

Management of Whiteflies, Whitefly-Vectored Plant Virus, and Insecticide Resistance for Vegetable Production in Southern Florida¹

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Introduction

Tomato is the most important vegetable crop in Florida, which leads all other states in fresh market production. The sweetpotato whitefly, *Bemisia tabaci* (SWF), was reported in Florida as early as 1900 by Quaintance. However, it was not until the invasion of a new biotype or species in 1986, named successively “biotype B,” *Bemisia argentifolii*, and more recently, Middle East-Asia Minor 1 (MEAM1), that it attained the status of key tomato pest.

The adult SWF is a small insect, approximately 1/16 of an inch in length and white in color due to a powdery covering of wax. Wings are held tent-like over the body while at rest in contrast to the somewhat larger greenhouse whitefly, which holds the wings flat. Whiteflies are usually found on the undersides of leaves, especially young leaves where the yellow, football-shaped eggs are laid upright and are attached by a tiny stalk inserted into the leaf surface. The mobile first instar or crawler stage hatches from the egg and settles on the leaf where it develops through three immobile semi-transparent scale-like nymphal stages, the last of which is yellowish with red eyes. As the plant grows, leaves bearing successive nymphal stages tend to be found lower

down on the plant. Development from egg to adult can be as short as two weeks during warm weather.



Figure 1. Newly emerged adult SWF with eggs and young nymphs.

Credits: Lyle Buss, UF/IFAS

Whiteflies feed by sucking sap from the leaves, and in doing so, can debilitate the plant, promote growth of sooty mold on excreted honeydew, cause irregular ripening of the fruit and transmit viral pathogens, the worst of which is *Tomato yellow leaf curl virus* (TYLCV). The virus can be acquired by the whitefly as a nymph or adult and is retained for the

1. This document is ENY-735 (IN695), a publication of the Entomology and Nematology Department, UF/IFAS Extension. Publication date: March 2007. Revised March 2015. Please visit the EDIS Website at <http://edis.ifas.ufl.edu>.
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duration of life. TYLCV is common in Florida and causes severe stunting, shortened internodes, interveinal chlorosis, upward curled leaves and flower abscission. Fruit set shuts down once a plant is infected and early infection may result in little or no yield. Therefore, protecting young crops from whitefly attack is a priority.



Figure 2. Tomato plant infected with *Tomato yellow leaf curl virus*
Credits: UF/IFAS.

Cultural Control

Whiteflies can be partially excluded from greenhouses with insect-proof screens or netting, but in Florida, most tomato production is open field. Therefore, the best way to protect new crops is to distance them in time and space from sources of whiteflies and virus. A tomato-free summer period of two months can provide an effective barrier against carryover of whiteflies and virus from the spring to fall crops in the southern production areas, whereas winter has typically provided a better break in the south-central area and north Florida/Georgia production areas. For this reason, whitefly populations and virus incidence are typically worse during spring in the south and during fall in the south central region. Rapid crop destruction and field sanitation are important cultural management practices, and successive plantings in close proximity should be avoided.

Alternate hosts of TYLCV include common bean (*Phaseolus vulgaris*) and some varieties of pepper (*Capsicum annuum*), including varieties that do not show virus symptoms (Polston et al. 2006). Weeds have been identified as important reservoirs of TYLCV in some parts of the world (Papayiannis et al. 2011). However surveys of weeds in Florida have not revealed significant wild hosts of the virus (Polston et al. 2009).

Another form of cultural control is the use of TYLCV-resistant or tolerant cultivars that express little or no disease symptoms. The genetic sources of resistance are increasing in number, and the horticultural characteristics of resistant varieties are becoming more acceptable to growers and the marketplace. Elimination or reduction of the virus threat through use of resistant cultivars increases the margin of tolerance to whiteflies, allowing for a threshold of 0.5 nymphs per leaf to avoid irregular ripening.

