S. K. Raj
Rajarshi Kumar Gaur
Zhimin Yin *Editors*

Virus Diseases of Ornamental Plants

Characterization, Identification, Diagnosis and Management

Springer

Virus Diseases of Ornamental Plants

S. K. Raj • Rajarshi Kumar Gaur • Zhimin Yin
Editors

Virus Diseases of Ornamental Plants

Characterization, Identification, Diagnosis and Management

Springer

Editors
S. K. Raj
Plant Molecular Virology Laboratory
CSIR-National Botanical Research Institute
Lucknow, Uttar Pradesh, India

Rajarshi Kumar Gaur
Department of Biotechnology
D.D.U. Gorakhpur University
Gorakhpur, India

Zhimin Yin
Plant Breeding and Acclimation Institute – National Research Institute (IHAR-PIB)
Młochów Research Center
Młochów, Poland

ISBN 978-981-16-3918-0 ISBN 978-981-16-3919-7 (eBook)
https://doi.org/10.1007/978-981-16-3919-7

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Contents

1 Tospovirus Diseases of Ornamental Plants: Characterization, Identification, Diagnosis and Management 1
G. Karthikeyan, K. Nagendran, Shweta Kumari, R. Priyanka, C. Senthilraja, and Betsy D. Haokip

2 *Potyvirus* Infecting Ornamental Plants Grown in the Neotropical Region 23
M. Amelia V. Alexandre, Ligia M. L. Duarte, Alexandre L. R. Chaves, and Elliot W. Kitajima

3 Viruses of Some Bulbous Ornamental Flowers from *Liliaceae* Family 61
Nikolay Manchev Petrov, Mariya Ivanova Stoyanova, and Rajarshi Kumar Gaur

4 Current Status of Major Viruses, Viroids, and Phytoplasma Infecting Petunia: Diagnosis, Characterization, and Commercial Impact 77
Karmveer Kumar Gautam, Susheel Kumar, and Shri Krishna Raj

5 Detection, Characterization, and Management of Potyviruses Infecting Gladiolus, an Important Plant for Floriculture Trade 93
Charanjeet Kaur and Shri Krishna Raj

6 Current Status of Three Virus Genera (*Badnavirus*, *Cucumovirus*, and *Potyvirus*) in *Canna* Species in India 117
Aarti Kumari, Charanjeet Kaur, Susheel Kumar, Puneet Singh Chauhan, and Shri Krishna Raj

7 Molecular Characterization and Diversity Analysis of Viruses Infecting Orchids Plants: Global Scenario 127
Malyaj R. Prajapati, Jitender Singh, Koushlesh Ranjan, R. P. Pant, and V. K. Baranwal

8 Detection and Characterization of Plant Viruses Infecting *Hibiscus rosa-sinensis* L. 151
Smriti Mall, Vineeta Pandey, Aarshi Srivastava, and Rajarshi Kumar Gaur

9 Molecular Characterization of Viruses Occurring on Some Ornamental Shrubs Grown in India 165
Ashish Srivastava, Suwarna Verma, Tripti Singhal, and Shri Krishna Raj

10 Virus-Diseases Reported on *Calendula officinalis* 181
Akil A. Khan and Shoeb Ahmad

11 Viruses and Satellites Infecting Hollyhock (*Alcea rosea*) Plants: An Update 191
Manish Kumar and Supriya Chakraborty

12 Major Viral Diseases of *Salvia* spp., Diagnosis, and Their Management Strategies 211
Soumya Sinha and Abdul Samad

13 A Current Overview of Viruses of Chrysanthemum in India: Perspective and Prospective 231
Susheel Kumar, Karmveer Kumar Gautam, and Shri Krishna Raj

14 Chrysanthemum Production, Viral Diseases and Their Management 261
Ruchi Gupta, Ashutosh Gupta, Shampi Jain, Doomar Singh, and Neeraj Verma

15 Viruses Infecting Bulbous Ornamental Plants and Their Diagnosis and Management 277
S. Madhavan, V. Balasubramanian, and R. Selvarajan

16 Molecular Characterization of Cucumber Mosaic Virus Strains Infecting Gerbera Cultivars and Its Disease Management 301
Karmveer Kumar Gautam, Susheel Kumar, and Shri Krishna Raj

17 Viruses Infecting *Narcissus tazetta* and Their Possible Management 313
Rashmi Raj, Susheel Kumar, P. S. Chauhan, and S. K. Raj

18 Begomoviruses Infecting *Jatropha* Species Grown for Ornamental Values 331
Sunil Kumar Snehi and S. K. Raj

19 Begomovirus Interaction with Ornamental Plants: Recent Advances and Methods for Engineering Resistance 345
Rachana Singh and S. K. Raj

20 Begomovirus on Ornamental Plants: Diversity and Management 359
Seweta Srivastava, N. N. Tiwari, Malyaj R. Prajapati, R. K. Jain, Jitender Singh, and A. K. Tiwari

21 Begomovirus Diseases of Ornamental and Fruit Plants: Discoveries and Management Approaches 381
Muhammad Shafiq Shahid and Abdullah Mohammed Al-Sadi

22 Next-Generation Molecular Diagnostics for Plant Viruses 397
Ashish Srivastava, Sonal Srivastava, Taruna Gupta, and Narayan Rishi

About the Editors

S. K. Raj did his Ph.D. degree in Botany (Plant Virology) from CSIR-National Botanical Research Institute (NBRI), Lucknow (registered at Kanpur University, Kanpur), in 1990 on the topic "Characterization of a virus causing ring spot disease in Brinjal (*Solanum melongena* L.) and its management." He started his carrier as Scientist B at Molecular Virology Laboratory, CSIR-NBRI, Lucknow, India, in 1986 and continued as Chief Scientist/Sr. Deputy Director/Prof. AcSIR till his superannuation on 31 July 2015. He has been a visiting scientist at the Institute of Genetics and Crop Research, Gatersleben, Germany, in 1991 (INSA-DFG fellowship) with Prof. R. M. Leiser; and at Scottish Crop Research Institute, Dundee, UK, in 1997 (INSA-Royal Society fellowship) and 2000 (DBT fellowship) with Prof. Micheal Taliansky to carry out research on molecular biology of plant viruses with special reference to develop viral resistance in plants through pathogen-derived resistance strategies utilizing viral genes. He had been the principal investigator of many projects funded by the Department of Biotechnology (Govt. of India), U.P. Council of Science and Technology (UP-CST), and Department of Science and Technology (Govt. of India). Out of his research work, he has published more than 211 research papers in national and international journals and guided twelve Ph.D. students. He has been honored by Vigyan Ratan Award 2010–2011 from Uttar Pradesh Science and Technology (UPCS&T), Lucknow, U.P. Government, India, for his scientific contributions in the area of Plant Virology and Biotechnology. He has been conferred Plant Pathology Leadership Award 2012 and honored and elected as the Fellow of Indian Virological Society by the Indian Virological Society, New Delhi, India, in 2013. At present he has been actively engaged in science by contributing his services to national research institutes, scientific organizations, and universities in India.

Rajarshi Kumar Gaur earned his PhD in 2005 and is now Professor in the Department of Biotechnology at Deen Dayal Upadhyaya Gorakhpur University, Gorakhpur, Uttar Pradesh, India. His Ph.D was on molecular characterization of sugarcane viruses, viz., mosaic, streak mosaic, and yellow luteovirus. He received MASHAV fellowship of Israel government for his postdoctoral studies and joined the Volcani Centre, Israel, and BenGurion University, Negev, Israel. In 2007 he received the Visiting Scientist Fellowship from Swedish Institute Fellowship, Sweden, to work in the Umeå University, Umeå, Sweden. He received Post-Doc Fellowship from ICGEB, Italy, in 2008. He has made significant contributions on sugarcane viruses and published 130 national/international papers, authored 17 edited books, and presented about 50 papers in national and international conferences. He has visited several laboratories of USA, Canada, New Zealand, UK, Thailand, Sweden, and Italy. Currently, he is handling many national and international grants and international collaborative projects on plant viruses and disease management.

Zhimin Yin received a PhD in agricultural sciences with specialization in horticulture in 2002 at the Department of Plant Genetics, Breeding and Biotechnology, Faculty of Horticulture and Landscape Architecture, Warsaw Agricultural University—SGGW and now works on plant virology at the Plant Breeding and Acclimatization Institute—National Research Institute (IHAR-PIB), Młochów Research Center, Poland. He has worked on 2 international and 7 national projects, published 33 research articles, 5 book chapters, 20 conference papers, and gave 42 oral presentations in national/international conferences, invited lectures, and seminars. He was awarded for his PhD study and scientific achievements by SGGW-Poland in 2001, 2002, and 2007, Ministry of Education of China in 2004, Polish Academy of Sciences in 2007, and IHAR-PIB in 2016 and 2018. He has made scientific visits to SASA UK and ECU USA and was the Polish representative of the PVYwide organization.

