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Review Article

Tropical ornamental plants: Brazilian overview of viral infections and management

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Abstract

Ornamental plants, which were originally grown for magical or esthetic reasons, have gained industrial status in recent decades, contributing economically to the development of several countries. The presence of pathogens, especially viruses, can interfere in production by causing symptoms in leaves and flowers, thereby depreciating the product and affecting normal plant growth. Furthermore, perennial species can act as a natural reservoir for other crops. Depending on the species, viruses can be transmitted by vegetative propagation, contact, insect vectors, pollen and seeds. As such, knowledge of the genetic diversity, geographic distribution and biological properties of viruses may contribute to preventing future infections. In this review, a number of tropical species infected by viruses reported in Brazil are presented, highlighting the first occurrences of new viral species. Aspects related to virus control and management in ornamental plants are also discussed.

Keywords: plants native to the Americas, plant virus control, plant viruses.

Resumo

Plantas ornamentais tropicais: panorama brasileiro de infecções virais e manejo

As plantas ornamentais, que nos seus primórdios, eram cultivadas por razões mágicas ou estéticas ganharam, nas últimas décadas, o status de indústria, contribuindo economicamente para o desenvolvimento de diversos países. A presença de patógenos, especialmente os vírus, pode interferir na produção por causarem sintomas em folhas e flores, depreciando o produto, além de afetar o desenvolvimento normal da planta. Além disso, espécies perenes podem atuar como reservatório natural de vírus para outras culturas. Dependendo da espécie, os vírus podem ser transmitidos por propagação vegetativa, contato, insetos vetores, pólen e sementes. Portanto, o conhecimento da diversidade genética, da distribuição geográfica e propriedades biológicas dos vírus pode contribuir para a prevenção de futuras infecções. Nesta revisão, são apresentadas algumas espécies tropicais infectadas por vírus descritos no Brasil, destacando-se primeiras ocorrências e descrição de novas espécies virais. Discute-se também aspectos relacionados ao controle e manejo de vírus em plantas ornamentais.

Palavras-chave: controle de fitoviroses, fitovírus, plantas nativas das Americas.

Introduction

Human beings have been using ornamental plants since ancient times. In ancient gardens, species not found in the wild were juxtaposed. Wind and insect hybridization occurred and gardeners selected the plants (Gessert, 2021). Later, floriculture was undertaken for economic reasons until it became a highly profitable and competitive global market (Mitrofanova et al., 2018). Among the largest producers are the Netherlands, Israel, Thailand, Colombia, Ecuador and Mexico (Alexandre et al., 2021).

Despite the considerable diversity of native species with ornamental potential, most of those grown, commercialized and consumed in Brazil are exotic and originate from improved genetic material adapted and developed abroad, mainly by companies from the Netherlands, Germany, Japan, Thailand and others (Junqueira and Peetz, 2017). One of the problems in floriculture is the spread of pests and diseases in the cultivation of flowers and ornamental plants, which mainly affects flower quality. Pests such as thrips can cause direct damage, especially to flowers, and can be vectors of viruses and other diseases (Cardoso and Vendrame, 2022).

Plant viruses, which are small obligate infectious agents, comprise DNA or RNA as genetic material and hijack the host machinery for their replication and protein expression. They are therefore responsible for devastating yield losses in several economically important crops worldwide (Srivastava et al., 2021).

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Unlike the invasion of phytopathogenic bacteria or fungi, viruses are introduced directly into the plant cell by vectors, mostly arthropods (insects and mites) or through wounds (Baruah et al., 2020).

Despite the increase in ornamental plant production, studies on the infection and damage caused by viruses remain scarce.

In the present study, we will focus on tropical species, highlighting plants native to the Americas naturally infected by viruses reported in Brazil in recent decades (Table 1).

We decided not to describe the expression of virus-related symptoms since they may be variable, depending on the host (species or cultivar), plant development stage, environmental conditions (temperature, light and water availability), viral isolate or strain.

