BULLETIN 341 REPRINTED JUNE 1940

INSECTS INFESTING STORED FOODS

HAROLD H. SHEPARD

UNIVERSITY OF MINNESOTA
AGRICULTURAL EXPERIMENT STATION

CONTENTS

Insects Infesting Stored Foods[1]

Harold H. Shepard[2]

THIS BULLETIN contains information on the biology and control of the common insect pests of flour and other ground or processed cereals, dried fruits, dried-milk products, cured meats, nuts and their products, various spices, and many other foods that undergo some manufacturing process and subsequent storage. The pests of whole grain and other seeds have been discussed in a separate bulletin. Such household pests as cockroaches, ants, flies, and silverfish, common elsewhere in stored products, are discussed in separate circulars. Because of their short storage period, most fresh foods such as fruits and vegetables, do not become infested except by those field insects that remain on them after harvesting.

It is not pleasant to think of eating food upon which insects have been crawling and feeding. Although such food is usually considered unclean, and most people will not eat it if they know of its condition, if the insects are not germ carriers there is no evidence that it is at all injurious. The greatest damage to food by insects is not the amount actually eaten but that which is rendered unfit or undesirable for human consumption by the mere presence of the insects. In some cases an entire business has been ruined because the buying public found insects in its products.

If one includes the insect damage to stored grains, it is likely that the total annual loss of stored food products, from the beginning of storage at harvest to the time of home consumption, amounts to nearly a half billion dollars in the United States alone. The large amounts of food thrown away or requiring reconditioning result in losses that could for the most part be prevented at little cost. Carelessness, lack of attention to details, and lack of information regarding a few simple entomological facts are responsible for most of such losses. If the following information is studied and the suggestions are followed, it should be relatively easy to overcome these obstacles, either in food-processing establishments or in the home.

[1] Accepted for publication November 10, 1938.

[2] In 1921 the Minnesota Agricultural Experiment Station published Bulletin 198, "Insects Infesting Stored Food Products," 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 from the original work of Dr. Chapman and wishes by this note to indicate his indebtedness for that assistance.

FLOUR-MILLING PROBLEMS

Retail customers often blame the miller for the presence of insects in flour and other ground cereals although the source of the difficulty is in the wholesale or the retail grocery. The best proof of innocence the miller can produce is an establishment free from insects. The volume of business, the construction of the buildings, and the amount of dust constantly accumulating make the flour mill a favorable place for insects and a difficult place in which to combat them.

So far as milled products are concerned, the miller is near the source of insects compared to the various dealers who pass these products on to the consumer. Although none of the insects that attack the raw material—the unmilled grain—do any extensive damage to the milled products, it is important to distinguish between the insects that attack the sound grain and those that follow them as secondary pests in the damaged grain. These secondary pests also work in the milled products. The insects that attack the sound grain "grind" it, and the material left is much like that which comes from a mill so far as the ability of other insects to attack it is concerned. It is of the greatest importance that the miller should realize fully the hazard involved in buying grain that has been damaged to any extent by insects. It may contain some of the secondary insects that become primary pests of the milled products.

Insects that live in mills are confined largely to the elevators and mills or the warehouses and stores through which the milled products pass on their way to the consumer. They are passed from one mill to another in empty sacks that are exchanged or returned. Because insect eggs are not easily seen, sacks may be thought to be free from insects although they contain hundreds of eggs that will hatch in a few days. An ordinary cleaning of the sacks may remove all the insects but leave the eggs. The only safe method is to fumigate or heat sacks when they are returned and before they are brought into the mill. A little time spent in such treatment will save much time in trying to rid the mill of the insects once they have entered. Leaky, badly patched sacks are likely to promote infestation of the flour; neat, tight sacks help to prevent infestation as well as to give a good impression of the product.

For the sake of his own business, the miller must watch the products that go out so that they may not endanger the business of his customers. Not only should his packaging be carefully done to prevent leakage and subsequent infestation, but the cars and trucks for transporting his goods should be cleaned thoroughly before loading. However, the extent to which flour is infested while in transit is often overestimated. The time involved, a week or less, is too short for insects to develop throughout the shipment. Ordinarily relatively few adult insects will migrate to the sacks; those that do are found mostly in the sacks near the walls of the railroad car.

Cotton and Wagner (1938) list several ways by which a flour mill may become infested: 1. Insects entering with the grain stream. 2. Insects from infested clear or low-grade flour used in blending operations. 3. Insects from infested flours returned to the mill from grocers' warehouses and elsewhere. 4. Insects in returned bags. 5. Insects in second-hand machinery purchased for installation in the plant. 6. Insects from infested feeds stored in the mill.

A study of the species of insects occurring in the mill streams of flour mills in Kansas, Oklahoma, and Missouri showed *Tribolium* comprised 84.65 per cent of all the insects taken, *Laemophloeus* 7.95 per cent, and *Tenebroides* 3.16 per cent (according to Good, 1937). More than 25 species were found in the remaining 4.24 per cent. "The low-grade flour elevator boot showed the highest average population, with three of the middlings elevator boots, the fourth, second, and fifth, next in order. . . . The high population in the low-grade flour elevator boot is probably due to the position that the low-grade-flour stream occupies in the milling system and the inability to redress such flour properly, coupled with its greater palatability to insects." (Good, 1937.)

A recent development in milling practice has been the installation of redressing machinery for the removal of foreign material that has been accidentally incorporated in the flour during the process of manufacture. If a fine enough bolting cloth is used, all stages of insect life can also be removed by this process. The machinery must be so constructed and located as to eliminate any chance for insect infestation to contaminate the flour between the time it passes through the cloth and the time it reaches the packer bins. Reels, because of their construction, are undesirable for this purpose. The conveyors in the reels are so arranged that it is a simple matter for insects removed in the redressing process to crawl over into the conveyor that handles the finished flour. Because sifters are so constructed that the tail over and finished flour are handled by separate spouts having no connection, they should be used instead of reels. This feature makes it impossible for insects to crawl from one stream into the other.

BREAKFAST FOODS

Special products put up in packages cost more than ordinary bulk foods because they have additional protection and they are often made of selected materials. When customers know that the product is clean, they are usually willing to pay the extra cost of packing. If the packaged products show the slightest evidence of insect injury, they are at once robbed of their superior character and can not compete in the market with bulk products. For this reason the manufacturer of any special food product can not neglect the insect question. Most manufacturers take pride in advertising their product as superior in that it is guaranteed to be free from insects.

As insects get into the manufacturing plant in the same manner as described for flour mills, the same careful cleaning is necessary, as well as the inspection of bags and raw materials as they enter the building.

Usually breakfast food is packaged at a temperature high enough (over 130° F.) to insure the death of all stages of any insect. Insect injury to packaged cereals of this type can be caused only by insects that enter after packaging. This seems impossible when one sees the care with which the packages are sealed; subsequent handling, however, often cracks the corners of the packages slightly. If the common Indian-meal moth deposits an egg in the crack, another infested package will be on its way to hurt the manufacturer's reputation. Good quality of the box and its wrappings is the most important factor in preventing insect infestation in cereals that are packaged while hot.

BAKERS' PROBLEMS

The baker handles so much flour that his problems are often the same as those of the flour miller. He should watch all shipments of flour to prevent acceptance of seriously infested stock. If possible, he should have a tight flour-storage room especially arranged to prevent contamination back and forth from the mixers. This flour room should be cooled to about 50° F. to prevent insect development. New supplies of flour are best kept separated from the older lots which should be used up first.

Since the bakery is hot much of the time and shortening, sugar, and chocolate may contaminate some departments, particularly underneath machinery, roaches are usually an additional problem for the baker. All favorite roach hiding places should be sprayed weekly, preferably at night, with a small electric sprayer delivering a driving mist of pyrethrum-oil spray to penetrate the cracks. The removal of quarter round from the base of wooden partitions (if the partition itself can not be dispensed with), the replacing of wooden floors, platforms, partitions, and drying equipment by smooth concrete or metal surfaces with rounded corners, and the liberal use of hot water and steam make for fewer hiding places for roaches and for their efficient control.

MISCELLANEOUS CEREAL PRODUCTS

The coarser cereals such as bran are not only more palatable for most cereal insects but easier for them to penetrate rapidly. Once such cereals are infested, they can never be reconditioned by sifting to free them of insects.

Wheat germ, now so much used in health foods for its vitamin content, is particularly liable to infestation. It is possible, however, to keep it refrigerated until it is used, a temperature of 50° F. being required to prevent infestation from the outside, and exposure to freezing temperatures to kill eggs in the material in case the latter has been subject to infestation following its manufacture.

Macaroni and allied products should not be stored near grain infested with weevils.

FOODS HIGH IN FAT AND PROTEIN

Many of the stored-product insects can not develop at all in starchy foods, especially those low in protein and moisture, such as wheat flour. Others develop more abundantly in foods containing considerable protein than in the more starchy foods. A family of beetles known as the dermestids, including the hide beetle, the larder beetle, and the carpet beetles, develop almost exclusively on products of animal origin high in protein and fat.

Dried skim milk is not nearly so liable to infestation by insects as is dried buttermilk, which may become heavily infested with dermestids if stored long in a warm place. Cheeses are liable to injury by cheese mites and the cheese skipper.

Nut meats, such as walnuts, and peanuts are likely to become infested by the saw-toothed beetle. Walnuts are sometimes infested by the Indian-meal moth. Milk chocolate and chocolate candies are sometimes attacked by the saw-toothed beetle.

MISCELLANEOUS FOODS

Roasted coffee is almost never attacked by stored-product insects, although recently some dermestid larvae were found in ground coffee.

Spices, such as paprika and chili powder, are subject to infestation by dermestids and the drugstore beetle. Crushed red peppers have been seen heavily infested by the Indian-meal moth. It is important to keep insects out of the raw materials from which such products are made because their eggs can not be removed by sifting and the insects will show up afterwards in the finished goods.

Vinegar flies often appear around the mill where prepared mustard is mixed before being packed in jars.

Dried fruits, such as raisins and prunes, are often severely damaged by the Indian-meal moth. Cold storage will prevent injury, although upon removal from the cold the fruits are again liable to damage.

FOODS IN THE HOME

Insect pests of food products first come into the home with packages of food. All flour, meal, breakfast food, dried fruits, nuts, and similar materials may contain insects. Breakfast foods in sealed packages are usually "sterilized" by heat or other means at the time of packing. They are safe, then, unless the wrapper has holes or folds through which insects may crawl. Sometimes insects cut very small round holes in the wrapper by which they can enter or leave the container. These holes, bits of meal webbed together with silk, and the insects themselves should be watched for, and packages bearing them destroyed immediately. The grocer can not be expected to take back infested goods if kept very long after their purchase. Insects may have entered them after they were bought. Groceries should be looked over before being put away. The grocer will be glad to cooperate if he is treated fairly in such matters. Moreover, if a package is received containing insects, do not judge the merchant too severely, for he has to handle in large quantities goods that may previously have been exposed to insects in warehouses, wholesale stock rooms, and railroad cars. He has no control over insect infestation of foods until they reach his own establishment. It should be realized that it is easy for him to miss an infested package now and then. He will appreciate having it called to his attention immediately.

