Grains and seeds in storage are subject to the attack of a group of insects which have adapted themselves to a diet of dried vegetable matter. Fortunately, the species which cause serious damage are relatively few in number. The following are representative of the most dangerous pests of stored grain: the rice and granary weevils, the lesser grain borer, the saw-toothed grain beetle, the flat grain beetle, the cadelle, the confused flour beetle, the red flour beetle, the Indian meal moth and the Angoumois grain moth. Leguminous seeds are attacked by the cowpea weevil, bean weevil and pea weevil. The rice and granary weevils, the lesser grain borer and the Angoumois grain moth breed within grain and seed kernels and are the primary pests of stored grain (See Figures).

**Damage caused by insects:** Once grain becomes infested it loses much of its value as human food. It is difficult or impossible to remove all insect forms from infested grain by present day modern cleaning methods. When infested grain is milled, insect contamination carried over into the milled product may be sufficient to cause its condemnation by the Food and Drug Administration. Wheat containing one percent or more of insect-damaged kernels is subject to action under the Federal Food Laws. Mills have found that wheat with more than 0.5 percent of infested kernels is unfit for milling.

In addition to the direct loss by feeding, insects cause other kind of damage to stored grain. Many species feed almost entirely on the germ of the grain so that its viability is reduced. The mere presence of insects in grain causes it to heat. In extreme cases the translocation of water vapor from the heating portion, to the cooler surface grain may cause deterioration, rotting,

---

1/ Mr. Cotton, now retired from the Division of Stored Products Insects, Bureau of Entomology, U. S. Dept. of Agriculture is now living in Fort Lauderdale, Florida.
Life stages of the rice or black weevil in wheat: a, Well-grown larva; b, pupa; c, adult feeding upon kernel. Note in c the hole in lower portion of kernel made by the adult on leaving the seed and at two points higher up shallow holes made by the adult in feeding upon the seed after emergence. The adult rarely measures more than one-eighth of an inch in length.

Life stages of the granary weevil in wheat: a, Well-grown larva; b, pupa; c, adult. Note hole in kernel made by the adult in order to leave the seed and hole that it is eating into the kernel for the purpose of laying eggs. The adult is never more than three-sixteenths of an inch long.

Drawings from USDA Farmers' Bul. 1260 Stored Grain Pests.
molding, sprouting and a musty odor. A lowering of the grade of grain is caused by off odors or insect damage, and the milling quality and milling yield of infested grain is reduced.

Sources of infestation: In the Southern states a certain amount of insect infestation occurs in the field. A number of the common storage pests are strong fliers and fly out to the field of maturing grain or seed from sources on farms or from nearby storages. Some seeds such as wheat are largely protected from weevil attack in the field by the glumes or husk which is removed by threshing. However, they may be infested in the field by the Angoumois grain moth. Corn may be heavily infested in the field. The corn husk when undamaged affords considerable protection from insect infestation, but damage by the earworm and other agencies cause breaks in this barrier.

Leguminous seeds are invariably infested in the field by Bruchids. Besides field infestation, infestation in stored grain and seed originates in storage facilities that have not been properly cleaned or by the migration of insects from nearby infested stores or accumulations of feed, grain or other infested dry food product.

Feed requirements of insects: The insect pests of stored grains and seed depend on their food supply for their water requirements. Seed or grain that is low in moisture is unfavorable for their development. The true grain weevils cannot breed in grain with a moisture content less than 9 percent, and their breeding is restricted in grain unless the moisture content is above 11 percent. The bran beetles, of which the saw-toothed grain beetle and red flour beetle are typical, do not breed in clean grain or seed unless the moisture content is 11 percent or above, or the temperature is above 80°F. If the seed contains floury dust or broken kernels, the beetles can breed in it regardless of the moisture content.

Temperature requirements: Temperatures above 95°F. are not favorable for the development of most seed-infesting insects. Temperatures below 70°F. greatly
The lesser grain borer in and on wheat kernels: a, The well-grown larva; b, the pupa; c, two adult weevils. Adult borer is about one-eighth of an inch long.

Angoumois Grain Moth (larva)

Angoumois Grain Moth (adult)

Top drawing from USDA Farmers' Bul. 1260 Stored Grain Pests. Bottom drawing from Bul. 389 North Carolina Experiment Station.
retard their development. A temperature of 65° prevents reproduction of the flour beetles, and 60° is approximately the lowest temperature at which the rice and granary weevils reproduce. Grain mites are more hardy and can breed in seed kept between 40° and 50° F., but only when seed moisture is above 12 percent.

**Preventive measures:** Early harvest of grain and seed is desirable to prevent field infestation.

Grain and seed should not be placed in storage unless it is dry enough for safe storage.

Drying and cleaning should be practiced when necessary to put seed in good condition for storage.