Table 1. Main viruses infecting tropical ornamental plants in Brazil

Species/Families	Virus (acronyms, Genus)	References
Alstroemeria sp./Alstroemeriaceae	Alstroemeria mosaic virus (AlMV, *Potyvirus*) Chrysanthemum stem necrosis virus (CSNV, *Orthotospovirus*) tomato spotted wilt virus (TSWV, *Orthotospovirus*) tobacco streak virus (TSV, *Ilarvirus*) *Carlavirus* species**	Rivas et al., 2013; Kitajima, 2020
Allamanda cathartica/Apocynaceae	cucumber mosaic virus (CMV, *Cucumovirus*) *Dicorhabdovirus* species**	Kitajima, 2020
Anthurium spp./Araceae	(CMV, *Cucumovirus*) Dasheen mosaic virus (DsMV, *Potyvirus*)	Kitajima, 2020
Bougainvillea spectabilis, *B. glabra/* Nyctaginaceae	Bougainvillea chlorotic vein banding virus (BCVBV, *Badnavirus*)*	Chagas et al., 2004; Alexandre et al., 2015
Several/Cactaceae	Cactus virus X (CVX, *Potexvirus*) Opuntia virus X (OpVX, *Potexvirus*) Schlumbergera virus X (SchlVX, *Potexvirus*) Zygocactus virus X (ZyVX, *Potexvirus*) Opuntia virus 1 (OpV1, *Opunvirus)*	Duarte and Alexandre, 2017; Kitajima, 2020; Fontenele et al., 2020
Selenicereus megalanthus/Cactaceae	(CVX, *Potexvirus*)	Reichel et al. 2002
Caladium bicolor/Araceae	Caladium virus X (CalVX, *Potexvirus*)* Dashenn mosaic virus (DsMV, *Potyvirus*)	Rivas et al., 2005 Duarte and Alexandre, 2017
*Canna paniculata/*Cannaceae	Canna yellow streak virus (CaYMV)/ *Potyvirus*)	Alexandre et al., 2017
*Costus spiralis/*Costaceae	Costus stripe mosaic virus (CoSMV, *Potyvirus*)*	Alexandre et al., 2020
Eucharis grandiflora/Amaryllidaceae	(CMV, Cucumovirus) Hippeastrum mosaic virus (HiMV, *Potyvirus*) (TSWV, *Orthotospovirus*)	Kitajima, 2020
Helianthus annuus/Asteraceae	Bidens mosaic virus (BiMV, *Potyvirus*) tobacco streak virus (TSV, *Ilarvirus*) tobacco necrosis virus (TNV, *Nepovirus*) sunflower chlorotic mottle virus (SCMoV, *Potyvirus*)	Kitajima, 2020; Bello et al., 2023
Hibiscus spp./Malvaceae	Hibiscus chlorotic ringspot virus (HCRSV, *Betacarmovirus*)	Kitajima, 2020
Hippeastrum/Amaryllidaceae	bean yellow mosaic virus (BYMV, *Potyvirus*) Hippeastrum mosaic virus (HiMV, *Potyvirus*) groundnut ringspot virus (GRSV, *Orthotospovirus*)	Duarte and Alexandre, 2017; Kitajima, 2020
Mandevilla sp./Apocynaceae	Catharanthus mosaic virus (CatMV)/ *Potyvirus*)	Favara et al., 2020
*Petunia hybrida/*Solanaceae	cauliflower mosaic virus (CaMV,*Caulimovirus*) Petunia veinbanding virus (PetVBV, *Tymovirus*)* tobacco mosaic virus (TMV, *Tobamovirus*)	Alexandre et al., 2000; Duarte and Alexandre, 2017
Schefflera sp./Araliaceae	Schefflera ringspot virus (SRV, *Badnavirus*)	Kitajima, 2020
Schlumbergera truncata/Cactaceae	(OpVX, SchlVX, ZyVX, *Potexvirus*)	Duarte and Alexandre, 2017
*Seemannia sylvatica/*Gesneriaceae	(CMV,*Cucumovirus*)	Duarte and Alexandre, 2017
*Torenia fournieri/*Linderniaceae	Alternanthera mosaic virus (AltMV, *Potexvirus*)	Duarte et al, 2008
*Tradescanthia spathacea/*Commelinaceae	(CoSMV,*Potyvirus*)	Favara et al., 2021
Zinnia elegans/Asteraceae	(BiMV/*Potyvirus*), (SuCMoV/*Potyvirus*) (TMV, *Tobamovirus*), (GRSV/*Orthotospovirus*)	Duarte and Alexandre, 2017; Kitajima, 2020; Oliveira et al., 2022

*virus species described in Brazil; ** unidentified virus species

***Alstroemeria* sp. – Alstroemeriaceae**

Despite being endemic to South America, this species has been genetically abroad since the 1980s, especially in The Netherlands and Ecuador. Due to its wide variety of colors, alstroemeria has become one of the main cut flower crops in the world (Tombolato et al., 2004; Alexandre et al., 2021).

In Brazil, Alstroemeria mosaic virus (AlMV) has been identified in commercial production in the states of São Paulo (SP) and Minas Gerais (MG) (Rivas et al., 2013), as well as in Ecuador and Mexico (Alexandre et al., 2021). Symptoms associated with AlMV in alstroemeria vary from asymptomatic to mosaic, chlorosis and chlorotic spots on leaves, and color break on the flowers, depending on the cultivars, growing conditions, and time of year.

Viruses such as chrysanthemum stem necrosis virus (CSNV), tomato spotted wilt virus (TSWV), an unidentified *Carlavirus* species, cucumber mosaic virus (CMV) and tobacco streak virus (TSV) have been reported in SP (Kitajima, 2020).

***Allamanda cathartica* L. (golden trumpet) – Apocynaceae**

A native plant, but not endemic to Brazil (Souza and Lorenzi, 2012), it occurs in the phytogeographic domains of the Amazon, Cerrado and Atlantic Forest, and is widely cultivated in gardens and urban landscape in all regions of the country.

Two viruses are related in this species: CMV in SP and DF (Fig 1A), and a species of *Dicorhabdovirus*, transmitted by *Brevipalpus*, in a residential garden in Manaus (AM) (Kitajima, 2020). In addition, species of *Begomovirus* have been described outside Brazil.

***Anthurium* spp – Araceae**

Araceae, which successfully conquered substrate-poor environments, is one of the main epiphyte families, and is frequently found in the Atlantic Forest. *Anthurium* is the highest ranked genus in the family, with over 500 species, all American (WFO, 2023). The genetic improvement of *Anthurium* produced several varieties, with plants of different sizes and flowers of different colors. This ornamental is the second most commercialized tropical “flower” in the world, after orchids.

