VEGETABLE/ HORTICULTURAL CROPS

Spotted Wilt Virus
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Tomato Spotted Wilt Virus

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Tomato spotted wilt virus (TSWV) causes serious diseases of many economically important plants representing 35 plant families, including dicots and monocots. This wide host range of ornamentals, vegetables, and field crops is unique among plant-infecting viruses. Another unique feature is that TSWV is the only virus transmitted in a persistent manner by certain thrips species. At least six strains of TSWV have been reported; the symptoms produced and the range of plants infected vary among strains. Although previously a threat only to crops produced in tropical and subtropical regions, today the disease occurs worldwide, largely because of wider distribution of the western flower thrips and movement of virus-infected plant material. Early and accurate detection of infected plants and measures to reduce the vector population are discussed as critical steps for disease control.

Causal Agent

TSWV is the only member of an RNA-containing virus group that has membrane-bound spherical particles 70-90nm in diameter. Tomato spotted wilt, first described in Australia in 1919, was later identified as a virus disease. It is now common in temperate, subtropical, and tropical regions around the world. Heavy crop losses in the field were reported in the 1980s in tomato in Louisiana and in tomato and lettuce in Hawaii. Other southern states reporting losses in tomato in recent years include Mississippi, Arkansas, Florida, Alabama, Georgia, and Tennessee.

In recent years, TSWV has caused heavy crop losses in a wide variety of greenhouse-grown vegetable and ornamental plants across the United States and Canada. This upsurge in virus occurrence is attributed to the increased distribution of both the western flower thrips and virus-infected cuttings in the greenhouse industry. A lettuce-type strain is more commonly recovered from vegetables; an impatiens strain more readily infects ornamentals.

There have been reports of TSWV infection in 174 plant species to date; a partial list appears in Table 1. Although an early study reported seed transmission of TSWV at a high rate in *Cineraria* and tomato, a later study found only 1 percent infection. The virus is present only in the seed coat and not in the embryo. Seed transmission is thus not considered important for disease spread.

Weed hosts serve as important virus reservoirs for TSWV and have been identified in Louisiana and Hawaii. A short list of some common weed hosts appears in Table 2. Although many of these weeds may not behave as perennials in many regions of the

Table 1. Partial host range of TSWV in crops grown in greenhouses or in temperate regions of the United States and Canada.

Ornamentals

Potted crops	*Indoor/Outdoor cut flowers*
Chrysanthemum	Gypsophila
Cyclamen	China aster
Gloxinia	Zinnia
African violet	Snapdragon
Cineraria	Calendula
Calceolaria	Dahlia
Primrose	Chrysanthemum
Rieger begonia	Cosmos
Nonstop begonia	Gerbera
Gerbera	Gladiolus
Calla lily	Delphinium
Amaryllis	Peony
Ranunculus	Anemone
Christmas pepper	Stephanotis
Sinningia	Stock
Exacum	
Hydrangea	
Geranium	

Bedding plants/ Hanging baskets	*Perennials*
Salvia	Peony
Forget-me-not	Delphinium
Morning glory	Poppy
Verbena	Phlox drummondii
Nasturtium	Campanula
Dusty-miller	Dahlia
Begonia	Aster
Impatiens	Gaillardia
New Guinea impatiens	Coreopsis
Ageratum	Tiger lily
Calendula	Evening primrose
Coleus	Lobelia
Dahlia	Columbine
Marigold	Lupine
Petunia	
Snapdragon	
Zinnia	

Field Crops	**Vegetables**	
Tobacco	Tomato	Celery
Peanut	Pepper	Bean
	Potato	Cowpea
	Eggplant	Spinach
	Lettuce	Cucumber
	Endive	Cauliflower

United States and Canada, they may survive in protected areas in and around greenhouses and thus serve to "carryover" both virus and thrips.

Vectors

Tomato spotted wilt is one of only a few viruses transmitted by thrips and is by far the most important. Nine species are reported as vectors: *Frankliniella occidentalis* (western flower thrips); *F schultzei; F. fusca* (tobacco thrips); *Thrips tabaci* (onion thrips); *T setosus; T moultoni, F. tenuicornis, Lithnps dorsalis;* and *Scirtothrips dorsalis.* The first four are considered the most important vectors because of their wide distribution and the overlapping host ranges of these species and TSWV.