Grain or seed that is dry (12 percent or less) and clean will store best.

**Farm stored grain:** Store grain on the farm in weather-tight, rodent-proof, bins, preferably of steel; spray walls and floors of bins and adjacent woodwork of farm buildings with a residual type spray at least 2 weeks before they are used to store grain. Clean up and dispose of litter, waste grain, and feed that has accumulated in and around farm buildings. Fumigate grain within 2 to 4 weeks after placing small grains or shelled corn in storage and if desirable treat with a protective dust or spray.

**Seed storage warehouse:**

1. Clean up warehouse inside and outside before storing seeds. Burn or remove all refuse.

2. Apply a DDT or Malathion residual spray after clean-up and before seeds are stored.

3. Apply a Malathion protective treatment to the seeds as they go into storage. This is to eliminate any low level of insect infestation present, and prevent the build-up of insect infestations.

4. Apply a Malathion surface stack spray on a routine schedule to prevent build-up of insect infestations.
5. Apply synergized pyrethrum space spray if desired, to supplement surface spray against moths. This can be applied routinely or as needed.

**Residual sprays:** Spray floors, walls, beams and ceiling of the interior of the empty warehouse. Spray outside walls up to the height of 6 or 8 feet. Spray ground to a distance of about 6 feet from the building where possible.

Use a 2.5 percent DDT emulsion spray, or a 3 percent Malathion emulsion spray. Apply at the rate of 2 1/2 gallons per 1,000 square feet, or just before the point of run-off. Use a power sprayer. If preferred, a wettable powder can be used in place of the emulsion. The above sprays can be obtained by mixing 2 1/2 gallons of water, 1 quart of 25 percent DDT emulsifiable emulsion concentrate or 1 pound of 50 percent DDT wettable powder; or 1 pint of 57 percent Malathion emulsifiable concentrate or 2 1/2 pounds of 25 percent Malathion wettable powder. Use only premium grade Malathion.

**Residual sprays for farm bins:** For the treatment of empty bins for storing grain intended for human food, the Malathion sprays recommended for use in seed warehouses can be used or sprays containing 2.5 percent Methoxychlor or 0.5 percent of pyrethrins. These latter insecticides should be obtained in the form of a wettable powder or emulsifiable concentrate and mixed with water according to the directions on the labels. Apply the finished sprays at the rate of 2 gallons per 1,000 square feet. Use a garden sprayer or a power sprayer as needed.

**Protective sprays for stacks of seed:** For spraying stacks of bagged seed use a 1 percent Malathion wettable powder spray at the rate of 2 gallons per 1,000 square feet. This concentration can be obtained by mixing 10 oz. of 25 percent Malathion (premium grade) wettable powder in 2 gallons of water. Repeat treatment in 2 weeks and monthly thereafter while seeds are in storage. Use power equipment. A piston pump is necessary for applying wettable powder sprays because the inert ingredients cause a gear pump to wear out rapidly.
**Space sprays for mechanical generators:** Pyrethrins 0.5 %, piperonyl butoxide 5.0 %, tetrachloroethylene 50.0 % and deodorized kerosene 44.5 %. Apply at rate of 1 pint per 10,000 cubic feet of space above the load, or 2 gallons to an average warehouse 100 x 100 with 15 to 20 feet above the load.

**Space sprays for thermal type generators:** Pyrethrins 0.2 %, piperonyl butoxide 2.0 %, tetrachloroethylene 50.0 % and deodorized kerosene 47.8 %. Apply at the rate of 2 1/2 pints per 10,000 cubic feet of space above the load or 5 gallons in an average warehouse 100 x 100 feet with 15 or 20 feet of space above the load. Several such sprays are available commercially. Use them as directed on the labels.

**Fumigation:** Fumigation is a rapid method of destroying insect life in stored grain or seed. Fumigation of grains and seed on the farm where infestations originate is important, but it is no less important to fumigate them in the elevator or warehouse after they leave the farm.

Fumigants are chemicals which in their vapor phase are poisonous to insect and animal life that are exposed to them.

There are 3 types of fumigants; gaseous, liquid, and solid. Gaseous fumigants are those which are in the gas phase at normal temperatures. Examples are Methyl bromide and hydrocyanic acid. Liquid fumigants are those which are normally liquids, but, which vaporize rapidly when exposed to the air. Examples are carbon disulfide, carbon tetrachloride, ethylene dichloride, ethylene dibromide, chloropicrin, propylene dichloride, acrylonitrile, and numerous combinations of these chemicals. Solid fumigants are those which are normally in the solid state, but, which give off toxic gases when exposed to the moisture of the atmosphere. Examples are calcium cyanide (Cyanogas) and hydrogen phosphide (Phostoxin).