It is easier to rid the kitchen or pantry of insects before they begin to increase than to do so after every crack and corner is the home of a "bug" family. If one sees moths or beetles around where food is kept, they may be coming from a small bag of meal, a partially used can of nuts, or an opened box of cookies back in some forgotten corner. It is time, then, to explore and clean out such old and useless lots of food. A thorough clean-up is usually enough to get rid of food insects. Sometimes beetles may lodge in cracks in a wooden flour bin, or some other inaccessible location. They may be killed by squirting machine oil into the corners and cracks around the cupboard shelves and bin. Foods should be kept only in the necessary quantities, especially in summer. Whenever possible they should be kept in tight containers, so that if one is infested the rest will not become contaminated.

LIFE HISTORY OF A TYPICAL STORED-FOOD INSECT

All insects hatch from eggs with the exception of a few that are born alive. A typical insect life history is that of the confused flour beetle. All stages of its life are illustrated on page 9. The eggs, which are only about one-fiftieth of an inch long or less, hatch in about ten days 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. 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 does not move about or feed. During this stage the larva is transformed into an adult beetle with wings. 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.

The adult insects mate and lay eggs, but they never grow. All the growing is done in the larval stage. Adult beetles feed and may live for a year, during which time they crawl or fly about. Adult moths feed very little, if any, and live for only a few days or weeks. The life cycle of these insects consists of four stages: adult, eggs, larvae, and pupae. With this in mind, no one should ever believe any of the stories about insects developing from the germ of the wheat or from anything other than insect eggs.

DESCRIPTIONS OF THE PRINCIPAL INSECTS INFESTING STORED FOODS

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 and related organisms includes several that at times may be just as destructive as beetles or moths. Among these are mites, which are not insects at all; cheese skippers, which are the larvae of a fly; book lice, and a few others.

Structure of a Typical Insect

To understand the descriptions of the insects, 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 fig. 1). The

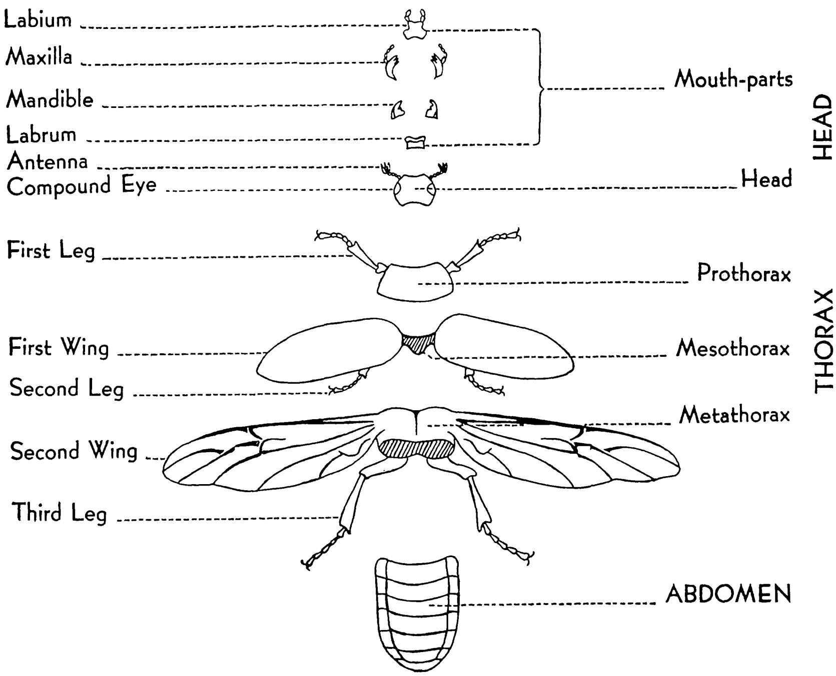

FIG. 1. BODY OF ADULT BEETLE SEPARATED TO SHOW PARTS (AFTER CHAPMAN)

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 the last two subdivisions each bear 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.

Fig. 2. Confused Flour Beetle, *Tribolium confusum*, Adult (Enlarged)

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 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.

Confused Flour Beetle, *Tribolium confusum* Duval

The confused flour beetle (fig. 2) is the most common beetle infesting flour in Minnesota. It is dark reddish brown, about one sixth of an inch in length, flattened, and somewhat oval in outline. It crawls about slowly. When rubbed between the fingers it gives off a rather sharp pungent odor.

The common "flour worms" are its larvae (fig. 3). They vary in length from about one twenty-fifth of an inch at the time of hatching to about one fourth of an inch when full grown. Their color varies from white, for a short time after each molt, to yellow. This is the color usually seen. The covering of these larvae is not so hard as that of the "meal worms" *(Tenebrio* spp.) nor so soft as that of the cadelle *(Tenebroides)*. As they are smaller than the two species just mentioned, and are usually associated with the adult

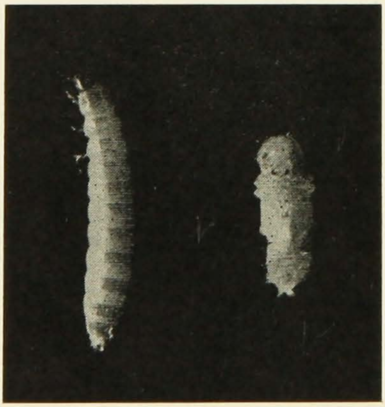

Fig. 3. Confused Flour Beetle, *Tribolium confusum*, Larva and Pupa (Enlarged)

beetles, they can be distinguished from other beetles commonly found in cereal products.

The pupae (fig. 3) are seen less often than the other stages just described, because they are inactive. They are white and about one sixth of an inch long.

The eggs (fig. 4) are so small that they are scarcely distinguishable with the unaided eye in the finest flour. They are only one seventy-fifth of an inch long and are oval. When first laid they are covered with a fluid which causes particles of flour to adhere to them, with the result that the appearance of the eggs varies with the character of the material in which they are laid. The eggs are laid singly and are scattered about in the flour. The female beetle may live for nearly a year and lay one or two eggs every day during this time.

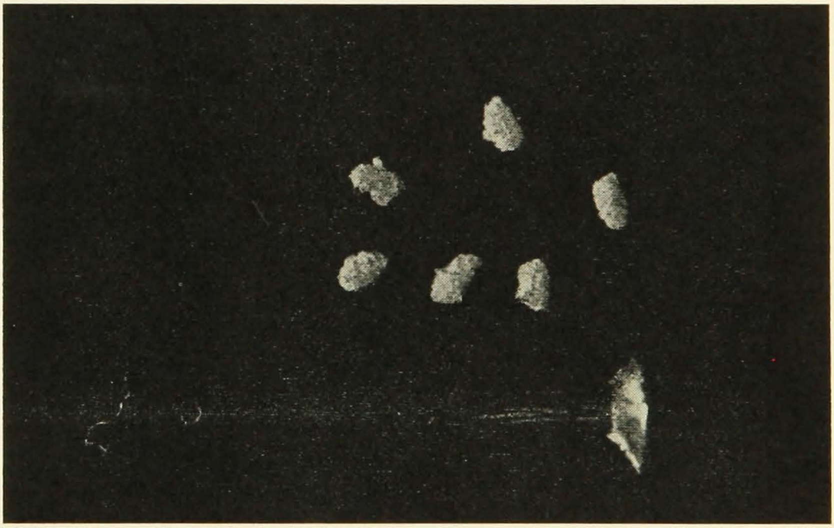

FIG. 4. CONFUSED FLOUR BEETLE, *Tribolium confusum*, EGGS WITH THE HEAD OF A COMMON PIN FOR COMPARISON (ENLARGED ×10½)

At a temperature of 80° F. the eggs hatch in about a week. The growth of the larvae is rapid in a favorable food, which may be practically any flour or cereal used for human food. The larvae mature in about twenty-two days at a temperature of 80° F. The pupal stage lasts ten days under these conditions. The lower the temperature, the more time is required for development. At very low or very high temperatures, however, development ceases and the insects are killed (table 1).

The confused flour beetle feeds on nearly all grain and vegetable products, primarily on the ground products of grains. It can not attack uninjured grain. However, it is often found in wheat that has either been crushed or been injured by other insects. It may be found in small numbers in sound grain and also in other materials that are not suitable for food, but experiments have shown that it can not obtain sufficient food from such sources and soon dies.

Table 1. The Effect of Temperature on the Confused Flour Beetle

Temp., °F.	Summary of data from various sources
0	Average time to kill adults, 9 minutes
10	Average time to kill adults, 14 minutes
21	Average time to kill adults, 8.4 hours
45	Average time to kill adults, 14 days; maximum, 22 days
54	No eggs are laid
63	Eggs are laid and hatch, but larvae die before completing development
72	Life cycle completed in 93 days
81	Life cycle completed in 37 days
90	Life cycle completed in 27 days
100	Life cycle completed in about 38 to 40 days; egg viability reduced about 25 per cent
106	Larvae unable to complete their development
111	Average time to kill adults, 7.5 hours; maximum, 14.5 hours
115	Average time to kill adults, 66 minutes
118	Average time to kill adults, 26.5 minutes
122	Average time to kill adults, 7 minutes

It has often been said that these beetles show a preference for the lower grades of flour. The germ and other parts of the grain are not removed from the lower grades; these are known to increase reproduction and to decrease the length of the life cycle. The lower grades of flour may become infested more often than the higher grades partly because they are not sifted through such fine bolting cloth and are not handled with the same care.

The confused flour beetle has been found in wheat, barley, oat, rye, corn, and rice flour; bran; breakfast foods; grains ground or rolled in various ways; peanuts; and various shelled nuts. It will feed for some time in sugar and corn starch but can not lay eggs and develop without other food.

These beetles may be killed by a temperature of 120° F., or by the use of a poisonous gas. During the process of fumigation the beetles often crawl away into cracks, and hence some may survive. They have a natural enemy in a small mite that feeds on all stages of the insect. Apparently all the eggs attacked are killed, but the effect on the other stages is less noticeable.

Red Flour Beetle, *Tribolium castaneum* (Herbst)

The red flour beetle (*Tribolium castaneum,* formerly known as *T. ferrugineum*) is so much like the confused flour beetle that it is not possible ordinarily to make much distinction between the two species. The red flour beetle differs from the confused flour beetle in the structure of the antennae and the shape of the eyes. It takes flight for short distances, while the confused flour beetle does not fly, and it appears to require higher temperature and moisture conditions for development. In general, the red flour beetle is the more southern species, although it sometimes occurs in large numbers in flour mills as far north as Minnesota. It appears to be somewhat less resistant to fumigants than the confused flour beetle.

Saw-toothed Grain Beetle, *Oryzaephilus surinamensis* (Linn.)

The adult saw-toothed beetle is slender, brown, and smaller than *Tribolium,* being only about one tenth of an inch in length. The sides of the thorax bear six tooth-like projections which give it its common name. This is one of the most common beetles occurring in flour, cereal products, and many other foods. The larvae are smaller than those of the confused flour beetle, which they resemble.

