# Microbial Insecticides

SYNTHETIC CHEMICAL INSECTICIDES provide many benefits to food production and human health, but they also pose some hazards. In many instances, alternative methods of insect management offer adequate levels of pest control and pose fewer hazards. One such alternative is the use of microbial insecticides—insecticides that contain microorganisms or their by-products. Microbial insecticides are especially valuable because their toxicity to nontarget animals and humans is extremely low. Compared to other commonly used insecticides, they are safe for both the pesticide user and consumers of treated crops. Microbial insecticides also are known as biological insecticides, bio-rational insecticides, insect pathogens, and biological control agents.

Microbial insecticides are comprised of microscopic living organisms (viruses, bacteria, fungi, protozoa, or nematodes) or the toxins produced by these organisms. They are formulated to be applied as conventional insecticidal sprays, dusts, or granules. Each product's specific properties determine the ways in which it can be used most effectively. This publication, one of a series on alternative methods of insect management, has been developed to help readers make the most effective use of microbial insecticides. It summarizes the strengths and weaknesses of products available commercially (and a few still under development), describes the types of microorganisms formulated for insect control, and lists the most promising uses for microbial insecticides.

With the exception of insecticidal products containing nematodes, all the microbial insecticides discussed in this publication are regulated by the United States Environmental Protection Agency (US EPA). (Nematodes used for insect control are multicellular parasites, and parasites and predators are not regulated as pesticides by the US EPA.) Although this publication provides background information on microbial insecticides, readers should consult product labels for specific application directions. All insecticides should be used only in the manner specified on the product label.

## Advantages of Microbial Insecticides

Individual products differ in important ways, but the following list of beneficial characteristics applies to microbial insecticides in general.

- The organisms used in microbial insecticides are essentially nontoxic and nonpathogenic to wildlife, humans, and other organisms not closely related to the target pest. The safety offered by microbial insecticides is their greatest strength.
- The toxic action of microbial insecticides is often specific to a single group or species of insects, and this specificity means that most microbial insecticides do not directly affect beneficial insects (including predators or parasites of pests) in treated areas.
- If necessary, most microbial insecticides can be used in conjunction with synthetic chemical insecticides because in most cases the microbial product is not deactivated or damaged by residues of conventional insecticides. (Follow label directions concerning any limitations.)
- Because their residues present no hazards to humans or other animals, microbial insecticides can be applied even when a crop is almost ready for harvest.
- In some cases, the pathogenic microorganisms can become established in a pest population or its habitat and provide control during subsequent pest generations or seasons.

NOTE: The information in this circular is provided for educational purposes only. Trade names of insecticides have been used for clarity, but reference to trade names does not imply endorsement by the University of Illinois or the Illinois Department of Energy and Natural Resources. Discrimination is not intended against any product. The reader is urged to exercise the usual caution in making purchases or evaluating product information.

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## Disadvantages of Microbial Insecticides

The limitations or disadvantages listed below do not prevent the successful use of microbial insecticides. Understanding how these limitations affect specific microorganisms will help users to choose effective products and take necessary steps to achieve successful results.

- Because a single microbial insecticide is toxic to only a specific species or group of insects, each application may control only a portion of the pests present in a field, garden, or lawn. If other types of pests are present in the treated area, they will survive and may continue to cause damage. Conventional insecticides are subject to similar limitations because they too are not equally effective against all pests. Nonetheless, the negative aspect of selectivity is often more noticeable for microbials.
- Heat, desiccation (drying out), or exposure to ultraviolet radiation reduces the effectiveness of several types of microbial insecticides. Consequently, proper timing and application procedures are especially important for some products.
- Special formulation and storage procedures are necessary for some microbial pesticides. Although these procedures may complicate the production and distribution of certain products, storage requirements do not seriously limit the handling of microbial insecticides that are widely available. (Store all pesticides, including microbial insecticides, according to label directions.)
- Because several microbial insecticides are pest-specific, the potential market for these products may be limited. Their development, registration, and production costs cannot be spread over a wide range of pest control sales. Consequently, some products are not widely available or are relatively expensive (several insect viruses, for example).

## BACTERIA

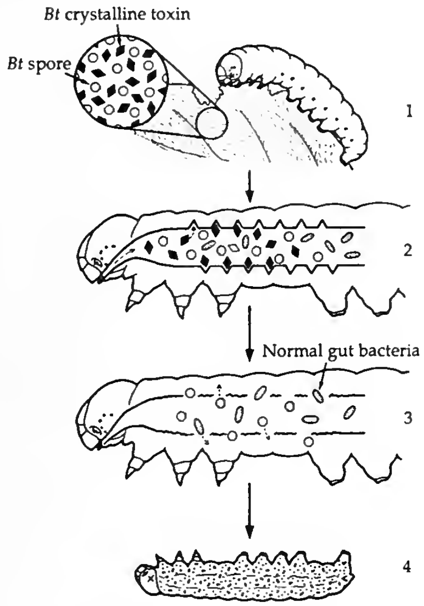
Bacterial pathogens used for insect control are spore-forming, rod-shaped bacteria in the genus *Bacillus*. They occur commonly in soils, and most insecticidal strains have been isolated from soil samples. Bacterial insecticides must be eaten to be effective; they are not contact poisons. Insecticidal products comprised of a single *Bacillus* species may be active against an entire order of insects, or they may be effective against only one or a few species. For example, products containing *Bacillus thuringiensis* var. *kurstaki* kill the caterpillar stage of a wide array of butterflies and moths. In contrast, *Bacillus popillae* (milky spore disease) kills Japanese beetle larvae but is not effective against the closely related annual white grubs (masked chafers in the genus *Cyclocephala*) that commonly infest lawns in Illinois.

