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Managing Thrips in Pepper and Eggplant[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, thrips vectoring of plant diseases, the cost of using control tactics, and the loss of pesticides due to resistance.

The key pest thrips in pepper and eggplant is the western flower thrips, *Frankliniella occidentalis*. It was introduced and became established in northern Florida in the mid 1980's. The western flower thrips emerged as the key pest problem in central and southern Florida in 2005 (Frantz and Mellinger 2009, Figure 1). Another invasive species is the melon thrips, *Thrips palmi*. It is adapted to tropical climates and became established in southern Florida in the early 1990's, where it has become a pest of pepper and eggplant. The chilli thrips, *Scirtothrips dorsali*, is a recent invader in central and southern Florida where it has the potential to develop as a pepper and eggplant pest.

Growers in all regions initially responded to these invasive thrips by the calendar application of broad-spectrum insecticides. This has resulted in a classic '3R' 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 the broad-spectrum insecticides. Scientific papers that review information on the situation in Florida are Funderburk (2009), Frantz and Mellinger (2009), and 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 virus occur frequently in numerous crops in northern Florida, but the disease occurs only sporadically in central and southern Florida where it is not considered a serious problem at the present time.

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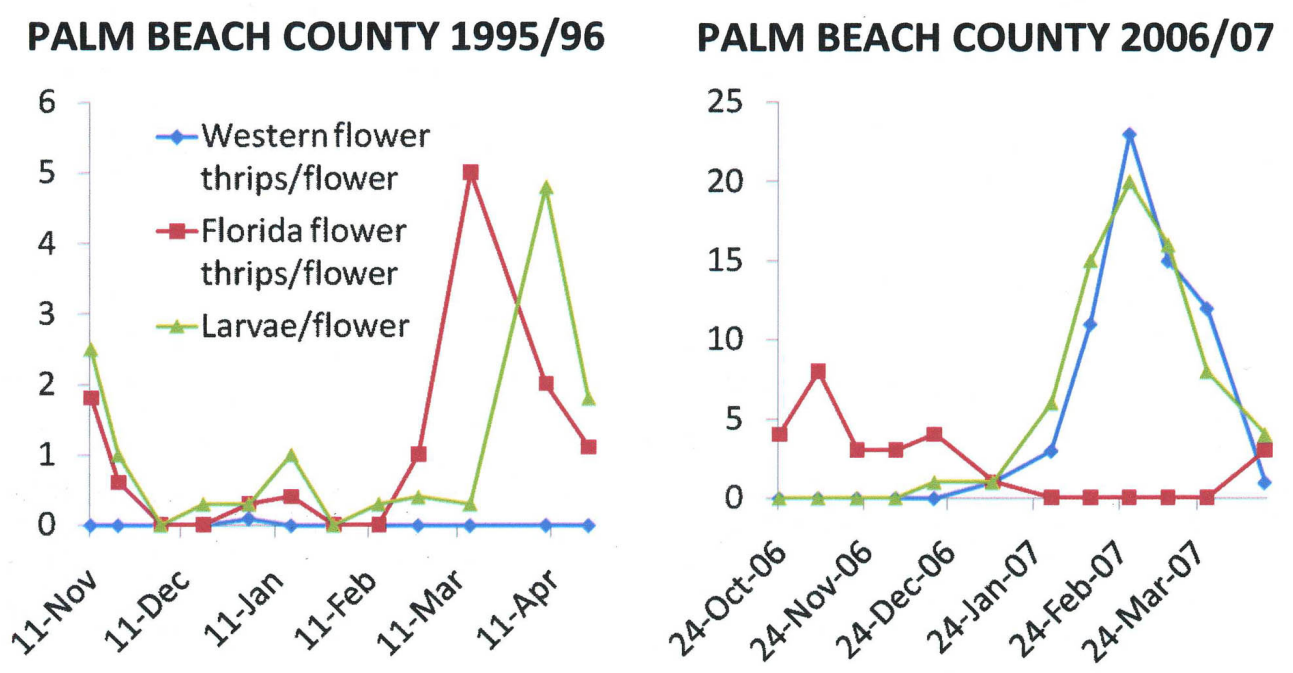

Figure 1. Population dynamics of thrips in commercial pepper in South Florida. Adapted from Frantz and Mellinger (2009).