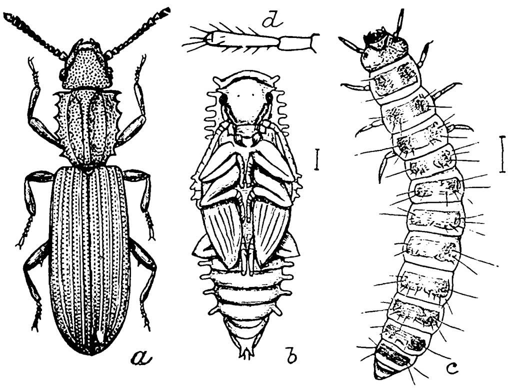

FIG. 5. SAW-TOOTHED GRAIN BEETLE, *Oryzaephilus surinamensis*

a, Adult; *b,* pupa; *c,* larva (From U. S. Dept. Agri.)

Figure 5 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.

The saw-toothed beetle feeds upon various meals, breakfast foods, flour, grain debris, dried meats, dried fruits, chocolate, and other materials. Its name is misleading, for it is not a true grain beetle but one that feeds principally on ground products. It commonly migrates all over an infested building. It is sometimes a pest in damp grains, especially oats.

The eggs are long. They hatch in a week or less if the temperature is about 80° F. The larvae are long and active and crawl about as they feed. In about three weeks, in warm weather, they attain their full size and form cells by sticking particles of material together with a substance that they secrete. Often they crawl into a crack and surround themselves with particles of food glued together to complete these cells. In the cells the pupal stage of ten days or less is spent, then they emerge as adults. The whole life cycle, from egg to adult, requires from three to ten weeks, depending upon moisture and temperature.

The small size of this beetle enables it to crawl into small cracks and crevices, thus escaping when efforts are made to get rid of it by cleaning. The methods to be used against it are similar to those recommended for the confused flour beetle.

Flat Grain Beetle, *Laemophloeus minutus* Oliv.

This very small beetle is fairly common, being found principally in cracks and crevices of flour bins and mills. After the *Tribolium* species, it is the beetle found in largest numbers in flour mills.

The adult is about one tenth of an inch long, is flat, narrow, and reddish brown in color. Its long slender antennae together with the narrowing of the thorax near the posterior end will identify it.

This beetle apparently lives best in undisturbed places where the relative humidity is high. It has not been found commonly in sound grain, despite its common name, but rather in flour or meal, especially when the latter becomes stale and moldy.

A closely related species is the rust-red grain beetle, *Laemophloeus ferrugineus* (Steph.), which has the same habits but is less common. At 83° F. and 65 per cent relative humidity the life cycle requires from 30 to nearly 50 days, depending upon the type of food available. Another species, identified as *Laemophloeus turcicus* Grouv., has been found in a Minneapolis flour mill.

Cadelle, *Tenebroides mauritanicus* (Linn.)

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

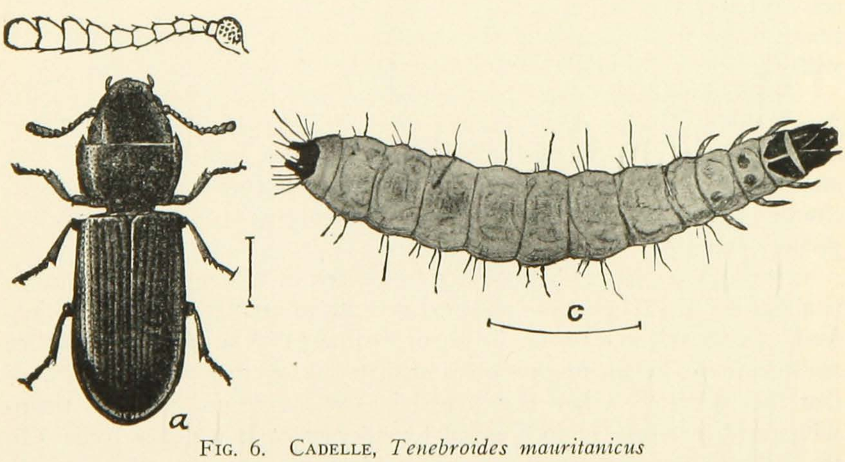

FIG. 6. CADELLE, *Tenebroides mauritanicus*
a, Adult, with greatly enlarged antenna above; *c*, larva (From Chittenden)

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 and dark 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 materials 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 can not eat more than a small portion of unground grain as the embryo is all that is soft enough.

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. They may burrow into wood adjoining their food, pupating or hibernating there, possibly for months, coming out to infest a fresh lot of food.

This beetle, like the meal worm, requires a year for complete development from the egg to the adult which is ready to lay eggs again. 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 the larvae will survive.

These beetles are often found in large numbers in warehouses, which means either that regular cleaning is not being done, or that goods are being held in storage for longer periods than is necessary.

Yellow Meal Worm, *Tenebrio molitor* Linn.
Dark Meal Worm, *Tenebrio obscurus* Fabr.

These two beetles are so much alike in both habits and the nature of the damage they do that they will be treated together.

The adult beetles are black and a little more than half an inch long. They are more easily confused with the cadelle than with any of the other insects found in stored food products, but can be distinguished by the fact that the sides of the body are continuous in both these beetles, while there is a constriction in the body of the cadelle.

The larvae are long, yellow or dark brown in color, with a hard external covering that makes them resemble wireworms in appearance. When full grown the larvae are more than an inch long and are hardly to be confused with any other insects found in stored food products.

These beetles are found primarily in rather coarsely ground cereals. They also have a preference for damp and slightly moldy material. For this reason they are usually found in accumulations of meal in dark, damp, out-of-the-way places such as under granaries, elevators, and warehouses.

The adults usually emerge in the spring and lay eggs in the material that is to serve for the young larvae. The larvae are white when they hatch, but later become yellowish brown in color in the case of the yellow meal worm, or dark brown in the case of the dark meal worm. The larvae attain their full length, an inch or more, by the middle or latter part of summer. They usually remain in this condition until the following spring, when they transform to the pupal stage.

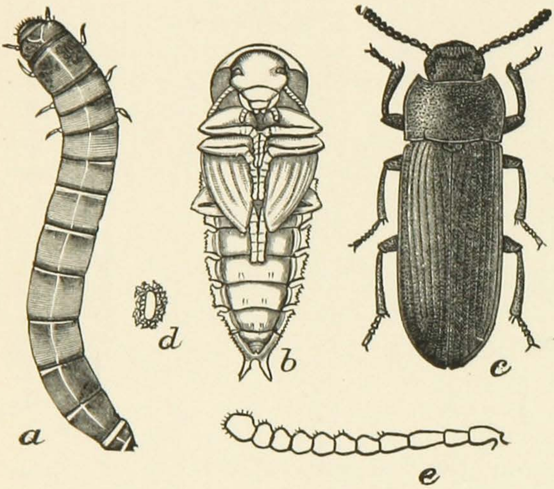

FIG. 7. MEAL WORM, *Tenebrio molitor*

a, Larva; *b*, pupa; *c*, adult female; *d*, egg with case; *e*, antenna (From Chittenden)

The larvae usually come to the surface of the meal to pupate, and the white pupae are found on the surface of the food or in corners of the bin. The adults emerge from the pupal stage and feed at night or in dark and secluded places.

It is evident from the life history and habits of these beetles that one way to keep a place free from them is to have no accumulations of cereals lying about in secluded places where they may become damp and moldy. As the life cycle requires a full year for completion, it is further evident that careful and frequent cleaning will keep a place free from these pests.

Mediterranean Flour Moth, *Ephestia kühniella* Zell.

The adult moth has a wing expanse of less than an inch. The ground color is gray with transverse black bars. While at rest, the position in which it is usually seen, the fore part of the body is elevated, giving a distinct slope to the wings which are wrapped about the body. The attitude of the moth while at rest is the most reliable characteristic by which to distinguish it, as the markings disappear when the wings become worn.

The larvae, when full grown, are from one half to five eighths of an inch long, white, often with a distinct pink tinge. Its color and the fact that it is usually found in silken tubes that are spun in the flour are the best distinguishing characters.

The small white eggs are laid in crevices or scattered about over machinery and in conveyors and spouts. At a temperature of between 80 and 90° F., they hatch in about three days, and the larvae attain their full growth in about forty days. During the early part of their lives they are confined to their silken tubes, which they spin throughout the flour in bins, machinery, or out-of-the-way places about the mill. When they are full grown they leave the flour and search for places where they can spin their cocoons. As they crawl about, an enormous amount of silk is spun, which mats together the flour and meal and clogs the bolters, purifiers, spouts, and other machinery. It is often necessary to close the mill and give all the machinery a thorough cleaning in order to rid it of the web.

Perhaps no insect has received more attention from flour millers than the Mediterranean flour moth. It is widespread in distribution and is said to be present in 99 per cent of the flour mills. However, it is no longer the most important pest of the cleaner mills, the *Tribolium* flour beetles having become the most important where fumigation has been more commonly practiced. Because the moth is the more easily killed, it is almost entirely suppressed by efforts to control the beetle.

Several other less well-known species of *Ephestia* moths are becoming important as stored-food pests. They are not easily distinguished from one another by their appearance. One of these is the tobacco moth,

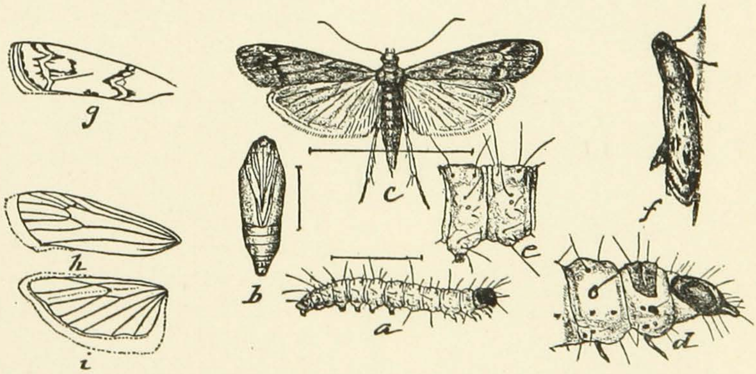

FIG. 8. MEDITERRANEAN FLOUR MOTH, *Ephestia kühniella*

a, Larva; *b*, pupa; *c*, adult; *d*, head and thorax of larva; *e*, abdomen of larva; *f*, adult from side; *g*, *h*, *i*, wings.

Ephestia elutella (Hbn.), also known as the chocolate moth. Besides tobacco and chocolate, it infests cereals, dried fruit, and nuts. Unlike the Mediterranean flour moth, it is of little importance in flour. The almond moth, *Ephestia cautella* (Walk.), a serious pest of dried fruits, occurs in shelled nuts, but is of little importance in grain products. The raisin moth, *Ephestia figulilella* Greg., is a common pest of dried fruits in California. Although in general it is less common than the tobacco moth and the almond moth, it feeds on the same type of foods. Both the tobacco moth and the raisin moth are capable of maintaining themselves in the field in some temperate regions.

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 to 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 small white eggs are laid singly or in groups on or near the material that is to serve as food for the larvae. The female appears able to select such locations as the rough edges of damaged boxes of breakfast food upon which to lay her eggs. As a result, the moth is particularly serious in grocery stores. A single female may lay as many as 350 eggs. At ordinary summer temperatures the eggs hatch in four or five days and the larvae develop in about four weeks. Hence, under favorable conditions, the complete cycle may be passed in a little more than a month.

