Chapter 14

INSECT CONTROL IN POSTHARVEST PEANUTS

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Postharvest peanuts, in all forms, are subject to attack by insects and mites with subsequent damage, contamination, and deterioration from the time they are harvested until they are utilized or consumed. A main objective of the warehouseman during peanut storage is to keep insect damage and contamination at or below some preselected economic or regulatory threshold. A portion of this objective must be achieved utilizing a physically sound facility and a program of good sanitation. However, the goal of desired insect control will usually not be accomplished without the use of pesticides. The proper use of these pesticides will depend upon a knowledge of the pests, the pesticides approved for use, and where and how to apply them effectively and safely. The amount of deterioration caused by insects and mites depends largely upon the moisture content of the peanuts and the form in which they are stored. The treatment of peanuts during harvesting, handling and drying, which is explained in detail in other chapters, affects the loss in quality from insects. If stored as inshell or farmers stock peanuts, the percentage of cracked and damaged pods, loose shelled kernels, degree of seed maturity at time of harvest, and amount of foreign material are some of the major factors that will have a direct bearing on the peanut quality after storage. Sound, unbroken pods, having a moisture content of below 9% will store for long periods (up to 1 year) without insect damage. The type of warehouse, and its construction, will also influence the rate of peanut deterioration through its physical effects upon the storage environment.

While many of the pests of postharvest peanuts are cosmopolitan and many of the control procedures set forth in this chapter will be applicable worldwide, the authors are writing primarily for a United States of America audience.

BIOLOGY, ECOLOGY, AND RECOGNITION OF PESTS

The number and variety of insect species found in peanut warehouses and shelling plants are quite extensive. Peanuts in storage, particularly farmers stock peanuts, may contain extraneous plant materials; therefore, the insect species found associated with these peanuts may not always be feeding on the peanuts but rather on the extraneous plant materials including fungi. Such insects, however, should be considered as contaminants as also are the arthropod parasitoids and predators of the phytophagus pests. The following list of insects and associated arthropods will illustrate the great variety of insects infesting peanuts. This list is not all inclusive but records insect species found in peanut warehouses and shelling plants mostly in the southeastern United States. The first 21 species listed are described briefly and represent some of the major insect pests of stored peanuts or typical examples of stored-product insects. The remainder are listed by groups and arranged by common name or alphabetically.

Latin Name	Common Name
Plodia interpunctella (Hübner)	* Indian meal moth
Ephestia cautella (Walker)	* Almond moth
Corcyra cephalonica (Stainton)	* Rice moth
Tribolium confusum Jacquelin duVal	* Confused flour beetle
Tribolium castaneum (Herbst)	* Red flour beetle
Oryzaephilus surinamensis (L.)	* Sawtoothed grain beetle
Oryzaephilus mercator (Fauvel)	* Merchant grain beetle
Latheticus oryzae Waterhouse	* Longheaded flour beetle
Cryptolestes pusillus (Schöenherr)	* Flat grain beetle
Lasioderma serricorne (F.)	* Cigarette beetle
Stegobium paniceum (L.)	* Drugstore beetle
Attagenus megatoma (L.)	* Black carpet beetle
Trogoderma inclusum LeConte	Larger cabinet beetle
Tenebroides mauritanicus (L.)	* Cadelle
Araecerus fasciculatus (De Geer)	* Coffee bean beetle
Carpophilus dimidiatus (F.)	* Corn sap beetle
Typhaea stercorea (L.)	* Hairy fungus beetle
Ahasverus advena (Waltl)	* Foreign grain beetle
Tenebrio molitor L.	* Yellow mealworm
Alphitobius diaperinus (Panzer)	* Lesser mealworm
Liposcelis sp.	Booklouse - several species
Sitotroga cerealella (Olivier)	* Angoumois grain moth
Aglossa caprealis (Hübner)	Murky meal moth caterpillar
Pyralis farinalis (L.)	* Meal moth
Rhyzopertha dominica (F.)	* Lesser grain borer
Prostephanus truncatus (Horne)	* Larger grain borer
Sitophilus zeamaiz Motschulsky	* Maize weevil
Sitophilus oryzae (L.)	* Rice weevil
Caulophilus oryzae (Gyllenhal)	* Broadnosed grain beetle
Cathartus quadricollis (Guérin-Méneville)	* Squarenecked grain beetle
Lophocateres pusillus (Klug)	Siamese grain beetle
Tribolium audax Halstead	* Black flour beetle
Palorus ratzeburgi (Wissmann)	* Smalleyed flour beetle
Palorus subdepressus (Wollaston)	* Depressed flour beetle
Gnathocerus cornutus (F.)	* Broadhorned flour beetle
Gnathocerus maxillosus (F.)	* Slenderhorned flour beetle
Cynaeus angustus (LeConte)	* Larger black flour beetle
Cryptolestes ferrugineus (Stephens)	* Rusty grain beetle
Cryptolestes trucicus (Grouvelle)	Family Cucujidae
Blapstinus pratensis LeConte	Family Tenebrionidae
Dermestes ater De Geer	* Black larder beetle
Dermestes maculatus De Geer	* Hide beetle

Anthrenus verbasci (L.)	* Varied carpet beetle
Trogoderma variabile Ballion	* Warehouse beetle
Trogoderma sternale Jayne	Family Dermestidae
Trogoderma sternale plagifer Casey	" "
Trogoderma sternale complex Casey	" "
Attagenus elongatulus Casey	" "
Stelidota geminata (Say)	* Strawberry sap beetle
Carpophilus hemipterus (L.)	* Driedfruit beetle
Carpophilus humeralis (F.)	Pineapple beetle
Carpophilus marginellus Motschulsky	Family Nitidulidae - sap beetle
Carpophilus pallipennis (Say)	" "
Carpophilus freemani Dobson	" "
Carpophilus mutilatus Erichson	" "
Carpophilus pilosellus Motschulsky	" "
Stelidota chontalensis Sharp	" "
Stelidota strigosa (Gyllenhal)	" "
Haptoncus luteolus (Erichson)	" "
Conotelus stenoides Murray	" "
Coleopterus unicolor Say	" "
Alphitophagus bifasciatus (Say)	* Twobanded fungus beetle
Aphitobius laevigatus (F.)	* Black fungus beetle
Platydema ruficorne (Sturm)	Redhorned grain beetle
Ptinus clavipes (Panzer)	Brown spider beetle
Gibbium psylloides (Czenpinski)	Shiny spider beetle
Melanophthalma distinguenda (Comolli)	Minute brown scavenger beetle
Eufallia unicostata (Belonia)	Family Lathridiidae
Corticaria sp.	" "
Anthicus cervinuis La Ferté-Sénectère	Family Anthicidae
Anthicus ephippium La Ferté-Sénectère	" "
Anthicus vicinus La Ferté-Sénectère	" "
Notoxus calcaratus Horn	" "
Carcinops pumilio Erichson	Family Histeridae
Carcinops quatuordecimstriata Stephens	" "
Euspilotus sp.	" "
Hister coenosus Erichson	" "
Apantales sp.	Family Braconidae-a parasite
Aspilota sp.	" "
Bracon hebetor Say	" "
Rhaconotus sp.	" "
Cephalonomia tarsalis (Ashmead)	" "
Mesostenus gracilis Cresson	Family Ichneumonidae-a parasite
Venturia canescens (Gravenhost)	" "
Xylocoris flavipes (Reuter)	Family Anthocoridae-a predator
Xylocoris vicarius (Reuter)	" "
Lasiochilus pallidulus Reuter	" "
Euborellia annulipes (Lucas)	* Ringlegged earwig
Musca domestica L.	* House fly
Fannia canicularis (L.)	* Little house fly
Hermetia illucens (L.)	* Black soldier fly
Hylemya platura (Meigen)	* Seedcorn maggot
Euxesta notata (Wiedemann)	Family Otitidae
Bradysia sp.	Family Sciaridae
Pseudoleria pectinata(Loew)	Family Heleomyzidae
Xyletinus peltatus (Harris)	Family Anobiidae
Tricorynus ventralis (LeConte)	" "
Catorama sp.	" "
Litargus balteatus LeConte	Family Mycetophagidae
Pharaxonotha kirschi Reitter	Family Ctryptophagidae
	"Mexican grain beetle
Cryptoserphus abruptus (Say)	Family Proctotrupidae
Monotama sp.	Family Rhizophagidae
Scatopse fuscipes Meigen	Family Scatopsidae
Anisopteromalus calandrae (Howard)	Family Pteromalidae
Scenopinus fenestralis (L.)	A windowpane fly
Scenopinus glabrifons (Meigen)	" "
Scenopinus nubilipes Say	" "
Antillocaris pilosulus (Stol)	Family Lygaeidae
Pseudopachybrachius vinctus (Say)	" "
Xyonysius californicus (Stol)	" "
Tetramorium guineense (F.)	* Guinea ant
Glycyphagus sp.	Family Acaridiae-a mite
Caloglyphus sp.	" "
Tyrophagus sp.	" "
Melichares sp.	Family Aceosejidae-a mite
Cheyletus sp.	Family Cheyletidae-a mite
Pyemotes sp.	Family Pyemotidae-a mite
Withius subruber (Simon)	A pseudoscorpion
Order Araneida	Spiders-several species

* Common name approved by the Entomological Society of America Committee on Common Names of Insects, 1978, College Park, MD.

The presence of insects, their contamination, or their damage to our food and feed are unacceptable to most people and often to domestic animals. This presence of insects in our food products is exceeded in importance only by those insects that attack our person and cause discomfort and transmit disease. Usually a discussion of insect pests and their associates which are found in postharvest peanuts will include mites and other assorted arthropods as well. Unfortunately, it will be impossible to treat all of the pest species in this presentation. However, the most important and examples of some of the common insects will be discussed briefly including a description, a typical life history, and the type of damage caused. The interested reader desiring more information or detail is referred to the literature cited.

Indian Meal Moth - *Plodia interpunctella* (Hübner)

Description. This species is a rather attractive moth with a wing spread of nearly 19 mm (Figure 1) or length of 8 to 13 mm with wings folded. It is one of the most troublesome moths that attack stored peanuts. It was described in 1827 by Hübner, and was first referred to as the Indian meal moth by Fitch be-

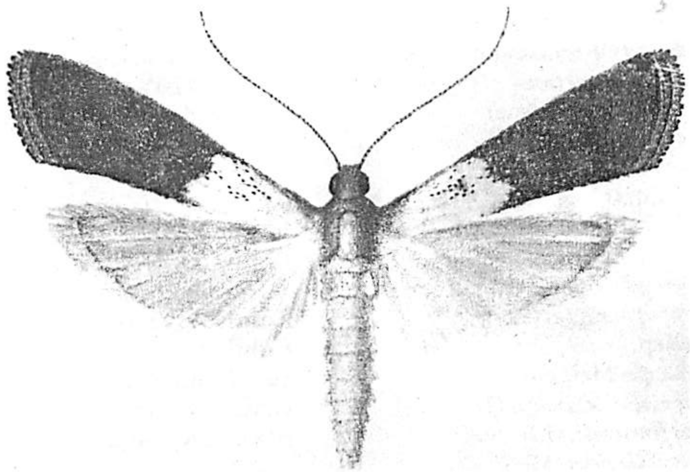

Fig. 1. Indian meal moth with wings spread. Adult has a wing expanse of about 19 mm. (USDA photo.)

cause he found the larvae feeding in corn meal (Cotton, 1963). It is easily distinguished from other peanut-infesting moths by the peculiar markings of the forewings, which are reddish-brown with a copper luster on the outer two-thirds, but whitish gray on the inner or body ends (Figure 2A). The hind wings are uniformly silver gray and fringed with hairs. When at rest the wings are folded closely together along the center of the body and are marked with a conspicuous, prominent reddish-brown band. The larva, when fully grown, is from 9 to 19 mm in length (average about 13 mm), varying widely in size with different foods and climatic conditions (Figure 2B). It is dirty white, sometimes varying to yellowish, greenish, or pinkish hues.

Life History. In the northern limits of its range, the moth overwinters in the larval stage. However, in heated situations or in warmer climates, development is continuous throughout the year. Adults are active at night or in dark places with the peak activity in the early evening and early morning hours.

Each female lays from 50 to 350 eggs, singly or in groups, on the food material. The egg usually hatches in 2-5 days and small whitish larva emerge. The larva feed on a wide variety of stored food products. As it crawls about, the larva spins a web and leaves a silken thread. In heavy infestations, the surface of the peanut mass may be completely covered with silken webbing (Figure 3).

The fully grown larva seeks a hiding place in peanut stems or warehouse crevices, spins a silken cocoon, and transforms into a light brown pupa. The adult develops and subsequently emerges from the cocoon. The pupal stage, in warm situations, will last from 4 days to 2 weeks. The entire life cycle in warm weather can be accomplished in 5 to 8 weeks.

Type of Damage. Types of damage and contamination include "worm-cut" seed (Figure 4), live and dead insects, silk and matted webbing, cast skins, frass, and larval droppings.

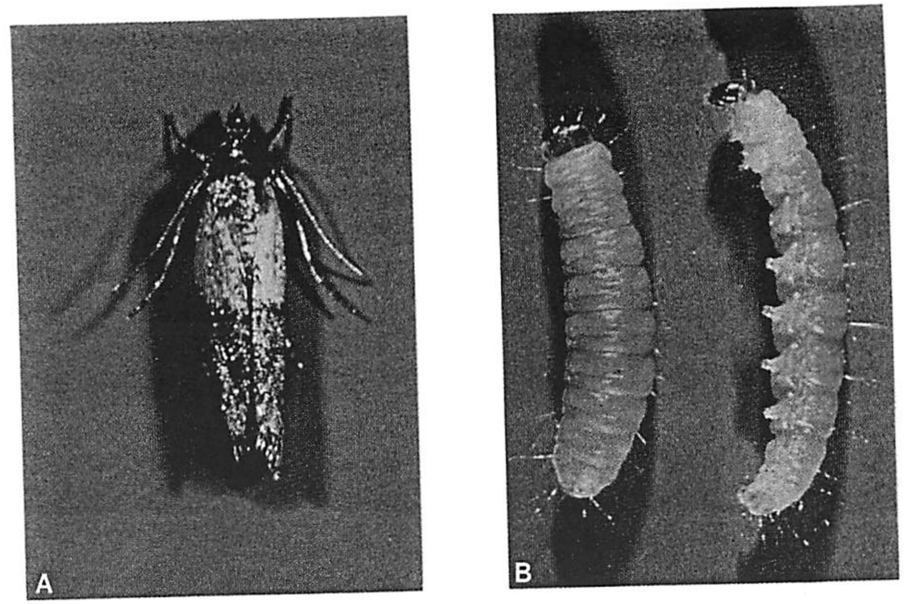

Fig. 2. Indian meal moth, *Plodia interpunctella* (Hübner). A. Adult, about 11 mm long with wings folded; B. Larvae, about 13 mm long when full grown. (USDA photos.)

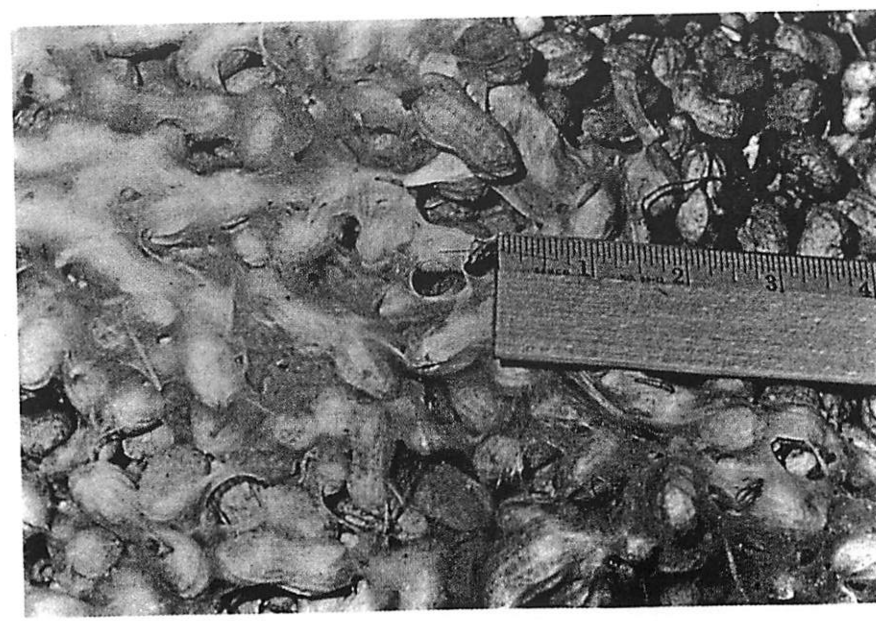

Fig. 3. Moth webbing on surface of farmers stock peanuts in a warehouse. (USDA photo.)

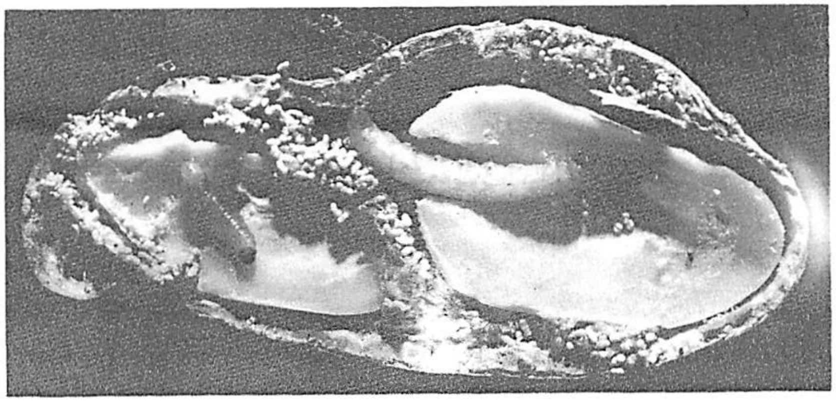

Fig. 4. Indian meal moth larvae inside peanut pod showing "worm-cut" damage, frass, and webbing. (USDA photo.)