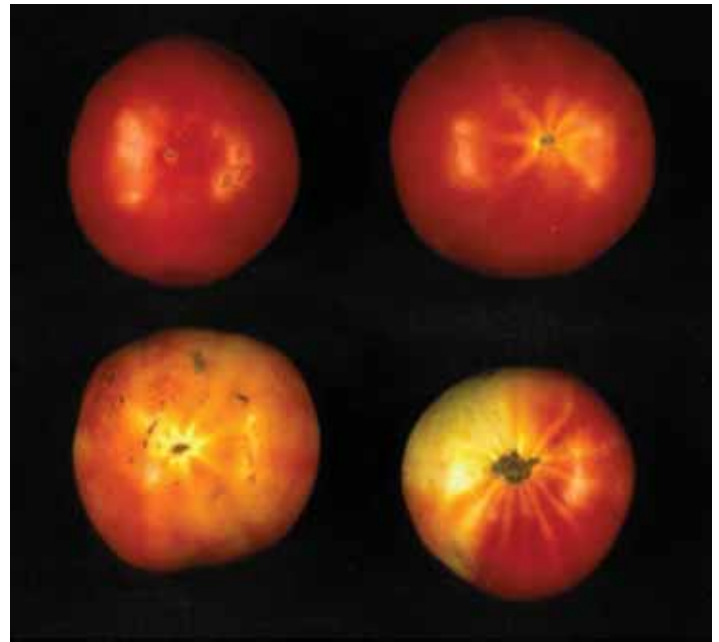


Figure 3. Normally ripened tomato (top left) compared with fruit affected by tomato irregular ripening of varying intensity caused by feeding of SWF nymphs on foliage.
Credits: UF/IFAS.

Biological Control

Whiteflies have many natural enemies, including parasitic wasps, and predators, such as plant bugs, mites, ladybird beetles, lacewings and others. Pest management including whitefly control in much greenhouse tomato production of Europe, Canada, and to a lesser extent the United States, includes or depends completely upon biological control aided by TYLCV-resistant cultivars. The predaceous mite *Amblyseius swirskii* is widely used to control whiteflies in non-tomato crops, while in tomato, the parasitic wasp *Eretmocerus* spp. and predaceous plant bugs, such as *Nesidiocorus tenuis*, are used alone or in combination to control whiteflies. Although these practices are not yet common in the open-field cropping systems of Florida, the biological control that occurs in weeds and other non-sprayed host plants during fallow periods is a major factor in reducing whitefly populations during fallow periods.

Insecticidal Control – Soil Applications

Florida growers rely heavily on insecticidal programs to combat whiteflies and subsequent virus outbreaks. Young plants are most susceptible to virus, so protection early in the cropping cycle is a must. Soil-applied systemic insecticides are translocated to growing tissues where whiteflies typically reside and are therefore necessary to provide the continuous protection needed by young, rapidly growing plants. Transplants in the production house are usually drenched with a systemic insecticide about a week before planting and again at or shortly after transplanting in the field. Transplant house applications have typically been made with imidacloprid and the field drench with imidacloprid, thiamethoxam, or dinotefuran, all neonicotinoid (group 4A) insecticides (Table 1).

Even though most Florida tomato growers refrain from making foliar applications of neonicotinoids, widespread dependence and overuse of these products has resulted in reduced effectiveness, and alternatives would be welcome. The anthranilic diamide cyantraniliprole (also known as cyazypyr, group 28) was registered for use on Florida tomato in 2014 and is available for application as a soil formulation (Verimark™). It can be applied in the soil or transplant tray. Flupyradifurone (Sivanto®) is in a different (4D) subgroup and therefore may pose less risk of cross resistance to the 4A neonicotinoids. Confining use of each mode of action to a single soil application per crop will help preserve effectiveness over time. Later soil applications with a different mode of action can be made by injection through drip irrigation once roots systems have developed.

Foliar Applications

Careful scouting is important to determine when the effectiveness of the initial soil application has worn off. At this point, it is typically necessary to apply foliar sprays. Numerous insecticides are available for this purpose, some being more effective on nymphs and others on adults. Once the crop has established, and barring large scale migration of adults from offsite, the main objective will be controlling in-field reproduction, i.e. nymphs. Useful products for this include cyantraniliprole = cyazypyr (Exirel™), buprofezin (Courier™), pyriproxyfen (Knack®), spiromesifen (Oberon®), spirotetramat (Movento®), soaps and oils. These are listed by mode of action in Table 2 to assist in planning a program of rotation to avoid insecticide resistance. In addition, several microbial and botanical insecticides are available which can also be used. Another advantage to products mentioned above is their relative selectivity, and

thus greater compatibility, with beneficial insects and mites compared to broad-spectrum insecticides that are typically used to target adults and are best used late in the crop if at all. Control of adults with products such as pyrethroids (group 3) with or without organophosphates (group 1B) may be needed at the end of the crop to limit migration to new crops, although 1B products are less compatible with harvesting due to longer pre-harvest intervals. Control of other pests such as leafminers, caterpillars or spider mites may also need to be considered and activity of insecticides on these is also mentioned in Table 2.