With regard to viruses, CMV has been described in plants from Mogi das Cruzes (SP), Cilevirus from Cruz das Almas (BA) and Dasheen mosaic virus (DsMV) in a commercial field in SP (Kitajima, 2020). Several *Orthotospovirus* species described worldwide have yet to be reported here.

***Bougainvillea glabra* Choisy, *B. spectabilis* Willd. (paperflower) -- Nyctaginaceae**

Brazilian native species are often cultivated in different countries, not only for the beauty of their bracts, but also for their easy adaptation to several climates.

Bougainvillea chlorotic vein banding virus (BCVBV) (Fig 1B) was first described in samples collected in SP (Brazil) (Chagas et al., 2001), and later in samples from Campinas, Ourinhos and Piracicaba - SP; Andradas and Uberlândia - MG; Seropedica -RJ and Brasilia - DF (Alexandre et al., 2015). They have also been reported in Taiwan, China, India, Malaysia and Egypt. CMV, Impatiens necrosis spotted virus (INSV) and Clerodendron yellow mosaic virus (ClYMV) have been reported less frequently abroad (Kitajima, 2020).

Cactaceae

With about 1,500 species in around 100 genera, Cactaceae is one of the most interesting and diverse angiosperm families in hot and arid America. With approximately 230 species native to Brazil distributed in 36 genera, they are highly appreciated as ornamental plants, particularly *Cereus* spp. (mandacaru), *Opuntia* spp. (palms), *Hylocereus* spp. (pitayas), *Pereskia* spp., among others (Hershkovitz and Zimmer, 1997; Souza and Lorenzi, 2008). Cacti are culturally, economically, and ecologically important, and since Europeans arrived in the Americas, have been exported all over the world (Fontenele et al., 2020).

The following *Potexvirus* viruses occur in Brazil in several species of Cactacae (Kitajima, 2020): cactus virus X (CVX), *Opuntia* virus X (OpVX), *Schlumbergera* virus X (SchVX) and *Zygocactus* virus X (ZyVX). In 2008, Duarte et al. reported the first occurrence of mixed infections of SchVX and ZyMV in *Hylocereus undatus*, ZyVX, SchVX and OpVX in *Schlumbergera truncata*. ZyMV was reported for the first time in *Opuntia tuna*, a Cactaceae from the Caribbean (Labra et al., 2003) introduced into Brazil.

***Caladium bicolor* (Aiton) Vent. (Heart of Jesus) – Aracaeae**

A bulbous plant native to Brazil, widely used for the beauty of it colorful leaves, Florida (USA) being the largest commercial producer. *Caladium* virus X (CalVX) and DsMV were recorded in Brazil from samples collected in SP (Rivas et al., 2005; Kitajima, 2020).

***Canna paniculata* Ruiz & Pav. (Canna lily) – Cannaceae**

The genus encompasses ten species, four of which are native to Brazil, including *C. paniculata*. In the 19th century, several hybrids were introduced into Europe and the USA. These species are currently cultivated for the beauty and color shades of their leaves and flowers.

Canna yellow streak virus (CaYSV) (Fig. 1C), the most important virus related to the development of Canna species and hybrids, is responsible for large production losses, mainly in Europe. The virus was described in 2007 in the UK, and later in the Netherlands, Israel, Belgium and the USA (Monger et al., 2007) and Brazil, in 2017, based on samples from Piracicaba - SP (Alexandre et al., 2017).

***Costus spiralis* (Jacq) Roscoe – Costaceae**

The family exhibits pantropical distribution, with seven genera, including three genera and 20 species in Brazil. The Brazilian species are concentrated in the Amazon region, but species such as *Costus arabicus* and *C. spiralis* (Souza and Lorenzi, 2012) are also found in the Atlantic Forest. In Brazil, the virus was first reported in *Costus* species in 2020, in a *C. spiralis* sample collected in SP (Alexandre et al., 2020). The virus, named *Costus* stripe mosaic virus (CoSMV) was accepted by ICTV as a new *Potyvirus* species. It was also described infecting a *Tradescantia spathaceae* sample from Piracicaba - SP (Favara et al., 2021).

***Eucharis* x *grandiflora* Planch. & Linden (Amazon lily) – Amaryllidaceae**

Genus native to Brazil widely used in gardens, flowerbeds and pots for the beauty of its leaves and white flowers. In Japan, it is used primarily as a cut flower. The disease known as *Hippeastrum* mosaic has been long known and reported in several countries, but its characterization occurred in the 1970s.

In Brazil, *Hippeastrum* mosaic virus (HiMV) was first described in *E. grandiflora* from Campinas - SP and Brasilia - DF (Alexandre et al., 2011). TSWV and CMV have also been described (Cilli et al., 2002; Kitajima, 2020).

***Helianthus annuus* L. (common sunflower) – Asteraceae**

First domesticated from its wild ancestor by indigenous American peoples, *Helianthus* is native to North America, Canada and Northern Mexico. Extensive hybridizing has resulted in a large number of cultivars` providing a wide range of flower colors, shapes and sizes. The development of Brazilian cultivars for ornamental purposes enabled sunflower production in several regions, such as Nova Friburgo - RJ, Roraima state and Vale do São Francisco (Curti et al., 2012).