Thrips Biology and Ecology

Native species of thrips are common in Florida pepper and eggplant (Funderburk et al. 2000, Frantz and Mellinger 2009). In northern Florida, the most common species is the eastern flower thrips (*Frankliniella tritici*) followed by the Florida flower thrips (*Frankliniella bispinosa*). In central and southern Florida, the Florida flower thrips is the only common native species. Adults of eastern flower thrips, Florida flower thrips, western flower thrips, and melon thrips aggregate in flowers, while larvae of these species are found in flowers and on fruits (Hansen et al. 2003). Thrips are cryptic and hide under the calyx on fruits or where fruit contacts stems or leaves.

A review of the scientific literature relating to the biology and ecology of western flower thrips is found in Reitz (2009). Population 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 of the species mentioned have a high reproductive potential.

The life stages of thrips include an egg, larva I, larva II, pupa I, pupa II, and adult. Developmental times at optimal temperatures of egg, larvae, and pupae are about 6, 5, and 5 days, respectively, for each 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. About 30 to 40 days are necessary for a complete generation during the winter in northern Florida (Toapanta et al. 1996, 2001). Generations develop more rapidly as the temperatures increase in the spring, and populations become very abundant in the near absence of natural enemies in the early spring in northern Florida (Northfield et al. 2008). Population numbers decline greatly in summer and fall as natural enemies become important factors affecting their abundance. In central and southern 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 and melon thrips are suppressed, but not completely eliminated, by interspecific competition with the native thrips. Since they share most of the same noncrop hosts, the invasive species are much less common as a result of interspecific competition (Paini et al. 2008).

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). 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 southern Florida. 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

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 the insects 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 is spread to various cells and organs, including the salivary glands. The virus is transmitted to an uninfected plant when the saliva is injected into the plant tissue during feeding (Figure 2).

Figure 2. A pepper with Tomato spotted wilt.

In crop systems, the virus is transmitted by the adult thrips. Importantly, adult thrips that have not acquired the virus as larvae are not able to transmit the virus. This is due to a barrier in the midgut of the adult thrips, through which the viral particles cannot pass.

Only certain species of thrips are able to transmit tomato spotted wilt virus (Sherwood et al. 2001a,b). Aphids and whiteflies are not vectors. At least seven species of thrips are vectors of tomato spotted wilt virus. The tomato spotted wilt virus has a worldwide distribution, with a known plant host range of over 926 species.

Epidemics of tomato spotted wilt virus 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. Tomato spotted wilt virus 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 tomato spotted wilt virus (Momol et al. 2004). Usually primary spread of the disease (initial entry into a crop) is due to infections caused by incoming viruliferous adults to a crop 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 (within a crop) is caused by viruliferous adults that acquired the virus as larvae feeding on an already infected plant. 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 northern Florida are the result of primary spread although some secondary viral infections occur late in

the spring season (Momol et al. 2004). The lack of epidemics of tomato spotted wilt disease in central and southern Florida suggests that the Florida flower thrips is not an efficient vector capable of acquiring tomato spotted wilt virus from uncultivated plant species. It is capable of acquiring and transmitting tomato spotted wilt virus from pepper under laboratory conditions, although less efficiently than the western flower thrips (Avila et al. 2006). The eastern flower thrips, the melon thrips, and the chilli thrips are not competent vectors of tomato spotted wilt virus.

Management Programs for Western Flower Thrips and Tomato Spotted Wilt Virus

Economic thresholds. Adults of the eastern flower thrips and the Florida flower thrips cause little if any damage to pepper and eggplant, and they beneficially out-compete the western flower thrips and the melon thrips. No damage has been observed even when densities of 20-25 of these native species per flower were present (Funderburk 2009).

The adults of the invasive western flower thrips and melon thrips that inhabit pepper and eggplant flowers also cause little if any damage. At least 6 western flower thrips and melon thrips adults per flower can be tolerated without damage.

The adults of all species of thrips feed on petals and other flower structures, but this injury does not result in economic damage. Egg-laying on the small fruit of the flower by the western flower thrips (typical in tomato and some other crops) is not typical in pepper and eggplant.

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' (Figure 3). Adults of the western flower thrips and the melon thrips and larvae of all species cause flecking. At least two larvae per small, medium, or large fruit on average in a field are tolerable. Growers need to take action to control when populations of larvae reach two per fruit on average (Funderburk 2009).

Figure 3. A pepper fruit with 'flecking' caused by feeding of thrips.

