Tomato Spotted Wilt Virus Survey Among Greenhouse Ornamentals in Pennsylvania

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ABSTRACT

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Symptoms associated with infection by the tomato spotted wilt virus (TSWV) were documented among bedding, potted, perennial, and foliage plants growing in commercial greenhouses in Pennsylvania. Previously unreported hosts were identified, including four bedding, seven potted, 16 perennial, and seven foliage plants. Of 316 bedding plants infected, 95% were infected with the impatiens strain of TSWV (TSWV-I), and impatiens (*Impatiens wallerana*) and begonias (*Begonia* spp.) were most frequently infected. Of the 266 potted plants infected, 93% were infected with TSWV-I, and cineraria (*Senecio* × *hybridus*), cyclamen (*Cyclamen persicum*), and New Guinea impatiens (*Impatiens* × *hybridus*) were the most frequently infected. Of the 85 perennial plants infected, 96% were infected with TSWV-I, and buttercup (*Ranunculus* spp.) and bee balm (*Monarda didyma*) were most frequently infected. The 38 foliage plants all were infected with TSWV-I.

Greenhouse ornamentals may become infected by tomato spotted wilt virus (TSWV) and currently include a minimum of 41 species (14). In 1990, Law and Moyer (9) reported the isolation of a serologically distinct isolate of TSWV (TSWV-I) from New Guinea impatiens (*Impatiens* × *hybridus*). This virus is commonly representative of a group of isolates obtained from greenhouse-grown ornamentals distributed over the eastern half of the United States. The western flower thrips (WFT) (*Frankliniella occidentalis* (Pergande)) is the primary vector of TSWV among crops within greenhouses (12,13). At one time, WFT was restricted in its range to the western United States and Canada, but it is now a widespread floricultural pest across North America (2).

Pennsylvania has approximately 700 growers of greenhouse crops with production concentrated in eight counties surrounding Philadelphia (6). Since 1988, the Pennsylvania Department of Agriculture (PDA) Bureau of Plant Industry has required growers of greenhouse crops to rogue plants infected with TSWV and to control WFT. Further, it is currently the policy of the PDA to quarantine greenhouse crops infected with TSWV until the virus and WFT are brought under control. It is currently believed that greenhouses in Pennsylvania are not exposed to indigenous populations of WFT, thus making control feasible. Plants infected with TSWV received in Pennsylvania from sources outside of the state are returned or destroyed. TSWV is the first virus disease for which such stringent quarantine restrictions have been instituted. This is largely attributable to the extensive host range of the virus and the significant losses incurred.

To add to existing knowledge on host range and distribution of TSWV among greenhouses in Pennsylvania and to for-

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mulate control strategies, studies were conducted to determine the relative proportions of TSWV-I and TSWV-L, a lettuce strain, among ornamentals grown in the greenhouse, the greenhouse ornamental species most frequently infected by TSWV in Pennsylvania, and the range of symptoms associated with infection by TSWV.

MATERIALS AND METHODS

Plants exhibiting symptoms of disease, regardless of suspected causal agent, were collected by regional plant inspectors of the PDA during yearly routine inspections of commercial greenhouses. Symptoms were recorded on arrival at the diagnostic facilities of PDA. Data presented was collected from December 1989 to February 1991. In addition, weekly surveys of commercial greenhouses were conducted by The Pennsylvania State University (PSU) during February–May 1990. Plants that showed symptoms of necrosis, chlorosis, distortion, or stunted growth were collected.

Infection by TSWV in collected samples was determined serologically by enzyme-linked immunosorbent assay (ELISA) using a polyclonal antiserum to TSWV-I (Agdia, Elkhart, IN) and TSWV-L (PDA, Harrisburg, PA). To minimize background reactions, assays were run according to the cocktail ELISA procedure of Flegg and Clark (7) using reagents of Clark and Adams (4) and an alkaline phosphatase detection system. A positive control of infected *Chenopodium quinoa* Willd., tomato (*Lycopersicon esculentum* Mill.), cyclamen (*Cyclamen persicum* Mill.), or cineraria (*Senecio* × *hybridus* (Willd.) Regel) was included in each test. Healthy tomato leaves also were used as controls in each plate.

