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Managing Thrips and Tospoviruses in Tomato[1]

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Several invasive species of thrips have established in Florida and are causing serious economic losses to vegetable, ornamental, and agronomic crops. Damage to crops results from thrips feeding and egg-laying injury, by the thrips vectoring of plant diseases, the cost of using control tactics, and the loss of pesticides due to resistance. Western flower thrips (*Frankliniella occidentalis*), which was introduced and became established in north Florida in the early 1980s, is the major thrips pest of tomatoes. The western flower thrips did not become an economic problem in central and south Florida until 2005 (Frantz and Mellinger 2009). Two other invasive species, melon thrips, *Thrips palmi*, and chilli thrips, *Scirtothrips dorsalis,* are not damaging pests of tomato.

Growers in all regions of Florida initially responded to the threat of the western flower thrips by the calendar application of broad-spectrum insecticides. This has resulted in a classic "3" R situation: resistance to insecticides (including new reduced-risk insecticides), resurgence of thrips populations due to the killing of natural enemies and competitor native species of thrips, and replacement with various other pests that are induced by the application of broad-spectrum insecticides. Several scientific papers are available that review information on the situation in Florida (Funderburk 2009; Frantz and Mellinger 2009; Weiss et al. 2009).

The western flower thrips is the most efficient vector of *Tomato spotted wilt virus* (TSWV). This virus is one of about twenty known species of tospoviruses (Sherwood et al. 2001a, b). Epidemics of tomato spotted wilt (TSW) occur frequently in numerous crops in north Florida. Historically, it was thought that TSW occurred sporadically in central and south Florida. Most infections were confined to a few isolated plants in a field, transplants, mainly pepper, which originated from planthouses in Georgia. Secondary spread (i.e., within the field) away from the initial site of infection was rarely, if ever, seen. In the last two decades, growers and scouts have begun to report a few instances where increased incidence of secondary spread has occurred. In a few cases, TSW has appeared in fields in south Florida, in which transplants did not come from Georgia or other areas where TSW is established.

Tomato chlorotic spot virus (TCSV) and Groundnut ringspot virus (GRSV) are two recently emerged tospoviruses in Florida. TCSV and GRSV were frequently detected in solanaceous crops and weeds with tospovirus-like symptoms in south Florida and occurred together with TSWV in tomato and pepper in south Florida (Webster et al. 2015). Tomato spotted wilt virus was the only tospovirus detected in tomato in other survey locations in north Florida and the rest of the continental US, with the exceptions of TCSV in

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tomato in Ohio, and GRSV from tomato in South Carolina and New York, all of which were first reports. Currently, TCSV is the predominant tospovirus in south Florida and has also become widespread in the Caribbean. Although predominantly solanaceous hosts are known for TCSV and GRSV, increasing numbers of non-solanaceous hosts have recently been reported for TCSV in Florida and the Caribbean. These hosts include lettuce (*Lactuca sativa*), sweet basil (*Ocimum basilicum*), purslane (*Portulaca oleracea*) and several other common weeds, and annual vinca (*Catharanthus roseus*) and several other ornamental crops (Estévez and Adkins, 2014; Raid et al. 2017; Warfield et al. 2015). Because different tospoviruses induce similar symptoms in all these hosts, serological or molecular tests are needed to accurately determine which virus is present.

Like TSWV, TCSV and GRSV are transmitted by thrips. Western flower thrips and common blossom thrips (*Frankliniella schultzei*) are confirmed vectors of these new tospoviruses (Webster et al. 2015). The fact that the diseases caused by tospoviruses are beginning to appear more widely and with greater frequency across south Florida is cause for concern. The close relationship between these new tospoviruses indicates that integrated management strategies directed against TSWV, including the use of metalized (UV-reflective) mulch, and biologically based thrips management may also be effective for these new tospoviruses.

Thrips Biology and Ecology

A review of the scientific literature relating to the biology and ecology of western flower thrips is found in Reitz (2009). Native species of thrips are common in Florida tomato (Momol et al. 2004; Frantz and Mellinger 2009). In north Florida, the most common species is the eastern flower thrips (*Frankliniella tritici*) followed by the Florida flower thrips (*Frankliniella bispinosa*). In central and south Florida, the Florida flower thrips is the only common native species. Adults of eastern flower thrips, Florida flower thrips, and western flower thrips aggregate in flowers, while larvae of these species are found both in flowers and on fruits. Thrips are cryptic and hide under the calyx on fruits or where fruit contacts stems or leaves.

