An annotated list of plant viruses described in Paraguay (1920–2023)

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Abstract: Despite an economy based mostly on agriculture, literature on viral diseases of plants is scarce in Paraguay. Only recently, researches on plant viruses took an impulse resulting in a precise identification of many of them affecting plants either cultivated or not. To provide reliable information regarding plant viruses present in Paraguay, an annotated list of them was prepared, covering descriptions from 1920 to present day. There have been some important outbreaks with severe yield losses in crops as cucurbits, citrus, sesame, bean, maize, peanuts and tomato. Many of older descriptions are included for their historical significance, but most identifications made require confirmation. On the other hand, recent descriptions have been completed, based on several assays, especially molecular characterization. This list is organized alphabetically following scientific names of the plant species found naturally infected by viruses, with comments about symptoms, geographical distribution, incidence, identification procedures, and other information, with due literature references. It is based on a compilation of publications made on plant virus diseases in Paraguay. Described virus species, in a total of 38 recognized by ICTV, belonging to 17 different genera (Alphaendornavirus, Ampelovirus, Begomovirus, Benyvirus, Carlavirus, Cilevirus, Closterovirus, Comovirus, Cucumovirus, Dichorhavirus, Fabavirus, Luteovirus, Ophiovirus, Orthotospovirus, Potexvirus, Potyvirus and Tobamovirus), besides two unclassified, and four unidentified. There is also a case of viroid described in Citrus spp. Infections caused by potyviruses are the most numerous. These viruses were described in more than 40 plant species, belonging to 18 botanical families. Because of crop diversity and richness in native flora, many more viruses must be present in Paraguay, which future works will certainly reveal, especially with the increase in manpower involving researches, especially cooperative with foreign centers, on plant viruses, which has been very limited until now. Also, knowledge on existing viruses may have relevance in understanding their epidemiology and provide the basis for their control strategies and quarantine measures, to avoid new variants of existing viruses or new viruses being introduced.

Keywords: Plant virus identification; plant species; virus species.

Una lista comentada de virus de plantas descritos en Paraguay (1920–2023)

Resumen: A pesar de una economía basada principalmente en la agricultura, la literatura sobre enfermedades virales de las plantas es escasa en Paraguay. Sólo recientemente se han impulsado las investigaciones sobre los virus de plantas, lo que ha permitido identificar con precisión muchos de ellos que afectan a plantas cultivadas o no. Para brindar información confiable sobre los virus de plantas presentes en el Paraguay, se elaboró una lista comentada de los mismos, abarcando descripciones desde 1920 hasta la actualidad. Se han producido algunos focos importantes con severas pérdidas de rendimiento en cultivos de cucurbitáceas, cítricos, sésamo, frijol, maíz, maní y tomate. Muchas de las descripciones más antiguas se incluyen por su importancia histórica, pero la mayoría de las identificaciones realizadas requieren confirmación. Por otro lado, las descripciones recientes han sido completadas, basadas en varios ensayos, especialmente de caracterización molecular. Esta lista está organizada alfabéticamente siguiendo los nombres científicos de las especies de plantas que se encontraron naturalmente infectadas por virus, con comentarios sobre síntomas, distribución geográfica, incidencia, procedimientos de identificación y otras informaciones, con las debidas referencias bibliográficas. Se basa en una recopilación de publicaciones realizadas sobre enfermedades virales de plantas en Paraguay. Especies de virus descritas, en un total de 38 reconocidas por el ICTV, pertenecientes a 17 géneros diferentes (Alphaendornavirus, Ampelovirus, Begomovirus, Benyvirus, Carlavirus, Cilevirus, Closterovirus, Comovirus, Cucumovirus, Dichorhavirus, Fabavirus, Luteovirus, Ophiovirus, Orthotospovirus, Potexvirus, Potyvirus y Tobamovirus), además de dos sin clasificar y
Introduction

1. Agriculture in Paraguay

The territorial area of Paraguay is roughly 406,000 km², with an estimated population of 7.2 million (Hanratty & Meditz, 1988). The main agricultural products are soybean (planted area 3.4 million Ha), maize (800,000 Ha) and wheat (400,000 Ha), followed by crops as sugarcane, cassava, rice, citrus, sorghum, mate herb, and in smaller scale, tobacco, pineapple, oily seeds, sesame, etc. Agricultural inputs represent a market of approximately US$ 2 billion, with agrochemicals accounting for about 1/3 of this value (CAPECO, 2023).

The Paraguayan economy has been very favorable in the last decade, with an average gross domestic product (GDP) growth of approximately 5%, higher than the average for the continent. Export growth and favorable international prices for primary products led to this result (Brozón, G. R., & Nakayama, H. D., 2023). Paraguay’s main export product is soybean, and its production directly influences the national GDP (Morinigo et al., 2018). In 2020, Paraguay was the fourth largest producer of soybeans in the world. In 2022, incomes of 2.8 Million dollars came from export of soybeans and derivatives (CAPECO, 2023). Soybean frontier expansion continues principally in the Paraguayan Chaco, where approximately 700,000 ha of land are considered suitable for soybean production (Henderson et al., 2021).