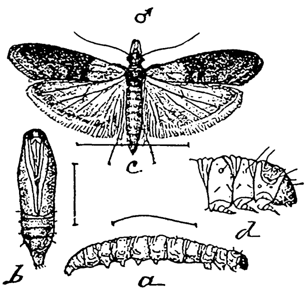

FIG. 9. INDIAN-MEAL MOTH, *Plodia interpunctella*

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

A list of the materials infested by this moth would include nearly all products used for human food—all sorts of cereals, flour, dried fruits, dried roots, some spices, and nuts as well as nut candy. When this insect is found, a thorough cleaning is necessary, as it will spread from one material to another.

Unlike the Mediterranean flour moth, the Indian-meal moth is not a serious pest of flour mills.

Meal Snout Moth, *Pyralis farinalis* Linn.

The meal snout moth is more often found in dirty damp places than where it is clean and dry, and it seems to prefer coarse bran and other materials, especially if damp and spoiled, to the more finely ground cereals.

The adult has a wing expanse of about three fourths of an inch and is the most beautiful of all insects that infest stored food products. The fore wings are a dark chocolate brown at the ends, while the middle is dusky white with two wavy white lines separating the lighter and darker areas on each wing. The coloring, together with the fact that the moth usually bends the tip of the abdomen up over the back when disturbed, will serve to identify it.

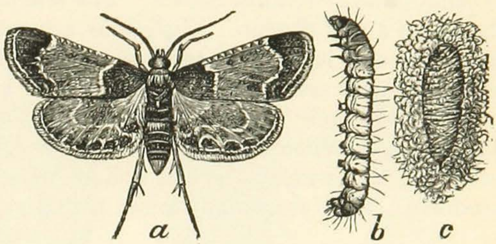

FIG. 10. MEAL SNOUT MOTH, *Pyralis farinalis*
a, Adult; *b*, larva; *c*, pupa in cocoon (From Chittenden)

The larvae resemble those of the Mediterranean flour moth in their habit of living in silken tubes which they spin in the material that they infest. They are about an inch long when mature and are a grayish white in general color, darker at the ends, and the head is brownish red. The pupal stage is spent in a silken cocoon.

The life cycle requires about eight weeks at summer temperature. It is reported as infesting hay, straw, and other roughage as well as bran, meal, and flour. As it is usually found in accumulations of material in damp places, the best remedy is a careful cleaning.

Rice Moth, *Corcyra cephalonica* (Staint.)

The rice moth, a rather uncommon pest in the United States, has been known to cause damage to rough rice and to chocolate products in this country. The adult moth is grayish brown or tawny in color, with a wing spread of about half an inch. The larvae are somewhat like those of the Indian-meal moth in appearance. They spin a dense webbing as they become nearly grown, attaching particles of food to the walls of their silken tubes.

Grain Weevils

The granary weevil, *Sitophilus granarius* Linn., and the rice weevil, *S. oryzae* Linn., common pests of whole grain, will also breed successfully in macaroni and other hard products such as pearled barley. Although the adult weevils may feed awhile in milled cereals such as flour, they will not lay their eggs in such material unless it has become moist and subsequently caked, as the weevil larvae require hard masses of food at least as large as a wheat kernel in which to burrow during their development. (See Minnesota Agricultural Experiment Station Bulletin 340, pp. 11-12).

Drugstore Beetle, *Stegobium paniceum* (Linn.)

Because of its ability to attack a large variety of foods, the drugstore beetle is one of the most injurious and hardest to combat of all insects in stored food products. The adult is about one tenth of an inch in length and is reddish brown. The antennae end in three large joints that form a sort of club. The larvae are small white grubs covered with silky hair and have three pairs of small legs. The end of the abdomen is usually bent under the body, giving the larvae an arcuate appearance.

The life cycle requires about two months during warm weather. The larvae combine the characteristics of "grubs" that work within hard products, as kernels of grain, and of those that crawl about in milled products. They are usually found within grains, macaroni, or other food

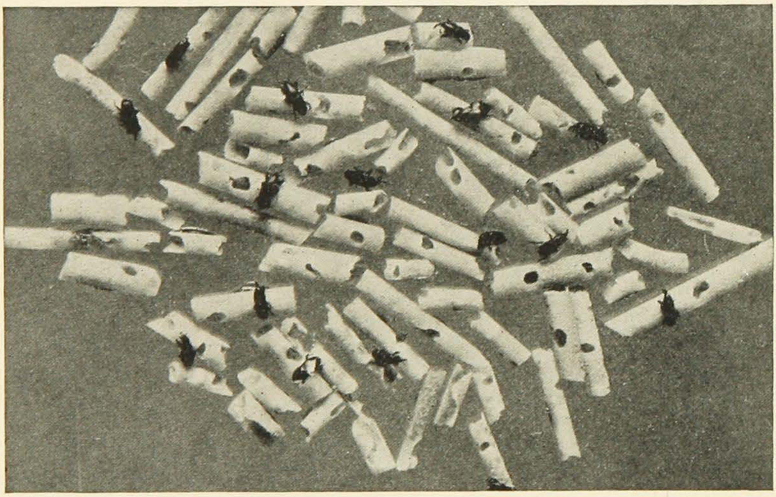

Fig. 11. Granary Weevil and Its Work in Spaghetti
(Slightly enlarged; from Chapman)

material, and the pupae are either in the larval burrows or in cases formed by fastening food particles together. The adults feed on the same food as the larvae.

The list of the foods in which the drugstore beetle has been found includes more than a hundred items, among them grains and grain products, drugs, peppers, spices, and other plant products. Once it infests a warehouse, practically everything in the place must be examined, for a few beetles may escape in some unthought-of material.

Cigarette Beetle, *Lasioderma serricorne* (Fabr.)

The cigarette or tobacco beetle resembles the drugstore beetle in appearance and habits. The adult is only about one sixteenth of an inch long and is covered with fine hairs. It differs from the drugstore beetle in that the last three joints of the antennae are about the same size as the others, and the insect as a whole is less flattened. The larva resembles that of the drugstore beetle, but it is more hairy, the end of the body is bent under to a much less degree, and the head is very differently marked.

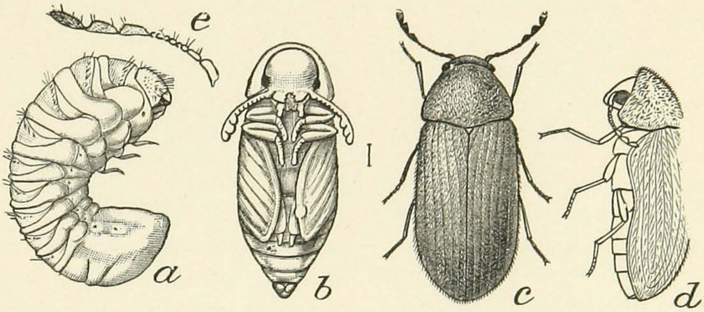

FIG. 12. DRUGSTORE BEETLE, *Stegobium paniceum*
a, Larva; *b,* pupa; *c,* adult, dorsal view; *d,* adult, lateral view; *e,* antenna (From Chittenden)

While this beetle is primarily a pest in tobacco, it infests many food products, such as spices and cayenne pepper. As the "tow bug," it is sometimes reported occurring in overstuffed furniture that contains flax tow.

White-marked Spider Beetle, *Ptinus fur* Linn. and Hairy Spider Beetle, *P. villiger* (Reitt.)

The six rather long legs and the equally long antennae of these oval-bodied beetles as well as their inability to fly give them the appearance of spiders. The beetles are about one eighth of an inch long and the general color is brown with blotches of yellowish-white hairs on each

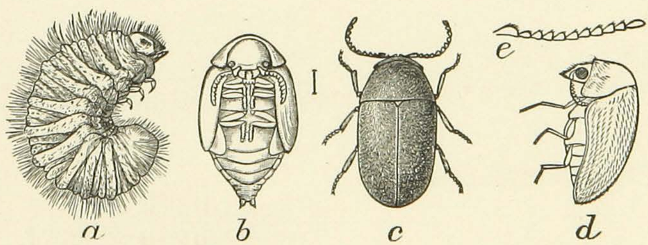

FIG. 13. CIGARETTE BEETLE, *Lasioderma serricorne*
a, Larva; *b,* pupa; *c* and *d,* adult (From Chittenden)

side of the body. The male beetles are usually smaller, more slender, and lighter in color than the females. The larvae are small white grubs, which when full grown make cases of the food material cemented together. The entire life cycle takes a little less than four months under favorable conditions.

This is a rather serious pest at times for it can live in a wide variety of materials. It is reported as attacking flour, meal, various groceries, bookbindings, clothing, and paper. Cases are reported in which it has completely overrun general stores, country elevators, and warehouses. Usually such infestations arise from flour, feeds, and grain falling through cracks in the floor, as in a warehouse or a loading platform, then becoming caked and moldy on the damp surface of the ground. As spider beetles are most serious in cold climates, the adults emerge and invade buildings above the food in which they bred, most often from March to May although some reports are for August. The location of the material from which they breed may be determined by observing the presence of pupal cells on the surface of woodwork or decaying wooden debris associated with the moldy food under the building.

Spider beetles are relatively common, although not numerous, in basements of homes and similar locations throughout their range. It is only when food conditions are right that they become noticeable by their habit of migrating in large numbers at the time of emergence from their pupal cells. Moisture and relatively low temperature are conditions suitable for the development of spider beetles. The adult beetles have been seen crawling actively over sacks of flour in a warehouse at 38° F., when most stored-product insects would have been unable to move or would have been killed within a few weeks.

Several other species of spider beetles, notably *Mezium americanum* Laporte and *Niptus hololeucus* (Fald.), may occur in small numbers in undisturbed food products.

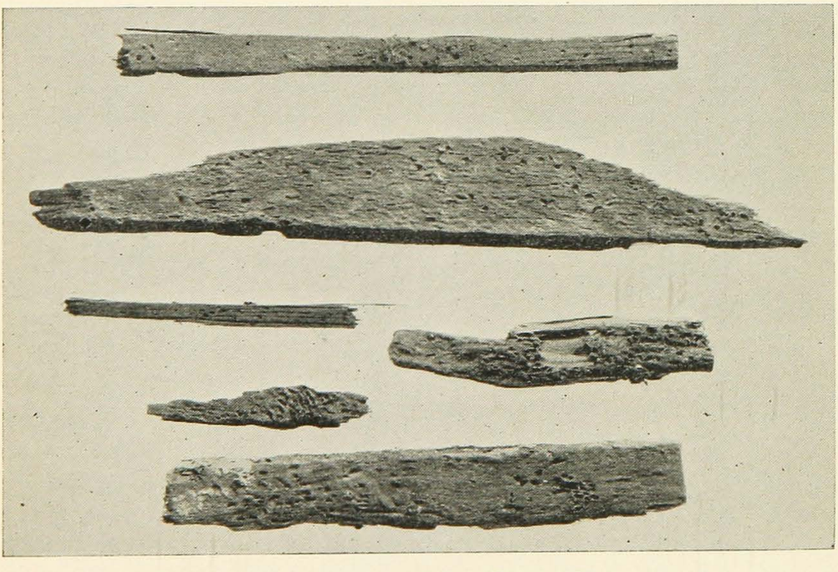

Fig. 14. Wooden Debris Bearing Spider Beetle Holes and Cocoons

Dermestid Beetles

Several members of the family of beetles known to entomologists as the Dermestidae are important pests of stored foods. They are rather general feeders, although they prefer foods high in fat and protein. Some, in fact, will hardly feed on cereals at all.