The microbial insecticides most widely used in the United States since the 1960s are preparations of the bacterium *Bacillus thuringiensis* (abbreviated as *Bt*). *Bt* products are produced commercially in large industrial fermentation tanks. As the bacteria live and multiply in the right conditions, each cell produces (internally) a spore and a crystalline protein toxin called an endotoxin. Most commercial *Bt* products contain the protein toxin and spores, but some are cultured in a manner that yields only the toxin component.

When *Bt* is ingested by a susceptible insect, the protein toxin is activated by alkaline conditions and enzyme activity in the insect's gut. The toxicity of the activated toxin is dependent on the presence of specific receptor sites on the insect's gut wall. This necessary match between toxin and receptor sites determines the range of insect species killed by each *Bt* subspecies and isolate. If the activated toxin attaches to receptor sites, it paralyzes and destroys the cells of the insect's gut wall, allowing the gut contents to enter the insect's body cavity and bloodstream. Poisoned insects may die quickly from the activity of the toxin or may die within 2 or 3 days from the effects of septicemia (blood-poisoning). Although a few days may elapse before the insect dies, it stops feeding (and therefore stops damaging crops) soon after ingesting *Bt*.

*Bt* does not colonize or cycle (reproduce and persist to infect subsequent generations of the pest) in the environment in the magnitude necessary to provide continuing control of target pests. The bacteria may multiply in the infected host, but bacterial multiplication in the insect does not result in production of abundant spores or crystalline toxins. The usual result is that few or no infective units are released into the environment when a poisoned insect dies. Consequently, *Bt* products are applied much like synthetic insecticides. *Bt* treatments are inactivated fairly rapidly (within one to a few days) in many outdoor situations, and repeated applications may be necessary for some crops and pests.

**Action of *Bacillus thuringiensis* var. *kurstaki* on caterpillars**




(1) Caterpillar consumes foliage treated with *Bt* (spores and crystalline toxin). (2) Within minutes, the toxin binds to specific receptors in the gut wall, and the caterpillar STOPS FEEDING. (3) Within hours, the gut wall breaks down, allowing spores and normal gut bateria to enter the body cavity; the toxin dissolves. (4) In 1-2 days, the caterpillar dies from septicemia as spores and gut bacteria proliferate in its blood.

Adapted from Abbot Laboratories, "Mosquito Control: Taking the Bite Out of Summer"

Until the early 1980s, commercial *Bt* products were effective only against caterpillars. In recent years, however, additional isolates that kill other types of pests have been identified and developed for insecticidal use. The nature of the crystalline protein endotoxin differs among *Bt* subspecies and isolates, and it is the characteristics of these specific endotoxins that determine what insects will be poisoned by each *Bt* product. *Bt* formulations that are now commercially available fall into one of the following broad categories.

***Bt* formulations that kill caterpillars.** The best-known and most widely used *Bt* insecticides are formulated from *Bacillus thuringiensis* var. *kurstaki* isolates that are pathogenic and toxic only to larvae of the butterflies and moths. Many such *Bt* products have been registered with the United States Environmental Protection Agency. The most common trade names for these commercial products include Dipel®, Javelin®, Thuricide®, Worm Attack®, Caterpillar Killer®, Bactospeine®, and SOK-Bt®, but many small companies sell similar products under a variety of trade names. These products are commercially successful and widely available as liquid concentrates, wettable powders, and ready-to-use dusts and granules. They are used to control many common leaf-feeding caterpillars, including caterpillar pests on vegetables (especially the "worms" that attack cabbage, broccoli, cauliflower, and Brussels sprouts), bagworms and tent caterpillars on trees and shrubs, larvae of the gypsy moth and other forest caterpillars, and European corn borer larvae in field corn. Several of these products are used to control Indianmeal moth larvae in stored grain. One product with a very specific target is Certan®, formulated from *Bacillus thuringiensis* var. *aizawai*, and used exclusively for the control of wax moth larvae in honeybee hives.

*Bt* products that kill caterpillars are NOT effective against other types of pests; they will not

**Caterpillar Targets for *Bt*:**

Common caterpillar pests that are controlled effectively with *Bacillus thuringiensis* var. *kurstaki* (*Bt*) include

- European corn borer in corn
- Indianmeal moth in stored grain
- cabbage looper
- imported cabbageworm
- diamondback moth
- tomato/tobacco hornworm
- gypsy moth
- spruce budworm
- tent caterpillars
- fall webworm
- mimosa webworm
- bagworms
- spring and fall cankerworm

Common caterpillar pests that are NOT controlled by normal applications of *Bt* include

- corn earworm (on corn)
- codling moth
- peach tree borer
- squash vine borer

control aphids, beetles, flies, or additional pests other than caterpillars. Even certain caterpillars are not effectively controlled by *Bt*, especially those that live in the soil or bore into plant tissues without consuming a significant amount of the *Bt* applied to plant surfaces. (Again, *Bt* is a stomach poison that must be ingested to be effective.) The peach tree borer in stone fruits, corn earworm in corn, and the cutworms that clip off field crops or garden plants are examples of caterpillars seldom controlled by *Bt* treatments. *Bt* is not registered for the control of codling moth larvae that attack apples and pears because these larvae do not feed much (if at all) on treated surfaces.

***Bt* formulations that kill mosquito, black fly, and fungus gnat larvae.** Production of a second group of *Bt* insecticides began in the early 1980s. These products utilize *Bacillus thuringiensis* var. *israelensis* (*Bti*), a subspecies that kills the larvae of certain Diptera (the insect order containing the flies and mosquitoes). The main targets for *Bti* are the larval stages of mosquitoes, black flies, and fungus gnats; it does not control larval stages of "higher" flies such as the house fly, stable fly, or blow flies. Mosquitoes that are most susceptible to *Bti* include species in the genera *Aedes* and *Psorophora*. *Anopheles* and *Culex* species are controlled only when higher than normal rates of *Bti* are applied. *Bti* products that are available commercially include Vectobac®, Teknar®, Bactimos®, Skeetal®, and Mosquito Attack®.

