Bt biopesticide – marvel or mistake?

Conventional pesticides such as DDT and organophosphates have not only become less effective as target insect populations evolve resistance, but have killed non-target predators and parasites that otherwise keep pest insects in balance. Thus, under some conditions, pest populations have exploded to uncontrollable levels, decimating whatever crops or gardens they happen to feed upon. Furthermore, these persistent pesticides have accumulated throughout aquatic and terrestrial food webs (connected food chains within an ecosystem), creating ecological imbalances and impairing human health. Global concerns regarding pesticide resistance, environmental degradation, and human health problems have led to the development of biologically based, narrow-spectrum pesticides with fewer long-term hazards. Over the last several decades, more farmers, forest and landscape managers, and gardeners have turned to these more environmentally friendly methods of pest control, including Bt.

An introduction to Bt

Bt is an acronym for *Bacillus thuringiensis*, a naturally occurring species of bacteria found world-wide in the soil and on plants. Nearly 100 years ago, this bacterium was discovered to have pesticidal properties if consumed by the larvae of specific insects. Many subspecies, varieties, and strains of Bt have been identified since then, and it's likely many others have yet to be discovered. Though genes from Bt have also been used in genetically modified organisms, this article will focus only on the use of the microbe as an applied insecticide.

The strains of Bt characterized so far affect members of three insect Orders: Lepidoptera (butterflies and moths), Diptera (mosquitoes and biting flies), and Coleoptera (beetles). Commercially-available, EPA-registered Bt products include:

- *B.t. aizawai* (Lepidoptera) – used for wax moth larvae in honeycombs
- *B.t. israelensis* (Diptera) – frequently used for mosquitoes (see sidebar at end)
- *B.t. kurstaki* (Lepidoptera) – frequently used for gypsy moth, spruce budworm, and many vegetable pests
- *B.t. san diego* and *tenebrionis* (Coleoptera) - frequently used for elm leaf beetle, Colorado potato beetle

B.t. kurstaki is the most commonly used Bt formulation, as it will kill many leaf-feeding larvae on vegetables, shrubs, fruit trees and conifers. There is abundant scientific literature on this biopesticidal organism.

Other Bt isolates have been characterized but not yet registered by the EPA. These include:

- *B.t. galleriae* – (Coleoptera) – used on Japanese beetles
- *B.t. japonensis* and *kumamotoensis* – (Coleoptera) – used on several turf beetle species

Local isolates of Bt probably represent an underutilized, yet powerful, biological control resource. In China, 30 new strains of Bt were isolated from drylands, gardens, and rice fields; from these, one highly toxic strain was able to kill 100% of treated diamondback moth larvae (*Plutella xylostella*). Similarly high toxicities were found in ten new Bt strains isolated from leaf and soil samples in Poland and in four new strains discovered in Mexico. Local bacterial populations have the advantage of being adapted to local insect host; thus, it is logical to expect to find powerful biocontrol agents in the pest's backyard.

Mode of action

Bacillus thuringiensis strains produce crystalline proteins (called δ-endotoxins) that, when consumed by particular insect larvae, have a poisonous effect upon the lining of the gut. While some of the toxicological details are still a topic of scientific debate, we do know that the crystalline proteins manufactured by the bacteria are toxic, causing the cell membranes in the gut to split open and thus kill the larvae. The specificity of these toxins for insect physiology means that other animals are not affected by the bacteria.

Bt found naturally on or applied to leaf surfaces must be ingested by the feeding form or an insect (the larvae) to have an effect; in other words, Bt has no effect on adult insects. Susceptible larvae that ingest the toxin are not killed immediately, but die over the next few days. They do stop feeding, however, and thus plant damage is halted. Larvae that survive the toxin may be more susceptible to other environmental stresses, such as cold temperatures or low levels of botanical insecticides. This type of synergistic effect underscores the importance of utilizing Bt as part of an integrated pest management plan.

