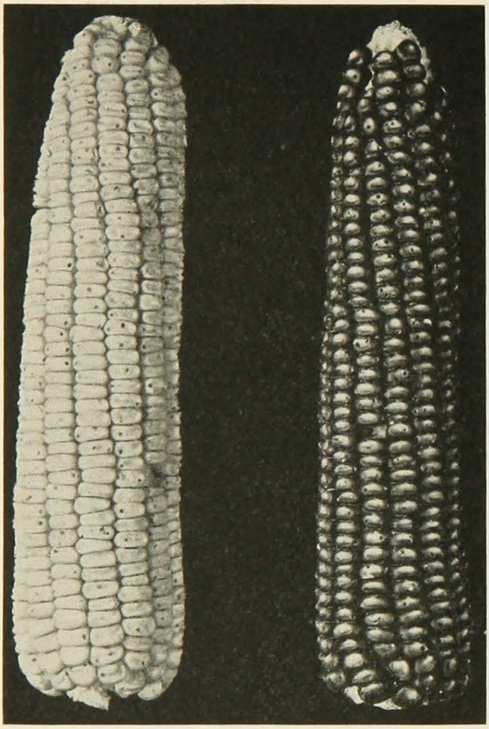


FIG. 4. Corn ears badly injured by the Angoumois grain moth

be distinguished from the other common moths infesting stored products by the narrow, pointed wings bearing wide fringes. The eggs are laid on or near the grain; they are white when laid but soon change to pink or reddish. The newly hatched larva bores into a kernel where it spends its developmental life. Under favorable conditions the cycle from the laying of the egg to the appearance of the full-grown moth may be passed in five weeks.

In the South the adult moths lay their eggs on the green grain in the field. The larvae hatch and enter the kernels, which are entirely hollowed out by the time the larvae reach maturity. The second generation of moths lays eggs about harvesttime. Wheat in the stack is often damaged. After the wheat is in the granary, the moths continue to work and pass through generation after generation; six a year have been recorded where the temperature is high.

In Minnesota the work of this insect has been noticeable in seedhouses and granaries. When corn or wheat has small round holes in the kernels, one each in wheat, but several in some kernels of corn, one may be sure that the Angoumois grain moth is present. All infested material should either be destroyed or treated as described on pages 24 to 29.

Bean Weevil
Acanthoscelides obtectus (Say)

The bean weevil causes a great amount of damage to beans in storage. Any case of "buggy" beans is almost certainly a case of bean weevil.

The adults vary greatly in size, averaging about one eighth of an inch in length. The wing covers are mottled with light and dark spots. The larvae are legless grubs.

The eggs may be laid in the pod in the field. The larvae burrow into the beans and eat out a cavity. When mature they form a cell near the surface and transform within it. A small round spot can be seen on the bean after this cell has been formed. When the adult is ready to emerge, it removes a portion of the outer coat of the bean, leaving a circular opening through which it emerges.

If the temperature is high, the life cycle may be only about 30 days. The fact that the pest continues to breed while the beans are in storage makes it serious. If the temperature is high enough, the adults will emerge throughout the winter and lay their eggs loosely among the dry beans. Thus they multiply throughout the year and if not checked will destroy the beans entirely. Several related weevils which infest beans and cowpeas in the South attach their eggs to the surface of the bean.