Unusual hosts or previously undescribed hosts that tested positive for TSWV were tested a second time to verify infection. In some cases, sap from selected positive samples was used to inoculate *C. quinoa, Nicotiana benthemiana* Domin., and *N. glutinosa* L. Inoculations were performed by triturating tissue in TSC-PEG buffer (0.01 M Tris, 0.01 M sodium sulfite, 0.1% cysteine HCl, and 4% polyethylene glycol 8000, pH 7.8) (1) with a mortar and pestle, and the extract was applied to Carborundum-dusted leaves. Symptomatic tissue from assay hosts was used in conjunction with ELISA to confirm the presence of TSWV.

RESULTS

Incidence of TSWV in Pennsylvania greenhouses. During 1989, many bedding and potted plants from Pennsylvania greenhouses exhibited symptoms indicative of TSWV although TSWV-L was rarely detected. With antisera to TSWV-I available since November 1989, the presence of TSWV-I in Pennsylvania greenhouses was verified. TSWV was identified in 19 of the 20 greenhouses surveyed by PSU and 129 of 491 greenhouses inspected by PDA, representing 46 of 67 (69%) counties in Pennsylvania (Fig. 1).

During 1989–1990, plants infected with TSWV worth an estimated $675,000 (retail) were destroyed under the direction of PDA. This figure does not include plants routinely destroyed by growers as part of a disease management program. Although the greatest incidence of infection was for impatiens (*Impatiens wallerana* J. D. Hook) and New Guinea impatiens, more than half of the total monetary loss ($351,000) was associated with roguing entire crops of cineraria.

Bedding plants. Twenty-five genera of bedding plants were infected with TSWV. Four of these are previously unreported hosts including dusty-miller (*Centaurea cineraria* L.), everlasting flower (*Helichrysum bracteatum* (Venten.) Andr.), prairie-gentian (*Eustoma grandiflorum* (Raf.) Shinn.), and basil (*Ocimum basilicum* L.). Vegetable transplants also were infected with TSWV, including 23 pepper (*Capsicum annuum* L.), 17 tomato, two lettuce (*Lactuca sativa* L.), and two eggplant (*Solanum melongena* L. var. *esculentum* Nees) samples. Infection of impatiens and begonias (*Begonia* spp.) by TSWV represented 41% (131) and 22% (70), respectively, of the total (316) infected bedding plant samples (Table 1).

Nearly one-half (48%) of the samples infected with TSWV showed symptoms of spotting on the leaves. Other frequently observed symptoms of infection included patchy, irregular necrotic areas (43%), mottling/mosaic (39%), and ring spots (34%). Less frequently observed symptoms included chlorosis (24%), distortion (20%), and stunting (14%).