The western flower thrips is the chief TSWV vector in greenhouse settings around the world, as well as in Hawaii's vegetable growing region. *T tabaci* is widely distributed in tropical, warm, and cool temperate areas around the world. *F occidentalis* and *F fusca* both occur in the United States, Mexico, and as far north as Canada. Until recently, thrips problems in greenhouses were usually due to *Frankliniella trilici* (not a vector of TSWV), known simply as "flower thrips" or eastern flower thrips.

Table 2. Common weed hosts for TSWV by plant family.

Latin name	*Common name*
Amaranthaceae	
Amaranthus spinosus (+ 2 other species)	Spiny amaranth
Caryophyllaceae	
Stellaria media	Chickweed
Chenopodiaceae	
Chenopodium album	Lamb's-quarters
C. ambrosoides	Mexican tea
C. murale	Nettleleaf goosefoot
Compositae	
Arctium lappa	Burdock
Bidens pilosa	Spanish needle (beggar ticks)
Galinosoga parviflora	Galinsoga
Sonchus oleraceus	Sowthistle
Convolvulaceae	
Ipomoea congesta	Blue morning glory
Cruciferae	
Capsella bursa-pastoris	Shepherd's purse
Leguminosae	
Crotalaria mucronata	Smooth rattle pod
Melilotus officinalis	Sweet yellow clover
Malvaceae	
Malva parviflora	Cheese weed
Plumbaginaceae	
Limonium latifolium	Statice
Portulacaceae	
Portulaca oleraceae	Purslane
Solanaceae	
Solanum nigrum	Black nightshade
Tropaeolaceae	
Tropaeolum majus	Nasturtium (viewed as a weed when growing around farm borders)
Verbenaceae	
Verbena litoralis	Verbena

The vector-virus relationship between thrips and TSWV is important to understanding how virus spread occurs. While the virus can be acquired only by the larval stage, transmission is due almost exclusively to adult thrips. Larvae of *T tabaci* can acquire the virus within 15 minutes. Larvae cannot transmit the virus immediately, but after a latent (incubation) period of 3-10 days (depending on the vector species), transmission occurs. Once thrips become infective, they can transmit virus for a maximum period of 22-30 days, or for the remainder of their adult lives. Adults do not transmit virus to their progeny. Overlapping stages in the thrips life cycle can account for continuous virus spread. The generalized life cycle for the western flower thrips is presented in fig. 17.

Several biological characteristics of the western flower thrips make control extremely difficult. Eggs of this species are inserted into leaf or petal tissue, which protects them from insecticides. After 21/2-4 days, the eggs hatch into larvae that usually remain protected in flower buds or terminal foliage. The insect passes through two larval stages, both of which feed in these protected areas (fig. 1). The first larval stage lasts 1-2 days, the second 2-4 days. Toward the end of the second larval stage, the insect stops feeding and usually moves down into the soil or leaf litter to pupate; a few may pupate on the plant. The insect passes through prepupal and pupal stages of 1-2 days and 1-3 days in duration, respectively, when no feeding and little movement occur. While in the soil, the insect misses exposure to insecticides directed at the foliage. The adults, which can survive 30-45 days and lay 150-300 eggs, feed primarily in protected areas of the plant such as flowers and terminals. Western flower thrips adults are tiny (1-2mm), slender insects that can vary in color from straw-yellow to brown and have long fringed wings (fig. 2).

The pest's rapid developmental time (egg to adult in $7^1/2$-13 days at fluctuating temperatures) and reproductive rate can allow an undetected infestation to quickly become a major problem. Although not strong fliers, they fly readily and can be carried on wind currents or on clothing. They can fly from a sprayed to an unsprayed area, or can move into or out of a greenhouse through doors or vents. They can survive and reproduce on a variety of weeds inside and outside a greenhouse. Some preliminary observations in Canada indicate that western flower thrips may overwinter outdoors in the Northeast. Effective chemical control is complicated by insecticide resistance.

Besides vectoring TSWV, thrips feeding causes the collapse of plant cells, leading to deformed plant growth, flower deformation, and silvery areas and flecking on expanded leaves. Tiny greenish-black fecal specks may be seen on leaves or petals.

TSWV in the Greenhouse

In recent years, tomato spotted wilt virus has caused symptoms and crop losses on a wide variety of greenhouse vegetable and ornamental plants across the United States and Canada. Tomato and gloxinia crops in particular have been devastated. This upsurge in virus occurrence is attributed to the increased distribution of the western flower thrips which is commonly found in greenhouses in New York, other states, and Canadian provinces.