Some insects have already developed resistance to Bt, most importantly the diamondback moth (*Plutella xylostella*), regarded as one of the most destructive crop pests worldwide. It is a particulary resiliant species, reported to be the first insect to develop resistance to DDT and almost every other synthetic insecticide. Bt-resistant insects apparently are able to detoxify the bacterial proteins quickly and thus survive. Interestingly, Bt resistance appears to harm the insect's fitness when Bt is not present; in other words, resistant individuals do not reproduce well so that resistance is quickly lost in the larger population when Bt is not applied. This "resistance instability" may explain why Bt resistance is uncommon in pest insect populations.

Human health and safety

All strains, subspecies, and varieties of Bt used as pesticides must be extensively tested for both human and environmental safety. Regulatory agencies, such as the USEPA, require thorough evaluations of the active microbial ingredient before they can be registered as pesticides. *Bacillus thuringiensis* has been extensively used for four decades in biopesticidal formulations due to its environmental and human health records.

Bt is considered to be "practically non-toxic" to humans and other vertebrates. It can cause a "very slight irritation" if inhaled, and can cause eye irritation. These acute effects are considered to be minor; there are no chronic toxicities. Bt is not carcinogenic, mutagenic, or teratogenic: in other words, it does not cause cancer, induce chromosomal mutations, or lead to birth defects in exposed animals.

Bt does not persist in the brains, lungs, or digestive systems of animals including humans. While Bt has been found in fecal samples of exposed greenhouse workers, no GI symptoms were associated with its presence. In fact, Bt appears to be a normal component in the feces of vegetable-consuming animals, where it apparently causes no problem. Since Bt is a normally-occuring bacteria often found on leaf surfaces, this should not be a surprise or a cause for concern.

Like the active bacterial ingredient, the inert ingredients in Bt formulations have also been studied and modified for safety. Newer formulations employ preservatives, like sorbitol, that are safer than the xylene used decades ago. Likewise, granular and microcapsule formulations reduce the inhalation hazard. Volatile agents associated with some Bt formulations likewise do not appear to constitute a significant health hazard.

In the 50 years that Bt has been used for insect control, there have been few reports of human pathogenicity, suggesting that the commercially available products are free from non-Bt microbes and can be safely used around people. In contrast, there are often significant human health risks associated with the pest insects themselves. Many larvae are protected by urticating (barbed) hairs, which can irritate skin and mucous membranes. Dermatitis, conjunctivitis, and/or respiratory disorders have resulted in people who have been in contact with pine processionary moth *Thaumetopoea pityocampa*, cypress processionary moth *Thaumetopoea wilkinsoni*, and grapeleaf skeletonizer *Harrisina brillians*.

Environmental and ecological impacts

In addition to their excellent record on human health, Bt products are globally recognized by researchers in many disciplines as an environmentally safe means of controlling pest insects. There is an extensive and reliable body of science demonstrating the environmental safety of Bt, allowing governmental and health organizations to recommend their use on a variety of landscapes worldwide.

Specifically, no danger has been found to aquatic communities accidentally exposed to Bt (but see sidebar) or to non-target organisms including beneficial insects, amphibians, fish, and mammals. A number of researchers have demonstrated the general safety of Bt formulations to natural predators of pest insects. By and large, these predators belong to different orders than those affected by most Bt formulations, including spiders (Araneae), ladybugs (Coleoptera), true bugs (Hemiptera), and ants (Hymenoptera).

There are few reports of Bt lethality upon non-target organisms, such as leaf-feeding caterpillars. Another researcher has suggested that clay soils may bind the bacterial toxin, increasing its environmental persistence and possible toxicity to non-target species. Though the preponderance of the evidence does not agree with these reports, all researchers concur that Bt monitoring must continue to explore these exceptions and to modify Bt usage as needed.

Urban use

Increasingly, land managers are recognizing the environmental advantages of reduced chemical treatments in urban areas. Given their extraordinary record in human and environmental health and safety, Bt products are increasingly applied to urban parks and landscapes to control gypsy moth (*Lymantria dispar*), cypress and pine processionary moth (*Thaumetopoea wilkinsoni* and *Thaumetopoea pityocampa*), fall webworm (*Hyphantria cunea*) and other nuisance insects. These insects are of particular concern because of their abilities to denude trees, invade woodpiles, houses, and vehicles in search of pupation sites (fall webworm), and cause human health problems as mentioned earlier.