Crop production in 2021 in Paraguay was 10.5 million tons of soybean, 4.0 million tons of maize, 7.2 million tons of sugarcane, 3.3 million tons of cassava, 1.1 million tons of rice, 900 thousand tons of wheat, 116 thousand tons of mate herb and 29.8 thousand tons of cotton (MAG, 2023).

Concerning livestock, beef exports went from 82 million kilos in 2004 to 232 million kilos in 2013 according to the United Nations Comtrade Database - (UN Comtrade 2014). According to the Central Bank of Paraguay, the export of these agricultural commodities is currently representing almost 40% of the GDP. Interestingly, the logistics of these exports are mostly based on very efficient river transportation, with many portuary terminals installed along the rivers Paraguay and Paraná (BCP, 2017).

Concerning the Japanese community in Paraguay also played an important role in the development of agricultural research. Research and technical assistance centers were created in Pirapó, Yguazú and La Paz, which, formed the so-called Agricultural Technology Center in Paraguay (CETAPAR), funded by the Japan International Cooperation Agency (JICA). With the help of Japanese specialists, soybean crop was introduced in these regions as well as the adaptation of vegetable crops and the creation of new varieties as the melon ‘Luna Yguazú’ and tomato ‘Súper Cetapar’. More recently, the so-called National Institute of Biotechnology (INBIO), which is a non-profit civil association, has been funding research to promote the development of national biotechnology research (Beintema et al., 2000; IPTA, 2022).

Presently, the National Council for Science and Technology (CONACYT), created in 1997, became more active in recent years with increased budget, funding a large number of research projects...
and providing scholarships, including to agricultural sciences. (Ekboir et al., 2003).

The Agricultural College of the National University of Asuncion (UNA) in San Lorenzo was founded in mid-1950s to offer undergraduate courses in agronomy and veterinary science. Two decades later, these courses served as the basis of the Faculty of Agronomy and Veterinary Sciences. Research at UNA was limited due to limited budget. Although the Research Projects Directorate (DIPR) has funded research for full-time faculties, it has been on a limited scale. In September 1974, the Superior University Council separated the Faculty of Agronomy and Veterinary Sciences into two independent faculties, and retained the Faculty of Agronomic Engineering. Finally, in 1994, the name of the Faculty of Agronomic Engineering was changed and it became the Faculty of Agrarian Sciences (FCA) (Ekboir et al., 2003).

3. A brief history of plant virology in Paraguay

The first mention of a plant viral disease in Paraguay goes back to 1920, when Spegazzini published a paper on citrus diseases. On inspections made in Paraguay in 1919, he described lesions on stems and trunk, but not on fruits, and designated the disease as ‘lepra explosiva’, attributing wrongly the causal agent as *Amyliroa aurantiorum*. Bitancourt (1955) commented that the symptoms observed by Spegazzini were caused by citrus psoriasis. Fawcett & Bitancourt (1940) toured several South American countries from April 17th to 22nd, 1937 to examine citrus diseases. Visits were made in the region of Asunción, Trinidad and San Lorenzo, where they found leprosis symptoms on sweet oranges, calling attention to differences in symptoms between leprosis symptoms in Florida and South America. In that same decade, Howard Porter, served with the Food supply division of the Institute of Inter-American Affair (U.S.) and worked with IAN from July 1946 to August 1947, and described what appears to be the first documented geminivirus symptoms in tomato crops in the country (Porter, 1947).

The study of plant viruses in Paraguay has begun with the collaborations of Japanese experts. During the period 1986 to 1988, Toshihiko Katusbe from the Japan International Research Center for Agricultural Sciences (JIRCAS) established the first partnerships. In surveys of 14 major crops, more than 50 kinds of diseases were identified, five of them, in strawberries, citrus, sugarcane and soybean, were attributed to a virus (Katusbe & Romero, 1991).

Starting July 1991, for three years, Dr. Kenichiro Shohara, a Japanese consultant at JICA, conducted a comprehensive survey on plant viral diseases in Paraguay. In FCA/UNA, he worked with local staff members from the Department of Agronomy and Phytopathology. The regions that were surveyed included Asunción and surrounding regions that produce agricultural products in the triangle of Asunción, Ciudad de Este, and Encarnación. A large number of viruses were found, and most of them were recognized using transmission assays, serology, and electron microscopy, while some were only recognized based on symptoms. These results were published in Spanish and Japanese (Shohara, 1995; Shohara et al., 1994).

From April 1997 to March 2002, the framework of the “Project for the Improvement of Vegetable Production Technology for Small-Scale Farmers in Paraguay”, six JICA experts worked with IAN and DEAG to develop technology improvement activities, led by Dr. Takashi Ishijima (Ishijima & Okwara, 2002). Among those six experts, Dr. Yutaka Kimura investigated the chemical management of tospovirus and geminivirus vectors in tomato crops and the density of vector insect populations. In the same JICA Project, Dr. Tamito Sakurai (Department of Biology and Environmental Sciences, National Agricultural Research Center for Tohoku Region, Japan) studied the transmission of tospovirus by adults of *Frankliniella schulzeti* collected in tomato fields in Paraguay in February of 2000, in collaboration with Dr. Yutaka Kimura and Dr. Takashi Ishijima (Sakurai, 2004).