Infection by TSWV-I was observed in 95% of the samples tested. However,

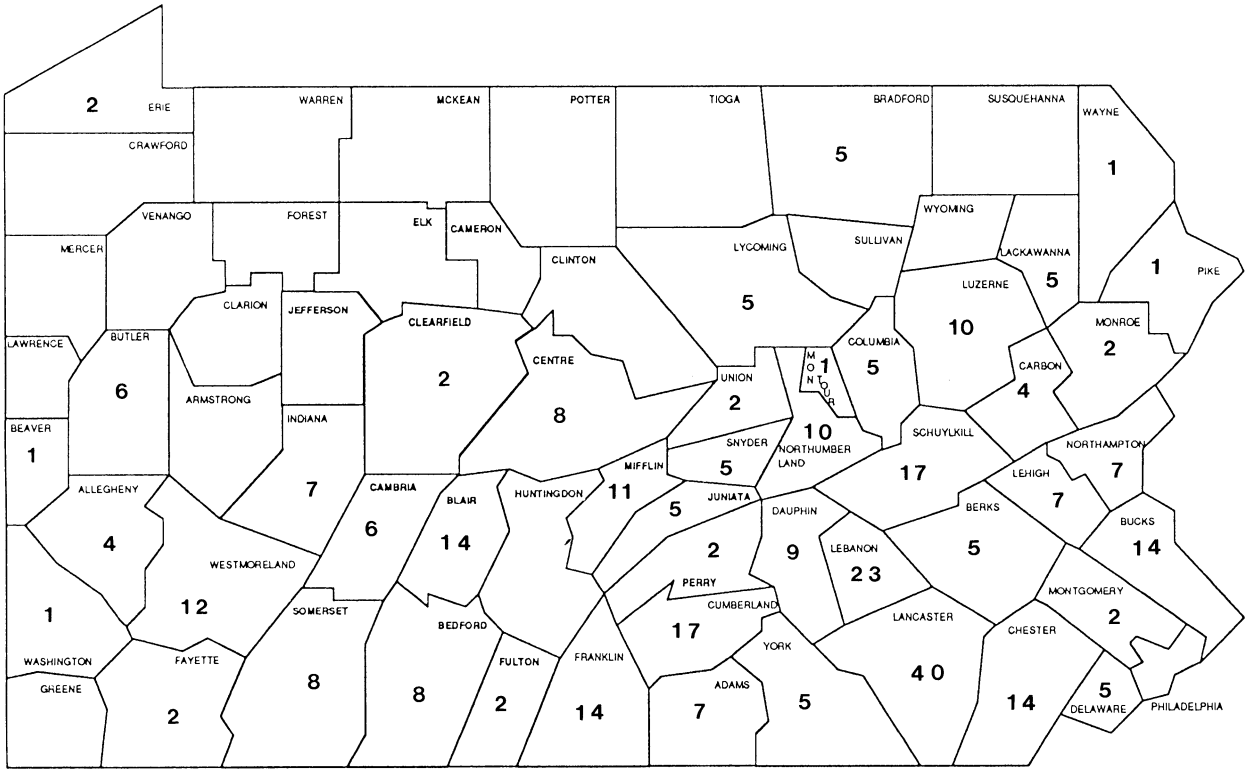

Fig. 1. Distribution of counties in Pennsylvania where plant species (indicated by numbers) grown in the greenhouse were infected with tomato spotted wilt virus (TSWV).

TSWV-L infected seven of the eight geraniums (*Pelargonium* spp.) and six of the seven dahlias (*Dahlia* spp.) sampled. In addition, one sample each of begonia, dahlia, and two samples of geranium (*P. peltatum* (L.) L'Hér. ex Aiton) were infected with both TSWV-L and TSWV-I.

Potted plants. Twenty-three genera of potted plants were infected with TSWV, including the previously unreported hosts eucharis (*Eucharis grandiflora* Planch. & Linden), lantana (*Lantana* sp.), prickly pear (*Opuntia* sp.), oxalis (*Oxalis* sp.), azalea (*Rhododendron* sp.), rohdea (*Rohdea* sp.), and streptocarpus (*Streptocarpus* spp.). Infection of cineraria, cyclamen, and New Guinea impatiens by TSWV represented 22% (58), 21% (57), and 16% (43), respectively, of the total number (266) of infected potted plant samples (Table 2).

More than one-half (55%) of all infected samples showed symptoms of general necrosis. Other frequently observed symptoms included ring spots (47%) and chlorotic/necrotic spots (41%). Symptoms observed less frequently included mottling/mosaic (35%), distortion (23%), chlorosis (19%), and stunting (11%).

Infection by TSWV-I was observed in 93% of the infected potted plants sampled. One sample each of chrysanthemum (*Chrysanthemum* × *morifolium* Ramat.), gardenia (*Gardenia jasminoides* Ellis), lantana, primula (*Primula vulgaris* Huds.), azalea, and gloxinia (*Sinningia speciosa* (Lodd.) Hiern) was infected with both TSWV-L and TSWV-I.

Perennials. Twenty-five genera of perennials were infected with TSWV, including the following 16 previously unreported hosts: bishop's weed (*Aegopodium podagraria* L.), wormwood (*Artemisia dracunculus* L.), aubrietta (*Aubrietta* sp.), daisy (*Bellis* sp.), barberry (*Berberis* sp.), brachycome (*Brachycome iberidifolia* Benth.), turtlehead (*Chelone* sp.), columnea (*Columnea* sp.), foxglove (*Digitalis* sp.), bee balm (*Monarda didyma* L.), obedient plant (*Physostegia virginiana* (L.) Benth.), polemonium (*Polemonium* sp.), stonecrop (*Sedum* sp.), goldenrod (*Solidago* sp.), and veronica (*Veronica* sp.). Infection of buttercup (*Ranunculus* spp.) and bee balm by TSWV represented 20% (17) and 18% (15), respectively, of the total number (85) of infected perennial plant samples (Table 3).