Almond Moth - *Ephestia cautella* (Walker)

Description. This species commonly infests peanuts in storage. It is a rather dull, grayish-brown moth with a wingspread measuring 14 to 20 mm. The forewings are narrow, especially at the base, grayish to yellowish with dark markings which may appear as obscure bands across the wings. The hind wings are a dirty whitish color. When at rest the wings are folded closely together along the center line of the body with the moth ranging in length from about 8 to 14 mm (Figure 5A). The larva is a whitish caterpillar and when fully grown is about 13 mm long. It may be distinguished from the Indian meal moth larva by the rows of black dots on each side of its body giving it a striated appearance (Figure 5B). The larva spins silken webs which may appear as masses intermingled with food and excrement, like those of the Indian meal moth.

Life History. The life cycle and habits of the almond moth are similar to that of the Indian meal moth. Up to 300 eggs per female are laid by simply dropping the eggs singly or in groups on the food material (Figure 5C). In optimum conditions at 28 C and 70% R.H., the egg hatches in 3 days and development from egg to adult takes an average of about 35 days on peanuts. The larva move freely through the peanuts contaminating them with webbing and frass (Figure 5D). It feeds indiscriminately on the seed, often damaging many more than needed for development. When it is mature, it enters a wandering phase trailing a fine silken thread until pupation. In a heavy infestation, the surface of the peanut mass or parts of the building structure can be completely covered with silken webbing.

Type of Damage. Since 1960 the almond moth has become increasingly of greater economic importance as a pest of stored peanuts. Even though the almond moth has not developed the high rate of malathion resistance as has the Indian meal moth, it nevertheless has become more prevalent and is undoubtedly the number one moth pest of peanuts. It is basically more tolerant than the Indian meal moth to the insecticidal protectants presently applied on peanuts. In commercial peanut warehouse studies conducted by Redlinger (1977), the almond moth was the most prevalent of 18 insect species collected and comprised about 70% of the total number of insects collected during the

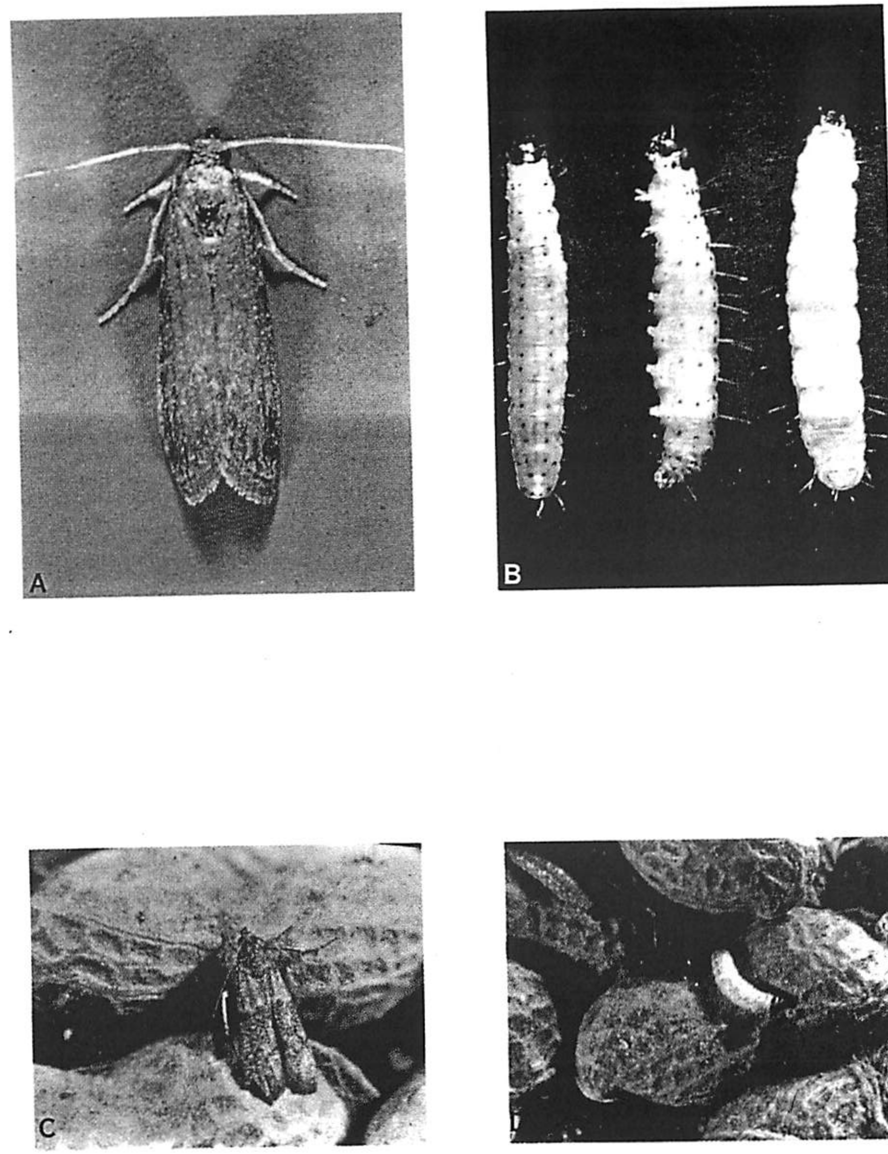

Fig. 5. Almond moth, *Ephestia cautella* (Walker). A. Adult, about 12 mm long; B. Larvae, average about 13 mm long when full grown; C. Moth on surface of inshell peanuts; D. Larvae moving around on peanut surface. (USDA photo.)

storage year. The larva feed and burrow into peanut seed causing "worm-cut" damage. Loss of product also occurs through contamination by live and dead insects, cast skins, frass, webbing, and fecal pellets.

Rice Moth - *Corcyra cephalonica* (Stainton)

Description. The rice moth is found infesting storage areas in the southern USA, but it is not normally as prevalent as the almond or Indian meal moths. This species has a wing expanse of 14 to 24 mm and is pale, grayish-brown buff or tawny colored with a tuft or crest of scales on the head. The wings are without spots but the veins are slightly darkened. With its wings folded along its body, this moth is 12 to 15 mm long, slightly larger than the other 2 moths (Figure 6A). The larva somewhat resembles that of the Indian meal moth with long fine hairs and a dark brown head and prothorax. When fully grown, the larva averages about 15 mm long (Figure 6B) and varies from white to a dirty, slightly bluish gray with occasional tints of green.

Life History. The larva is mobile and feed upon and within the seed. Infes-

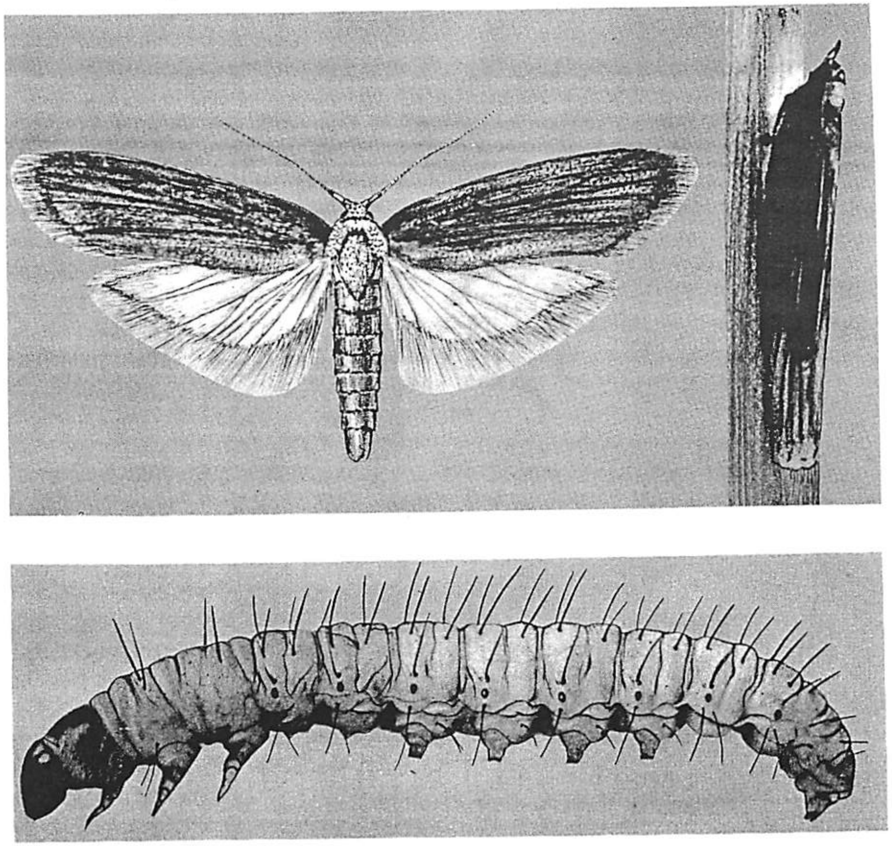

Fig. 6. Rice moth, *Corcyra cephalonica* (Stainton). A. Adult, left - dorsal view with wingspread of about 14 to 24 mm; right - side view with wings folded to body; B. Larva, about 15 mm long when full grown. (USDA photo.)

tation causes aggregation of seed by the presence of webbing. When mature, the larva contructs a dense cocoon which may be distinguished from those of other moth species in peanuts by its opaque white appearance and extreme toughness. The adult lives 1 to 2 weeks and each female lays from 100 to 200 eggs. Most of the eggs are laid within a few days after emerging from the cocoon. In summer, the development period from egg to adult is about 6 weeks.

Type of Damage. Damage by this pest, as with all moth pests, is done by the larva. When feeding upon the seed, it spins dense silken tubes, webbing the seed onto the walls of the tubes and producing a dense webbing over the surface as it becomes fully grown. "Worm-cut" damage is similar to that of the almond and Indian meal moths. Other damage or contamination include live and dead insects, cast skins, frass, and larval droppings.

Confused Flour Beetle - *Tribolium confusum* Jacquelin duVal

Description. The confused flour beetle is found widespread over the world and is found throughout this country; however, it is more abundant in the northern states. It is a general feeder on farinaceous material but is often recorded as attacking peanuts (Bissell and DuPree, 1946; LaHue et al. 1959; Feakin, 1973). Its close resemblance to the red flour beetle masked its identity until about 100 years ago, when the differences in these closely related insects were discovered. Thus, it derived its common name. The adult is a shiny, flattened, oval reddish-brown beetle about 3.5 mm long (Figure 7A). The head and upper parts of the thorax are densely covered with minute punctures. The wing covers are ridged lengthwise and are sparsely punctured between the ridges. The larvae are white, tinged with yellow, and with the last body segment terminating in a two-pointed fork (Figure 7B). When fully grown, they are about 5 to 6 mm long.

Life History. The average life of the confused flour beetle is about 1 year, but some have been known to live as long as 3 3/4 years. The female lays about 450 eggs, loosely in flour or other food material in which the adults live. The egg is small and white and covered with a sticky secretion, and readily adheres to the sides of sacks, boxes, and other containers and soon become covered with flour or meal. Consequently, fresh material placed in the containers is rapidly infested. The egg hatches in 5 to 12 days and the small, wiry, larva emerge. The larva undergo from 5 to 12 molts during their development and transform into small naked pupa. At first white, the pupa gradually change to yellow and then to brown and, shortly afterwards, transform into an adult beetle. In summer, the period from egg to adult requires about 5 to 6 weeks under favorable weather conditions, but the life cycle is greatly prolonged by cold weather, as is true of all peanut pests.

Type of Damage. The confused flour beetle damages peanuts and peanut products by eating them and by contaminating them with their live and dead bodies, cast skins, and fecal pellets. The fecal pellets contain uric acid. In addition, when heavily populated, the odoriferous glands on the thoracic and abdominal segments secrete a pungent, irritating liquid containing quinones, which contaminate the food products.

Red Flour Beetle - *Tribolium castaneum* (Herbst)

Description. The red flour beetle was named and described long before the confused flour beetle. The 2 species are very similar in life history, habits, and appearance (Figures 7 & 8), and this caused great confusion among earlier students of these insects. However, there are important differences in appearance between the 2, and they can be distinguished from each other with the aid of a magnifying glass. The segments of the confused flour beetle antennae gradually increase in size from the base to the tip whereas the last few segments of the red flour beetle antennae are abruptly much larger than the other segments, forming enlarged tips. Also, the head margins of the confused flour beetle are expanded and notched at the eyes. These differences between the 2 species are shown in Figure 9A & 9B. When the eyes are observed from the underside of the body, the eyes of the red flour beetle are large and the width of each eye is equal to the distance separating them. In the confused flour beetle, the width of each eye is about 1/3 the distance separating them and they appear much smaller.

Life History. The red flour beetle and the confused flour beetle have similar feeding and breeding habits. The developmental period of the 2 insects is very similar. However, at high temperatures, the developmental period of the red flour beetle from egg to adult is usually somewhat shorter and the female has a higher fecundity than that of the confused flour beetle. Athough it is cosmopolitan, the red flour beetle is found more commonly in the southern United States, where it causes very serious damage to stored peanuts. Unlike the confused flour beetle (which is unable to fly), the red flour beetle is a strong flyer and its power of flight may account for the rapid dissemination from one warehouse to another. The red flour beetle is regarded as a major pest of stored peanuts in many parts of the world. In the USA it has been observed in large populations infesting mechanically damaged pods and loose shelled kernels of farmers stock peanuts. Howe (1956) reported peanuts were much less satisfactory as red flour beetle food than wheat meal. Larval development is much slower and more variable on peanuts than on wheat meal. The development period (egg to adult) on peanuts ranged from 32 to 93 days depending on temperature and humidity.

Type of Damage. Both the red flour beetle adult and larva feed on the surface of the peanut seed and often burrow into the seed, increasing the percentage of splits and lowering shelling outturn (Figure 10). Applebaum (1969) reported that the red flour beetle attacks and develops well on the germ and only after the germ is destroyed does it feed to any extent on the less nutritional cotyledons. These observations differ from those previously reported by Howe (1956) that the germ was seldom attacked and its presence had no observable influence. This deterioration is particularly evident when the germinative capacity of the peanuts is considered. The role of the red flour beetle in the deterioration of stored shelled peanuts has been reviewed by Howe (1965). While loss in weight may average about 4.5% during 12 months storage (Parkin, 1956), germination may fall to 27% after 6 months under conditions of artificial infestation (Kadkol et al., 1957). The free fatty acid content of the peanut oil increases concurrently many fold, resulting in additional deterioration of quality (Duerden and Cutler, 1957; Davey et al., 1959). Other kinds of

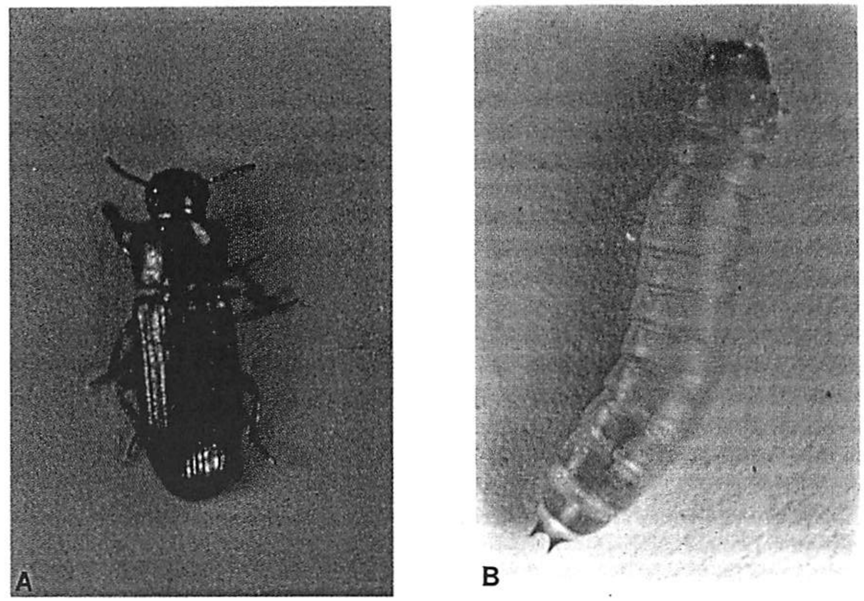

Fig. 7. Confused flour beetle, *Tribolium confusum* Jacquelin du Val. A. Adult, about 3.5 mm long; B. Larva, about 5 mm long. (USDA photo.)