Characteristics of flower thrips include a wide feeding range of plant host species, an ability to disperse rapidly, a short generation time, and production of male offspring without mating. All the species mentioned have a high reproductive potential. However, tomato is a poor reproductive host for those species, including the western flower thrips. The adults can reach high numbers in the flowers of tomato, but the number of larvae in relation to adults is always low.

The life stages of thrips include egg, larva I, larva II, pupa I, pupa II, and adult. Developmental times at optimal temperatures of eggs, larvae, and pupae are about 6, 5, and 5 days, respectively, for every species (Reitz 2008; Tsai et al. 1996). The adults of all species feed on flower tissues and pollen. Pollen feeding greatly increases the number of eggs produced.

Development of thrips is slower at cool temperatures. The minimum temperature required is about 10°C or 50°F. About 30 to 40 days are necessary for a complete generation during the winter in north Florida (Toapanta et al. 1996, 2001). Generations develop more rapidly as temperatures increase in the spring. Populations become very abundant in the near absence of natural enemies in the early spring in north Florida (Northfield et al. 2008). Populations decline greatly in summer and fall as natural enemies become an important factor affecting their abundance. In central and south Florida, natural enemies are present year-round.

Plant species that serve as reproductive hosts vary with each individual species of thrips (Northfield et al. 2008; Paini et al. 2007). Adults also commonly feed in the flowers of plants that are not reproductive hosts. Western flower thrips are suppressed, but not completely eliminated, by interspecific competition with the native thrips. Since western flower thrips share most of the same non-crop hosts as eastern flower thrips and Florida flower thrips, interspecific competition is an important factor in keeping western flower thrips numbers generally low (Paini et al. 2008; Northfield et al. 2011).

Many predaceous arthropod groups help to suppress thrips populations. Minute pirate bugs (Family Anthocoridae) are the most important predators of thrips (Funderburk et al. 2000). Western flower thrips also suffer more severe predation by minute pirate bugs than do the native thrips (Reitz et al. 2006). Species of anthocorids occur nearly worldwide. The species *Orius insidiosus* occurs throughout eastern North America, Central America and the Caribbean, and South America. *Orius pumilio* also occurs with *O. insidiosus* in central and south Florida (Shapiro et al. 2009). Other thrips predators include the big-eyed bugs (Family Lygaeidae), damsel bugs (Family Nabidae), lacewings (Family Chrysopidae), predatory thrips (primarily in the family Aeolothripidae), and predatory mites (Family Phytoseiidae).

Tomato Spotted Wilt Virus

TSWV is circulative and replicative, which means that the virus is circulated by the insect hemolymph (blood) and replicates in the insect's internal tissues. The cycle of virus acquisition and transmission begins with larval feeding on infected plant tissue (de Assis Filho et al. 2005). The virus passes through the midgut of the insect and spreads to various cells and organs, including the salivary glands. The virus is transmitted to an uninfected plant when saliva is injected into the plant tissue during feeding (Figure 1).

Figure 1. Tomato spotted wilt symptoms on fruit of tomato.
Credits: Ozan Demirozer

In crop systems, the virus is transmitted by adult thrips. Importantly, adult thrips that have not acquired the virus as larvae are not able to transmit the virus. Only certain species of thrips are able to transmit TSWV (Sherwood et al. 2001a, b). Aphids and whiteflies are not vectors. At least seven species of thrips are vectors of TSWV. The virus has a worldwide distribution, with a known plant host range of over 926 species.

Epidemics of TSW occur in many geographic regions worldwide. The severity and timing of epidemics in a particular cropping system are the result of interactions between the thrips vector, the pathogen host plants, and the pathogen. TSWV has been found to infect plant species of natural vegetation that are found growing close to susceptible crops, and in some situations natural vegetation is an important source of viruliferous adult thrips that transmit to susceptible crops. In other situations, susceptible crops are the source of viruliferous adults invading new fields.