Several viruses have been reported in São Paulo state, including Bidens mosaic virus (BiMV), TSV and tobacco necrosis virus (TNV), the last isolated from the roots of asymptomatic plants (Kitajima, 2020). Sunflower chlorotic mottle virus was first described in Brazil in 2023 (Bello et al., 2023)

***Hibiscus* spp. - Malvaceae**

Family with predominantly pantropical distribution, with around 70 genera and 750 species occurring in Brazil. A number of *Hibiscus* species, such as *H. bifurcatos*, are native to Brazil, but the most commercialized is *H. rosa-sinensis*, originating in Asia and containing more than 5000 varieties (Souza and Lorenzi, 2012). The following viruses have been described in different regions of the country: Hibiscus green spot virus (HGSV) found in SP, RJ, MG, AM and DF; hibiscus chlorotic ringspot virus (HCRSV) in the DF; *Clerodendrum* chlorotic spot virus (ClCSV) in RJ, Campinas and Piracicaba - SP and Manuas - AM; hibiscus latent virus Fort Pierce (HLV-FP) in Limeira, Piracicaba and Águas de São Pedro - SP; and hibiscus golden mosaic virus (HGMV) in Igarapé-Mirim - PA (Kitajima, 2020).

***Hippeastrum* sp. (amaryllis)– Amaryllidaceae**

Hippeastrum, with about 60 species, has two diversity centers: Bolivia, Peru and Southeast/South Brazil. It is the largest genus of the family and has the widest geographic distribution in the country, with about 30 species (Oliveira et al., 2017). Although some species occur at high altitudes, characterized as temperate climates, the genus is essentially tropical and subtropical (Meerow, 2009). In Brazil, several amaryllis species are epiphytes in the Atlantic Forest (Souza and Lorenzi, 2012).

Known as amaryllis, interest in these bulbous species has increased in recent years due to their large beautiful flowers in a wide variety of colors (Tombolato, 2004; Kharrazi et al., 2017). The commercial varieties *Hippeastrum* x *hybridum* Hort come from interspecific crossings (Tombolato, 2004). The first hybrid amaryllis was produced in England in 1799 from *H. vittatum* and *H. reginae* hybridization, with many additional hybrids created during the first 25 years of the 19th century, when new species were collected in South America and exported to Europe (Meerow, 2009).

Hippeastrum sp. can be propagated by seeds, lateral bulbils, double scales and tissue culture (Kharrazi et al., 2017). However, seeds are normally used to develop new varieties due to the wide variation in floral traits, plant shape and flowering time. Vegetative propagation is the most widely used for commercialization. However, producers face several problems, such as the spread of pathogens, especially viruses, which, in addition to reducing growth, make it difficult to obtain virus-free plants for export (Duarte and Alexandre, 2017).

Mosaic symptoms may be associated with infection by the bean yellow mosaic virus (BYMV) or HiMV, belonging to the genus *Potyvirus*. However, chlorotic spots on leaves may be associated with the presence of groundnut ringspot orthotospovirus virus (GRSV). None of these viruses seem to cause symptoms in flowers (Duarte and Alexandre, 2017). In Mexico, leaf yellow mottle symptoms in amaryllis (*Hippeastrum*× *hybridum* Leopoldii) from commercial nurseries and home gardens were associated with CMV (Gutierrez-Villegas et al., 2004).

***Mandevilla* sp. (Dipladênia) - Apocynaceae**

The genus is native to South and Central American forests, with more than 50 species occurring in Brazil. This perennial rustic creeper, which belongs to the family Apocynaceae, is used throughout the world as an ornamental since it exhibits flowers of varying colors, with some species applied in popular medicine. *Catharanthus* mosaic virus (CatMV) was initially described as *Catharantus roseus* in Brazil, the United States and Saudi Arabia, and later in *Mandevilla* plants from Piracicaba, Mogi das Cruzes and Limeira - SP (Favara et al., 2020).

***Petunia hybrida* Villm. – Solanaceae**

Petunias are popular Solanaceae species spread by seeds and vegetatively, with numerous phenotypes (Grandifloras, Multifloras, Millifloras, Waves, Hedgifloras, etc.), series and cultivars available on the world market. Continued domestication by flower breeders has produced a wide range of floral colors and patterns (Griesbach, 2007). With geographic origin in South America, around 30 species of *Petunia* have been reported in Argentina, Bolivia, Brazil, Paraguay and Uruguay. *Petunia integrifolia* (Hook.) Schinz & Thell. seeds were sent to Europe in 1823 and the first hybrids appeared in 1834, in England, from hybridization between *P. axillaris* (Lam.) Britton, Sterns & Poggenb. *P. nyctaginiflora* Juss. and *P. integrifolia* (Hook.) Schinz & Thell. (Sink, 1984).

In *Petunia* x *hybrida*, the co-occurrence of cauliflower mosaic virus (CaMV, *Caulimovirus*) with a new *Tymovirus* species, called Petunia vein banding virus (PetVBV) (Fig. 1D, 1E), has been reported (Alexandre et al., 2000). Natural infection by tobacco mosaic virus (TMV) was associated with color break in flowers (Duarte and Alexandre, 2017).

***Schefflera* sp. (Umbrella tree) – Araliaceae**

Schefflera J.R. Forst. & G. Forst, the largest and most wide-ranging genus of Araliaceae, with over 580 accepted species, is found throughout the more humid tropical and subtropical parts of the world (Frodin et al., 2010). There are about 300 species in the Americas, with several representatives in Brazil, including 22 in the southeast region alone (Fiaschi and Pirani, 2007).