Regarding local scientists, González-Segnana, from the Biology Department at FCA/UNA, was the first full-time plant virologist in Paraguay starting in September 1989. He earned his master’s degree at the Universidade Federal de Viçosa and characterized an isolate of Orchid Ringspot Tobamovirus (ORSV) from Paraguay (González-Segnana, 1989). He also received additional training, especially on citrus viruses, at the Citrus Research and Educational Center (CREC) of the University of Florida, in Lake Alfred, and he devoted his initial works on surveying Citrus tristeza virus (CTV) in Paraguay.

Starting in 2005, a close cooperation program was developed between González-Segnana’s group and the Departamento de Fitopatología e Nematología (ESALQ) from Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Universidade de São Paulo (USP), Piracicaba campus. The beginning of cooperation occurred when E.W. Kitajima, a plant virologist from ESALQ, arrived in Paraguay to investigate citrus leprosis and first met González-Segnana. In the years that followed, Kitajima visited Paraguay several times, and along with González-Segnana and his team, visited several agricultural production areas in Paraguay. One important problem on sesame grown in San Pedro was identified as viral nature, caused by Cowpea aphid-borne mosaic virus (CABMV) (González-Segnana et al., 2011), and subsequent studies resulted in an efficient control. This cooperation extended also with Argentinian research groups of National Institute of Agricultural Technology (INTA) from Bella Vista and Concordia, on citrus viruses (Cáceres et al., 2013). Because of this cooperation program, starting 2014, Esquivel-Fariña, a student of González-Segnana, did his graduate studies (MS 2014/2016; Ph.D 2017/2020), working with Tomato chlorosis virus (ToCV), supervised by J.A.M. Rezende, at the LFN/ESALQ (Esquivel-Fariña, 2016; 2019). He also received additional training as a visiting PhD student at the U.S. Agricultural Research Station in Salinas (CA) under the supervision of Dr. William Wintermantel. After returning to Paraguay, Esquivel-Fariña served successively as a researcher for the Ministry of Agriculture and a private company, surveying plant viruses in Paraguay, and recently joined the FCA/UNA.

Material and Methods

The present list was inspired on by a similar one, prepared for plant viruses and viroids described in Brazil (Kitajima, 2020), and it is based on a list of publications about plant viruses described in Paraguay beginning with the seminal paper by Spegazzini on citrus leprosis in 1920 to recent works in 2023. Such list was prepared by the authors, compiling publications made on plant viruses found in Paraguay, by local specialists or foreign visitors, and also of the viruses detected in samples collected in Paraguay and analyzed elsewhere. Following the model used by former listings (Sastry et al., 2019; Kitajima, 2020), this list was prepared by the scientific name of hosts, in alphabetical order, and within each species, viruses found naturally infecting...
them, with details about site of occurrence, incidence, symptoms and procedures for their identification, and the pertinent reference. In addition, a complementary, reverse list, by viruses and host plants they found infecting was prepared, relaying on the most recent listing organized by ICTV-ICTV_Master_Species_List_2021_v2.xlsx (ICTV, 2022). In older papers, identification of viruses was made by symptoms, serology and in a few cases, by electron microscopy. Only in recent descriptions, more reliable molecular detection and identification were used.

**Results and Discussion**

The literature search resulted in finding a total of 38 virus species, belonging to 17 genera, presently recognized by ICTV, besides two still unclassified and two, unidentified, and one classified viroid species. The pathogens were infecting more than 40 plant species, belonging to 18 botanical families. *Potyvirus* was, by far, the genus with the most representatives described in Paraguay, comprising 16 species and two unidentified members, followed by *Potexvirus*, with four species, and *Begomovirus*, *Tobamovirus* and *Orthotospovirus*, with two species each.

On the host side, the *Fabaceae* family had the highest number of virus-infected species, with eight, followed by *Solanaceae*, with seven. Cucumber mosaic virus and Cowpea aphid-borne virus were viruses found infecting more plant species, each with seven [see list of plant species and the reverse list of viruses (Table 1) below].

Since the territory of Paraguay faces strongly agricultures regions of Brazil (states of Paraná and Mato Grosso do Sul) and Argentina (provinces of Formosa, Corrientes and Misiones), it is likely that many viruses, present in these areas may already occur in Paraguay. Indeed, recently epidemy of “huanglongbing” (HLB), caused by the phloem bacterium *Candidatus Liberibacter*, and transmitted by the psyllid *Diaphorina citri*, a serious problem for citrus crops in Brazil, reached Paraguay in 2013 (Mora-Aguilera et al., 2013), seven years after first detection in the state of São Paulo, Brazil (Sanches et al., 2018).

Recent impulse in scientific research in Paraguay, including in agricultural sciences, with a new generation of specialists, it is expected that an exponential increase in knowledge on viral diseases will occur, with an ever growing number of plant viruses being discovered in Paraguay.

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**Table 1.** List of plant viruses and viroids described in Paraguay, with the plant species found infected by them, in the nature.