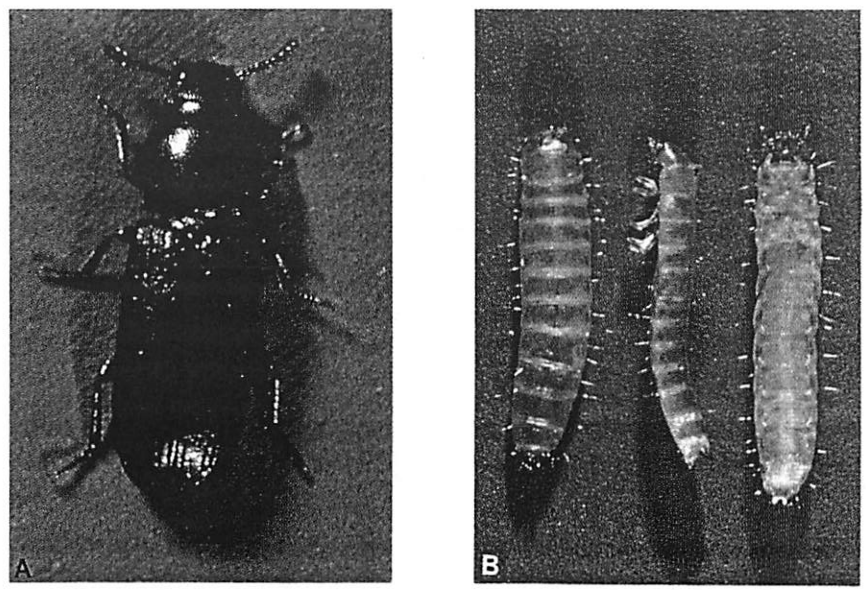

Fig. 8. Red flour beetle, *Tribolium castaneum* (Herbst). A. Adult, about 3.5 mm long; B. Larvae, about 5 mm long. (USDA photo)

damage or contamination include cast skins, frass, live and dead insects, quinones, and excrement.

Sawtoothed Grain Beetle - *Oryzaephilus surinamensis* (Linnaeus)

Description. This beetle is slender, flat, brown, and about 2.5 mm long. It gains its name from the peculiar structure of the thorax, which bears 6 sawtooth-like projections on each side (Figure 11A). The flattened body is well adapted for crawling into crevices. Its wings are well developed, but there is no record of the beetle being observed in flight. The larva is small, slender, yellowish-white with a brown head (Figure 11B). When fully grown it is about 3 mm long. It has 3 pairs of legs and a pair of abdominal prolegs, with the abdomen tapering to the tip.

Life History. The adult generally lives for 6 to 10 months, but some may live as long as 3 years. The female lays from 50 to 300 eggs. She drops them loosely in the foodstuff or tucks them into a crevice in a seed. The small, slender, white egg hatches in 3 to 5 days.

The young larva do not stay within a single seed but crawl about freely and actively, feeding as they go. During summer, it becomes fully grown in about 2 weeks. The number of larval molts is usually 3, but it may vary to 2 to 4. The full-grown larva construct delicate cocoonlike coverings by joining together small fragments of foodstuffs with a sticky secretion. Within this cell, the larva change to the pupal stage, which lasts about 1 week. In summer, the developmental period from egg to adult is about 4 weeks but may vary from 20 to 75 days depending on temperature, relative humidity, and food. There may be 6 or 7 generations annually.

Type of Damage. The sawtoothed grain beetle attacks, in both the larval and adult stages, all dried-stored foods of vegetable origin, especially grain and grain products such as flour, meal, breakfast food, stock and poultry feeds, copra, nut meat, candy, and dried fruit. Its small size and flattened shape enables it to readily penetrate packages, where its presence, rather than its damage, makes the food products unsaleable and unpalatable. Other kinds of contamination include cast skins, frass, and live and dead insects.

Merchant Grain Beetle - *Oryzaephilus mercator* (Fauvel)

Description. This species is a narrow flattened beetle about 2.5 to 3.5 mm long and is often confused with the sawtoothed grain beetle as it has similar sawtooth-like projections on either side of its body (Figure 12A). The larva is yellowish-white and is about 3 mm long when fully grown (Figure 12B).

The merchant grain beetle is also slightly larger and is a darker brown than the sawtoothed grain beetle. The larva is nearly the same in appearance. The merchant grain beetle may be distinguished from the sawtoothed grain beetle by the eye diameter being larger than the temple region behind the eye, and the head being rectangular. A comparison with the smaller eyes and more triangular head of the sawtoothed grain beetle may be made from Figure 13A & B.

Life History. The merchant grain beetle appears to prefer oilseed products, including tree nuts, and is less commonly found in grain than the sawtoothed grain beetle. Cereal products are more likely to be infested with this insect

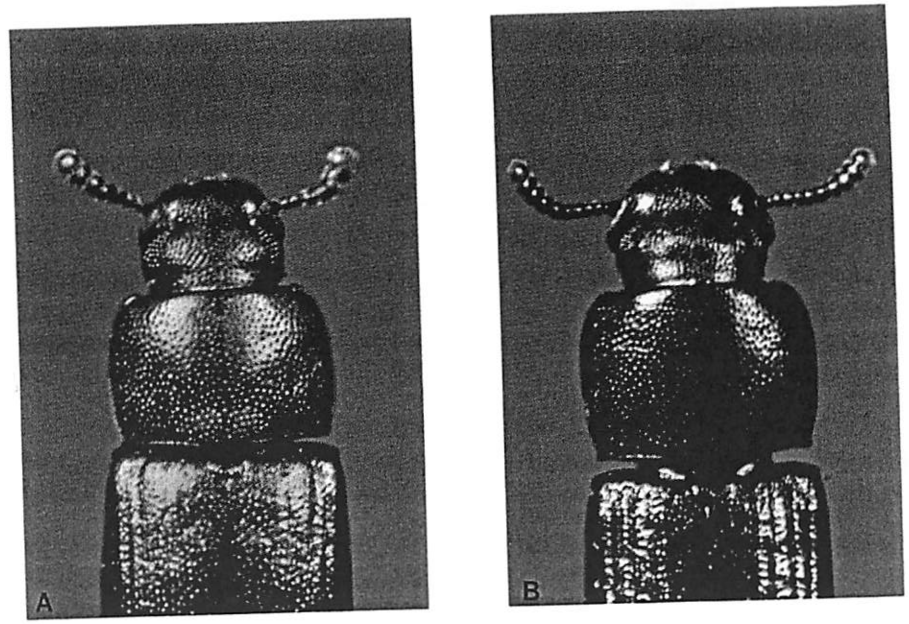

Fig. 9. Anterior comparison of red and confused flour beetles. A. Red flour beetle adult; B. Confused flour beetle adult. (USDA photo.)

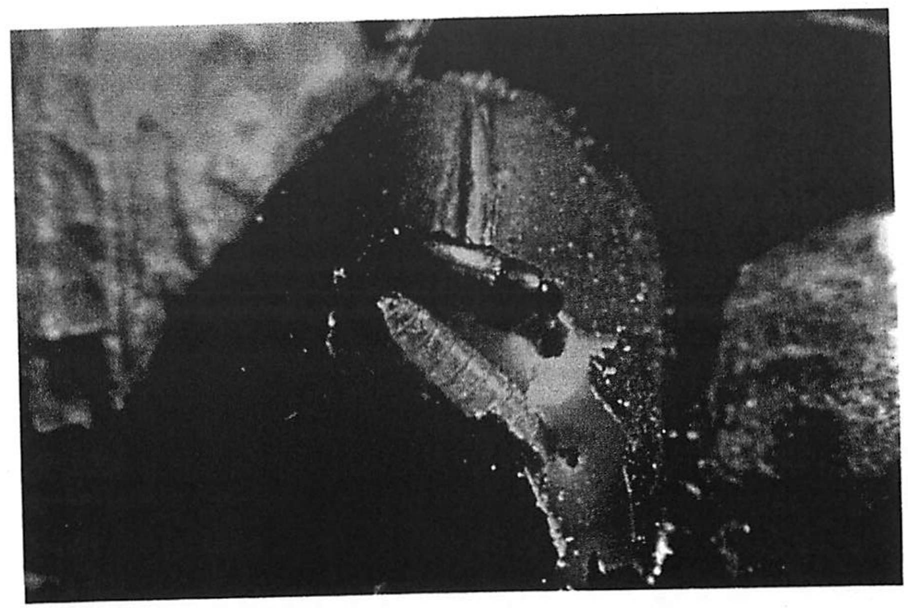

Fig. 10. Red flour beetle adult and larva feeding and tunnelling into a peanut kernel. (USDA photo.)

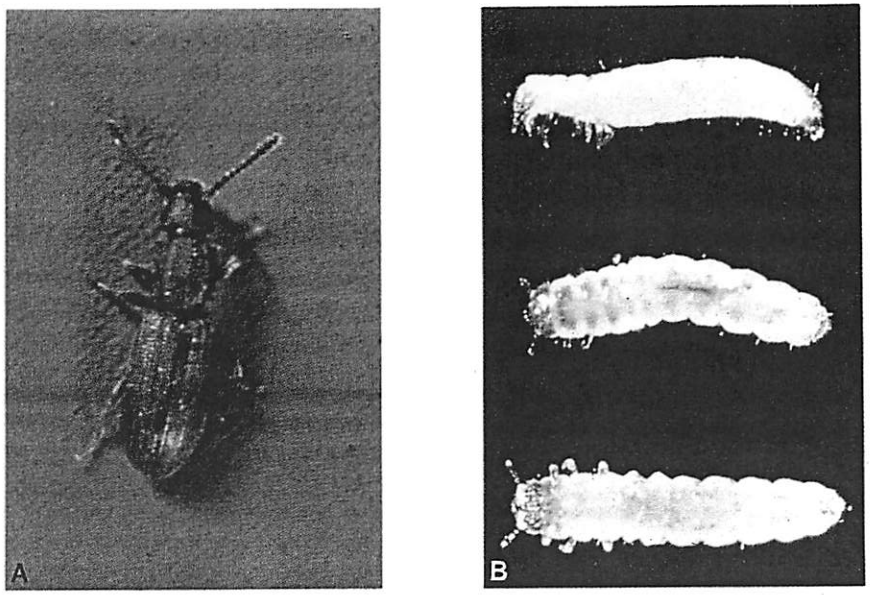

Fig. 11. Sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.) A. Adult, about 2.5 mm long; B. Larvae, about 3 mm long. (USDA photo.)

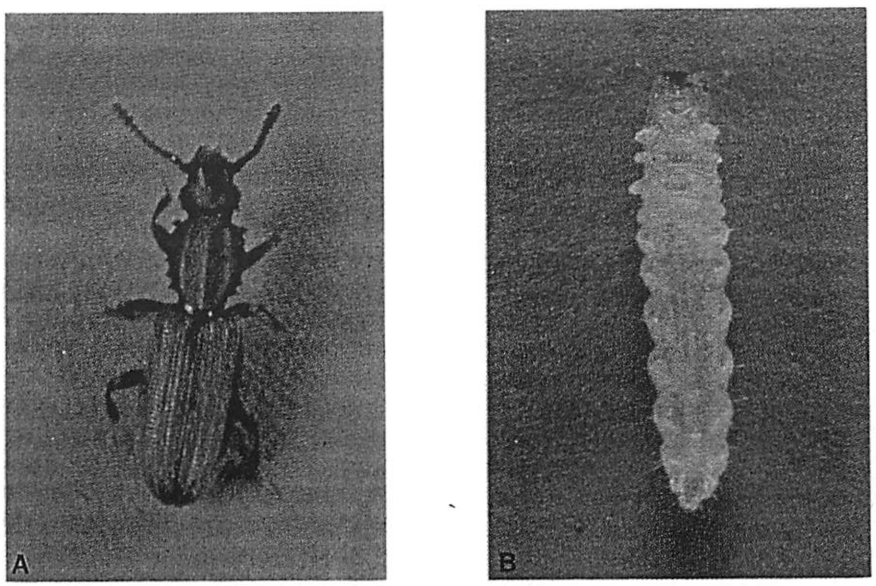

Fig. 12. Merchant grain beetle, *Oryzaephilus mercator* (Fauvel). A. Adult, about 3 mm long; B. Larva, about 3 mm long. (USDA photo.)

than the grain itself. The development of the merchant grain beetle is similar to that of the sawtoothed grain beetle.

Type of Damage. The adult and larva burrow into the peanut seed causing "worm-cut" peanuts and an increased percentage of split seed. Loss occurs through contamination of product by live and dead insects, cast skins, frass, and excrement.

Longheaded Flour Beetle - *Latheticus oryzae* Waterhouse

Description. The longheaded flour beetle is a slender, flattened beetle slightly more than 3 mm long. It is somewhat similar in form to the confused flour beetle, but is narrower and pale yellowish brown (Figure 14A). The beetle is further differentiated from the confused flour beetle by the peculiarly shaped antennae. The last segment on the tip is smaller than the next 4 segments; from there, to the base, there is a gradual decrease in size. It has a minute canthus behind each eye, partially dividing it. A view of the larva is shown in Figure 14B.

Life History. The eggs are laid in the commodity and hatch after an incubation period of 3 to 10 days. Under favorable conditions, there are 6 or 7 larval instars but the number may increase on poor diets and at low temperatures. The minimum temperature for completion of the life cycle is near 25 C (Hafeez and Chapman, 1966). This species requires a rather high temperature (35 C) and humidity (85%) for optimum development; at these conditions, mortality was very low and development was completed in an average of 22 days.

Type of Damage. The longheaded flour beetle has been reported from most parts of the world infesting various stored commodities. In the United States it is more widespread in the southern and midwestern states, where it is found in warehouses and processing plants. It is often found infesting peanuts during warm weather and usually after they have been in storage for a number of months. The peanut seed and products are damaged by being eaten and contaminated from cast skins, frass, feces, and live and dead insects.

Flat Grain Beetle - *Cryptolestes pusillus* (Schönherr)

Description. The flat grain beetle is cosmopolitan. It is one of the most common insect pests and one of the smallest of the beetles found damaging stored peanuts. It is a minute, flattened, oblong, reddish-brown beetle about 1.6 mm long, with elongate filiform antennae about two-thirds as long as the body in the male and about one-half the length of the body in the female (Figure 15A). The white egg is very small and hatches into minute whitish, elongate larva with pronounced tail-horns (Figure 15B).

Life History. This insect is not a primary pest of peanuts or peanut products. It usually follows the attack of more vigorous pests and may develop in great numbers when found in association with other species. This insect is a scavenger and may infest peanuts that are in the upper limits of moisture for safe storage and peanut products that are in poor or moldy condition.

The female deposits small white eggs in crevices in the peanuts or drops them loosely upon broken peanut material. The larva is particularly fond of the

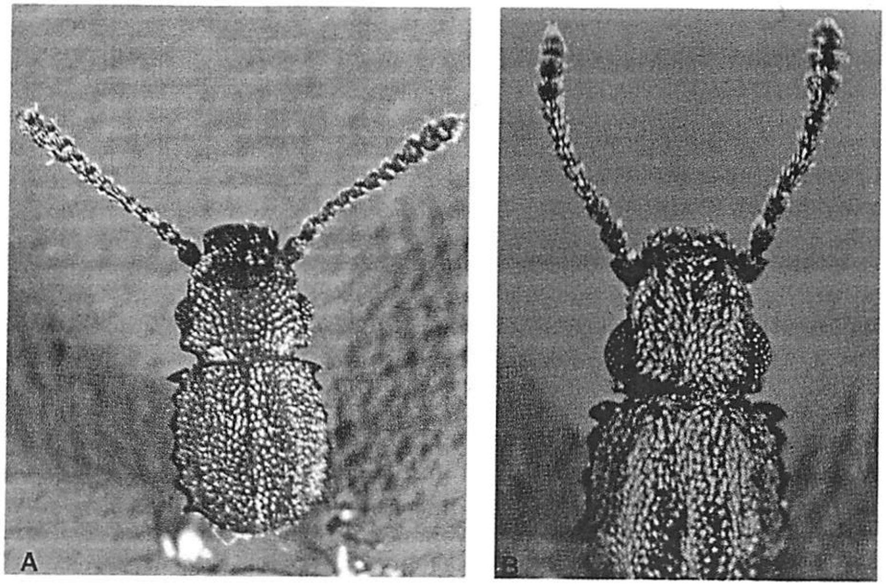

Fig. 13. Anterior comparison of sawtoothed and merchant grain beetles. A. Sawtoothed grain beetle adult; B. Merchant grain beetle adult. (USDA photo.)

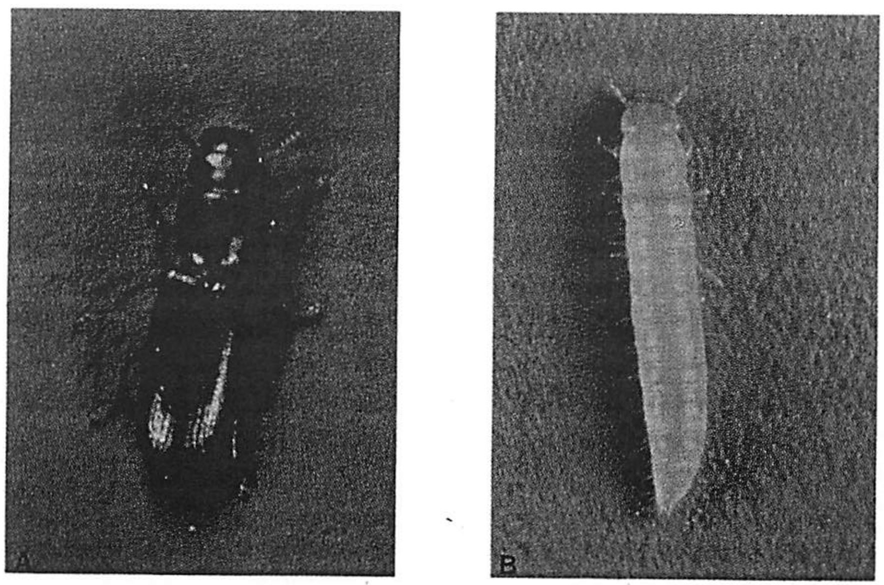

Fig. 14. Longheaded flour beetle, *Latheticus oryzae* Waterhouse. A. Adult, about 33 mm long; B. Larva. (USDA photo.)

germ, and, in infested grain, many seed are found uninjured except for the removal of the germ. Both the adult and larva is cannibalistic and will feed on both live and dead insects. The larva has 4 instars and, when fully grown, forms a tough cocoon of a gelatinous substance to which food particles adhere. It transforms into the pupal stage in this cocoon and later emerges as an adult. Under favorable conditions, this insect may develop from egg to adult in about 5 weeks, but the average period of development in summer is about 9 weeks.