In *S. actinophylla* (Endl.) Harms, native to Australia and southern New Guinea and introduced into Brazil, an unidentified *Cilevirus* associated with green spots and ringspots in senescent leaves has been described. In umbrella tree plants with chlorotic ringspot symptoms on their leaves, badnavirus-like particles in the cell cytoplasm of these lesions were observed by electron microscopy. The virus was tentatively named Schefflera ringspot virus (SRV) (Kitajima, 2020).

***Schlumbergera truncata* (Haw.) Moran (False Christmas cactus) – Cactaceae**

The genus *Schlumbergera* was established by Lemaire in 1858 for the Brazilian epiphyte *Epiphyllum russellianum* Hook. (*Schlumbergera epiphylloides* Lem.) (Hunt, 1969). The species *Schlumbergera truncata* (Haw.) Moran, established in the 1910s, popularly known as false Christmas cactus, is also a species native to Brazil, found mainly in the Southeast region, and widely cultivated and marketed for its beautiful flowers (Hunt, 1969; Souza and Lorenzi, 2012).

False Christmas cactus plants showing discreet chlorotic spots were diagnosed with mixed infection of three *Potexvirus* species: OpVX, SchVX and ZyVX (Duarte and Alexandre, 2017).

***Seemannia sylvatica* (Kunth) Baill. - Gesneriaceae**

Native species of Bolivia, Brazil, Ecuador, Peru and Paraguay cultivated as ground cover, in shaded areas and pots. This species was described as an “NT” or near threatened species on the Red List of Brazilian Flora (CNCFlora, 2013). In Brazil, CMV was described as naturally infecting this species (Duarte and Alexandre, 2017).

***Torenia fournieri* Linden ex E. Fourn. (Wishbone plant) – Linderniaceae**

The genus, native to Brazil, contains some full sun ornamental species such as *T. fournieri* and is widely used, especially in pots and flowerbed borders (Souza and Lorenzi 2012). Alternanthera mosaic virus (AltMV) has been described in several ornamental plants in Australia, Italy, the USA (Hammond et al., 2006) and on a rural property in Brazil in São Paulo state, in 2008, the first report of AltMV occurring naturally in Brazil (Duarte et al., 2008).

***Tradescantia spathacea* Sw. – Commelinaceae**

The family exhibits pantropical distribution and is grown in full sun or partial shade. This species is native to Mexico and multiplies vegetatively through clump division (Souza and Lorenzi, 2012). Favara et al. (2021) first described CoSMV naturally infecting *T. spathacea* (Fig. 1E).

***Zinnia* – Asteraceae**

Zinnias are annual species grown worldwide in flowerbeds and cut flowers (Stimart and Boyle, 2007), displaying flowers with diversified colors and petal shapes (Martins et al., 2021). According to The Plant List (2013), the genus *Zinnia*, whose center of diversity is Mexico (Stimart and Boyle, 2007), comprises 24 species. However, *Z. elegans* L. is the most widely cultivated species and most important in terms of economic value. *Z. peruviana* (L.) L., which extends from the Southern United States to Argentina, is also grown as an ornamental in Brazil (Stimart and Boyle, 2007; Souza and Lorenzi, 2012).

The occurrence of two Potyvirus species has been reported in zinnia in Brazil: BiMV and SuCMoV. TMV and GRSV were also detected (Kitajima, 2020; Oliveira et al., 2022).