Tospovirus Diseases of Ornamental Plants: Characterization, Identification, Diagnosis and Management

1

G. Karthikeyan, K. Nagendran, Shweta Kumari, R. Priyanka, C. Senthilraja, and Betsy D. Haokip

Abstract

Ornamental industry is one of the commercial sectors contributing maximum for the growth of agriculture. Ornamental crops are grown for its aesthetic value and are categorized as flowering, foliage, shrubs and trees. Due to their perennial nature and availability throughout the year, they are very prone for the infection of several viruses. The *Orthotospovirus* is one of the most devastating viruses of ornamental plants and flower crops worldwide. It is one among the virus genera infecting ornamental crops across 46 countries belonging to the six continents. The diseases caused by orthotospoviruses (order *Bunyavirales*; family Tospoviridae; genus *Orthotospovirus*) are emerging as a significant limiting factor for the sustainable production of ornamental crops around the globe. These orthotospoviruses are known to be transmitted through thrips vector in a persistent and propagative manner. Till date 18 species of orthotospoviruses are reported to be infecting more than 600 plant species of ornamental crops belongs to all categories. Asian continent is found to show maximum diversity harboring nine different orthotospovirus species. Symptoms of orthotospovirus infections are highly variable with the host and the virus species interactions. In this chapter information on symptomatology, transmission, distribution, diagnosis, host-pathogen interactions and management of tospoviruses on ornamental plants are consolidated and presented in an organized manner.

G. Karthikeyan (✉) · R. Priyanka · C. Senthilraja · B. D. Haokip
Department of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore, India
e-mail: gandhikarthikeyan@tnau.ac.in

K. Nagendran · S. Kumari
Division of Crop Protection, ICAR-Indian Institute of Vegetable Research, Varanasi, India

S. K. Raj et al. (eds.), *Virus Diseases of Ornamental Plants*,
https://doi.org/10.1007/978-981-16-3919-7_1

Keywords

Tospoviruses · Thrips · Epidemiology · Host-pathogen interaction · Diagnosis · Management

1.1 Introduction

Ornamental plants are grown for their aesthetic value. Maintaining visual appearance of ornamental plants is the major component of ornamental production facilities. There are different groups of ornamental plants, and they are classified based on their life span as annual, biennial and perennials. Similarly, based on their aesthetic part of the plant, they are grouped as flower crops, foliage/shrubs and trees. In recent days, ornamental industry has attained remarkable growth and has developed into commercial branch of modern agriculture. Economy of ornamental industry depends in sale of potted plants, tree nursery production, seed material for flower bulbs and other propagation materials and their maintenance. The Netherlands, the USA and Japan are the pioneer countries of ornamental production (Kazinczi et al. 2007).

The ornamental plants are affected by several biotic and abiotic stresses. Among them the diseases caused by viruses impose a serious threat to the ornamental industry. Tospoviruses are the plant-infecting viruses belonging to the genus *Orthotospovirus* under the family *Bunyaviridae* and are thrips transmissible. These viruses cause significant quality and quantity losses in horticultural crops including ornamentals in many parts of the world (Pappu et al. 2009). INSV infection causes crop losses in flower production of *Dendranthema* spp. (51%) and *Sinningia speciosa* (100%) (Matteoni and Allen 1989). The utilization of molecular tools enabled the characterization of tospoviruses in to 30 species grouped under five different serogroups (EPPO 2020; Chu et al. 2001). Ubiquitous nature of tospoviruses adds every day new hosts to their host range list. Due to the thrips transmissible nature, wide and overlapping host ranges of thrips and tospoviruses, lack of effective and economical management options and lack of resistant sources in hosts contribute to the repeated occurrence of tospoviruses in diverse crops both under open and protected cropping conditions (Daughtrey et al. 1997; Brown et al. 2005; Gent et al. 2006). Several reviews and book chapters extensively organized the various aspects of tospoviruses and its thrips vector in recent years (Whitfield et al. 2005; Kazinczi et al. 2007; Pappu et al. 2009; Turina et al. 2016). In this chapter, we summarized the current status of tospovirus epidemics in ornamental crops.

1.2 Host Range of Tospoviruses on Ornamental Crops

The economic impact of tospoviruses are increasing every day by causing huge losses in terms of quality and quantity in a wide variety of ornamental crops. The host range of tospoviruses is highly variable between the species. In global scenario, around 204 plant species were reported to be infected by 18 different tospovirus species (Table 1.1). Tospoviruses are infecting all kind of ornamentals such as flowering, foliage/shrubs, grasses and trees of annuals, biennials and perennials. Nearly eight different tospovirus species are affecting the cultivation of chrysanthemum in several countries. Tomato spotted wilt virus (TSWV) and impatiens necrotic spot virus (INSV) are the two major tospoviruses threatening the ornamental crop cultivation. Both of them were known to infect around 600 species of ornamental plants (Daughtrey et al. 1997; Ullman 1998). Alstroemeria necrotic streak *virus* (ANSV), alstroemeria yellow spot *virus* (AYSV), calla lily chlorotic spot *virus* (CCSV) and ligustrum necrotic ringspot *virus* (LNRV) are the tospovirus species having very narrow host range and documented only on ornamental crop plants. The chrysanthemum stem necrosis *virus* (CSNV) is found to infect ornamental crops such as chrysanthemum, *Callistephus* spp., *Eustoma grandiflorum*, *Gerbera* and lisianthus. The INSV is having intermediate host range than the TSWV and commonly infecting annuals and perennial ornamentals. Iran and the USA are the two countries found to have wider host range for the tospovirus infection among ornamental crops. Many tospovirus species are known to infect weed species very often which are playing a major epidemiological role in disease dissemination. Tree ornamentals such as *Cycas* sp., *Ficus benjamina*, *Schefflera*, etc. are also infected by tospoviruses.

1.3 Symptomatology of Tospoviruses on Ornamental Crops

In ornamentals, tospovirus infection produces symptoms similar to the other biotic and abiotic stresses. Tospovirus symptoms on floral crops include concentric ring spots; line or zonal patterns, malformation and necrosis of apical shoots and flowers, necrosis of leaf petiole, reduced growth, etc. were reported (Fig. 1.1) (Kazinczi et al. 2007). Chrysanthemum plants are very often observed with chlorotic and necrotic spots on leaves and stems, stunted growth and death of young plants upon infection of TSWV and INSV (Cho et al. 1989). TSWV produces chlorotic or black ringspot and line pattern of leaves, malformed leaves and terminal bud necrosis on impatiens; chlorotic and necrotic ringspot of leaves, stem necrosis and terminal bud necrosis on *Eustoma*; mild mosaic and ringspot of leaves on *Zinnia*; and reddish concentric brown rings on the leaves and malformed flowers on *Gloxinia* (Antignus et al. 1997). TSWV infection reduces the floral fresh weight, number of petals, number of flowers per plant and inhibiting adventitious sprouting of buds in perennials (Whitfield et al. 2003). CSNV infection causes mild or severe streaks on stem, wilting of leaves and stems, chlorotic and necrotic spots and rings on leaves, necrosis of the stem and floral receptacles, necrotic lesions surrounded by yellow halo on leaves and distinct dark stem lesions on chrysanthemum (Verhoeven et al. 1996; Duarte et al. 1995; Mumford et al. 2003). Persley et al. (2006) observed ringspots, line patterns, chlorotic blotches and necrotic etching on *Hoya* spp. upon capsicum chlorosis virus (CaCV) infection. CCSV caused chlorotic spots on their leaves and stems of *Zantedeschia* species in Taiwan (Lin et al. 2006). IYSV infection in plants of *Alstroemeria* spp. show necrotic streak symptoms (Okuda et al. 2005).

Table 1.1 Distribution and host range of tospoviruses infecting ornamental crops

Continent	Country	Number of hosts	Hosts
1. Alstroemeria necrotic streak virus (ANSV)			
North America	USA	1	*Hoya carnosa*
South America	Colombia	1	*Alstroemeria* sp.
2. Alstroemeria yellow spot virus (AYSV)			
Europe	Netherlands	1	*Alstroemeria* sp.
3. Calla lily chlorotic spot virus (CCSV)			
Asia	China	1	Spider lily
Asia	Taiwan	1	Calla lily
4. Capsicum chlorosis virus (CaCV)			
Asia	China	5	*Rieger begonias*, *Gloxinia*, orchids, African violet, *Crossandra*
Asia	India	1	*Hippeastrum*
Asia	Indonesia	1	Orchids
Asia	Iran	1	*Rudbeckia hirta*
Asia	Taiwan	4	Orchids, *Hippeastrum*, calla lily, *Scadoxus multiflorus*
Asia	Thailand	1	*Hymenocallis littoralis*
Australia	Australia	1	*Hoya* sp.
North America	USA	2	*Hoya* sp., *Gloxinia*
5. Chrysanthemum stem necrosis virus (CSNV)			
Asia	China	1	*Chrysanthemum*
Asia	Japan	3	*Chrysanthemum*, *Lisianthus*, *Eustoma grandiflorum*
Asia	South Korea	1	*Chrysanthemum*
Australia	New Zealand	1	*Chrysanthemum*
Europe	Belgium	1	*Chrysanthemum*
Europe	Netherlands	1	*Chrysanthemum*
Europe	Russia	1	*Chrysanthemum*
Europe	Slovenia	2	*Chrysanthemum*, *Gerbera*
Europe	UK	1	*Chrysanthemum*
South America	Brazil	4	*Chrysanthemum*, *Lisianthus*, *Callistephus* spp., *Eustoma grandiflorum*
6. Groundnut bud necrosis virus (GBNV)			
Asia	India	8	Orchids, *Phaius* sp., *Anthurium*, periwinkle, *Gerbera*, jasmine, *Dahlia*, *Chrysanthemum*
7. Groundnut ringspot orthotospovirus (GRSV)			
South America	Brazil	1	*Hippeastrum*
South America	Paraguay	1	*Petunia*
8. Hippeastrum chlorotic ringspot virus (HCRV)			
Asia	China	9	