Type of Damage. The flat grain beetle larva is so small it has little difficulty entering the cracked pods of in-shell peanuts, tunneling through the seed, feeding on the germ and causing increased numbers of worm-cut and damaged splits. The beetle is found associated with the heating of bulk stored peanuts and grain. In processing plants, any locations where product fragments may collect, along with high moisture conditions, can serve as an incubation area for the flat grain beetle. Peanuts or peanut products may become contaminated with the insects' dead bodies, cast skins, and fecal pellets.

Cigarette Beetle - *Lasioderma serricorne* (Fabricius)

Description. The cigarette beetle is found in all temperate and subtropical regions and infests tobacco and many other stored products. It breeds in a variety of seeds and is found attacking peanuts, especially those left in storage for long periods. This insect is a small, stout, oval, reddish-yellow or brownish-red beetle Figure 16A, with the head bent down nearly at a right angle to the body. This gives the beetle a humped or rounded appearance when viewed from the side, as shown in Figure 16B. The wing covers are not striated. It varies in size, but is usually about 2.5 mm long. The antennae are saw-like and the same thickness from base to tip. The young larvae have an arc-like or grub-like shape and are yellowish-white with brown heads and covered with fine hairs (Figure 16C).

Life History. The adult beetle lives 2 to 4 weeks, and, during this time, each female may lay as many as 100 eggs. The egg is laid among or on the larval food and hatches in 1 to 2 weeks at summer temperatures. The larval stage lasts from 5 to 10 weeks and the larva shuns light. The pupal and prepupal periods last about 2 to 3 weeks and are passed in a fragile cell of food and waste material cemented together with a secretion. The developmental period from egg to adult is quite variable but, under favorable conditions, is 8 weeks or less. Depending on temperature conditions, there are 3 to 6 generations per year.

Type of Damage. The insects damage seed and cause contamination from dead bodies, frass, and excrement.

Drugstore Beetle - *Stegobium paniceum* (Linnaeus)

Description. The drugstore beetle is very similar in appearance to the closely related cigarette beetle but is more elongate in proportion to width and has distinctly striated wing covers. It is known as the drugstore beetle from its habit of feeding on pharmaceutical drugs. It can be readily distinguished from the cigarette beetle by the club-shaped antennae and the striations on the wing covers. The adult insect is about 2.5 mm long and has a cylindrical, uniformly light brown body covered with a fine, silky pubescence (Figure 19A & B). The

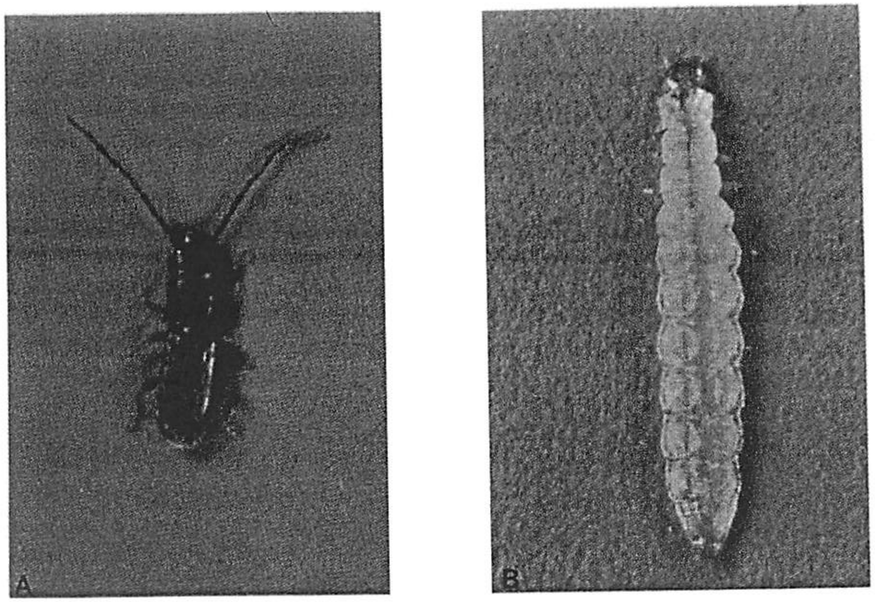

Fig. 15. Flat grain beetle, *Cryptolestes pusillus* (Schöenherr). A. Adult, about 1.6 mm long with characteristic long antennae; B. Larva, about 1.6 mm in length. (USDA photo.)

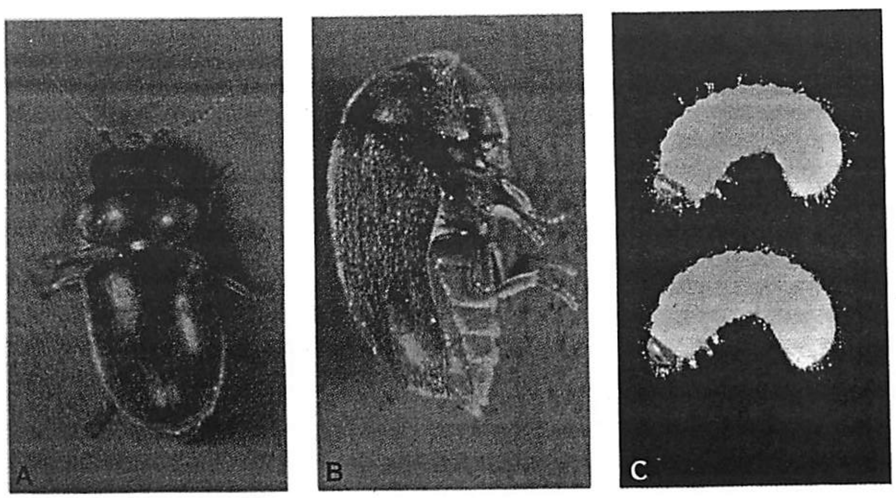

Fig. 16. Cigarette beetle, *Lasioderma serricorne* (F.). A. Adult, about 2.5 mm long (dorsal view); B. Adult (side view); C. Larvae. (USDA photo.)

larva, or grub (Figure 19C), is considerably less hairy than that of the cigarette beetle.

Life History. The drugstore beetle may lay as many as 75 eggs, usually singly, in almost any dry organic substance. The small white grub emerges from the egg and then tunnels through these substances. There are 4 to 6 larval instars and, depending on temperature, development may range up to 5 months. When fully grown, they pupate in small cocoons for a period ranging from 12 to 18 days. However, the entire life cycle, depending upon food and temperature, may be completed in less than 2 months. Adults may live from 2 to 12 weeks.

Type of Damage. This insect is a very general feeder that attacks a great variety of stored foods, seeds, and other materials, and it reportedly "eats anything except cast iron." It is frequently found in storehouses and granaries around the world. The insects damage seed and cause contamination from dead insect bodies, frass, and excrement.

Black Carpet Beetle - *Attagenus megatoma* (Fabricius)

Description. This beetle is a small oval beetle 2.8 to 5 mm long and about half as wide as its length (Figure 18A); the head and thorax are black, but the wing covers are black or dark reddish-brown and are covered with short hairs. Its legs and antennae are dark yellow. The larva is easily recognized. It is elongate and rather cone-shaped, up to 7 to 10 mm in length, reddish or golden-brown, covered with short, scalelike, appressed hairs, and has a tuft of long hairs at the end of the body (Figure 18B).

Life History. The small pearly-white egg, which is very fragile and rarely seen, is deposited in a crack or crevice containing a source of food. It hatches in 6 to 11 days in warm weather, but may require up to 16 days under cool weather conditions. The larva are often found in abundance in cracks in the floors of warehouses where foodstuffs have accumulated. Larval development is slow, ranging from 250 to 600 days. In the spring, these larvae transform into adults, which swarm over bagged material stored there. The larva molts 5 to 11 times and up to 20 times when conditions are unfavorable. Because the larva of the black carpet beetle develops slowly, there is never more than 1 generation each year. Pupation takes place within the last larval skin and the period is about 1 to 3 weeks. If conditions are unfavorable, the life cycle may be prolonged to 2 or 3 years. The adult, which emerges in the spring and early summer, lives 2 to 4 weeks, and each female lays about 100 eggs. This beetle is cosmopolitan.

Type of Damage. The black carpet beetle larva normally do not cause much damage to peanuts or cereal products, but prefer to breed in cracks in the floor of warehouses and plants where product fragments accumulate. The larva will usually be found in conjunction with heavy populations of other insect pests, perhaps feeding on the dead bodies of other insects as well on peanut products. Also, the larva are able to bore into packaged food containers and thus provide an opening for infestation by other insect pests. Thus, it may be responsible for much more damage than is accredited to it. Peanut products are damaged by the feeding insects as well as contamination from their dead bodies, cast skins, and fecal pellets.

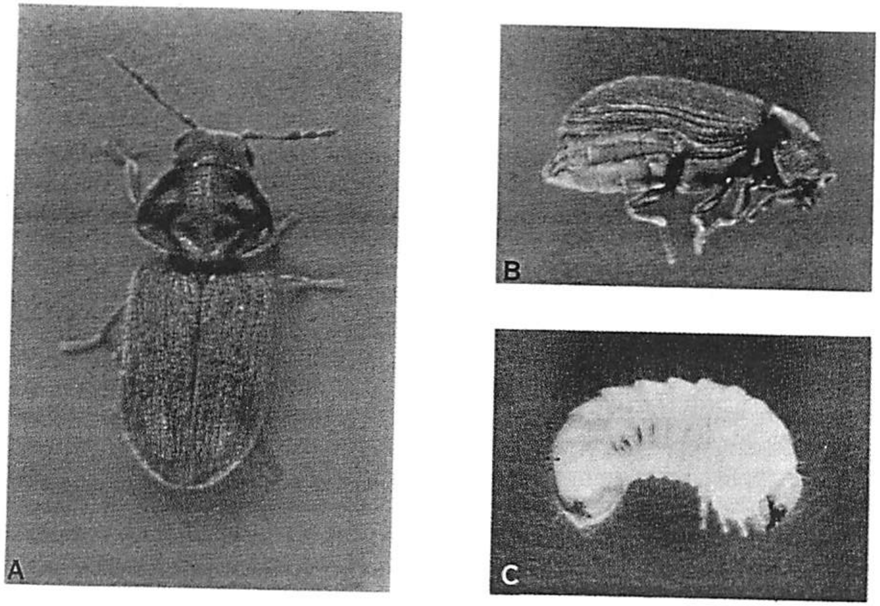

Fig. 17. Drugstore beetle, *Stegobium paniceum* (L.). A. Adult, about 2.5 mm long (dorsal view); B. Adult (side view); C. Larva. (USDA photo.)

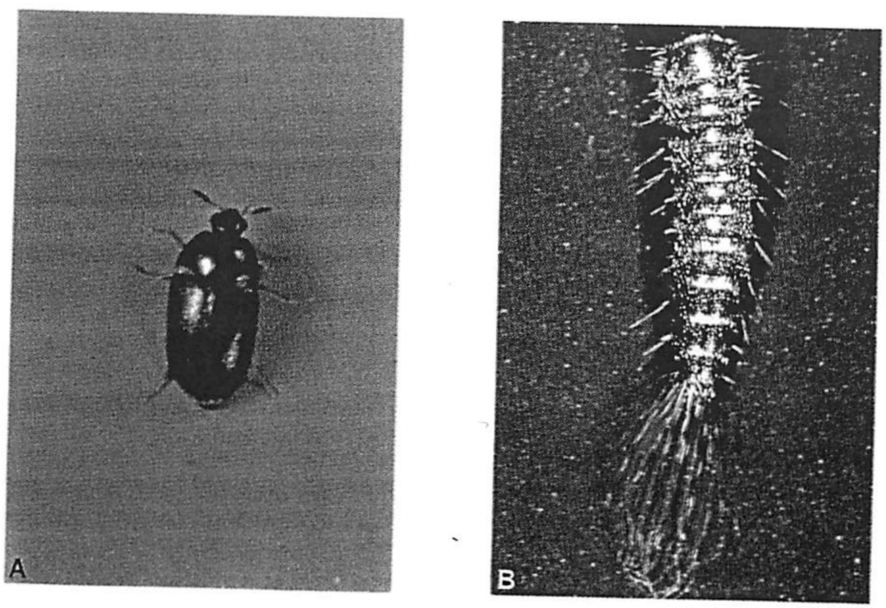

Fig. 18. Black carpet beetle, *Atagenus megatoma* (F.). A. Adult, about 4 mm long; B. Larva, about 9 mm long. (USDA photo.)

Larger Cabinet Beetle - *Trogoderma inclusum* LeConte

Description. The larger cabinet beetle is the most frequently found member of the *Trogoderma* species in USA peanut warehouses and processing plants and is a common pest of grain, seed, and other stored products (Figure 19A). Other species of the genus that occur in this country and are likely to be confused with it are *T. glabrum* (Herbst), *T. grassmani* Beal, *T. ornatum* Say, *T. variabile* Ballion, *T. simplex* Jayne, *T. sternale* Jayne, and *T. teukton* Beal. Many of these species were little known as pests of stored products before surveys were made for the khapra beetle, *Trogoderma granarium* Everts, as part of the quarantine measures restricting its entry into the USA. The adult of the larger cabinet beetle is 2 to 5 mm long and requires neither water nor food for the attainment of its full fecundity and longevity. The female is about 1 1/3 times the size of the male. The beetle is reddish-brown to black with indistinct, paler markings on the wing covers. The egg is whitish, translucent, and about 0.5 mm long. One end of the egg has hair or thread-like projections, which adheres to any object it contacts.

The larva is stout, and, at rest, the back is yellowish brown (Figure 19B). However, the areas between the segments, which are visible during movement, and the underside are very pale yellow. The last 3 segments of the body are almost covered by tufts of dense, specialized hairs. The fully grown larva may attain a length of about 7 mm. This larva is difficult to distinguish from the larva of related species.

Life History. The adults mate 1 to 2 days after emerging from the pupal skin. The female may lay up to 100 eggs deposited loosely or inserted in grooves or cracks in the commodity. The egg hatches at room temperature in 8 to 12 days. The larval life under warehouse conditions may be 5 months or longer and, under good conditions with temperatures above 26 C, may be less than 4 weeks. The pupal stage may last from 4 to 14 days, and the adult lives from 1 week to 2 months. The life cycle may vary from 7 weeks to several years, depending upon the temperature and the food supply. It usually overwinters in the larval stage.

Type of Damage. Peanut products are damaged by the feeding insects as well as contamination from their dead bodies, cast skins, fecal pellets, and other damage similar to that described for the black carpet beetle.

Cadelle - *Tenebroides mauritanicus* (Linnaeus)

Description. The cadelle is widespread in distribution over the world and is frequently found in shelling plants, warehouses, mills, granaries and storehouses where it infests dried fruit, nuts, flour, meal, and grain. This insect is an elongate, oblong, flattened, shining black or dark reddish-brown beetle 7 to 12 mm long, the largest of the major peanut-damaging insects (Figure 20A). The head and prothorax are nearly separated from the rest of the body, to which it is attached by a rather loose, prominent joint. The larva (Figure 20B) ranges between 16 and 25 mm long; it is creamy white with a black head and prothorax, 2 black or dark plates on the upper part of the segment just behind the prothorax, and a dark plate with 2 stout dark horny projections on the tip of the abdomen. Its size and other characteristics makes it easy to recognize.

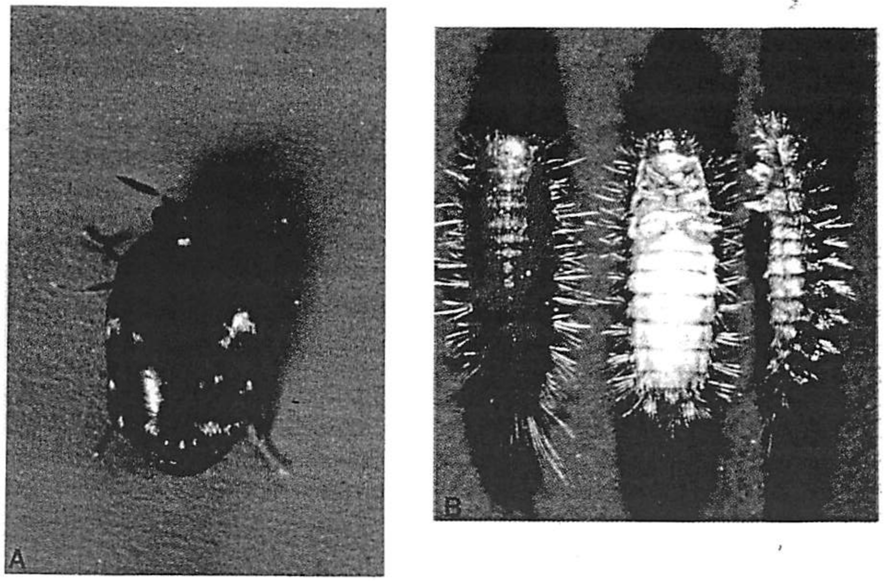

Fig. 19. Larger cabinet beetle, *Trogoderma inclusum* LeConte. A. Adult, about 4 mm long; B. Larvae, about 7 mm long. (USDA photo.)