<table>
<thead>
<tr>
<th>Realm: <strong>Monodnaviria</strong></th>
<th>Kingdom: Shotokuvirae</th>
<th>Phylum: Cressdnaxiphicota</th>
<th>Class: Repensiviricetes</th>
<th>Order: Geplafuvirales</th>
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</thead>
<tbody>
<tr>
<td>Family: Geminiviridae</td>
<td>Genus: Begomovirus</td>
<td>Species: Sweet potato leaf curl virus</td>
<td>Ipomea batatas</td>
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<tr>
<td></td>
<td></td>
<td>Tomato yellow spot virus</td>
<td>Leonurus sibiricus</td>
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</tbody>
</table>

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<thead>
<tr>
<th>Realm: <strong>Ribovira</strong></th>
<th>Kingdom: Orthornavirae</th>
<th>Phylum: Kitrinoviricota</th>
<th>Class: Alsuviricetes</th>
<th>Order: Hepelivirales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Family: Benyviridae</td>
<td>Genus: Benyvirus</td>
<td>Species (unc.): Wheat stripe mosaic virus</td>
<td>Triticum aestivum</td>
<td></td>
</tr>
</tbody>
</table>

| Family: Bomoviridae     | Genus: Cucumovirus     | Species: Cucumber mosaic virus | Brassica rapa |
| Family: Ampeloviridae   | Genus: Ampelovirus     | Species: Pineapple mealy bug wilt-associated virus** | Ananas comosus |
| Family: Clesperoviridae | Genus: Closterovirus   | Species: Citrus tristeza virus | Citrus spp    |

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List of plant viruses described in Paraguay

<table>
<thead>
<tr>
<th>Family</th>
<th>Genus</th>
<th>Species/Species Group</th>
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<tbody>
<tr>
<td>Endornaviridae</td>
<td>Alphaendornavirus</td>
<td>Capsicum baccatum var. pendulum</td>
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<tr>
<td>Kitaviridae</td>
<td>Cilevirus</td>
<td>Citrus spp</td>
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<tr>
<td></td>
<td></td>
<td>Hibiscus rosa-sinensis</td>
</tr>
<tr>
<td>Virgaviridae</td>
<td>Tobamovirus</td>
<td>Several orchid genera</td>
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<tr>
<td></td>
<td></td>
<td>Nicotiana tabacum</td>
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<tr>
<td></td>
<td></td>
<td>Solanum lycopersicum</td>
</tr>
<tr>
<td>family</td>
<td>Genus</td>
<td>Species</td>
</tr>
<tr>
<td>Virgaviridae</td>
<td>Potexvirus</td>
<td>Cassava common mosaic virus</td>
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<td></td>
<td></td>
<td>Cymbidium mosaic virus</td>
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<td></td>
<td></td>
<td>Potato virus X**</td>
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<tr>
<td></td>
<td></td>
<td>Strawberry mild yellow edge virus</td>
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<tr>
<td>Tombusviridae</td>
<td>Luteovirus</td>
<td>Barley yellow dwarf virus</td>
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<tr>
<td>Tospoviridae</td>
<td>Orthotospovirus</td>
<td>Groundnut ringspot orthotospovirus</td>
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<tr>
<td>Tospoviridae</td>
<td>Orthotospovirus</td>
<td>Tomato spotted wilt orthotospovirus</td>
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<td></td>
<td></td>
<td>Arachis hypogaea</td>
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<td></td>
<td></td>
<td>Petunia x hybrida</td>
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<td></td>
<td></td>
<td>Solanum lycopersicum</td>
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<tr>
<td></td>
<td></td>
<td>Acanthospermum hispidum</td>
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<tr>
<td></td>
<td></td>
<td>Nicotiana longiflora</td>
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<td></td>
<td></td>
<td>Physalis sp.</td>
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<td></td>
<td></td>
<td>Solanum lycopersicum</td>
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<table>
<thead>
<tr>
<th>Phylum: Pisuviricota</th>
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<tbody>
<tr>
<td>Class: Pisoniviricetes</td>
</tr>
<tr>
<td>Order: Picornavirales</td>
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</tbody>
</table>

**Family:** Secoviridae  
**Subfamily:** Comovirinae  
**Genus:** Comovirus  
**Species:** Cowpea severe mosaic virus

**Genus:** Fabavirus  
**Species:** Broad bean wilt virus*

<table>
<thead>
<tr>
<th>Phylum: Stelpaviricetes</th>
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<tbody>
<tr>
<td>Class: Stelpaviricetes</td>
</tr>
<tr>
<td>Order: Patatavirales</td>
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</table>

**Family:** Potyviridae  
**Genus:** Potyvirus  
**Species:** Bean common mosaic virus**  
*Bean common mosaic necrosis virus**  
*Bean yellow mosaic virus**  
*Cowpea aphid-borne mosaic virus*

**Class:** Stelpaviricetes  
**Order:** Patatavirales  
**Family:** Pospiviroidae  
**Genus:** Pospiviroid  
**Species:** Citrus exocortis viroid**

**Other viruslike cases:**  
**Isometric particles, unidentified**  
**Manihot esculenta**  
**Stevia sp.**

*Based on ICTV Master Species List 2021 v.2.*  
**Pending confirmation by serological or molecular detection.*
List of plant species infected by viruses and viroids, described in Paraguay (1920–2023)

A

*Acanthospermum hispidum* DC (Bristly starbur) Asteraceae

**Orthotospovirus**

**Tomato spotted wilt orthotospovirus** *(TSWV)*

*A. hispidum*, locally known as Toro-rati, is a common wild plant with antifungal activity with potential use in medicine (1). ELISA made on samples of bristly starbur plants with leafroll and yellows symptoms showed a positive reaction against TSWV antibodies (2). Ref.: (1) Portillo et al. Journal of Ethnopharmacology 76(1): 93. 2001; (2) Shohara, K. Shokubutsu boeki 49(2): 32. 1995.

