

Biorational Insecticides for Integrated Pest Management in Tomatoes¹

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IPM and Biorational Insecticides

Integrated pest management (IPM) can be defined as the use of all available means to maintain pest populations below levels that would cause economic loss while minimally impacting the environment. The tactics utilized in IPM programs include chemical, cultural, physical, and biological control. Most management programs rely heavily upon the use of insecticides applied when periodic scouting indicates that pests have exceeded a pre-determined threshold. Insecticides provide quick control of pests but often require repeated applications to provide long term management. It has long been recognized by researchers and, more recently, by IPM practitioners that the integration of biological control (mortality induced by natural enemies including parasites, predators, and pathogens) into IPM programs is essential for long term, stable management of pests. Repeated applications of insecticides can lead to the development of resistance in the target pest and can reduce the natural enemy populations, leading to resurgence of the target pest(s) and outbreaks of secondary pests, i.e. those normally kept under

control by their natural enemies. Therefore, knowledge not only of the effect of an insecticide on the target pest but also on non-target natural enemies is essential. Although this information has been collected for at least the last 50 years for some insecticides, the term “biorational” has only recently been proposed to describe those insecticides that are efficacious against the target pest but are less detrimental to natural enemies. The term at times has been used to describe only those products derived from natural sources, i.e. plant extracts, insect pathogens, etc. However, we choose to define a biorational pesticide as “any type of insecticide active against pest populations, but relatively innocuous to non-target organisms, and, therefore, non-disruptive to biological control” (Stansly et al. 1996). An insecticide can be “innocuous” by having low or no direct toxicity, or by having systemic or by moving rapidly into the leaf through the leaf surface, or by having short field residual, thereby minimizing exposure of natural enemies to the insecticide.

As will be seen in the present discussion, the “biorationality” of an insecticide is almost always

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1. This is document ENY-684, one of a series of the Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Reviewed: March 2005 and June 2009. Please visit the EDIS Web site at <http://edis.ifas.ufl.edu>.
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relative, i.e. the toxicity of one insecticide is compared to that of other insecticides, or is almost never broad spectrum, i.e. an insecticide can be innocuous to one natural enemy or even some life stages of one natural enemy but can be toxic to another natural enemy or other life stages.

Traditionally, soaps/detergents, oils and botanicals, i.e. neem products (products made with azadirachtin extracted from neem tree seeds), have been termed biorational; however, in the present discussion, systemic insecticides, insect growth regulators and products containing *Bacillus thuringiensis* or its components will be included. In addition, the “biorationality” of several new products that are available, or will soon be available, also will be discussed.

Tomato Pests in Florida

It is always necessary to consider the entire pest complex when designing an IPM system for a particular crop because actions taken to control one pest may impact another pest or its natural enemies. The present discussion will focus on tomatoes, although many vegetable crops have the pests and pesticides in common with tomatoes. The silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring [a.k.a., the B strain of the sweetpotato whitefly, *B. tabaci* (Genn.)], is the key and most damaging insect pest of tomatoes in Florida. Adults, eggs, and the four, scale-like nymphal life stages all occur on the undersides of the leaves, making control with contact insecticides more difficult. Adults can transmit plant viruses, particularly geminiviruses, that are extremely damaging, especially tomato yellow leaf curl virus (TYLCV), and feeding by nymphs induces a systemic disorder of fruit called irregular ripening.

The southern armyworm, *Spodoptera eridania* (Cramer), is the most abundant armyworm species on tomatoes in south Florida and the yellow-striped armyworm, *S. ornithogalli* (Guenée), is the most abundant species in north Florida. The beet armyworm, *S. exigua* (Hübner), is a more difficult species to control that may be damaging to tomato but generally is more abundant on other vegetable crops such as pepper. All three species deposit eggs in hair-covered masses on the undersides of leaves where hatching larvae feed gregariously. Older larvae

disperse and may cause significant defoliation but cause most economic damage when they feed on fruit. The tomato fruitworm, *Helicoverpa zea* (Boddie), lays eggs singly on foliage or flowers and hatching larvae, unlike those of armyworms, seek out developing fruit into which they bore.

Leafminers, principally *Liriomyza trifolii* (Burgess), and the tomato pinworm, *Keiferia lycopersicella* (Wals.), were the key pests of Florida tomatoes in the 1970's and early 1980's, but efficacious, and to some extent, selective insecticides and the appearance of the silverleaf whitefly have reduced their pest status. Leafminers lay their eggs in the upper surface of leaves where hatching larvae form characteristic serpentine mines. High levels of defoliation can result, particularly when secondary micro-organisms invade the mines causing them to coalesce and leaflets to become necrotic. The tomato pinworm deposits eggs singly on the undersides of leaves where hatching larvae immediately bore into the leaves and form blotch mines. Older larvae may roll and tie leaflets together but inflict most damage when they bore into fruit, usually unseen under the calyx.

