# BIOLOGICALL BASED CONTROLS

#  Pheromones and Other Semiochemicals

Attractant pheromones, which are intraspecific chemical signals, and other attractant semiochemicals have been identified for over 40 species of stored-product insects over the past 40 years. There are two broad categories of pheromone systems recognized in stored-product insects, which follow life-history models for insects in general. Species with short-lived, usually non feeding adult stages utilize female-produced sex pheromones in which a receptive adult female “calls” by releasing one or more attractant compounds and one or more males respond upwind to the pheromone after which mating occurs. The female sex pheromone system is exemplified in many species of stored-product moths, predominated by species in the Pyralidae, subfamily Phycitinae, and beetles in the families Anobiidae, Bruchidae, and Dermestidae. Clothes moths in the family Tineidae have interesting pheromone systems in which males orient toward larval food sources and then produce pheromones in a resource-based manner. while females produce attractant pheromones for males. Stored-product species with long-lived, feeding adults, all examples of which are beetles, utilize male produced aggregation pheromones that attract both males and females. Release and perhaps production of the pheromones by males is closely tied to feeding or contact with food: Males locate food, produce pheromones, attract females and other males, and mate; females oviposit at that site, where larvae ultimately develop. Aggregation pheromone systems have been described for stored-product pests in the families Bostrichidae Curculionidae, Cucujidae and Silvanidae and Tenebrionidae (Pheromones provide highly sensitive tools for insect detection, because a pheromone trap may detect the presence of an insect while numerous traditional samples would detect none, and pheromones are highly specific to a target species.

Pheromones are commercially available for approximately 20 species of stored-product insects as slow-release formulations of lures to be used in monitoring traps (Among those that can be purchased, the most commonly used pheromones are those for *P. interpunctella*, the cigarette beetle, *Lasioderma serricorne* (F.) (Coleoptera: Anobiidae), the red and confused flour beetles, Tribolium castaneum and T. confusum Jacquelin du Val, respectively, and the warehouse beetle, *Trogoderma variabile* Ballion (Coleoptera: Dermestidae). The efficacy of pheromone-baited sticky traps vary according to their placement within a building (i.e., proximity to walls, floors, and ceilings), and other flat landing sites enhance the response of *P. interpunctella* males to pheromone-baited traps. For beetles that tend to land and crawl to an odor source, traps are designed to sit on a floor or flat surface and capture insects that walk into the trap, which eventually become stuck to the trapping surface or ensnared inside the trapping receptacle. Barak & Burkholder developed a trap with horizontal layers of corrugated cardboard in which responding beetles walked through the tunnels of corrugations to reach a cup of oil into which they fell and became suffocated. A popular alternative design is what appears as a ramp-and-pitfall trap, in which beetles walk to the trap, climb up an inclined side of the trap, and then fall into a receptacle of oil. The oil in these floor traps serves both as a trapping medium and as a pheromone synergist or additive attractant, as many formulations are grain-derived. Odors from larval foods that also serve as attractants for adult moths, technically considered kairomones, were developed for monitoring females of *P. interpunctella* and other stored-product moths

When attractant traps are used properly in value-added food systems, they can be a key component of IPM. Detection is the simple determination of the presence or absence of a pest species using pheromone traps, and monitoring refers to the collection of trap capture data over space and time in a building. Use of pheromone traps in bulk grain situations is not as informative as direct and indirect sampling of grain (see below), and pheromone-trapping will usually result in high trap captures that are not informative, or worse, in the case of aggregation pheromones that attract females, might attract pest insects in to the grain .Traps in food processing and warehouse facilities need to be distributed fairly evenly over the entire area of interest at a density that is cost-effective for the manager, and they must be checked for insects on a regular basis over time, perhaps every one or two weeks throughout the season of interest or the entire year. Application of trapping data with spatial analysis or geographic information software can be used to visualize locations in a building with high or low probability of encountering a pest insect or infestation but sometimes simple manual observation of collected trap captured at over time will be highly useful information to a pest manager. Traps provide relative population samples. The manager should be attentive to increases in insect numbers in traps at one or more locations relative to other locations, and to increases or decreases in numbers at one time compared to past sampling times. In addition, pheromone traps can be used to help determine the efficacy of a management tactic, such as fumigation or heat treatment, by comparing trap captures before and after the treatment Pheromones can also be used to suppress and control pest populations of stored-product insects. Mass-trapping males with a sex pheromone can theoretically control a population if a large number of males are removed from the population). Male moths such as *P. interpunctella* can inseminate an average of six females in their life times; thus, a few surviving males in a population under mass-trapping treatment could maintain the reproductive rate of the population at a level similar to that without mass-trapping. Despite the perceived challenge of effective mass-trapping of storage moths, several reported examples are known from Europe and from the United States for food stored for retail (the attract-and-kill, or attracticide, method is similar to mass-trapping, but instead of using traps, which can saturate with dead moths and need servicing, an insecticide-treated surface is coupled with the pheromone lure so that males contact the insecticide briefly and then die soon after Mating disruption, in which a treatment area is saturated with an unnaturally high concentration of synthetic sex pheromone and males are unable to locate and successfully mate with females, has proven successful for stored-product moths under controlled conditions (and recently in commercial field settings). Government registration of a pheromone for the expressed purpose of controlling an insect pest population is required in the United States. Primary registration of the synthetic sex pheromone of stored-product moths, Z, E-9,12-tetradecadienyl acetate, was recently granted. This registration, which considers the pheromone an insecticide yet does not set illegal residue levels for exposed foods as is done with many other insecticides, allows for grains and foods to be present when using this pheromone to control stored-product moths. This is perhaps the first registration of a sex pheromone for mating disruption for indoor use in the United States.