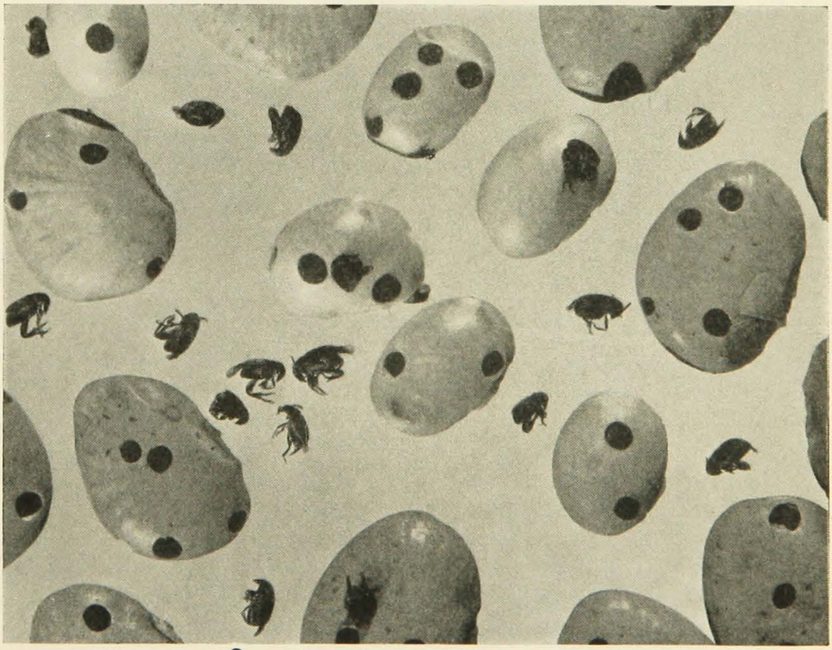


FIG. 5. Beans infested with bean weevil, *Acanthoscelides obtectus*

The best preventive measure is to plant beans that are free from all weevils. The seed should be carefully inspected, for if weevils are present they will emerge in the field and the new crop will be infested. If the seed is clean and no infested beans are growing near, the crop will be free from weevils.

If the beans are infested, the weevils should be killed at once. This may be done by fumigating with a gas or by heating the beans. For small amounts of beans that can be conveniently placed in the oven, heating is the more convenient method. For larger quantities, the use of gas is better.

If beans are stored over winter where the temperature is less than 40° F., weevils will not develop even if they are present. If beans or peas are stored in heavy cotton sacks rather than loosely woven bags, weevils cannot spread from infested lots to uninfested ones.

The pea weevil, *Bruchus pisorum* (L.), resembles the bean weevil in general appearance but is slightly larger and has more conspicuous markings on the wing covers. The adult beetle is about one fifth of an inch long.

The general description of the life history of the bean weevil will apply here with one important exception—the newly hatched larvae of the pea weevil cannot enter dry peas, and so the insect cannot breed continuously in stored peas. The eggs are laid on the pod in the field and the larvae enter the green peas. If the peas are put into storage for seed, the development is completed and the adult normally emerges the following spring. However, if peas are exposed to a high temperature they emerge a little earlier. If the peas are infested they may be kept in storage through the second winter with the result that all adult beetles die and leave no progeny. Care should be taken to prevent any adult beetles from escaping to the pea fields to lay their eggs.

Saw-Toothed Grain Beetle

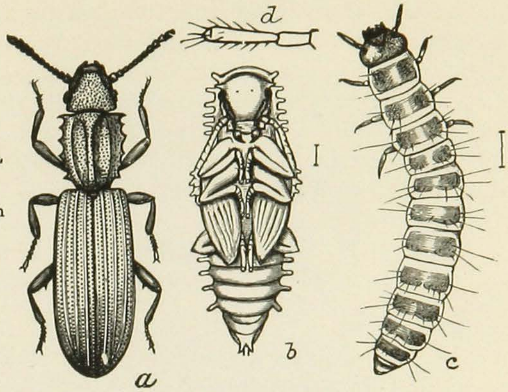
Oryzaephilus surinamensis (L.)

The adult saw-toothed beetle is slender, brown, and only about one tenth of an inch in length. The sides of the thorax bear six tooth-like projections from which it gets its common name. This is one of the most common beetles occurring in flour, cereal products, and many other foods.

Figure 6 shows the larva, pupa, and adult. The thorax of the adult and pupa distinguishes them from all other beetles. The larva is more difficult to distinguish from those of other species. Its great activity and the large relative size of the legs and the antennae are the best guides, together with the species of adult beetles associated with it.

FIG. 6. Saw-toothed grain beetle, *Oryzaephilus surinamensis*

a, adult; *b*, pupa; *c*, larva (from U. S. Dept. of Agr.)



The adult female tucks its eggs into crevices where they hatch in a week or less. The larvae are active and crawl about as they feed. In three weeks or more they become full-sized and form pupal cells by sticking particles of material together, sometimes in a protected crack. The pupal stage of 10 days or less is spent in the cell, after which the adult beetle emerges. The whole life cycle, from egg to adult, requires from three to 10 weeks, depending upon moisture and temperature conditions.

Under the impression that it is a grain weevil, this species is the one Minnesota farmers send in most often for identification. Although it is found frequently in large numbers in stored seed corn, in oats that have been held over one or more seasons, or in other grain in farm bins, it can do little actual damage to whole grain by feeding.

The insect often builds up a large population in and around feed bins and troughs, from which it migrates rapidly to the grain bins where it can feed only upon grain particles in the chaff and grain. Overstocking the feed room so that considerable quantities of ground feeds are exposed to these insects for a period of two months or more may lead to the development of undesirable numbers of these or similar cereal pests that overrun the grain bins. Although these insects may be doing no actual damage in the grain, the grain dealer does not always distinguish between such an insect and the weevil which really does injure the grain.

