COOPERATIVE EXTENSION SERVICE
UNIVERSITY OF KENTUCKY—COLLEGE OF AGRICULTURE

Bt Basics for Vegetable Integrated Pest Management

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Bt is an often misunderstood but extremely valuable insect pest management tool used in both organic and conventional vegetable crop production systems. Control failures and disappointments occur, however, when Bt's unique mode of action is poorly understood and/or the commercial product is misused or improperly applied. IPM educators need to provide a basic understanding of Bt and its use as a component of best management practices for vegetable crops, especially for cole crops (Brassicaceae). This publication provides the most important information needed regarding Bt and its use in vegetable crops. It is intended for use by IPM trainers, Extension workers, and crop advisors in their farmer education programs. (ID-156A, *Growers' Guide to Bt*, is available for farmers.)

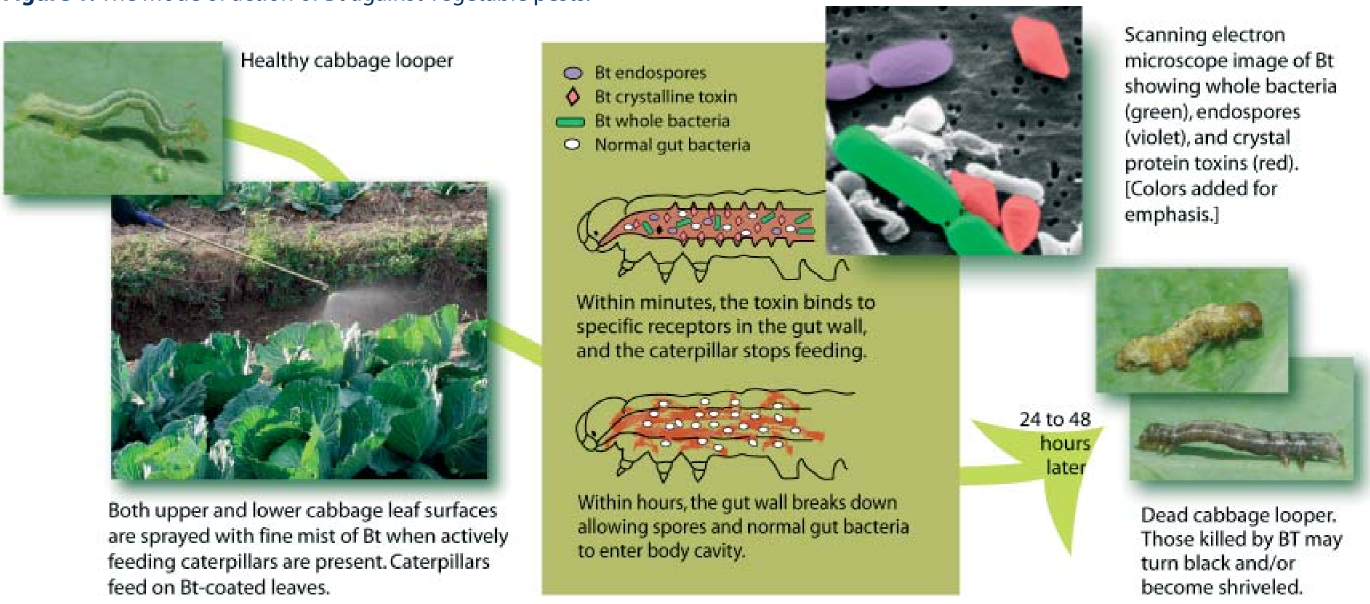
What is Bt?

"Bt," first discovered in Japan in 1901, refers to a spore-forming bacterium, *Bacillus thuringiensis,* which occurs naturally in soils. Some leaf-feeding caterpillars (larvae of butterflies and moths) are killed when they eat very small amounts of leaves or other plant parts that have been coated (sprayed) with Bt. Thousands of strains of Bt bacteria exist and a few of these have been used to manufacture what have been termed microbial or biological insecticides. Most of these commercial products contain crystal-shaped proteins and living spores (Figure 1), from Bt bacteria. There are many commercial brands of Bt; two Bt subspecies are commonly used against caterpillars that feed on cabbage and other vegetable crops.