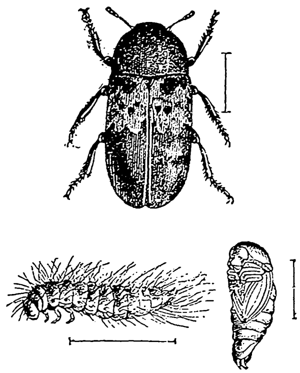

FIG. 15. LARDER BEETLE, *Dermestes lardarius*, ADULT, LARVA, AND PUPA

The larder beetle, *Dermestes lardarius* Linn., is one of the larger, more conspicuous species. The adult varies from one fourth to one third of an inch in length. Its general color is dark brown with a conspicuous band of pale yellowish brown across the base of the wings. The larva is covered with moderately long brown hairs and bears two short, curved spines on the last segment. The life cycle requires forty or fifty days in warm weather.

The adults and larvae, especially the latter, feed largely on animal matter such as ham, bacon, cheese, butter, moldy bread, and garbage. The larvae may bore into spoiled hams upon which they are feeding. Cured meats often must be wrapped tightly to protect them from these insects. When larder beetles become numerous, the larvae may burrow into soft wood and fiber insulation nearby to pupate. The destruction from this source may be considerable at times.

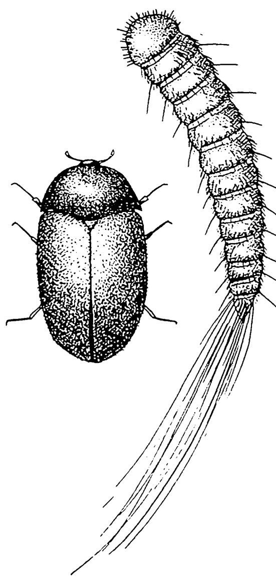

FIG. 16. BLACK CARPET BEETLE, *Attagenus piceus*, LARVA AND ADULT

The hide or leather beetle, *Dermestes vulpinus* Fabr., is similar to the larder beetle in appearance, habits, and life history. It differs, however, in that the adult bears no yellowish transverse band. It is probably the more common species in raw hides, hence the name. Frequently it becomes so numerous in summer around the incinerator and partly burned garbage from the latter in an apartment house that it migrates throughout the building, causing much annoyance.

The large cabinet beetle, *Trogoderma ornata* (Say), is a smaller species which infests dry products high in protein but not so high in fat. Its food is often of vegetable nature rather than animal, namely, the germ of stored seed grains and other seeds and nuts and their protein-containing products.

The adult is about one eighth of an inch long and is black spotted with gray and light brown. The larva is brown above and white below, and the body is covered with reddish-brown hairs that are slightly longer at the posterior end. (See Minnesota Agricultural Experiment Station Bulletin 340, p. 19, fig. 9.)

Another species of the same genus, *Trogoderma versicolor* Cruetz, is almost exactly like the preceding species, although it may be distinguished by the shape of the eyes and other characteristics. It has been found in foods such as dried buttermilk that has been stored a year in a warehouse.

The black carpet beetle, *Attagenus piceus* (Oliv.), can develop normally on foods relatively low in nutritive value, such as wool, feathers, and fur. Its development is slower on these materials, however, than in fish meal, dried meat scrap, and wheat germ. The life cycle varies from as little as eight to ten months to as much as two or three years, depending upon both food and temperature conditions.

The adult beetle is elliptical in outline and about one eighth of an inch long, although it is remarkably variable in size. It is black, with yellowish legs and antennae. The larvae are covered with short shiny brown hairs and bear a tuft of relatively long hairs forming a conspicuous tail at the end of the body. It is well known in the home as a pest of rugs and stored woolens.

Square-necked Grain Beetle, *Silvanus gemellatus* Duv. = *Cathartus quadricollis* Guer.

This species is one of the smaller beetles, and less abundant in the North than in the South. The adult is very small, slender, flat, and reddish brown in color. The rectangular thorax with its smooth straight sides is quite characteristic. In Minnesota this species is not common, although it is found occasionally in dried fruits. When temperatures are high, the entire life cycle requires only a little more than three weeks for completion.

Foreign Grain Beetle, *Ahasverus advena* Waltl.

This species is another small reddish-brown beetle, found primarily in damp, moldy cereals. The adult is about one tenth of an inch long and is much broader in proportion to its length than are most of the other beetles except the drugstore beetle. It can be distinguished from the latter by the horizontal head and the barrel-shaped prothorax.

The foreign grain beetle is never found in clean, dry places but usually where materials have become moldy and out of condition.

Black Fungus Beetle, *Alphitobius piceus* (Oliv.)

This beetle resembles the meal worm adults in form and color but is considerably smaller and proportionately broader. The eyes are divided so that they appear to lie one pair on the upper and one on the lower surface of the head. The insect is found in locations similar to those in which meal worms are found, especially in dark damp corners beneath machinery, under grain and flour sacks, and in the holds of ships.

A similar related species, the lesser meal worm, *Alphitobius diaperinus* (Panz.), is commonly found in damp flour-mill basements, and it feeds on many foodstuffs that are out of condition because of moisture.

Two-banded Fungus Beetle, *Alphitophagus bifasciatus* (Say)

The two-banded fungus beetle is common in waste feeds in the stock barn and elsewhere. It is said to be a scavenger, feeding on the molds in moist and spoiled cereals. The adult beetle is less than an eighth of an inch long and is oval. It is reddish brown with two broad black bands across the wing-covers.

Broad-horned Flour Beetle, *Gnathocerus cornutus* (Fabr.), and Slender-horned Flour Beetle, *G. maxillosus* (Fabr.)

The broad-horned flour beetle is a robust, reddish-brown beetle resembling other common flour beetles, but easily distinguished by the stout horns with which the jaws of the males are armed. The species

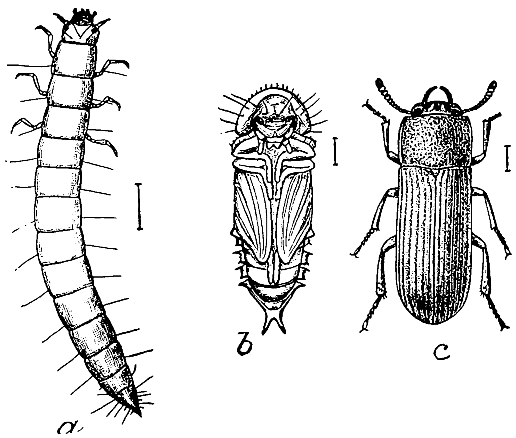

FIG. 17. SLENDER-HORNED FLOUR BEETLE, *Gnathocerus maxillosus*
a, Larva; *b,* pupa; *c,* adult (From U. S. Dept. Agri.)

is much less common than the confused flour beetle, although it sometimes occurs with that species in large numbers. It is found in grain and milled products of various kinds.

The slender-horned flour beetle usually occurs farther south.

Small-eyed Flour Beetle, *Palorus ratzeburgi* (Wissm.)

The adult beetle is reddish brown and about one twelfth of an inch long, with habits similar to those of the confused flour beetle. It can be distinguished by its small size. It is usually found in flour and meal, in places which have long been used for storing such products. Because of its small size, it is able to penetrate the smallest cracks and may often escape ordinary cleaning. *Palorus depressus* (Fabr.) has also been reported from Minnesota.

Long-headed Flour Beetle, *Latheticus oryzae* Waterh.

The long-headed flour beetle is much like the confused flour beetle in form, but the head is longer and the antennae are somewhat different. Furthermore, the insect is smaller and is pale yellow instead of reddish brown.

This insect, although reported as an important pest in various stored products from most parts of the world, has only been known to occur in the United States during the last quarter century. It is reported from flour mills in Minnesota.

Red-legged Ham Beetle, *Necrobia rufipes* (DeG.)

The red-legged ham beetle is primarily an insect that lives outdoors on dead animal matter, but it often gains access to cured meats in storage. The adult is about one fifth of an inch long, steel-blue, with reddish legs. The larvae are white grubs with two small hooks or tubercles at the tip of the body. The grubs usually work in the fatty portions of the ham and just under the skin.

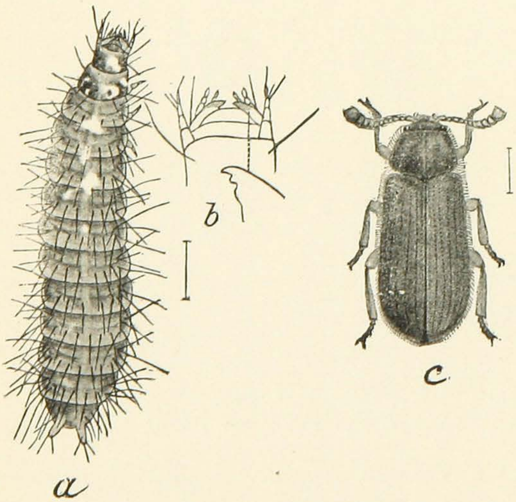

FIG. 18. RED-LEGGED HAM BEETLE, *Necrobia rufipes*
a, Larva; *b*, head of larva; *c*, adult
(From Chittenden)

The egg stage lasts four or five days at 70° to 85° F.; lower temperatures may extend the stage to two weeks. The life cycle varies in duration from 66 to 163 days, with an average of 115 days at 74° to 78° F. daily mean temperature.

This beetle is not a serious pest in the home, and it can easily be detected. All infested portions of the meat should be cut out and burned. The rest will then be uninjured.

In warehouses and packing plants, the beetle may prove very destructive. The best preventive treatment is to wrap the meat carefully in material that will make it impossible for the beetles to gain access. No ham or dried meat should be left exposed at summer temperatures.

Vinegar Fly, *Drosophila ampelophila* Loew.

The vinegar or pomace fly, as this and several related species are termed, becomes numerous wherever fruit juices, vinegar, and overripe fruits and vegetables are exposed. Canneries and prepared-mustard mills are often troubled with these pests. Cracks in wooden equipment provide constant breeding quarters. Pomace and waste fruit should be buried or spread at some distance from the factory.

The vinegar fly is a tiny, yellowish or reddish, two-winged fly. Its eggs are often deposited in cracks in fruit, and the young white maggots, which hatch in about a day, develop in the fermenting tissue. Development is rapid, the life cycle being about eight days at 85° F. and eleven to thirteen days at 75° F.

Cheese Skipper, *Piophila casei* Linn.

The maggots, called cheese skippers, infest hams, bacon, and cured fish, as well as cheese. The adult is a black fly about the size of the common housefly. The maggots are white and legless. They propel themselves by bending in an arc and then straightening out suddenly. They may also crawl about, especially when they have attained full growth and are seeking a crack in which to pupate.

The adults fly about and lay their eggs on meat or cheese. The life cycle requires three or more weeks, depending upon the temperature.

Cheese and cured meats should be stored at a temperature of less than 43° F. or carefully protected with a screen having at least 24 meshes to the inch. Infested portions may be cut out and thrown away and the remainder carefully examined daily to make sure that all larvae have been eliminated.