*Bti* is most effective for mosquito or black fly control when it is used on a community-wide basis by mosquito abatement district personnel. In general, any attempts to reduce the prevalence of mosquito-breeding sites and treat remaining sites are most effective when undertaken on such a scale. For most homeowners or farmers, eliminating sites that periodically serve as sources of standing water (such as tires and empty containers) and controlling weeds around ponds or drainage lagoons is more effective than applying *Bti*.

*Bti* products are formulated for spray or granular applications. *Bti* formulated on corn cob granules is effective against mosquito larvae developing in tires and other artificial containers. (The "Asian tiger mosquito," *Aedes albopictus*, develops in these containers.) The corn cob granules can be blown into tire piles to provide good penetration and uniform treatment; residual control is also greater when corn cob granules are used. *Bti* is not very effective for the control of mosquito larvae in turbid water or waters containing high levels of organic pollutants.

*Bti* has also been used effectively for the control of fungus gnat larvae in greenhouses and in mushroom culture beds. For these uses, *Bti* is applied as a drench to potting soils or culture media. Not all *Bti* products are labeled for fungus gnat control.

Although not a *Bt*, another bacterium that is pathogenic to certain mosquitoes is *Bacillus sphaericus*. *Bacillus sphaericus* is especially active against larvae of mosquitoes in the genera *Culex*, *Psorophora*, and *Culiseta*. Effectiveness against larvae of *Aedes* species varies. *Aedes vexans* is very susceptible, but *Aedes aegypti* (the yellow fever mosquito) and *Aedes albopictus* are not. *Bacillus sphaericus* kills *Anopheles* larvae in laboratory tests, but field results have not been promising. Because *Anopheles* mosquitoes are true surface feeders, the bacterium would have to remain on the water surface for an extended period to be effective. *Bacillus sphaericus* formulations tested up to now do not remain at the surface long enough to be effective.

In addition to infecting a different group of mosquito species than *Bti*, *Bacillus sphaericus* is a potentially valuable insecticide because it remains effective in stagnant or turbid water. Although *Bacillus sphaericus*, as it occurs naturally, does cycle and maintain itself in the environment, insecticidal formulations currently under development do not cycle in water to infect subsequent generations of mosquito larvae. EPA registration of *Bacillus sphaericus* is pending.

***Bt* formulations that kill beetles.** Another group of *Bt* isolates, including those from *Bacillus thuringiensis* var. *san diego* and *Bacillus thuringiensis* var. *tenebrionis*, are toxic to certain beetles. Within the order Coleoptera (the beetles), species exhibit great differences in susceptibility to these isolates, presumably because of differences in the insects' gut wall receptor sites where the bacterial toxins must attach. Consequently, the range of susceptible hosts for the beetle-targeted *Bt* formulations does not include all beetles, or even all of the species within a beetle family or subfamily.

In 1988, *Bacillus thuringiensis* var. *san diego*, sold under the trade name M-One®, was first registered for use against larvae of the Colorado potato beetle. This product also kills elm leaf beetle adults and larvae, but it is not pathogenic or toxic to some other key beetle pests, such as the corn rootworms and other related species. Registration of Trident®, a very similar product containing *Bacillus thuringiensis* var. *tenebrionis*, is pending. Considerable research effort is now directed to identifying and developing additional *Bt* isolates that are active against more or different beetle species. Although entomologists and consumers alike will need to consider the specific target insect when judging the potential for these new products, *Bt* formulations effective against beetles seem to offer great promise.

**Using *Bt* insecticides.** Insecticides containing *Bt* can be very effective for insect control in a variety of situations. Reviewing a few key facts about these products can help users obtain the best results possible. Each *Bt* insecticide controls only certain types of insects; therefore, it is essential to identify the target pest and to confirm that the *Bt* product label states that the insecticide is effective against that pest. Separate stages of insects differ in their susceptibility to *Bt*; isolates that are effective against larval stages of butterflies, moths, or mosquitoes will not kill adults. Because susceptible insects must consume *Bt* to be poisoned, treatments must be directed to the plant parts or other material that the target pest will eat. Where this is not possible (for example, where pests bore into plant tissue without feeding much on the surface of foliage or fruits), *Bt* is usually not very effective. *Bt* does not kill susceptible insects immediately. Poisoned insects normally remain on plants for a day or two after treatment, but they do not continue feeding and will die soon.

Where *Bt* is applied to plant surfaces or other sites exposed to sunlight, it is deactivated rapidly by direct ultraviolet radiation. To maximize the effectiveness of *Bt* treatments, sprays should thoroughly cover all plant surfaces, including the undersides of leaves. Treating in the late afternoon or evening can be helpful because the insecticide remains effective on foliage overnight before being inactivated by exposure to intense sunlight the following day. Treating on cloudy (but not rainy) days provides a similar result. Production processes that encapsulate *Bt* spores or toxins in a granular matrix (such as starch) or within killed cells of other bacteria also provide protection from ultraviolet radiation. Registration and sale of products containing encapsulated *Bt* are forthcoming.

Some *Bt* isolates (not those used in currently available insecticides) produce significant amounts of an additional toxin called thuringiensin, an exotoxin that is released outside the bacterial cell wall. Research is underway to develop commercial insecticides containing this toxin. Although thuringiensin might be lauded as "natural" because it is produced by living organisms, it is nonetheless toxic to a wide range of animal species and humans. As thuringiensin insecticides are registered and become available, users should recognize the difference between thuringiensin and other *Bt* products. Thuringiensin is much more toxic and should be handled much more cautiously.

