2 Biology, Behavior, and Ecology of Stored Grain and Legume Insects

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Stored grains and legumes are subject to insect infestation and deterioration from molds and bacteria. In 1990, postharvest losses in the United States were estimated to be $500 million per year (Harein and Meronuck 1991). The United States estimates that in developed countries the average minimum overall losses from biological degradation is 10% (National Research Council 1978), while in developing countries that estimate may be up to 20%. In sub-Saharan Africa losses are estimated to be around $4 billion a year (World Bank and FAO 2011). High environmental temperatures and moisture, along with dockage and broken kernels, provide conditions that accelerate mold and insect development within the grain mass, increasing grain losses. Storage infestations may originate in the field by highly mobile insects leaving the storage site and flying to grain standing in the field. They may also move to newly stored grain from fields and infested grain bins nearby. Insect populations can reach high levels when left unchecked in grain bins, subfloors, or aeration ducts, and in grain-moving equipment or discarded grain. These areas must be kept free of insects to reduce migration to newly harvested grain.

Insect movement within the grain mass is determined by seasonal conditions and grain temperature. During summer and fall, insect infestations will be found on the grain surface and distributed in clumps throughout the grain mass. In cold weather, especially in bins where the fines have not been redistributed or removed from the core, insects congregate at the center and lower portions of the grain and may escape detection until numbers increase. This is compounded by the fact that in cold grain (typically grain below 50 to 55^{0}F), insects are not mobile and are easier to miss in random sampling.

A major concern with the presence of insects is potential to vector disease organisms. Many stored-grain insects possess hairs and indentations on their exoskeletons that can act as mechanical vectors of pathogens. Maize weevils have been shown to carry numerous fungi species, including *A. niger, A. glaucus, A. candidus, Penicillium islandicum, P. citrinum, Paecilomyces, Acremonium, Epicoccum, F. semitectum*, and yeasts (Smalley 1989, Dix 1984). Smalley (1989) noted that they were particularly loaded with *A. flavus* and *F. moniliforme*. Dix (1984) found that adults did not suffer from aflatoxicoses despite carrying a high density of spores. Hairy fungus beetle has been reported to carry *Salmonella enterica* serovar Infantis and is capable of transmitting it over long distances (Hold et al. 1988). They are also known to feed on aflatoxin, a contaminant in peanuts and grain, with no apparent deleterious effects (Tsai et al. 2007).

Association with other fungi or fungal toxins has been found in other stored product insects including lesser mealworm and confused flour beetle with zearelenone (Eugenio et al. 1970) and confused flour beetle with *F. graminearum* and *F. tricinctum* (Wright 1973). Dunkel (1988) examined the effects of other toxins on black carpet beetle (*Attagenus unicolor*) and confused flour beetle and found that ochratoxin A, citrinin, rubratoxin B and patulin had little or no effect on growth of confused flour beetles and slightly affected larval growth of black flour beetles.

The most favorable grain moisture range for stored-grain insects is from 12 to 18%. In many cases, insect infestation amplifies mold problems in grain by exposing otherwise hidden endosperm surfaces to molds, transporting mold spores to new areas, and encouraging mold germination in microhabitats made moist by insect metabolic activity (Sinha and Wallace 1966). Insect and mold metabolic activity can raise grain temperatures to 43^0C (110^0F). Tsai et al. (2007) observed feeding behavior of hairy fungus beetles in laboratory experiments and noted that the bodies of the mold-feeding larvae were "always coated with fungal spores, especially when fed cultures of *A. flavus* and *P. purpurogenum*. Newly molted larvae and pupae were whitish and free of fungal spores on the surface of their bodies, but quickly covered once feeding resumed." This insect has been shown to feed on aflatoxin, with no toxic effect to the insect (Tsai et al. 2007).

Insect populations should be controlled before grain is damaged by insect boring, feeding, and mold germination. Grain should be inspected every 21 days when grain temperature exceeds 15°C (60°F). Plastic pitfall traps should be used to monitor insects and record the species and number. Grain temperatures should also be monitored. The number of insects in each trap should be recorded and charts constructed to track changes in population size. Increasing numbers of insects indicate that management tactics need to be changed to prevent grain-damaging infestation levels. Grain can be inspected by screening or sieving and searching screens for insects and by examining kernels for damage, checking grain for webbing, and investigating off-odors.

Some insects damage grain by developing inside kernels, feeding on the inner endosperm, and producing holes in the kernel through which adults exit. The entire life cycle (egg, larva, and pupa) takes place inside the kernel, and the insect can survive only when whole kernels are present. These insects are known as internal feeders or primary pests. Examples of internal feeders include maize weevil, rice weevil, granary weevil, lesser grain borer, bean weevil, cowpea weevil, and larvae of Angoumois grain moth.

Other insect species develop on the cracked or broken kernels and grain dust, which can be produced by harvesting or binning procedures. They can also enter the kernel through feeding damage created by internal pests. These insects are known as external feeders, bran bugs, or secondary pests. They include Indianmeal moth, psocids, grain mites, flour beetles, saw-toothed grain beetles, flat grain beetle, rusty grain beetles, and cadelle beetle.