Often a large proportion of the insects may be removed by running the grain through a fanning mill; they should then be destroyed before they have an opportunity to escape. If much grain is to be kept in the barn along with the hay and ground feed supplies necessary for keeping livestock through the winter, the farmer needs to keep his barn in better order than if he keeps his whole grain in a separate granary.

Often the saw-toothed grain beetle is reported in large numbers in seed corn stored in the farmhouse. After the corn is removed in the spring, the storage room should be cleaned thoroughly so there will be little or no chaff and meal to provide food for the insects. Cleanliness in such storage is important, for these active insects will migrate all over a building. They will show up soon in the kitchen and infest flour and other cereals as well as raisins, nuts, and chocolate. The insect is so small that some are likely to escape even a thorough cleaning by hiding in cracks in the floor and walls.

Indian-Meal Moth

Plodia interpunctella (Hbn.)

This moth infests almost any food material and is one of the most common pests in grocery stores. The adult has a wing expanse of one half or three fourths of an inch. One of the best distinguishing characters of the adult moth is the light grayish marking on the inner third of the fore wings. When the moth is at rest, this appears as a light band across the anterior third of the wings. The rest of the wings is reddish brown.

The larva is about one-half inch long when fully grown and varies in color. The ground color is whitish but may be variously tinted with yellow, green, or even pink.

The Indian-meal moth sometimes occurs in large numbers in shelled seed corn. The caterpillars ordinarily feed in broken material. Their presence is indicated by the webbing or silk which they spin wherever they feed. Often rather extensive injury to the germ of sound kernels may occur.

Cadelle

Tenebroides mauritanicus (L.)

The adult is a shiny black beetle about one third of an inch long. It has a constriction between the head and the thorax that distinguishes it from the adult of the "meal worm" (*Tenebrio*). The larvae are about three fourths of an inch long when fully grown and are much broader and softer than the other beetles found in stored food products. They are of a dirty white color except for the black head

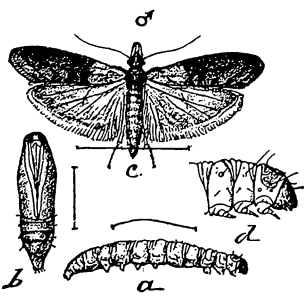


FIG. 7. Indian-meal moth, *Plodia interpunctella*

a, larva; *b*, pupa; *c*, adult; *d*, head and thorax of larva (from Riley and Howard)

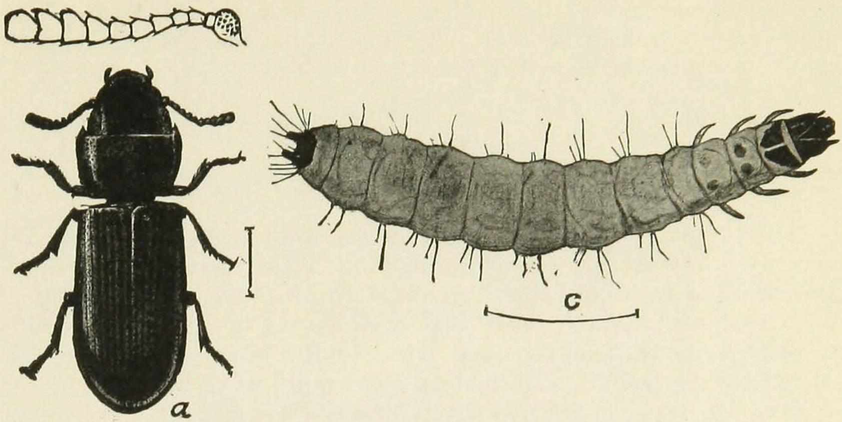


FIG. 8. Cadelle, *Tenebroides mauritanicus*
a, adult with greatly enlarged antenna above; c, larva (from Chittenden)

and dark brown spots on the thorax and two brown spines on the end of the body. The pupa is found in a cell formed of flour or other material and is soft and white, with an old larval skin clinging to the end of its body.

There has been some disagreement as to whether this beetle should be considered a "grain," a "flour," or a "meal" beetle. Inspection of storage places has shown that it is usually found in ground cereal products. It can attack unground grains, as wheat and oats, and usually confines itself to the embryo, which shows that it cannot eat more than a small portion of unground grain, the embryo being all that is soft enough. However, when seed grain has been attacked it is just as completely ruined as if it had been consumed.