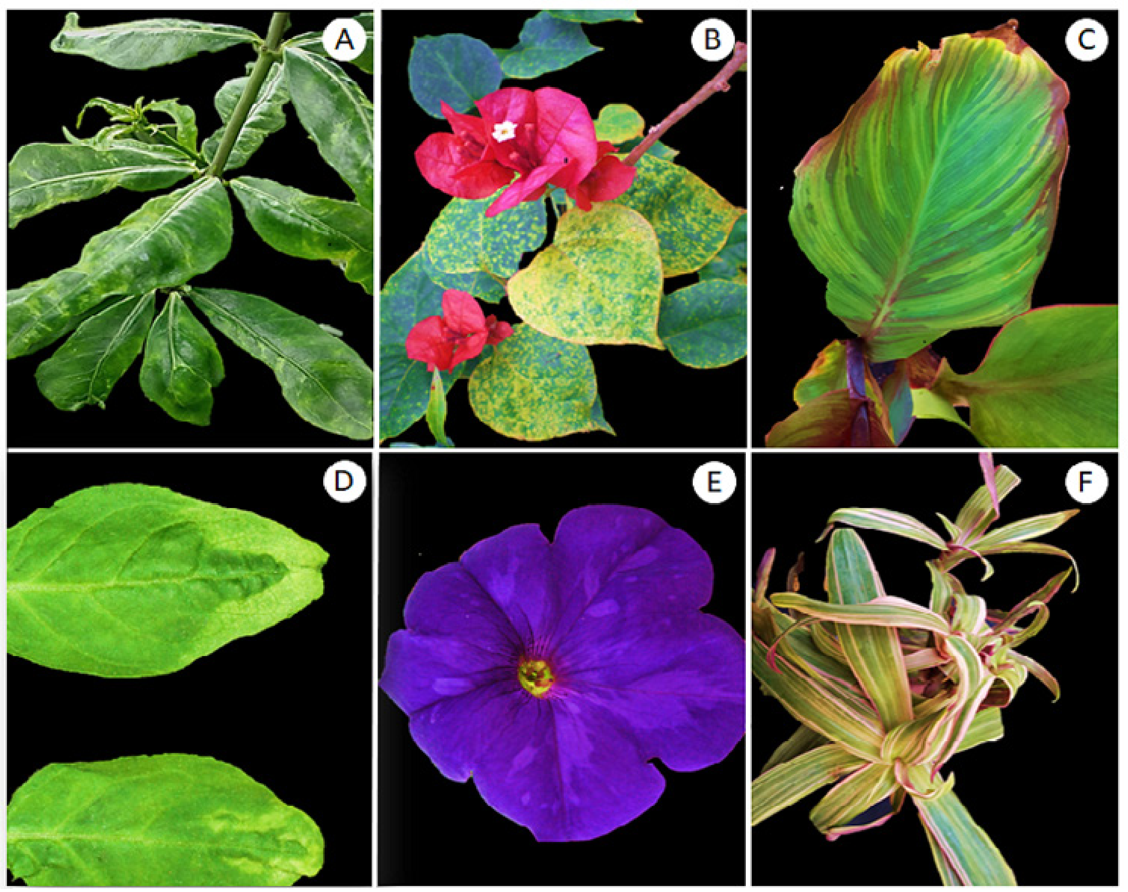

Figure 1. Ornamental plants naturally infected with a virus. A=*Alamanda* x cucumber mosaic virus (CMV), B=*Bougainvillea* x Bougainvillea chlorotic vein banding virus (BCVBV), C=*Canna paniculata* x Canna yellow streak virus (CaYSV), D=*Petunia* leaves x tobacco mosaic virus (TMV) E= *Petunia* flower x tobacco mosaic virus (TMV) and F=*Tradescantia* x Costus stripe mosaic virus (CoSMV)

Management of viruses in ornamental plants

The biodiversity and heterogeneity aspects of agroecosystems and climatic characteristics of Brazil, associated with the growing trade in agricultural products, favor the introduction and establishment of a range of phytopathogens (fungi, bacteria, viruses, phytoplasmas, viroids and nematodes) that can cause negative impacts and incalculable damage to different crops, if management recommendations are not effective (Brainer, 2019). On the other hand, the diversity of Brazilian environmental conditions favors the adaptation and production of native or exotic species from tropical, subtropical and temperate climates. However, the recent practice of intensive monoculture in open or protected field systems (greenhouses) combined with the international trade in propagative plant organs and seedlings can facilitate the introduction, establishment and dissemination of phytopathogens that may cause future epidemics or endemics in regions where ornamental plants are grown (Nazarov et al., 2020).

Depending on the interactions established with their hosts and/or arthropod (insects, mites) and nematode vectors, viruses can damage several ornamental species (Masciaa and Gallitelli, 2016). Thus, detecting and identifying viruses in ornamental species is essential, even when they do not induce symptoms that compromise commercialization (productivity and visual aspects), since these pathogens can act as reservoirs and pose a risk to local producers who cultivate species belonging to other segments, such as horticulture, fruit growing and the commodities market (Freitas-Astua et al., 2010). Zerbini et al. (1997) reported the occurrence of lettuce mosaic virus (LMV) in *Gazania* spp. and associated this potential source of virus inoculum with recent lettuce mosaic outbreaks in the Salinas Valley (California – USA).

The large-scale production of ornamental species in Brazil is relatively recent. As such, little is known about the interactions of viruses and their vectors in cultivated areas under tropical and subtropical conditions, thereby hindering adequate management recommendations (Alexandre et al., 2021).

Sanitation

Sanitation has been one of the safest and most reliable measures for ornamental plant producers. Replacing fertilized soil with sterile organic or mineral substrates that ensure root support, water retention and nutrient absorption eliminates many seedling production problems caused by soil phytopathogens. *Tobamovirus* species do not require vector arthropods for their transmission but can remain infective for several years in plant organic matter incorporated into the soil (Daughtrey et al., 1995).

In the field or in greenhouses, ornamental plants can become sources of viral inoculum and as such, those that are not harvested and/or sold should be eliminated (Runia, 1995). In addition, tools and water used for irrigation are also means of introducing tobamoviruses. Thus, it is recommended that tools be physically (heat) or chemically (5% sodium hypochlorite) decontaminated (Ehret et al., 2001). A practical example of management was spraying *Mirabilis jalapa* leaf extract before cutting the leaves of *Chenopodium giganteum* (syn. *C. amaranticolor*) with a blade infected by AltMV-T, obtaining 83.3% infection inhibition (Duarte et al., 2008).

It is also recommended that weeds acting as reservoirs for several virus species and their respective vectors, such as thrips, aphids, whiteflies, beetles, mealybugs and mites, be controlled in the vicinity of cultivated areas (Daughtrey et al., 2005).

Propagative organ from healthy stocks

The ornamental plant industry is highly competitive and in order to quickly introduce new varieties and hybrids into the market, invests heavily in seedling production by vegetative propagation using "in vitro" micropropagation techniques through meristem culture in a nutrient medium, non-rooted cuttings, bulbs and rhizomes obtained from stocks or "mother" plants associated with thermotherapy (Raju and Olson, 1985). These stock plants must be kept under protected structures behind screens to prevent the entry of virus vector insects, and handling must be carried out with sterilized cutting tools (Karthikeyan et al., 2021).