Although the issue of thuringiensin's toxicity to mammals is a unique characteristic that does not detract from the overall safety of registered microbial insecticides, users are advised to handle all microbial insecticides cautiously. Bacterial spores, mold spores, and virus particles become "foreign proteins" if they are inhaled or rubbed into the skin. As such, they can cause serious allergic reactions. The dusts or liquids used to dilute and carry these microorganisms also can act as allergens or irritants. These problems do not prevent the safe use of microbial insecticides, but they do mean that users should not breathe dusts or mists of microbial insecticides. Users should wear gloves, long sleeves, and long trousers during application and wash thoroughly after completing the application. These are commonsense precautions that will help to prevent unexpected reactions and minimize any effects from unknown toxicity.

Recent advances in biotechnology have resulted not only in improved prospects for developing new *Bt* insecticides but also in an ability to place *Bt* toxins within crop plants in a variety of ways. For example, genes directing the production of *Bt* toxins can be incorporated into certain plant-dwelling bacteria. When these altered bacteria grow and multiply within an inoculated host plant, the *Bt* toxin is produced within the plant. Efforts are underway to test this type of *Bt* "application" in corn to control the European corn borer. Although the development of this technology may seem ideal, the season-long, high-level control it would provide would also pose a great risk for the development of insect resistance to the *Bt* toxin. As genes for production of insecticidal compounds are added to crop plants, developers must also devise methods of preventing or managing insecticide resistance in target pests.

**Other bacterial insecticides.** Insecticides sold under the trade names Doom®, Japidemic®, Grub Attack®, and the generic name "milky spore disease" contain the bacteria *Bacillus popillae* and *Bacillus lentimorbus*. These bacteria cannot be grown in fermentation tanks; instead, they are "cultivated" in laboratory-reared insect larvae. Products containing *Bacillus popillae* and *Bacillus lentimorbus* can be applied to turf and "watered in" to the soil below to control the larval (grub) stage of the Japanese beetle and, less effectively, some other beetle grubs. When a susceptible grub consumes spores of these bacteria, they proliferate within it, and the grub's internal organs are liquified and turned milky white (hence the name, milky spore disease). These symptoms develop slowly, often over a period of three to four weeks following initial infection.

*Bacillus popillae* and *Bacillus lentimorbus*, unlike *Bt*, do cycle in the environment if a substantial grub population is present at the time of application. When grubs killed by these bacteria break apart, a new batch of spores is released into the soil. These spores can survive (waiting to infect another grub) beneath undisturbed sod for a period of 15 to 20 years. Consequently, lawn applications of milky spore disease bacteria might not have to be repeated each year.

Unfortunately, *Bacillus popillae* and *Bacillus lentimorbus* offer limited usefulness in Illinois and other Midwestern states because the predominant lawn grubs in this region are annual white grubs, which are larvae of beetles called chafers (genus *Cyclocephala*). These larvae are not susceptible (or are only slightly susceptible) to milky spore disease.

## VIRUSES

The larvae of many insect species are vulnerable to devastating epidemics of viral diseases. The viruses that cause these outbreaks are very specific, usually acting against only a single insect genus or even a single species. Most of the viruses that have been studied for use as potential insecticides are nuclear polyhedrosis viruses (NPVs), in which numerous virus particles are "packaged" together in a crystalline envelope within insect cell nuclei, or granulosis viruses (GVs), in which one or two virus particles are surrounded by a granular or capsule-like protein crystal found in the host cell nucleus. These groups of viruses infect caterpillars and the larval stages of sawflies.

Viruses, like bacteria, must be ingested to infect insect hosts. In sawfly larvae, virus infections are limited to the gut, and disease symptoms are not as obvious as they are in caterpillars. In caterpillars, virus particles pass through the insect's gut wall and infect other body tissues. As an infection progresses, the caterpillar's internal organs are liquified, and its cuticle (body covering) discolors and eventually ruptures. Caterpillars killed by virus infection appear limp and soggy. They often remain attached to foliage or twigs for several days, releasing virus particles that may be consumed by other larvae. The pathogen can be spread throughout an insect population in this way (especially when rain drops help to splash the virus particles to adjacent foliage) and by infected adult females depositing virus-contaminated eggs. Dissemination of viral pathogens is deterred by exposure to direct sunlight, because direct ultraviolet radiation destroys virus particles. Although naturally occurring epidemics do control certain pests, these epidemics rarely occur before pest populations have reached outbreak levels.

The development and use of virus-based insecticides have been limited. Unlike *Bt*, insect viruses must be produced in live host insects. Production is therefore both expensive and time-consuming. Because viruses are genus- or species-specific, each viral insecticide has a limited market. These economic factors, coupled with the fact that some virus insecticides are considerably less effective than available synthetic chemical insecticides, have limited their development.

Nonetheless, although they are not well known or widely available, several insect viruses have been developed and registered for use as insecticides. Most are specific to a single species or a small group of related forest pests, for example the gypsy moth, Douglas-fir tussock moth, spruce budworm, and pine sawfly. They are not commercially available but are produced and used by the United States Forest Service. Forest pests are especially good targets for viral pathogens because the permanence of the forest environment contributes to cycling of the pathogen (transmission from one generation to the next). The forest canopy also helps to protect viral particles from destruction by ultraviolet radiation.

Other insect viruses investigated for use as insecticides include those that infect the alfalfa looper, soybean looper, armyworms, cabbage looper, and imported cabbageworm. Although some of these viruses have been formulated and applied in field tests, none has been registered or sold commercially. Both the codling moth GV (Decyde®) and the *Heliothis* NPV (Elcar®) were at one time registered by the US EPA and produced commercially, but these products are no longer registered or available.