It has been said that the cadelle is beneficial to a certain extent, in that it attacks and destroys other grain insects. Experiments have shown that under ordinary conditions this is due more to chance than anything else and that it does not make any special effort to devour other insects. When feeding in grain, where its food is limited, it will readily eat other insects.

The larvae are very troublesome because of their habit of eating holes in paper sacks and other food containers. As they are among the largest of the insects that infest stored food products, the holes make it possible for practically all other insects to enter the packages in which these beetles have eaten holes. They may burrow into wood adjoining grain in bins, pupating or hibernating there, possibly for months while the bin is empty, coming out to infest a fresh lot of grain placed in the bin.

This beetle, like the "meal worm," requires a year for complete development from the egg to the adult. This is a distinct advantage to all who are trying to keep their storage places clean. If the place is thoroughly cleaned several times each season there is little chance that any of the larvae will survive.

Large Cabinet Beetle

Trogoderma ornata (Say)

This insect is a general feeder in dry animal matter as well as vegetable matter that contains relatively large amounts of protein and oils. The adult, about one eighth of an inch long, is black spotted with gray and light brown. The larva is brown above and white below, the body being covered with reddish-brown hairs that are slightly longer at the posterior end to form a sort of tail.

The egg stage lasts from 10 to 16 days. The larvae vary in the length of time required for development, even under favorable conditions. In somewhat unfavorable foods the life may be greatly lengthened. The larval stage, therefore, varies from five months to nearly four years. The pupa develops in 11 to 17 days. Adult beetles live from 10 to 32 days after reaching maturity.

A second species of *Trogoderma* (*T. versicolor* Creutz.) is a common related insect with about the same appearance, habits, and life history. The two are distinguished in that the eyes are round in *T. ornata* and emarginate in front in *T. versicolor*. In the course of

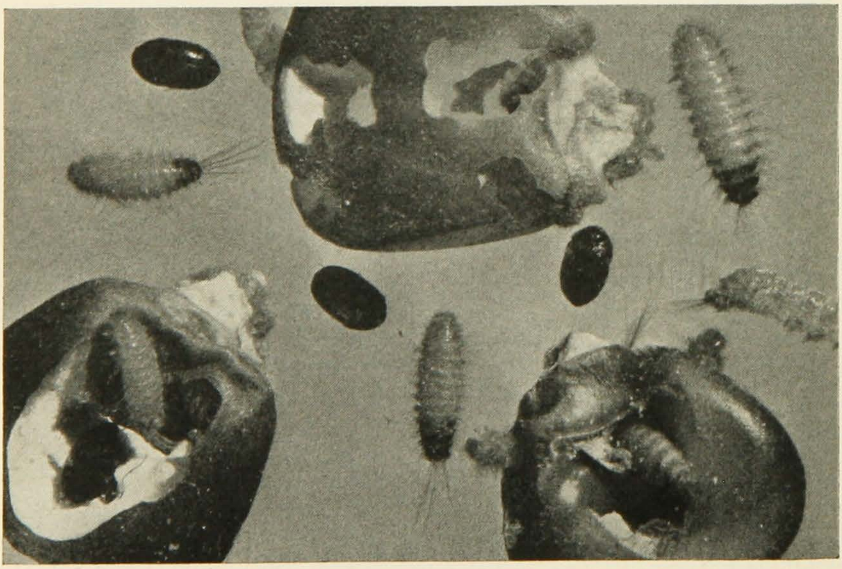


FIG. 9. The large cabinet beetle working in shelled corn

time it is likely that differences in their habits will be recognized.

The two species are often found in seed collections or seeds stored for periods long enough for their development. They have been reported in the seeds of flax, castor bean, cayenne pepper, cotton, peanut, clover, rice, wheat, corn, pumpkin, bean, and millet.

Psocids or Book Lice

Several species of small louse-like insects, known as "book lice," occur in grain, the most common one probably being *Troctes divinatorius* (Müll.). These insects are usually tiny, pale, soft-bodied, wingless creatures. However, some are darker colored and some develop winged individuals. Because of their small size they may be confused with mites, but they are true insects with six legs, distinct head, and relatively long antennae. Book lice do not produce the characteristic sweetish odor that mites give off when present in grain in large numbers.

Book lice are seldom of any great importance in stored grain, although they have been known to form a layer of live and dead insects an inch deep over the surface of shelled corn in a bin. Apparently these insects do no damage to grain and seeds unless they become so numerous as to cause the material to heat, an effect which is rare. The insects feed only in dust and broken material from the grain, sometimes becoming numerous in dust around conveyor belts in seedhouses. Clover seed has been seen rather heavily infested with winged book lice, but the insects were probably not injuring the seed. Fanning will remove most of the lice and will aerate the material so that further development is not likely.