Flower thrips in the genus *Frankliniella* are small, feather-winged insects that inhabit flowers where feeding and egg laying may cause dimples on fruit at the blossom end or “zippering” or “catfacing” on the sides of fruit. Some species can transmit tomato spotted wilt virus which is more prevalent in north Florida than in south Florida. Green and brown species of stink bugs, particularly the southern green stink bug [*Nezara viridula* (L.)], and leaffooted bugs, especially *Leptoglossus phyllopus* (L.) and *Phthia picta* (Drury), deposit egg masses on the undersides of leaves where hatching nymphs may feed gregariously. Older nymphs and adults cause most damage by feeding on fruit with their piercing-sucking mouthparts. Stink bugs cause a lightened blotch beneath the fruit surface. Leaffooted bug punctures usually are deeper, often causing distortion of fruit as the fruit grow and expand. Discolored zones may develop around punctures, especially with leaffooted bugs, due to the introduction of secondary microorganisms which may lead to fruit rot.

Soap, Oil, and Neem

Insecticidal soap (and detergents), horticultural mineral oil (HMO) and neem products containing azadirachtin have been investigated for their effects on the silverleaf whitefly (Price et al. 1990; Price and Schuster 1991; Butler et al. 1993; Liu and Stansly 1995a, 1995b; Stansly, unpublished data) and selected natural enemies (Price and Schuster 1991, Liu and Stansly 1996, Stansly and Liu 1997, Schuster and Stansly 2000). These studies showed that soap, neem, and oil were all toxic to whitefly nymphs, although coverage was particularly important for oil. Oil was also repellent to whitefly adults but reduced yields of tomato in the field when applied at a concentration higher than 2%. Oil was relatively non-toxic to adults of two species of lacewings [*Chrysoperla rufilabris* (Burmeister) and *Ceraochrysa cubana* (Hagen)] or to adults of a small, lady beetle species [*Nephaspis oculatus* (Blatchley)], and was moderately toxic to larvae of a major whitefly parasite species (*Encarsia pergandiella* Howard) and to larvae of a non-trash bearing species of lacewing (*C. rufilabris*). Oil was highly toxic to adults of the parasite species, to eggs of both lacewing species and, to a lesser extent, to lady beetle eggs. Toxicity was again mitigated by coverage. Soap was highly toxic to whitefly adults, but only when wet. Soap caused only slight effects on the parasite species and was moderately toxic to adults of both lacewing species and to larvae of the non-trash bearing lacewing species. Conversely, soap was highly toxic to young lady beetle larvae. Neem reportedly reduces or inhibits feeding by whitefly adults and is practically non-toxic to both species of lacewings and to the parasite. In general, trash bearing lacewing larvae were less susceptible to all three biorational pesticides than non-trash bearing larvae, even when considering the broad-spectrum pyrethroid bifenthrin.

The potential of a liquid dish detergent and an HMO (Sunspray Ultrafine) to cause phytotoxicity on tomato also was investigated. It was found that applications of 0.5% or more detergent applied twice weekly delayed production (Vavrina et al. 1995). Weekly applications were less damaging. On the other hand, no phytotoxic effect was seen on pepper from weekly applications of concentrations of HMO

up to 2% applied with or without mancozeb plus copper (Vavrina et al. 1996).

Bacillus thuringiensis Products

The non- or low toxic effects of products based upon the bacterium, *Bacillus thuringiensis* Berliner, are documented for numerous species of natural enemies of numerous pests (as summarized for leafminer parasites in Schuster et al. 1996). Products for control of lepidopterous larvae are based upon two subspecies of *B. thuringiensis*: *kurstaki* (i.e. Dipel, Javelin) and *aizawai* (i.e. XenTari) or a combination of the two (i.e. Agree). As with insecticidal products, there is a time line of product evolution. The first generation products are based on wild-type isolates collected directly from nature (i.e. Dipel, Javelin, XenTari). Second generation products are based upon conjugation of the two subspecies (i.e. Agree). Third generation products are based upon the so-called *Psuedomonas*-based delivery system (insertion of *B. thuringiensis* genes into *Psuedomonas* bacteria for the purpose of increasing field persistence, i.e. Match). Fourth generation products are based upon new *B. thuringiensis* strains constructed using recombinant DNA technology (i.e. Crymax, Lepinox).