If additional viral insecticides are registered or if currently registered products become more widely available, their effective use will depend upon applicators remembering the following key facts: Most viruses are host-specific and effective only against immature stages of the target species; users must be sure to match the pathogen and the target pest correctly. Virus particles are killed by ultraviolet radiation; treating in the evening or on cloudy days should increase their effectiveness.

## FUNGI

Fungi, like viruses, often act as important natural control agents that limit insect populations. Most of the species that cause insect diseases spread by means of asexual spores called conidia. Although conidia of different fungi vary greatly in ability to survive adverse environmental conditions, desiccation and ultraviolet radiation are important causes of mortality in many species. Where viable conidia reach a susceptible host, free water or very high humidity is usually required for germination. Unlike bacterial spores or virus particles, fungal conidia can germinate on the insect cuticle and produce specialized structures that allow the fungus to penetrate the cuticle and enter the insect's body. Fungi do not have to be ingested to cause infections. In most instances, as fungal infections progress, infected insects are killed by fungal toxins, not by the chronic effects of parasitism.

Fungal pathogens differ in the range of life stages and species they are able to infect. Many important fungal pathogens attack eggs, immatures, and adults of a variety of insect species. Others are more specific to immature stages or to a narrow range of insect species.

Several factors have limited the development of fungal insecticides in the United States. Although fungal pathogens (at least some species) can be produced on artificial media, large-scale production of most pathogens has not yet been accomplished. Precise production and storage conditions must be established and maintained to ensure that infective spores are produced and stored without loss of viability before they are applied. Once applied, pathogenic fungi often are effective only if environmental conditions are favorable; high humidity or rainfall usually is important. Where fungal pathogens are incorporated in soil to control belowground pests, the adverse effects of ultraviolet radiation and desiccation are minimized, but other microorganisms that act as competitors or antagonists often alter pathogen effectiveness.

Although no fungal pathogens are currently registered or commercially available in the United States, one or more fungi are used in Great Britain, China, the Soviet Union, and additional countries in eastern Europe and South America. Fungi used as insecticides include the following:

*Beauveria bassiana*: This common soil fungus has a broad host range that includes many beetles. It infects both larvae and adults of many species. One or more companies currently are developing preparations of this fungus for EPA registration; the Colorado potato beetle is a key target pest in research and development efforts. Understanding the interactions between *Beauveria bassiana* and other soil microorganisms may be the key to successful use of this fungus.

*Nomuraea rileyi*: In soybeans (especially in the southeastern United States), naturally occurring epidemic infections of *Nomuraea rileyi* cause dramatic reductions in populations of foliage-feeding caterpillars. Research directed at predicting disease outbreaks caused by this fungus may help in determining the need for application of insecticides.

*Verticillium lecanii*: This fungus (once sold under the trade name Vertelec®) has been used in greenhouses in Great Britain to control aphids and whiteflies.

*Lagenidium giganteum*: This aquatic fungus is highly infectious to larvae of several mosquito genera. It cycles effectively in the aquatic environment (spores produced in infected larvae persist and infect larvae of subsequent generations), even when mosquito density is low. Its effectiveness is limited by high temperatures.

*Hirsutella thompsonii*: Although preparations of this pathogen were once registered by the US EPA and marketed under the trade name Mycar®, it is no longer available commercially. *Hirsutella thompsonii* is a pathogen of the citrus rust mite.

## PROTOZOA

Protozoan pathogens naturally infect a wide range of insect hosts. Although these pathogens can kill their insect hosts, many are more important for their chronic, debilitating effects. One important and common consequence of protozoan infection is a reduction in the number of offspring produced by infected insects. Although protozoan pathogens play a significant role in the natural limitation of insect populations, few appear to be suited for development as insecticides.

Species in the genera *Nosema* and *Vairimorpha* seem to offer the greatest potential for use as insecticides. Pathogens in these genera attack Lepidopteran larvae and insects in the order Orthoptera (the grasshoppers and related insects). The one protozoan currently available in a registered insecticidal formulation is the microsporidian *Nosema locustae*, a pathogen of grasshoppers. It is sold under such trade names as NOLO Bait® and Grasshopper Attack®. It is most effective when ingested by immature grasshoppers (the early nymphal stages). Infections progress slowly; where the pathogen kills the grasshopper, death occurs three to six weeks after initial infection. Not all infected hoppers are killed.

*Nosema locustae* has been used to reduce grasshopper populations in rangeland areas, and adequate control has been achieved when treatments were applied to large areas while hoppers were still young. Although not all grasshoppers in the treated area are killed by *Nosema locustae,* infected hoppers consume less forage and infected females produce fewer viable eggs than do uninfected females. *Nosema locustae* persists on egg pods to provide varying degrees of infection the following season. The effectiveness and utilization of *Nosema locustae* for rangeland grasshopper control are likely to increase as research continues.

Unfortunately, small, one-pound packages of *Nosema locustae* preparations developed for sale to gardeners and homeowners offer much less utility (or none). The mobility of grasshoppers, coupled with the fact that infected hoppers are not killed until a few weeks after they ingest the pathogen, means that application of baits containing *Nosema locustae* to individual lawns or gardens is unlikely to reduce grasshopper densities or damage substantially. (Knowing that you infected some grasshoppers that may or may not die later in someone else's garden may be somewhat satisfying, but it doesn't help very much if your goal was to prevent damage to your vegetables.)