Grain or Flour Mites
Tyroglyphus farinae (DeG.)

Mites are microscopic, pale, soft-bodied creatures closely related to spiders. Several species are found in grain, flour, and other stored food products, but the one most often injuring grain is *Tyroglyphus farinae* (DeG.). The specimen in figure 10 belongs to a closely related species, probably *T. longior* (Gerv.), which looks very much like the common *T. farinae* and which also occurs in stored products of various kinds. When present in large numbers mites give off a sweetish, musty odor which is so characteristic that one who has had experience can detect their presence without seeing them.

"The small size of mites and their habits of life make them difficult to combat. The females usually lay from 20 to 30 eggs, although there is reason to suspect that they sometimes lay many more. The eggs are scattered about in the food and are small oval iridescent structures which sometimes adhere to particles of flour and at other times are entirely free. Their period of incubation varies from three

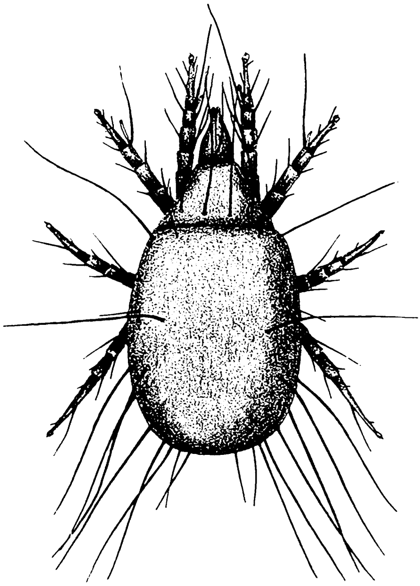


FIG. 10. Mite, *Tyroglyphus* sp.

or four days to several weeks depending upon temperature and other factors," according to R. N. Chapman.

"The larval stage lasts for five or more days and the nymphal stage for six or more days depending upon the variable environmental factors. Thus the entire life cycle may be shortened to about seventeen or eighteen days under the most favorable conditions of high temperature and humidity."[2]

It may safely be said that there is no more difficult pest to combat. Its small size, rapidity of multiplication and development, and peculiar habits fit it for life in stored food products. Under certain conditions, some of the mites pass into a resting stage known as "hypopus." In this condition they are covered with a hard crust which prevents them from drying out. They can then live without food for months, during which time they may be blown about with dust or carried about on mice or flies. If at any time conditions are favorable, they will emerge from this peculiar stage and reproduce. All the mites may seem to have disappeared from a bin which was formerly infested, but as soon as new material is stored in it they again appear.

There are often several species of predaceous mites associated with *Tyroglyphus* and in some cases it has been supposed that they preyed upon *Tyroglyphus*. Observations have shown that while the predaceous mites do actually destroy many of *Tyroglyphus*, they

[2] Eighteenth Rept. State Ent. Minn., 1920, p. 21.

have least effect where there is enough moisture for the rapid development of the host, and the greatest effect in drier places. However, in these latter places many of the *Tyroglyphus* are in the hypopial stage, in which they apparently escape their enemies.

A list of the foods of these mites includes about every one known. All sorts of cereal products, cottonseed and flaxseed meals, grains, cheese, meats, dried fruits, bulbs, roots of plants, skins, hair, feathers, and many other organic materials are known to have been attacked.

It has recently been discovered that mites require a minimum of about 11 per cent of moisture in their food. Hence many of the foods listed above may remain free from mites as long as the moisture content is below this point. However, when a small portion of the food has the required 11 per cent of moisture, the mites start work in this portion, provided it becomes infested. When once started, they raise the moisture content of the surrounding material by giving off moisture themselves. In this way they can cause trouble in places which originally seemed too dry for them.

Screening and fanning of grain and seeds will usually reduce an infestation and aerate the material sufficiently to overcome the trouble. Sometimes turning the grain or running it into an empty elevator to cool and aerate it is all that is necessary.

In case of a serious infestation, strenuous measures may be necessary. Fumigation is not very effective. A careful inspection should be made and all infested material should be burned or heated to a temperature of at least 140° F. After premises are cleaned, all corners, cracks, and crevices should be thoroughly sprayed with a contact spray. If there is no danger of fire, kerosene may be used.

Minor Pests of Stored Grain

Several species of small beetles sometimes occur in large numbers in grain that is in poor condition, either because of high moisture content or because of excessive weevil injury. Infestation by these pests usually is a sign that something is wrong.