**Fumigation methods:** Gaseous type fumigants can be applied by forcing them under pressure into warehouse spaces or under tarpaulins. They are also well adapted for fumigating grain in bins, flat warehouse storages, or railroad
boxcars by the recirculation or forced distribution method. This latter method requires the use of an aeration system. The fumigant is introduced into the aeration system and may be either pushed or pulled through the grain as desired. In general, the system consists of a floor duct or ducts, or a series of perforated lateral ducts radiating from a central floor duct, connected with a blower or blowers capable of forcing the fumigant through the grain with an airflow rate of approximately 0.1 cfm per bushel per minute, and a return duct or ducts from the blower to the overspace above the grain. The return duct can be located within the bin or warehouse or other structure, or on the outside.

Liquid types may be applied either by the gravity penetration method or by forced distribution. By gravity the liquid is applied to the surface grain as a coarse spray and the vapors allowed to sink by gravity down through the grain mass. By the forced distribution method the liquid is applied to the surface grain and the vapors pulled rapidly through the grain by means of an aeration system.

Solid fumigants such as calcium cyanide (Cyanogas) are applied by means of an automatic applicator to the grain stream as it enters the bin. It is adapted chiefly for use in grain elevators. Hydrogen phosphide (Phostoxin), one of the newer fumigants, is applied manually to the grain stream as it enters the bin. In flat storages it may be introduced into the grain mass by the use of probes.

All fumigants are toxic to the operator who uses them as well as to insects. They should only be used by operators trained in their application and equipped with properly designed gas masks equipped with canisters designed to protect against the fumigant being used.

Effect of fumigants on seed: Many fumigants affect the viability of seed, particularly if dosages are excessive, seed moisture high, temperature high and exposure period long. To avoid damage and loss of viability due to fumigation, seed should be fumigated only if the moisture content is below 12 percent, preferably below 10 percent; seed should be in bags to facilitate aeration; exposures
should not exceed 24 hours, preferably 12 hours or less; fumigation temperatures should not be over $85^\circ F$.

Standard mixtures of carbon disulfide and carbon tetrachloride, or ethylene dichloride and carbon tetrachloride are considered safe to use at dosages up to 6 gallons per 1,000 bushels. Also the above mixtures to which 5 percent ethylene dibromide is added. Acrylonitrile, chloropicrin, and ethylene dibromide have been reported by Richardson to be detrimental to germination.

For space fumigation hydrocyanic acid can be used at the rate of one pound per 1,000 cubic feet of space without fear of damage to germination.

Dosages of fumigants which have been used successfully for different grains when fumigated under different types of storage conditions and at different temperatures are available and can be obtained by addressing the Stored Product Branch, U.S.D.A., Plant Industry Station, Beltsville, Maryland. Leaflets are also obtainable from the same source on the subjects of Protecting Stored Seed from insect attack and Suggestions for Insect Control in Seed Warehouses.

After fumigating grain or seed which is to be stored for any length of time, a surface treatment with a protective spray or dust should be applied as insurance against moth attack.

**Protective treatments for grain or seed:** As a preventive measure, the use of a grain protectant is often of great importance. A grain protectant is any substance that is mixed with grain to prevent the attack and subsequent infestation of stored grain insects. Whereas fumigants act quickly and effectively they do not offer any long time protection against insects. A good protectant will remain effective for months.

A protectant is applied to grain or seed as a dust or spray. Grain dealers prefer a spray since it is cleaner and does not add to the amount of dust normally present in grain.

Dusts or sprays can be applied to grain as it is being loaded into the
storage bin from trucks, or as it is being moved by augers from one bin to another. They may also be applied in the combine hopper, so that by the time the grain is placed in storage the protectant and grain are thoroughly mixed. Uniformity of application and distribution is desirable.

At the present time the number of protectants approved for use by the Food and Drug Administration are limited to (1) a mixture of pyrethrins and piperonyl butoxide and (2) Malathion.

Pyrethrin formulations: For wheat or other small grains likely to be downgraded if inorganic dust carriers are used, a dust with a powdered wheat base containing 1.1% piperonyl butoxide and 0.08% pyrethrins should be used at a dosage of 75 pounds per 1,000 bushels. For feed grains to be used on the farm or for seeds a dust with a talc base containing 10.0% piperonyl butoxide and 0.06% pyrethrins can be used at the rate of 100 pounds per 1,000 bushels. For use on seed grains where there is a possibility that the treated seed may be used in preparing feeds or in milling for foods a pyrethrum slurry formulation is available. It is prepared as a wettable powder consisting of 0.75% pyrethrins and 10.0% piperonyl butoxide on an inert inorganic carrier. It is applied at the rate of 1 pound per 100 bushels of seed or 4.5 grams per bushel using any standard slurry type treater. When used alone the same amount of water should be employed as when making an application in which a fungicide is included. It has been successfully used with virtually all the common fungicides, including Arasan, Spergon, Thiram, Ceresan, Phygon and Orthocide 406. It is not recommended for treating small garden type seeds.