(continued)

Table 1.1 (continued)

Continent	Country	Number of hosts	Hosts
			Hymenocallis littoralis, *Oxalis corniculata*, *Philodendron*, *Crinum asiaticum*, *Zephyranthes candida*, *Clivia miniata*, spider lily, *Ficus elastic*, *Hippeastrum*
9. Impatiens necrotic spot virus (INSV)			
Africa	Egypt	1	*Tropaeolum*
Asia	China	5	Begonia, orchids, spider lily, *Hymenocallis*, *Gentiana* spp.
Asia	Japan	10	*Anemone coronaria*, *Begonia*, *Chrysanthemum*, *Eustoma* sp., *Gentiana* sp., *Gerbera jamesonii*, *Pericallis*, *Exacum* spp., *Cyclamen*, *Eucharis* spp.
Asia	South Korea	2	*Hoya* sp., *Peperomia obtusifolia*
Asia	Iran	29	African violet, *Impatiens*, *Alstroemeria*, *Pelargonium* spp., *Cycas* spp., *Rosa* spp., *Scindapsus* spp., *Ficus* spp., *Gazania* spp., *Erica* spp., *Syngonium*, *Gladiolus* spp., *Anthurium*, *Codiaeum*, *Cheiranthus*, *Dieffenbachia*, *Philodendron* spp., *Zinnia*, *Althaea* spp., *Bougainvillea* spp., Chamomile, Marigold, *Dracaena* spp., *Pilea cadierei*, *Cissus* spp., *Spathiphyllum* spp., *Leucanthemum vulgare*, *Dahlia* spp., *Dianthus barbatus*
Asia	Israel	3	*Anemone*, *Impatiens*, *Torenia* spp.
Australia	New Zealand	9	*Begonia*, *Freesia refracta*, *Gardenia jasminoides*, *Gerbera jamesonii*, *Hibiscus rosa-sinensis*, *Impatiens*, *Primula*, *Ranunculus* sp., *Cyclamen*
Europe	Belgium	1	*Impatiens*
Europe	Bosnia and Herzegovina	1	*Begonia* spp.
Europe	Bulgaria	1	*Hydrangea* spp.
Europe	Czech Republic	11	*Columnea* sp., *Curcuma* sp., *Impatiens*, *Hippeastrum*, *Aeschynanthus* spp., *Anthurium*, *Philodendron* spp., *Osteospermum* spp., *Verbena* spp., *Saxifraga stolonifera*, *Cyrtomium falcatum*
Europe	Finland	1	*Lobelia* spp.
Europe	Germany	2	*Anemone*, *Impatiens*
Europe	Hungary	3	*Impatiens*, *Eustoma* sp., *Cyclamen*
Europe	Italy	22	*Antirrhinum*, *Scindapsus* spp., Periwinkle, calla lily, *Oncidium*, *Primula* spp., *Peperomia* spp., *Clarkia amoena*, *Anemone* spp., *Ruscus* spp., *Lobelia* spp., *Cyclamen*, *Cordyline*, *Ranunculus*, *Maranta* spp., *Episcia* spp., *Spathiphyllum* spp., *Isotoma axillaris*, *Limonium*, *Dahlia* spp., *Delphinium* spp., *Dianthus* spp.
Europe	Poland	1	*Impatiens*
Europe	Portugal	10	

(continued)

Table 1.1 (continued)

Continent	Country	Number of hosts	Hosts
			Pelargonium spp., *Gazania spp., Gladiolus* spp., *Sinningia* spp., *Penstemon*, *Ruscus* spp., *Aphelandra*, *Helichrysum* spp., *Gerbera* spp., *Hydrangea* spp.
Europe	Russia	4	*Gloxinia*, *Impatiens*, *Ruellia*, *Streptocarpus*
Europe	Serbia	3	*Begonia* sp., *Impatiens*, *Tulip* sp.
Europe	Spain	1	*Asplenium*
Europe	The Netherlands	5	*Impatiens*, *Iris*, *Lysimachia*, *Nerine* spp., *Gentiana* spp.
Europe	UK	3	*Impatiens*, *Pericallis*, *Opuntia* spp.
North America	Canada	2	*Begonia*, *Impatiens*
North America	Costa Rica	6	*Antirrhinum majus*, *Hippeastrum* sp., *Impatiens*, *Iris* sp., orchids, *Plectranthus*
North America	Mexico	1	*Impatiens*
North America	USA	46	*Abelia* spp., *Antirrhinum*, Begonia, *Browallia speciosa*, *Calceolaria* spp., *Callistephus*, *Dianthus* sp., *Digitalis* sp., *Epidendrum* spp., *Eustoma* sp., *Gloxinia* spp., *Hosta* sp., *Hoya wayetii*, *Impatiens*, *Maranta leuconeura*, *Monarda didyma*, *Nemesia*, *Nipponanthemum*, *Ocimum basilicum*, *Lobelia* spp., orchids, snapdragon, *Schizanthus* spp., *Pelargonium* spp., periwinkle, *Pericallis*, *Primula* spp., *Sinningia* spp., *Penstemon*, *Exacum* spp., *Cyclamen*, *Weigela*, *Scaevola*, *Hydrangea* spp., *Mimulus* spp., *Oxydendrum arboreum*, *Ilex glabra*, *Photinia fraseri*, *Gaillardia* spp., *Diascia* spp., *Sempervivum* spp., *Dahlia* spp., *Franklinia* spp., *Halesia carolina*, *Rhaphiolepis indica*, *Calycanthus floridus*
10. Iris yellow spot virus (IYSV)			
Asia	Israel	4	*Lisianthus*, *Eustoma* sp., *Hippeastrum*, *Lilium* spp.
Asia	Japan	3	*Eustoma* sp., *Lisianthus*, *Alstroemeria*
Europe	Iran	5	*Chrysanthemum*, *Cycas* spp., *Pelargonium*, *Rosa* spp., *Scindapsus* spp.
Europe	Netherland	3	*Iris*, *Eustoma* sp., *Impatiens* spp.
Europe	Poland	1	*Chrysanthemum*
Europe	UK	2	*Lisianthus*, *Eustoma* sp.
North America	USA	1	*Eustoma* sp.
11. Lisianthus necrotic ringspot virus (LNRV)			
Asia	Japan	1	Lisianthus
12. Pepper chlorotic spot virus (PCSV)			
Asia	China	1	Erigeron
13. Tomato chlorotic spot virus (TCSV)			

(continued)

Table 1.1 (continued)

Continent	Country	Number of hosts	Hosts
North America	USA	4	Periwinkle, *Marsdenia floribunda*, *Hoya wayetii*, *Schlumbergera truncata*
South America	Argentina	1	*Eustoma*
South America	Brazil	5	*Bouvardia*, *Dieffenbachia*, *Mirabilis jalapa*, *Spilanthes oleracea*, *Eustoma*
14. Tomato spotted wilt virus (TSWV)			
Asia	China	10	*Argyranthemum*, *Bidens*, *Chrysanthemum*, *Dahlia*, *Geranium*, *Iris*, *Platycodon grandiflorus*, *Tropaeolum majus*, *Zinnia*, *Campanula* spp.
Africa	Egypt	1	*Chrysanthemum*
Asia	India	4	*Antirrhinum majus*, *Callistephus*, *Chrysanthemum*, marigold
Asia	Iran	30	*Althaea*, *Anthurium*, *Asplenium*, *Calendula* spp., *Canna indica*, *Codiaeum variegatum*, *Cupressus sempervirens*, *Cycas* spp., *Dahlia* spp., *Dieffenbachia amoena*, *Dracaena* spp., *Erica* spp., *Ficus benjamina*, *Gazania* spp., Jasmine, *Mirabilis jalapa*, orchids, *Pericallis*, *Philodendron* spp., *Pteris cretica*, *Rosa* spp., *Saintpaulia ionantha*, *Rudbeckia* spp., *Salvia* spp., *Schefflera*, *Scindapsus* spp., *Strelitzia reginae*, marigold, *Torenia fournieri*, *Zinnia*
Asia	Israel	2	*Eustoma*, *Pittosporum tobira*
Asia	Japan	11	*Arctotis*, *Callistephus*, *Chrysanthemum*, *Pericallis*, *Valeriana fauriei*, *Dahlia* spp., *Dimorphotheca sinuate*, *Eustoma*, *Felicia amelloides*, *Ranunculus* spp., *Verbena* spp.
Asia	Jordan	2	Gerbera, marigold
Asia	Saudi Arabia	1	Periwinkle
Asia	South Korea	11	*Angelica gigas*, *Anthurium*, *Impatiens*, *Brugmansia* sp., *Chrysanthemum*, *Eustoma*, *Gerbera*, *Hoya* sp., *Peperomia*, *Ranunculus*, *Nasturtium*
Africa	Zimbabwe	2	*Chrysanthemum*, *Gypsophila*
Australia	Australia	5	Spider lily, *Agapanthus*, *Gladiolus* spp., *Lupinus* spp., *Tanacetum* spp.
Australia	New Zealand	9	Chrysanthemum, *Cineraria* sp., *Dahlia*, *Hoya* sp., *Impatiens*, *Ocimum*, *Pinellia tripartita*, marigold, *Ornithogalum* spp.
Europe	Belgium	1	*Lobelia* spp.
Europe	Bosnia and Herzegovina	2	*Chrysanthemum*, *Gloxinia*
Europe	Bulgaria	14	*Leuzea carthamoides*, lisianthus, *Adenium*, *Althaea*, *Calendula* spp., *Helichrysum bracteatum*, *Hydrangea* spp., *Inula helenium*, *Physostegia* spp., *Salvia* spp., marigold, *Thymus vulgaris*, *Verbena* spp., *Zinnia*