Bacillus thuringiensis is a bacterium that is pathogenic to larvae of certain insects, particularly lepidopterous insects, and, as such, can induce mortality through infection; however, the resting stage, or endospore, of the bacterium contains endotoxins which are capable of paralyzing and lysing the insect gut, thereby causing mortality through starvation. The endotoxins are not equally toxic to all species of Lepidoptera (Table 1); therefore, wild strain selection, conjugation or recombinant DNA techniques have been used to develop *B. thuringiensis* products that have different arrays of endotoxins to alter or broaden the spectrum of activity of the product (Table 2). Numerous studies have been conducted on the efficacy of *B. thuringiensis* products on lepidopterous pests of tomatoes. In general, the products are effective against armyworm and fruitworm larvae (Kund et al. 1999). From the standpoint of resistance management, products with different arrays of endotoxins should be alternated; however, many

products contain endotoxins in common (Table 2). Nevertheless, it would be prudent to rotate wild-type *B. thuringiensis* var. *kurstaki* products (i.e. Dipel, Javelin) with either wild-type *B. thuringiensis* var. *aizawai* products (i.e. XenTari) or with genetically modified *B. thuringiensis* products (i.e. Agree, Crymax, Lepinox, Mattch).

New Insecticides

The biorational status of older insecticides in the organophosphate, carbamate, pyrethroid, and avermectin classes has been studied and reported previously, at least for parasites of leafminers and the tomato pinworm (as summarized in Schuster et al. 1996, Schuster 2000). A number of new insecticides in new chemical classes have recently become available or will likely become available in the near future (Table 3). Unfortunately, little or nothing is known about the relative toxicity of these compounds to the natural enemies of interest to Florida vegetable growers; however, the biorational nature of the compounds can be predicted by the spectrum of activity and other characteristics of the compounds.

The nicotinoids are a relatively new class of compounds (Table 3), although imidacloprid has been available for use on tomatoes since 1994. Thiamethoxam received approval by the EPA in 2001. All of the nicotinoids are highly systemic (i.e. they are distributed through the plant, primarily to new growth, when applied to the roots) and are translaminar (i.e. readily absorbed into the leaf through the leaf surface). Soil-applied imidacloprid and thiamethoxam have provided control of the silverleaf whitefly for 3 months on tomato (Stansly and Connor 1998b). Foliar applications of imidacloprid, thiamethoxam, and acetamiprid controlled whitefly nymphs, but not as well as soil applications. Foliar applications of thiamethoxam and acetamiprid also controlled whitefly adults. Not only are soil applications of the nicotinoids more effective than foliar applications in controlling whiteflies, the impact of soil applications on natural enemies would be expected to be less than that of foliar applications because most natural enemies would not be exposed directly to the compounds.

Pymetrozine is another insecticide in a new class of compounds that is active against both aphids and whiteflies (Table 3). It is active against both nymphs and adults and has long residual activity because it is absorbed translaminarily and apparently is translocated to new foliage (Nicholson et al. 1996). Because the compound is translaminar and systemic and because it is highly specific to Homoptera (aphids and whiteflies), it should have minimal impact on natural enemies.

Pyriproxyfen and buprofezin are two new products for controlling whiteflies (Table 3). Although both are insect growth regulators (IGRs) and both negatively impact development of immature life stages of whiteflies, they are in different chemical classes and affect whiteflies differently. Neither kills adults, but treated adults lay infertile eggs. Furthermore, eggs treated with pyriproxyfen fail to hatch while those treated with buprofezin tend to hatch normally. Pyriproxyfen interferes with the final molt of the whitefly from pupa to adult while buprofezin interferes with all nymphal molts. Both products are recommended for application to tomatoes as the effects of soil-applied imidacloprid diminishes. A threshold of 5 nymphs or pupae/10 leaflets has been established to time the applications (Schuster 1999). Because the IGRs affect development, control of whiteflies is not rapid. Although both of the IGRs would be expected to have minimal impact on natural enemies, pyriproxyfen has been shown to be highly toxic to pupae and moderately toxic to larvae of the whitefly parasite *E. formosa* Gahan, but not to the whitefly parasites *E. pergandiella* and *E. transvena* (Timberlake) (Liu and Stansly 1997). Buprofezin was toxic to larvae but not pupae of the whitefly parasite *Eretmocerus tejanus* Rose & Zolnerowich and was relatively non-toxic to larvae and adults of the parasite *E. mundus* Mercet (Jones et al. 1995, 1998).