In North Florida, the western flower thrips adults are the key vector of tomato spotted wilt virus; however, therapeutic control of the adults in the flowers with insecticides does not prevent their successful transmission of the virus to the plant (Reitz et al. 2003). Preventative tactics, such as ultraviolet-reflective mulches and resistant cultivars, must be used to prevent primary spread of tomato spotted wilt virus by the adults of the western flower thrips.

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 important to know the species in order to make management decisions. A few flowers should periodically be placed in a small container with 70% alcohol (Figure 4). The container can be shaken to dislodge the thrips which can then be examined under a microscope with at least 40X magnification to determine the species. Shifts in the species of thrips through the growing season can be evaluated in this way. It is best for growers to have a competent scout that can provide this service. Contact your county agent for advice and help.

Densities of thrips and minute pirate bugs in the flowers are determined by picking the flower and placing it on a white board. Gently tear open the flower and the thrips and minute pirate bugs will emerge onto the board where the adults and immature stages are readily distinguished and counted. Flowers also can be placed in containers with 70% alcohol and shaken vigorously. The thrips and minute pirate bugs

Figure 4. Placing pepper flowers in vials with 70 % alcohol.

will fall to the bottom of the vial where they can be distinguished and counted. Counting the thrips from ten flowers from each of several locations in a field is usually sufficient to estimate density for scouting purposes. Examine small, medium, and large fruits directly for thrips, taking care to look under the calyx. Examine and count the thrips on at least several fruit from each of several locations in the field. Special care needs to 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.

Biological Control. Thrips in peppers and eggplant are controlled naturally by minute pirate bugs. The scout can calculate the predator to prey ratio to predict the effectiveness of the minute pirate bugs in controlling thrips (Funderburk et al. 2000, Reitz et al. 2003). Under field conditions, about one predator to 180 thrips is sufficient for suppression of the populations of thrips. When the ratio reaches about one predator to 40 thrips, thrips populations are controlled.

In northern Florida, minute pirate bugs are not active during the winter and early spring. There usually is a lag time in spring pepper and eggplant during which populations of thrips buildup before natural populations of the minute pirate bug invade in sufficient numbers to suppress and control thrips (Funderburk et al. 2000, Reitz et al. 2003). The number of thrips can exceed 10 per flower in untreated spring pepper and eggplant during this lag period, but there usually is no damage to the fruits. Minute pirate bugs are active year round in central and southern Florida. They will rapidly invade fields in sufficient numbers to prevent population buildup of thrips.

Minute pirate bugs are effective predators of the adults and larvae of all thrips species (Ramachandran et al. 2001, Reitz et al. 2003), although the predator has distinct prey preferences. The larvae are the first to be suppressed, followed by adult western flower thrips (Baez et al. 2004). Adults of the eastern flower thrips and the Florida flower thrips are the more mobile and, as a consequence, they are better able to escape predation (Reitz et al. 2006).

Conservation Biological Control and Reduced-Risk Insecticides. An integrated pest management biological control program is the most effective way to manage thrips in pepper and eggplant (Funderburk et al. 2000, Reitz et al. 2003, Srivistava et al. 2008). This integrated pest management program has been adapted to local conditions throughout Florida. Spinosyn insecticides represent a unique mode of action (Group V insecticides). The spinosyns spinosad and spinetoram are the most effective insecticides presently available to suppress western flower thrips. They are reduced-risk insecticides that only minimally suppress populations of minute pirate bugs at labeled rates. Other insecticides labeled for fruiting vegetables with efficacy against thrips that conserve populations of minute pirate bugs are listed in Table 2. Reduced-risk insecticides that are not efficacious against the western flower thrips but conserve minute pirate bugs are useful in the control of other pests. These are also listed in Table 2.

Ultraviolet-Reflective Mulch. An effective integrated pest management program employs reduced-risk insecticides, natural infestations of minute pirate bugs, and cultural tactics including ultraviolet-reflective mulch (Reitz et al. 2003). The ultra-violet reflective mulch repels the migrating adults of the western flower thrips and this reduces spread of the tomato spotted wilt virus. Such mulches result in a delay in the buildup of populations of

thrips of all species and of minute pirate bugs. Overall, the benefits of the ultraviolet reflective mulch outweigh the initial reduction in biological control.

