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NEBRASKA FARMERS are well aware that the warfare against destructive insects is not ended when their grain is in the bin. The garnered crops become immediately subject to attack by various insect pests of stored grain, commonly called "weevils." The loss from this attack becomes of special seriousness when unusually large stocks of grain are being held in the granaries and cribs on the farm and in warehouses. More or less at all times, but especially during periods when grain prices are low, it may be found advantageous to store the grain for an advance in price or for later feeding at home. Also, in taking advantage of recently enacted laws, the tendency is to hold grain in storage for a longer time than formerly. At the close of 1939 about twice the amount of wheat was in storage in Nebraska as compared to the close of 1938. Frequently a new crop of grain goes into storage before the preceding older grain leaves the farm, and, due to inadequate storage space, the crops are not kept separated, thus promoting an early infestation of the new grain from the older grain that has become infested. Under such conditions the damage by stored grain pests becomes a matter of unusual importance.

KINDS OF STORED GRAIN INSECTS

In Nebraska there are nearly 30 kinds of insects that injure stored grain more or less. Some are beetles and their larvae, others are the caterpillars of moths. To farmers and grain men most of these are dubbed "weevil," although that name is properly to be applied only to two kinds of beetles, the true granary weevil and the rice or black weevil. These are both snout-beetles, having the head prolonged beneath into a long snout or beak. The other species of beetles principally concerned are often called "bran bugs," and include the following: the cadelle; the saw-toothed, the square-necked, the foreign, the flat, and the two-banded grain beetles; the confused, the rust-red, the black, the small-eyed, and the broad-horned flour beetles; the yellow, the dark and the lesser meal worms; the drug store beetle; the "tow bug" or cigarette beetle; and the common, the black, and the varied carpet beetles. The moths principally concerned are the Angoumois grain moth, Indian meal moth, meal snout moth, sorghum seed moth, and Mediterranean flour moth.

The true granary weevil and the rice or black weevil are probably the most destructive of all the beetles infesting stored grain in Nebraska. The granary weevil is a shiny, dark brown to blackish snout-beetle, about one-sixth of an inch long, with spaced elongate punctures, arranged in rows, on its thorax (Fig. 1, *e*). It cannot fly, so does not infest grain in the field. The rice weevil is a dull brownish to blackish weevil of the same size and general appearance as the granary weevil, but usually with four light reddish or yellowish spots on the wing-covers and with dense, rounded punctures, not arranged in rows, on the thorax (Fig. 1, *c*). The adults of this species

readily fly from old infested grain to new grain in bins or standing grain in the field. Both of these weevils develop inside the grain and attack not only the small grains and corn but also various other kinds of seeds.

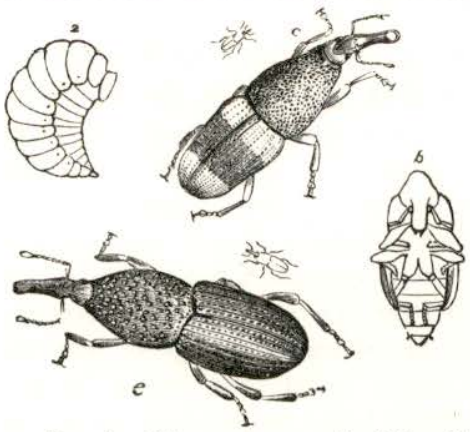

FIG. 1.—The grain weevils (*Sitophilus*): *e*, the true granary weevil (*S. granaria*) enlarged about 6x, natural size at side; *c*, the rice weevil (*S. oryzae*), same; *a*, larva, enlarged about 4x; *b*, pupa, same. (From Packard, 1869.)

The several other species of beetles and their larvae that are found in stored grain for the most part feed upon broken grains. Sometimes they feed within the punctures produced by weevils. Mill and elevator men usually refer to them as "bran bugs."

The adult cadelle is a black, flattish beetle about one-third of an inch long, that can hardly be mistaken for any of the other stored grain beetles (Fig. 2, *a*). The mature larvae are broad and flattish, about three-fourths of an inch long, whitish in general color, with the head, some marks on the thorax, and the rear segment black, the latter ending in two sharp, horny points (Fig. 2, *b*). The larvae of this insect are probably more commonly noticed than those of any other of the stored grain beetle pests.