A resistance monitoring program for the neonicotinoids in southern Florida demonstrated that tolerance in *B. tabaci* increased 8 fold on the average from 2000 to 2006 for imidacloprid and about 15 fold from 2003 to 2006 for thiamethoxam. Tolerance of sweetpotato whitefly to neonicotinoids varies among different populations in Florida, although in most areas, susceptibility to dinotefuran remained high. Neonicotinoids are given the mode of action number 4A by the Insecticide Resistance Action Committee (IRAC). Sulfoxaflor (Closer® SC) is a new Group 4C insecticide produced by Dow Agrochemical that is registered for use on tomato in Florida. Bayer Crop Science anticipates registering Flupyradifurone (Sivanto®, IRAC Group 4D) was registered in 2015 for use on tomato. Cross-resistance has not been demonstrated between these new insecticides and the neonicotinoids. However, all Group 4 insecticides have the same mode of action (nicotinic acetylcholine receptor agonists). All neonicotinoids can be applied as a spray to the foliage, and clothianidin (Belay®), dinotefuran (Venom®, Scorpion®), imidacloprid (Admire Pro® and others), thiamethoxam (Platinum®) and Sivanto are effective when applied to the soil. From the perspective of resistance management, the use of Group 4A insecticides for management of *B. tabaci* and TYLCV in tomato should be limited to nursery 1 week prior to planting, a single soil application, or foliar spray up to six weeks after planting but no later.

Verimark®, the soil-applied formulation of cyantraniliprole (= cyazypyr) is a systemic group 28 insecticide effective against SWF. Like the neonicotinoids, Verimark can be applied as a drench in transplant water or it may be injected through the drip once plants have established an adequate root system. If an at-plant application is chosen, then a neonicotinoid could be applied later to the foliage or preferably through the drip or as a drench. Again, in the interest of maintaining effectiveness of these valuable products, only one application each of an insecticide containing the 4A or

28 mode of action is recommended per crop, regardless of target pest.

Flubendiamide (Belt[®]) and chlorantraniliprole = rynaxypyr (Coragen[®]) are diamide insecticides used to manage caterpillar pests on tomato and other horticultural crops, and Coragen is also used for leafminer control. Durivo[®] (soil application) and Voliam Flexi[®] (foliar) contain chlorantraniliprole and thiamethoxam, the same active ingredients as Coragen and Platinum respectively. With the registration of Verimark and Exirel, diamide insecticides are now available to target pests of tomato at each stage of development: nursery, at-plant, vegetative and fruiting. The risk is high that SWF and other pests of tomato will develop resistance to diamide insecticides if they are overused. Growers using Verimark for early season protection against SWF and TYLCV should not use Group 28 insecticides for management of leafminer and caterpillars in the same crop or at a minimum should avoid the use of this mode of action for at least five weeks after the application of Verimark. Other options with different modes of action are available for control of worm pests if needed.

Biotype Q of the SWF is prevalent in the Mediterranean region and is resistant to many of the commonly used insecticides for managing whiteflies, including the pyrethroids, neonicotinoids, pymetrozine and insect growth regulators (Courier and Knack). Resistance in biotype Q is more stable than in biotype B, i.e. resistance appears not to diminish even in the absence insecticide exposure. Although biotype Q has been found in greenhouses and nurseries in 22 states including Florida, it has not yet been detected in the field in Florida. Nevertheless, it represents a potential threat to vegetables and other crops in Florida and another reason why resistance management guidelines should be strictly adhered to. These include rotation of insecticide modes of action as well as crop hygiene and cultural controls mentioned below.