How does Bt work?

It is very important to understand that Bt does not work like most conventional insecticides. While very effective against certain insect pests, Bt has no contact or "knockdown" effect (i.e., pests are not killed instantly after spraying). Insects must eat a minute amount of Bt-coated plant material to be killed. When enough Bt is consumed, toxins in the crystal proteins paralyze the caterpillar's mouth and gut (Figure 1). Pests begin to move slowly and *stop feeding within minutes to an hour* after consuming a sufficient dose. The toxins break down the insects' gut wall within hours, allowing Bt spores and the insects' normal gut contents to invade the body cavity. This causes death by starvation, septicemia (blood poisoning), and/or osmotic shock within 24 to 48 hours. Some larvae killed by Bt may become discolored or turn black; dead larvae often become shriveled (Figure 1) and fall from the plant where they are not easily observed by farmers or IPM scouts.

Figure 1. The mode of action of Bt against vegetable pests.



Why should vegetable growers use Bt?

Bt has many advantages. It is nontoxic to humans, fish, and animals and leaves no toxic residue on fruits and vegetables. Most Bt products are exempt from pesticide tolerance limits and have no preharvest interval (waiting period). The toxins found in Bt are biodegradable and do not persist in the environment. Bt is also very specific in that it kills only certain types of insects. Unlike many conventional insecticides, most strains of Bt are nontoxic or only mildly toxic to beneficial insects[1]. Natural enemies (predators and parasitoids) of insect pests are protected and help control these pests. Several species of parasitic wasps (especially *Diadegma* spp.) contribute significantly to the natural control of diamondback moth (DBM); DBM control becomes much more difficult when these parasitoids are eliminated by harsh insecticides.

Beneficial insects like this diamondback moth parasitoid (*Diadegma* sp.) are not harmed by Bt.

When used as part of an integrated pest management program, Bt also protects natural enemies that can enhance natural control of important pests *in addition to* the target pest(s). When Bt was used to control beet armyworm in California, for example, *Liriomyza* leafminers became much less of a problem in celery and processing tomatoes. In this case, Bt allowed natural enemies of leafminers to survive and help control the pest, reducing the need for other insecticide applications.

Bt does not kill beneficial insect predators like this spined soldier bug (*Podisus maculiventris*) shown here attacking imported cabbageworm.

Can Bt be used for certified organic vegetable production

In most cases, yes. Many formulations of Bt are made using natural processes and have been approved by the Organic Materials Review Institute for certified organic production; however, some Bt products are genetically modified and are not approved (see Table 1). Check the OMRI Web site <www.omri.org> and contact your state certifying agency for a list of approved brands.

What vegetable crop pests are controlled by Bt?

Two subspecies of Bt (Bt *kurstaki* and Bt *aizawai*) are most often used against cabbage and other vegetable pests (see label below and Table 1). These control only larvae of butterflies and moths and not beetle larvae or other insects. Other Bt products have been developed for use against unrelated pests. Bt *tenebrionis* (Novodor®), for example, can be used to control larval stages of the Colorado potato beetle (Table 1). Other forms of Bt are used to control mosquito larvae, fungus gnats (in greenhouses), etc.

This Bt product label indicates that its active ingredient is Bt *kurstaki.*

Many commercial formulations of Bt *kurstaki* and Bt *aizawai* are available for use on vegetable crops; the only reliable way of identifying the most effective Bt product for the target pest(s) is through local field trials. Table 1 lists most of the Bt products on the market in the United States in 2005. General differences[2] between Bt *kurstaki* and Bt *aizawai* products are discussed on page 4.

[1] Bt *aizawai* technical grade active ingredient is moderately toxic to honeybees, green lacewings, and a predatory mite (*Metaseiulus occidentalis*); risk to beneficial insects is minimal when used according to the product label.

[2] These distinctions in efficacy between Bt *kurstaki* and Bt *aizawai* are relative because although the typical *aizawai* crystalline toxins (Cry1C and Cry1D) are more effective on *Spodoptera* species, Cry1Ab and Cry1Aa in *kurstaki* strains are moderately effective against *Spodoptera* as well.