Two types of synergized pyrethrum spray formulations are available commercially. One is in the form of an emulsifiable concentrate to be diluted with water; the other contains a solvent as a carrier and comes ready prepared. Both types contain pyrethrins and piperonyl butoxide in the ratio of 1 to 10.

Recommended dosages are 2 gallons of the solvent base spray per 1,000
bushels and from 4 to 5 gallons of the water base spray. At these dosages pro-
tection will last for one season. The U. S. Food and Drug Administration has set
a tolerance of 3 ppm for pyrethrins on grain and 20 ppm of piperonyl butoxide.

**Malathion:** The U. S. Food and Drug Administration has set a tolerance of
8 ppm of Malathion in stored grain, wheat, barley, oats, rye and sorghum. The
U.S.D.A. has approved registration at one pint of the 57 % premium grade
Malathion emulsifiable concentrate in 2 to 5 gallons of water per 1,000 bushels of
grain or as a 1 % premium grade dust at 60 pounds per 1,000 bushels. The treat-
ment is considerably more effective in dry than in damp grain. Do not treat grain
with a moisture content above 13 %.

For seed treatment a dosage of approximately 4 pints of 57 % premium
grade emulsifiable concentrate per 100,000 pounds of seed should give good pro-
tection. The manufacturers recommend that for field and garden seed 1/2 pint in
1 - 2 1/2 gallons of water per 500 bushels of seed be used or 30 pounds of
Malathion premium grade wheat flour dust per 500 bushels.

**Other materials:** In the treatment of seed, where surplus stocks will not
be used as food or feed, poisonous dusts can be used. Three percent DDT in an
inert dust carrier such as pyrophyllite can be used to treat seed at the rate of
1/2 oz. per bushel. As a slurry add 2 oz. of 50 % DDT wettable powder to 1 gal-
lon of water. This amount is sufficient to treat 30 bushels of seed.

**Surface treatments against the Indian meal moth:** As a surface treatment
to protect grain or seed in storage against invasions of the Indian meal moth or
other moths apply (1) premium grade Malathion 57 % emulsifiable concentrate to
the surface of clean, uninfested grain or seed at the rate of 1/2 pint in 1 to 2
gallons of water per 1,000 square feet or surface grain or (2) Malathion 1 % pre-
mium grade wheat flour dust at the rate of 30 pounds per 1,000 square feet, or
(3) Pyrethrins 0.3 % by weight, synergist 3.0 % by weight and deodorized kerosene
96.7 % applied at the rate of 1 pint per 1,000 sq. ft., or (4) for shelled corn spray
surface with unsulfonated, technically white or refined mineral oil 100 to 200 seconds viscosity (Saybolt 100° F.), free of objectionable odors at the rate of 2 quarts per 100 square feet of surface grain.

**Insecticidal residues:** In the control of insect infestations in grain chemicals are used which leave residues. The provisions of the Miller Amendment to the Food, Drug and Cosmetic Act stipulate that the residue of any pesticide remaining in or on raw agricultural products as a result of using such pesticide in the production or preservation of the product must not exceed tolerances established under the Act. All grains and seeds are classed as raw agricultural products.

Many of the common grain fumigants such as carbon disulfide, carbon tetrachloride, ethylene dichloride, chloropicrin and hydrogen phosphide (phostoxin) are exempt from the need of a tolerance, since their residues disappear rapidly or do not remain in amounts sufficient to be hazardous.

Tolerances of 25 ppm of hydrocyanic acid and 50 ppm of inorganic bromide have been established for grain. Residues of hydrocyanic in grain, resulting from fumigation with either calcium cyanide (Cyanogas) or liquid HCN, are transitory so that repeated fumigations do not normally create a problem.

Residues of inorganic bromide will result from fumigation with methyl bromide or liquid fumigants containing ethylene dibromide. This residue is fixed and cannot be removed by aeration. Each time grain is fumigated, additional residue of inorganic bromide accumulate. Where the history of previous treatments of raw grains is unknown the user would do well to have the inorganic bromide content determined before giving an additional fumigation.

Residues resulting from the treatment of grain with chemically inert or chemically active dusts or sprays may also be objectionable although tolerances have been established for certain materials. Chemically inert dusts, although they may not be poisonous, cause grain to be down-graded. Dusts or sprays containing pyrethrins and piperonyl butoxide may be safely used to treat grain if pyrethrin
residues do not exceed 3 ppm and piperonyl butoxide residues do not exceed 8 ppm.

Seeds which are treated with poisonous dusts such as DDT or methoxychlor must not be used for human or animal food.

Methoxychlor residues resulting from the spraying of empty bins must not exceed 2 ppm.