Managing Diamide Resistance in Florida Tomato[1]

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Diamides belong to a class of insecticides that disrupt ryanodine receptors, the intracellular calcium channels that play a central role in muscle and nerve function. Diamide insecticides are systemic—they can be taken up by the plant's foliar vascular system and, with the exception of flubendiamide, by the roots. Systemic insecticides can be applied to the plant in transplant water, through drip irrigation, and directly to the foliage. There are presently two diamide insecticides available for use on tomatoes in Florida: chlorantraniliprole and cyantraniliprole. Flubendiamide is an additional diamide that is under review by the US Environmental Protection Agency. However growers may use insecticides containing flubendiamide that they presently have on hand. Chlorantraniliprole and cyantraniliprole are also referred to as rynaxypyr and cyazypyr, respectively. Chlorantraniliprole, the active ingredient in Coragen, became available in 2008, and flubendiamide, the active ingredient in Belt, became available in 2009. Cyazypyr became available in 2013, sold as Verimark for soil application and Exirel for foliar application. Diamide insecticides have been assigned the mode of action classification number 28 by the Insecticide Resistance Action Committee (www.irac-online.org). This number appears on the label of any insecticide containing diamides. Chlorantraniliprole, flubendiamide, and cyantraniliprole are available in additional formulations and in some products combined with other insecticides (Table 1).

Flubendiamide is primarily active against caterpillar pests. Key caterpillar pests of Florida tomato that can be managed with flubendiamide include cutworms, tomato fruitworm (*Helicoverpa zea*), tomato pinworm (*Keiferia lycopersicella*), southern armyworm (*Spodoptera eridania*), beet armyworm (*Spodoptera exigua*), and yellowstriped armyworm (*Spodoptera ornithogalli*). Other caterpillar pests attacking tomato that can be managed with flubendiamide include tobacco hornworm (*Manduca sexta*), cabbage looper (*Trichoplusia ni*), and soybean looper (*Pseudopludia includens*).

Table 1. Insecticides containing diamides available for management of pests of Florida tomato and other crops.

Product	MOA#	Active ingredient(s)
Coragen	28	Chlorantraniliprole
Durivo (soil)	28 + 4A	Chlorantraniliprole + thiamethoxam
Voliam Xpress	28 + 3	Chlorantraniliprole + lambda cyhalothrin
Voliam Flexi (foliar)	28 + 4A	Chlorantraniliprole + thiamethoxam
Belt	28	Flubendiamide
Vetica	28 + 16	Flubendiamide + buprofezin
Verimark (soil)	28	Cyantraniliprole
Exirel (foliar)	28	Cyantraniliprole

Chlorantraniliprole is effective against the same complex of caterpillar pests of tomato as flubendiamide. In addition, chlorantraniliprole suppresses nymphs of the silverleaf whitefly, *Bemisia tabaci* biotype B, and can be used to manage the larvae of serpentine and vegetable leafminers (*Liriomyza sativae* and *L. trifolii*). Cyantraniliprole is effective against both adults and nymphs of the silverleaf

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whitefly, in addition to killing leafminer and caterpillar pests. The silverleaf whitefly vectors *Tomato yellow leaf curl virus* (TYLCV), which can cause devastating losses in tomato in Florida and other regions of the world.

As with any insecticide, repeated use of diamide insecticides on successive generations of the same pest may lead to the development of insecticide resistance. In order to avoid the development of resistance to diamides by targeted pests of tomato, group 28 insecticides should be rotated with insecticides possessing different modes of action. Insecticide modes of action available for management of silverleaf whitefly, caterpillars, and leafminers on Florida tomato are listed in Table 2.

In order to conserve the efficacy of diamide and other insecticides, a "treatment window" approach can be employed. A treatment window is a period of time that is defined by the crop stage, the biology of the pest complex attacking the crop, or a combination of both. In order to avoid treating successive generations of whiteflies, caterpillars, and leafminers to the same mode of action, a five week treatment window should be used. Tomato crops are most vulnerable to TYLCV during the first five–six weeks after transplanting, so the first five week treatment window is the most important time to treat to protect the plants from viruliferous whiteflies. Planting resistant varieties, destroying crop residues that serve as a reservoir for TYLCV, and using reflective mulches are key strategies for reducing early infection of the tomato crop. At-plant applications of Group 4 insecticides or cyantraniliprole may also provide important early-season protection from viruliferous whiteflies. Group 4 insecticides include the neonicotinoid insecticides imidacloprid (Admire, many generics), thiamethoxam (Platinum) and dinotefuran (Venom), as well as the butenolide insecticide flupyradifurone (Sivanto Prime). Because of the importance associated with insecticides that can help suppress transmission of TYLCV, the early season may be considered a priority "treatment window" for use of cyantraniliprole.

If a diamide is used during the first five weeks after transplanting, alternate modes of action should be used instead of diamides for the next five-week treatment window. In this scenario, insecticides that do not include active ingredients with a group 28 mode of action would be used for suppression of whitefly, leafminers, and caterpillars during this second treatment window. For example, group 6 and 17 materials could be used for leafminer, and group 11, 18, and 22 materials could be used for caterpillar management. "Softer" materials, including materials that have not been assigned an IRAC MOA number, can be included in these insecticide rotations when appropriate. (Spinosyns, group 5 insecticides, are effective against leafminers and caterpillars but should be reserved for thrips management whenever possible. This is because the spinosyns are among the most effective insecticides for managing thrips, and excessive use of spinosyns can lead to the development of resistance among thrips populations.)

Table 2. Modes of action available for management of whitefly, caterpillars, and leafminers on Florida tomato.

MOA #	Grouping or action site	Active ingredient examples	Silverleaf whitefly	Caterpillars	Leafminers
3	Pyrethroid	Beta-cyfluthrin*, bifenthrin, esfenvalerate, zeta-cypermethrin	x	x	
4A	Neonicotinoid	Acetamiprid, clothianidin*, dinotefuran, imidacloprid, thiamethoxam	x		
4D	Butenolide	Flupyradifurone	x		
5	Spinosyns	Spinosad, spinetoram		x	x
6	Avermectins	Abamectin		x	x
7C	Juvenile hormone mimics	Pyriproxifen	x		
9B	Selective hemipteran feeding blocker	Pymetrozine*	x		
11	Microbial disruptor of insect midgut membrane	*Bacillus thuringiensis* subspecies *aizawai*; subspecies *kurstaki*		x	
15	Inhibitors of chitin biosynthesis	Novaluron	x (nymphs)	x	x
16		Buprofezin	x (nymphs)		
17	Dipteran molting disruptor	Cyromazine			x
18	Ecdysone receptor agonist	Tebufenozide, methoxyfenozide		x	
21A	METI insecticides	Fenpyroximate	x		
22	Sodium channel blocker	indoxacarb		x	
23	Lipid biosynthesis inhibitor	Spiromesifen, spirotetramat	x		
28	Ryanodine receptor modulators	Chlorantraniliprole,**, cyantraniliprole	Cyantraniliprole	x	x
		Flubendiamide		x	
—	unknown	Azadirachtin	x	x	
—	unknown	*Beauvaria bassiana*	x		
—	unknown	Cryolite	x		
—	unknown	Insecticidal soap	x		
—	unknown	Extract of *Chenopodium ambrosioides*	x		x
—	unknown	Stylet oils	x		x

*Suppression (uneven or liminted control) of whitefly.
**Supression of whitefly nymphs.