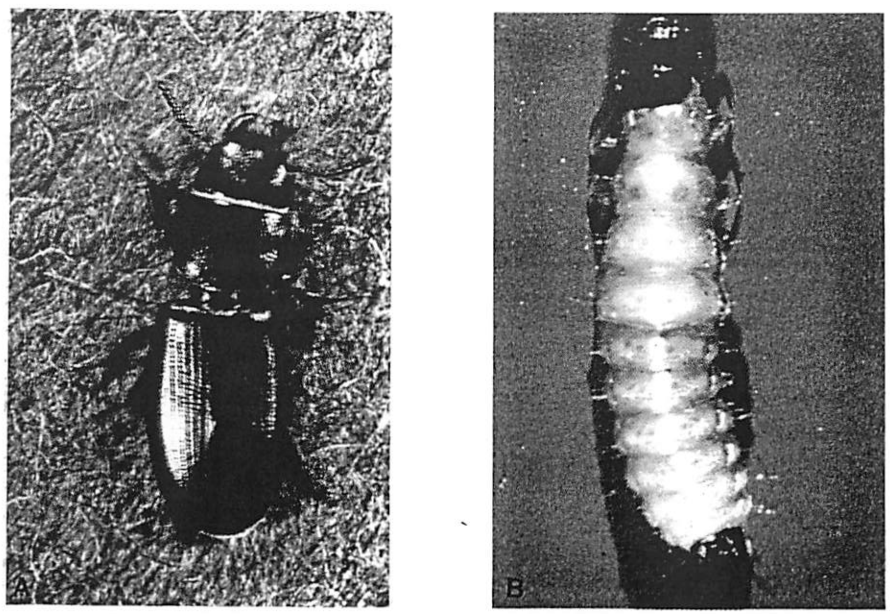

Fig. 20. Cadelle, *Tenebroides mauritanicus* (L.). A. Adult, about 10 mm long; B. Larva, about 20 mm long. (USDA photo.)

Life History. The female beetle oviposits during most of her life, and, under favorable conditions, she may lay over 1,000 eggs. The white eggs may be laid in clusters, 10 to 60 at at time, in the food material or packed in small crevices. The egg hatches in 7 to 14 days to produce grayish-white, soft-bodied larva. When provided with favorable foods, temperature, and humidity, the larva readily mature in 8 weeks. However, under normal warehouse conditions, an appreciably longer developmental time, up to 14 months, is required. Most larva molt 3 or 4 times, but under unfavorable conditions it may molt several more times. Both the larva and the adult can live for long periods without food and often remain hidden in the woodwork of a facility long after the peanuts have been removed. When new peanuts are put into the storehouse, they become infested in a surprisingly short time.

The larva complete their growth and then seek some secluded place to pupate. The cadelle is one of the longest-lived of the insects that attack stored products; many of the adults live for more than 1 year and some of them for nearly 2 years. Cadelles are predaceous on other insects and may devour any larva that gets in their way. They avoid light and therefore will be found hiding in dark corners, under boards or other debris, or under and between stored bags in warehouses.

Cadelles are true hibernating insects. Both larvae and adults bore deep into the woodwork of processing plants and warehouses where they may survive the winter. There may be 2 generations each year.

Type of Damage. Both the larva and adult feed and have the destructive habit of going from seed to seed devouring the germs, but the endosperm may be eaten as well.

They frequently bore into the timbers of the bin or other receptacle that holds the infested material. The restless larvae and adults cause much damage by gnawing holes through sacks, cardboard, waxed, and other paper containers making entrance holes for other stored-product insects. Other kinds of contamination include cast skins, frass, larval droppings, and live and dead insects.

Coffee Bean Weevil - *Araecerus fasciculatus* (De Geer)

Description. The coffee bean weevil is a very active, robust, beetle 3 to 5 mm in length. It is dark brown mottled with patches of light and dark brown pubescence. The beak is short and wide. This insect may be easily recognized from Figure 21A. The antenna is 11-segmented with the 3 apical segments distinctly larger than the other segments. The eyes are entirely without emargination. The egg is shiny white and ovoid in shape. The mature larva is 4.5 to 6 mm in length; white, footless, fleshy grub with body curved, wrinkled, and profusely covered with long hairs (Figure 21B). The head is very pale or straw colored (Cotton, 1921).

Life History. This weevil is found in many tropical and subtropical countries and is very abundant in the southern United States, where it breeds in peanuts, dried fruit, coffee berries, cornstalks, corn, and the seed and seed pods of an almost endless variety of plants. When conditions are right, it is often found infesting farmers stock peanuts. It is a strong flier and is frequently seen in the cornfields of the south on exposed and damaged ears. It prefers food material with a high moisture content and breeds well on commodities that are relatively soft. El Sayed (1935) reported the development period from egg to adult varies from about 29 to 69 days depending upon the type of food, temperature, and moisture. Under optimum conditions, each female may lay up to 90 eggs. Ovipositing females force the ovipositor into the food material with a series of thrusts and then deposit an egg. On maize, egg laying took about 8 minutes. Most eggs, usually more than 98%, are thus concealed within the food. Adults live from 20 to 134 days depending upon the type of food, temperature, and relative humidity.

Type of Damage. A wide range of commodities are liable to attack by this species. Damage is caused by the feeding of larvae and adults on the seed, resulting in damaged or "worm-cut" seed. Other kinds of contamination include cast skins, frass, and live and dead insects.

Corn Sap Beetle - *Carpophilus dimidiatus* (Fabricius)

Description. The corn sap beetle may be readily recognized by its peculiar wing covers, which are short and truncate, leaving the tip of the abdomen exposed. It is a small, oblong, ovoid, dark brown beetle with lighter colored wing covers and is 2 to 3.5 mm long (Figure 22A). The egg is narrowly obovate, whitish, opalescent, shiny, smooth surfaced. The full grown larva is 5 to 6 mm long, white or yellowish-white with abdomen ending in 2 amber brown protuberances (Figure 22B). The larval stages are very active and move quickly when disturbed.

Life History. The corn sap beetle may overwinter in either the pupal or adult stage. Oviposition in the south commences early in March, females depositing from 175 to 225 eggs each. The adult beetle lives about 63 days in summer and as long as 200 days in winter. Under optimum summer conditions, the life cycle may be completed in 18 days, whereas in winter it may extend over 150 to 200 days. The beetle prefers food of 15 to 33% moisture content and can survive on food of higher or lower moisture content, but probably cannot mature to the adult stage in rice containing less than 10% moisture (Balzer, 1942). It has been found infesting peanuts of less than 10% moisture.

Type of Damage. The corn sap beetle is attracted to high moisture peanuts, corn, rice, and other grain. This insect normally feeds in moldy or decaying fruit and other vegetative forms, such as high moisture peanuts and grain. The larva damages sound peanuts by causing "worm-cut" damage, increase in split seed, and poor shelling outturn. Peanuts and peanut products are contaminated with live and dead insect bodies, cast skins, frass, and excrement.

Hairy Fungus Beetle - *Typhaea stercorea* (Linneaus)

Description. This insect resembles the drugstore beetle in general appearance but is smaller. It can be distinguished from the drugstore beetle by the shape of its antennae, which are clavate (club shape) instead of irregularly serrate (Figure 23A). It is a small brownish beetle about 2.2 to 3 mm long and is covered with hairs. The whitish to pale brown larva (Figure 23B) is 4 to 4.5 mm long when mature (Hinton, 1945).

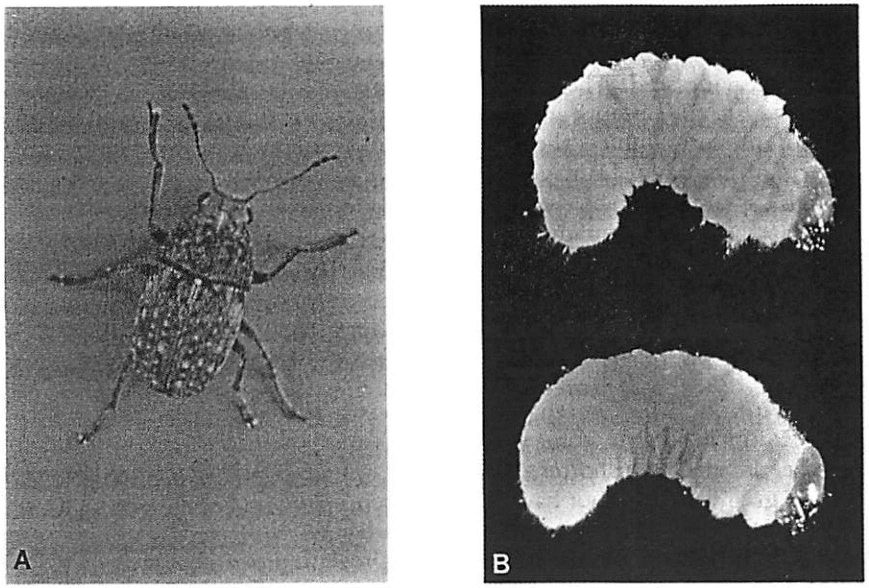

Fig. 21. Coffee bean weevil, *Araecerus fasciculatus* (DeGeer). A. Adult, about 4 mm long; B. Larvae (grub-like), about 5 mm long. (USDA photo.)

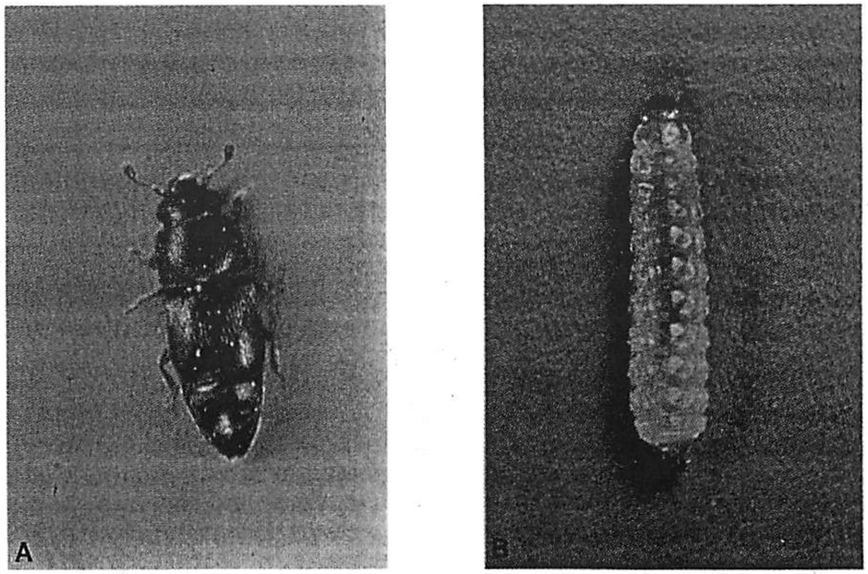

Fig. 22. Corn sap beetle, *Carpophilus dimidiatus* (F.). A. Adult, about 3 mm long; B. Larva, about 5 mm long. (USDA photo.)

Life History. The hairy fungus beetle is frequently found in corn fields where it is attracted to decaying seed of exposed ears. It is also found on high moisture farmers stock peanuts where it is apparently attracted to the immature or decaying seed. The larva and adult feed on fungi associated with the kernels. After the peanuts are dried and placed in storage, there is little evidence of infestation unless there is a moisture problem.

Type of Damage. Damage occurs mostly on moldy or decaying seed and through contamination by the presence of live and dead insects, cast skins, and fecal materials. Such contamination probably transfers fungal spores that further contaminate. Some fungi produce toxins harmful to man and other animals.

Foreign Grain Beetle - *Ahasverus advena* (Waltl)

Description. The foreign grain beetle is a small reddish-brown beetle about 2 mm in length, somewhat similar in appearance to the sawtoothed grain beetle, although shorter and stouter (Figure 24). It differs from the sawtoothed grain beetle by not having the sawtooth-like projections on each side of the thorax. The antennae are long and rather prominent. The prothorax is nearly square and has a prominent tooth or projection at each apex.

Life History. This species is cosmopolitan in distribution and appears to have originated in America (Woodroffe, 1962). It occurs on a very wide variety of stored materials including peanuts and other oilseed products. Usually it is found in large numbers only in the presence of high moisture and molds which it requires for optimum development and oviposition. On a rolled oats-yeast medium the life cycle, egg to adult, ranged from 19 to 27 days (Davis and Mills, 1975). High humidities favor rapid growth, and below 58% RH, the larva will not complete development. The egg is usually laid singly, but sometimes in clusters of 2 or 3. There are 4 or 5 larval instars and larval periods range from 11 to 19 days. Before pupation, the larva secludes itself by forming a chamber of food particles cemented together, then secretes from its anal aperture a brownish fluid which cements the larva to the substrate. Pupal stage lasts from 3 to 5 days. Females began laying eggs 3 to 4 days after emergence and each female may lay more than 200 eggs. Adult beetles may live more than 10 months.

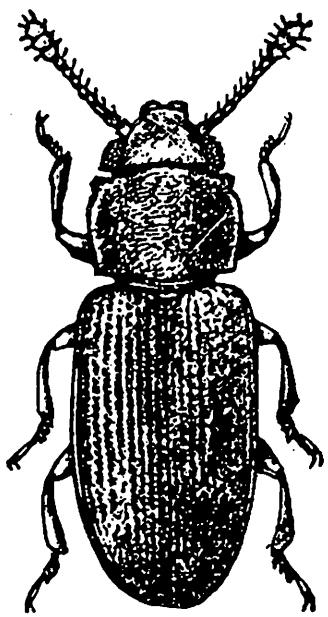

Fig. 24. Foreign grain beetle, *Ahasverus advena* (Waltl), adult. (USDA photo.)

Type of Damage. Woodroffe (1962) found that the foreign grain beetle was able to maintain itself and cause direct damage to peanuts at 30 C and 70% RH in the apparent absence of mold. However, most stored foodstuffs are deficient in some factor required by the beetle for development, and successful breeding is limited to moldy products. Peanuts are damaged by the feeding insects, and the product is contaminated by their dead bodies, cast skins, and excrement.

Yellow Mealworm, *Tenebrio molitor* Linnaeus

Description. The yellow mealworm is one of the largest insects that infests stored cereal products. Though this insect is considered cosmopolitan in the USA, it is abundant only in the northern states while *Tenebrio obscurus* F., the dark mealworm, occurs throughout the country (Cotton and St. George, 1929).

The adult is a polished dark brown or black beetle about 16 mm long (Figure 25A). Its thorax is finely punctated, and its wing covers are longitudinally striated or grooved. When fully grown, the larva is about 25 mm long and is yellowish, shading to yellowish-brown toward each end and at the articulation of each segment (Figure 25B). The yellow mealworm gets its name from the yellowish color of the larva.

Life History. The female lays bean-shaped white eggs covered with a sticky secretion that causes the flour, meal, or grain dust in which they are laid to adhere to them. The egg hatches after about 4 days to a week at warm spring or summer temperatures or in about 2 weeks or longer at lower temperatures. The slender larva that emerges is white but soon turns yellow and assumes the form shown in Figure 25B.

There is but 1 generation each year. The adults begin to appear in the latitude of Washington, D.C., in late May and early June and may be found until late in August. The female beetles are quite prolific, and each may lay as many as 500 eggs. The larva become fully grown in about 3 months, but, instead of transforming into the pupal and adult stages, they continue to feed and molt until cold weather and then hibernate. The larva molt, or cast their skins, many times in the course of their lives. In late spring or early summer, they transform into the pupal stage in which they remain for about 2 weeks.

Type of Damage. Because the yellow mealworm has but 1 generation each year and is entirely an external feeder upon seed, it is not a serious pest of peanuts. When found in peanuts they are removed in the screening and shelling

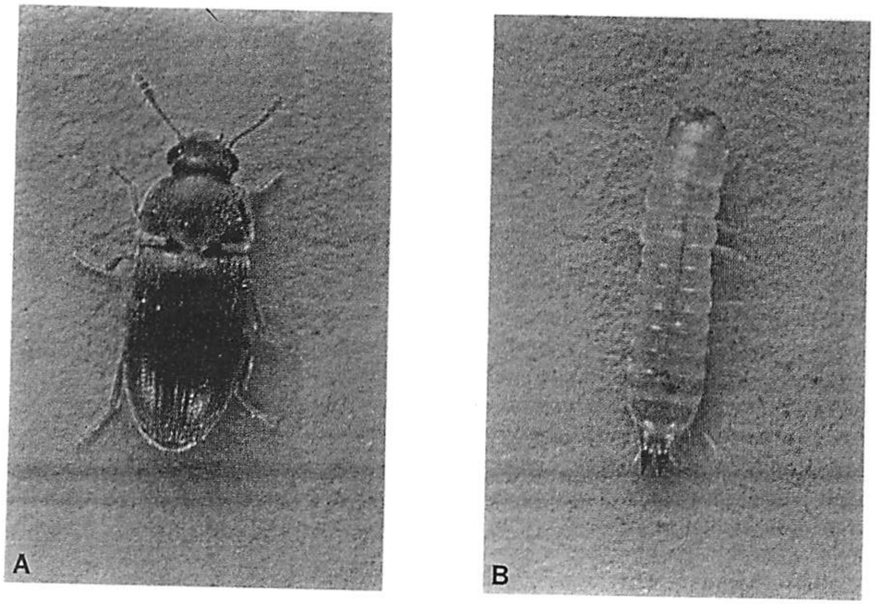

Fig. 23. Hairy fungus beetle, *Typhaea stercorea* (L.). A. Adult, about 3 mm long; B. Larva, about 4 mm long. (USDA photo.)