Spotting of the leaves was present on 62% of the samples infected with TSWV. General necrosis also was a primary symptom of infection occurring on 53% of the samples. Mottling/mosaic (40%), foliar distortion (33%), and chlorosis (28%) and ring spots (22%) also were frequently observed symptoms. Nearly all (96%) of the samples that tested positive for TSWV were infected with TSWV-I.

Foliage plants. Seven of the 13 genera of foliage plants infected with TSWV were previously unreported hosts and included lipstick vine (*Aeschynanthus pulcher* (Blume) G. Don), bird's-nest fern (*Asplenium nidus* L.), dracaena (*Dracaena* spp.), swedish ivy (*Plectranthus australis* R. Br.), nephthytis (*Syngonium podophyllum* Schott), piggyback plant (*Tolmiea menziesii* (Pursh) Torr. & A. Gray), and spiderwort (*Tradescantia*

Table 1. Incidence of tomato spotted wilt virus (TSWV) and associated symptoms on bedding plants in commercial greenhouses in Pennsylvania

Host	TSWV strain[a]		Symptom (no. of plants infected)									
	I	L	Distortion	Stunt	Wilt	Leaf drop	Mottle/ mosaic	Necrosis	Ring spots	Spots	Chlorosis	Bronzing
Alstroemeria aurantiaca	1			1				1				
Begonia spp.	67		4	4	3	1	44	25	14	12	11	1
		2	1				2	1				
	1	1						1				
Browallia sp.	1		1	1							1	
Capsicum annuum	23		11	8			8	14	5	11	4	
Celosia cristata	1						1	1	1	1	1	
Coleus blumei					1			4	1			
Dahlia spp.		5					1	4	2	1	2	
	1							1				
	1	1							1	1		
Eustoma grandiflorum	1		1				1		1			
Gomphrena globosa	2							2	1	2	1	
Helichrysum bracteatum	1							1		1		
Impatiens wallerana	130		25	18		11	29	48	67	85	29	
		1		1				1	1			
Lactuca sativa	2		2									
Lobelia erinus	8		3				5	2	1	7	2	
Lychnis chalcedonica	3						2	1	3	1	1	
Lycopersicon esculentum	16		4				3	13	1	6	5	
		1		1				1		1	1	
Ocimum basilicum	3		1	1			3					
Pelargonium × *hortorum* (2N)		2								2		
	1						1			1		
Pelargonium peltatum		3					2		1	1		
	2	2	1				1	1			2	
Petunia × *hybrida*	1						1					
		1					1					
Phlox spp.	16		1	2			8	6	4	6	8	
Portulaca grandiflora	2		1	1			1			2		
		1								1		
Senecio × *hybridus*	1						1					
Salvia splendens	2						1		1	2	1	
Solanum melongena var. *esculentum*	2	1					1	2	2		1	
Tagetes spp.	3			1			1	3		3	1	2
Verbena × *hybrida*	8		5	5			5	3	1	4	6	
Total	300	20	20%	14%	1%	4%	39%	43%	34%	48%	24%	1%

[a] TSWV-I = impatiens strain; TSWV-L = lettuce strain.

Table 2. Incidence of tomato spotted wilt virus (TSWV) and associated symptoms on potted plants in commercial greenhouses in Pennsylvania