Psocids or Book Lice

Several species of small louse-like insects, known as "book lice," the most common one probably being *Troctes divinatorius* (Müll.), occur in and around cereals and other food products. These insects are tiny, pale, soft-bodied, wingless creatures. 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 are seldom of any great economic importance, but they are often seen in and on furniture and machinery in dust accumulations. Apparently they can exist for long periods on minute quantities of food.

Mites

Mites, classified as Acarina, are microscopic, pale, soft-bodied creatures, closely related to spiders. Several species occur in food products. The most common one in flour and other cereals is probably the flour mite, *Tyroglyphus farinae* DeG. The specimen in figure 19 belongs to a closely related species, probably *T. longior* Gerv., which looks much like the common *T. farinae* and which also occurs in stored products of various sorts. When mites become numerous, species of predaceous mites sometimes prey on them, so that by the time the mites are noticed, the original pests may almost entirely have disappeared.

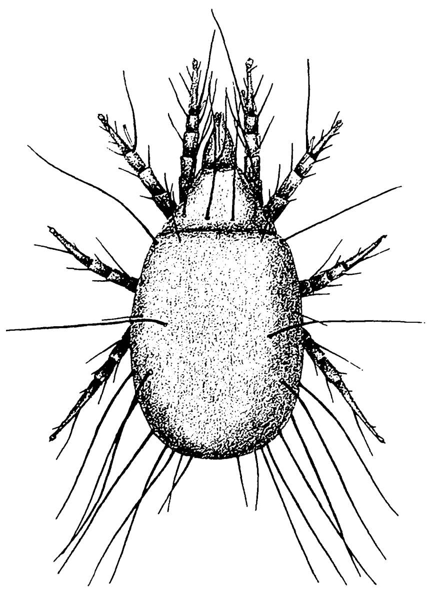

FIG. 19. MITE, *Tyroglyphus* sp.

Various species of mites, such as *Tyroglyphus farinae,* are common pests of cheese and are then known as "cheese mites." A brown powder over the surface and in the small depressions in the cheese is an indication of the presence of mites. Fumigants are often used for their control.

The adult female lays twenty to thirty eggs or more, scattered about, in, or on the food. The period of incubation varies from three or four days to longer periods of several weeks. The larval stage lasts for five or more days and the nymphal stage for six or more days. Hence the life cycle may occupy as little as fourteen days under very favorable conditions.

Mites of various species occur in all cereal products, dried fruits, cheese, dried meats, and many other articles of food. They are common in neglected corners contaminated with moldy flour, sour milk, and the like.

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 pass into a resting stage known as the "hypopus." In this condition they are covered with a hard crust which prevents them from drying out and allows them to 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 that was formerly infested, but as soon as new material is stored in it they reappear.

Miscellaneous Insect Pests

Several groups of insects are of common occurrence in and around buildings in general. Whenever these insects can find desirable food, they become pests. A list of such general pests includes several species of roaches, a number of kinds of ants feeding on both sweet and fatty materials, silverfish, house centipedes, and others. Because these pests occur more generally than most of those thought of as strictly stored-food pests, they have been described in separate circulars with recommendations for their control.

CONTROL OF INSECTS IN STORED FOOD PRODUCTS

The manner in which insects develop under various special conditions of food manufacture and handling has been discussed earlier in this bulletin. Discussion of a general nature follows.

Storage of food products, especially those most liable to insect infestation, should be as brief as possible. The sooner foods are consumed after their manufacture, the less the chance of infestation and consequent dissatisfaction of the consumer. This principle applies to the housewife in her capacity as a food handler as much as it does to the miller, baker, or grocer.

Food storage over a greater or less period is necessary, however, so the conditions of storage must be made as discouraging to insects as possible. Many foods may be kept free from insects for long periods merely by storing in a relatively cool and dry place. Fresh lots should be kept separate from older ones, and the older ones should be used first. Stock liable to infestation should not be stored near materials less liable to insect damage. In other words, middlings and whole wheat flour should not be stored next to white flour if this can be avoided.

Often a product entirely free from insects when packaged becomes infested before it is consumed. Frequent observations indicate that this is usually the result of ill-advised economy in the package stock used. Packages leaving a plant in good condition may be damaged slightly at the corners with ordinary handling, and some insects seem to have an uncanny sense that aids them in placing their eggs on such damaged packages so that the young larvae may crawl inside.

In the construction of buildings in which foods are to be manufactured, it is important to avoid having dark, damp corners inside and beneath the building which are attractive hiding-places for insects. Machinery and plumbing should be open and easy to clean beneath and behind. The floors and walls are easier to care for if they are smooth and the corners are rounded and tight. Wooden partitions, with their cracks, beading, and quarter round, provide ideal hiding places for many kinds of insects. A number of manufacturers are replacing wooden driers, lockers, and cabinets with metal equipment designed for easier cleaning.

The idea that fumigation of a building is the one easy way to get rid of insects appears to have become rather general. Fumigation is often too expensive and is seldom a satisfactory substitute for a clean-up. Except under special conditions, fumigation is an emergency measure.

Cleanliness is the most important means of insect control. The use of the word "cleanliness" here is somewhat different from the usual sense. In a house apparently kept "spick and span," some condition may have been overlooked that appears insignificant, yet it makes possible the multiplication of some kinds of insects. Cleanliness with respect to insect control under storage conditions involves the frequent clean-up and disposal of accumulations, old lots and foreign material, that may harbor and support insect pests of products stored nearby. When a lot is moved or used up, the space it occupied should be cleaned. Before a new lot is stored, the space it is to occupy should be inspected. Here the best weapons are brooms, air-pressure hose, and vacuum cleaners.

High Temperature

Heat is an important means of killing insects. It is often relatively cheap and is easy to apply. All insects die within a few minutes at 120° to 125° F. The chief difficulty lies in raising their surroundings, such as the interior of a sack of flour or seeds, to that temperature. The rate of heat transfer into stored products is relatively slow, hence the treatment is more effective when the product can be spread out in a thin layer.

In oven-heating for small quantities, the material should be placed in pans, not more than an inch and a half or two inches deep. The pans may then be placed in the oven and the heat turned on. A gas oven, with the fire as low as it will burn well, will heat the surface of the material to a temperature of about 180° F. in fifteen minutes. The center of the material will then have reached a temperature of about 120° F. The heat should be turned off at this point and the material left in the oven with the door closed for half an hour.

When any cereal product is heated, other than one used for making raised bread and pastry, the only danger is that of scorching. For flour used in baking, a temperature of 174° F. or higher must be avoided and a thermometer should be used. For ordinary breakfast foods and meals, a thermometer is advisable but not absolutely necessary. Frequent stirring will give more uniform heating and will reduce the possibility of scorching the material.

Many manufacturers of food products are installing small rooms built especially for use in sterilizing insect-infested materials, especially flour sacks before they are returned for re-filling. It is relatively easy to provide controls to insure a constant temperature of about 130° F.

The safest method of handling special products is to "sterilize" them at the factory and pack them in tightly sealed containers. Such products will remain free from insects for all time provided the packages are not broken open or exposed to insects which will eat their way into the packages.

"Sterilization," as used in this connection, means freeing the product of all insect life. In its true sense, sterilization means doing away with all life, including bacteria. Since bacteria are present everywhere, are

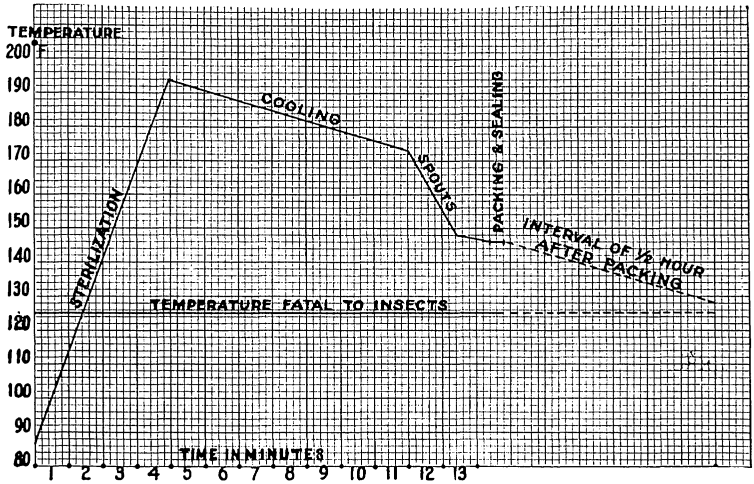

FIG. 20. TEMPERATURE OF CEREALS DURING PROCESS OF STERILIZATION AND PACKING

much harder to kill than insects, and relatively few of them are harmful, there is no reason for ordinary cereals being made sterile in the true sense.

The "sterilization" of cereal products is usually accomplished by means of fumigation, electricity, or heat. The heat method is almost universally employed. Fumigation is expensive and is accompanied by a certain amount of danger. Aside from a few secret processes, this method is seldom used.

An electrical treatment, which appears to be giving satisfaction, involves the passage of sealed packages on a conveyor belt through a high-frequency, high-potential field. As the electricity passes through paper with little interference, it is possible to do away with all danger of having insects enter the material between the time of "sterilization" and the sealing of the packages by exposing the sealed packages in this manner.

Heat is the oldest, most common, and most satisfactory method of "sterilizing" products. It may be derived from steam, hot air, or electricity and should be applied just before the material is placed in the package. Any type of machine that will keep the material in constant motion and heat all portions equally is satisfactory. Machines on the market should be examined with the view of determining which will produce the most even and constant temperature, combined with economic installation and operation.

The cereal should pass from the sterilizer directly to the packer. Sterilization will not prevent insects from re-entering the product; it simply kills all eggs and all stages of insects present at the time of treatment. If the product is then packed and sealed, it will be permanently free from insects. Figure 20 illustrates a satisfactory method of handling a product for sterilization and cooling. For half an hour after the packages are sealed, it will be noticed that the product remains at a temperature above that which is fatal to insects. Any insects that are in the packages before they are filled are killed by the temperature of the product after it is in the package. This procedure is common in the manufacture of breakfast cereals.

Some complications may arise with regard to the moisture in the product. A certain amount of moisture will be given off from the product in the form of vapor. Ordinarily this may accumulate like dew upon the product as soon as it cools again. This does not mean that the moisture content of the product has been increased. On the contrary, it is decreased because some of the vapor has escaped. When first cooled, most of the moisture will be condensed near the outside of the package because this will be the coolest place. Later, however, the material near the center of the package will absorb the excess moisture from that near the outside and the moisture will again be equally distributed throughout the product. If water has been added to the process of manufacture, it is necessary to pass the product into a bin after it is cooled and leave it there while the moisture is being redistributed. Such bins must be closely guarded to prevent insects from getting into the product.

Table 2. The Radiating Surface Per Linear Foot, and the Linear Feet of Pipe Required to Make One Square Foot of Radiating Surface

Size of pipe in inches	Radiating surface per linear foot	Linear feet of pipe per sq. ft. of radiating surface
1	0.346	2.9
1¼	.434	2.3
1½	.494	2.0
2	.622	1.6
2½	.753	1.3

Entire buildings may often be heat-treated satisfactorily, especially in hot weather. Not all buildings are tight enough to be heated up to 120° F., but as a rule any mill that can be heated to 70° F. in the winter can easily be heated to 120° during the hot days of summer. Where there is not enough radiation, it is often cheaper to install, temporarily, the necessary pipes than to fumigate with hydrocyanic acid gas. When pipes are installed, they should be near the floor and well distributed about the sides of the building. As heat rises, it will be necessary to have more radiation on the lower floors than on the upper ones. The following scale of cubic feet of capacity to each square foot of radiation has been suggested (Dean, 1913).