The next category of storage insects is mold feeders, and although they are external feeders, they do not directly damage the grain through feeding. Instead, these insects contaminate the grain mass through their presence and metabolic activity. Metabolic activity generates heat and produces water through the process of condensation, which encourages mold growth and grain spoilage (Magan et al. 2003). The growth of insect populations in the vicinity of these hot spots can significantly reduce grain quality through metabolic wastes and contamination from body parts or fragments. Mold feeders usually indicate that grain is going out of condition and that some mold growth has occurred. Common mold feeders include foreign grain beetle, rusty grain beetle, hairy fungus beetle, and psocids.

Insects such as grasshoppers, wasps, stinkbugs, butterflies, ground beetles, and lady beetles have been observed in stored grain but do not feed on the grain. They are usually trapped in the grain during harvesting and binning or become trapped after flying into the bins. They do not damage grain and can be removed in the cleaning process. No insect control action is needed.

Insects damage grain by boring holes into the kernels and reducing grain quality through weight, nutritional, or quality loss; spreading and encouraging mold germination; adding to the fatty acid content of the grain; and leaving quantities of uric acid that cause grain rancidity. While feeding, insects also create fines and broken kernels that reduce airflow through the grain when aeration fans are used. This reduction in air flow can cause an increase in temperature, compounding the problem. In addition to the direct damage, the presence of insects in a grain sample can result in cash discounts for the grain.

Two live insects in 1,000 grams of wheat, rye, or triticale cause the grain to be graded as "infested," resulting in significant cash discounts to the seller. The presence of live insects does not affect the numerical grade of the grain. In corn, barley, oats, soybeans, and sorghum, the conditions required for grain to be graded as infested are different. Grain may be designated as infested if a 1,000-gram sample contains more than one live weevil, one live weevil plus any five or more other live insects, or no live weevils but 10 other live insects injurious to stored grain.

Insect tolerances are stricter in finished commodities such as flour or cornmeal. For example, the defect action level (or the maximum number of insects permitted before the item is considered contaminated) set by the Food and Drug Administration for insect and insect fragments in cornmeal is one or more whole insects (or equivalent) per 50 grams or an average of 25 or more insect fragments per 25 grams (Food and Drug Administration 2009).

Identifying the specific pest found within a sample is important because insects have different damage potentials, biologies, behaviors, growing temperatures, moisture requirements, and reproductive potentials. Insect species create different types of damage and have different activity periods. Identification of the insect is the first step in understanding and controlling insect problems. Knowledge of insect biology is necessary for integrated pest management programs. The following is a summary of the major insects that can be found in stored grains and legumes and a description of the biology, behavior, and ecology of each.

Stored Grain Insect Pests

Granary weevil *Sitophilus granarius* (L.)

Average minimum life cycle

38 days at 30°C and 70% relative humidity (RH).

Distribution

Worldwide, but primarily temperate zone, northern distribution.

Biology

Eggs – Up to 250 per female, average 200; internal feeder – eggs laid inside the grain.

Larvae – Within grains; can survive at least 10 weeks at 5°C.

Adults – 2 to 3 mm long (⅕ inch), flightless; easily overwinter in unheated buildings and bulk grain.

Granary weevils feed on unbroken and broken grain kernels, including barley, buckwheat, corn, millet, oats, rice, rye, and wheat. They have been reported from birdseed, sunflower seeds, and chestnuts (Lyon 2011). They do not do well in finely ground material such as flour but can survive on many manufactured cereal materials such as kibbled pet food, macaroni, spaghetti, cereal, and noodles. If the grain is milled into a particle size smaller than needed for larval development, oviposition will not occur. Generally one to two eggs are oviposited into the endosperm or germ of a single kernel. When more than one egg is oviposited, only one adult will emerge from a single grain due to larval cannibalism. Eighty percent of eggs hatch when conditions are good; eggs laid by older females have lower hatchability rates (Arbogast 1991). Oviposition rate increases as food availability increases, indicating that in a grain bin with unlimited food supply, oviposition will be at the maximum rate (Fava and Burlando 1995).

Larvae are creamy white with a tan head and legless. They spend their entire lifetime within the kernel, hollowing out the kernel as they burrow. Development from egg to adult at 21°C (69.8°F) ranges from 57 to 71 days, depending on grain moisture (Khan 1948, Richards 1947). At warmer temperatures, development times are shorter. For instance, at 25°C (77°F), development is complete in 45 days. There are four larval instars, the last one forming a pupal cell out of frass, flour, and larval secretions at the end of the burrow. Newly emerged adults do not immediately leave the kernel. They often remain inside the kernel while their adult cuticle hardens and may feed there for up to a week. Adults live seven to eight months, moving around the grain mass throughout the day. There can be four generations per year. Adults will feign death when disturbed.

Granary weevils are unable to fly and generally do not infest standing grain. Their primary mode of locomotion is walking, but they are easily distributed when infested grain is transported from one site to another through infested harvesting equipment, auger systems, legs, bins, trucks, or barges.

Granary weevils are shiny reddish-brown and similar in appearance to maize and rice weevils. All weevils have a prolonged head or snout, which is distinctive and separates them from other beetles. The adults can be identified by the presence of elongated pits on the thorax, and also by the absence of flight wings and four light-colored markings on the wing covers. They are tolerant of low temperatures and cold climates and are seldom found in semitropical areas. They are 3.1 to 4.8 mm (⅛ to 3⁄16 inch) in size, depending on the size of the grain fed in as larvae.