The adult meal worms are dark brown to black beetles about five-eighths of an inch long (Fig. 3, *c*). The larvae are either waxy yellow or brownish in color, about an inch long when fully grown, with hard wire-like bodies, which makes them resemble wireworms (Fig. 3, *a*). The various species of grain beetles (Fig. 4) and flour beetles (Fig. 5) are smaller than the cadelle or meal worms, and are not so easily distinguished from each other.

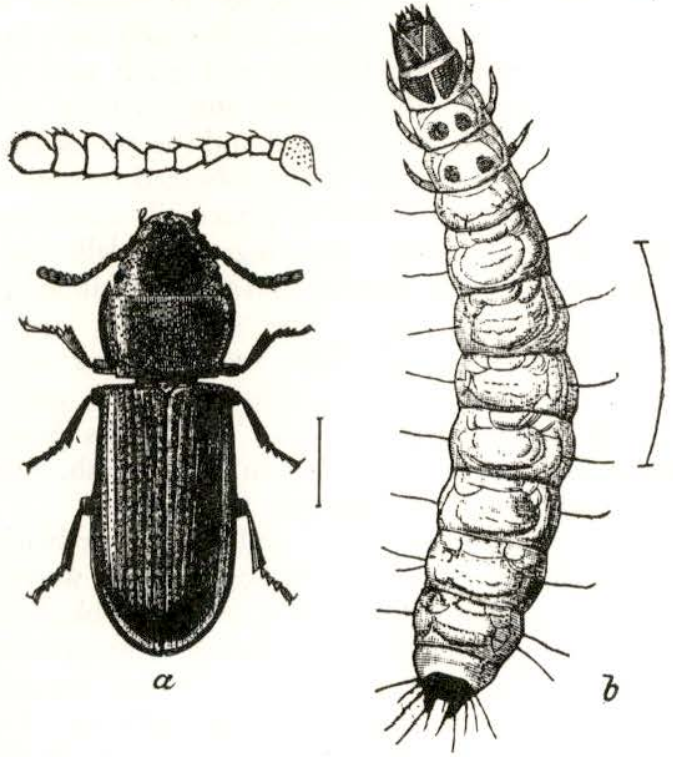

FIG. 2.—The cadelle (*Tenebroides mauritanicus*): *a*, adult beetle, enlarged 5x; *b*, larva, enlarged 4x. (From Chittenden, 1896.)

FIG. 3.—The dark meal worm (*Tenebrio obscurus*): *a*, meal worm, and *c*, adult — natural size; *b*, pupa, enlarged; *d*, *e*, *f*, *g*, *h*, antenna and mouth parts of meal worm, much enlarged. (Riley in Le Baron, 1874.)

The Angoumois grain moth is a light grayish brown or buffy mottled moth, with narrow, pointed and fringed wings having an expanse of about one-half inch (Fig. 6, *c*). Its larvae feed within the grains, hollowing them out as they grow (Fig. 6, *a*, *f*). They work commonly in ear corn, boring into the grains and filling them with holes (Fig. 7.)

The adult Indian meal moth has wings of two colors, their basal third being grayish and their outer two-thirds a reddish brown with a coppery luster, and the expanse nearly three-fourths of an inch (Fig. 8, *c*). The larvae are one of the more common species found in grain or shelled corn where they feed upon the germ, making it unfit for seeding purposes (Fig. 8, *a*). As the nearly mature larvae move over the surface of the grains they spin a web, until in some cases a tough, dirty, silken blanket is formed. The Mediterranean flour moth is more common in flour mills than in stored grain (Fig. 9).

Psocids, or book lice, are tiny, pale, soft-bodied, louse-like chewing insects about one thirty-second of an inch long that often occur in stored grain. Mites that infest stored grain are almost microscopic in size but about the same color as the psocids. They are seldom seen by the farmer or elevator man. While psocids infrequently are of economic importance, mites may become so numerous as to render the grain unfit for food.

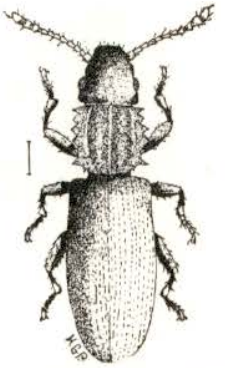

FIG. 4. — The saw-toothed grain beetle (*Oryzaephilus surinamensis*), enlarged about 8x. (From Bruner, 1893.)