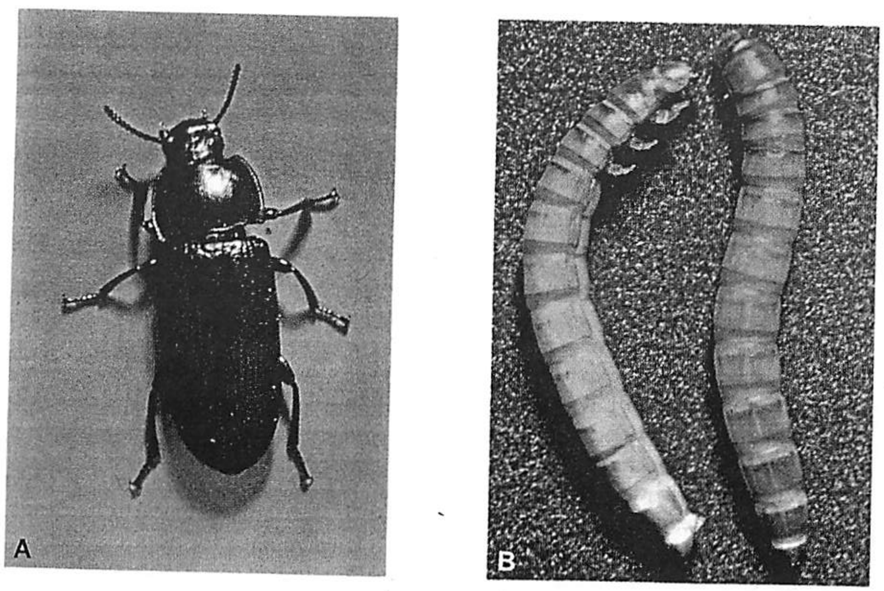

Fig. 25. Yellow mealworm, *Tenebrio molitor* L. A. Adult, about 16 mm long; b. Larvae, about 25 mm long. (USDA photo.)

process. The well-grown larva, however, can do serious injury under certain conditions, as when the product is held for long periods without being moved.

Lesser Mealworm - *Alphitobius diaperinus* (Panzer)

Description. The adult lesser mealworm resembles the yellow mealworm in form and color but is considerably smaller. It is due to this great resemblance of both adult and larval stages that this insect owes its common name. The adult beetle is oval in shape, black or very dark reddish brown, and about 5-7 mm long (Figure 26A). The surface of the thorax is finely and sparsely punctated. The larva is yellowish brown and closely resembles the young larva of the yellow mealworm in form and appearance (Figure 26B).

Life History. The lesser mealworm is cosmopolitan in distribution and is commonly associated with stored products that are damp or slightly out of condition. It has been found in many different habitats including poultry houses. When reared on a diet of ground wheat, the development period from egg to adult ranged from 42 to 97 days depending on temperature (Wilson and Miner, 1969). The egg is cemented to the food substrate with a clear sticky secretion and incubation period ranged from 3 to 10 days. There were 6 to 11 larval instars and the duration of the immature stage ranged from 35 to 96 days. The mean optimum development time from egg to emergence was about 46 days at 32 C. Preiss and Davidson (1971) found that the average life span of the adult beetle is probably greater than 400 days with some beetles living over 2 years. The average number of viable eggs deposited over a 3-month period was 3.5 per day with one female depositing 2,684 eggs in 703 days at room temperature.

Type of Damage. This insect is commonly found in warm, damp, or musty locations. They feed upon high moisture seed, peanut meal, or grain residues. Their presence in warehouses and processing plants is indicative of poor storage conditions involving high moisture and lack of proper sanitation. Product is damaged by feeding insects and contaminated by their dead bodies, cast skins, and excrement.

Booklice - *Liposcelis* spp.

Grain and oilseeds and their products are sometimes found to be swarming with minute insects scarcely larger than a pinhead. Peanuts, rice, grain, and flour are particularly attractive to them. They are known as booklice, owing to their superficial resemblance to chicken lice and their occasional presence in books. There are over 100 species of the order Psocoptera in the United States, and only a few of these are known to be pests or nuisances by their presence. Some of the more important booklice belong to several closely related species of the genus *Liposcelis,* which will serve as an example for the groups.

Description. The booklouse is about 1 mm in length, pale-gray or yellowish-white, wingless, soft bodied, louselike insect with a fairly large well developed head. It has chewing mouth parts, poorly developed eyes, and long slender antennae (Figure 27). The rear pair of legs are long and well developed. The common booklouse is wingless, although some closely related members in the

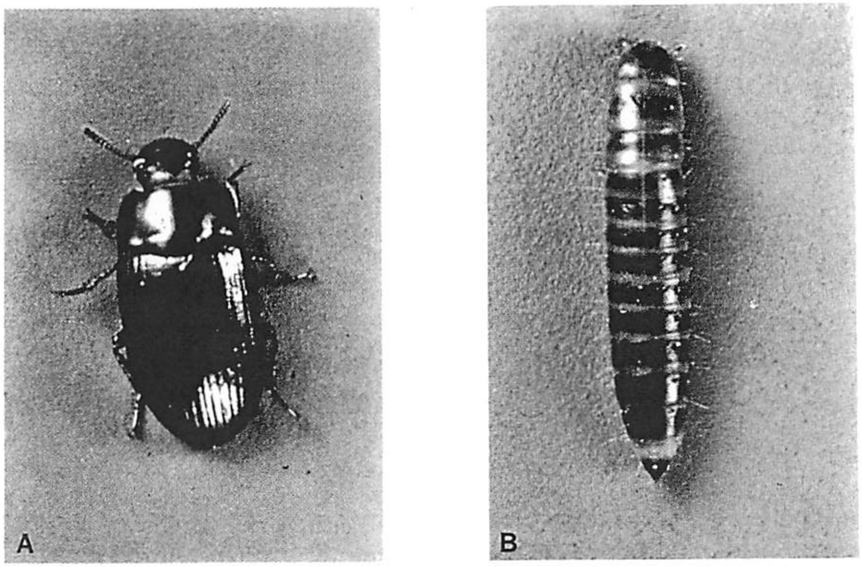

Fig. 26. Lesser mealworm, *Alphitobius diaperinus* (Panzer). A. Adult, about 6 mm long; B. Larva, about 10 mm long. (USDA photo.)

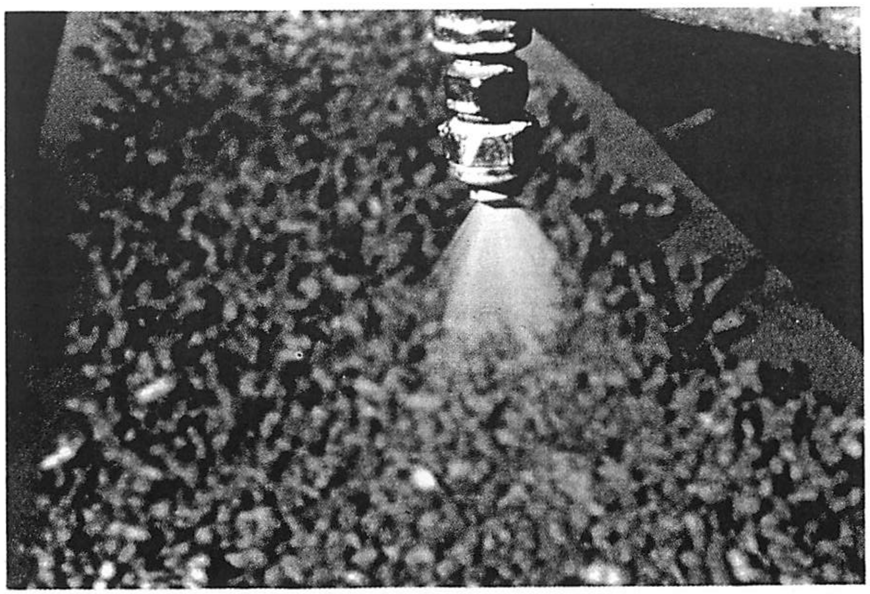

Fig. 28. Spray nozzle applying a protectant on farmers stock peanuts going into storage. (USDA photo.)

order Psocoptera have wings. The egg is white, ovalshaped, and covered with a crusty coating. The young nymph is colorless, almost transparent, but acquires a little more gray color with each molt.

Liposcelis bostrychophilus Badonnel has been reported as an important predator of eggs of the Indian meal moth (Lovitt and Soderstrom, 1968). Finlayson (1933) reported a closely related species, the common booklouse, *L. divinatori-*

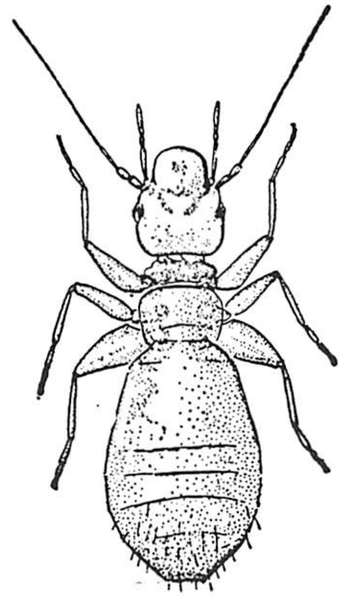

Fig. 27. Booklouse adult, about 1 mm long. (USDA photo.)

us (Müller) and the larger pale booklouse, *Trogium pulsatorium* (L.), known a the "death watch," as predators on eggs of the Angoumois grain moth. These species are similar in appearance and habits and are found under the same cir cumstances. The larger pale booklouse may be distinguished from the com mon booklouse by its slightly larger size, diminutive wing covers, and well developed eyes.

Life History. Booklice feed on a great variety of organic matter, both (plant and animal origin, especially under somewhat moist or moldy cond tions. All favor the same living conditions, namely moisture, warmth, an darkness in an undisturbed location.

Some females are believed to reproduce without mating, but males ar sometimes found associated with them. Each female may lay as many as 10 eggs. The egg hatches in 10 to 14 days and the resulting nymph will molt times before adulthood. The newly hatched young resembles the adult in for and general appearance but is smaller and lighter in color. In summer, th developmental period from egg to adult is about 3 weeks. Booklice may repr duce continuously the year around under proper conditions, producing many as 6 generations. Adults may live almost a year. These insects are wide distributed in North America and Europe.

Type of Damage. Under certain conditions of temperature and moistur booklice may develop in large numbers in warehouses or plants where peanuts and grain are stored.

They are primarily mold feeders but may also feed upon any starchy material, books, and papers which have developed microscopic molds due to a warm, dark, and damp environment. For the most part they are incapable of doing important economic damage, except that created by their presence or through the contamination of foodstuffs.

CONTROL OR MANAGEMENT OF PESTS

Contributing Factors

Many factors make insect prevention and control in stored farmers stock peanuts one of the more difficult problems in the entire field of stored-product entomology. Heavy population densities result from the long, warm fall storage season, the abundant food supply, the absence of cold winter weather which normally would reduce the insect infestations to low levels, and the large residual populations of insects present in peanuts with the advent of warm spring weather. Proper control measures are difficult or impossible to apply in many storage warehouses because of their design and construction. Also, the poor construction or stage of deterioration of the storage structure readily allows insects access to the stored peanuts.

An important factor contributing to the insect problem is the change in harvesting practice from stacking peanuts to windrowing and combining the peanuts. In addition, the combines are sometimes operated improperly at high cylinder speeds or at aggressive picking action which results in mechanical damage to the peanut. Thus, combining the peanuts causes an increase in number of cracked pods and loose shelled kernels, a condition that favors the insects by providing easy access to the seed which further increases the severity of the problem during storage. Also, the combined peanuts are brought into storage earlier than stacked peanuts, providing more time to develop heavy infestations in the warehouse during the warm, humid fall season. Several generations of insects can develop before cool weather. Careless handling and excessive or unnecessary trampling of the peanuts cause additional cracking and shelling. Insect infestation during the first season of storage is confined almost exclusively to the seed in cracked pods and in the loose shelled kernels. Solid pods are relatively resistant against insect invasion and are rarely infested during the first 12 months of storage.

In the high peanut producing areas, harvesting practices have changed to large tractor-powered combines equipped with bulk holding tanks. When these storage tanks become full, the peanuts are dumped into trucks or trailers and transported to drying facilities. However, in some areas, peanuts may still be harvested and stored in burlap bags. This is sometimes done by small producers or by producers saving peanuts for seed purposes. There is a danger of adding to the insect infestation by using old, infested burlap bags to catch the peanuts coming from the combine. It is important to use only clean or new bags for this purpose or bags that have been properly fumigated. In the past, some warehousemen have made available a fumigation service to farmers interested in having infested bags fumigated. This is especially important if the peanuts are to be stored in sacks as is the case in small seed producing facilities. Holding the peanuts on the farm for a time, even for an overnight period, before they are taken to the warehouse can be an added source of trouble if the holding area is infested with insects from old peanuts, feed, or grain. Infestation can be picked up even from contaminated truck beds, drying wagons, and combines. All equipment used in harvesting or transporting peanuts is a potential source of insect infestation if not cleaned properly.

Many of the insect species that cause the most damage in storage were commonly present in the incoming peanuts. When this situation was first observed, it was thought to be due to unusual conditions during that particular harvest season. However, extensive observations during 4 full seasons beginning in 1955 showed that the same situation occurred each season (LaHue et al., 1959). Insects were present in all peanut stocks arriving at warehouses over a wide area in Georgia, where conditions were representative of much of the entire peanut production region. Surveys of hundreds of truckloads of peanuts arriving at warehouses in Georgia during the harvest period revealed that insect infestation was already present in practically all peanut stocks as received (Redlinger, 1962). The level of infestation was low, but was sufficient to start a vigorous infestation in the storage warehouses. Nearly every instance of heavy infestation on arrival was found to have occurred while the peanuts were held for drying on the farm near infested feed or grain.

Additional sources of infestation exist in many warehouses where old peanuts are lodged on or in ledges, beams, between double-walled partitions, window sills, elevators, elevator wells, conveyors, dump pits, and other places. Spilled peanuts, grain, or animal feeds under or near the warehouse may also be sources of infestation.

Facility Treatments

Sanitation. Sanitation or facility cleanup has proved to be an important factor in controlling insects. Before storing peanuts, thoroughly clean the warehouse and its surroundings. Clean up trash and old remains or spillage of peanuts, grain, or animal feed inside and around the warehouse. Pay particular attention to areas underneath loading platforms and underneath the building if it is raised off the ground. Material often collects in such places, becomes heavily infested with insects, and serves as a source of infestation for new-crop peanuts when they are brought in. Warehousemen or shellers operating farmers stock cleaners should not allow screenings or siftings to accumulate near the premises. Studies have shown that 97 to 99% of the insects are removed by aspiration and vibrational screening of farmers stock peanuts during the cleaning operation prior to shelling (Payne et al., 1970). If the siftings are not removed from the shelling plant, fumigated, or disposed of daily, the insects may fly back to the warehouse or shelling plant to reinfest the peanuts.

Clean out elevators, conveyors, elevator or conveyor wells, dump pits, and other spots where old peanuts and refuse have collected. Sweep down the walls, window sills, rafters, beams, ledges, and other parts of the building where old peanuts, grain, debris, and dust can lodge. Sweep or pick out loose accumulations from cracks in wooden and concrete floors. Some warehousemen utilize high pressure air nozzles to remove the debris from cracks and crevices. A high-volume vacuum cleaner may also be used to excellent advantage.

Burn, bury, or remove from the premises all refuse collected in these operations. When warehouse sanitation was first recommended, several tons of peanuts were cleaned from some of the warehouses having double walls or partitions (Redlinger, 1962). This source of food supply would carry over a large population of stored-product insects until the new-crop peanuts were harvested. Today warehousemen recognize the importance of a good sanitation program and start their warehouse cleanup as soon as the buildings are emptied. When all the debris has been collected and removed, some warehousemen having older type wooden warehouses wash the inside from top to bottom with a firehose and nozzle. This affords a clean surface for the application of a residual spray. This method should be used with caution because of the excessive moisture and the potential for supporting mold growth and mycotoxin production.

Residual Insecticides. Apply a residual spray after the warehouse is cleaned. If there is an extended time period of several months, then a second residual spray application should be made, preferably 1 or 2 weeks before any peanuts are brought in. Spray the floors, walls, beams, and ceiling of the interior of the empty warehouse. Spray the outside walls of the building up to a height of 2 or 3 m, or to the eaves if they are not too high. Spray the ground to a distance of about 2 m from the building where possible. If the warehouse is a raised structure, spray the pillars and at least 1 m of the underside around them and around the edges of the building where possible.

Use a 3% malathion emulsifiable concentrate (EC) or wettable powder (WP) spray. If available, a pyrethrins plus piperonyl butoxide EC or WP spray may be applied at the rate of 63.5 plus 634.7 mg active ingredient ai/m^2 of surface area. Apply the spray at the rate of about 81 mL/m^2 , or just before the point of runoff. If there is much area to cover, it is best to use a power sprayer with enough pressure for good penetration into cracks and protected places.