Tebufenozide, indoxacarb, spinosad and emamectin benzoate are new insecticides (Table 3) that have indicated good control of the southern armyworm (Schuster 2001) and the tomato pinworm (Stansly and Connor 1998a, Stansly et al. 2000), although control of the latter with tebufenozide has not been as good as with the other products (Stansly

and Connor 1998a, Schuster 1998, Schuster 2000). Methoxyfenozide and novaluron also give good control of the southern armyworm (Schuster, unpublished data) but their activity against the tomato pinworm are not known at this time. Spinosad and emamectin benzoate also have activity against leafminers (Stansly and Connor 1988a), spinosad is active against thrips (Eger et al. 1998), and novaluron is active against whitefly nymphs (Schuster, unpublished data). Indoxacarb has been inconsistent in leafminer and stink bug control (Stansly and Connor 1998a). While much is known regarding the spectrum of activity of these new compounds against pest insects, less is known regarding their effects on natural enemies of interest in Florida vegetables. Tebufenozide, methoxyfenozide and novaluron are IGRs and would be expected to have minimal impact on natural enemies; however, this has not been demonstrated. Spinosad has been shown to have short-term toxicity to the mite *Phytoseiulus persimilis* Athias-Henriot, a predator of spider mites (Price, unpublished data); however, spinosad was much safer than the pyrethroid cypermethrin for this predator as well as for *E. formosa*; and generalist predators, including the insidious flower bug [*Orius insidiosus* (Say)], a lacewing (*C. rufilabris*), and the convergent lady beetle (*Hippodamia convergens* Guérin-Méneville) (Schoonover and Larson 1995). In another trial, indoxacarb slightly reduced survival of *O. insidiosus* adults but did not affect survival of *C. rufilabris* larvae, while spinosad had no negative impact on survival of either species (Ruberson and Tillman, unpublished data).

Conclusion

From the preceding discussion it is clear that pesticides are available that are effective against most of the life stages of most of the important insect pests of tomatoes and other vegetables, and that these pesticides can be less detrimental to certain natural enemies of these pests. It is also clear that no single pesticide is completely safe to all life stages of all natural enemies. Thus, the biorational nature of pesticides depends upon the time, pest and crop upon which they are used. Therefore, in order to maximize the effectiveness of these biorational products in managing pests and to more fully integrate biological control into IPM programs, it is essential to have a

thorough knowledge of the life stages of the pests and natural enemies that are present. Only periodic, thorough scouting that includes an assessment of natural enemies can provide this information

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Table 1. Relative toxicity of *Bacillus thuringiensis* endotoxins to larvae of selected species of Lepidoptera.

Species	Endotoxin					
	IA(a)	IA(b)	IA(c)	IC	ID	IIA
Diamondback Moth	+++	+++	++++	+++	++	-
Cabbage Looper	+++	+	++++	+++	++	++++
Beet Armyworm	-	+	-	-	++	+
Fall Armyworm	-	+	-	-	++	+
Fruitworm/Earworm	+	++	+++	-	+	++

++++ = LC₅₀ <10µg/175mm²; +++ = LC₅₀ 10-100µg/175mm²; ++ = LC₅₀ 100-1,000µg/175mm²; + = LC₅₀ 1,000-10,000µg/175mm²; - = LC₅₀ >10,000µg/175mm².

Table 2. Relative amounts (increasing number of "s") of endotoxins present in selected *Bacillus thuringiensis* products. A "-" indicates the endotoxin was not present.

Product	Endotoxin					
	IA(a)	IA(b)	IA(c)	IC	ID	IIA
Dipel/Javelin	+	+	+	-	-	+
Mattch	-	-	+	+	-	-
Agree	+	+	+	+	+	-
XenTari	+	+	-	+	+	-
Crymax	-	-	+++	+	-	+
Lepinox			+	+		+

Increasing number of "+" indicate increasing relative concentration of the indicated endotoxin while a "-" indicates the endotoxin is not present.
*Hybrid.

Table 3.

Chemical Action	Common Name	Trade Name	Target Pests
Systemics (nicotinoids)	Imidacloprid	Admire/Provado	Whiteflies, aphids
	Thiamethoxam	Platinum/Actara	Whiteflies, aphids
	Acetamiprid	Assail	Whiteflies, aphids
Insect Growth Regulators	Pyriproxyfen	Knack	Whiteflies, aphids
	Buprofezin	Applaud	Whiteflies
	Tebufenozide	Confirm	Leps.
	Methoxyfenozide	Intrepid	Leps.
	Novaluron	Diamond	Whiteflies, Leps.
Miscellaneous	Pymetrozine	Fulfill	Aphids, whiteflies
	Spinosad	SpinTor	Leps., leafminers
	Indozacarb	Avaunt	Leps.
	Emamectin benzoate	Proclaim	Leps., leafminers