The unusual virus-vector relationship is a challenge in efforts to manage TSW (Momol et al. 2004). Primary spread of the disease (i.e. the initial entry into a crop) represent three quarter of the plant infection and is due to infections caused by incoming viruliferous adults from outside sources that include uncultivated and cultivated plant hosts. Adults persistently transmit, meaning that they are infected for life, and their control with insecticides does not prevent transmission due to the short time of feeding for infection to occur (Momol et al. 2004).

Secondary spread (i.e. infection occurring within a crop) represent a qurter of the plant infection and is caused by viruliferous adults that acquired the virus as larvae feeding on an infected plant and move to another plant in the same crop. For secondary spread, thrips need to colonize and reproduce on infected plants within a crop. Control of the larvae before their development to adults is effective in preventing secondary spread. Most viral infections in north Florida are the result of primary spread, although some secondary viral infections occur late in the spring season (Momol et al. 2004). The historic lack of epidemics of TSW in central and south Florida suggests that the Florida flower thrips is not an efficient vector capable of acquiring TSWV from uncultivated plant species. It is capable of acquiring and transmitting TSWV from pepper under laboratory conditions, although less efficiently than the western flower thrips (Avila et al. 2006). The eastern flower thrips, melon thrips, and chilli thrips are not competent vectors of TSWV.

Table 1 lists different types of tactics effective in managing primary and secondary spread of TSW. Each type of tactic is discussed in the text that follows.

Table 1. Tactics useful in managing primary and secondary spread of tomato spotted wilt virus and other tospovirus species in tomato.

Primary Spread	Secondary Spread
Resistant cultivars	Resistant cultivars
Ultraviolet-reflective barriers and mulches	Ultraviolet-reflective barriers and mulches
Systemic acquired resistance inducer	Systemic acquired resistance inducer
Optimal fertility	Optimal fertility
	Insecticides for suppression of thrips larvae

Management Programs for Western Flower Thrips and Tomato Spotted Wilt Virus

Economic Thresholds

Adults of the eastern flower thrips and Florida flower thrips cause little if any damage to tomato, and they beneficially out-compete the western flower thrips. No damage has been observed even when densities of 20–25 of these native species per flower were present (Funderburk 2009; Demirozer et al. 2012). The adults of all species of thrips feed on petals and other flower structures, but this injury does not result in economic damage. The adults of the invasive western flower thrips that inhabit tomato flowers cause damage by laying eggs in the small fruit (Salguero Navas et al. 1991). An average of one western flower thrips adult per flower can be tolerated without damage, but growers need to take action at this threshold.

Thrips feed by sucking the contents of the epidermal cells of the plant. When feeding occurs on fruit, it results in a damage symptom called "flecking" (Ghiudu et al. 2006), which may not become evident until the fruit ripens although the feeding occurred on immature fruits. Adults of the western flower thrips and larvae of all species cause flecking (Figure 2). At least two larvae per small, medium, or large fruit on average in a field are tolerable, but this is the action threshold (Funderburk 2009; Demirozer et al. 2012).

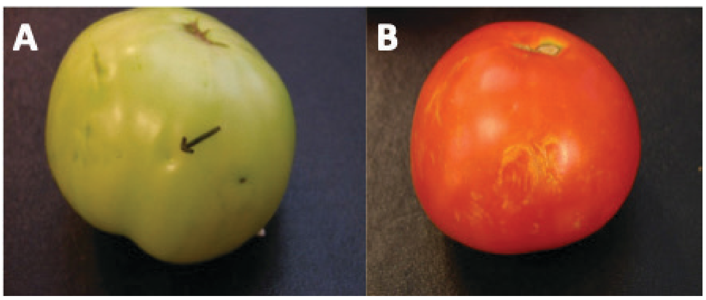

Figure 2. (A) Tomato fruit with "dimpling" caused by egg laying of the western flower thrips and (B) fruit with "flecking" caused by feeding of thrips larvae.
Credits: Joe Funderburk, UF/IFAS

Scouting

Because the native flower thrips occur in large numbers in the flowers of fruiting vegetables where they out-compete the damaging invasive species, it is necessary to accurately identify the species in order to make management decisions. A few flowers should periodically be placed in a small container with 70% alcohol (Figure 3, Funderburk et al. 2019). The container can be shaken to dislodge the thrips, which can then be examined by a specialist under a microscope with at least 40× magnification to determine the species of the adults. Shifts in the relative abundance of species of thrips throughout the growing season can be determined in this way. Thrips identification is quite complex, and it is best for growers to have a competent scout who can provide this service. Contact your county agent for advice and help.