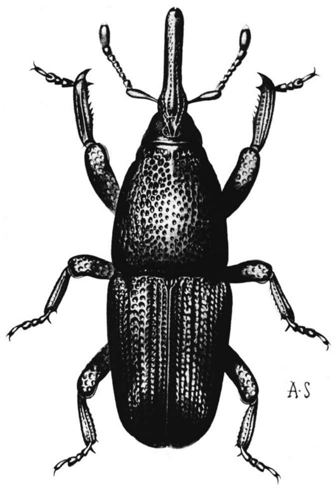

Figure 1. *Rice weevil (from Linsley and Michelbacher 1943) (3 to 4.6 mm long)*

Rice weevil
Sitophilus oryzae (L.)

Average minimum life cycle

25 days at 29.1˚C (84.4˚F) and 70% RH.

Distribution

Tropical and temperate areas; least cold tolerant of all the grain weevils.

Biology

Eggs – Laid in grains in the field and storage.

Larvae – Feed internally within a grain kernel.

Pupae – Found within the kernel.

Adults – Fly, 3⁄32 inches long; normally do not overwinter in temperate areas unless in warm grain.

Rice weevils (Figure 1), like granary weevils, are pests of whole grains such as wheat, corn, barley, sorghum, rye, oats, buckwheat, cottonseed, and rice. Like granary weevils, they prefer whole grains but have been reported to feed on beans, nuts, processed cereals, spaghetti, macaroni, pasta, cassava, birdseed, nuts, pet food, and decorative Indian corn. They are internal feeders, and the entire development cycle occurs within the kernel. Eggs are laid when the environmental temperature is between 13.0 and 35.0˚C, with maximum oviposition occurring between 25.5 and 29.1˚C (77.9˚F-84.4˚F) (Birch 1945a). Usually, one small white egg is deposited into a cavity created by the female. The cavity is about as deep as the length of the snout of the weevil. After laying the egg, she slowly withdraws the ovipositor, filling the cavity with a gelatinous material that hardens as a plug to protect the newly laid egg. Egg hatch generally takes five days, and hatchability is about 75% (Arbogast, 1991). Maximum oviposition occurs one to two weeks post-adult emergence.

Developmental times from egg to adult range from 25 days at 29.1˚C to an average time of 35 days at 27˚C (80.6˚F)(Arbogast 1991; Sharifi and Mills 1971a) with maximum developmental times at 18.2˚C taking 94 days if one larvae is in the kernel. If three eggs are oviposited into a kernel, the developmental period increases to 110 days at 18.2˚C (64.8˚F) or 36 days at 29.1˚C (84.4˚F) (Birch 1945b), probably as a result of competition for food. Lower grain moisture content (about 11%) will add four to five days to the normal developmental period (Arbogast 1991). There are four larval instars, each about five days, and a pupal period of five days. Adults emerge and may remain in the kernels up to five days and live on average about three months, although some have been known to live over a year.

Rice weevils can fly and easily distribute themselves throughout a storage facility. Because of their flight ability, they may also infest grain while it is still standing in the field, especially if the harvest is delayed and the temperatures are mild. Because of this fact, it is important to inspect incoming loads for this pest, even if the loads are coming directly from the field. Although very similar in appearance to the other grain weevils, rice weevils are 2 mm in length (generally slightly smaller than maize weevils), have small longitudinally elliptical punctures on the thorax except for a smooth narrow strip extending down the middle, and possess red/yellow oval-shaped markings on the forewings. They are less tolerant of cold temperatures than the granary or maize weevil. Freezing is an easy method to control this pest. Rice weevils have a wide distribution, including both temperate and tropical areas.

Maize weevil
Sitophilus zeamais Motschulsky

Average minimum life cycle

26 days at 30˚C (86˚F) and 75 to 76% RH.

Distribution

Tropical and temperate areas, warm humid areas where corn is grown are favored but can be found in colder climates like Canada.

Biology

Eggs – 300 to 400 per female; laid in cereals grains in the field and storage.

Larvae – Feed in grain.

Pupae – Found within kernel.

Adults – 3 to 3.5 mm long (⅛ to 3⁄16 inch).

The maize weevil has a host range similar to the rice and granary weevil, and although it is commonly found on maize, it can feed on most cereal grains, including wheat, barley, sorghum, rye, and rice. Maize weevils prefer whole grains but have been reported to feed on many processed grain products including pet food and pastas. They have a wider tolerance for host moisture content, even feeding on stored apples. Typically one egg is laid per kernel (Lathrop 1914; Gomez et al. 1982), but on occasion more than one adult may emerge. If multiple eggs are laid, larvae compete with active aggression among the seed occupants (Guedes et al. 2010). Immature survivorship is only 18% (Throne 1994). Eggs are not laid if relative humidity is below 60% (Arbogast 1991). Infestations of immatures can be determined by staining the kernels to readily see the oviposition plug place in the egg cavity to protect the immature weevil. The life cycle of the maize weevil averages 35 days at 27˚C (80.6˚F) (Sharifi and Mills 1971b) with a maximum development time of 110 days at 18˚C (64.4˚F). Survivorship of all immature life stages is highest at 25˚C (77˚F) (Throne 1994). Minimum temperature for development is 13˚C (55.4˚F). The egg, larva, and pupa stages are rarely seen because they are confined to the inside of the grain kernel. Eggs are creamy white and barely visible to the naked eye. Hatchability is about 90%, and first instar larval mortality can be as high as 30% at 50% RH (Arbogast 1991). Larvae are creamy white with a brown head and legless. They go through four instars before pupating within the kernel. During the four to five months of cold winter weather, the larva remains within the kernels. There are generally four to five generations per year in most grain storage facilities. Heated storage buildings may house twice that many generations. Adults live about four to eight months.