*Allium schoenoprasum* L. (Chives) Amaryllidaceae

**Potyvirus**

**Potyvirus unidentified**

A still unidentified presumed potyvirus causing mosaic symptoms on chives was observed by electron microscopy analysis, as deduced by the detection of elongated particles ca. 760 nm long in leaf extracts of symptomatic onion plants (1). Ref.: (1) Shohara K Shokubutsu boeki 49(2): 32. 1995.

*Amaranthus hybridus* L. (Amaranth) Amaranthaceae

**Potyvirus**

**Cowpea aphid-borne mosaic virus** *(CABMV)*

Cowpea plants displaying chlorotic spots and mosaic were found in Choré, San Pedro, next to a bean plantation with high incidence of virus-like symptoms. Mechanical inoculation in indicator plants, serology and molecular (RT-PCR) assays confirmed CABMV infection in plants of *A. hybridus*. (1).


*Ananas comosus* (L.) Merr. (Pineapple) Bromeliaceae

**Closterovirus**

**Pineapple mealybug wilt-associated virus** *(PMWaV)*

Plant samples collected from Paraguay and maintained at the USDA-A RS National Clonal Germplasm Repository in Hilo, Hawaii, were tested positive for PMWaV by ELISA test (1). The natural infection has not been confirmed since then, and its actual presence in the country is unknown.


*Arachis hypogaea* L. (Groundnut, peanut) Fabaceae

**Potyvirus**

**Peanut mottle virus** *(PMoV)*

Natural infections of peanut plants showing mosaic and mottle symptoms were reported in the Central Department. The presence of 740 nm viral particles was confirmed by electron microscopy analysis of infected tissue. Mechanical inoculation produced local lesions in *Chenopodium quinoa*. The causal virus was tentatively identified as Peanut mottle virus *(PMoV)*, but it needs to be confirmed.


*Carica papaya* L. (Papaya) Caricaceae

**Potyvirus**

**Papaya ringspot virus-P** *(PRSV-P)*

Leaf extracts of papaya plants showing mosaic symptoms revealed the presence of elongated, ca. 750 nm particles by electron microscopy. Cucumber was able to be infected mechanically. The causal virus was tentatively identified as PRSV-P (1). In November 2020, papaya trees showing symptoms of leaf size reduction, yellow and severe mosaic, and...
ringspots on the fruits were found in the Asunción Central department. PRSV-P infection was confirmed by RT-PCR and serologic assays. Ref.: (1) Shohara, K. Shokubutsu boeki 49 (1): 32. 1995; (2) Esquivel-Fariña, A. et al., Journal of Plant Pathology 104(1), 451. 2022.

*Chrysanthemum sp. Asteraceae
Carlavirus

Chrysanthemum virus B (CVB)
Elongated particles, ca. 670 nm long, possibly a carlavirus, were detected by electron microscopy, in leaf extracts of asymptomatic chrysanthemum plants, and tentatively identified as CVB, pending confirmation (1). Ref.: (1) Shohara, K. Shokubutsu boeki 49 (1): 32. 1995.

*Citrullus lanatus* Thumb. Matsui & Nakai (Watermelon)
Cucurbitaceae

Cucumovirus

Cucumber mosaic virus (CMV)
CMV was detected using electron microscopy, transmission assays, and serology in mosaic-bearing watermelon plants (1). Ref.: (1) Shohara, K. Shokubutsu boeki 49 (1): 32. 1995

Potyvirus

Zucchini yellow mosaic virus (ZYMV)
The presence of 750 nm particles in extracts of watermelon leaves with mosaic symptoms was detected by electron microscopy analysis. Based on mechanical transmission tests and serology this potyvirus was identified as ZYMV (1). Ref.: (1) Shohara, K. Shokubutsu boeki 49 (1): 32. 1995.

*Citrus spp. Rutaceae
Claostrivirus

Citrus tristeza virus (CTV)
Surveys conducted between 1986 and 1988 on major crops in Paraguay revealed several viral diseases on citrus crops, including CTV (1). Shohara in 1991-1993 also identified CTV in citrus plant samples showing leaf curling symptoms based on the presence of 1800 nm particles in leaf extracts by electron microscopy, and confirmed by serology (2). Using a technique combining serology and electron microscopy (MEIAD), CTV was detected in samples from Paraguay (3). By the end of the nineties, CTV had infected 96% of the citrus trees in the eastern regions of Paraguay. Interestingly, no CTV was detected in citrus plants grown in the Dept. Boquerón. The initial plants were imported into Texas by German colonizers in 1930. It is likely that the hot and dry conditions of the region do not favor the aphid vectors, thus avoiding incoming of CTV, since no citrus plants were introduced from other regions (4). In 2007, CTV was detected in selected grapefruit clones through a biological test using subtle lemon (Citrus aurantifolia) as an indicator plant, in the Depts. of San Pedro and Concepción (5).