Nearly every greenhouse ornamental is subject to TSWV; the only major crops that have not shown symptoms in the past two years are geranium, poinsettia, and rose. Vegetatively propagated ornamentals are the most likely source for a TSWV infestation since the virus is not seed borne. Virus spread is rapid in a greenhouse with a western flower thrips popUlation; some plants will develop symptoms within 5 days offeeding by infected thrips.

The western flower thrips, sometimes highly resistant to many currently registered pesticides, has typically been slow to be detected and identified when introduced to a greenhouse and difficult to control once its presence is known. TSWV has occurred in greenhouse crops previously, but its impact is much greater now that a more widespread, highly efficient, uncontrollable vector has been introduced.

TSWV in the Field

The natural occurrence of TSWV in the field is well documented and is a serious problem in many southern states. Infections on greenhouse bedding plants now present an additional threat to neighboring vegetable growers, to vegetable growers who acquire transplants from greenhouses, and to vegetable producers who grow a crop such as "hothouse" tomatoes to maturity. In several cases in New York, TSWV has spread from ornamental plants (e.g., hanging flower baskets) to vegetable transplants (tomato and pepper seedlings) and even into tomato greenhouse units established for the vine-ripe tomato crop.

Additionally, TSWV-infected tomato seedlings have been transplanted to the field, resulting in heavy losses in that crop and subsequently spreading to adjoining pepper and potato fields. The common denominator in each case has been the innocent intermixing of virus-infected ornamentals with vegetable seedlings. The common practice of intermixing species to maximize available greenhouse space (such as including hanging baskets above bench and floor plantings of vegetables) adds to the potential for virus spread. Growers should realize that growing plants from seeds in the same greenhouse with plants from cuttings poses a serious and unnecessary risk to seed crops. Wherever possible, vegetatively propagated crops should be grown in greenhouse units separate from seed crops of vegetables or ornamentals.

Another method of introducing TSWV into fields occurred in 1989 with TSWV-infected tomato transplants shipped from the south. Growers in northeastern and north central regions of the country received infected seedlings from Georgia and were forced to reject the shipments, rogue fields already planted, or plow under many acres to destroy this additional inoculum source.

Figure 1

Figure 2

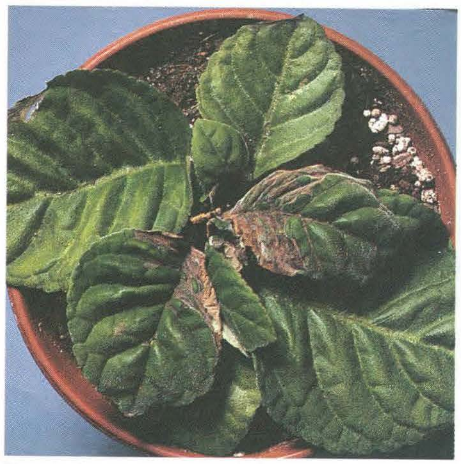

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7


Figure 8


Figure 9


Figure 10


Figure 11


Figure 12


Figure 13


Figure 14


Figure 15

Figure 16

Symptom Expression and Recognition

Symptoms for tomato spotted wilt virus infection are fairly unique to each of its many hosts. Cultivars will also vary in their symptom expression. Common manifestations of TSWV are ringspots (yellow or brown rings) or other line patterns, black streaks on petioles or stems, necrotic leaf spots, or tip dieback.

Multiple strains of TSWV account for some of the differences in symptom type, severity, and host range that have been observed. Plants are also more susceptible at certain times in their life cycles; gloxinia, cineraria, and calceolaria will be most profoundly affected when infected 4-6 weeks after seeding. Temperature may also exert a strong influence on symptom expression; affected cyclamen, gloxinia, cineraria, calceolaria, and New Guinea impatiens show the strongest symptoms during winter months. In contrast, symptoms appear during the summer on marigold, calendula, salvia, and dahlia.

Symptoms on Ornamentals

Gloxinia. When very young «4-6 weeks) plants are infected, they may turn brown and collapse. Browning of the new growth may be confused with the common crown rot caused by *Phytaphthara parasitica* (fig. 3) Plants infected at an older stage of growth may show yellow or brown leaf spotting, or brown oak-leaf patterns in the leaves, often accompanied by distortion of the normal outline (fig. 4)

Chrysanthemum. There is a wide variation among cultivars in response to the virus and in attractiveness to the thrips. The cultivar 'Polaris' is highly susceptible. Black stem streaks, leaf scorch, and wilt are typical of TSWV-infected mums (fig. 5).