Adult maize weevils are slightly larger — 2.5 to 4.0 mm (0.1 to 0.16 inch) — than rice weevils. They have circular punctures on the thorax compared to oval punctures on the rice weevil and more distinct colored spots on the forewings. Maize weevils are stronger fliers than rice weevils.

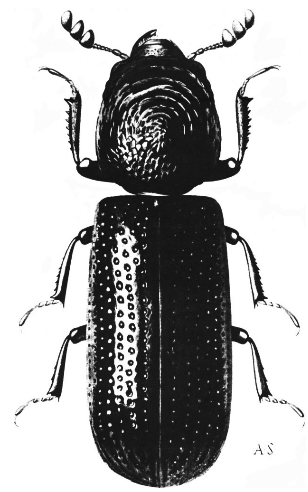

Figure 2. *Lesser grain borer (from Linsley and Michelbacher 1943) (2 to 3 mm long)*

Lesser grain borer
Rhyzopertha dominica F.

Average minimum life cycle

25 days at 34˚C (93.2˚F).

Distribution

Worldwide; both adults and larvae are voracious feeders.

Biology

Eggs – 300 to 500 per female, laid on grain surface, often in groups.

Larvae – Eat into grain and feed on grain dust.

Pupae – Usually form cell inside grain, but may leave grain to pupate in grain dust; stage lasts five to eight days.

Adults – Voracious feeder, reddish brown, bullet shaped cylindrical body, clubbed shaped antennae (Figure 2).

The lesser grain borer is a small (3 mm [⅛ inch]) black-brown, highly destructive insect related to some wood boring beetles. It is easily identified by its shape. The body is slim and cylindrical, similar in shape to a bullet. The head is tucked up under the thorax and the hood shaped rounded neck shield. The hood is covered with pits that get gradually smaller toward the posterior. The 10-segmented antenna is clubbed with the last three segments forming a loose club.

The eggs, up to 500 per female, are laid outside the whole kernels and young larvae bore inside. Moisture content of the grain is critical to oviposition and development. Wheat with moisture content below 8% is not suitable to oviposition. Egg development takes 32 days at 18.1°C (64.6°F) but only five days at 36°C (96.8°F). The effect of this temperature range is even more subtle for larval development. A 3-degree increase in temperature (25 to 28°C) (77 to 82.4°F) results in a 17-day increase in larval development. Larvae are white and c-shaped. They have four to five larval instars if on whole grain, or two to seven (usually three to four) if feeding on whole meal. The limiting temperatures for larval development are 18.2°C (64.8°F) and 38.6°C (101.5°F) (Arbogast 1991). Both the larvae and adults are voracious feeders and leave fragmented kernels and powdery residues. The larvae may complete their development in the grain residue. Adults usually remain within the kernel for a few days prior to emergence. Mated females start ovipositing about two weeks later and continue for about four months.

Lesser grain borers infest all types of cereal grains, but prefer wheat, corn, or rough and brown rice. Tropical in origin, possibly from the Indian subcontinent, they also feed on peanuts, nuts, birdseed, cocoa beans, and beans as well as processed products such as macaroni, tobacco, and dried spices. They do well in the flour created by the initial infestation of beetles. Grain infested with lesser grain borer has a characteristic sweet and slightly pungent odor. This odor contains the male-produced aggregation pheromone that has been demonstrated to be an effective lure for use in insect traps. The lesser grain borer flies, but because of its size it is easily caught by air currents. Flight times are influenced by season and light conditions (Potter 1935). For example, peak flight activity occurs during May and again in September through October (Toews et al. 2006). They don't appear to infest standing grain (Hagstrum 2001) but may survive outside the grain environment on seeds and acorns of other plants (Jia et al. 2008).

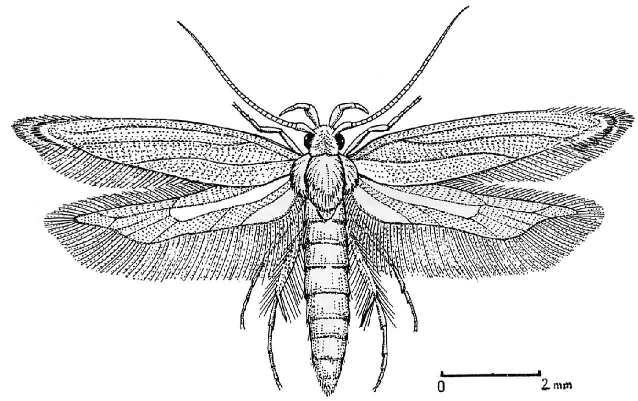

Figure 3. *Angoumois grain moth (from Hill 2002) (6 to 9 mm long)*

Angoumois grain moth *Sitotroga cerealella* (Olivier)

Average minimum life cycle

35 days at 30°C (86°F) and 75 to 76% RH.

Distribution

Tropical grains (maize, paddy, sorghum); attacks before harvest.

Biology

Eggs – 40 to 150 eggs laid on grain surface.

Larvae – Bore into grain, stay until pupation.

Pupae – Form in grain.

Adults – Non-feeding, short-lived, wingspan 5 to 6 mm (½ to ⅝ inch), dark spot on wings, long fringe on fore and hind wing, hind wing margin taper to a fingertip projection on tip (Figure 3).