Although faster, seedlings obtained by vegetative propagation pose a greater risk of infection, compared to seeds, which can be treated with thermotherapy to eradicate viruses. However, prolonged exposure to heat can reduce the germination percentage. This technique is rarely used by the flower seed industry (Agarwal and Sinclair, 1996).

Table 2 shows some positive results of virus-free ornamental plants by cultivating shoot meristems or their combination with other biotechnological procedures.

Table 2. Biotechnological methods used in the production of virus-free ornamental plant seedlings

Ornamental species	Procedures	Viruses
Alstromeria sp (alstroemeria)	meristem culture	*Alstroemeria* mosaic virus (AlMV)
Chrysanthemum sp (chrysanthemum)	meristem culture and thermotherapy	*Chrysanthemum* virus B (CVB);
	meristem culture	cucumber mosaic virus (CMV);
	meristem culture	tomato spotted wilt virus (TSWV), impatiens necrotic spot virus (INSV) and Iris yellow spot virus (IYSV)
Chrysanthemum morifolium (Florist's chrysanthemum)	meristem culture and thermotherapy	CVB
	meristem culture	CMV tomato aspermy virus (TAV)
Dianthus gratianopolotanus (carnation)	meristem culture	carnation mottle virus (CarMV); carnation latent virus (CLV); potyviroses
Zinnia elegans (zinnia)	meristem culture and thermotherapy	LSV
Impatiens hawkerii (New Guinea impatiens)	meristem culture	TSWV and CMV
Phlox paniculata (garden flox)	meristem culture and thermotherapy	CLV; CarMV; CMV; tobacco mosaic virus (TMV); tospoviroses; potyviroses
Viola odorata (sweet violet)	meristem culture	Viola mottle virus (VMV); CMV; bean yellow mosaic virus (BYMV)

Adaptado de Hammond *et al.,* (2016)

All propagating organs, including seeds, should be screened for the presence of viruses through bioassays (mechanical inoculation or grafting) on indicator plants, serological (ELISA) and molecular (PCR and RT-PCR) techniques (Schaad and Frederick, 2002). Various ornamental plant species, including foliage, potted and cut flowers such as lily, iris, gladiolus, chrysanthemum, impatiens and geranium, used for seed or seedling production should be indexed (Klopmeyer, 2000).

Genetic engineering

Obtaining resistant varieties and hybrids is still the most recommended control for plant viruses. Disease-resistant ornamental plants can be obtained without altering desirable quality characteristics through gene transfer (Hadidi et al. 1998). There are three ways of obtaining virus-resistant plants: natural resistance (conventional breeding), through genes derived from viral sequences (pathogen-derived resistance), and genes from various other sources (Azadi et al., 2016).

Advances in conventional breeding programs depend on identifying sources of resistance genes. However, this is a difficult process for the ornamental plant segment due to the species diversity intended for the production of potted and cut flowers, as well as foliage, which is generally susceptible to a wide range of virus species (Hsu, 2006). In addition, breeding programs invest heavily in the appearance characteristics of ornamental plants rather than obtaining pathogen-resistance genes (Deroles et al., 2002). The large number of releases and the rotation of cultivars and hybrids produced per season also make it difficult to maintain possible disease-resistance genes (Castilon and Kamo, 2002). In addition, when a resistance gene is identified in germplasm banks, multiple backcrossings are necessary for its introgression, which may result in reduced expression (Deroles at al., 2002).

Pathogen-derived resistance (transgenic) has been an important tool to introduce effective resistance genes and increase the productivity and quality of ornamental species in an ecologically correct manner, aiming to reduce the use and dependence on chemical products to control virus vectors (Hsu, 2006).

Positive resistance results have been obtained for viruses that infect a wide range of ornamental hosts, as follows: Transgenic plants of chrysanthemum, “Polaris”, containing the nucleocapsid (N) gene of a dahlia isolate of tomato spotted wilt virus (TSWV) was resistant when submitted to transmission tests with vector thrips (Sherman et al., 1998); Chrysanthemum research has obtained transgenic plants resistant to Chrysanthemum virus B (CBD) (Mitiouchkina et al., 2006); work developed by Kumar et al. (2012) demonstrated the possibility of producing CMV resistant to transgenic chrysanthemum plants; cape margarite and gerbera plants resistant to TSWV were also obtained from transgenics in scientific studies carried out by Allavena et al. (2000) and Korbin et al. (2002), respectively. Other promising results have been obtained with lily cultivars resistant to CMV (Lipsky et al., 2002), dendrobium with partial resistance to Cymbidium mosaic virus (CymMV) (Borth et al., 2006), gladiolus with resistance to bean yellow mosaic virus (BYMV) (Kamo et al., 1997) and CMV (Kamo et al., 2010); *Alstroemeria* sp. resistant to Alstroemeria mosaic virus (AlMV) (Park et al., 2010), *Phalaenopsis* sp. and *Dendrobium* sp. resistant to CymMV and Odontoglossum ringspot virus (ORSV) (Koh et al., 2014). It is important to note that all these examples are experimental, that is, not used at the commercial level. However, the prospects offered by genetic transformation are highly promising for the ornamental plant market.