## NEMATODES

To be accurate, nematodes are not microbial agents. Instead, they are multicellular roundworms. Nematodes used in insecticidal products are, however, nearly microscopic in size, and they are used much like the truly microbial products discussed previously. Nematodes used for insect control infect only insects or related arthropods; they are called entomogenous nematodes.

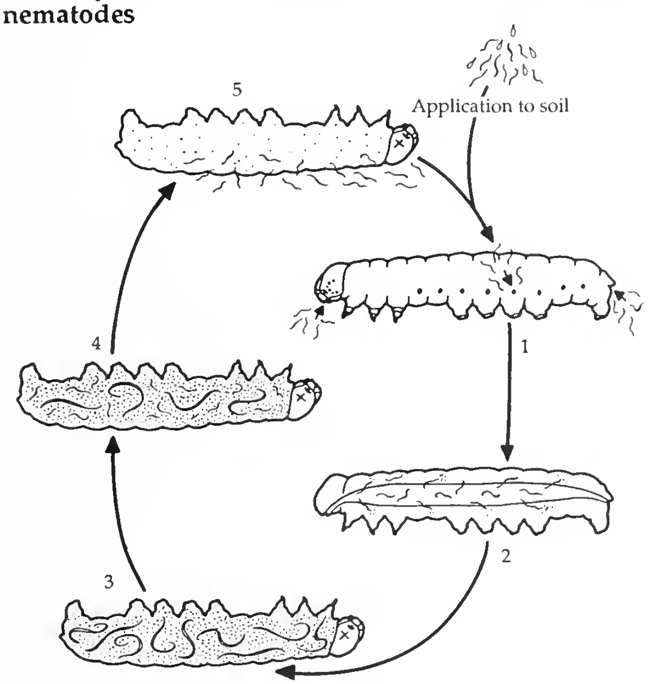
The entomogenous nematodes *Steinernema feltiae* (sometimes identified as *Neoaplectana carpocapsae*) and *Heterorhabditis heliothidis* are the species most commonly used in insecticidal preparations. Within each of these species, different strains exhibit differences in their abilities to infect and kill specific insects. In general, however, these nematodes infect a wide range of insects. On a worldwide basis, laboratory or field applications have been effective against over 400 pest species, including numerous beetles, fly larvae, and caterpillars.

The infectious stage of these nematodes is the third juvenile stage often referred to as the J3 stage or the "dauer" larva. Nematodes in this stage survive without feeding in moist soil and similar habitats, sometimes for extended periods. *Steinernema* species infect host insects by entering through body openings—the mouth, anus, and spiracles (breathing pores). *Heterorhabditis* juveniles also enter host insects through body openings, and in some instances are also able to penetrate an insect's cuticle. If the environment is warm and moist, these nematodes complete their life cycle within the infected insect. Infective juveniles molt to form adults, and these adults produce a new generation within the same host. As the offspring mature to the J3 stage, they are able to leave the dead insect and seek a new host.

Symbiotic bacteria associated with entomogenous nematodes actually cause the death of infected insects. Once inside an insect host, nematodes empty their gut bacteria into the insect's bloodstream. The nematodes then feed on these bacteria as they multiply. The insect dies from bacterial septicemia. These entomogenous nematodes and their associated bacteria (*Xenorhabdus nematophilus* and *Xenorhabdus luminescens*) have been tested extensively for toxicity to nontarget organisms, and they are considered to be nontoxic and nonpathogenic to plants and mammals.

Large-scale production of nematodes has been initiated, and a few insecticides containing entomogenous nematodes are now marketed. These products contain infective juveniles (the J3 stage) and are formulated for application as sprays or drenches. Although *Steinernema* and *Heterorhabditis* species have been shown to be effective against a great number of insect species in laboratory experiments, their host range in field applications is often limited by temperature and moisture conditions in the target insect's habitat. Although controlled desiccation has been used successfully for the formulation of some insecticidal products containing nematodes, desiccation in the field usually kills entomogenous nematodes. Consequently, nematodes are most effective when applied to control insects in moist soil, plant tissues, or other protected habitats. Their viability and persistence in soil varies greatly depending upon soil moisture and temperature and other organisms present. The following examples illustrate situations in which nematodes are likely to provide effective insect control.

**Life cycle of *Steinernema* sp. entomogenous nematodes**




(1) Infective juveniles enter the gut or respiratory system through body openings (mouth, anus, and breathing pores). (2) Infective juveniles actively penetrate the gut wall, enter the body cavity, and release bacteria. (3) As bacteria multiply, host dies of septicemia; juveniles feed on bacteria and host tissues and develop into adults. (4) Adults mate and reproduce; 2-3 generations are produced if conditions are adequate. (5) When the food supply is exhausted, a new generation of infective juveniles exits the host and searches for a new one.

Adapted from Woodring and Kaya (1988)

For the control of annual white grubs in grass sod, entomogenous nematodes should be effective when applied at the right time to adequately watered turf. If applications are made when grubs are present (early to late August in Illinois, with correct timing dependent upon latitude and annual variations in weather), nematodes (and synthetic insecticides) need to remain active only for a period of several days to reduce grub damage. Because most homeowners and turf managers are able to irrigate, they can effectively "water in" nematode applications and keep soils moist enough to favor nematode survival and grub infection. Although nematodes may survive for extended periods (up to several months) in cool, moist soils, homeowners should probably expect that nematodes will persist for only two to four weeks following application for grub control.

Nematodes also have been used effectively in trials against root weevil larvae and similar soil pests attacking nursery plants, ornamental plantings, garden crops, and potted plants. The ability to maintain soil moisture is an important factor in the success of these treatments.