Bt use in urban areas requires a significant public education effort. This was illustrated several years ago when citizens and environmental groups became upset with the aerial spraying done in parts of Oregon and Washington to control invasions of gypsy moths (*Lymantria dispar*) and attempted to get an injunction to halt spraying. The presiding judge found no scientific proof that Bt was hazardous to people and that the eradication of the moth populations was of greater environmental concern. Obviously, close communication with the public is critical when Bt products are used, so that environmental and health concerns can be addressed. In addition, governmental organizations must be proactive in enforcing safety regulations and establishing buffer zones in populated areas to reduce perceived risk and engender citizen trust.

Unfortunately, some gray literature (i.e. not peer-reviewed) ignores the decades of scientific research on Bt and instead uses scare tactics against Bt. These unbalanced articles serve only to upset the general public and do not advance either the research, or the discussion, that must continue to take place regarding Bt and other biopesticides. It is naïve to assume that growers and landscape managers will give up Bt and simply sit back to watch their livelihood collapse; if safe and practical alternatives are not available, they will resort to conventional methods. This is not the direction we need to move.

Bt as part of an Integrated Pest Management (IPM) program

Like any other pest control method, Bt works best as part of an integrated management plan. The philosophy of such a plan is to reduce pests to acceptable levels, not to eliminate them completely. As we've discovered – much to our detriment - attempts to exterminate pests result in resistant pest populations and environmental degradation.

Bt has become a cornerstone of IPM systems, accounting for more than 90% of the biological insecticides currently used. Though Bt has been used successfully by itself, the practice of IPM generally incorporates Bt, with other biological, cultural, mechanical, and chemical controls. A great deal of research worldwide has explored the use of Bt in concert with these associated methods:

Cultural: Crop rotation; minimium tillage; shelter strips

Mechanical: Removal of pest (eggs and larvae); removal of infested materials

Biological: Parasitoids; pathogens, including Bt, fungi, granulosis virus and nucleopolyhedrosis virus; predators

Chemical: Botanical insecticides such as neem; pheromone baiting/mating disruption; pyrethrins and pyrethroids

Practical considerations

Like any other living organism, Bt activity is affected by environmental factors including temperature, rainfall, pH, and sunlight. Bt applied to leaf surfaces, for example, can be degraded by solar UV or washed off by irrigation or rainfall. Many of these limitations have been addressed through the development of new Bt formulations that protect the organism from deactivation. Still, there are other factors that influence effectiveness of this biocontrol agent.

Only the feeding larval stage is susceptible to Bt, and thus **timing of application** is of paramount importance. While this may be during the spring for many leptidopteran pest species, for coleopteran pests in turf application is only effective in the fall. Cold weather decreases effectiveness, perhaps because larval feeding activity is reduced.

Location of the target insect also influences Bt effectiveness. Boring insects, though susceptible to Bt in laboratory trials, can escape Bt exposure if feeding in protected sites. Likewise, it is difficult, if not impossible, to spray the crowns of tall trees from the ground.

In such cases, a cherry-picker could be used for spraying individual trees, but larger areas are more effectively managed through aerial spraying.

As with any other pesticide, Bt must be considered as an option, not a magic bullet, for pest management. **Consumer education** is critical in this regard to avoid improper or overapplication of Bt. Misapplication of Bt at the wrong time or on the wrong species can lead to pest resistance.

<u>Economic feasibility</u>

In its infancy, use of Bt was costly to produce and to apply; while formulation is still expensive, new production techniques have been developed that promise to lower the cost in developing countries. Bt is more cost effective to use now, since application costs have decreased. Proponents hope that the environmental and human health benefits would more than offset the economic costs.