Floor	Cubic feet
1	50
2	60
3	75
4	90
5	110

"In case steam pipe is used for the radiation, either 1¼ or 1½ inch is recommended as the most practical size." (Dean, 1913.)

Water taps should be provided to draw off the water that collects as a result of the condensing of the steam when the pipes are cold. A pressure of from 25 to 50 pounds should be used to heat the building rapidly.

In recent years it has been found that the newer unit heaters with forced circulation of the heated air reduce the expense and increase the efficiency of superheating.

A hot day in summer should be chosen for heating. A windy, cold, or rainy day is obviously unsuited. If Saturday is chosen and the heat is turned on just as soon as the machinery is stopped, the desired temperature should be reached some time on Sunday and should be held for several hours in order that it may penetrate any accumulations of flour or other products. Early Monday morning the heat may be turned off and the windows opened to allow the place to cool off in time for the regular business of the day.

Thermometers should be put in three or four places on each floor of the building and the heating should be continued until the thermometers near the floor of the first story show a temperature of at least 120° F. for some time. Failures with this method are due to careless temperature regulation.

Precautions should be taken to see that the building is tightly closed and that no part of any room is cut off from free air circulation with the rest of the room. Each floor of the building should be shut off from all the others, so that each floor becomes a separate unit and the hot air does not all rise to the top floor. Elevators and carriers should be closed.

Low Temperature

Aside from the fact that storage at moderately low temperatures (40° to 55° F.) is effective in the *prevention* of insect damage because the insects lie dormant, temperatures below freezing may be utilized to kill many stored-product insects as the latter are usually highly susceptible to freezing. Small lots of flour, cereals, and other products may be set out in the cold for a day or two during subzero weather.

Some flour mills and other establishments make a regular practice in zero weather of draining the water pipes and opening the buildings for a week end. The results in insect control are worth many dollars that would otherwise be lost in insect-damaged goods or spent for fumigation service.

Wherever stocks of materials that are liable to insect attack, such as flour and nuts, are kept for some time before being made up into finished products, it is a wise plan to provide cold-storage facilities. The temperature need be no lower than 50° F. to stop not only reproduction and development but ordinary movement of the common confused flour beetle, which may be taken as fairly typical of stored-product insects in general. At 45° F. the adult flour beetle dies in three weeks or less. Air conditioning has been developed so that the temperatures for some operations, as in the baking industry, can be kept low enough to reduce markedly the development of insects.

Contact Sprays

As careful cleaning can not always be followed by heating or fumigation, it is often desirable to use a spray. Once every year or so, 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 all cracks so the surface can be cleaned easily.

Various sprays on the market are efficient contact insecticides, that is, they kill insects when they actually come in contact with them. Most of these sprays are composed of pyrethrum extract in a base of kerosene or a similar light mineral oil. Kerosene or turpentine may be used alone. Gasoline is too dangerous from the standpoint of fire hazard, although all these sprays must be kept away from fire. Some sprays have a strong odor that may to a certain extent repel insects.

Contact sprays are good only for insects flying around or located on or near a surface that can be sprayed. They are used in warehouses that can not be fumigated, but where insects may be hiding in cracks or on the walls at clean-up time. They are useful in the home to squirt into cracks and corners of the cupboards and shelves to kill insects and their eggs that can not be reached by ordinary cleaning methods.

Contact sprays are used most efficiently in movable and stationary sprayers, which derive their power from an electric motor, an air-line, or a steam-line. They are used for killing flying insects with the foggy spray or for driving the fine spray into cracks, beneath machinery, and into places hard to reach with ordinary equipment.

Fumigation

A fumigant differs from the other types of insecticides only in that it is gaseous during its effective period and the insects must breathe in a certain dose to be killed. The gas must be strong enough and must be confined long enough to provide a killing dose for the insects. It will leak out of a loosely constructed building or bin, so fast that such places can not be fumigated economically. The more gasproof a building can be made by virtue of its construction and by sealing doors and windows, the more likely is a fumigation to be successful. Special fumigation vaults can be made so tight that relatively very much less fumigant need be used in them.

The situations for which fumigation is used may be divided into four classes, namely, general, or large-scale fumigation of mills, warehouses, homes, and other types of entire buildings; bin fumigation for stored foodstuffs; vault fumigation at atmospheric pressure for bag sterilization and treatment of returned goods; and vacuum fumigation for the treatment of highly absorptive baled and package goods, and the rapid handling of perishable products.

General fumigation of a building should be done only by an experienced person. Usually hydrocyanic acid gas is used, although there are several substitutes that are as yet not so well developed for this work. Most cities have rigid ordinances regulating the fumigation of buildings.

In bin fumigation, less dangerous fumigants, usually liquid, may be employed. The proper quantity is either poured directly on the stored products or on sacks or blankets laid over them. Then either the bin is closed tightly or the fumigated products are covered carefully with canvas or other tight material to prevent the escape of the fumigant as much as possible.

Atmospheric vault fumigation is becoming common in industries that regularly have quantities of products to be freed of insect infestation. It is called "atmospheric" to distinguish it from vacuum fumigation discussed in the following paragraph. A vault for fumigation purposes may be built relatively cheaply as long as it is tightly made of non-porous material. It should be arranged for handy loading and unloading. It should be furnished with fans for circulation of the gas during the fumigation and for evacuation of the gas at the end of the treatment and may be equipped with appropriate connections for gas-cylinder attachment, as well as pressure gauges, scales, and thermometers for the proper control of gas concentration and temperature. If a liquid fumigant is used, it should be sprayed into the vault. In the old-fashioned pan method of exposing liquid fumigants, evaporation takes place too slowly to give best results.

In vacuum fumigation, a heavy steel vault capable of withstanding considerable external pressure is filled with the commodity to be treated, the air is pumped out, and the fumigant is introduced in place of the air. By this method the gas is taken into the commodity much more rapidly and the insects are made more susceptible to the gas. Because of the speed with which penetration takes place, the period of exposure can be reduced and valuable time saved in the handling of certain types of products. Whereas 12- to 24-hour exposures are common in atmospheric vault fumigations, vacuum fumigations are often for only 90 minutes.

Table 3. Dosages of Various Fumigants to Kill the Confused Flour Beetle in Five Hours at 77° F.

Fumigant	Concentration in milligrams per liter
Hydrocyanic acid	1.1
Chloropicrin	7.0
Methyl bromide	14.4
Ethylene oxide	31.2
Methyl formate	37.5
Ethylene dichloride	73
Carbon disulfide	91
Trichlorethylene	268
Carbon tetrachloride	405

In general, the state in which a fumigant is handled depends upon its boiling point. Mixtures with carbon dioxide, the boiling point of which is many degrees below zero, must be handled in heavy metal cylinders at several hundred pounds pressure. As liquid hydrocyanic acid gas boils at 78° F., it is under so little pressure in a cylinder that it must be pumped into the building to be treated. The common liquid fumigants such as ethylene dichloride (boiling at 183° F.) and carbon disulfide (boiling at 115°) may be poured from light tin containers or glass bottles.

Regardless of the special conditions relative to each space being fumigated, the effectiveness of a fumigant depends largely upon its specific toxicity for the kinds of insects involved, the amount used, and time it is allowed to remain in the space, and the temperature during fumigation.

In table 3 is shown the relative effectiveness of various fumigants against the confused flour beetle, an insect which is rather resistant to fumigation. The dosages given are those to kill the insects in empty glass jars and can not be used, except in a relative way, for determining dosages for fumigating stored products.

The more fumigant used, the shorter the time required to get results. On the other hand, the longer the fumigant can be kept in contact with the products being fumigated, the more likely no insects will survive.

High temperatures have a marked effect in increasing the toxic action of an insect fumigant (table 4). Whenever possible, fumigation of a building should be undertaken on a warm day as it will be more successful at the higher temperature. Fumigation vaults should be equipped with heaters. Bin fumigation is seldom successful when the contents are at temperatures below 65° to 70° F.

The depth of penetration of a fumigant is proportional to the concentration of gas and the time during which it acts. Large bags of flour should not be piled closely, but should be separated so they are exposed to the gas on all sides. When a fumigant is applied to materials in a tight bin, the downward diffusion of the gas is not so 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 surface. This is the result of absorption of the gas by the top layer, 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 product has taken up all it can. Often it is impossible, or at least impractical, to fumigate bins after filling, because of the difficulty of securing penetration to the bottom.

Various products differ in their capacity for absorbing gases. Nut meats and other food products rich in fat absorb large quantities of fat-soluble gases, whereas products high in water content will absorb water-

Table 4. The Effect of Temperature on the Effectiveness of Some Fumigants Against the Confused Flour Beetle; Exposure Time, 5 Hours; Dosages in Milligrams per Liter

Temperature, ° F.	Chloropicrin	Carbon disulfide	Ethylene dichloride
		mgm. per liter	
59	12.3	140	120
68	9.9	108	87
77	7.0	91	73
86	5.0	68	57
95	2.4	40	60

soluble ones. Products such as flour take up large quantities because of their fine particles, but they can be aired quickly if spread out in a thin layer or sifted. Heating drives off absorbed fumigants rather rapidly.

At lower temperatures, absorption is increased. Hence temperature is important in the fumigation of stored products aside from its relation to the toxicity of the fumigant or the activity of the insects being fumigated. At higher temperatures, less fumigant is made ineffective by absorption in the product.

It is important to remember that no fumigant is safe to breathe long. Many of the liquid fumigants, such as carbon disulfide, ethylene dichloride, and carbon tetrachloride, have an anesthetic effect and soon produce drowsiness. This may be the only warning to the operator to get into the fresh air before it is too late. Two or three men should work together to avoid accidents.

HYDROCYANIC ACID is in general the most effective of all insect fumigants. Although it is highly dangerous to handle, large quantities are used safely by experienced fumigators. Hydrocyanic acid comes in several forms, each with its own advantages and special uses. The principal ones are sodium cyanide for use with sulfuric acid, calcium cyanide dust from which the gas is liberated by atmospheric moisture, liquid cyanide in metal cylinders, and various preparations in which the cyanide is absorbed by paper disks or clay. Directions for the use of cyanide, as well as the other fumigants, accompany the preparations or may be obtained from the manufacturer or the Minnesota Experiment Station. Hydrocyanic acid is only used in the general fumigation of entire buildings.

While hydrocyanic acid gas is very poisonous and is very soluble in water, it is gradually given off by foodstuffs when they are exposed to the air after fumigation. In the United States Public Health Service Reports, experiments are described in which it was found that mice were not affected when closely confined with bread and milk which had recently been fumigated with an ordinary amount of hydrocyanic acid. The mice even ate this food after fumigation without showing signs of poisoning. When the dosage was doubled and the time of fumigation prolonged, some of them died. Those that died had not eaten any of the food but were evidently killed by the gas given off by the bread and milk. When the food was aired before feeding it to the mice, there were no symptoms of poisoning. Although the possibility of poisoning from food materials that have been exposed to cyanide gas is somewhat remote, great care should be taken not to expose to excessive dosages foodstuffs that may reach the consumer before being properly aired or those that may be highly retentive of the gas.