Table 1. Commercial Bt products available for cabbage and other vegetable crop pests (2005).

	Bt subspecies									
	Bt *kurstaki*[2]							Bt *aizawai*		Bt *tenebrionis*
Trade Name	**DiPel**	**Crymax**[1]	**Condor**	**Lepinox**	**Biobit HP**	**Javelin**	**Deliver**	**XenTari**	**Agree**[1]	**Novodor**
Manufacturer	Valent	Certis	Certis	Certis	Valent	Certis	Certis	Valent	Certis	Valent
Formulation(s)[3]	DF, ES	WDG	F	WDG	WP	WG	WG	DF	WG	FC
Potency[4]	17600-32000	na	na	na	32000	53000	na	35000	25000	15000
OMRI approved (for organic)[5]	yes	no	no	no	yes	yes	yes	yes	yes	no
Crop & Pest[6]										
Broccoli, Cabbage, Cauliflower, other brassicas										
Cabbage looper	X	X	X	X	X	X	X	X	X	
Diamondback moth	X	X	X	X	X	X	X	X	X	
Imported cabbageworm	X	X	X	X	X	X	X	X	X	
Armyworms (general)	X	X	X	X	X	X	X	X	X	
Sweet Corn										
Armyworms (general)	X	X	X	X	X	X	X	X		
Corn earworm	X (ES)						X	X		
European corn borer	X	X	X	X			X	X	X	
Lettuce, endive, escarole										
Cabbage looper	X	X	X	X		X	X	X	X	
Pepper										
European corn borer		X	X	X		X	X			
Armyworms (general)	X	X	X	X	X	X	X	X	X	
Spinach										
Cabbage looper	X	X	X	X	X	X	X	X	X	
Tomato										
Colorado potato beetle										X
Cabbage looper	X	X	X	X	X	X	X	X	X	
Tomato fruitworm	X	X	X	X	X	X	X	X	X	
Tomato hornworm	X	X	X	X	X	X	X	X	X	
Tomato pinworm		X	X	X	X	X	X			
Eggplant										
Armyworms (general)	X	X	X	X	X	X	X	X		
Colorado potato beetle										X
Potato										
Colorado potato beetle										X
European corn borer	X (ES)	X	X	X		X	X			

1. These products contain crystal proteins from both Bt *kurstaki* (Cry 1Ac) and Bt *aizawai* (Cry 1C).
2. Another Bt *kurstaki* product, Thuricide HPC, is sold by several companies including Bonide, American, etc.; it is intended primarily for the home garden market and not intended for use by commercial growers.
3. DF = Dry flowable, F = oil flowable, FC = water-based flowable concentrate, ES = oil-based emulsifiable suspension, WP = wettable powder, HPC = high potency concentrate in water, WDG or WG = water dispersible granules.
4. Number of effective killing units (crystal proteins, spores, etc.) per milligram of the product as determined by bioassy; potency for Novodor is expressed as units per gram. These data should not be used to compare products that use different test insects (see text); "na" = information not available.
5. OMRI status as of 2005; check current label.
6. An 'X' in the table indicates that these specific crop and pest combinations appear on the product label; see current product labels for additional labelled crops and pests.

Bt *kurstaki*:

Controls diamondback moth (*Plutella xylostella,* or DBM), cabbage looper (CL, *Trichoplusia ni*), imported cabbage worm (ICW, *Pieris rapae*), and tomato fruitworms (*Heliothis/Helicoverpa* spp.). Keep in mind that there are differences among commercial strains of Bt *kurstaki.* Some, but not all, *kurstaki* products are effective against beet armyworm (*Spodoptera exigua*) and small larvae of cluster caterpillar (*Spodoptera litura*)[3].