(continued)

Table 1.1 (continued)

Continent	Country	Number of hosts	Hosts
Europe	Czech Republic	3	*Campanula* spp., *Columnea*, *Gazania* spp.
Europe	France	4	Dahlia, *Arum* spp., *Dimorphotheca sinuate*, *Salvia* spp.
Europe	Germany	1	Lysimachia
Europe	Greece	9	*Aristolochia clematitis*, Periwinkle, *Dimorphotheca sinuate*, *Fuchsia* spp., *Gazania* spp., *Justicia brandegeeana*, *Portulaca* spp., *Salvia* spp., marigold
Europe	Hungary	3	*Aristolochia clematitis*, *Echinacea purpurea*, *Heuchera sanguinea*
Europe	Italy	21	Chrysanthemum, *Coprosma repens*, *Gerbera*, *Iberis semperflorens*, *Anemone coronaria*, *Arctotis*, *Arum* spp., *Asclepias*, *Dimorphotheca sinuate*, *Euphorbia*, *Eritrea*, *Eustoma*, *Gazania* spp., *Limonium perezii*, *Nerium oleander*, orchids, *Polygala myrtifolia*, *Primula* spp., *Ranunculus* spp., *Ruscus racemosus*, *Verbena* spp.
Europe	Lithuania	2	*Dicentra Formosa, Lilium* spp.
Europe	Montenegro	6	*Aquilegia* sp., *Calceolaria* sp., *Chrysanthemum*, *Gerbera*, *Petunia*, *Primula* sp.
Europe	Poland	5	*Chrysanthemum*, *Ocimum*, *Dieffenbachia amoena*, *Hippeastrum* spp., *Hydrangea* spp.
Europe	Portugal	11	*Anthurium*, *Aphelandra*, periwinkle, *Fuchsia* spp., *Gazania* spp., *Gerbera*, *Gladiolus* spp., *Helichrysum bracteatum*, jasmine, *Penstemon* spp., *Sinningia speciosa*
Europe	Russia	1	*Streptocarpus*
Europe	Serbia	7	*Brugmansia* sp., *Chrysanthemum*, *Dahlia*, *Gerbera*, *Impatiens*, *Petunia*, *Sinningia speciosa*
Europe	Spain	1	*Ficus benjamina*
Europe	The Netherlands	11	*Adenium*, *Anthurium*, *Columnea*, *Dahlia* spp., *Hippeastrum* spp., *Impatiens* spp., *Iris*, *Lobelia* spp., *Lysimachia* spp., *Nerine* spp., *Schizanthus* spp.
Europe	Turkey	1	*Ranunculus*
Europe	UK	4	*Impatiens*, *Delphinium* spp., *Paeonia* spp., *Verbena* spp.
North America	Canada	7	Periwinkle, *Cyclamen persicum*, *Fuchsia* spp., *Gaillardia* spp., *Impatiens* spp., orchids, *Verbena* spp.
North America	Mexico	1	Zinnia
North America	USA	76	Orchids, *Chrysanthemum*, *Dahlia*, *Eustoma*, *Hoya* sp., *Lobelia* spp., *Matricaria*, *Pittosporum tobira*, *Stokesia*, *Tulbaghia violacea*, *Adenium*, *Anemone coronaria*, *Aeschynanthus*, *Aglaonema*, *Anthurium*, *Antirrhinum*, *Aphelandra*, *Arum* spp., Begonia, *Calceolaria* spp., *Callistephus chinensis*, periwinkle,

(continued)

Table 1.1 (continued)

Continent	Country	Number of hosts	Hosts
			Celosia cristata, *Centranthus ruber*, *Clarkia amoena*, *Cordyline terminalis*, *Cosmos* spp., *Cyclamen persicum*, *Delphinium* spp., *Digitalis* spp., *Dracaena* spp., *Eucharis grandiflora*, *Exacum* spp., *Gardenia jasminoides*, *Gerbera*, *Gladiolus* spp., *Gomphrena globosa*, *Helichrysum bracteatum*, *Hosta* spp., *Hydrangea* spp., *Impatiens* spp., *Lupinus* spp., *Melampodium divaricatum*, *Opuntia* spp., *Osteospermum*, *Pedilanthus*, *Penstemon* spp., *Peperomia* spp., *Pericallis*, *Petunia* spp., *Phlox* spp., *Pinus* spp., *Pittosporum tobira*, *Plectranthus australis*, *Portulaca grandiflora*, *Primula* spp., *Ranunculus* spp., *Rhododendron* spp., *Rohdea* spp., *Rudbeckia* spp., *Saintpaulia ionantha*, *Salvia* spp., *Schizanthus* spp., *Schlumbergera truncate*, *Sedum* spp., *Lychnis chalcedonica*, *Sinningia speciose*, *Stephanotis floribunda*, *Streptocarpus* spp., *Syngonium podophyllum*, *Tradescantia* spp., *Tropaeolum majus*, *Verbena* spp., *Veronica* spp., *Weigela florida*, *Zantedeschia* spp.
South America	Argentina	2	*Alstroemeria*, *Eustoma*
South America	Brazil	2	*Eucharis grandiflora*, *Campanula* spp.
South America	Ecuador	1	*Chrysanthemum*
South America	Venezuela	2	*Chrysanthemum*, *Gerbera*
15. Tomato yellow ring virus (TYRV)			
Asia	Iran	22	*Tropaeolum*, *Cineraria*, *Gazania*, *Chrysanthemum*, *Alstroemeria*, Anemone, *Antirrhinum* spp., *Althaea* spp., *Beaucarnea recurvata*, *Bougainvillea* spp., *Dahlia*, *Dieffenbachia*, *Dracaena*, *Ficus benjamina*, *Impatiens*, *Jasminum*, *Pelargonium*, *Pericallis hybrida*, *Rosa* spp., *Spathiphyllum*, *Syngonium*, marigold
16. Tomato zonate spot virus (TZSV)			
Asia	China	3	*Bidens*, *Crinum asiaticum*, *Iris*
17. Watermelon bud necrosis virus (WBNV)			
Asia	India	1	*Chrysanthemum*
18. Watermelon silver mottle virus (WSMoV)			
Asia	Taiwan	1	Calla lily

Source: NCBI database and Sastry et al. 2019

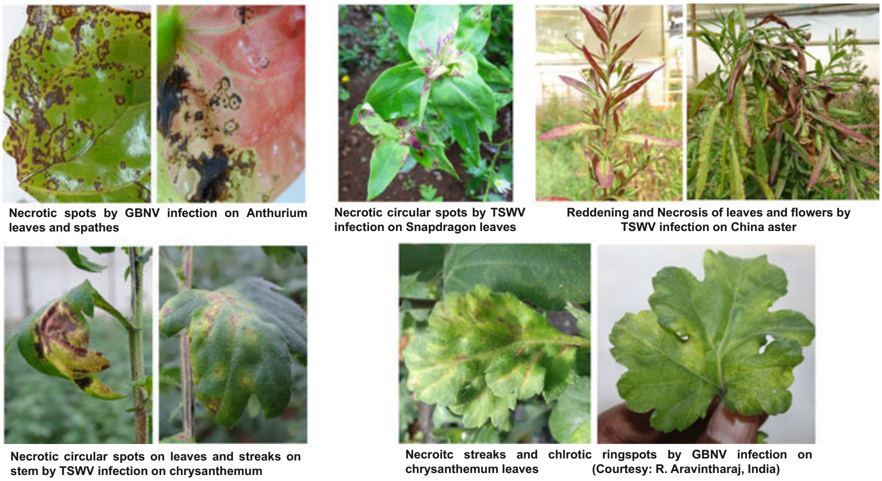

Fig. 1.1 Symptom variation of tospovirus infection on different ornamental crops

1.4 Transmission of Tospoviruses

Vectors play a major role in dissemination of tospoviruses and escalating them as devastating pathogen in the global status. The tospoviruses are transmitted by thrips (Thysanoptera: Thripidae) in a persistent, circulative and propagative manner (German et al. 1992). Among the 5500 known thrips species, nine species (*Frankliniella* sp., *Thrips* sp. and *Scirtothrips* sp.) were reported to be associated with tospoviruses (Mound 1998). All thrips species transmitting tospoviruses are polyphagous in nature and distributed worldwide causing the tospovirus a menace to ornamentals. Transmission of tospoviruses by thrips undergoes specific virus-vector interaction. One of the most interesting features is adults thrips were not able to acquire the virus in the thrips-tospovirus interaction. Tospoviruses acquired by first and second instar larval stage alone can able to transmit virus in their adult stage (Ullman et al. 1992; Sakimura 1963). Once thrips acquire the virus, it remains infectious throughout its life span because of its transstadial transmission nature (Wijkamp and Peters 1993; Wijkamp et al. 1995).