Do Not Spray Insecticides That Enhance Western Flower Thrips. Most broad-spectrum insecticides, including pyrethroids, organochlorine, organophosphate, and carbamate insecticides, kill minute pirate bugs and the competing native species of thrips (Funderburk et al. 2000, Reitz et al. 2003, Srivistava et al. 2008). A number of insecticides have been shown to greatly enhance western flower thrips reproduction and subsequent populations (Figure 5). These are listed in Table 3.

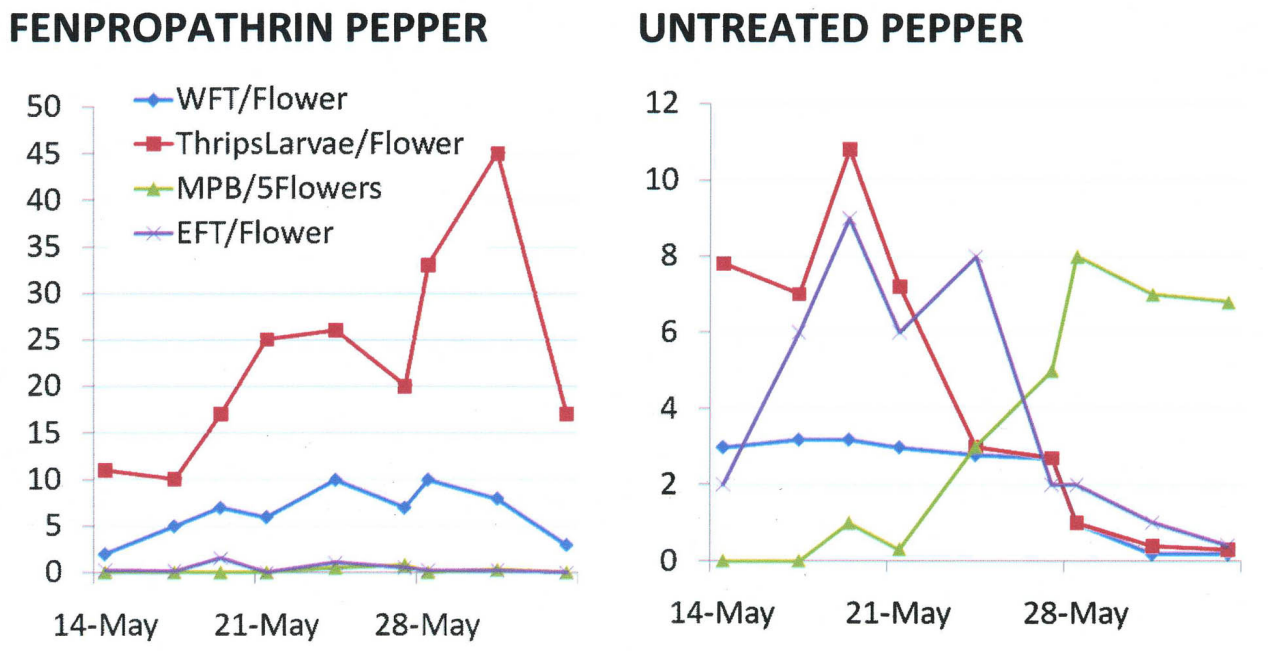

Figure 5. Population dynamics of western flower thrips (WFT), eastern flower thrips (EFT), and minute pirate bugs (MPB) in north Florida. Adapted from Funderburk et al. (2000).

Plant nutrition. Over-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 tomato spotted wilt virus (S. R. Reitz, unpublished). This is due to an increased level of aromatic amino acids in over-fertilized plants that results in increased preference and performance of the females of the western flower thrips.

Refugia Plantings. Many wild and cultivated species of plants serve as hosts for minute pirate bugs and other natural enemies. Minute pirate bugs usually occur in large numbers in all regions of Florida and they will naturally invade pepper and eggplant fields. However, it is desirable, especially on large farms with multiple plantings of susceptible crops, to maintain certain plant hosts as refugia for thrips and their natural enemies. Plantings of native species of sunflowers next to pepper fields have been shown to increase the number of minute pirate bugs in pepper fields as a direct function of distance to the sunflower refugia (Frantz and Mellinger 2009). Mexican or Bolivian sunflower (*Tithonia diversifolia*) is a perennial plant that flowers over much of the year in southern Florida. Maintaining refugia where thrips are not exposed to insecticides also helps to reduce the risk of development of insecticide resistance in thrips populations. Usually, plants that are not sprayed with insecticides serve as hosts for the native species of thrips. The invasive pest species are outcompeted by the native species.