Grain or seeds in good condition do not often harbor the foreign grain beetle, *Ahasverus advena* (Waltl.), although this species is relatively common in Minnesota and feeds in damp or moldy grain.

The square-necked grain beetle, *Cathartus quadricollis* (Guér.), is not common in Minnesota but is sometimes found in accumulations of small grains. In the South, where it is said to be essentially an outdoor species, it feeds on damaged or exposed corn ears, especially on the germ.

The flat grain beetle, *Laemophloeus minutus* (Oliv.), is the smallest beetle commonly found in stored grain. It is flat and reddish brown with relatively long antennae without swollen tips or clubs. It is not a primary pest of grain, but is usually associated with grain weevils, feeding on the injured kernels as they become moldy.

GRAIN-INSECT CONTROL

Prevention

In Minnesota new grain does not become infested with injurious insects until it is threshed; it becomes subject to their work during transportation and storage. Hence it is particularly important in this region that the new crop be kept separate from old lots. Old grain should be entirely removed from a bin, and the bin swept out thoroughly before the new crop is put in. Seeds for planting the grain that is kept over from one season to another should be stored some distance from other grain whenever possible. Because insect pests of feeds often migrate to grain bins to feed in the grain chaff, milled feeds for the stock and poultry are best kept some distance from the granary. Although they may do little actual damage to the whole grain, the latter will be graded lower when sold with insects present.

Cleanliness is highly important wherever grain is stored. Grain dust and chaff must not be allowed to accumulate, for various insects thrive in such material and migrate into the grain. Not only floors in and around a grain bin should be kept clean, but also the upper surface of timbers, elevator pits, basements, and the space under the wooden floors of country feed stores that do a grain elevator business.

Methods of storing grain and seeds to protect them from insect attack are cold storage, dry storage, and airtight storage. Cold storage is the oldest and most common method. Experiments have shown that there is very little insect activity at 45° F. and that nearly all insects are inactive at 43°. Therefore, a temperature of 40° or 43° F. is all that is necessary. A lower temperature involves needless expense.

It has been shown that few insects can develop in cereal products whose moisture content is 20 per cent below normal. While it is necessary to make more specific recommendations with regard to dry storage, when cold storage is impossible it is of the greatest importance to watch the moisture content of the products placed in storage. If the percentage of moisture is high, it is advisable not to attempt long storage in summer.

Airtight storage for the prevention of insect attack in cereal products is a recent development. Results obtained experimentally in England indicate that it might be applied to large-scale storage. Insects cannot live without a certain amount of oxygen, and carbon dioxide in rather high concentrations is poisonous to them. Since both the weevils and the wheat consume oxygen and give off carbon dioxide, it is only a matter of time until the atmosphere in airtight storage will kill the insects.

Temperature

Cold—Aside from the fact that storage at moderately low temperatures is effective in the prevention of insect damage because the insects lie dormant, still lower temperatures may be used to kill stored grain insects for they are highly susceptible to freezing.

Cooling of grain at the terminal elevators by dropping it through cold air in winter is a common practice in elevator management. The large masses of grain involved will not warm up much, even during the hot summer months. The low temperatures attained will not kill many grain insects but will keep them inactive so they cannot injure the grain either by their feeding or by the products of their respiration.

In the smaller masses of grain stored on a farm the temperature in the center of the grain in winter may be low enough, however, to kill all grain pests, with the exception of the saw-toothed grain beetle which seems to be resistant to cold. Farm grain bins situated near or over horse or cow stalls do not always reach a temperature low enough to kill grain weevils.

Small samples of grain or seeds such as beans may be freed of insects by exposing to zero weather for a few days. Some establishments take advantage of the low temperatures of the Minnesota winter by draining the water pipes and opening the buildings for the week end. Such a practice is worth many dollars that would otherwise be lost in insect-damaged goods or spent for fumigation service.

The following data were published in 1926 by William Robinson and give the time of exposure to different temperatures required to kill the grain weevils, *Sitophilus granarius* and *S. oryzae*. The highest temperature given for either species is approximately that at which the species becomes merely inactive.

Heat—Insects and all their stages are killed by heating to 120° or 130° F. The lower the temperature, the longer the exposure necessary to obtain results. In general, the heating of grain is not practical

Table 3. Time Required to Kill Grain Weevils at Various Low Temperatures

Temperature ° F.	Granary weevil	Rice weevil
45	....	350 hours
35	875 hours	160
30	545	98
20	100	14
10	70	3.5
0	2.5	1.5

unless the moisture content is excessive; otherwise there is weight shrinkage, an obvious disadvantage when grain is sold by weight. Where a grain drier is to be used anyway, it may be made to give insect control.