Cyclamen. Cyclamen infected with TSWV may have fairly subtle symptoms that are hard to identify. One common characteristic is the appearance of "thumbprints" on the leaves; e.g., virus ringspots in green concentric lines against a chlorotic background (fig. 6) These strange circular areas may be in the center of the leaf or may appear as half-moons at the leaf edge. Round brown necrotic spots may show on some leaves. A brown necrosis of the petiole that bleeds into the leaf blade is typical on older leaves.

Impatiens. *Impatiens sultani,* the bedding plant impatiens, is stunted and shows black spots on the leaves, often surrounded by chlorotic zones. Sections of the stems may also be blackened (fig. 7) Double-flowered impatiens show dramatic leaf spotting.

New Guinea impatiens. Again, cultivars respond differently; many are symptomless while others develop a black stem dieback and collapse entirely. Stunting, black discoloration at the base of the leaf, brown leaf spots, or distortion of leaves may occur (fig. 8).

Rieger begonias. Symptoms vary from brown vein necrosis to yellow mottle patterns on the leaf blade (fig. 9).

Begonia semperflorens. Brown dead areas at the base of the leaf, extending into the petiole, are common.

Cineraria. Symptoms of the disease on cineraria are black streaks on petioles (fig. 10), pale leaf blotches that gradually darken, and wilting and death of lower leaves.

Symptoms on Vegetables

Tomato. Symptoms expressed on leaves, petioles, stems, and fruit will vary, depending on the stage plants are infected. Young leaves may show small, dark-brown spots and eventually die (fig. 11). Dark brown streaks also appear on stems and leaf petioles. Growing tips are usually severely affected with systemic necrosis and greatly stunted growth (fig. 12) The plant may exhibit one-sided growth. Tomato fruit set on severely infected plants will display very characteristic symptoms: immature fruit have mottled, light green rings with raised centers; the unique orange and red discoloration patterns on mature fruits make them,unmarketable (fig. 13)

Pepper. The virus may cause sudden yellowing and browning of young leaves which later become necrotic. Long necrotic streaks appear on stems extending to the growing tips. Fruit formed after infection display large necrotic streaks and spots while younger fruit may be completely necrotic (fig. 14). '

Potato. Broad dark spots and necrotic ringsp'ots, often with chlorotic halos, occur on both the lower and up'per leaves of affected plants (fig. 15) •

Verification of Diagnosis

Virus identification requires special laboratory techniques. A commonly used serological test is ELISA (enzyme-linked immunosorbent assay). Other procedures include mechanical inoculation to a series of diagnostic hosts and electron microscopy. Many cases have been noted where serological tests are negative, despite definite symptoms of TSWV on the sampled plant tissue. Verification of the virus; presence in symptomatic impatiens was particularly difficult until a .new, more sensitive antiserum was recently developed at North Carolina State University. Still, false negatives are possible. Until more reliable tests are developed, growers should consider that positive lab tests are indeed confirmation of the disease, but that negative lab tests may only reflect an inability to detect all strains of the TSWV under all circumstances. If symptoms suggestive of TSWV appear in the greenhouse at the same time that western flower thrips populations are heavy, it is quite possible that the virus is present despite negative lab test results. Control measures should not be delayed while waiting for lab confirmation.

How to Monitor Thrips and Control Spread of TSWV

A. In the greenhouse

Since there is no direct way to attack the virus other than roguing visibly infected plants, it is necessary to aim control efforts'at its thrips vectors. The primary greenhouse vector is the western flower thrips. Resistance to specific organophosphates, carbamates, and synthetic pyrethroid insecticides is known in certain populations. Early detection of a thrips infestation is critical because the symptoms of their feeding are often not noticed until after the damage has occurred, and because small infestations are easier to control.

Yellow sticky cards provide an easy way to detect the onset of an infestation (fig. 16) These should be placed just above the crop canopy, at about one/1 000 sq. ft., as well as near do'ors and vents to monitor the movement of thrips from the outside'. Blue sticky cards catch more thrips, but since other insect pests (e.g., aphids, whiteflies, leafminers, fungus gnats) are not attracted to blue, yellow cards are preferred for general pest monitoring. The number of thrips/card should be recorded and graphed weekly to monitor population levels and aid in control decisions. Flowers can be checked for thrips by tapping a blossom ov~r a sh~et of paper, but it is more efficient to use sticky cards for detection and monitoring. Yellow or white flowers seem particularly attractive to thrips. . ,:

Although effective thrips management can be difficult, adequate control can be achieved by a combination of physical, cultural, and chemical control measures. Prevention is the obvious first step; it is easier to prevent an infestation than to manage an established one. Growers should avoid purchasing plant material infested with thrips, Eliminate weeds from insid,e the greenhouse and the adjacent exterior. Avoid carrying over bng-term plants that might serve as reservoirs of thri'ps 'and/or virus.