Frankliniella occidentalis (western flower thrips), a notorious insect pest, exists globally and is the most important vector of TSWV (Goldbach and Peters 1994). In petunia, *F. occidentalis* appeared to be the most effective in transmitting four tospoviruses tested (TSWV, INSV, tomato chlorotic spot *virus* (TCSV) and groundnut ringspot virus (GRSV)) in comparison to other thrips species through leaf disk assay. Also, one among four populations of *T. tabaci* was able to transmit TSWV in a low transmission efficiency (Wijkamp et al. 1995). Upon, ingestion of tospovirus by both adults and larvae of *F. occidentalis*, barrier in midgut prevents the virus movement out of the midgut of adults. Virions accumulated within epithelium gut of adults, whereas virions are seen in the midgut epithelia, fat body, brain, nerve cells, haemocoel and salivary glands of larvae (Ullman et al. 1992). Nagata and De Avila (2000) studied the transmission efficiency of CSNV by *F. schultzei* (78.1%), *F. occidentalis* (65.1%) and *T. tabaci* (0.0%). High CSNV titre was found in 75.9% of *F. schultzei* and 97.4% of *F. occidentalis* adults. Studies of Sharman et al. (2020) showed *Thrips palmi*, *F. schultzei* and *Microcephalothrips abdominalis* were transmitting CaCV, while no transmission was achieved with *F. occidentalis*. Medeiros et al. (2004) reported the activation of immune system in *F. occidentalis* upon acquiring TSWV. Beside thrips transmission, the dissemination of tospovirus also occurs through vegetatively propagated material such as tubers, corms, cuttings, etc. in many ornamental species (Wilson 2001; Adkins 2003). TSWV persists in flower bulbs and roots of lilies and dahlias (Kazinczi et al. 2007). Transmission of tospovirus through seeds does not occur among ornamentals (Mumford et al. 1996; Antignus et al. 1997). Major vectors of tospoviruses infecting ornamental crops are described in Table 1.2.

Table 1.2 Vectors of orthotospovirus species infecting ornamental crops

Virus	Vector
ANSV	*Frankliniella occidentalis*
AYSV	*Thrips tabaci*
CCSV	*T. palmi*
CaCV	*Ceratothripoides claratris*, *F. schultzei*, *T. palmi*
CSNV	*F. gemina*, *F. occidentalis*, *F. intonsa*, *F. schultzei*
GBNV	*F. schultzei*, *Scirtothrips dorsalis*, *T. palmi*
GRSV	*F. gemina*, *F. intonsa*, *F. occidentalis*, *F. schultzei*
HCRV	Unknown
INSV	*F. fusca*, *F. intonsa*, *F. occidentalis*, *F. schultzei*
IYSV	*F. fusca*, *T. tabaci*
LNRV	Unknown
PCSV	Unknown
TCSV	*F. intonosa*, *F. occidentalis*, *F. schultzei*
TSWV	*F. bispinosa*, *F. cephalica*, *F. fusca*, *F. gemina*, *F. intonsa*, *F. occidentalis*, *F. schultzei*, *T. setosus*, *T. tabaci*
TYRV	*Microcephalothrips abdominalis*, *T. tabaci*
TZSV	*F. occidentalis*
WBNV	*T. palmi*
WSMoV	*T. palmi*

Source: (EPPO 2020)

1.5 Occurrence and Distribution of Tospoviruses on Ornamental Crops

Tospoviruses are a highly cosmopolitan virus genus to have a worldwide distribution. The tospoviruses infecting ornamental crops are reported in 46 countries distributed representing all 6 continents (Fig. 1.2). TSWV and INSV are predominant tospovirus species infecting wide host range and are distributed across 38 and 26 countries on ornamental crops, respectively. TSWV is found to be prevalent among six continents and INSV in five continents and are ubiquitous infecting varieties of crops. INSV has become a serious pathogen on flower crops cultivated in greenhouse conditions in the USA (Daughtrey et al. 1997). Among the 18 ornamental-infecting tospoviruses, nine viruses, viz. CCNV, GBNV, HCRV, LNRV, PCSV, TYRV, TZSV, WBNV and WSMoV, seem to be restricted only to Asian countries. Totally 14 tospovirus species are infecting ornamental crops of Asian continent. Interestingly, GBNV is found on eight ornamental plants only in India, while HCRV infects nine plants only in China. In the Australian continent, four species (CaCV, CSNV, INSV and TSWV) are infecting different plant species such as *Hoya* sp., chrysanthemum, *Begonia*, *Cyclamen*, *Freesia*, *Gardenia*, *Gerbera*, *Hibiscus*, *Impatiens*, *Primula*, *Ranunculus*, spider lily, *Agapanthus*, *Gladiolus*, *Lupinus*, *Tanacetum*, *Cineraria*, *Dahlia*, *Ocimum*, *Pinellia*, marigold and *Ornithogalum*. Among the different countries, maximum of eight different tospovirus species are distributed across the China followed by six in the USA and five in Iran, Japan and the Netherlands (Table 1.1).

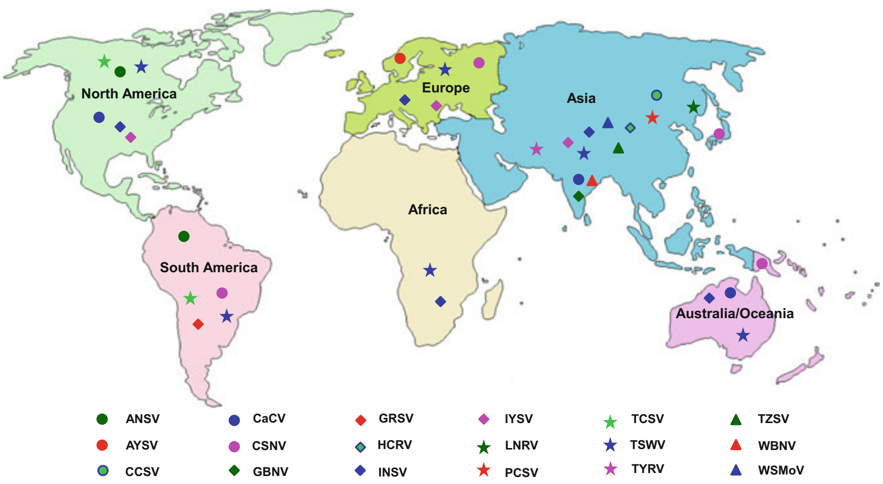

Fig. 1.2 Geographical distribution of tospoviruses species infecting ornamentals in different continents

1.6 Diagnostics of Tospoviruses

In this omics era, several sophisticated methods were utilized to detect tospoviruses. Exploiting viral properties such as morphology, transmission ability, serological property and nucleotide sequence identity is employed for tospovirus identification and characterization.

1.6.1 Visual Observation

Tospoviruses produces wide range of symptoms on ornamental plants upon infection. But some peculiar symptoms such as chlorotic or necrotic lesions, ringspots with concentric rings, green island mosaic on leaves, bronzing, chlorosis, tip necrosis and wilting are commonly seen across the hosts irrespective of tospovirus species infected. As they are infecting extensive hosts, symptom expression varies according to the hosts and virus interaction (Mumford et al. 1996). It is not feasible to identify the virus species based on the symptomatology, and therefore the serological and molecular tools are extensively used in the tospovirus detection.

1.6.2 Morphology

Use of electron microscope (EM) in the visualization of plant viruses was first demonstrated with tobacco mosaic virus (Kausche et al. 1939). EM has been extensively used to view the characteristic morphology of enveloped quasi-spherical particles of tospoviruses. Tospovirus-like particles of 90–120 nm in diameter were detected from the leaf extracts of chrysanthemum when negatively stained with 2% uranyl acetate (Duarte et al. 1995; Verhoeven et al. (1996). Gera et al. (1999) visualized INSV from the leaf-dip preparations prepared from leaf samples of *Anemone coronaria* plants through transmission electron microscopy (TEM). EM is used as a preliminary detection method of tospoviruses, and it does not satisfy their complete identification.

1.6.3 Bioassay

Mechanical inoculations on indicator plants such as *Nicotiana* sp., *Vigna unguiculata* (cowpea), etc. are used for the generic detection of tospoviruses. They produce characteristic local or systemic symptoms on indicator hosts. Inoculation of TSWV from chrysanthemum produced local chlorotic, concentric rings that later turned to necrotic spots 6 days post inoculation (DPI) on cowpea and pig weed (Renukadevi et al. 2015). Though it does not lead to identification at species level, it can be used for subsequent identification by other techniques.