Seeds in sacks and any cereals or other products known to be infested may be heated in a room designed for the purpose. A seedhouse or mill may well provide a small, well-insulated room with a large radiator for heating the room to about 130° F. and keeping it at that temperature. Sacked material should be left in the room until the center of the sacks has reached the temperature in the room.

In heating small quantities of beans or other seeds, these directions for oven treatment should be followed. The seeds should be spread rather thinly in shallow pans and heated to from 120° to 145° F. for several hours. The temperature should not be raised much higher because the resulting plants may be weakened or germination destroyed entirely. Temperatures below 120° may not heat the seeds through sufficiently to kill the insects in the time they are exposed.

Experiments on the effect of temperature on the percentage of germination of seed have shown that a temperature of 125° to 130° F. for eight hours or more will have little effect. Most of the trouble reported seems to be due to a failure to observe proper precautions. It is necessary to protect seeds near the source of heat much more than those some distance away.

Experiments have also shown that heating to a temperature from 124° to 154° F. for two hours has practically no effect on the germination of beans and that this is about six times as long as is necessary to kill the weevils. The author states that the effect upon all seeds was much the same.

Fumigation

Small amounts of material may be put in cans, barrels, bins, or boxes, or piled together in sacks and fumigated. In all cases it is necessary to be able to confine the gas so that it will penetrate the material before it escapes. Larger amounts may be in bins, granaries, elevators, or freight cars. Sacks of cereal or grain may be piled together in the corner of a room and covered with blankets on the exposed sides, but this method is less satisfactory than the others. For larger amounts, a small tight building made especially for the purpose is most satisfactory. As it may be needed every year, it is also economical.

The depth of penetration of a fumigant is proportional to the concentration of gas and the time during which it acts. When a fumigant is applied to grain in a tight bin, the downward diffusion of the gas is not as rapid as is usually supposed. The concentration of a heavier-than-air fumigant does not become stronger at the bottom of the bin than toward the top, but varies inversely with the depth below the grain surface. This is the result of absorption of gas by the top layer of grain, preventing much of it from moving downward. The dosage of fumigant must be great enough to provide a toxic dose for the insects after the grain has taken up all it can. When large quantities of grain are fumigated, it is often advisable to mix the fumigant with the grain while the bin or elevator is being filled.

It has been demonstrated that the fumigants advised in this bulletin have no injurious effect on the germination of seeds when they are used at the recommended dosages. Seeds, however, must be thoroughly mature and dry, otherwise they may be injured by fumigation. Ethylene oxide seriously injures the viability of seeds and should not be used for their fumigation.

Ordinarily small quantities of grain are fumigated by sprinkling the liquid fumigant over the surface of the grain, then covering the grain or closing the fumigated space as tightly as possible. Because rapid evaporation to form a high concentration of the gas quickly is desirable, sprinkling the fumigant is more effective than exposing it in shallow pans, as is sometimes recommended. If the grain temperature is 75° to 80° F., fumigation will be much more successful than if it is 65° or lower.

If the grain is more than four to six feet deep in an open bin, results may be unsatisfactory unless the grain can be spread out at less depth. Sometimes a hollow pointed probe with a funnel top and perforations along the tube is used to introduce liquid fumigant below the surface of the grain.

If a special room or building is to be built for granary purposes it should be made as nearly gas-tight as possible. Especial care should be taken with the corners, for cracks at these points will allow the escape of gas that should be retained in the grain for good results.

Ethylene dichloride is an effective fumigant for stored products in sacks or bins. Its advantages are low cost, low fire hazard, rather high toxicity to insects, and relatively low toxicity to persons. It burns, although not readily. When mixed three parts to one of carbon tetrachloride, it is free from fire hazard. This mixture is obtainable already prepared. The odor of ethylene dichloride is not at all objectionable. Although the danger of asphyxiation while using the fumigant is not great there is an anesthetic action. If much of it is inhaled, a feeling of giddiness may ensue. If this happens, the user should go into the open air at once. Ethylene dichloride evaporates rather slowly, so it should be thrown directly on grain or exposed by soaking bags in it. The vapor is much heavier than air. Ethylene dichloride has a specific gravity of 1.27 at 67°; a gallon weighs 10.4 pounds. Fourteen pounds of the 3 to 1 mixture to 1,000 cubic feet is an effective dosage at ordinary temperatures. It should be allowed to act for 24 hours. It is usually not wise to attempt to fumigate when temperature is below 60° or 65° F.