In Midwest field crops, nematodes offer less promise for the control of major soil pests such as cutworms, corn rootworms, wireworms, and grubs. For the most part, these crops are not irrigated, and the inability to control soil moisture is a major factor limiting the success of nematode applications. Although timing applications to correspond with periods of adequate soil moisture might prove helpful, research efforts have not yet produced successful results in nonirrigated crops. For irrigated field crops, the cost of nematode products will also be an important factor that will determine whether or not large-scale use can be practical and economical.

Nematodes are not appropriate for termite control. Entomogenous nematodes are infectious to termites, but they are not likely to provide the long-term persistence needed in a termiticide. In soils around and under buildings, low moisture levels and the probable long-term absence of host insects would, in most cases, prevent nematode survival (persistence). Consequently, the need for long-term control would require repeated applications of nematodes at intervals not yet determined. Because repeated applications are impractical and undesirable, nematodes are not recommended for termite control.

Until further research provides data on specific pests, we recommend against the use of nematodes to control most above-ground insects. When nematodes can be placed in moist, protected environments where insects are confined (such as tunnels bored into tree trunks or other plant tissues), treatments can be effective. When nematodes are applied to exposed foliage or other locations where desiccation occurs rapidly, treatments are not likely to be effective.

Although commercial availability is likely to increase, nematodes are currently sold primarily by mail order from gardening supply houses (or wholesale to large-volume purchasers). Trade names include Scanmask® and BioSafe®; some products simply use the scientific name of the nematode. Nematodes are not considered by the US EPA to be pathogens, and nematode producers are not required to complete the same EPA registration process required of producers of other microbial pesticides. This exemption means reduced start-up costs for the manufacture of

# MICROBIAL INSECTICIDES

*A Summary of Products and Their Uses*

| PATHOGEN | PRODUCT NAME | HOST RANGE | USES AND COMMENTS |
|---|---|---|---|
| BACTERIA | | | |
| *Bacillus thuringiensis* var. *kurstaki* (*Bt*) | Bactur®, Bactospeine®, Caterpillar Killer®, Dipel®, Futura®, Javelin®, SOK®-Bt, Thuricide®, Topside®, Tribactur®, Worm Attack® | caterpillars (larvae of moths and butterflies) | Effective for foliage-feeding caterpillars (and Indian-meal moth in stored grain). Deactivated rapidly in sunlight; apply in the evening or on overcast days and direct some spray to lower sufaces of leaves. Does not cycle extensively in the environment. Available as liquid concentrates, wettable powders, and ready-to-use dusts and granules. Active only if ingested. |
| *Bacillus thuringiensis* var. *israelensis* (*Bti*) | Bactimos®, Mosquito Attack®, Skeetal®, Teknar®, Vectobac® | larvae of *Aedes* and *Psorophora* mosquitoes, black flies, and fungus gnats | Effective against larvae only. Active only if ingested. *Culex* and *Anopheles* mosquitoes are not controlled at normal application rates. Activity is reduced in highly turbid or polluted water. Does not cycle extensively in the environment. Applications generally made over wide areas by mosquito and blackfly abatement districts. |
| *Bacillus thuringiensis* var. *san diego* | M-One® | larvae of Colorado potato beetle, elm leaf beetle adults | Effective against Colorado potato beetle larvae and the elm leaf beetle. Like other *Bt*s, it must be ingested. It is subject to breakdown in ultraviolet light and does not cycle extensively in the environment. |
| *Bacillus thuringiensis* var. *tenebrionis* | Trident® | larvae of Colorado potato beetle | Registration pending. Very similar to *Bacillus thuringiensis* var. *san diego* (M-One ). |
| *Bacillus thuringiensis* var. *aizawai* | Certan® | wax moth caterpillars | Used only for control of wax moth infestations in honeybee hives. |
| *Bacillus popilliae* and *Bacillus lentimorbus* | Doom®, Japidemic®, Milky Spore Disease, Grub Attack® | larvae (grubs) of Japanese beetle | The main Illinois lawn grub (the annual white grub, *Cyclocephala* sp.) is NOT susceptible to milky spore disease. The disease is very effective against Japanese beetle grubs (not a major pest in Illinois) and cycles effectively for years in the soil. |
| *Bacillus sphaericus* | (in development) | larvae of *Culex*, *Psorophora*, and *Culiseta* mosquitoes, larvae of some *Aedes* spp. | Not registered or available commercially as of 1989. Active only if ingested. Under development for use against *Culex*, *Psorophora*, and *Culiseta* species; also effective against *Aedes vexans*. Remains effective in stagnant or turbid water. Commercial formulations will not cycle to infect subsequent generations. |
| FUNGI | | | |
| *Beauveria bassiana* | (in development) | many soil-dwelling insects | Not registered or available commercially as of 1989. Under development for control of Colorado potato beetle and several other beetle pests. High moisture requirements, lack of storage longevity, and competition with other soil microorganisms are problems that remain to be solved. |