Recommendations

Crop Hygiene

Field hygiene should be a high priority and should be an integral part of the overall strategy for managing whitefly populations, TYLCV incidence, and insecticide resistance. These practices will help reduce the onset of the initial infestation of whitefly, regardless of biotype, and lower the initial infestation level during the cropping period.

- **Establish a minimum 2-month crop free period during the summer, preferably from mid-June to mid-August in south and south central Florida.**

- **Disrupt the virus-whitefly cycle in winter by creating a break in time and/or space between fall and spring crops, especially tomato.**
- **Destroy crops quickly and thoroughly after harvest, killing whiteflies and preventing re-growth.**
 - Promptly and efficiently *destroy all vegetable crops within 5 days of final harvest* to decrease whitefly numbers and sources of plant viruses like TYLCV.
 - Use a contact desiccant (“burn down”) herbicide in conjunction with a heavy application of oil (not less than 3 % emulsion) and a non-ionic adjuvant to destroy crop plants and to kill whiteflies quickly.
 - Time burn down sprays to avoid crop destruction during windy periods, especially when prevailing winds are blowing whiteflies toward adjacent plantings.
 - Destroy crops block by block as harvest is completed rather than waiting and destroying the entire field at one time.

Pre-Plant Cultural Control Practices

Reduce overall whitefly populations and avoid introducing whiteflies and TYLCV into crops by strict adherence to good cultural practices.

- Plant whitefly and virus-free transplants.
 - Use transplants grown in isolation from production fields.
 - Inspect transplants for whiteflies and other pests and diseases
- Delay planting new fall crops as long as possible.
- Do not plant new crops near or adjacent to old, infested crops, especially of tomato but also of other whitefly sources such as cucurbits or possible sources of TYLCV like pepper or beans.
- Use determinant varieties of grape tomatoes to avoid extended cropping season.
- Use TYLCV resistant tomato cultivars (see additional information below for list) where possible and appropriate, especially during historically critical periods of high virus pressure.
 - TYLCV tolerant tomato cultivars that are available include Charger, Rally, Tribute (Sakata), RidgeRunner, SevenTY III (Syngenta), Security 28 and 8845 (Harris Moran). Check the *Vegetable Production Handbook for Florida* for new TYLCV-tolerant varieties.

- Continue whitefly control even on TYLCV resistant cultivars which can still host the virus and are subject to tomato irregular ripening.
- Use UV reflective (metalized) mulch on plantings that are historically most commonly infested with whiteflies and infected with TYLCV.
- Use a soil application containing a neonicotinoid (group 4A) or cyantraniliprole (group 28) no more than once each during a single crop (Figure 4).
 - Do not repeat with a foliar application of either mode of action. If only foliar applications of these insecticides are to be made, than restrict each mode of action to a single 6-week period within any crop cycle.

Post-planting Practices

- Scout for whitefly adults and apply a short reentry interval insecticide if necessary prior to cultural manipulations such as pruning, tying, etc.
- Rogue tomato plants with symptoms of TYLCV at least until second tie.
 - Plants should be treated for whitefly adults prior to roguing and, if nymphs are present, should be removed from the field, preferably in plastic bags, left in the sun and then disposed of as far from production fields as possible.
- Manage weeds within crops to minimize interference with spraying
- Dispose of cull tomatoes as far from production fields as possible.
 - If deposited in pastures, fruit should be spread instead of dumped in a large pile to encourage consumption by cattle. The fields should then be monitored for germination of tomato seedlings, which should be controlled by mowing or with herbicides.
- Avoid u-pick or pin-hooking operations unless effective whitefly control measures are continued.
- Destroy old crops within 5 days after last harvest, destroy whitefly infested abandoned crops, and control volunteer plants with a desiccant herbicide and oil.
- Plant non-host cover crops such as Sudex during summer fallows or rye grass during winter to discourage weeds and volunteer crop plants from growing and being infested by whiteflies.
- As control of whitefly nymphs diminishes following soil applications, use rotations of insecticides of other chemical classes as needed based on scouting recommendations. (Figure 4).
 - Consult the Cooperative Extension Service for the latest recommendations.
- Use selective rather than broad-spectrum control products where possible to conserve natural enemies and enhance biological control.
- Do not apply insecticides on weeds on field perimeters.
 - These could kill whitefly natural enemies, and thus interfere with biological control, as well as select for biotype Q, if present, which is more resistant to many insecticides than biotype B.