Figure 3. Placing tomato flowers in vials with 70% alcohol.
Credits: Joe Funderburk, UF/IFAS

Densities of Thrips

Thrips densities in flowers can be determined by picking the flowers and placing them on a white board. Gently tear open the flower and the thrips will emerge onto the board where the adults and the larvae are readily distinguished from each other and counted. It is not possible to distinguish eastern flower thrips, western flower thrips, and Florida flower thrips from one another in the field. Counting the thrips from ten flowers from each of several locations in a field is usually sufficient to estimate densities of species for scouting purposes. Examine small, medium, and large fruits directly for thrips, taking care to look under each calyx. Examine and count the thrips on at least four fruits from each of several locations in the field. Special care must be taken to examine the small fruits frequently as the eggs generally are laid during the flower stage, and larvae on the small fruit is the first indication of a developing problem.

Ultraviolet-Reflective Mulch

The ultraviolet-reflective mulch in the typical raised-bed plastic mulch production system of Florida repels the migrating adults of the western flower thrips and this reduces the primary and secondary spread of TSW. The use of ultraviolet-reflective mulch also reduces the influx of eastern flower thrips and Florida flower thrips (Momol et al. 2004). This cultural tactic is most effective from early to midseason before the plants grow to cover the mulch. Application of certain fungicides and other pesticides reduces the UV reflectance and hence the efficacy of the mulch. A single application of copper and mancozeb fungicide can reduce the reflectance by approximately 49%.

Acibenzolar-S-methyl

Acibenzolar-S-methyl (Actiguard®) is a systemic acquired resistance inducer that influences the salicylic acid pathway in the plant. This product has been shown to reduce the incidence of infection of TSWV (Momol et al. 2004). Its use has minimal impacts on populations of the flower thrips. The product is particularly effective against bacteria and it is an excellent replacement for foliar pesticides for bacterial and fungal disease control.

Insecticides

Populations of invasive western flower thrips that became established in Florida probably arrived resistant to most of the traditional classes of broad-spectrum insecticides. Resistance has been documented for pyrethroid, carbamate, and organophosphate classes of insecticides. Flaring of western flower thrips and the non-target pests is possible when any broad-spectrum insecticide is used. For this reason, their use in tomato is being phased out as new, safer, more selective insecticides in different chemical classes are becoming available (Table 2). Certain organophosphate and carbamate insecticides have some level of efficacy against western flower thrips, but these should be used very selectively. Their use may be warranted but only in particular instances when nontarget effects would be minimal. An example would be near the end of the production season, as re-entry and pre-harvest intervals on the label allow.

The most efficacious insecticides for western flower thrips in tomato and other crops are in the spinosyns class. No other insecticide class provides this level of control. However, some level of resistance to spinosyns has been documented in pockets in Florida (Weiss et al. 2009). The label for spinosyns has a limit on the number of applications per season. Growers should always follow the label and not exceed the label wording. Only use Insecticide Action Committee group 5 insecticides (spinosyns) a maximum of 2 sprays per crop. Avoid sequential sprays on sequential crops. Cyantraniliprole and acetamiprid have performed best after the spinosyns in the trials. Other insecticides that have shown significant suppression against the adults and larvae of western flower thrips include flonicamid, spirotetramat, and Requiem® (terpenes). Azadirachtin, potassium salts of fatty acids, and other insecticides are available commercially, and these provide some suppression of western flower thrips (Table 2).

The focus of management is not on killing the maximum number of thrips; rather it is on preventing damage. Dimpling and flecking is only damaging at high levels, and both can be reduced to tolerable levels by limited suppression of western flower thrips adults and larvae. It is important to use different insecticides from different chemical classes when multiple applications of insecticide are justified during the production season. In north Florida, three to five weekly spaced insecticide applications are sometimes justified to prevent unacceptable damage from dimpling and flecking. The weekly applications are sufficient as well to prevent secondary spread of TSW (Momol et al. 2004). In the past, these applications included spinosad and certain broad-spectrum organophosphate insecticides. The organophosphate can be replaced with the newer, safer insecticides (Dripps et al. 2010; Srivistava et al. 2013).