Commodity Treatments

Extensive laboratory and field tests have shown an insecticidal protective treatment followed by periodic surface treatments, sprays, or aerosols are necessary to protect farmers stock peanuts against insect damage during storage. The purpose of the protectant is to eliminate any insect infestation which may be present at the time the peanuts are placed in storage and to prevent reinfestation during a 1-year storage period. The supplemental surface sprays applied periodically during storage maintain the residue on the exposed peanuts at a maximum allowable level on the surface of the peanuts: an area highly susceptible to reinfestation. An aerosol space treatment applied at daily intervals in lieu of surface sprays will help prevent reinfestation from outside sources. Malathion and synergized pyrethrins have been approved for both bulk and surface treatments. Tests conducted cooperatively between the USDA and several food industry firms showed that the recommended malathion treatment had no adverse effect on the odor or flavor of the peanuts or on peanut butter made from treated farmers stock peanuts (Redlinger, 1962). Dichlorvos is labeled as a space treatment both as a vapor evolved from impregnated polyvinyl chloride strips and as an aerosol.

Protectants. A protective bulk treatment consists of spraying the peanuts with an approved insecticide as they are placed in the bin or warehouse, or before they are bagged. A convenient place to locate the spray nozzle is at the discharge end of a conveyor (Figure 28). It is advisable to place baffles, a hood, or another deflection device to shield the area of the spray nozzle to reduce air currents and prevent excessive loss of the spray. The application should be a coarse wet spray rather than a fine mist. The spray should be applied uniformly, preferably by using a mechanical applicator that regulates the rate of application to the flow of peanuts. The size of the nozzle opening and the operating pressure on the spray line must be calibrated with the rate of flow of peanuts on the conveyor to give the proper rate of application. It is better to arrive at a combination in the lower range of pump pressures that will give effective performance of the nozzle used. In general, higher pump pressures tend to produce more of the fine, drifting spray mist that should be avoided. A gear pump is satisfactory for use with the emulsion spray. Positive displacement pumps that mix the required amount of insecticide and water immediately prior to application are very satisfactory. These have the advantage of not having to premix the spray in tanks and not having to calculate how much spray will be required for the day. When the malathion spray is premixed, it should be applied on the same day. Avoid mixing more spray than will be used for that particular day. The wettable-powder spray causes excessive wear on a gear pump, and it is therefore best to use a piston-type pump equipped with an agitator for this formulation. Use good spray equipment and control mechanisms that will start the spray when peanuts begin moving through the conveyor system and stop the spray when peanut movement stops. A flow meter should be installed in the spray system at ground level to alert the operator if the system becomes clogged. This can save time and trouble, save spray material, and prevent accidental overspraying of peanuts. Figure 29 shows a portion of the surface of a 6350 metric-ton warehouse that became infested with red flour beetles less than 3 months after storage. The protectant was improperly applied by spraying into the elevator buckets as the peanuts were going into storage. The peanuts did not have enough protectant to effect control.

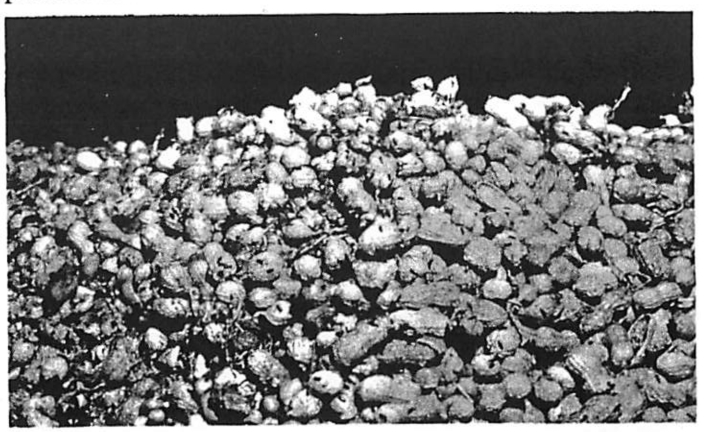

Fig. 29. Red flour beetle infestation on farmers stock peanuts in a 6350 metric-ton warehouse. (USDA photo.)

Premium-grade malathion and synergized pyrethrins have been approved for use on farmers stock peanuts, providing the residue on the shelled seed is within the established tolerance of 8 ppm for malathion, and 1 and 8 ppm for pyrethrins and piperonyl butoxide, respectively.

The rates of application, as recommended here, provide a theoretical residue deposit of 52.1 ppm for malathion on the farmers stock peanuts, but the insecticide residues on the seed after the shell is removed and discarded are well within the tolerance established under the Food, Drug, and Cosmetic Act. Residue analysis run on farmers stock peanuts immediately after treatment showed that only 70 to 85% of the actual malathion sprayed was recovered from farmers stock peanuts. The remainder is apparently lost during treatment. Also these residues decreased rapidly during the first few months of storage and at a more gradual rate thereafter.

The recommended formulations and quantities for the protective treatment of farmers stock peanuts are outlined in USDA Agriculture Handbook Number 584(1982). This publication is for sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

There may be several formulations of premium-grade malathion labeled for use on farmers stock peanuts. The emulsifiable concentrates may contain from 56 to 85% of premium-grade malathion. Follow label instructions for diluting the concentrate for that particular formulation, which should correspond to about 54 g active ingredient per metric ton of peanuts. Although malathion is more effective and economical than synergized pyrethrins, it is still far from being the perfect treatment. Through widespread use over the past 20 years, many of the stored-product insects have developed resistance to its use resulting in control failures. Research is being continued on the evaluation of other insecticides that may have more favorable physical and chemical properties than malathion. Several compounds show considerable promise but have not been labeled for use (Zettler, 1974a; Redlinger, 1976; Redlinger and Simonaitis, 1977).

Surface Sprays. The supplemental surface sprays consist of a series of insecticide applications over the top of bulk-stored peanuts or over the outside surfaces of stacked bagged peanuts. This series should be started before the insects have an opportunity to become active or abundant in the warehouse. The surface sprays help maintain an insecticide level that is toxic to invading insects.

Either wettable-powder or oil-base sprays can be used. Both types of surface sprays have given satisfactory control of moth populations when properly applied on a routine schedule. The nature of action of the 2 formulations against the moths is different, however, and should be understood by the operator and the warehouseman. The wettable-powder spray is not rapidly toxic to the larvae upon direct contact. The deposit left on the peanuts is slow acting but becomes more effective as the number of applications increases. The larvae eventually die after several days of contact with the treated peanuts. The moth larvae migrating to the surface usually remain there for 1 or 2 weeks before pupating and during this time contact enough deposit to kill most of them. The moth population is thus held in check. The frequent applications recommended are to refresh and build up the deposit, not to produce immediate kill of the larvae present by contact action of the spray at the time of application. It is considered better to apply a larger amount of insecticide initially within label recommendations so the deposit will be more effective against the insects from the very beginning of the spray program.

The toxicity of the oil-base formulation is quite rapid to larvae and adults on contact at the time the spray is applied, because the oil content of the spray facilitates penetration of the insecticide through the insect cuticle. The resulting deposit on the peanuts, however, is not as effective as that from the wettable-powder spray. The moth control produced by the frequent applications of the oil-base spray is the result of killing the exposed larvae and adults directly hit at each spraying. Other larvae accumulate on the surface layer following an application, and they are killed by the next application.

As soon as the warehouse is filled, level off the top of the piles to eliminate peaks and mounds. Insects tend to migrate to these high spots and when an infestation becomes established in the peanuts below the surface the heavy concentrations are harder to control. Also a level surface is easier to spray and helps to prevent the surface from rolling or shifting. After the surface of the peanuts has been leveled, lay boards over the surface to serve as a catwalk for the spray operators and inspectors. Walking over the surface of sprayed peanuts disturbs the continuity of the deposit of insecticide, leaving areas that are vulnerable to insect attack which reduce the effectiveness of the treatment. Move and spray under the boards each time a surface treatment is made. Always leave enough headspace above the peanuts to permit workmen to perform these operations efficiently and effectively.

Farmers stock peanuts in bags should be arranged in carefully prepared stacks not more than $10m^2$. The stacks should be completely surrounded by 1-m aisles to enable the operator to spray thoroughly the outside surface of each stack of bags. The aisles also make it possible for the warehousemen to inspect the peanuts more thoroughly.

Power equipment is best for applying surface sprays. Small-capacity garden-type compressed-air sprayers do not have agitators and are therefore not satisfactory for applying wettable-powder sprays. They are inefficient and too slow for treating the large surface area in many warehouses. The spray stream from power equipment reaches further and requires less walking. Power sprayers have greater capacity and a higher rate of delivery and can do the job in less time with a minimum of maneuvering over the top of the pile. They also have agitators, which are necessary for wettable-powder sprays and desirable for emulsions. They have a constant nozzle pressure, which provides uniform application. A piston pump is necessary for applying wettable powders, because the inert ingredients cause excessive wear to the gear pump. The operating pressure and nozzle opening combination should be adjusted to deliver a coarse, wet spray.

The first surface treatment to bulk-stored farmers stock peanuts should be applied as soon as all of the peanuts are in the warehouse and the surface has been leveled. The schedule for treatments with malathion and synergized pyrethrins is shown below.

Malathion Supplemental Surface Sprays. Mix wettable powder containing 25% of premium-grade malathion at the rate of 8.5 g in 81.5 mLof water for each m^2 of surface area to be sprayed. The malathion spray should be applied on the same day it is mixed and must be agitated during application. Make first application when bin or warehouse is filled or stack of bagged peanuts is completed.

Frequency of application:

Southeastern production area: Apply first surface treatment not later than the first week in October. Apply second treatment 1 month later, followed by subsequent treatments at 2-month intervals.

Southwestern production area: If necessary a second treatment may be applied in 30 days after the first application. Apply the next treatment about March 1, followed by subsequent treatments at 2-month intervals.

Virginia production area: Apply second treatment about April 1, followed by subsequent treatments at 2-month intervals.

Synergized Pyrethrins Supplemental Surface Sprays. Both wettable-powder and oil-base surface sprays containing synergized pyrethrins have been approved for use on farmers stock peanuts. The formulations and rates of application are:

Wettable Powder Formulation:

Mix 2.8 g of wettable powder containing 2% of pyrethrins and 20% of piperonyl butoxide in 81.5 ml of water and apply on each m^2 of surface area to be treated.

Oil Solution:

Pyrethrins	0.2% (1.6 g ai/L)
Piperonyl butoxide	2.0% (16 g ai/L)

Petroleum distillate (deodorized kerosene) - 97.8%

Application rate: 61 mL/m^2 of surface area.

The pyrethrins content of the oil-base spray should not be less than 0.2%; otherwise, the volume of spray required/m^2 of surface becomes excessive. It is imperative that a good grade of petroleum distillate be used; otherwise tainting of the peanuts may result. Suggested specifications for the oil are as follows (Anonymous, 1961):

Specific gravity at 15.6 C	0.77-0.80
Flash point (Tag closed cup)	60 C minimum, 71.1-76.7 C preferrable
Initial boiling point	187.8 C minimum
Distillation and point	254.4 C maximum
Unsulfonated residue	97% minimum
Color	Water white
Odor	Neutral, no kerosene, naphtha, or residual odor

In the southeastern USA production area, the first application should be made as soon as all of the peanuts are in and the surface has been leveled, but not later than October 1. Use double the concentration of insecticide as per labeled recommendations for the first surface treatment, as well as for the second, which should be applied 7 days later. This is to build up a large residue deposit quickly. Later applications should be made at the concentrations specified and should continue at 7-day intervals through November. After that, the applications can be spaced at 15-day intervals through the remainder of the storage period.

In the southwestern USA production area, south of the latitude of Waco, Texas, the first application using double concentration as per labeled recommendations should be made immediately after the peanuts are in or stacks completed in the warehouse. The second treatment should be made within 15 days at the specified concentration. The next treatment should be made about March 1. Use double the concentration of insecticides for the first surface treatment in the spring, and then continue the treatments at normal concentrations at 7-day intervals through March, and at 15-day intervals thereafter. In areas north of Waco, where previous records show little or no fall infestation, spray applications may be deferred until April 1, with 7-day intervals through April and 15-day intervals thereafter.

In the Virginia production area, apply first treatment at double concentrations as soon as warehouse is filled and leveled similar to that in the southwestern area. Apply second treatment about April 1, and continue at 7-day intervals through that month and at 15-day intervals thereafter.

In calculating the area of piles of bulk peanuts or stacks of bagged peanuts to be sprayed, use the actual surface as the area, for it will be larger than the floor area under the pile or stack.

Fumigants - Conventional. Fumigants are widely used for the control of stored-product insects. This usage is attributed largely to the adaptability of fumigants for treating infested commodities without having to disturb them in any way. As an example, peanuts may be fumigated wherever they are stored, such as in a silo, warehouse, rail car, motor truck, or any structure that can be made sufficiently gas tight for the required length of time. Infestation and damage can be controlled immediately without the necessity of moving or transferring the affected peanuts. Thus, fumigation is an important technique needed to control insects in stored peanuts. This is especially true since certain insects have developed resistance to malathion. It should be remembered that fumigation is effective only in tight structures such as concrete silos, steel buildings with sealed joints, tight wooden structures with concrete floors or by covering with gas tight tarpaulins or plastic film. The size, shape, and type of construction of the storage facilities create individual problems in applying and maintaining the fumigant in concentrations sufficient to control insects in peanuts. Insect kill is accomplished only during the exposure period. After ventilation, the fumigant diffuses away leaving little or no residue and offers no residual protection. Thus, reinfestation can quickly occur unless preventive measures are taken. The fumigation must be conducted only by experienced operators who know how to do the job effectively and safely. The fumigator should realize that any fumigant that is toxic to insects is also toxic to human beings, and that it is necessary to take every precaution to avoid undue exposure to fumigant gases.

Methyl bromide and phosphine are currently the only fumigants that are registered for use on peanuts. Residue tolerances have been established for these fumigants under Section 408 (Miller Amendment) of the Food, Drug, and Cosmetic Act. These tolerances are 200 ppm of inorganic bromide resulting from methyl bromide fumigation and 0.1 ppm of phosphine on raw agricultural products and 0.01 ppm on processed commodities. Limited studies have been conducted with other fumigants previously used on peanuts, to develop data for consideration in proposing tolerances that will permit their use.

The dosage rate for methyl bromide varies between 16 and 32 g/m^3 for bulk-stored farmers stock peanuts, depending on temperature, the condition of the peanuts, and the tightness of the structure. Fumigate peanuts for 24 hours at 16 C or above and aerate promptly to avoid excessive residues. In silos, the methyl bromide should be recirculated. The dosage rate for shelled peanuts in bags in warehouses is 24 g/m³ and under tarpaulins, 32 g/m³. Bagged, shelled peanuts in freight cars, truck vans, and containers require 4.8 kg in a steel car 15 m long, 4.1 kg for a 12-m length car, and 2.7 kg for a truck van or container. Shelled peanuts in 1.0 metric-ton container boxes require a minimum of 64 g/m³ whether they are fumigated under tarpaulins, in freight cars, or in truck containers. Peanuts may be fumigated with methyl bromide in vacuum chambers at the rate of 40 g/m³ for 3 hours at 13 C or above at 150 mm sustained vacuum. Before peanuts are fumigated for the third time with methyl bromide, a chemical analysis should be made to determine whether the inorganic bromide residue is approaching the tolerance of 200 ppm. A trial lot should be fumigated and analyzed to determine whether an additional fumigation will cause any objectionable odor, flavor, loss of germination, or will exceed the tolerance. The quality of shelled peanuts, including germination, odor, and flavor, may be adversely affected after each successive fumigation with methyl bromide at dosages effective against exposed insects (Leesch et al., 1979). Methyl bromide fumigation of peanuts reduced germination and quality in direct proportion to the dosage applied and the number of fumigations.

The dosage rate and minimum exposure requirements for phosphine fumigation of peanuts varies with the type of aluminum phosphide formulation, temperature, and storage structure. Aluminum phosphide is sold in various formulations such as pellets, flat and round tablets, long narrow and square crepe paper bags, and prepacs. Minimum exposure requirements for various temperatures are given in Table 1. The dosage rate for farmers stock peanuts stored in silos or warehouses is 3.5 tablets or 0.3 bags of aluminum phosphide formulation/m³. Introduce tablets or bags among peanuts by probing in a manner to provide uniform spacing between individual tablets or bags. Dosage may be reduced in a well-sealed building. The suggested rate of application for bagged, shelled peanuts stored in warehouses or atmospheric fumigation chambers is 1.2 to 2.1 tablets; 5.8 to 7.1 pellets; and 0.1 to 0.2 bags/m³ of space. The rate for shelled peanuts in bags or 1.0 metric-ton containers under or in gas-tight tarpaulins, plastic film, freight cars, truck vans, or bulk hopper cars is 5.8 pellets, 1.2 tablets, or 0.1 bags/m³. Care should be exercised that neither the aluminum phosphide formulations nor the residual dust from the reacted aluminum phosphide come in contact with any processed food or animal feed. Fumigated peanuts should be aerated for 48 hours before offering to consumer. Neither germination nor quality of peanuts is adversely affected by phosphine, regardless of the dosage or the number of times the peanuts are fumigated (Leesch et al., 1979).

Table 1. Minimum number of days exposure for phosphine fumigation of peanuts at temperatures indicated.

Temperature	Type of Formulation		
C	Tablets	Pellets	Bags or Sachets
		No. days	
5-9			14
10-15			7
12-15	5	4	
16-20	4	3	
16-25			4
21 or above	3	2	
26 or above			3

Fumigants - Modified Atmospheres. In recent years there has been considerable research emphasis placed on finding new and different approaches to insect control. One method that appears to offer promise in stored peanuts, leaving no residue, is the utilization of controlled or modified atmospheres. This procedure utilizes carbon dioxide (CO_2) or nitrogen (N_2) gas to displace the normal storage atmosphere to achieve a new atmosphere with oxygen levels of 8 to 14% or 1 to 2%, respectively. This approach, particularly with CO_2, has been extensively researched both in laboratory and field studies for the insects that attack peanuts (Press and Harein, 1967a, b; Harein and Press, 1968; Pearman and Jay, 1970; Jay et al., 1970; Slay et al., 1980). Also, there have been several excellent studies on the effects of these atmospheres on quality, processing, germination, and the associated microflora (Jackson and Press, 1967; Wilson and Jay, 1975, 1976; Wilson et al., 1975; Marzke et al., 1976).