Rogue out plants that develop virus symptoms. Research in California shows that fine screens (400-mesh) or barriers over vents can help prevent the movement of thrips into a greenhouse. North Carolina is evaluating materials such as VisQueen® to cover plants on greenhouse benches. Greenhouse workers should avoid wearing yellow or blue clothing to deter the spread of thrips.

Chemical control involves the selection of proper insecticides, number and frequency of applications, application method (spray particle size), and pesticide rotation. Insecticides registered for thrips control that have shown good activity by chemical class include certain organophosphates, carbamates, chlorinated hydrocarbons, and botanicals. Most pyrethroid insecticides, used alone, generally provide only fair control of western flower thrips. It may be possible to improve the effectiveness of an insecticide by combining it with a pyrethroid insecticide. Being an irritant, a pyrethroid may flush thrips out of protected locations for exposure to more insecticide. Check with your Cooperative Extension agent or the most recent issue of *Cornell Recommendations for Commercial Floriculture Crops* for insecticides registered for thrips control. Some insecticides may damage certain plants, so be sure to follow all label directions.

Several insecticide applications should be made at 5-day intervals to significantly reduce a thrips infestation; none of the recommended insecticides is effective with one application. Five-day application intervals are more effective than 7-day intervals.

Ideally, insecticides should be applied with equipment that produces very small spray particles (<100 microns) that will penetrate the protected areas of the plant harboring thrips and provide the most efficient use of insecticide if coverage is thorough.

Rotating insecticides from different chemical classes may be an effective way to delay insecticide resistance. It is best, however, to use an effective insecticide for more than one pest generation before rotating to another material. Given the life cycle of western flower thrips, an effective insecticide should be used for at least 3 weeks before switching to an insecticide from another class of chemicals.

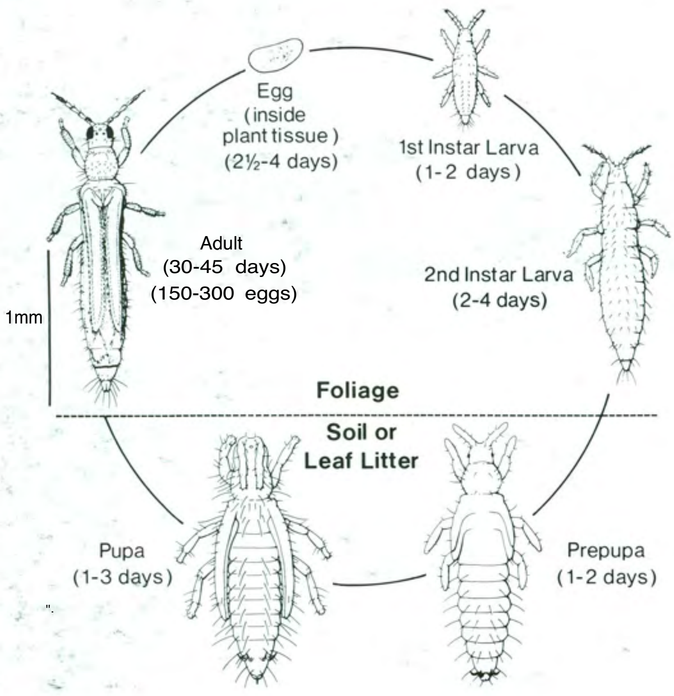

Figure 17

B. In the field

Although recent instances of field spread of TSWV have been noted in vegetables in New York State, occurrence is not as common as in many southern states. Tomato, pepper, and potatoes have been infected; it is likely that infected tomato transplants were the source of inoculum. More frequent occurrence of virus infection in southern states is related to the season-long availability of thrips and virus-reservoir crop and weed hosts. In Ontario, perennial weeds harboring TSWV were found just *outside* a greenhouse.

The chief control strategy in northern states begins in the greenhouse using exclusion and sanitation. Inspect incoming plant material for TSWV symptoms and thrips infestations. Remove symptomatic plants from the greenhouse premises as soon as they are detected. Monitor the greenhouse continually for thrips infestations and treat accordingly. Eliminate weeds that may harbor the virus below benches and outside the greenhouse. In the field, immediately rogue any plants showing disease symptoms and check for thrips. Insecticide sprays may be necessary.

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