Do Unto Your Neighbor, as You Would Have Them do Unto You

- **Look out for your neighbor's welfare.**
 - This may be a strange or unwelcome concept in the highly competitive vegetable industry but it is in the grower's best interest to do just that. Remember that everybody will feel the pain should the whiteflies develop full-blown resistance to insecticides, especially the neonicotinoids!
- **Know what is going on in the neighbor's fields.**
 - Growers should try to keep abreast of operations in upwind fields, especially harvesting and crop destruction, which both disturb the foliage and cause whitefly adults to fly

Efficacy indications generated by Florida researchers for insecticides labeled for use against whitefly on tomato in Florida and other relevant information are summarized and tabulated in Tables 1 and 2 by mode of action to facilitate planning a rotation program. IRAC (Insecticide Resistance Action Committee) provides additional information on general resistance management and on resistance classification of specific insecticides at its website: <http://www.irc-online.org>.

Insecticidal Control Practices.

- **Delay resistance to neonicotinoid and other insecticides by using a proper whitefly insecticide program. Follow the label!**
 - Apply a neonicotinoid **one time** to transplants in the production facility, 7-10 days before shipping. Use products in other chemical classes, including Fulfill, soap, etc. before this time.

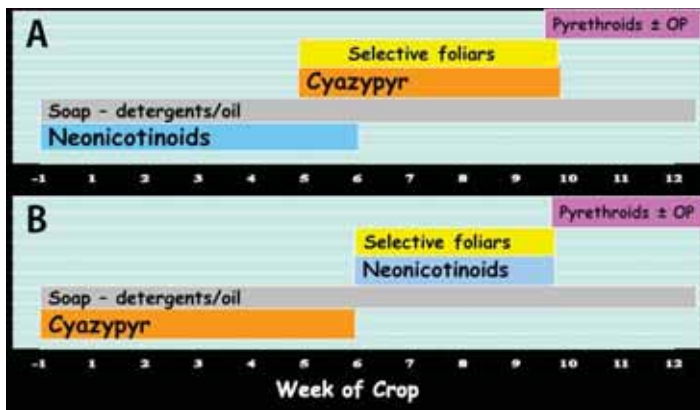


Figure 4. Two possible programs for insecticidal whitefly control: **A:** neonicotinoid drench just prior to and directly after planting followed later in the crop cycle by a soil application of cyantranilprole (cyazypyr) or by foliar applications of selective products mid-season, finishing with one or more pyrethroid sprays with or without an organophosphate (malathion) at the end of the season if necessary to reduce whitefly migration to other crops. Products such as soaps, oils or biologicals could be used any time as needed. **B:** Reversing the order of cyazypyr and neonicotinoid soil applications.

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Table 1. Mode of action (MOA), active ingredient, trade name, minimum reentry interval (REI), days to harvest (PHI) and other pests controlled by insecticides labeled for **soil application** to tomato for control of sweetpotato whitefly in Florida

MOA [^]	Active Ingredient	Trade Name	REI (hours)	Days to Harvest	Other pests controlled
4A	Clothianidin	Belay 50 WDG	12	21	Aphids, Colorado potato beetle
4A	Dinotefuran	Venom, Scorpion	12	21	
4A	Imidacloprid	Various	12	21	
4D	Flupyradifurone	Sivanto	4	45	
4A	Thiamethoxam	Platinum 75 SG	12	30	
28	Cyantraniliprole	Verimark	4	1	Worms, leafminers
4A, 28	Thiamethoxam + Chlorantraniliprole	Durivo	12	30	Aphids, worms, leafminers, stinkbugs
28	Chlorantraniliprole¹	Coragen	4	1	Worms, leafminers

[^]<http://www.irac-online.org>

Table 2. Mode of action (MOA) active ingredient, trade name, minimum reentry interval (REI) and days to harvest (PHI) and other pest controlled by insecticides labeled for **foliar application** to tomato for control of sweetpotato whitefly in Florida.