Indications are that controlled or modified atmospheres can be used with excellent results, i.e., equal to the more conventional chemical fumigants, if the storage facility can be made sufficiently tight to retain the gas. The use of CO_2 is limited by several factors. It is rather slow acting and the gas must be retained for periods ranging from 4 days up to 2 weeks. It requires rather large concentrations (40-60% or more) to reduce the storage oxygen level to 8 to 14% and maintain it at this level for the required period. Sufficient supplies of CO_2 are available but arrangements must be made in advance for delivery of the quantities needed. However, the authors believe that the use of CO_2 and N_2 fumigations will eventually be an important tool of many warehousemen in their efforts to control insects.

Aerosol Space Treatments

Insecticidal aerosols are used as space treatments in warehouses and processing plants for the prevention and control of stored-product insects. Space treatments with aerosols are easily applied, and the results are immediately noticeable and appear somewhat spectacular. For these reasons, many warehousemen favor the use of space treatments. Space treatments can prevent stored-product insects from infesting and contaminating packaged food items. When used properly, they can prevent insects from migrating either from an outside source or from an infested stack of commodities stored in the same warehouse. Aerosol space treatments, however, will not replace the need for fumigation nor should they be confused with fumigation. They are not the same. Fumigation is used to eradicate an existing infestation, whereas space treatments are used to control migration or prevent infestation of stored commodities. Space treatments do not penetrate the peanut mass, and usually no effective residue remains to protect the peanuts between treatments. Generally, space treatments should be used as a supplement to, and not as a substitute for, protectants or fumigation.

In recent years, the trend has changed from high-volume aerosol applicators to ultra-low-volume aerosol generators. An aerosol generator must have the capability of handling various formulations at the proper output to produce the desired particle size and to effect distribution within the confined area with a minimum of residue deposited.

There are 3 general classes of aerosol generators; mechanical, thermal and vapor. Any type is suitable, providing it is capable of producing at least 90% of the aerosol particles in the size ranging from 1 to 10 μ with the remaining 10% under 15 μ mass median diameter. This is the optimum range for insecticide particles impinging on the insect's body. A 10 μ droplet free falls in air at the rate of about 18 cm per minute (Brett, 1974). Aerosol particles of a mass median diameter of 10 μ or less are necessary in obtaining good distribution throughout large areas. These small droplets provide the longest period of air transport with the least amount of insecticide deposited as residue on commodities. In addition, aerosol particles produced from insecticides having vapor activity are suspended in the air until they evaporate to produce a toxic vapor. Thus, even longer periods of air transport and less deposit of residue are provided. Aerosol generators used as "in-place" applicators should have a large-volume fan to provide air movement for dispersing the aerosol particles throughout the free air space in the warehouse or processing plant. Daily applications of aerosols help to control only the exposed insect population; therefore, migration of stored-product insects can be minimized only as often as the aerosol is applied. Aerosols should be applied at dusk or at dawn. These are periods when insect activity is greater and thus more insects exposed. Treatments should be made during the hours when buildings are unoccupied. Treated buildings should be closed and ventilation kept at a minimum during application of the insecticide. Lock all entrances, post caution signs, and do not allow unprotected workers to enter buildings while being treated. Follow all precautions and directions as printed on the insecticide label.

The only insecticides approved for use at present that can be safely used in, on, or around stored food items are synergized pyrethrins, malathion, and dichlorvos. Of these, synergized pyrethrins is by far the most widely used in aerosol form. Unfortunately, it provides the least amount of protection for long-term storage, and the available supply from 1 year to the next is unstable. Malathion is seldom used as an aerosol because many of the stored-product insects have developed resistance to it; and dichlorvos, while extremely effective, has only a limited number of labeled or approved uses. Residue tolerances have been established for dichlorvos at 2 ppm from postharvest application in or on nonperishable packaged or bagged raw agricultural commodities that contain more than 6% fat, and at 0.5 ppm for commodities that contain 6% fat or less, and in or on nonperishable bulk-stored raw agricultural commodities regardless of fat content.

Pesticide residues in food commodities always present problems. They must be considered from a health and safety point of view, and they are strictly controlled by law. There is considerable evidence that aerosol particle size has a profound effect on the extent of food contamination. Also, most aerosol uses require application on a regular, scheduled basis which could cause buildup of residues in commodities exposed to multiple applications. Aerosol application methods are effective but need further investigation.

Insecticide formulations recommended for the mechanical and thermal-type generators are as follows:

Formulation No. 1 (for use in mechanical generators):

	(Percent by Weight)
Pyrethrins	0.5
Piperonyl butoxide	5.0
Tetrachloroethylene	50.0
Deodorized kerosene	44.5

Mixing directions when formulated on the job:

	Liters
Concentrate containing 5% of pyrethrins and 50% of piperonyl butoxide	1
Tetrachloroethylene	3
Deodorized kerosene	4

Application rate:
1.7 mL/m^3 of free air space above the load.

Formulation No. 2 (for use in thermal-type generators):

	(Percent by Weight)
Pyrethrins	0.2
Piperonyl butoxide	2.0
Tetrachloroethylene	50.0
Deodorized kerosene	47.8

Mixing directions when formulated on the job:

	Liters
Concentrate containing 5% of pyrethrins and 50% of piperonyl butoxide	0.5
Tetrachloroethylene	3.0
Deodorized kerosene	4.5

Application rate:
4.2 mL/m^3 of free air space over the load.

Caution: Operators should be especially cautious to avoid exposure to and prolonged breathing of tetrachloroethylene fumes. The maximum allowable concentration has been established at 100 ppm (Anon., 1980).

There are only a few labeled uses for dichlorvos as a space treatment in warehouses and plants. One such labeled use is a polyvinyl chloride resin strip (approximately 25.4 by 6.4 by 0.6 cm) impregnated with 18.6% dichlorvos and 1.4% related compounds. One strip is spaced in the warehouse for every 28.3 m^3 of warehouse capacity. The degree of control is directly related to the tightness of the overhead space. The life of the strip is between 3 and 4 months. The resin strips offer greater potential for the small warehouseman who ordinarily would not want to purchase an aerosol generator. Another labeled use is ULD(R) v-500, a 5% dichlorvos mixture labeled for use only in Micro-Gen(R) aerosol applicators. Instructions for application and precautions in using should be followed as stated on the label. The rate of application should be between 35.3 to 70.6 mg ai/m^3 applied during the hours when buildings are unoccupied. Repeat treatment at weekly intervals during season of peak insect activity.

Other dichlorvos labels are Lethalaire(R) A-50 labeled for the control of peanut insects, Lethalaire(R) A-40 for the control of flying and crawling insects, and Lethalaire(R) A-41 for warehouse insect control. Each of the 3 formulations have a 20% mixture of dichlorvos in a pressurized metal cylinder. The cylinder is fitted with a nozzle and solenoid actuator valve that is controlled automatically by a timing device. The electrically operated system can be installed to dispense measured volumes of insecticide at predetermined times, such as when warehouses are normally closed. Each cylinder-nozzle unit, when activated for a period of 1 minute, will treat approximately 944 m^3 of warehouse space at the rate of 35.3 mg ai/m^3. Up to 60 units, enough to treat 85 km^3, can be controlled by one timer. The insecticide mixture is contained in the cylinder under pressure with a liquid propellant which is also the solvent for the insecticide. When the cylinder is activated the propellant becomes an insecticide-carrying gas which evaporates. The pressurized aerosol units are mounted in the overhead space above the peanuts as per manufacturer's instructions. In overfilled peanut warehouses where there is a limited amount of free air space, the number of units and their placement are very critical factors for proper distribution of the aerosol. Overspace exhaust ventilating fans must be controlled so that treated warehouses will not be ventilated for a minimum period of 4 hours. The rate of application is calculated on the amount of free air space above the peanuts. Daily applications of 17.7 mg/m^3 will control moths and other exposed stored-product insects, including those that are malathion-resistant (Zettler and Jones, 1977; Zettler, 1981). An example of the number of dead moths killed in a peanut warehouse is shown in Figure 30. Dichlorvos was applied daily as an aerosol and the moth infestation was brought under control in a short time. When units are properly installed and activated daily from the time the first load of peanuts is received, supplemental surface sprays should be eliminated. This reduces the amount of labor required for supplemental surface sprays and eliminates the large volumes of water that are applied for each treatment. The potential of mycotoxins developing should be substantially reduced because of the elimination of water sprays.

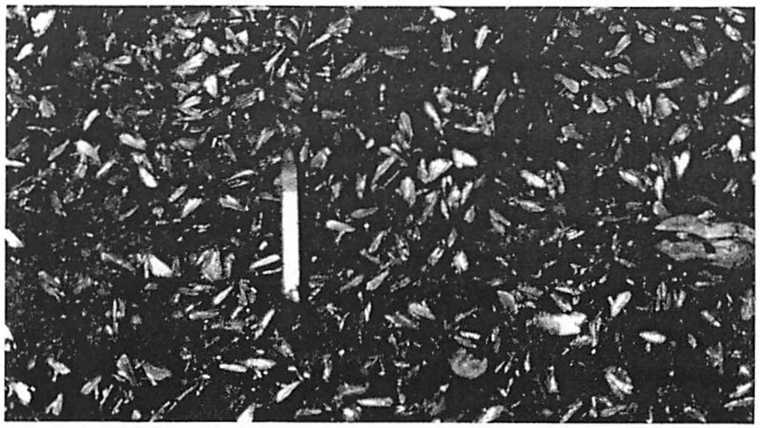

Fig. 30. Dead moths on a peanut warehouse floor following dichlorvos aerosol space treatment (paper match in center of picture for size comparison). (USDA photo.)

Insecticide Resistance

Malathion was registered in 1961 and immediately gained wide acceptance as a protectant for stored farmers stock peanuts. It remains today the most widely used protective treatment for stored peanuts. Synergized pyrethrins was registered for use about the same time but was not widely accepted by the industry because the longevity of residual effectiveness was somewhat shorter than that of malathion, it was more expensive, and the supply was not stable from 1 year to the next. Therefore, malathion became the insecticide of choice by warehousemen.

Stored-product insects attacking peanuts have been exposed to severe and long-term pressures from insecticidal treatments aimed at insect control to minimize damaged ("worm-cut") seed. As a result of the long-term selection pressures, some of these insects have become extremely resistant to insecticides, especially malathion, to the extent that control is often impossible with approved insecticides.

Insect resistance to malathion in recent years has become widespread and severe, resulting in control failures and substantial economic losses (Speirs et al., 1967; Zettler, 1974b, 1975). Even though high levels of resistance have been found, there is little cross-resistance to other insecticides (Speirs and Zettler, 1969; Zettler, 1974a; Zettler and Jones, 1977). The extent to which resistance can be overcome by increased dosages is severely limited by the level of residues acceptable, both domestically and internationally, on peanuts. Resistance up to 109-fold in the red flour beetle has been documented. Resistance in the Indian meal moth has increased so dramatically that it is now difficult to quantitate. Though it is known to exceed 206-fold for the larvae of most strains (Zettler et al., 1973), the true level of resistance cannot be determined. In most cases, when the Indian meal moth occurs in a storage facility, it cannot be controlled with malathion (Zettler, 1978). The almond moth shows lower resistance ratios than the Indian meal moth but is nearly as difficult to control owing to its high natural levels of tolerance to malathion (Zettler, 1978). These pests cause extensive damage to stored peanuts and have become a major economic threat to the peanut industry.

Temperature as a Control Treatment

The use of temperature extremes has been employed satisfactorily to prevent or control insect damage and infestation to stored peanuts. The use of refrigeration and its enhancement of maintaining commodity quality are well documented (Cotton and Frankenfeld, 1942; Thompson et al., 1951; Adler, 1960; Smith and Brown, 1961; Woodroof, 1966; Burrell and Laundon, 1967; Cline, 1970; Donahaye et al., 1974; Navarro, 1974; Smith, 1974; Mullen and Arbogast, 1979; Refrig. Res. Fd., 1980) and will not be further discussed. Ordinarily, high temperature is avoided during the drying and storage of nuts, but it has been reported that a temperature of 52 C for 6 hours destroyed insects in loose piles of dry peanuts without damaging the peanuts (Birdwell, 1918). Cotton et al. (1945) reported that temperatures of 49-54 C maintained in all parts of flour mills for 10 to 12 hours destroyed all insect life. Forced circulation of air was necessary to maintain this temperature throughout the treated area. As the insect pests of peanut shelling and processing plants are the same or similar to those found in the milling industry, the same regimes of heat should be effective.

Parasites, Predators, and Pathogens

The value of natural enemies of insect pests of peanuts has long been recognized, but their importance in the field has never been quantified. No use of these natural enemies has been made through augmentation or introduction. However, there is an ever-increasing volume of research on these natural enemies, particularly on the hemipterous bug, *Xylocoris flavipes*, and its potential for use (Simmons et al., 1931; Jay et al., 1968; Arbogast et al., 1971; LeCato and Davis, 1973; Press et al., 1973, 1974a,b, 1975, 1976, 1977, 1978; LeCato, 1975, 1976; Arbogast, 1975, 1976; LeCato and Collins, 1976; Arbogast, 1977; LeCato et al., 1977; Lum, 1977; Press and Flaherty, 1978; USDA, 1978).

The use of microorganisms as control mechanisms is also a viable field of research. The use of virus, bacteria, and protozoans is actively being investigated. Some microorganisms pathogenic to some stored-product insects have been reported: (1) nuclear polyhedrosis virus (Adams and Wilcox, 1968; Thompson and Redlinger, 1968; Hunter et al., 1973a,b); (2) granulosis virus (Arnott and Smith, 1968; Hunter, 1970; Hunter and Dexel, 1970; McGaughey, 1975); (3) cytoplasmic polyhedrosis virus (Smith, 1963); (4) iridescent viruses (Smith et al., 1961; Day and Dudzinski, 1966); (5) *Bacillus thuringiensis* (Berliner, 1915; Steinhaus, 1951; Steinhaus and Bell, 1953; Burgerjon and Yamvrias, 1959; Kantack, 1959; Yamvrias, 1962; Burges, 1964; Gibson and Wolf, 1964; Jafri, 1964; Laan and Wassink, 1964; Nwanze et al., 1975; McGaughey, 1975); (6) *Beauveria bassiana* (Steinhaus and Bell, 1953; Ferron and Robert, 1975); (7) *Beauveria tenella* (Ferron and Robert, 1975); (8) *Paecilomyces fumoso-roseus* (Ferron and Robert, 1975); (9) *Metarrhizium anisopilae* (Ferron and Robert, 1975); (10) *Nosema plodiae* (Kellen and Lindgren, 1968); (11) *Nosema heterosporum* (Kellen and Lindgren, 1974); (12) *Nosema whitei* (George, 1971; Milner, 1972; Burges and Weiser, 1973); (13) *Nosema invadens* (Kellen and Lindgren, 1973); (14) *Nosema oryzaephili* (Burges et al., 1971); and (15) *Sporomyxa tenebrionis* (Huger, 1967). However, only *Bacillus thuringiensis* has been registered for the control of the almond and Indian meal moths on peanuts, grain, soybeans, and sunflower seed.

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Chapter 15

GRADING, CLEANING, STORAGE, SHELLING, AND MARKETING OF PEANUTS IN THE UNITED STATES

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The entire production, marketing and processing system for peanuts in the United States is influenced by the price support program and the predominately edible use for peanuts produced in the country. Clearly defined official grading procedures for farmers stock peanuts (peanuts delivered from the farm) were developed for price support purposes, but they generally are the basis for price negotiations between the farmer and buyer. On the average, less than 20% of the peanuts produced in the USA are crushed for oil (USDA, 1979). Consequently, the grades for both farmers stock peanuts and shelled peanuts are intended to reflect the suitability of the peanuts for food.

The typical peanut handling, marketing and processing system for peanuts employed in the USA is diagrammed in Figure 1. Each stage of the system is discussed below.

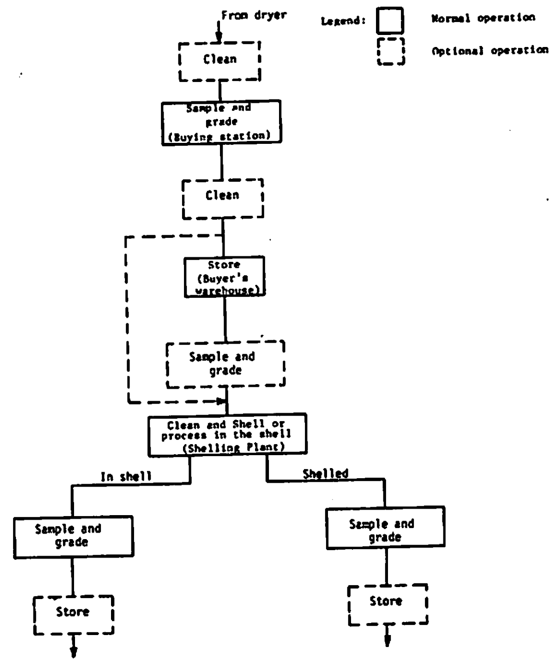

Fig. 1. Typical USA peanut marketing processing operations.