HOW GRAIN BECOMES INFESTED

Infestations by the rice or black weevil and Angoumois grain moth may start with eggs being laid in the field. The adults of these two stored grain pests can fly freely from place to place. But usually the infestation starts in the bin, and frequently is due to the storing of grain in bins that were infested previously. Original infestations occur through the introduction of infested grain from some other place, or by the pests entering the bin after grain has been placed in it. Infested mill feed and chicken feed in storage also start infestations.

After the new grain is placed in a previously infested bin, or the insects find the grain, their increase is rapid. A single female beetle or moth may lay from 50 to 200 or 300 eggs. Some kinds require a year for a

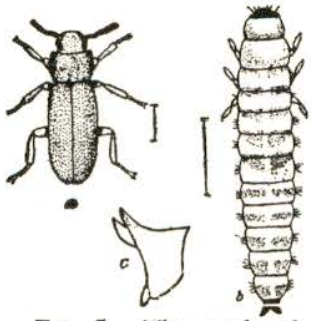

FIG. 5.—The confused flour beetle (*Tribolium confusum*): *a*, beetle; *b*, larva — enlarged about 4x; *c*, outline side view of tip of abdomen of larvae—much enlarged. (From Bruner, 1893.)

generation, while others require only a few weeks for a generation in the warmer part of the year, and develop as many as six generations annually. Rapid increase is often augmented during the colder months by the natural heating of the grain which results from excessive moisture content, and in this way the pests sometimes breed continuously through the year.

PREVENTION OF INFESTATION

It is very important that new grain should be placed, whenever possible, in thoroughly clean bins in which there is no old grain. New grain should be put in empty bins that have been cleaned and made as nearly air-tight as possible. In cleaning a bin, preparatory to putting new grain in it, it should first be swept thoroughly to get rid of all the grain dust and trash that have accumulated on the floor or in the cracks, crevices and burrows in the woodwork of the bins. These sweepings should be removed and burned immediately. They should never be simply thrown out, because the pests may crawl back to attack the new grain. After sweeping, the bin should be sprayed or scrubbed with some disinfesting liquid that will not impart an odor to the stored grain. The Illinois Station has recommended a mixture of one gallon of miscible oil (such as is used for spraying dormant trees), three ounces of lye, and nine gallons of water, to make ten gallons of a spray, which is sufficient quantity to cover about 500 square feet of bin surface. Scrubbing the bin thoroughly with boiling hot lye water made by dissolving a pound of crystal lye to each gallon of boiling water, and working this solution into the cracks of the floor and the walls of wooden bins has also proved satisfactory.

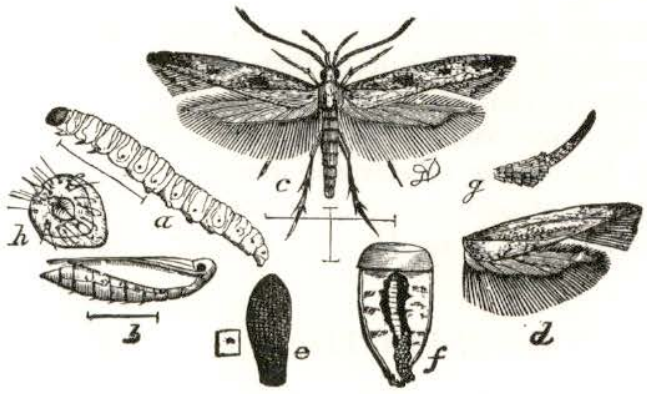

FIG. 6.—The Angoumois grain moth (*Sitotroga cerealella*): *a*, caterpillar, *b*, pupa, *c*, moth, *d*, wing of a paler form—enlarged about 1½x; *e*, egg, *g*, labial palpus of male moth, *h*, last segment of pupa —much enlarged; *f*, grain of corn cut open to show larva at work—natural size. (From Riley, 1884.)

Wooden bins usually are not very tight, so where damage by stored grain pests is anticipated and before the grain is put in, the floors and walls of the bin should be lined with building paper or with several thicknesses of newspaper overlapped at the edges. Then if and when pests later appear in the grain stored in the bin, a successful fumigation can be made with minimum trouble and cost. Stored grain should be inspected in the fall and subsequently once a month during the warm weather of the following year to detect the presence of insect pests, and grain found to be seriously infested should be fumigated immediately.