CHLOROPICRIN is a tear gas which was used in warfare during the World War. It is very effective against most insects. In some cases it is undesirable because so much is absorbed that it is hard to air out. The fact that minute, relatively safe concentrations produce so much discomfort that a person is driven out by the gas makes fumigation with chloropicrin comparatively free from accidents to persons entering places that are being fumigated. The dosage varies from two to five pounds of chloropicrin per 1,000 cubic feet, depending upon conditions. Chloropicrin is applied either by atomizing it into the machinery and rooms to be fumigated, or by pouring it over sacks hung on the walls or laid over stored products. It is suitable as either a general or a local fumigant.

METHYL BROMIDE is a new fumigant finding considerable application in the food industries in vacuum fumigation, in the treatment of fresh vegetables, and in atmospheric chambers. It will probably be developed for other purposes in the near future. It may be purchased in metal cylinders and in combination with carbon dioxide. Methyl bromide is not inflammable. One to 2.5 pounds are required to a thousand cubic feet.

ETHYLENE OXIDE is used at present principally in combination with carbon dioxide (one part ethylene oxide and nine parts carbon dioxide) in vacuum fumigation. It is adapted for use wherever gas-cylinder connections can be made, especially in vaults. Ethylene oxide by itself is inflammable and explosive, but the carbon-dioxide mixture is not inflammable. The latter is used at about 20 pounds to a thousand cubic feet.

CARBON DISULFIDE is a well-known liquid fumigant, effective and handy to use but, unfortunately, highly explosive. It is recommended to be used only in small buildings at some distance from the house, barn, or factory; otherwise the use of carbon disulfide is likely to void fire insurance policies. Under average conditions, about eight pounds to a thousand cubic feet are required.

ETHYLENE DICHLORIDE, usually mixed with one third the volume of carbon tetrachloride, is used as a non-inflammable substitute for carbon disulfide. It is less effective than carbon disulfide but much more effective than carbon tetrachloride alone. It is used at the rate of fourteen pounds or more to a thousand cubic feet. Both ethylene dichloride and carbon tetrachloride are liquids at ordinary temperatures.

Although sulfur dioxide, produced by burning sulfur candles, is effective in killing insects, the gas injures flour and some other foods and may injure fabrics if the air is moist. Formaldehyde is not effective as an insect fumigant. Several other chemicals are being used successfully as insect fumigants but in smaller quantities. In general, they are not so easily obtained as the ones discussed.

In case much fumigation is to be done, it is well to obtain the literature relative to several fumigants so the one best suited to the needs of the individual may be obtained.

LITERATURE

BACK, E. A. 1920. Insect control in flour mills. U. S. Dept. Agri. Bull. 872.

BACK, E. A., and COTTON, R. T. 1926. Biology of the saw-toothed grain beetle, *Oryzaephilus surinamensis* Linné. Jour. Agri. Res. 33:435-452.

————. 1926. The cadelle. U. S. Dept. Agri. Dept. Bull. 1428.

————. 1932. Hydrocyanic acid gas as fumigant for destroying household insects. U. S. Dept. Agri. Farmers' Bull. 1670, 20 pp.

————. Revised 1937. Industrial fumigation against insects. U. S. Dept. Agri. Circ. 369, 59 pp.

Back, E. A., Cotton, R. T., and Ellington, G. W. 1930. Ethylene oxide as a fumigant for food and other commodities. Jour. Econ. Ent. 23:226-231.

Bedwell, E. C. 1931. Dermestid beetles attacking wood. Ent. Mon. Mag. 67: 93-94.

Blaisdell, F. E. 1892. List of drugs found infested by *Sitodrepa panicea.* Insect Life 5:33.

Cathcart, W. H. 1938. What every baker should know about insect and rodent pests. Amer. Bakers Assoc. Mon. Bull. 2(2):34-38; 2(3):59-63.

Chapman, R. N. 1918. The confused flour beetle (*Tribolium confusum* Duval). 17th Rept. State Ent. Minn. pp. 73-94.

————. 1923. The possibility of transmitting a Calendra infestation from wheat to macaroni thru the processes of milling and manufacturing. Jour. Econ. Ent. 16:341-348.

————. 1924. Nutritional studies on the confused flour beetle, *Tribolium confusum* Duval. Jour. Gen. Physiol. 6:565-585.

Chapman, R. N., and Baird, L. 1934. The biotic constants of *Tribolium confusum* Duval. Jour. Expt. Zool. 68:293-304.

Chapman, R. N., and Johnson, A. H. 1925. Possibilities and limitations of chloropicrin as a fumigant for cereal products. Jour. Agri. Res. 31:745-760.

Chittenden, F. H. 1896. The grain-feeding *Palorus* found in the United States. Ent. News 7:138.

Cotton, R. T. 1923. Notes on the biology of the cadelle, *Tenebroides mauritanicus* Linné. Jour. Agri. Res. 26:61-68.

————. 1927. Notes on the biology of the mealworms, *Tenebrio molitor* Linné and *T. obscurus* Fab. Annals Ent. Soc. Amer. 20:81-86.

Cotton, R. T., and Good, N. E. 1937. Annotated list of the insects and mites associated with stored grain and cereal products, and of their arthropod parasites and predators. U. S. Dept. Agri. Misc. Publ. 258, 81 pp.

Cotton, R. T., and Roark, R. C. 1927. Ethylene dichloride—carbon tetrachloride mixture; a new non-burnable, non-explosive fumigant. Jour. Econ. Ent. 20:636-639.

————. 1928. Ethylene oxide as a fumigant. Ind. & Eng. Chem. 20:805.

Cotton, R. T., and St. George, R. A. 1929. The meal worms. U. S. Dept. Agri. Tech. Bull. 95.

Cotton, R. T., and Wagner, G. B. 1938. Practical methods for insuring the production of insect-free flour. U. S. Dept. Agri., Bur. Ent. and Plant Quar., mimeog. bull. E-419, 8 pp., 11 figs.

DEAN, G. A. 1913. Mill and stored-grain insects. Kansas Agri. Expt. Sta. Bull. 189.

DEONG, E. R., and ROADHOUSE, C. L. 1922. Cheese pests and their control. Calif. Bull. 343.

DITMAN, L. P., CORY, E. N., and BUDDINGTON, A. R. 1936. The vinegar gnats or pomace flies—their relation to the canning of tomatoes. Maryland Bull. 400.

DONOHOE, H. C., and BARNES, D. F. 1934. Notes on host materials of *Ephestia figulilella* Gregson. Jour. Econ. Ent. 27:1075-1077.

FISK, F. W., and SHEPARD, H. H. 1938. Laboratory studies of methyl bromide as an insect fumigant. Jour. Econ. Ent. 31:79-84.

GOOD, N. E. 1933. Biology of the flour beetles, *Tribolium confusum* Duv. and *T. ferrugineum* Fab. Jour. Agri. Res. 46:327-334.

————. 1937. Insects found in the milling streams of flour mills in the southwestern milling area. Jour. Kansas Ent. Soc. 10:135-148.

GOODWIN, W. H. 1922. Heat for control of cereal insects. Ohio Agri. Expt. Sta. Bull. 354.

HAMLIN, J. C., REED, W. D., and PHILLIPS, M. E. 1931. Biology of the Indian-meal moth on dried fruits in California. U. S. Dept. Agri. Tech. Bull. 242.

HERMS, W. B. 1917. The Indian meal moth, *Plodia interpunctella* Hübn., in candy and notes on its life-history. Jour. Econ. Ent. 10:563.

HERRICK, G. W. 1926. Insects injurious to the household and annoying to man. 478 pp. Macmillan Co.

HERRICK, G. W., and GRISWOLD, G. H. Revised 1934. Common insects of the household. N. Y. (Cornell) Extension Bull. 202, 62 pp.

HOWARD, L. O., and MARLATT, C. L. Revised Ed. 1896. The principal household insects of the United States. With a chapter: Insects affecting cereal and other dry vegetable foods, by Chittenden, F. H. U. S. Dept. Agri., Div. Ent. Bull. 4, n.s.

MACKIE, D. B. 1938. Methyl bromide—its expectancy as a fumigant. Jour. Econ. Ent. 31:70-79.

MUTCHLER, A. J., and WEISS, H. B. 1927. The dermestid beetles of New Jersey. N. J. Dept. Agri., Bur. Stat. and Insp. Circ. 108, 31 pp.

NAGEL, R. H., and SHEPARD, H. H. 1934. The lethal effect of low temperatures on the various stages of the confused flour beetle. Jour. Agri. Res. 48:1009-1016.

OOSTHUIZEN, M. J. 1935. The effect of high temperature on the confused flour beetle. Minn. Agri. Expt. Sta. Tech. Bull. 107, 45 pp.

PEPPER, J. H., and STRAND, A. L. 1935. Superheating as a control for cereal-mill insects. Montana Agri. Expt. Sta. Bull. 297.

REED, W. D., and LIVINGSTONE, E. M. 1937. Biology of the tobacco moth and its control in closed storage. U. S. Dept. Agri. Circ. 422, 38 pp.

RICHARDS, O. W., and THOMSON, W. S. 1932. A contribution to the study of the genera *Ephestia,* Gn. (including *Strymax,* Dyar) and *Plodia,* Gn. (Lepidoptera, Phycitidae), with notes on parasites of the larvae. Trans. Ent. Soc. London 80:169-250.

RUNNER, G. A. 1919. The tobacco beetle: an important pest in tobacco products. U. S. Dept. Agri. Bull. 737, 77 pp.

SCHWARDT, H. H. 1934. The saw-toothed grain beetle as a rice-mill pest. Univ. Arkansas Agri. Expt. Sta. Bull. 309, 14 pp.

SHEPARD, H. H., LINDGREN, D. L., and THOMAS, E. L. 1937. The relative toxicity of insect fumigants. Minn. Agri. Expt. Sta. Tech. Bull. 120, 23 pp.

SHEPPARD, E. H. 1936. Notes on *Cryptolestes ferrugineus* Steph., a cucujid occurring in the *Trichogramma minutum* parasite laboratory of Colorado State College. Colo. Expt. Sta. Tech. Bull. 17, 20 pp.

SIMMONS, P. 1927. The cheese skipper as a pest in cured meats. U. S. Dept. Agri. Bull. 1453.

SIMMONS, P., and ELLINGTON, G. W. 1925. The ham beetle, *Necrobia rufipes* DeGeer. Jour. Agri. Res. 30:845-863.

WAGNER, G. B., and COTTON, R. T. 1937a. Eggs of the common flour infesting insects and how to remove them. Amer. Miller 65:51-54.

————. 1937b. Flour redressing machinery and its relation to insect infestation in the flour mill. Northwestern Miller 190:47.

WAGNER, G. B., COTTON, R. T., and JONES, E. T. 1938. Contamination: a study of what mill insects leave in flour. Amer. Miller 66:40-41.

WAGNER, G. B., COTTON, R. T., and YOUNG, H. D. 1936. The machinery-piping system of flour-mill fumigation. U. S. Dept. Agri., mimeog. Circ. E-396.

ZACHER, F. 1927. Die Vorrats-, Speicher- und Materialschädlinge und ihre Bekämpfung. 366 pp., 8 col. pls. Berlin.

LIST OF ILLUSTRATIONS