Virus-induced gene silencing (VIGS), which consists of suppressing the expression of a virus target gene preventing its establishment in the host, may also be a good strategy for managing viruses (Cline et al., 1988). Thus, viral genome fragments are incorporated into the plant genome through RNA or DNA molecules called gene vectors, which will carry, transfer and express heterologous genes (Castillon and Kamo, 2002). When infected, the plant will trigger a defense response. Many of these viral vectors are derived from positive-strand RNA viruses such as potato virus X (PVX), TMV and TRV, which contain a mono-, bi-, or tripartite genome (Purkayastha and Dasgupta, 2009). The TRV vector has been tested for chrysanthemum, impatiens, four o’clock flowers and poppy (Reid et al., 2009).

Direct interference in virus vectors

In general, viruses are introduced into the host plant cell during insect, mite and phytophagous nematode feeding, as well as during soil fungal infection (Brault et al., 2010). Insects belonging to the orders Hemiptera (aphids, mealybugs, whiteflies and leafhoppers), Coleoptera (beetles) and Thysanoptera (thrips) transmit more than 50% of viruses in the field (Fereres and Moreno, 2009). It should be noted that the same virus family and genus can be transmitted by more than one vector order. However, a virus will only be transmitted by species belonging to a single vector order (Bragard et al., 2013). Thus, transmission is dependent on a unique interaction between viruses and their respective vectors, which are divided into: (1) Non-persistent: virus acquisition and transmission occur within seconds to minutes during brief superficial probing of plant epidermis cells; (2) Semi-persistent: virus acquisition and transmission occur within minutes to hours during the feeding process on the plant epidermis or phloem cells, (3) Persistent: virus acquisition occurs within hours and transmission can last for hours, days or until the end of the vector’s life cycle, and is carried out exclusively during feeding on phloem cells. In addition, the virus may (circulative transmission) or may not multiply (propagative transmission) in the vector’s body (Jeger, 2020)

Measures to control a virus spread in the field should be implemented according to the interaction between the virus and its respective vectors (Gallet et al., 2018). According to Hull (2002), virus control aimed at their vectors in the field is grouped into four classes:

(i) Reducing vector populations

Insecticides are not the best solution to control vectors that transmit non-persistently and semi-persistently (Jones, 2018), given that the insect can feed on a sprayed plant before the active ingredient acts on the vector. In addition, insecticides can act on the insect's central nervous system and induce hyperactivity, resulting in an increase in test bites and, consequently, virus transmission and dissemination. Insecticides are efficient when vectors colonize the plant and transmit phloem-resistant viruses. Thus, new biotechnological techniques based on the production of genetically modified plants that produce aphid-repellent substances have also been developed (Will and Vilcinskas, 2013). Gene silencing aimed at reducing proteins that inactivate the salivary gland and, therefore, cause vector aphids to die by starvation is also another technique that has been developed (Whyard et al., 2009). Monitoring vector populations with sticky traps that indicate periods of increased vector transmission may also be a good management strategy. Association with preventive insecticide spraying is recommended to control peaks in persistently transmitted virus vectors (Jones, 2018). The use of blue, white or yellow sticky traps to attract thrips, an orthotospovirus vector in ornamental plants, has been reported (Chen et al., 2004). Biological control is a worldwide trend and an effective and compatible strategy in integrated pest management (IPM) programs. However, the population density of natural enemies must be increased for biological pest control to be effectively applied. As such, the following strategy can be used: maintain a rose crop where aphid colonies increase rapidly, thereby attracting natural enemies such as ladybugs and lacewings. The larvae of these insects are aphidophagous, thus controlling aphid populations. Parasitoids, nematodes and entomopathogenic microorganisms including fungi, bacteria and viruses have been used to control aphids and thrips in locations where lily, spathiphylum, begonia and orchids are cultivated (Bueno et al., 2016).

(ii) Reducing viral sources

The use of virus-free seeds and propagating organs drastically reduce primary infection caused by the entry of viruliferous vectors into the production field. In addition, removing sources of infection in and around the crop, removing plant debris from a previous season and, if necessary, establishing a time gap between harvests, are techniques that will also help reduce viral sources (Nazarov et al., 2020).

(iii) Interfering with the landing attraction or repellency behavior of the vector

This interference occurs with the use of colored reflective surfaces such as straw covers of kaolin films that repel the vectors, preventing the virus from spreading. In open and protected crops, physical barriers and anti-aphid screens, respectively, should be used (Antignus, 2012).

(iv) Transmission interference

Applying mineral oils or non-sulfonated residues on the plant shoots reduces virus transmission efficiency, especially in greenhouses where sowing and seedling production are carried out. The mode of action interferes with virus binding to the vector (Raccah, 1986).

Final considerations

The control and management methods described are general practices, recommended worldwide to control viruses in the various segments of the horticulture industry, including ornamental plants, but are not specific to the tropical and sub-tropical system. Nevertheless, with a number of adaptations, the Brazilian ornamental plant sector has increased substantially in recent years. Thus, more studies should be carried out, aimed at using native species and better disease control.

Author contribution

MAVA: Conceptualization, and writing of the original draft and proofreading the text.**LMLD:** Writing of the original draft. **ALRC:** Writing of the original management and control draft.

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