HEATING AND INSECT INFESTATION

Heating of stored grain may be caused by too much moisture in the grain, and is often accompanied by stored grain pests developing in it. Stored grain containing not over 14 per cent of moisture is regarded as safe under all ordinary temperature conditions. At temperatures not higher than 70°F., the grain may safely contain 15 per cent of moisture, and 16 per cent at temperatures not higher than 60° F. If corn containing 17 per cent or more of moisture is cribbed, it is saved from spoiling only by the low winter temperatures, and it may dry out sufficiently during the winter so that when the weather warms again in the spring it will be safe; otherwise there is danger of spoilage in the spring. Fumigation will not prevent nor stop heating of the grain if it contains an excess of moisture, but if the grain has been dried thoroughly before storing, and heating due to insect pests breeding in it develops, fumigation will promptly stop the heating.

FUMIGATION

Fumigation is the standard method of controlling stored grain pests, and consists of applying some chemical in liquid form and allowing it to vaporize into a heavy, penetrating, insect-killing gas which poisons or asphyxiates the insects. For the successful fumigation of a bin

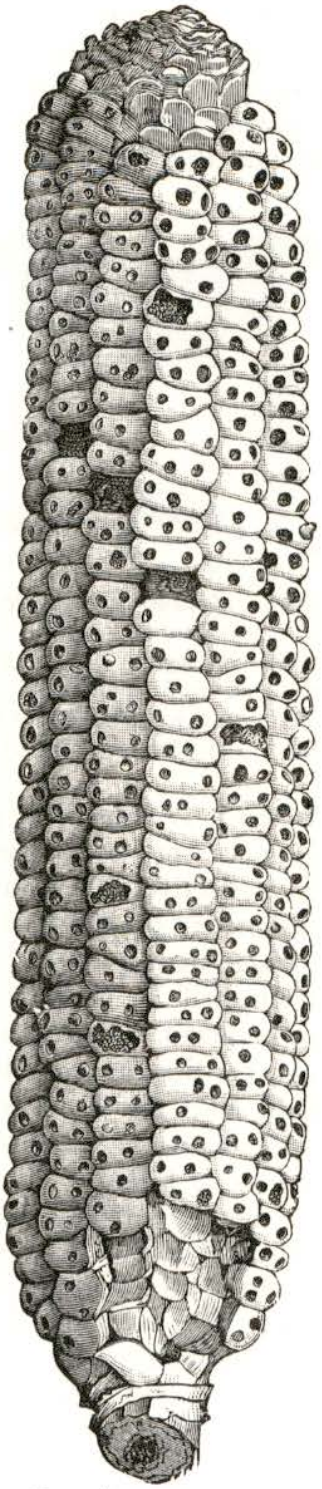

FIG. 7.—Ear of pop corn showing work of Angoumois grain moth. (From Riley, 1884.)

of infested grain, a fumigant must be used the vapor of which is sufficiently heavy and penetrating to reach the pests well below the surface of the grain, and sufficiently poisonous quickly to kill all insect life with which moderate concentrations of the vapor come into contact. The ideal fumigant would be one that does not injure the germination or palatability of the fumigated grain nor objectionably affect the baking quality of the flour made from the treated grain. Also this fumigant should readily form a non-inflammable and non-explosive gas that is not disagreeable or dangerous to the operator, and should be commercially available at a reasonable cost.

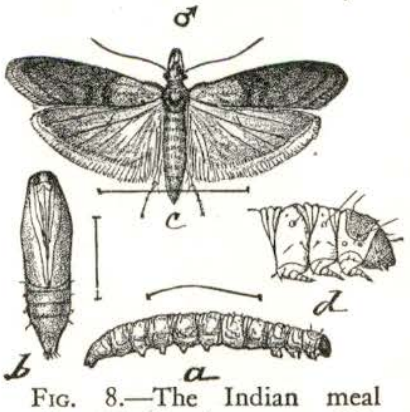

FIG. 8.—The Indian meal moth (*Plodia interpunctella*): *a*, caterpillar; *b*, pupa; *c*, adult moth—enlarged about 2½x; *d*, head and thorax of caterpillar—much enlarged. (From Riley and Howard, 1889.)

In fumigating stored grain with heavier-than-air gases, there are certain requirements that must be met if satisfactory results are to be secured. The bin must be made as nearly air-tight as possible. These heavy vapors are very penetrative, and unless the bin is quite tight they will seep out and the effects of the fumigation will largely be lost. The ordinary wooden bin usually is not tight enough without some special preparation. When it is lined with paper, as previously mentioned, it is ready for fumigation. Any crack allows the gas to escape, and the more that escapes the less effective the fumigation will be. No fumigation should even be attempted in a poorly constructed, leaky grain bin, for the gas must be held with the grain for some hours if the pests are to be killed.