1.6.4 Serological Methods

Serological method detects the presence of virus particle directly through the interaction between coat protein of virus (antigen) and the immunoproteins raised against the antigen in warm-blooded animals (antibody). Enzyme-linked immunosorbent assay (ELISA) is a very commonly used serological assay for the detection of tospovirus. Variants of ELISA such as double antibody sandwich [(DAS)-ELISA] and triple antibody sandwich [(TAS)-ELISA] are performed using antibody that has been raised against the specific tospovirus species. Based on the same principle, other methods such as dot immuno-binding assay, lateral flow assay, tissue immunobinding assay, etc. are being carried out. As there are five sero-groups prevalent among the tospoviruses, cross reaction of particular antibody with other tospovirus members will occur commonly in the serological assays. Through this method, presence or absence of tospovirus can be ascertained, but the species level identity cannot be confirmed. To confirm the identity of tospovirus species, application of molecular method will be of more helpful. Shahraeen et al. (2002) utilized the TAS-ELISA assay to detect INSV among the various ornamental plants grown in commercial nurseries and field in Iran. Renukadevi et al. (2015) used DAS-ELISA technique to detect the TSWV in chrysanthemum.

1.6.5 DNA Technology

The development of PCR and nucleic acid-based assays such as RT-PCR and quantitative (q) RT-PCR provides a simple, quick and precise means for tospovirus detection. According to the ICTV nomenclature, species are defined on the coat protein (N) sequence with amino acid identity of >90% than that of previously described tospovirus species called as new species (Plyusnin et al. 2011). Therefore, sequencing of tospovirus genome is indispensable for its proper identification. For generic identification, conventional RT-PCR assays using universal degenerate primers are used. Several utilized degenerate primers for the preliminary detection of tospoviruses in ornamental plants (Chu et al. 2001; Renukadevi et al. 2015; Huang et al. 2018; Basavaraj et al. 2020). Naidu et al. (2007) documented the natural infection of impatiens necrotic spot virus on *Monarda didyma* in Washington State by molecular method. RT-PCR assay using species-specific primer followed by sequencing of amplified fragments allows confirmation of tospovirus at species level. Uga and Tsuda (2005) developed multiplex RT-PCR for the simultaneous detection of five tospoviruses (WSMoV, TSWV, INSV, MNSV and IYSV) in ornamental crops. Charoenvilaisiri et al. (2014) standardized a multiplex RT-PCR-ELISA to detect and differentiate four tospovirus species found in Thailand, viz. CaCV, MYSV, TNRV and WSMoV. Targeted viral genomes amplified and labelled with digoxigenin (DIG) in a single RT-PCR reaction followed by distinguishing four species by parallel hybridizations with species-specific biotinylated probes in streptavidin-coated microtiter wells were used in ELISA detection. Assay sensitivity was 10 to 1000-fold higher than conventional RT-PCR. Real-time RT-PCR assay based on TaqMan probe has been demonstrated for the detection and quantification of TSWV in infected plant samples. Assay detected TSWV in 500 fg of total RNA and sensitized TSWV to tenfold higher than ethidium bromide staining (Roberts et al. 2000).

1.7 Molecular Biology of Tospoviruses

Tospoviruses are having a tripartite genome of ssRNA molecules comprising a total of five open reading frames (ORFs) enveloped inside the quasi-spherical particles with a diameter of 80–120 nm. The three single-stranded RNA (ssRNA) segments are denoted as S, M and L RNAs with 2.9 kb, 5 kb and 8.9 kb in size, respectively (Fig. 1.3). The L RNA is of negative polarity and encodes a putative 331-kDa RNA polymerase that may be associated with the ribonucleoprotein complex. The other two genomic RNAs use an ambisense coding strategy. The M RNA encodes a nonstructural (NSm) protein (34 kDa) in the viral (v) sense and a protein (155 kDa) to serve as the precursor for the Gn (95 kDa) and Gc (58 kDa) glycoproteins in the viral complementary (vc). The NSm protein may be involved in cell-to-cell movement of nonenveloped ribonucleocapsid structures. Tubular structures are specifically formed when the NSm gene is expressed in both plant and insect cell systems. The Gn and Gc glycoproteins are believed to form spikes on the viral envelope which help in virus acquisition and transmission by thrips. The S RNA encodes in the ‘v’ sense a 52-kDa nonstructural (NSs) protein that forms filamentous inclusion bodies, and in the ‘vc’ sense, a 29-kDa nucleocapsid protein (NP) encapsidates viral RNAs (Adkins et al. 1996; de Haan et al. 1990, 1992; Kormelink et al. 1992; van Poelwijk et al. 1997; Chu and Yeh 1998; Law et al. 1992; Satyanarayana et al. 1996; Whitfield et al. 2005). RNA molecules are generally seen as pseudocircular because of highly conserved and complementary first eight nucleotides (5’-AGAGCAAU and 3’-UCUGCUUA) at the termini of all RNA segments. These sequences act as promotor region for viral RNA replication and protein transcription (Turina et al. 2016; Kormelink 2011).

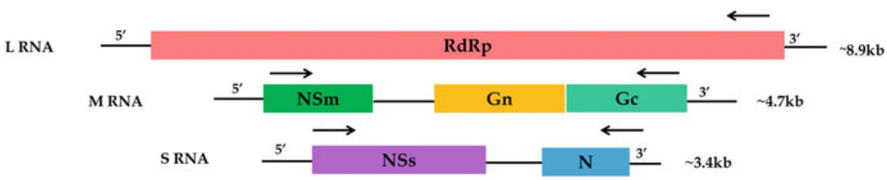

Fig. 1.3 Genome organization of tospovirus

1.8 Host-Pathogen Interaction

Host-pathogen interaction is a multifaceted process, mediated by the pathogen- and host-derived molecules which mainly include proteins, sugars and lipopolysaccharides. Plant viruses move cell to cell via plasmodesmata through the vascular system. Plant viruses encoding nonstructural proteins such as movement protein are specifically required for movement within their hosts. Movement proteins can able to increase the plasmodesmal size exclusion limit (SEL) to facilitate cell-to-cell movement of virions (Boevink and Oparka 2005). In the tospovirus infection cycle, only very few host factors involved were studied at various stages in plants. Interaction between DNA-J protein of host with NSM (movement protein) of TSWV suggested the movement of infectious ribonucleoproteins possible involvement of a mechanism that requires Hsp-70 (Soellick et al. 2000; von Bargen et al. 2001). Also, another chaperone protein (At-4/1) which shares homology with α-helical domains of ankyrin-, myosin- and kinesin-like proteins showed to be involved in both intra- and extracellular movement of TSWV virions (Paape et al. 2006; Morozov et al. 2014). Investigation on changes in the jasmonic acid (JA) and salicylic acid (SA) pathways upon TSWV inoculation through thrips revealed upregulation in the SA pathway in the infected plants than the healthy plants. Although feeding of thrips normally induces JA pathway, virus infection counteracts and suppresses the JA (antiherbivore response) pathway. These facilitate the thrips to get more attracted towards the infected plants rather than the healthy plants. This interaction supports the dissemination of the TSWV by thrips (Maris et al. 2004; Abe et al. 2012; Turina et al. 2016). Though few of the factors involved in tospovirus-host interaction were studied in model plants such tobacco and *Arabidopsis*, no factors were understood with the interaction of tospovirus-ornamental plants.

1.9 Management of Tospoviruses in Ornamental Crops

Early detection gives rise to early implementation of effective management strategies that can limit crop damage and economic loss. Several management strategies were demonstrated under open field and controlled conditions grown crops against tospoviruses across agricultural and horticultural crops. But information on tospovirus management in ornamental crops are limited. In general, management of tospoviruses can be achieved through cultural, biological, chemical, host plant resistance and biotechnological interventions. These interventions may target tospovirus as well as its thrips vector. Monitoring crops for thrips using yellow or blue sticky traps, checking every 7 days for thrips in foliage or flowers by tapping over a white surface or blowing lightly into buds or open flowers to draw thrips out for detection is helpful in controlling the thrips population. Proper maintenance of greenhouses plays an important role in the management strategy of tospoviruses in ornamental crops. All plant materials should be inspected before it is brought into the greenhouse and preferably kept in a separate section for a week or more before incorporating the new material into the production area, to assure that thrips are not introduced into the main production area. The greenhouse should be kept free of weeds inside and outside since both thrips and tospoviruses are easily harboured on greenhouse weed plants. Virus indicator plants can also be employed in the greenhouse. Growing crops with proper isolation distances from the TSWV source of inoculum provided there are no weed plant playing reservoir host in between will contain the disease spread (Coutts et al. 2004). Several cultural practices demonstrated to slow down the spread of tospoviruses are periodical removal of virus sources, avoidance of side-by-side and continuous plantings, planting of non-host barrier crops, growing under thrips proof net, mulching with black-silver polythene sheet, installation of yellow sticky traps, etc. under open field conditions (Jones 2004; Priyanka et al. 2019).

Use of insecticides in the management of thrips vector is the primary strategy for management of tospoviruses. Generally, the insecticides used in the thrips management can be grouped as broad-spectrum insecticides (pyrethroids, neonicotinoids, organophosphates and carbamates) and narrow-spectrum insecticides (pyridalyl and lufenuron) (Mouden et al. 2017). Regular use of broad-spectrum insecticides invites resistance development in thrips and detrimental to the natural enemies. Spinosad and spinetoram are being extensively used to manage thrips efficiently due to its tendency to be compatible with natural enemies (Gao et al. 2012; Li et al. 2016). However, the use of insecticides will ultimately lead the development of resistance in insect vectors. Therefore, it is necessary to use the insecticides accurate, precise and safe (He et al. 2020).