Propylene dichloride is sometimes substituted for ethylene dichloride. It does not vaporize quite as readily, but otherwise it has about the same properties.

Carbon tetrachloride is likewise a liquid at ordinary temperatures. It evaporates at about the same rate as ethylene dichloride. It is somewhat heavier, its specific gravity being 1.58. The odor is not objectionable, although it is not as pleasant as that of ethylene dichloride. The same directions and precautions should be observed as to the method of application. Carbon tetrachloride is noninflammable, in fact it is sometimes used as a fire extinguisher. The main disadvantage in its use is its low toxicity to insects. The dosage should be from 20 to 30 pounds to each 1,000 cubic feet of space. The amount depends upon the temperature; in hot weather less fumigant is required than in cold. This is true of most fumigants, but temperature seems to affect the toxicity of carbon tetrachloride much more than it does most of the other common fumigants.

Carbon disulfide is used in the same way as carbon tetrachloride. It is better known and more satisfactory. However, it is explosive and should never be used near a light or a fire. For this reason it should be limited to use in buildings built for the purpose. Ordinarily the use of carbon disulfide voids the fire insurance policy. Although it is somewhat more effective in killing insects, its use is not advised in view of the safer materials that have been made available within recent years.

Various mixtures of chemicals are on the market as liquid grain fumigants. Most of these are composed chiefly of the compounds just mentioned, but others may contain materials which will injure grain or seeds. A fumigant sold under a trade name without formula should be investigated carefully before it is used. No matter how fine the sales talk in its favor, one should either find out the ingredients involved or have expert opinion on the safety of the mixture before purchasing.

Contact sprays composed of mineral oil as a base, and containing kerosene, creosote products, or paradichlorobenzene, are absolutely useless for application to grain as a fumigant. Furthermore, their application will ruin the grain for feed or milling purposes.

Chloropicrin is one of the tear gases used in World War I. Its advantages are its extremely high toxicity to insects, its noninflammability, and its warning qualities. Although it is toxic to human beings, very small noninjurious traces of it are so annoying that one absolutely cannot remain near exposed chloropicrin. On the other hand, it does not evaporate readily. It must either be sprayed into the space to be fumigated or be diluted with equal parts of carbon tetrachloride to improve its evaporative powers. It is often necessary for the operator to wear a gas mask in making a chloropicrin fumigation. A further disadvantage is the degree to which it clings to fumigated goods and resists airing. Two pounds of chloropicrin to 1,000 cubic feet of space is the dosage required to fumigate bins and tanks.

Hydrocyanic acid gas is perhaps the most satisfactory fumigant to be used on a large scale in elevators. It is very poisonous and must always be used with the greatest care. However, when all precautions are taken by an experienced man, the work can be done safely. Granular calcium cyanide is the form usually used for fumigating grain in elevators. Cyanide is fed into the grain stream just before it enters the elevator, thus insuring even distribution of fumigant particles throughout the mass of grain.

Spraying Floors, Walls, and Other Surfaces

As careful cleaning cannot always be followed by heating or fumigating, it is often desirable to use a spray. Once a year the cleaning should be followed by a thorough painting that will fill all cracks where pests may hide. If the paint is applied with an air brush, it will fill practically every crack and make the surface easily cleaned.

Several commercial sprays on the market seem to be efficient as contact insecticides; that is, they kill insects when they actually come in contact with them. Many of these sprays have a strong odor that may to a certain extent repel insects. Kerosene or turpentine may be used as sprays, but precautions must be taken against fire. Because of fire hazard, gasoline is too dangerous. Cracks should be treated by squirting machine oil or kerosene into them from an oil can. A spray does not penetrate well unless a power sprayer is used.

Cleaning and treating the grain bin should be done long enough before the new grain is stored so the bin can air out. The time for airing depends on what is used. Grain absorbs odors and should be handled accordingly if it is to be of good quality for food purposes.

Miscellaneous Methods of Grain Treatment

Copper carbonate dust is sometimes used on seed wheat in storage to prevent the carrying over of disease spores on the seed. The dust also prevents insect damage. Dusted grain may be safely held for planting the second season. Copper carbonate is applied to wheat at the rate of two ounces per bushel. It should **not** be applied to grain intended for animal or human consumption.

Seed corn is said to be effectively protected from insect injury by dipping the ears in oil emulsions and miscible oils such as are used for spraying fruit trees. The emulsions are diluted one part to 10 parts of water.

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