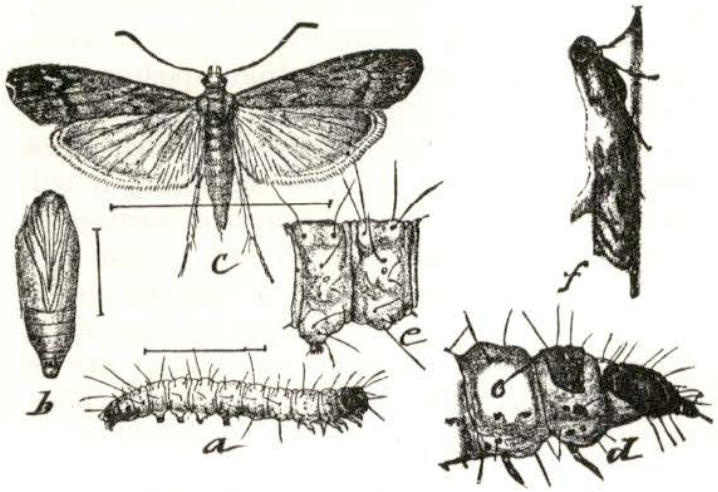

FIG. 9.—The Mediterranean flour moth (*Ephestia kuehniella*): *a*, caterpillar; *b*, pupa; *c* and *f*, adult moth—enlarged 2x; *d*, head and thorax of caterpillar; *e*, abdominal segments of same—much enlarged. (From Riley and Howard, 1889.)

Another point is the fact that when the temperature of the grain is lower than 60° to 65°F., the fumigation of that grain will not be successful in killing the pests. No fumigation should be attempted under such conditions. Temperatures of 70° F. or over usually permit successful fumigation, but the ideal temperatures of the grain for fumigation are 80° to 90° F. Where the temperature is less than 80° F., the amount of the fumigant used must

be increased. In general, the higher the temperature the more rapid the evaporation and the penetration of the fumigant, the more the air will take up the vapor before becoming saturated with it, and the more readily the insects will succumb to the effects of the vapor because of their more rapid breathing. Another point is that the grain must be dry if the fumigation is to be satisfactory. Lastly, the fumigation should not be put on during a period of rapid air movement.

The methods of using any of these heavier-than-air fumigants are much the same. If the temperature of the grain is 80°F. or higher, the liquid may be evaporated from shallow pans or basins placed on top of the grain. At lower temperatures the liquid should be evenly sprinkled directly on the grain. If the grain is more than four feet deep, a piece of pipe should be thrust into the grain and some of the liquid poured down through the pipe to near the bottom of the bin, not neglecting the corners. Before the liquid is placed or poured, some arrangement should be made for covering over the treated grain to confine the vapor. A large tarpaulin is good for this, but several overlapped sheets of newspaper covered with horse blankets or grain sacks may be used effectively. The best procedure is to level off the top of the grain, lift the tarpaulin or other covering, place or pour the liquid, replace the cover, close up the bin and get away. The bin should be kept closed for 24 to 48 hours, according to the temperature and the tightness of the bin. At the end of the period of fumigation the bin should be opened and aired for a few days before the building is entered for any considerable length of time or any fire brought into it. If the grain is to be used for seed, it should be shoveled over a few times to help the fumes to escape.

Carbon Bisulphide

For many years the standard heavier-than-air fumigant for stored grain pests has been carbon bisulphide. This comes in the form of a heavy, nearly colorless liquid that evaporates quickly on exposure to air, forming a very ill-odored vapor that is 2.63 times as heavy as air, and therefore very penetrating downward. It is highly poisonous to insects when used in moderate concentrations, not injurious to the germination of the fumigated grain, not dangerous to healthy operators taking reasonable care, and easily available at a reasonable cost. The currently quoted cost in small quantities is around 25 cents a pound, but in 50-pound and 100-pound drums may be purchased for about 9 cents a pound, and in 550-pound drums for about 7 cents a pound. The objections to the vapor of carbon bisulphide are that it is *very inflammable,* and will flash and burn from a flame or even a static spark at temperatures as low as –4°F., and at a temperature, without any flame, of 297° F. or above, which is a lower ignition point than that of gasoline vapor; that it is *highly explosive* when mixed with air at concentrations of 6 per cent or more; that it has an *extremely disagreeable* odor; and that being a sulphur compound it acts as a *reducing reagent* on wheat and flour, so that wheat that has had a