Biological means of tospovirus management can be achieved by targeting either the virus or the insect vector. Yoon et al. (2020) developed a novel approach in the management of TSWV in chrysanthemum by combining application of soil-dwelling predatory mite (*Stratiolaelaps scimitus*) @ 60/m^2 placed in soil along with foliar spray of four essential oil mixtures (cinnamon oil, cinnamon bark oil, oregano oil and thyme oil). These treatments were toxic to eggs, larvae and adults of *F. occidentalis*. Treatment has reduced the incidence of TSWV to 0.93% in comparison to chemical insecticides (32.05%) and untreated controls (84.85%) in chrysanthemum. *Amblyseius cucumeris*, another predatory mite, gave excellent control of *F. occidentalis* on *Impatiens* and reduced the spread and severity of TSWV under glasshouse conditions in the UK (Bennison et al. 2002). Another approach in management of tospoviruses in ornamental crops is development of resistant varieties. Some of the resistance genes such as *Tsw* and *Sw-5* were identified in solanaceous vegetables and are deploying resistance against TSWV (Turina et al. 2016). Unfortunately, resistance source identification against tospoviruses among the ornamental crops was in infant stage. Biotechnological interventions such RNAi, clustered regularly interspaced short palindromic repeats (CRISPR)-associated protein 9 (Cas9) and exogenous application of dsRNA to mediate resistance against tospovirus have been demonstrated by several workers (Tabein et al. 2020; Carbonell et al. 2019). Though these findings were demonstrated in other crop plants, these tospoviruses are also known to infect ornamental crops too. Therefore, these biotechnological tools are inviting major attention among the researchers to manage the tospoviruses.

1.10 Conclusion

The literature clearly indicates the prospective of tospovirus to cause damage to the ornamental crops worldwide. Though there are several reports for the infection of tospoviruses on ornamental crops, the coexistence of tospovirus with other viruses in combinations has to be studied in detail. When the vector is considered, most of the research findings of other crops are being considered for ornamental crops. However, it is essential to explore the involvement and distribution of thrips species in different ornamental crops and tospovirus interactions. Further, understanding of genome diversity, biology, geographical distribution and molecular and serological diagnostics of different tospoviruses in ornamental crops can contribute for the development of effective management strategies to prevent further spread of tospoviruses.

References

Abe H, Tomitaka Y, Shimoda T, Seo S, Sakurai T, Kugimiya S, Tsuda S, Kobayashi M (2012) Antagonistic plant defense system regulated by phytohormones assists interactions among vector insect, thrips and a tospovirus. Plant Cell Physiol 53(1):204–212

Adkins S (2003) Tomato spotted wilt virus. In: Pernezny K, Roberts PD, Murphy JF, Goldberg NP (eds) Compendium of pepper diseases. American Phytopathological Society, St. Paul, pp 39–40

Adkins S, Choi TJ, Israel BA, Bandla MD, Richmond KE, Schultz KT, Sherwood JL, German TL (1996) Baculovirus expression and processing of tomato spotted wilt tospovirus glycoproteins. Phytopathology 86(8):849–855

Antignus Y, Lapidot M, Anaim M, Cohen J, Lachman O, Pearlsman M, Raccah B, Gera A (1997) Biological and molecular characterization of tomato spotted wilt virus in Israel. Phytoparasitica 25:319–330

Basavaraj YB, Siwach J, Kumar A, Bhattarai A, Qayoom N, Baranwal VK, Jain RK (2020) First report of natural infection by Capsicum chlorosis virus on Amaryllis (*Hippeastrum hybridum*) plants from India. Plant Dis 104(11):3086–3086

Bennison J, Maulden K, Barker I, Morris J, Boonham N, Smith P, Spence N (2002) Reducing spread of TSWV on ornamentals by biological control of western flower thrips. In: Thrips and Tospoviruses: proceedings of the 7th international symposium on Thysanoptera, pp 215–219

Boevink P, Oparka KJ (2005) Virus-host interactions during movement processes. Plant Physiol 138(4):1815–1821

Brown S, Csinos A, Díaz-Pérez JC, Gitaitis R, LaHue S, Levin-Nicholson J, Martinez N, McPherson R, Mullis S, Nischwitz C, Riley D, Sherwood J, Sisson V, Stephenson M, Wells L (2005) Tospoviruses. In: Solanaceae and other crops in the coastal plain of Georgia. University Georgia. (Research Report Number 704), p 40

Carbonell A, Lisón P, Daròs JA (2019) Multi-targeting of viral RNAs with synthetic trans-acting small interfering RNAs enhances plant antiviral resistance. Plant J 100(4):720–737

Charoenvilaisiri S, Seepiban C, Bhunchoth A, Warin N, Luxananil P, Gajanandana O (2014) Development of a multiplex RT-PCR-ELISA to identify four distinct species of tospovirus. J Virol Methods 202:54–63

Cho JJ, Mau RF, German TL, Hartmann RW, Yudin LS, Gonsalves D, Provvidenti R (1989) A multidisciplinary approach to management of *tomato spotted wilt virus* in Hawaii. Plant Dis 73:375–383

Chu FH, Yeh SD (1998) Comparison of ambisense M RNA of watermelon silver mottle virus with other tospoviruses. Phytopathology 88(4):351–358

Chu FH, Chao CH, Chung MH, Chen CC, Yeh SD (2001) Completion of the genome sequence of watermelon silver mottle virus and utilization of degenerate primers for detecting tospoviruses in five serogroups. Phytopathology 91(4):361–368

Coutts BA, Thomas-Carroll ML, Jones RAC (2004) Patterns of spread of tomato spotted wilt virus in field crops of lettuce and pepper: spatial dynamics and validation of control measures. Ann Appl Biol 145(2):231–245

Daughtrey ML, Jones RK, Moyer JW, Daub ME, Baker JR (1997) Tospoviruses strike the greenhouse industry: INSV has become a major pathogen on flower crops. Plant Dis 81 (11):1220–1230

de Haan P, de Avila AC, Kormelink R, Westerbroek A, Gielen JJ, Peters D, Goldbach R (1992) The nucleotide sequence of the S RNA of Impatiens necrotic spot virus, a novel tospovirus. FEBS Lett 306(1):27–32

de Haan P, Wagemakers L, Peters D, Goldbach R (1990) The S RNA segment of tomato spotted wilt virus has an ambisense character. J Gen Virol 71:1001–1007

Duarte LM, Rivas EB, Alexandre MAV, DeÁvila AC, Nagata T, Chagas CM (1995) Chrysanthemum stem necrosis caused by a possible novel tospovirus. J Phytopathol 143:569–571

EPPO (2020) PM 7/139 (1) Tospoviruses (genus Orthotospovirus). Bulletin OEPP/EPPO Bulletin 50(2):217–240. https://doi.org/10.1111/epp.12676

Gao Y, Lei Z, Reitz SR (2012) Western flower thrips resistance to insecticides: detection, mechanisms and management strategies. Pest Manag Sci 68(8):1111–1121

Gent DH, du Toit LJ, Fichtner SF, Mohan SK, Pappu HR, Schwartz HF (2006) Iris yellow spot virus: an emerging threat to onion bulb and seed production. Plant Dis 90(12):1468–1480

Gera A, Kritzman A, Cohen J, Raccah B (1999) First report of Impatiens necrotic spot tospovirus (INSV) in Israel. Plant Dis 83(6):587

German TL, Ullman DE, Moyer JW (1992) Tospoviruses: diagnosis, molecular biology, phylogeny, and vector relationships. Annu Rev Phytopathol 30:315–346

Goldbach R, Peters D (1994) Possible causes of the emergence of tospovirus diseases. In: Seminars in virology, vol 5(2). Academic Press, pp 113–120

He Z, Guo JF, Reitz SR, Lei ZR, Wu SY (2020) A global invasion by the thrip, Frankliniella occidentalis: current virus vector status and its management. Insect science 27(4):626–645. https://doi.org/10.1111/1744-7917.12721

Huang KS, Li SL, Sun JH, Wang YC, Jan FJ, Chen TC (2018) Development of a generic method for inspection of tospoviruses. Eur J Plant Pathol 150(2):457–469

Jones RA (2004) Using epidemiological information to develop effective integrated virus disease management strategies. Virus Res 100(1):5–30

Kausche GA, Pfankuch E, Ruska H (1939) Die Sichtbarmachung von pflanzlichem virus im Übermikroskop. Naturwissenschaften 27(18):292–299

Kazinczi G, Horváth J, Takács A (2007) Tospoviruses on ornamentals. Plant Viruses 1(2):142–162

Kormelink R (2011) The molecular biology of tospoviruses and resistance strategies. In: Elliott RM, Plyusin A (eds) Bunyaviridae: molecular and cellular biology. Plenum Press, New York, pp 163–191