The Angoumois grain moth was a major pest of crib-stored corn, but modern harvesting and storage procedures have significantly reduced losses due to this insect. It usually does not cause major damage to shelled corn, although in southern areas of the

United States, it can occasionally be a major problem, even in shelled corn. It requires whole grain for development, and is commonly found in corn, wheat, sorghum, peanuts, rice, and pearl millet, although it has been found as a museum pest feeding on dried plant material in a herbarium (Grabe 1942). The moth is more sensitive to low temperatures than other stored product moths and, as a result, is not common in unheated structures in the northern United States. They may be found coexisting with sawtoothed grain beetles, but if grain is infested with other internal feeders, such as maize weevil and lesser grain borer, Angoumois grain moth populations will be suppressed.

Adults are short-lived, do not feed, and are attracted to light. Oviposition occurs on the exterior of the seed, usually during the overnight hours (Cox and Bell 1991). As the larvae within the eggs mature, the eggs darken. Egg development can last 5 to 6, 6 to 7, or 10 days at 30°C (86°F), 25°C (77°F), or 20°C (68°F), respectively (Boldt 1974; Cox and Bell 1991). Eggs can hatch at temperatures as low as 12°C and as high as 36°C. Larvae are 5 mm (¼-inch long) and are yellow-white with brown heads. Larvae spend their entire lifetime within the kernel. In cold climates, larvae become dormant for four to five months. Pupation occurs within the kernel, lasting 8, 10 to 12, or 20 days at 30°C, 24°C to 27°C, and 20°C, respectively. Adults are short-lived, generally less than one week. Minimum temperature for population development is 16°C, optimum development occurs at 30°C, and maximum temperature for population development is 35°C to 37°C (Cox and Bell 1991).

Cowpea weevil *Callosobruchus maculatus* (F)

Average minimum life cycle

21 days at 30°C (86°F) and 70% RH.

Distribution

Worldwide, on legumes (pulses) both in store and in the field before harvest.

Biology

Eggs – Laid in pods before harvest or among seeds in storage.

Larvae – Enter and feed within one seed.

Pupae – Form in seed, which then shows characteristic "window" at seed exterior.

Adults – Non-feeding, short-lived (10 to 14 days), basal segments of antennae are reddish yellow, remainder of segments darker.

Cowpea weevils are not true weevils (they lack a snout) although they are weevil-like. Adults are reddish brown elongate beetles, about 3 mm (⅙ to ⅛ inch) in length (Texas AgriLIFE Extension 1999). They have two blackish red spots on the wing covers, which are short, not completely covering the abdomen. The exposed portion of the abdomen also has two blackish spots visible.

They infest stored legumes, including cowpeas (black-eyed peas), dried peas, chickpeas, lentils. These crops bring in more than 90 million dollars into the U.S. economy for the 1 million metric tons harvested each year. Tropical and subtropical in origin, they are commonly associated with legumes both in the field and in stored and packaged beans worldwide. They do not infest other cereal grains. Six to seven generations per year may occur under ideal storage conditions. They will feign death if disturbed, sometimes not resuming movement for 5 minutes. Males and females can be easily distinguished in the adult form. Females possess dark stripes on the sides of the enlarged plate covering the tip of the abdomen and are dark brown or almost black in coloration compared to the light-brown males.

Unlike other stored product insects, adults of this beetle can be found in two morphological body forms: one with wings and capable of flight, and the other without wings and flightless. The flying form is produced when larval rearing conditions are crowded, or in continuous light or dark (such as in storage), high environmental temperature, or low moisture content (Utida 1972; Beck and Blumer 2011), conditions often found in storage. In storage, the flightless form is common. The weevils breed on stored seeds while conditions are optimum. As the population grows and conditions become unsuitable, the winged form appears and disperses to breed on growing seeds in the field. Adults often are found in the field on flowers in the spring. Winged females oviposit on beans in the field and the resulting larvae are transported into storages at harvest. Adults that emerge from these larvae are flightless (Arbogast 1991).

In addition to morphological differences between the two flight forms, there are physiological and behavioral differences. Females of the flightless form lay more eggs, and those eggs have a different hatchability than females that fly. For example, at 15°C (59°F) flightless females lay 56.2 eggs compared to 20.0 eggs for flying females, whereas at 35°C (95°F), flightless females laid 77.1 eggs compared to 36.6 eggs for flying females (Utida 1972). Egg hatchability increases from 45.9 to 64.1% for flying versus flightless females at 15°C (59°F) but decreases from 22.5% (flying) to 1.8% (flightless) at warm temperatures at 35°C (95°F). Flying form females emerge with immature ovaries and oviposition is delayed three to four days. They withstand cooler temperatures and require higher humidity. Flying form adult longevity is twice as long as the flightless form.

Fecundity depends on the host, with poor oviposition on lentils (23 eggs per female) to optimal oviposition on broad beans (110 eggs per female) (Utida 1972). Females lay eggs on the outside of the seed and newly emerged larvae bore inside, multiple larvae inhabiting a single seed. Larvae are white and c-shaped. Damage occurs due to larval feeding. Larvae burrow into the seed and feed on the embryo and endosperm until pupation. Characteristic feeding includes larvae feeding very close to the surface of the bean, leaving a thin covering, often called a window, that is about 1 to 2 mm across. Average developmental periods at 28°C (84.4°F) and 75% RH range from 26 days on black-eyed cowpeas to 66 days on lentils.