Ophiomuriviridae

Ophiomurivirus citri [Citrus psorosis virus (CPsV)]
During the limited inspection made in 1937, Fawcett & Bitancourt observed mild cases of psorosis, based on symptoms, in citrus plants near Asunción (1). The presence of CPsV in Paraguay was confirmed during surveys conducted between 1986 and 1988 on major crops. More recently, the presence of CPsV in symptomatic citrus trees was reported in the city of Carlos A. López at Itapúa department (3).


Cileivirus

Citrus leprosis virus C (CiLV-C)
Just a few years after the disease was described in Florida, citrus leprosis was reported in Paraguay, in Asunción and named as “lepra explosiva” in 1920, by Spegazzini. At the time, he wrongly attributed the causal agent as a fungus *Amylioxa aurantiorum* (1). In 1937 Fawcett & Bitancourt visited Asunción and surroundings (Trinidad, San Lorenzo) as part of a long journey throughout several South American countries observing citrus diseases, and confirmed the presence of leprosis based on symptoms (2, 3). Further inspections revealed that citrus leprosis is widespread on orange and/or mandarin orchards in Paraguay (Boquerón, Concepción, San Pedro, Cordillera, Alto Paraná and Itapúa departments), the identification confirmed by electron microscopy and molecular assays (4). An extensive molecular survey on samples collected from several sites on the American continent, confirmed that Citrus leprosis virus C (CiLV-C) is the prevalent virus causing the citrus leprosis syndrome in Southern South America, including Paraguay (5). CiLV-C vector in Paraguay, as elsewhere, is identified as *Brevipalpus yothersi* (6).


Pospossivirovirus

Citrus exocortis viroid (CEVd)
The possible presence of CEVd in Paraguay, affecting citrus plants, was suggested based on symptoms observed in surveys during 1986 to 1988. The identification is still pending confirmation (1).


*Colocasia sp. (Yam) Araceae
Potyvirus

Dasheen mosaic virus (DsMV)
Electron microscopic analysis detected 750 nm particles in leaf extracts of yam plants showing mosaic symptoms, which were tentatively identified as DsMV (1).

*Crotalaria incana* L. Fabaceae

*Crotalaria juncea* L. Fabaceae

*Crotalaria spectabilis* L. Fabaceae

**Potyvirus**

**Cowpea aphid-borne mosaic virus (CABMV)**

Sesame crops have been found commonly infected by CABMV, occasionally resulting in significant losses. As part of studies to understand the epidemiology of this virus, surveys have been conducted to assess its presence in cultivated or spontaneous plants nearby sesame fields. Assays to detect CABMV included mechanical transmission to certain indicators (*Chenopodium quinoa*, *Vigna unguiculata*, *Sesamum indicum*) and ELISA using specific antiserum. During such inspections, three species of *Crotalaria* (*C. incana*, *C. juncea*, and *C. spectabilis*) showing mosaic symptoms were confirmed to be CABMV-infected (1). During the early survey made by Shohara in 1990’s (2), he found mosaic bearing *Crotalaria* sp. associated with the presence of potyvirus-like particles, and suggested infection by BYMV. It is likely that the virus that caused the infection was CABMV.


**Cucumis melo** L. (Melon) Cucurbitaceae

**Cucumis sativus** L. (Cucumber) Cucurbitaceae

**Cucumber mosaic virus (CMV)**

Samples of melon plants, exhibiting mosaic symptoms, were used in mechanical transmission assays, which resulted in the infection of NN tobacco (mosaic) and cowpea (local lesions). Electron microscopy detected isometric particles with a diameter of around 30 nm, and a serology test was positive for CMV (1).


**Potyvirus**

**Zucchini yellow mosaic virus (ZYMV)**

The presence of 750 nm particles was found in leaf extracts of mosaic bearing cucumber when examined by electron microscopy. The causal virus was determined to be ZYMV because of a positive serological reaction against ZYMV antiserum (1).


**Cucurbita maxima** Duch. (Pumpkin) Cucurbitaceae

**Cucumber mosaic virus (CMV)**

Isometric particles of approximately 30 nm were found in leaf extracts of field pumpkin plants with mosaic symptoms, by electron microscopy. Mechanical transmission assays resulted in infection of tobacco (mosaic) and cowpea (local lesions), while a serological test was positive for CMV antigen, confirming infection by this virus (1).


**Potyvirus**

**Watermelon mosaic virus (WMV)**

Leaf extracts of *C. maxima* plants showing mosaic symptoms were analyzed by electron microscopy, revealing the presence of potyvirus-like, elongated particles. ZYMV antigen was found to be negative in the serological test. The identity of this potyvirus has been tentatively suggested to be watermelon mosaic virus (WMV), but it has not yet been confirmed (1).