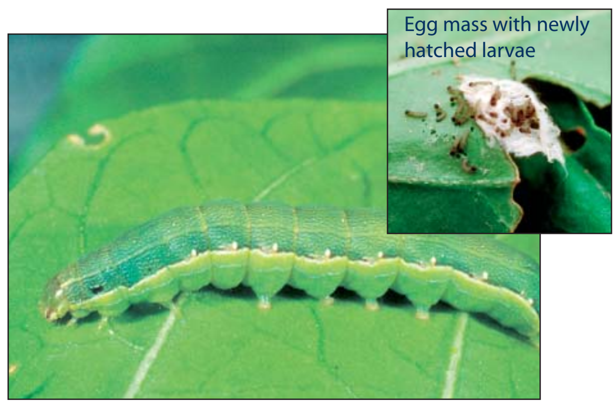
Bt aizawai:

Controls DBM, CL, ICW, tomato fruitworm, and armyworms (small larvae only). In general, Bt *aizawai* products are more effective against small larvae of cluster caterpillar and beet armyworm than Bt *kurstaki* products. Bt *aizawai* may still be effective in areas where DBM has developed resistance to Bt *kurstaki*.

Cabbage looper (*Trichoplusia ni*)

Diamondback moth (*Plutella xylostella*)

Imported cabbageworm (*Pieris rapae*)



Beet armyworm (*Spodoptera exigua*)

Tomato fruitworm (*Heliothis/Helicoverpa* spp.)

Cluster caterpillar (*Spodoptera litura*)[3]

[3] Cluster caterpillar (*Spodoptera litura*) occurs only in Asia and the Pacific region, including Australia and New Zealand.

What is the difference between these two types of Bt?

The two most common types of Bt are sold under various trade names (Table 1). These two subspecies contain different toxic crystal proteins (delta-endotoxins or "Cry" toxins) (see Table 2 and Figure 1). These toxins differ in their effectiveness against different pests. In addition, crystal proteins from both Bt *kurstaki* and Bt *aizawai* have been combined in some newer products to increase their effectiveness (Table 1). Table 2 lists the different crystal toxins found in two common Bt *kurstaki* and Bt *aizawai* products[4].

Table 2. Crystal protein toxins (Cry) found in two common forms of Bt used for cabbage and other vegetable pests.

Crystal toxins	Bt kurstaki	Bt aizawai
Cry 1Aa	+	+
Cry 1Ab	+	+
Cry 1Ac	**+**	--
Cry 2A	**+**	--
Cry 1C	--	**+**
Cry 1D	--	**+**

Note: *Different commercial Bt products may contain differing proportions of these toxins*; bold "**+**" signs indicate the most common differences. The gene for Cry2B protein is also present in both subspecies but is usually not expressed.

Have pests developed resistance to Bt?

Yes. Although it was very slow in coming, resistance to Bt *kurstaki* has been documented for diamondback moth in Thailand, Malaysia, the Philippines, China, Taiwan, Honduras, Costa Rica, Guatemala, New York, Florida, and Hawaii. Insects become resistant when 1) only one Bt subspecies is applied frequently as the only insecticide to control a pest, 2) when the pest has a short life cycle with many generations (like diamondback moth) over a long growing season (or where crops are grown continuously as in tropical/subtropical climates), and 3) when the treated pest population is isolated from populations of the same pest from nontreated areas. Some cabbage production areas in the tropics are relatively isolated with climates that permit 20 or more generations of diamondback moth to develop each year.

How can resistance to Bt be prevented or delayed?

"Resistance management" is especially a concern when Bt is used for diamondback moth control. Perhaps the best way to avoid resistance is to avoid continuous Bt applications and to use the product only when necessary. This requires frequent observations or scouting in the field and the use of treatment thresholds whenever possible. *Early detection of infestations is especially important* when Bt is used as the primary pest control tool.

Simple, presence/absence scouting methods and percentage-based thresholds have been used effectively in cabbage and other crucifer crop IPM programs. An example for cabbage is shown in Table 3.

Field scouting is essential to detect pest infestations early.

Table 3. Treatment thresholds for diamondback moth and other caterpillar pests in fresh market cabbage (Foster and Flood, 1995).

Growth stage	Threshold (% plants infested*)
After transplanting, before cupping	≥ 30%
Cupping to early heading	≥ 20%
Early heading to mature head	≥ 10%

*Percentage of plants that have one or more larvae of diamondback moth, cabbage looper, or imported cabbageworm; treat when the percentage of plants infested reaches or exceeds this number.

This is the "cupping" stage of cabbage growth. For more information see Cornell University Extension Bulletin No. 101 <www.nysaes.cornell.edu/pubs/fls>.