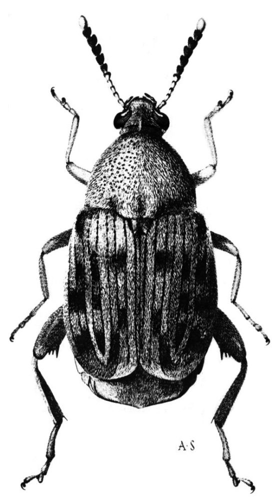

***Figure 4.** Bean weevil (from Linsley and Michelbacher 1943) (2 to 3.7 mm long)*

Bean weevil (dried bean weevil, common bean weevil) *Acanthoscelides obtectus* (Say)

Average minimum life cycle

28 days at 30°C (86°F) and 70% RH.

Distribution

Worldwide, primarily on common bean (*Phaseolus vulgaris*) but probably could be found on other species of *Phaseolus*. Found both in storage and in the field before harvest.

Biology

Eggs – Laid in pods before harvest or among seeds, maximum 70 to 75 eggs per female.

Larvae – Enter and feed within one seed.

Pupae – Form in seed, which then shows characteristic "window."

Adults – Non-feeding, short-lived, 3 to 5 mm long, grey beetle with short hairs on thorax, antennae have sawtooth like segments (Figure 4).

Bean weevils are not true weevils because they do not have a snout like rice or maize weevils. These beetles are small (3 to 5 mm (⅛ inch)), grayish-brown in color, oval in shape, and may be identified by brown or grayish spots on wing covers and fine yellow-orange hairs on the thorax. Bean weevils develop on the mature bean pods in the field but will also infest beans in storage facilities. They can be found worldwide, but are most common in subtropical areas. They develop primarily on common bean but have been found on other beans. This insect is also capable of feeding and reproducing on fungi (Sinha, 1971).

During her lifetime, a female may lay up to 70 eggs. Multiple whitish eggs are laid loosely on a single bean pod or in pod cracks (Godrey and Long 2008) and multiple larvae may emerge from a single bean, unlike many storage insects where just one insect emerges per seed. The first instar grub-like larva bores into the bean and causes the damage. Immature bean weevils suffer high mortality. At 25°C (77°F), 58% mortality has been reported (Arbogast 1991). Development can occur between 15 and 35°C (59 to 95°F) as long as the humidity is not too high or too low (Howe and Currie 1964; Arbogast 1991). Development is fastest (32 days) at 29°C (84°F), but may take as long as 92 days at 18°C (64.4°F).

Adults do not feed. When the product becomes heavily infested, adults will leave the beans and crawl up the walls of the storage facility or fly around, searching for fresh product to infest. Like many related species, bean weevils will feign death when disturbed. The insect produces a sweet "fruity" pheromone that gives cultures of newly emerged adults a pleasant smell. This insect can be controlled in packaged items in smaller quantities by heating the beans to 54°C (130°F) for 30 minutes to kill developing larvae within the kernels.

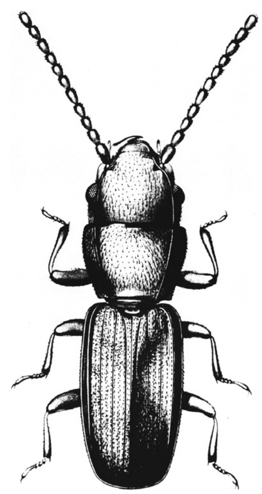

Figure 5. *Rusty grain beetle (from Linsley and Michelbacher 1943) (1.6 to 2.2 mm long).*

Rusty grain beetle *Cryptolestes ferrugineus* (Stephens))

Average minimum life cycle

21 days at 35°C (95°F).

Distribution

Worldwide; normally a secondary pest, but may attack damaged whole grains.

Biology

Eggs – 200 to 500 eggs may be laid, often in splits or cracks in grain.

Larvae – Prefer to feed on or near endosperm, particularly if grain is attacked by fungi.

Pupae – Create cocoon in the food material with silk.

Adults – Feed, fly, and can live six to nine months.

The rusty grain beetle (Figure 5) has a worldwide distribution and is often found in stored grain in the northern United States and Canada. Adults are cold-hardy and fly well in warm temperatures. This insect prefers high moisture grain or moist, decaying food. It has been recorded from wheat (bran, germ, and flour), rye, corn, rice, oats, barley, oilseeds, cassava root, dried fruits, and chilies, although the preferred host is wheat and development is optimum on this grain. Larvae feed preferentially on the germ of the whole kernels, but they also feed on the endosperm and sometimes hollow out the entire kernel. They cannot attack undamaged grains, although imperfections resulting from handling may permit feeding. Developmental period is shortest and oviposition is higher as cracked grain particle size increases (Sheppard, 1936; Throne and Culik, 1989). Mold growth promotes larval development with development shortest (22 days) on *Trichothecium roseum* (Persoon) Link *ex* S. F. Grey and *Fusarium moniliforme* Sheldon resulting in the longest developmental period (34 days) (Sinha 1965; Arbogast 1991).