# MICROBIAL INSECTICIDES

*A Summary of Products and Their Uses (continued)*

| PATHOGEN | PRODUCT NAME | HOST RANGE | USES AND COMMENTS |
|---|---|---|---|
| FUNGI (*continued*) | | | |
| *Lagenidium giganteum* | (in development) | larvae of most pest mosquito species | Not registered or available commercially as of 1989. Effective against larvae of most pest mosquito species; remains infective in the environment through dry periods. A main drawback is its inability to survive high summertime temperatures. |
| PROTOZOA | | | |
| *Nosema locustae* | NOLO® Bait, Grasshopper Attack® | grasshoppers and mormon crickets | Useful for rangeland grasshopper control. Active only if ingested. Not recommended for use on a small scale, such as backyard gardens, because the disease is slow acting and grasshoppers are very mobile. |
| VIRUSES | | | |
| Gypsy moth nuclear polyhedrosis (NPV) | Gypchek® virus | gypsy moth caterpillars | All of the viral insecticides used for control of forest pests are produced and used exclusively by the U.S. Forest Service. |
| Tussock moth NPV | TM Biocontrol-1® | tussock moth caterpillars | |
| Pine sawfly NPV | Neochek-S® | pine sawfly larvae | |
| Coddling moth granulosis virus (GV) | (see comments) | codling moth caterpillars | Commercially produced and marketed briefly, but no longer registered or available. Future re-registration is possible. Active only if ingested. Subject to rapid breakdown in ultraviolet light. |
| ENTOMOGENOUS NEMATODES | | | |
| *Steinernema feltiae* (=*Neoaplectana carpocapsae*) and other *Steinernema* species | Biosafe®, Scanmask®, also sold generically (wholesale and retail) | larvae of a wide variety of soil-dwelling and boring insects | *Steinernema feltiae* is the main nematode species marketed retail in the U.S. Because of moisture requirements, it is effective primarily against insects in moist soils or inside plant tissues. Prolonged storage or extreme temperatures before use may kill or debilitate the nematodes. Effective in cool temperatures. |
| *Heterorhabditis heliothidis* | currently available on a wholesale basis for large-scale operations | larvae of a wide variety of soil-dwelling and boring insects | Not commonly available by retail in the U.S.; this species is used more extensively in Europe. Available by wholesale or special order for research or large-scale commercial uses. Similar in use to *Steinernema* species but with some differences in host range, infectivity, and temperature requirements. |

products containing entomogenous nematodes, but it also means less standardization and less outside regulation of quality. As major producers of entomogenous nematodes gain a reputation for marketing high-quality products, consumers can expect these companies to practice effective quality control. Nonetheless, in the absence of extensive regulation, some suppliers are likely to market inferior products accompanied by exaggerated claims. Because of differences among nematode products and lack of regulation, buyers are urged to be careful consumers. These products offer a great deal of potential, but their efficacy is not as unlimited as some promotions suggest.

## SUMMARY

Microbial insecticides offer effective alternatives for the control of many insect pests. Their greatest strength is their safety, as they are essentially nontoxic and nonpathogenic to animals and humans. Although not every pest problem can be controlled by the use of a microbial insecticide, these products can be used successfully in place of more toxic insecticides to control many lawn and garden pests and several important field crop and forest insects. Because most microbial insecticides are effective against only a narrow range of pests and because these insecticides are vulnerable to rapid inactivation in the environment, users must properly identify target pests and plan the most effective application. But these same qualities mean that microbial insecticides can be used without undue risks of human injury or environmental damage. Consequently, microbial insecticides are likely to become increasingly important tools in insect management.

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# Botanical Insecticides and Insecticidal Soaps

Synthetic insecticides have played an important and beneficial role in the control of agricultural pests and the reduction of insect-borne diseases for more than forty years. Over time, however, certain risks and drawbacks associated with the use of synthetic insecticides have become increasingly apparent. Some synthetic insecticides leave undesirable residues in food, water, and the environment. Low doses of many insecticides are toxic to humans and other animals, and some insecticides are suspected carcinogens. As a result, many researchers, farmers, and homeowners are seeking less hazardous alternatives to conventional synthetic insecticides.

The ideal insecticide should control target pests adequately and should be target-specific (able to kill the pest insect but not other insects or animals), rapidly degradable, and low in toxicity to humans and other mammals. Two classes of insecticides that exhibit some of these characteristics are the botanical insecticides and the insecticidal soaps. Botanical insecticides, sometimes referred to as "botanicals," are naturally occurring insecticides derived from plants. Insecticidal soaps are soaps that have been selected and formulated for their insecticidal action.

Botanical insecticides and insecticidal soaps are promising alternatives for use in insect management. However, like conventional synthetic insecticides, botanicals and insecticidal soaps have advantages and disadvantages and should be judged accordingly. Each compound must be evaluated in terms of its toxicity, effectiveness, environmental impacts, and costs.

The strengths and weaknesses of botanical insecticides and insecticidal soaps are briefly summarized in this circular. Each compound is discussed in terms of its mode of action, mammalian toxicity, and practical uses. General information on the history and development of botanicals, insecticide toxicology, and state registration requirements is also presented. Insecticide toxicity is stressed throughout this circular. Even though botanicals and insecticidal soaps are naturally derived and are relatively safe to use if used properly, they are poisons and should be handled with the same caution as synthetic insecticides.

## Advantages of Botanical Insecticides and Insecticidal Soaps

Many compounds with diverse chemical structures and different modes of action are classified as botanical insecticides or insecticidal soaps. It is therefore difficult to present a detailed list of advantages or disadvantages that apply to all of the compounds included in this category. Some general advantages shared by most of these compounds are:

- **Rapid degradation.** Botanicals and insecticidal soaps degrade rapidly in sunlight, air, and moisture and are readily broken down by detoxification enzymes. This is very important because rapid breakdown means less persistence in the environment and reduced risks to nontarget organisms. Soaps and many botanicals may be applied to food crops shortly before harvest without leaving excessive residues.

- **Rapid action.** Botanicals and soaps act very quickly to stop feeding by pest insects. Although they may not cause death for hours or days, they often cause immediate paralysis or cessation of feeding.

- **Low mammalian toxicity.** Most botanicals and insecticidal soaps have low to moderate mammalian toxicity. There are exceptions, however; see pp. 4-5 for a general discussion of insecticide toxicities.

NOTE: The information in this circular is provided for educational purposes only. Trade names of insecticides have been used for clarity, but reference to trade names does not imply endorsement by the University of Illinois; discrimination is not intended against any product. The reader is urged to exercise caution in making purchases or evaluating product information.

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