[4] Toxins listed are from DiPel® (Bt *kurstaki*) and XenTari® (Bt *aizawai*).

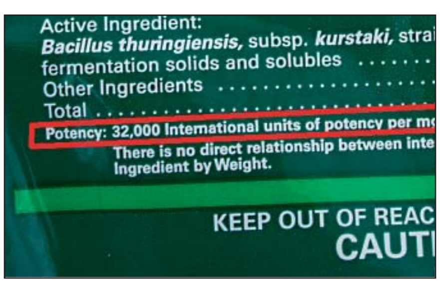
One of the most important principles of resistance management is to avoid continuous, repetitive use of the same insecticide (or different insecticides but with the same mode of action). Organic growers can alternate Bt with neem-derived azadirachtin (Neemix® and others) or products like the OMRI-approved version of spinosad (Entrust®). For conventional vegetable growers, Bt can be rotated with many other classes of insecticides although some of the benefits of Bt (conservation of natural enemies) could be compromised. Newer, "reduced risk" insecticides should be used whenever possible. Pyrethroid insecticides should be avoided.

It may also be beneficial to rotate between Bt *kurstaki* and Bt *aizawai*. These two subspecies share some crystalline toxins but differ in others (Cry1C, Cry1D, see Table 2). These different toxins can have different modes of action. For organic growers in the United States, it has become standard practice to use two to three Bt *kurstaki* product applications alternating with one Bt *aizawai* product application (see Table 1).

Another important resistance management strategy is to maintain a portion of the crop that is not sprayed with Bt or any other insecticide. This planting can be in a separate, nearby field or can be within the same field. The unsprayed portion acts as a "refuge" where Bt-susceptible individuals in the pest population are not killed. These susceptible insects mate with more resistant individuals found in the Bt-treated portion of the field. This helps delay the development of a pest population in which most individuals are resistant. It has been shown experimentally that using 10 percent of the crop area as a refuge delayed resistance to Bt *aizawai* in diamondback moth. It is not known, however, whether this approach will be effective or practical in small plantings of high-value commercial vegetable crops.

What does "potency" mean?

Manufacturers often provide potency data for their products; these data are usually reported in terms of International Units per milligram (IU/mg) or billions of International Units per kilogram (BIU/kg). This is often a source of confusion for both advisers and growers. Potency is a measure of the number of effective killing units of the product (crystal proteins, spores, etc.) in bioassays against cabbage loopers compared to the killing power of a Bt reference strain which is assigned an arbitrary potency value. This generally means that the higher the potency number, the more concentrated the product.



Potency is usually indicated on the product label.

It also offers some assurance to buyers that the product has been tested to ensure its biological effectiveness.

Unfortunately there are no federal standards for potency testing, and manufacturers often report potency against different species of test insects for different products. Some products, for example, may be more effective against diamondback moth than cabbage looper, so potency is reported in terms of diamondback moth units. It is therefore not possible to make direct comparisons of potency among products tested against different test insects. Potency reported for XenTari®, for example, is "35,000 Diamondback Moth Units per mg of product" while Dipel ES® contains "17,600 Cabbage Looper Units per mg of product."

Potency should not be used to adjust field application rates of the product. Different products may have very different percentages of active ingredient by weight (see product label). Only the manufacturer's label recommendations should be used to determine field application rates.

Which product should I recommend to farmers?

Local experience and field trials with various brand names and formulations will help you select the best Bt product for the intended pest(s). In some countries, for example, diamondback moth is more resistant to Bt *kurstaki* than to Bt *aizawai*. Also choose a formulation that is easy to use and that disperses well in water. Bt products are made through a fermentation process, and water-based liquid formulations will only last one season. Dry and oil-based formulations have a shelf life of at least two years. For water-based formulations, it is important to obtain fresh stock each year from reputable agricultural supply dealers. Lastly, buy only EPA-registered products and ask questions about the product you are buying.

Can Bt be mixed with other insecticides/pesticides? Should Bt be mixed with other pesticides?