Adult rusty grain beetles are reddish brown and about 1.5 to 2 mm (0.05 to 0.08 inch) in length. They have very distinct long, beaded antennae that project forward from the head in a characteristic v-shaped pattern. Adults are strong flyers, and especially prone to flight in warm weather. Females deposit eggs (200 to 500) loosely in the grain mass or in cracks or furrows in the grain kernel. They are white, oval, and 0.5 to 0.8 mm (0.02 to 0.03 inch). Unlike many stored product insects that have a distinct peak in oviposition, rusty grain beetles have a slight decline toward the end of their lifecycle (Arbogast 1991). Oviposition continues for up to 34 weeks, with average reported fecundity of 242 eggs per female (Davies 1949). Eggs hatch in three to five days at 30°C (86°F). Larvae — 3 mm (⅛ inch) — are creamy white and somewhat flattened. The head and a forked process on the posterior end of the larvae are slightly darkened. Larvae, as well as adults, are cannibalistic, consuming eggs, prepupae, and pupae (Sheppard 1936). There are 4 larval instars. The last one constructs a silk cocoon, often located within damaged kernels. The larval period lasts 32 to 37 days at 28.3°C (82.9°F) and the pupal stage lasts 5 days on corn meal. Development will not occur in very dry grain (moisture content less than 12%; RH less than 40%) (Canadian Grain Commission 2009). Adults emerge from seed 5 to 7 days after pupation. Temperature range for development is 17.5°C to 20°C (63.5°F to 68°F) to 40.0°C to 42.5°C (104°F to 108.5°F) with minimal development time at 35°C (95°F) at 21 days.

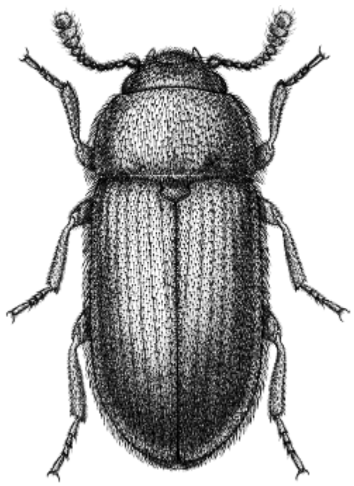

Figure 6. *Hairy fungus beetle (from Bousquet 1990) (2 to 4.3 mm long).*

Hairy fungus beetle *Typhaea stercorea* (L.)

Average minimum life cycle

15 days at 30°C (86°F) and 80 to 90% RH.

Distribution

Worldwide; commonly associated with moldy grain.

Biology

Eggs – Up to an average of 128 per day; laid singly in food.

Larvae – Mature larvae are white/pale brown, 4 to 4.5 mm.

Pupae – No pupal chamber built, pupate in food.

Adults – Broadly oval in shape; brown; 2 to 3 mm long (1⁄10 inch) with hairs on wing covers arranged in rows (Figure 6). Can fly and crawl into storage areas (as well as between storage areas).

The hairy fungus beetle is brown with a distinct three-segmented clubbed antenna. It has short stout hairs on the wing covers that are arranged in lengthwise rows down the back. It prefers to feed on mold and is a good indicator of moldy food. Larvae are whitish to pale brown, 4 to 4.5 mm (1⁄6 inch) long (Mason 2008). Dark projections at the tip of the abdomen are similar to those found on flour beetle larvae. Adults are strong fliers and often move into grain storages, railcars and food facilities by flight. The presence of this insect is a good indicator of grain going out of condition and probably indicates that mold is present in food. They are attracted to hot spots within the grain mass, and their metabolic heat and fecal material can contribute to the heating of a grain mass (Sinha and Wallace 1966; Tsai et al. 2007).

Tsai et al. (2007) determined that within a 24-hour period, females lay 128 eggs on *Aspergillus flavus*, 89 eggs on *Eurotium rubrum,* and 42 eggs on *Penicillium purpurogenum*. Eggs were laid singly on the fungal colony surface or embedded in the fungal mycelium. Larval development time at 30°C is shortest on *A. flavus* (181 hours) and longest on *E. rubrum* (333 hours) and *P. purpurogenum* (344 hours). The pre-pupal period is about 1 day and the pupal period is about 2 to 3 days (Tsai et al. 2007). The total developmental period may range from 15 to 107 days at 30°C to 15°C (86°F to 59°F) and 70 to 90% RH (Jacob 1988), and 9 to 25 days at 30°C (86°F) and 72% RH (Tsai et al. 2007). When larvae and adults feed in fungal masses, they quickly become covered with spores. Of greatest concern is that hairy fungus beetles can consume high levels of aflatoxin produced by *A. flavus* and show no detectable deleterious effects. It is possible that they are excreting the aflatoxin, which could indicate the ability to translocate aflatoxin.

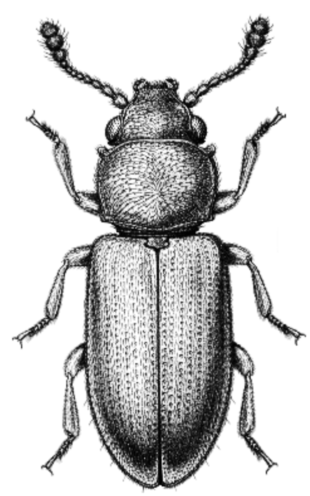

Figure 7. *Foreign grain beetle (from Bousquet 1990) (2 to 2.3 mm long).*

Foreign grain beetle *Ahasverus advana* (Waltl)

Average minimum life cycle

22 days at 27˚C (80˚F).

Distribution

Worldwide; primarily a secondary feeder, an excellent indicator of grain going out of condition due to the presence of mold.

Biology

Eggs – Deposited singly or in clusters.

Larvae – Feed on mold on grain, require high humidity for growth.

Pupae – Enclosed in chamber constructed of cemented food particles.