# Insect Natural Enemies

There is a guild of insect natural enemies associated with stored-product insects, and moisture as adapted to human-based habitats as are their prey and hosts. The literature on insect natural enemies has been reviewed by Scholler & Flinn¨. and Scholler et al. Several species¨ of parasitoid wasps from the Pteromalidae are solitary ectoparasitoids of internal-feeding grain-infesting species of beetles, and similarly there are several common species of Ichneumonidae and Braconidae as ecto- and endoparasitoids associated with stored-product Lepidoptera. Some species of free-living predatory beetles, true bugs (Heteroptera :Anthocoridae), and mites prey on any life stage of numerous species of stored-product insect pests that they can subdue and consume. Populations of parasitoids and predators in storage systems display delayed density dependency in their dynamics that are typical of other predator-prey and parasitoid-host systems in other insect communities, and population declines of stored product pest species are typically followed by increases in these natural enemy populations.

It is legal to add insect parasitoids and predators to bulk grain and to food warehouses in the United States under regulations passed by the Food and Drug Administration (FDA) and the U.S. Environmental Protection Agency (EPA). In short, insect natural enemies were technically designated insecticides so they could be regulated, and then they were exempted from a requirement of a tolerance level in food. The relevant FDA regulation for filth in food refers to the allowable number of insect fragments in finished food, such as flour for bread-making. Thus, fragments of pest insects and those of natural enemies are not differentiated, and the level cannot be legally exceeded. These key regulations allow the addition of insect natural enemies to stored-products systems and present an opportunity for biologically based management of storage pests with careful and knowledgeable use by pest managers. Commercial suppliers of natural enemies for stored-product pest management are limited at present, but examples of success on a small scale exist and the potential for further development is great.

# Microbial Insecticides

A number of insect pathogens have been tested for control of stored-product insects, but none is in common use because of lack of sufficient, broad-spectrum efficacy. Many tests have been conducted to synergize pathogens with other control technologies, particularly those that might be expected to increase efficacy of pathogens, such as DE. by presumably abrading the cuticle, or grain varietal resistance by delaying larval development. both of which might make the insect more susceptible to the pathogen. Laboratory evaluations of the commercially available fungi *Beauveria bassiana* and *Metarhizium anisopliae* and the bacterium *Bacillus thuringiensis* (Bt), alone or in conjunction with another insecticidal material such as DE ,generally result incomplete control of only some stages of some species, while other stages or species are poorly controlled (, Bt. generally has been most effective against Lepidoptera and Diptera, although some strains show increased efficacy for beetles); however, efficacy is still poor compared with conventional insecticides. This lack of efficacy limits the use of pathogens in commercial applications. Bt. has been registered for control of stored-product Lepidoptera for decades, but it has rarely been used because it does not control beetle pests. An effective granulosis virus specific for *P. interpunctella* was described and a method for low-cost mass-production was developed), but commercial adoption has been limited.

Spinosad is an insecticide derived from metabolites in the fermentation of the actinomycete bacterium *Saccharopolyspora spinosa*.

There is much interest in the use of spinosad on stored grain because other residual insecticides registered in the United States and elsewhere have limited efficacy against the major pest of stored wheat, *R. dominica*, either because of simple lack of efficacy or because of development of resistance. Spinosad is effective for season long control of *R. dominica* in stored wheat; it is highly toxic to larvae of many stored-product insects and shows good compatibility with insect natural enemies.