Host	TSWV strain[a]		Symptom (no. of plants infected)									
	I	L	Distortion	Stunt	Wilt	Leaf drop	Mottle/ mosaic	Necrosis	Ring spots	Spots	Chlorosis	Bronzing
Calceolaria crenatiflora	6		3	5			4	4			3	2
Chrysanthemum × *morifolium*		3						3		1		
	5		1	1			1	3	1		3	1
	1	1	1	1				1				
Cyclamen persicum	57		15	3	7		28	33	42	24	10	
Eucharis grandiflora	1								1	1	1	
Gardenia jasminoides	1	1					1	1				
Gerbera jamesonii	1						1		1	1		
Hydrangea sp.	1							1				
Impatiens × *hybridus*	41		14	8	2	3	8	28	20	22	1	3
		2						2	2	2		
Kalanchoe blossfeldiana	9						1	4	6	2	1	
		1							1		1	
Lantana sp.	1	1		1				1				
Lilium spp.	1						1	1				
(*Asiatic*)		1					1					
Opuntia sp.	1						1	1				
Oxalis sp.	1							1			1	
Pelargonium × *hortorum* (4N)	1		1				1		1	1		
		3							3			
Primula spp.	18		6	5			8	5	3	3	6	
	1	1								1		
Rhododendron sp.	1	1					1		1		1	
Rohdea sp.	1							1	1			
Schlumbergera truncata	14		4	1			12	4	2	5	11	
		7	2					5		7	3	
Senecio × *hybridus*	58		6	2	1		19	30	29	32	8	
Sinningia speciosa	14		6	2				12	3	7	1	
	1	1						1				1
		2					1	1				
Stephanotis floribunda	1								1			
Streptocarpus spp.	9		1				4	3	4	1		
Total	247	25	23%	11%	4%	1%	35%	55%	47%	41%	19%	3%

[a] TSWV-I = impatiens strain; TSWV-L = lettuce strain.

Table 3. Incidence of tomato spotted wilt virus (TSWV) and associated symptoms on perennials in commercial greenhouses in Pennsylvania

Host	TSWV strain[a]		Symptom (no. of plants infected)								
	I	L	Distortion	Stunt	Wilt	Mottle/ mosaic	Necrosis	Ring spots	Spots	Chlorosis	Bronzing
Aegopodium podagraria	1						1				
Anemone spp.	3					1	1		2		
Artemisia dracunculus	1									1	
Aubrieta deltoidea	1		1	1							
Bellis perennis	2		2	1	1	1	1		1		
Berberis spp.	5			1		3			4	1	
Brachycome iberidifolia	1		1	1	1				1		
Campanula spp.	4		2	1		3		1	3	1	
Centranthus ruber	5	1				4	3	2	2	2	
Chelone sp.	1		1			1					
Chrysanthemum × *superbum*	2		1	2			2		1		
Columnea spp.	5		3			5	2	2	2	1	1
		1			1		1	1	1	1	
Delphinium spp.	1		1			1	1				
Digitalis purpurea	1					1	1		1	1	
Monarda didyma	15		1			4	11	4	10	3	5
Nepeta cataria	1						1		1	1	
Osteopermum sp.		1	1	1		1					
Papaver sp.	1		1				1		1	1	
Penstemon spp.	5		1	1		3	1	2	4	1	
Physostegia virginiana	4						4	2	3	2	
Polemonium sp.	1					1			1		
Ranunculus spp.	16		10	2		1	11	1	9	3	2
		1	1			1					
Sedum spp.	4							3	2	3	
Sodidago sp.	1					1	1			1	
Veronica spp.	2					2	1	1	1	1	
Total	80	3	33%	13%	5%	40%	52%	22%	59%	28%	9%

[a] TSWV-I = impatiens strain; TSWV-L = lettuce strain.

Table 4. Incidence of tomato spotted wilt virus (TSWV) and associated symptoms on foliage plants in commercial greenhouses in Pennsylvania

Host	TSWV strain[a]		Symptom (no. of plants infected)							
	I	L	Mottle/ mosaic	Necrosis	Ring spots	Spots	Chlorosis	Leaf Drop	Distortion	Stunt
Aeschynanthus pulcher	2		1	1	2	2	2			
Aglaonema commutatum	1			1		1	1			
Aphelandra squarrosa	1			1					1	1
Asplenium nidus	1			1	1	1	1			
Dracaena spp.	5		3	2		4	3			
	1	1		1		1	1			
Hoya carnosa	6			3	5	5	2			
Pedilanthus tithymaloides	1			1	1					
Peperomia spp.	2			2	2	1				
Plectranthus australis	5			3	2	1	1			1
Syngonium podophyllum	1			1		1				
Tolmiea menziesii	4		2	2	3	2	1			
Tradescantia spp.	3		1	2		3				
Saintpaulia spp.	5		2	1	3	1	1	1	3	
Total	38	1	24%	58%	50%	61%	34%	3%	11%	5%

[a] TSWV-I = impatiens strain; TSWV-L = lettuce strain.

spp.). Spots (61%), general necrosis (58%), and ring spots (50%) were the most common symptoms of infection (Table 4). Infection by TSWV-I was observed in all 38 of the plants sampled. One sample of *Dracaena* spp. was infected with both TSWV-L and TSWV-I.