Adults – Feed on mold on grain, identified by bumps just behind the eyes and three-segmented antennal club (Figure 7).

The foreign grain beetle is easily identified by two bumps on the elytra just behind the eyes. It is light brown with antennae that terminate in a three-segmented club. It has a worldwide distribution and has been found in many commodities including raw grains and cereal products, peanuts, oilseeds, dried fruit, and spices. It prefers commodities that are moldy and is able to survive on mold cultures alone. It can consume several different fungal organisms, many common in stored grains (Shayesteh et al. 1989; David et al. 1974). Population development, specifically larval growth, requires high RH (92 to 75%), and none survive at 58% RH (David and Mills 1975).

Females do not oviposit continuously throughout life; rather, they start laying 3 to 4 days post-emergence and alternate 20- to 30-day oviposition bouts with 5- to 23-day non-ovipositional bouts. There are generally two to four rounds of ovipositional and non-ovipositional bouts. During an ovipositional bout, females usually lay 1 to 4 eggs singly or in clusters of 2 to 3 eggs per day but may lay up to 8 to 12 eggs per day on occasion (Arbogast 1991; David and Mills 1975). There are two peaks in oviposition during a female's lifetime; during the first 2 weeks and during the 4th month. At 27˚C (80˚F) eggs hatch in 4 to 5 days. Larvae feed within the food mass, progressing through 4 to 5 larval instars for about 2 weeks (11 to 19 days), after which they construct a pupal chamber by cementing food particles together and attaching themselves to the chamber with anal secretions (David and Mills 1975). Pupation lasts 3 to 5 days. Adult longevity varies depending on mating status; unmated males and females live 275 and 301 days respectively, while mated males and females live only 159 and 208 days, respectively.

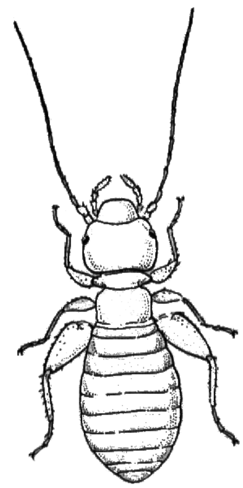

Figure 8. *Psocid (from Michelbacher 1953) (0.9 to 1.2 mm long).*

Psocid (also called booklice) *Liposcelis spp.*

Common Species in the U.S.

Lepinotus reticulatus*, *Liposcelis bostrychophila*, *Liposcelis brunnea*, *Liposcelis corrodens*, *Liposcelis decolor*, *Liposcelis entomophila*,** and ***Liposcelis paeta (Throne et al. 2006).

Average minimum life cycle

16.1 days at 35˚C (95˚F) and 75 to 80% RH for *Liposcelis decolor* to 24.6 days at 32.5˚C (90.5˚F) and 75% RH for *Liposcelis brunnea*.

Distribution

North America and Europe. Not injurious to stored grain. Common when moisture content or humidity is high.

Biology

Eggs – Oval translucent eggs are laid singly (up to 75 eggs in a lifetime for *L. bostrychophila*) 100 to 200 per female for other species.

Nymphs – No larval stage; young resemble adults

Adults – *L. bostrychophila* adults live an average of 3 months at 30°C (86°F); however, some species live up to 6 months. Some species are winged, but most are wingless (Robinson 1991).

Typical of many stored product insects, these soft-bodied insects have no larval stage. Rather, the young resemble the adults, but are smaller and paler in color. Psocids feed on a variety of animal and plant matter, including fungi, but do not actually damage grain. This insect reproduces by obligatory thelytokous parthenogenesis (only females are produced and no mating is required to produce offspring), which allows their populations to grow rapidly under certain environmental conditions. Although numerous species are associated with grain, L. *bostrychophila* has the most detailed biological information reported (Wang et al. 2000), and it will be the species referred to hereafter. *L. bostrychophila* oviposit 52 to 75 eggs in the temperature range of 20°C to 35°C (68°F to 95°F) with maximum oviposition occurring at 27.5°C (81.5°F) (Wang et al. 2000). The lower range for reproduction was calculated as 17.6°C (63.7°F), whereas the upper temperature range was estimated to be 36.5°C (97.7°F). Peak reproduction occurs 2 to 3 weeks after the pre-oviposition period (generally 4 days) terminates. Eggs, often adhered to a substrate, are laid on bags and commodities, and take 6 to 14 days at 20°C (68°F) to 32.5°C (90.5°F) to hatch (Turner, 1994; Wang et al. 2000). Nymphs go through four molts in 12 days at 32.5°C (90.5°F) to 28 days at 20°C (68°F). Adults are small (1 mm [0.4 inch]) light brown, soft-bodied insects. They have swollen hind femurs (part of leg closest to body) and flattened bodies (Figure 8).

Under humid conditions, populations can expand quickly, causing up to 10% weight loss (Opit et al. 2011), although they are generally thought to be a secondary pest. In some situations, they may be considered a pest of medical importance because some people exhibit allergic reactions after contact with an infested commodity. When populations are high, the insects may coat the grain surface and look like a "dust" or "carpet" moving or coating the grain surface. Psocids feed on a variety of animal and plant matter, preferring processed grain products, but are just as common in most whole grains. They are also found in museums displays and preserved insect collections. They prefer grain that is going out of condition that contains active fungal populations and may contribute to the growth of fungal populations because of moisture and organic matter produced as populations grow. Control is easy if the RH can be dropped to below 50%, but this may not always be possible or feasible.

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