Foliar					
MOA [^]	Active Ingredient	Trade Name	REI (hours)	Days to Harvest	Other pests controlled
1A	Methomyl¹	*Lannate LV, SP	48	1	Worms, aphids, stinkbugs
1B	Malathion²	Malathion 5 EC Malathion 57 % Malathion 8	12	1	
3A	Beta-Cyfluthrin³	*Baythroid XL	12	0	Worms, stinkbugs
3A	Bifenthrin	*Brigade 2EC (bifenthrin)	12	1	
3A	Bifenthrin & Zeta-Cypermethrin³	*Hero	12	1	
3A	Esfenvalerate³	*Asana XL (0.66EC)	12	1	
3A	Gamma-Cyhalothrin³	Declare	24	5	
3A	Lambda-Cyhalothrin³	Warrior II, Karate with Zeon*	24	1	
3A	Pyrethrins³	Pyganic Crop Protection EC 5.0	12	0	
3A	Zeta-Cypermethrin³	*Mustang	12	1	
4A	Acetamiprid	Assail 70WP, Assail 30 SG	12	7	Aphids, Colorado potato beetles
4A	Clothianidin	Belay 50 WDG	12	7	
4A	Dinotefuran	Venom, Scorpion	12	1	
4A	Imidacloprid	Various	12	0	
4A	Thiamethoxam	Actara	12	0	
4C	Sulfoxaflor	Closer SC	12	1	
4D	Flupyradifurone	Sivanto	12	1	
7C	Pyriproxyfen⁴	Knack IGR	12	7	
9C	Fonicamid¹	Beleaf 50 SG 2(ee	12	0	Aphids
9B	Pymetrozine	Fulfill	12	0	Aphids
15	Novaluron¹	Rimon 0.83EC	12	1	Worms, leafminers, thrips

Foliar					
MOA [^]	Active Ingredient	Trade Name	REI (hours)	Days to Harvest	Other pests controlled
16	Buprofezin ⁴	Courier 40SC	12	1	
21A	Fenpyroximate	Portal	12	1	Spider mites
23	Spirotetramat ⁴	Movento	24	1	Aphids, russet mite,
23	Spiromesifen ⁴	Oberon 2SC	12	1	Spider mites
28	Cyantraniliprole	Exirel	12	1	Worms, aphids, leafminers
28	Chlorantraniliprole ¹	Coragen	4	1	Worms, leafminers
3A + 4A	Beta-Cyfluthrin + Imidacloprid	*Leverage 360	12	0	Worms aphids stinkbugs
3A + 4A	Lambda-Cyhalothrin + Thiamethoxam	Endigo *	24	5	
3A + 6	Bifenthrin + Abamectin ¹	*Athena	12	7	Worms, pinworm spider mites
3A + 28	Lambda-Cyhalothrin + Chlorantraniliprole ¹	*Voliam Xpress	24	5	Worms leafminers, stinkbugs
4A + 28	Thiamethoxam + Chlorantraniliprole	Voliam Flexi	12	1	Worms aphids stinkbugs leafminers
16 + 28	Flubendiamide + Buprofezin ⁴	Vetica	12	1	
un	Azadirachtin ¹	Aza-Direct, Azatin XI, Neemix 4.5	4	0	
un	<i>Chromobacterium subtsugae</i> ¹	Grandevo	4	0	
un	<i>Isaria fumosorosea</i> Apopka Strain 97 ¹	PFR-97	4	0	
un	Synthetic extract of <i>Chenopodium ambrosioides</i> ¹	Requiem 25EC	4	0	
un	<i>Beauveria bassiana</i> Strain GHA ¹	Mycotrol O	4	0	
un.	<i>Metarhizium anisopliae</i> Strain F52 ¹	MET52 EC	0	0	
un.	Soap, Insecticidal	M-Pede 49% EC	12	0	Aphids, mites
un	Horticultural Mineral Oil	Saf-T-Side, JMS Stylet-Oil, Pure Spray Green	4	0	Aphids, mites

* Restricted use insecticide.

[^]<http://www.irac-online.org>.

¹Suppression only.

²Labelled for tomato but not whiteflies. Effective only if tank-mixed with a pyrethroid

³More effective if tank-mixed with Malathion

⁴Nymphs only