**Papaya ringspot virus-W (PRSV-W)**

**Zucchini yellow mosaic virus (ZYMV)**

Potyviruses infection of cucurbits has been considered a common occurrence in Paraguay. Shohara (1) reported a case that was tentatively determined to be caused by WMV. In 2017, during a routine survey, leaf deformation, chlorosis and stunting were observed in plants of *C. maxima* var. Zapallito in an experimental area located in the campus of the National University of Asuncion. A mixed infection with PRSV-W and ZYMV (2) was confirmed by both molecular and serological detection.

I

*Ipomea batatas* (L.) Lam. (*Sweet potato*) *Convulvulaceae*

Potyvirus

**Sweet potato feathery mottle virus (SPFMV)**

**Sweet potato virus G (SPVG)**

Begomovirus

**Sweet potato leaf curl virus (SPLCV)**

During an investigation on synergistic interactions of begomoviruses and the crinivirus *Sweet potato chlorotic stunt virus* (SPCSV), at the International Potato Center in Peru. SPFMV and SPLCV were detected in mixed infection with sweet potato virus G (SPVG) in samples originated from Paraguay, maintained in the collection of sweet potato accessions. Detection was based on grafting onto the indicator plant *I. setosa*, followed by PCR (1).


L

*Leonurus sibiricus* L. (*Chinese motherwort, Honeyweed*) *Lamiaceae*

Begomovirus

**Tomato yellow spot virus (ToYSV)**

ToYSV was identified, based on molecular assays, infecting two *L. sibiricus* plants displaying viral symptoms within citrus orchards in Major Otaño, Itapúa, Paraguay (1).


M

*Manihot esculenta* Kranz (*Cassava*) *Euphorbiaceae*

Potexvirus

**Cassava common mosaic virus (CsCMV)**

Symptomatic cassava leaf samples were collected in the early 1990s during a virus disease survey in Paraguay, and leaf extracts were loaded onto ELISA plates and dried. ELISA reactions were later carried out at CIAT, Colombia, and CsCMV was detected in cassava samples collected in Paraguay (1). Molecular characterization studies carried out on Brazilian, Colombian and Paraguayan isolates of CsCMV indicated that they were essentially similar (2).


Potyvirus

**Potyvirus unidentified**

Leaf extracts of cassava plants showing viral symptoms were analyzed by electron microscopy, revealing the presence of particles with 760 nm in in length, which were interpreted as being of potyviral nature. Further confirmation is needed for this finding (1).


Unidentified isometric virus

Isometric particles measuring 28 nm in diameter were observed in leaf extracts of cassava plants showing viral symptoms using transmission electron microscopy. No further confirmation of their viral nature is available.


N

*Nicotiana longiflora* Cav. (*Longflower tobacco*) *Solanaceae*

Orthotospovirus

**Tomato spotted wilt orthotospovirus (TSWV)**

TSWV was detected infecting *N. longiflora* plants by serology (1).


*Nicotiana tabacum* L. (*Tobacco*) *Solanaceae*

Cucumovirus

**Cucumber mosaic virus (CMV)**

Potyvirus

**Potato virus Y (PVY)**

Tobamovirus

**Tobacco mosaic virus (TMV)**

Tobacco plants with mosaic symptoms were examined using electron microscopy and serology. Presence of rod-like and flexuous particles, as well as of isometric particles ca. 30 nm diameter was observed in leaf extracts by electron microscopy. Serological analysis confirmed the presence of TMV, PVY and CMV in these samples (1).


O

*Orchids (several genera) Orchidaceae*

Dichorhabdovirus

**Dichorhavirus orchidacea [Orchid fleck virus (OFV)]**

Orchid fleck virus (OFV) was first reported to infect plants of *Dendrobium moschatum* in 2013. Plants exhibiting chlorotic and necrotic lesions on the leaves were observed in the municipalities of Asunción and Caacupé (1). Leaf samples showing virus-like symptoms were found in plants grown in commercial greenhouses in the Paraguayan municipalities of Asunción and Caacupé during 2014 and 2015. Mixed infections with *Cymbidium mosaic virus* (CymMV) and *Odontoglossum ringspot virus* (ORSV) were reported (2).


Potexvirus

**Cymbidium mosaic virus (CymMV)**

During surveys carried out by Shohara in the 1990’s, *Cattleya* and *Dendrobium* plants showing viral symptoms were analyzed by electron microscopy, which detected elongated particles 460–480 nm long and tentatively identified as CymMV (1). Further surveys carried out on commercial and private collection of orchids, during 2014 and 2015, virus-like symptoms were observed in plants of five orchid genera (*Cattleya, Dendrobium, Miltonia, Oncidium and Phalaenopsis*) grown in commercial greenhouses in the Paraguayan municipalities of Asunción and Caacupé. Presence of CymMV was confirmed in samples of all these genera by electron microscopy and RT-PCR assays (2).