Indeed, the economic comparisons between conventionally managed and IPM (including Bt) fields have demonstrated that not only was insect damage reduction approximately the same, but that IPM net profits were greater because of reduced insecticide costs. Though not included in these studies, the more intangible benefits associated with Bt-treated fields—such as reduction in pesticide resistance, less environmental damage, fewer human health risks—cannot be ignored and must be emphasized.

The big picture

There is no question that broad-spectrum, conventional pesticides can cause more problems than they solve. Not only is the pest killed, but so too are the beneficial predators and parasites, leading to future outbreaks of resistant pest populations. The negative, long-lasting effects of these pesticides on human and environmental health should not be ignored or considered collateral damage.

Once insects become resistant to chemical pesticides, the usefulness of that compound is finished, at least temporarily. The elegance of biocontrol systems, like Bt, is that the pesticide is a living organism – one that can evolve as its host becomes resistant. New strains of Bt and related species are discovered routinely. These specifically-targeted compounds are considered by the scientific community to be environmentally friendly, with little or no effect on humans, wildlife, pollinators, and most other beneficial insects. We continue to discover what we've always known—that it's easier to work with nature than against it.

Sidebar: Bt for mosquito control

Perhaps nowhere has Bt usage had such dramatic effects as in fighting mosquitoes and the illnesses they carry. Historically, mosquitoes have been implicated as transmitters for malaria, encephalitis, and dengue fever, but more recently have been recognized as the carriers of West Nile viruses and many other viruses, pathogens, and parasites. Mosquitoes of in the genera *Aedes*, *Anopheles*, *Culex*, *Psorophora*, and *Stegomyia* cause much human misery and have high societal costs associated with them.

Bacillus thuringiensis israelensis, or Bti, has been used effectively to kill many species of mosquitoes within these genera, as well as other biting flies in the Order Diptera worldwide; this has been demonstrated repeatedly through field studies in Africa, Asia, Australia, Eastern and Western Europe, India, and North America. Though not registered by the USEPA, *B.t. sphaericus* (Bs) also has activity against mosquito larvae, as does *B.t. jegathesan*. Field tests have shown significant reductions in both mosquito numbers and associated malarial cases.

Formulations are important with Bt products applied to aquatic systems. Dry preparations tend to be less successful, as the spores settle to the bottom and are not eaten by larvae, which tend to be near the surface of the water. Biofilms, fizzy tablets, and slow-release floating rings are more effective in this regard. The latter two formulations are readily available, inexpensive, and can be easily handled and applied by volunteers. They should be used anywhere that standing water – and mosquito larvae – accumulates. Treatments often need to be repeated to treat subsequent hatchings.

Though some mosquitoes have developed resistance to some *Bacillus* species, applying these biopesticides in rotation has overcome resistance. Use of other IPM choices, such as predatory fish, can help reduce larval numbers. Finally, new strains of Bti and Bs are constantly being discovered in rice fields, plantations, gardens, and other habitats with standing water.

Bti has generally been seen to be safe for non-target aquatic organisms, such as dragonflies, damsel flies, notonectid bugs, fishes, frogs and birds, according to the majority of studies that have been performed. Conflicting information comes from two studies in Minnesota: one over 3 years and the second over 6 years. The shorter of the studies reported severe declines in Diptera species, causing the authors to question the environmental safety of Bti. However, the longer study found no negative effects on zooplankton or bird populations resulting from insect decreases. These authors noted that the ecological complexity of wetland food webs and/or other environmental factors could nullify the impact of reduced insect numbers. Indeed, the first authors acknowledged that droughty years would cause a similar decline in insect populations, a completely natural situation from which one would expect the system to recover.

Conventional mosquito treatment has usually consisted of DDT, a highly toxic, broad-spectrum pesticide whose residues persist throughout food chains decades after their application. Though banned in the US since 1973, DDT is still legally applied to many regions of the world where malaria is a problem. Less devastating are the synthetic pyrethroids, which still kill about 150-200 non-target organisms for each adult mosquito killed. In comparison, Bt products represent a much gentler approach to mosquito management.

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