Bt products can be mixed with other insecticides and other pesticides; however, the possible negative impacts on natural insect predators and parasitoids should be considered. Many broad-spectrum conventional insecticides kill natural enemies together with pests. By mixing these products with Bt, one of Bt's most important benefits—the conservation of natural enemies—may be lost.

Any tank mix solutions used should remain close to pH 7 (between 6 and 8). Chemical pesticides that are alkaline should not be mixed with any Bt product; some Bt products should not be mixed with any of the common chlorothalonil-based vegetable fungicides (Bravo®, Echo®, Equus®, etc.).

Are there times when the Bt application rate should be increased?

Increased rates of Bt may be required when the crop foliage increases and/or when high caterpillar populations or older caterpillars are present. In addition, some product labels call for higher Bt rates to treat infestations of cabbage looper. If possible, Bt applications should be timed with egg laying (20% hatch) of the target pest. If that is not possible, Bt must be used *when insect larvae are small* and before economic thresholds are reached. Obviously this requires regular field scouting. Knowing the population dynamics of the target pest is essential to any IPM program and is especially important for good control with Bt. When obvious insect damage is visible, it may be a bit late for effective control with Bt at the lowest rates. In the absence of scouting or if overlapping generations or mixed insect pest species are present, regular calendar-timed applications may be the only effective control strategy.

What are some general guidelines for using Bt?

Size of larvae: Bt products are most effective against *small larvae* (1st and 2nd instar); large larvae, especially *Spodoptera* spp., are difficult to control with Bt.

Bt is most effective against small larvae; these larvae are killed before significant damage occurs. Photo shows a cabbage looper.

Effects of sunlight: Direct sunlight will inactivate Bt products as well as some other insecticides. It is highly recommended to do a thorough Bt application using nozzles above and on both sides of the crop foliage. It is very important to use a spray volume that will cover both sides of leaves and to make sure that the spray penetrates dense foliage. Bt that is shaded from direct sunlight by foliage will last longer. If practical, late afternoon applications will enhance Bt longevity.

Late afternoon applications will enhance Bt longevity as direct sunlight can inactivate this product.

Use of sticker: Since Bt products are not completely soluble, the use of a sticker or "spreader-sticker" is recommended on hard-to-wet crops such as cabbage. If heavy rainfall occurs within 24 to 48 hours after application, it is recommended to reapply Bt.

Irrigation method: Sprinkler irrigation or hand watering can wash off Bt. Drip irrigation will enhance pest control with Bt by reducing washing off of the product.

Shelf life: Dry and oil-based Bt products have a longer shelf life than water-based liquids. Water-based "FC" formulations will not last as long as most other formulations at high temperatures and *should be used for one growing season only*. Dry products may still be effective for three to four years when kept at or below 75°F to 85°F (25°C to 30°C). All Bt products should be kept as cool and dry as possible in storage.

Other: Continuous agitation of the mixture in the sprayer tank or recirculation is highly recommended.

Drip irrigation enhances pest control as it minimizes Bt wash-off.

What do farmers need to know about Bt?

Bt is not like other insecticides and farmers need to know how to use it properly. ID-156A, *Growers' Guide to Bt,* a fact sheet intended for commercial vegetable growers and gardeners, is available on the Web at <http://www.ca.uky.edu/agc/pubs/id/id156A/id156A.pdf>.

Reference

Foster, Rick and B. Flood (eds.). 1995. *Vegetable Insect Management with Emphasis on the Midwest*. Meister Publishing. Willoughby, Ohio. 206 p.

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Photo credits: Scanning electron micrograph of Bt in Figure 1 on page 1 courtesy of Dr. Brent Selinger, Department of Biological Sciences, University of Lethbridge, Alberta. *Diadegma* sp. photo on page 2 courtesy of Dr. Merle Shepard, Clemson University. Photo of a tomato fruitworm (*Heliothis/Helicoverpa* spp.) on page 4 courtesy of Alton N. Sparks, Jr., The University of Georgia <www.ipmimages.org>. All other photographs by the authors.

The use of trade names in this publication does not imply endorsement of the products named nor criticism of similar products not mentioned. This guide is for reference only; the most recent product label is the final authority concerning application rates, precautions, harvest intervals, and other relevant information.

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