DISCUSSION

This study documents symptoms associated with infection by TSWV among bedding, potted, perennial, and foliage plants grown under diverse conditions in commercial greenhouses in Pennsylvania. All disease symptoms observed on TSWV-infected plants may not have been caused by TSWV but may have, in part, been associated with management practices. Only 38% of all plants infected by TSWV exhibited the ring spots that are characteristic of infection by TSWV on some crops, including cyclamen, impatiens, cineraria, gloxinia, and begonia (11). Infected plants showing only mild disease symptoms may escape detection and provide inoculum for other plants. For instance, a range of mild symptoms may be observed on the Thanksgiving cactus (*Schlumbergera truncata* (Haw.) Moran) infected with either TSWV isolate and may include sunken chlorotic lesions, dark green spots, chlorosis, necrosis, and distortion (8). TSWV-L also has been isolated from symptomless Thanksgiving cacti. In at least one commercial greenhouse, Thanksgiving cacti infected with TSWV served as a common denominator for two nonoverlapping gloxinia crops that tested positive for TSWV (8).

In the absence of diagnostic symptoms, bedding plants infected with TSWV may escape detection at the wholesale greenhouse. The stresses incurred during transport of the plants to retail centers and the subsequent growing conditions on arrival may prompt further symptom development. However, many retail operators may be only seasonal plant handlers and may not have the experience to recognize even obvious symptoms associated with infection by TSWV.

The ramifications of bedding plants infected with TSWV may have an impact on the vegetable industry because in our survey, vegetable transplants were infected with TSWV-I. In 1988, prior to the survey, infection by TSWV-L resulted in significant crop loss in approximately 64.75 ha of tomato and pepper plants in Pennsylvania that had originated from a single local greenhouse. It is advisable, therefore, to keep vegetable and ornamental bedding plants separated within the greenhouse.

Mixing bedding plants with asexually propagated plants also should be avoided because stock plants from which cuttings are taken may serve as a reservoir for TSWV. Several genera of potted plants, including some of those that tested positive for TSWV in this survey, are asexually propagated and unrooted vegetative cuttings for potted plant production are imported in significant numbers (5). Visual symptoms alone are not adequate for detection of TSWV in propagative material because stock plants typically are exposed to a range of environmental conditions, and symptoms indicative of infection by TSWV may be transient. Therefore, primary propagators must ensure that cuttings are free of TSWV, and secondary propagators should invest in plant material indexed for TSWV. The risk associated with propagating and distributing cuttings from stock material that has not undergone rigorous testing is high.

Results from this study clearly show that foliage plants and perennials must be scrutinized more closely to understand the full impact of TSWV on the floriculture industry. Approximately 500 species of foliage plants are grown and sold nationwide (5) with Pennsylvania being one of the larger producers (3). The importance of herbaceous perennials in containers has increased in Pennsylvania in the past 5 yr (6). Perennials infected by TSWV may serve as reservoirs for TSWV and WFT in the greenhouse. Because TSWV is systemic, it may overwinter in perennials in root systems (10). Unsold perennials remaining in the greenhouse from year to year may come into contact with a wide variety of crops. Occurrence of WFT provides a dangerous link between the infected perennials and healthy plants. The role of perennials as reservoirs may become more significant as the perennials industry grows.

In summary, results of this study provide information on crop species at risk to TSWV and the symptoms associated with infection and will be helpful in managing this disease. TSWV will be a threat to floriculture for some time, for no other sector of horticulture involves as much distribution of plant material. Many greenhouse operators have been reluctant to initiate or maintain the stringent control strategies necessary to exclude or eliminate TSWV, many crops have been lost, and inferior plants are being sold to the public. Disease management strategies used in Pennsylvania have included the cooperation of PDA, PSU, and greenhouse growers and may be helpful to other states seeking to alleviate the losses resulting from TSWV and bring the levels of damage down to tolerable levels.

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