Tobamovirus

**Odontoglossum ringspot virus (ORSV)**

ORSV is believed to be the first virus formally studied in Paraguay. It was characterized during González-Segnana’s master’s dissertation in
1989 (1, 2), which analyzed ORSV isolates from Minas Gerais, Brazil, and Paraguay by biological analysis and electron microscopy. During surveys made by Shohara in the 1990’s, ORSV was found in Cattleya and Oncidium orchids also by biological tests and electron microscopy (3). Recent surveys confirmed the presence of ORSV, in mixed infection with CymMV in plants of several orchid genera, as shown by electron microscopy and molecular assays (4).


P

*Petunia x hybrida* (Petunia) Solanaceae
Orthotospovirus

Groundnut ringspot orthotospovirus (GRSV)

In 2018, flower growers in Luque County, Central Department, were forced to eliminate entire sets of GRSV-infected petunias due to a high incidence of necrotic ringspot symptoms on their leaves. Identification of the causal agent as an isolate of GRSV was made by serology and RT-PCR (1).


*Phaseolus vulgaris* L. (Common bean) Fabaceae
Potyvirus

Bean yellow mosaic virus (BYMV)

Flexible, elongated particles were found in leaf extracts of bean plants exhibiting mosaic symptoms. These particles were tentatively identified as Bean yellow mosaic virus (BYMV). Further confirmation is required by serological or molecular assays (1).


Bean common mosaic virus (BCMV), Bean common mosaic necrosis virus (BCMV)

Worrall et al., in their review on BCMV and BCMNV, they mention the presence of these viruses in Paraguay (p.16), possibly affecting bean plants, without details (1).


*Physalis sp.* Solanaceae
Orthotospovirus

Tomato spotted wilt orthotospovirus (TSWV)

*Physalis* spp. plants with virus-like symptoms were collected by Shohara during surveys carried out in the 1990’s. The biological assays were negative, but serology confirmed TSWV infection (1).


*Solanum lycopersicum* L. (Tomato) Solanaceae

Tomato mosaic virus (TMV)

TMV was detected on tomato plants with mosaic symptoms during Shohara’s survey. Identification was based on biological assays, electron microscopy and serology (1).


Orthotospovirus

Tomato spotted wilt orthotospovirus (TSWV)

Tomospovirus-like symptoms (necrosis and ringspots on the leaves) have frequently been observed in tomato fields. In the 90s, TSWV was serologically detected infecting tomato plants, which showed necrosis (1). TSWV is quoted as causing “vira-cabeza” in Ishijima’s manual on fruit vegetable crops, and considered to be transmitted by the dark form

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of Frankiñiella schultzei (2), which was confirmed experimentally by Sakurai (3).

Groundnut ringspot orthotospovirus (GRSV)

In 2018, tomato plants (cv. ‘Santa Clara’) showing typical tospovirus-like symptoms including chlorotic spots, concentric and necrotic rings on the leaves and stunting were found in high incidence (ca 50%), at the experimental field of FCA/UNA in San Lorenzo. The infection of GRSV on these tomato plants was confirmed by both serology and molecular assays.

*Solanum tuberosum L. (Potato) Solanaceae

Potexvirus

Potato virus X (PVX)

Electron microscopy and serology were used to detect PVX in samples from symptomatic potato leaves (1). The actual presence and distribution in the country is unknown.

Potyvirus

Potato virus Y (PVY)

Potato plants showing mosaic, dwarfism, vein necrosis and leaf rolling were analyzed by electron microscopy, resulting in the detection of flexible particles ca. 750 nm long. The causal agent was tentatively identified as PVY, but this requires confirmation (1).

Carlavirus

Unidentified carlavirus

Potato plants showing mosaic, dwarfism, vein necrosis and leaf rolling were sampled during a Shohara’s survey in 1990’s. Electron microscopy examination of leaf extracts revealed the presence of carlavirus-like particles, which was considered evidence for the presence of Potato Virus S or Potato Virus M, not yet confirmed (1).

*Sorghum bicolor L. (Sorghum) Poaceae

Sugarcane mosaic virus (SCMV)

Teyssandier in his review on sorghum diseases in Paraguay mentions the presence of the sugarcane mosaic virus in sorghum, but without providing any details. The actual presence and/or distribution of the in the country is unknown.

*Stevia sp. Asteraceae

Fabavirus

Broad bean wilt virus (BBWV)

Leaf extracts from Stevia plants with yellow symptoms were examined by electron microscopy revealing the presence of isometric virus-like particles ca. 25 nm. The virus has been tentatively identified as Broad bean wilt virus (BBWV), but it is still awaiting confirmation (1).

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Author Contributions
Arnaldo Esquivel-Fariña: writing the original draft, data collection, manuscript preparation, and critical revision, adding intellectual content.
Luis R. Segnana-González: data analysis and results interpretation, and critical revision, adding intellectual content.
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Conflicts of Interest
The authors declare that they have no conflict of interest related to the publication of this manuscript.

Ethics
This study did not involve human beings and/or clinical trials that should be approved by one Institutional Committee.

Data Availability
The data collected and generated during this study includes the available literature on plant virus description in Paraguay used in the analysis and can be accessed at https://zenodo.org/records/8387860. The authors confirm that all data necessary for reproducing the study findings are available in the designated dataset.

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