Avoid Spraying Insecticides That Enhance Western Flower Thrips

Most broad-spectrum insecticides, including pyrethroids, organophosphates, and carbamates, kill the native species of thrips that outcompete western flower thrips (Funderburk et al. 2000; Reitz et al. 2003; Srivistava et al. 2008; Srivistava et al. 2014). A number of insecticides have been shown to greatly enhance western flower thrips reproduction and subsequent populations in tomato. Unlike pepper, eggplant, and many other crops, natural enemies that feed on or parasitize thrips are not sufficient to suppress thrips populations in tomato. Moreover, application of broad-spectrum insecticides suppresses important natural enemies of other pests that effectively suppress spider mites, whiteflies, leafminers, and other pests.

Plant Nutrition

Fertilization above recommended rates of nitrogen for optimal production results in an increase in the numbers of all species of thrips and an increased incidence of TSW (Stavisky et al. 2002; Brodbeck et al. 2001). The increased level of aromatic amino acids in over-fertilized plants makes them more attractive to adult female western flower thrips and increases thrips reproduction and growth.

Host Plant Resistance

Numerous varieties of tomato that are resistant or tolerant to TSW are commercially available (Table 3). These varieties are resistant to the virus, but not to thrips feeding. The source of resistance in all of the resistant cultivars is the SW5 gene, and this resistance is single-gene dominant. The SW5 gene also confers resistance to TCSV and GRSV isolates in Florida. Strains of TSWV that have overcome resistance from the single-gene dominant trait have appeared in other geographical areas including California (Batuman et al. 2017; Rosello et al. 1998). Therefore, an integrated approach is necessary to reduce feeding by thrips and manage TSW using ultraviolet-reflective mulch, acibenzolar-S-methyl, and insecticides (Momol et al. 2004).

Vertical Integration of the Management Program

In north Florida, western flower thrips is the key pest of tomato, and consequently TSWV is the most damaging disease. The use of UV-reflective mulch has been effective in reducing populations of western flower thrips and the incidence of TSW. Whiteflies and whitefly-vectored viruses are occasional pests in north Florida, and UV-reflective mulch is also efficacious in reducing damage from these pests. Western flower thrips and other thrips species and thrips-vectored viruses can cause damage to tomato in south and central Florida; however, the primary arthropod pest of tomato in these regions is *Bemisia tabaci*, also known a *B. argentifolii*, the silverleaf whitefly. Growers use insecticides to manage whitefly-vectored viruses, particularly *tomato yellow leaf curl virus*, which can cause devastating losses. Insecticides applied to manage whiteflies on tomatoes and other crops that harbor thrips may impact thrips populations and thrips susceptibility to insecticides. Resulting resistance in western flower thrips populations has been a particular problem in Florida and elsewhere. Broad-spectrum insecticides applied against whiteflies or thrips frequently are responsible for flaring populations of non-target pests, including spider mites and leafminers.

Most tomatoes are treated with neonicotinoid insecticides at planting for control of whiteflies. Imidacloprid, thiamethoxam, or dinotefuran are commonly used. Soil applied neonicotinoid insecticides may suppress foliar-feeding thrips, but will have limited impact on thrips in flowers. Broad spectrum insecticides, such as endosulfan and pyrethroid insecticides, are used to control whitefly adults and can reduce both natural enemies of thrips and native thrips species, giving western flower thrips a competitive advantage. Pymetrozine is effective against whitefly adults and should not disrupt thrips management programs. Softer materials, such as azadirachtin-based products, microbial insecticides such as *Beauvaria bassiana*, and insect growth regulators used to manage whiteflies, are compatible with thrips management, but are directed at whitefly nymphs and will have limited efficacy in suppressing primary virus transmission by whiteflies coming into the field. Products that are effective against immatures will suppress secondary (within-field) spread.