# Botanical Insecticides

There is a plethora of studies on the use of plant extracts or whole plant materials for insect control, but few are used on a commercial scale ..Farmers of ten use home grown or naturally occurring plant materials for insect control in developing countries. Problems with botanical insecticides are lack of consistency, safety concerns, and sometimes odor. It is often falsely assumed that because a plant material is used as a food flavoring or medicine that extracts from the material will be safe for human consumption. Various extracts from the neem tree, *Azadirachta indica*, collectively referred to as the insecticide Neem, are commercially available botanical insecticides, and local formulations have been widely used in some parts of the world for stored-product insect control. However, commercial formulations show only moderate levels of efficacy). Crude pea flour, and the protein-rich fraction of field peas, *Pisum* spp., as well as that of other food legumes (e.g., species of *Pissum*, *Phaseolus,* and *Vignia*), are toxic and repellent to stored-product insects. Direct application of protein-enriched pea flour to bulk grain at 0.1% by weight resulted in substantial reductions in stored-grain beetle populations. and broad scale application of pea flour to the inside of mills reportedly resulted in insect control, but such control was not at commercially acceptable levels like those achieved with synthetic fumigants. Pyrethrum, a commercial mixture of compounds derived from *Chrysanthemum cinerariifolium*, is perhaps the most successful botanical insecticide throughout all modern pest control, and this is certainly the case for stored products. The active ingredients from pyrethrum are called pyrethrins. Synergized pyrethrum commonly contains the synergist piperonyl butoxide, commonly referred to as PBO, which suppresses metabolic degradation of pyrethrins in the insect. Synergized pyrethrum is commonly used as an aerosol in flour mills. and is usually combined with another insecticide that has longer residual activity because the pyrethrum achieves only quick knockdown of insect pests at best, while the other insecticide with which it is combined provides longer activity. Organically compliant pyrethrum, which lacks any synthetic synergist and is extracted from chrysanthemum flowers by methods approved by the USDA National Organic Program, has been registered in the United States in recent years and shows potential for managing stored-product insects. but registration of a stored-product use is pending and suitable efficacy has yet to be investigated.

# Insect Growth Regulators

Insect growth regulators (IGRs) used in stored product systems in the United States and elsewhere include the insect juvenile hormone analogs methoprene, hydroprene, and pyriproxyfen) All three compounds mimic the effects of sustained increased titer of insect juvenile hormone by disrupting normal development between larval instars and in metamorphosis from larvae to pupae and then from pupae to normal adults. These IGRs are not directly toxic to adults, although their potential effects on reproductive sterility have not been fully investigated. Another key attribute to these IGRs is their low levels of toxicity to mammals and inherent high level of food safety.

Methoprene was considered so nontoxic that it was exempted from a requirement of a tolerance by the EPA in the United States. The LD50 value of methoprene, when administered orally to rats, is >34500 mg/kg. Methoprene applied at 1 ppm to stored grain can retain insecticidal activity for over a year, perhaps owing to the environmentally protective environment of grain storage with regard to lack of temperature extremes and degradation from UV radiation.

Hydroprene is a structurally close isomer of methoprene with slightly more volatility and thus is considered to function better as an aerosol in space treatments of structures because of its ability to penetrate voids and spaces not treated directly. However, the structurally different pyriproxyfen has qualities slightly superior to hydroprene with regard to length of residual activity when applied to a variety of surfaces.

Despite safety and efficacy of IGRs for storage systems, they have not been widely adopted for stored grain when compared with traditional residual contact insecticides and fumigants, probably because of cost and lack of immediate knockdown. IGRs are widely used for aerosol treatment of food-processing and finished product storage areas, particularly when combined with pyrethrum or dichlorvos, which are added for immediate knockdown of active insect life stages. Increased use of IGRs may be attributed to pest managers seeking alternatives to methyl bromide. IGRs represent low-risk, biologically based insecticides with potential for more adoption in the food industry in the future. The chemically synthetic nature of IGRs,

**I**nsect growth regulators (IGRs): synthetic insecticides that mimic insect hormones and act by disrupting the normal development of immature stages of target insects use by the manufacturer as of this writing due to the lack of full approval for tolerance levels on stored grain by all international trading partners with the United States as called for under the Codex Alimentarius (internationally recognized standards or guidelines for food safety).