prolonged exposure or even repeated shorter exposures to the vapor produces a flour that may cause much trouble for both the miller and baker. Where the wheat has been exposed to the carbon bisulphide vapor for only a short time, the effect of fumigation may be less detrimental and may be overcome by the use of moderate quantities of oxidizing agents in the baking formula. But unfortunately, a load of wheat that has been excessively fumigated with carbon bisulphide, even when later mixed with several loads of unfumigated wheat, produces a flour very poor in baking qualities. Wheat fumigated with carbon bisulphide upon subsequent aeration gradually loses much of the undesirable effect of the fumigation, and after storage for some months may become considerably improved, but still remains inferior for milling and baking purposes to untreated wheat.

However, when used properly and with caution, carbon bisulphide is not an unsatisfactory fumigant for infested stored grain, and as a matter of fact there have been but few fires and explosions resulting from the use of carbon bisulphide, in spite of the admittedly great inflammability and explosiveness of its vapor, and most of these have been due to carelessness, where proper caution was not observed. No lighted lanterns, or lighted tobacco of any kind should be brought near to where carbon bisulphide fumigation is going on, and care should be taken about sparks from electric switches or made by striking metals together, and even about electricity produced by friction. Of course hot stoves and steam pipes are also dangerous. With care, carbon bisulphide can be used effectively and cheaply, and with reasonable safety, in grain fumigation, especially in isolated buildings.

Another precaution, since carbon bisulphide vapor is a poisonous gas to people as well as insects, is to avoid inhaling the vapor in any large amounts, or even in small amounts for a prolonged period. If, in fumigating with this chemical, there is felt any dizziness or nausea, the fresh air should be sought at once, where the ill effects will usually pass away within a few minutes. Also, since the vapor has an accelerating effect upon the heart action, persons having any heart trouble or weakness should not take any extended part in fumigating operations with carbon bisulphide.

Mixture of Ethylene Dichloride and Carbon Tetrachloride

Because of the dangerous inflammability and explosiveness of carbon bisulphide vapor, and its deleterious effect upon the milling and baking qualities of flour made from wheat that has undergone an excessive exposure to heavy concentrations of it, for a number of years past efforts have been made to find a substitute fumigant that would do the work as well and with entire safety and satisfaction. Probably the most promising of these, and one now gaining wide acceptance in the milling trade, is an ethylene dichloride-carbon tetrachloride mixture, consisting of a mixture of three parts by volume of ethylene dichloride and one part by volume of carbon tetrachloride. There are numerous labeled brands of this product now on the market. While this mixture evaporates readily, though

rather slowly, its vapor has good penetration (being over three times as heavy as air), and a not disagreeable odor, with relatively little danger to the operator (though breathing much of it sometimes causes difficulties, when fresh air should be sought at once). Most important of all, the mixture is *not inflammable,* ethylene dichloride requiring less carbon tetrachloride to render it non-inflammable than does carbon bisulphide. Its killing power is considerably less than that of carbon bisulphide, requiring more material to accomplish the same results, which increases the cost, which currently runs at about 6½ to 9½ cents a pound delivered in drums in Nebraska. Investigators report that this mixture has little or no effect on flour quality, in contrast with the effects of carbon bisulphide vapor.

Determining the Amount to Use

To determine the amount of liquid fumigant to use, first find the number of bushels of grain in storage, or compute in cubic feet the contents of the grain bin (length x width x height, in feet). In large, tight, ordinary wooden grain bins, at a temperature of around 75°F., minimal dosages of 1¼ pounds of carbon bisulphide to each 100 bushels of grain, or 1 pound to each 100 cubic feet of space, should be used. Where the bin is not entirely tight and there is sure to be some leakage, or where it is more than 5 feet deep, the amount should be increased to 1⅔ to 2½ pounds to each 100 bushels of grain, or 1½ to 2 pounds to each 100 cubic feet of space, according to the tightness and size of the bin. The mixture of ethylene dichloride and carbon tetrachloride should be used in very tight bins at the rate of about 5 pounds per 100 bushels of grain, more being required in less tight bins, up to 8 pounds per 100 bushels of grain.

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