It is recommended that growers anticipate key pests such as whiteflies or thrips and use preventive tactics to minimize their impacts. This minimizes the need for insecticides that can result in the flaring of nontarget pests.

Regular scouting and proper identification of pests is instrumental in preventing damage from occasional pests. There are soft insecticides available for most occasional pests, and these should be used if an occasional pest reaches a threshold, especially during early and mid-season. Broad-spectrum insecticides may be suitable late in the season when little time is left for flaring of non-target pest populations. Always follow the insecticide labels, and pay careful attention to re-entry and pre-harvest intervals.

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Table 2. Main insecticides for fruiting vegetables that control or suppress the adults and larvae of western flower thrips. Most are selective insecticides, generally with low toxicity to important natural enemies unless otherwise indicated. Detailed name and rates are provided in the *Vegetable Production Guide* https://edis.ifas.ufl.edu/publication/CV137.

Active Ingredient	Trade Name	Comment(s)
Spinetoram	Radiant®	Good control of adult and larval western flower thrips; minimize applications and apply a maximum of two per season to avoid resistance development
Acetamiprid	Assail®	Control of adult and larval western flower thrips; broad spectrum insecticide so use should be avoided except in appropriate circumstances
Cyantraniliprole	Exirel®	Recommended for suppression or in a rotation with other insecticides when multiple applications are required in the same season
Flonicamid	Beleaf®	Recommended for suppression or in a rotation with other insecticides when multiple applications are required in the same season
Spirotetramat	Movento®	Recommended for suppression or in a rotation with other insecticides when multiple applications are required in the same season
Terpenes	Requiem®	Recommended for suppression or in a rotation with other insecticides when multiple applications are required in the same season
Methomyl	Lannate®	Control of adult and larval western flower thrips; broad spectrum insecticide so use should be avoided except in appropriate circumstances
Capsicum oleoresin, garlic oil, soybean oil	Captiva®	Untested by University of Florida
Chromobacterium subtsugae	Grandevo®	Weak suppression; sometimes suitable in rotation with other insecticides when multiple applications are needed in the same season
Potassium salts of fatty acids	M-Pede®	Weak suppression; sometimes suitable in a rotation with other insecticides when multiple applications are required in the same season
Kaolin clay	Surround®	Suppression, multiple applications required; discontinue prior to harvest to avoid residues on fruit
Rosemary oil, geraniole and peppermint oil	EcoTrol® Plus	Weak suppression; sometimes suitable in a rotation with other insecticides when multiple applications are required in the same season

Table 3. Cultivars with resistance to tomato spotted wilt through the Sw-5 gene.

Large Round Determinate Types		
Amelia*	Mountain Merit	Southern Ripe*
	Primo Red	Summer Pick*
BHN 3353*	Quincy*	STM 2255*
BHN 602*	Red Bounty*	
BHN 1021*	Red Defender*	SV 7631*
Brickyard	Red Morning*	Tribeca*
Dixie Red*	Red Mountain*	
Finishline*	Red Snapper*	
Fletcher*	Summerhaven*	Volante*
Loretta*	Skyway	Winterhaven*
Plum or Roma Types		
BHN 685*	Monticello*	Rubia*
Conan	Muriel*	Shanty*
Galilea*	Patria	
Granadero	Picus*	Supremo
	Plum Regal*	Tachi
Health Kick		
Katya		
Large Round Indeterminate Type		
Imperial 643	Sophya	
Grape Type		
Mountain Vineyard*	BHN 1022*	
*Cultivars that have been evaluated under Florida conditions		

Table 4. Management Recommendations for Western Flower Thrips and Tomato Spotted Wilt Virus in Tomato.

In scouting program, distinguish between adult and larval thrips and identify adult thrips to species
Economic thresholds: about 1 western flower thrips per flower and about 2 larvae per fruit
Do not treat for Florida flower thrips and eastern flower thrips because they out-compete western flower thrips
Avoid using insecticides that induce western flower thrips
Use ultraviolet-reflective mulch and other ultraviolet-reflective technologies
Use TSWV resistant cultivars when available
Vertically integrate management of thrips and TSWV with management of other pests and diseases, including whiteflies and Lepidoptera, and whitefly-vectored viruses and other tomato diseases
Follow Best Management Practices for fertility and water management