Kormelink R, De Haan P, Meurs C, Peters D, Goldbach R (1992) The nucleotide sequence of the M RNA segment of tomato spotted wilt virus, a bunyavirus with two ambisense RNA segments. J Gen Virol 73(11):2795–2804

Law MD, Speck J, Moyer JW (1992) The M RNA of impatiens necrotic spot Tospovirus (Bunyaviridae) has an ambisense genomic organization. Virology 188(2):732–741

Li DG, Shang XY, Reitz SR, Nauen R, Lei ZR, Lee SH, Gao YL (2016) Field resistance to spinosad in western flower thrips *Frankliniella occidentalis* (Thysanoptera: Thripidae). J Integr Agric 15:2803–2808

Lin Y, Chen T, Chung M, Yeh S (2006) Sequence analysis of S RNA of Calla lily chlorotic spot virus, a new tospovirus. Acta Hortic 722:103–110

Maris PC, Joosten NN, Goldbach RW, Peters D (2004) Tomato spotted wilt virus infection improves host suitability for its vector Frankliniella occidentalis. Phytopathology 94 (7):706–711

Matteoni JA, Allen WR (1989) Symptomatology of tomato spotted wilt virus infection in florist's chrysanthemum. Can J Plant Pathol 11:373–380

Medeiros RB, Resende RDO, de Avila AC (2004) The plant virus tomato spotted wilt Tospovirus activates the immune system of its main insect vector, Frankliniella occidentalis. J Virol 78 (10):4976–4982

Morozov S, Makarova S, Erokhina T, Kopertekh L, Schiemann J, Owens R, Solovyev A (2014) Plant 4/1 protein: potential player in intracellular, cell-to-cell and long-distance signaling. Front Plant Sci 5:26

Mouden S, Sarmiento KF, Klinkhamer PG, Leiss KA (2017) Integrated pest management in western flower thrips: past, present and future. Pest Manag Sci 73:813–822

Mound LA (1998) So many thrips – so few tospoviruses? In: 7th international symposium on Thysanoptera, Reggio Calabria, Italy, pp 15–18

Mumford RA, Barker I, Wood KR (1996) The biology of the Tospoviruses. Ann Appl Biol 128:159–183

Mumford RA, Jarvis B, Morris J, Blockley A (2003) First record of Chrysanthemum stem necrosis virus (CSNV) in the UK. Plant Pathol 52:779

Nagata T, De Avila AC (2000) Transmission of chrysanthemum stem necrosis virus, a recently discovered tospovirus, by two thrips species. J Phytopathol 148(2):123–125

Naidu RA, Alabi OJ, Karthikeyan G, Nelson M, Morrell A (2007) First report of *Monarda didyma* infection with *Impatiens necrotic spot virus (Tospovirus)* in Washington State. Plant Health Progress. https://doi.org/10.1094/PHP-2007-1119-02-BR

Okuda M, Hanada K, Uematsu S, Fukumoto F, Mihira T, Ebihara Y, Iwanami T (2005) Necrotic streaks of alstroemeria (*Alstroemeria* spp.) caused by Iris yellow spot virus (IYSV). Japanese J Phytopathol 71(2):119–122

Paape M, Solovyev AG, Erokhina TN, Minina EA, Schepetilnikov MV, Lesemann DE, Schiemann J, Morozov SY, Kellmann JW (2006) At-4/1, an interactor of the tomato spotted wilt virus movement protein, belongs to a new family of plant proteins capable of directed intra- and intercellular trafficking. Mol Plant-Microbe Interact 19(8):874–883

Pappu HR, Jones RAC, Jain RK (2009) Global status of tospovirus epidemics in diverse cropping systems: successes achieved and challenges ahead. Virus Res 141(2):219–236

Persley DM, Thomas JE, Sharman M (2006) Tospoviruses – an Australian perspective. Australas Plant Pathol 35:161–180

Plyusnin A, Beaty BJ, Elliott RM, Goldbach R, Kormelink R, Lundkvist Å, Schmaljohn CS, Tesh RB (2011) Bunyaviridae. In: Virus taxonomy: ninth report of the international committee on taxonomy of viruses. Elsevier Scientific Publ. Co.

Priyanka R, Nagendran K, Aravintharaj R, Balaji CG, Mohankumar S, Renukadevi P, Karthikeyan G (2019) Characterization and management of watermelon bud necrosis virus infecting watermelon in India. Eur J Plant Pathol 153(3):759–770

Renukadevi P, Nagendran K, Nakkeeran S, Karthikeyan G, Jawaharlal M, Alice D, Malathi VG, Pappu HR (2015) First report of tomato spotted wilt virus infection of chrysanthemum in India. Plant Dis 99(8):1190

Roberts CA, Dietzgen RG, Heelan LA, Maclean DJ (2000) Real-time RT-PCR fluorescent detection of tomato spotted wilt virus. J Virol Methods 88(1):1–8

Sakimura K (1963) Frankliniella fusca, an additional vector for the tomato spotted wilt virus, with notes on Thrips tabaci, another vector. Phytopathology 53:412–415

Sastry KS, Mandal B, Hammond J, Scott SW, Briddon RW (2019) Encyclopedia of plant viruses and Viroids. Springer India, New Delhi, p 2936

Satyanarayana T, Mitchell SE, Reddy DVR, Kresovich S, Jarret R, Naidu RA, Gowda S, Demski JW (1996) The complete nucleotide sequence and genome organization of the M RNA segment of peanut bud necrosis tospovirus and comparison with other tospoviruses. J Gen Virol 77 (9):2347–2352

Shahraeen N, Ghotbi T, Mehraban AH (2002) Occurrence of Impatiens necrotic spot virus in ornamentals in Mahallat and Tehran provinces in Iran. Plant Dis 86(6):694–694

Sharman M, Thomas JE, Tree D, Persley DM (2020) Natural host range and thrips transmission of capsicum chlorosis virus in Australia. Australas Plant Pathol 49(1):45–51

Soellick TR, Uhrig JF, Bucher GL, Kellmann JW, Schreier PH (2000) The movement protein NSm of tomato spotted wilt tospovirus (TSWV): RNA binding, interaction with the TSWV N protein, and identification of interacting plant proteins. Proc Natl Acad Sci 97(5):2373–2378

Tabein S, Jansen M, Noris E, Vaira AM, Marian D, Behjatnia SAA, Accotto GP, Miozzi L (2020) The induction of an effective dsRNA-mediated resistance against tomato spotted wilt virus by exogenous application of double-stranded RNA largely depends on the selection of the viral RNA target region. Front Plant Sci 11. https://doi.org/10.3389/fpls.2020.533338

Turina M, Kormelink R, Resende RO (2016) Resistance to tospoviruses in vegetable crops: epidemiological and molecular aspects. Annu Rev Phytopathol 54:347–371

Uga H, Tsuda S (2005) A one-step reverse transcription-polymerase chain reaction system for the simultaneous detection and identification of multiple tospovirus infections. Phytopathology 95:166–171

Ullman DE (1998) Managing tospoviruses: developing a monitoring system for grower decision making. In: 14th conference on insect and disease management on ornamentals, Del Marc, CA. Society of American Florists, Alexandria, VA, pp 9–12

Ullman DE, Cho JJ, Mau RF, Hunter WB, Westcot DM, Custer DM (1992) Thrips-tomato spotted wilt virus interactions: morphological, behavioral and cellular components influencing thrips transmission. In: Advances in disease vector research. Springer, New York, pp 195–240

van Poelwijk F, Prins M, Goldbach R (1997) Completion of the impatiens necrotic spot virus genome sequence and genetic comparison of the L proteins within the family Bunyaviridae. J Gen Virol 78(3):543–546

Verhoeven JT, Roenhorst JW, Cotes I, Peters D (1996) Detection of a novel tospovirus in chrysanthemum. Acta Hortic 432:44–51

von Bargen S, Salchert K, Paape M, Piechulla B, Kellmann JW (2001) Interactions between the tomato spotted wilt virus movement protein and plant proteins showing homologies to myosin, kinesin and DnaJ-like chaperones. Plant Physiol Biochem 39(12):1083–1093

Whitfield AE, Campbell RL, Sherwood JL, Ullman DE (2003) Tissue blot immunoassay for detection of tomato spotted wilt virus in *Ranunculus asiaticus* and other ornamentals. Plant Dis 87:618–622

Whitfield AE, Ullman DE, German TL (2005) Tospovirus-thrips interactions. Annu Rev Phytopathol 43:459–489

Wijkamp I, Peters D (1993) Determination of the median latent period of two tospoviruses in Frankliniella occidentalis, using a novel leaf disk assay. Phytopathology 83:986–986

Wijkamp I, Almarza N, Goldbach R, Peters D (1995) Distinct levels of specificity in thrips transmission of tospoviruses. Phytopathology 85(10):1069–1074

Wilson CR (2001) Resistance to infection and translocation of tomato spotted wilt virus in potatoes. Plant Pathol 50(3):402–410

Yoon JB, Choi SK, Cho IS, Kwon TR, Yang CY, Seo MH, Yoon JY (2020) Epidemiology of tomato spotted wilt virus in *Chrysanthemum morifolium* in South Korea and its management using a soil-dwelling predatory mite (*Stratiolaelaps scimitus*) and essential oils. Virus Res 289:198128