Predaceous mites. Augmentative release of the predaceous mite *Amblyseius swirskii* has been shown to control western flower thrips in pepper and eggplant. Other pests controlled by this mite include whiteflies and broadmites. As few as 12 mites per

plant released early in the plant cycle may be sufficient to provide control for more than a month. The mite is available commercially from several suppliers.

Host plant resistance. Several varieties of pepper that are resistant or tolerant to tomato spotted wilt virus are commercially available. These are resistant to the virus, but not to thrips feeding.

Vertical Integration of the Management Program. Outbreaks of the western flower thips are known to be induced by the application of many insecticides. Prevention of pest outbreaks requires that management efforts against all pests be vertically integrated. This is accomplished by careful planning to use preventive tactics when necessary for other key pests.

For pepper weevil, the following practices are recommended:

- At least 3 months pepper-free fallow,
- Control of nightshade,
- Planting in isolated locations if possible,
- Avoiding sequential planting and rotate crops
- Short crop cycles,
- Removal and destruction of infested fruit
- Plow down and destroy old crops

Spidermites, broadmites and whiteflies can be controlled biologically or with compatible insecticides (Table 2).

Lepidoptera are occasional pests in pepper and eggplant that can be controlled with insecticides that do not kill minute pirate bugs and that do not induce western flower thrips in other ways (Tables 2 and 3). The number of insecticides included in these tables will increase following the release of this publication, so contact your county agent for updated information. Proper scouting to identify the species and to spray only when populations reach the economic threshold is recommended.

The conservation biological control program has been used by growers in North Florida since the late 90's, and their experience is that problems from whiteflies, aphids, and other pests were less than when they were following a calendar spray program or frequently using broad-spectrum insecticides to control their pests. Lady bugs are conserved as a consequence and this normally prevents problems from aphids.

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Table 1. Recommendations for Management of Western Flower Thrips in Pepper and Eggplant

1. In scouting program, distinguish between adult and larval thrips and identify adult thrips to species
2. Economic thresholds: about 6 adult western flower thrips and melon thrips per flower, and about 2 thrips larvae per fruit
3. Do not treat for adult eastern flower thrips and Florida flower thrips as they out-compete western flower thrips
4. When peppers are flowering use insecticides for thrips and other pests that conserve minute pirate bugs
5. Never use insecticides that induce western flower thrips
6. Use ultra-violet reflective mulches when forming beds.
7. Sunflower and other refugia provide a source for minute pirate bugs
8. Vertically integrate management of western flower thrips with other pests, including pepper weevil and Lepidoptera species
9. Follow BMP's for fertility and irrigation management

Table 2. Insecticides labelled or under review for fruiting vegetables that are compatable with the conservation biological program using *O. insidiosus*.

Insecticide (common name)	Activity	Source
spinosad	thrips and other taxa	Funderburk et al. (2000)
spinetoram	thrips and other taxa	Srivastava et al. (2008)
pyridadyl	thrips and other taxa	J. E. F., unpublished
Requiem™ (essential oils)	thrips, aphids, whiteflies	J. E. F., unpublished
methoxyfenozide	Lepidoptera	A. Weiss, unpublished
indoxacarb	Lepidoptera	Reitz et al. (2003)
Bacillus thuringiensis	Lepidoptera, coleoptera	J. E. F., unpublished
EcoTrol™ (essential oils)	thrips, aphids, whiteflies	J. E. F., unpublished
azadiracthin	various	http://www.koppert.com
cyromazine	Dipteran leafminers	http://www.koppert.com
fenbutatin	mites	http://www.koppert.com
pymetrazine	whiteflies, aphids	http://www.koppert.com

Table 3. Insecticides and insecticide combinations known to induce populations of *Frankliniella occidentalis* in pepper.

Insecticide (common name)	Source
fenpropathrin	Funderburk et al. (2000)
lambda-cyhalothrin	J. E. F., unpublished
dinotefuran	J. E. F., unpublished
zeta-cypermethrin & bifenthrin	J. E. F., unpublished
esfenvalerate	Funderburk et al. (2000), Hansen et al. (2003),
	Ramachandran et al. (2001), Reitz et al. (2003),
	Srivastava et al. (2008)