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Review Article

Iris yellow spot orthotospovirus pathosystem, virus host and vector (*Thrips tabaci*)

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ABSTRACT

Iris yellow spot orthotospovirus (IYSV) causes serious problems in the onion (*Allium cepa*) crop and is widely distributed in the producing areas of the country. In Mexico it was reported in 2010 as "yellow spot" on onion and other members of the genus *Allium*. Its main vector is *Thrips tabaci,* which causes direct damage by feeding and by being a vector of other viruses such as *Tomato spotted wilt orthotospovirus* and *Impatiens necrotic spot orthotospovirus*. Knowledge of the pathosystem of IYSV - *Thrips tabaci* - *Allium cepa* - weeds can contribute to an integrated management and awareness of pesticide use. The versatility of IYSV to infect more than 60 plant species (>20 families), most of which are present in Mexico, coupled with the wide host range of the vector, makes the interaction complex and leads to a better understanding of the diversity of alternate hosts of the vector and/or IYSV. At present, information on weed hosts of IYSV and the vector is limited, but their knowledge will provide a greater understanding of the disease. It is important to have a comprehensive knowledge of the virus, main host, alternate hosts, and vector in the country, in order to channel future research to counteract this problem and minimize losses caused by IYSV in the onion crop mainly.

Keywords: IYSV, *Allium*, weeds, host, *orthotospovirus*.

Introduction

Mexico is rich in a diversity of climatic environment that foster the production of a range of crops of national and international importance. An example, of this is the planting of onion (*Allium cepa*), which is produced in most states of Mexico. In 2023, a production of 1,528,450 tons was recorded, concentrated in 10 states, with Chihuahua standing out (Panorama agroalimentario, 2023). Despite its importance, it is affected by viral diseases, such as the *Leek yellow stripe virus* (LYSV) (Pérez-Moreno *et al.,* 2004; Velasquez-Valle *et al*., 2010), the *Tomato spotted wilt orthotospovirus* (TSWV), the *Tobacco etch virus* (TEV), the *Garlic latent common virus* (GLCV) (Velasquez-Valle *et al.,* 2010) and the *Iris yellow spot orthotospovirus* (IYSV) (Velásquez-Valle and Reveles-Hernández; 2011). The latter is of great economic importance in onions worldwide (Jones, 2005; Bag *et al*., 2009) and in other crops of the *Allium* genus (Bag *et al*., 2015; Weilner and Bedlan, 2013), with losses in seed production and reductions in bulb size (Bag *et al.,* 2010; Bag *et al.,* 2012b).

IYSV is the most devastating in *Allium* (Brewster, 2008) and is most important for its wide geographic distribution and range of hosts reported in recent years (Smith *et al.,* 2011; Ghotbi *et al.,* 2005; Sampangi and Mohan, 2007). In recent decades, the economic impact of *Orthotospoviruses* has increased, causing economic losses in a diversity of vegetables and ornamental plants (Turina *et al.,* 2016), due to the difficulty of combating insect vectors with insecticides and, implementing different management strategies to limit and prevent the introduction of *Orthotospovirus* into agricultural areas (Turina *et al.,* 2016). Therefore, it is important to know the IYSV in Mexico, its range of hosts that can be reservoirs of the virus and eventual emergence of the disease; in addition to this, the alternate hosts of the virus vector.

Taxonomic and genomic classification of the IYSV. The *Iris yellow spot orthotospovirus* belongs to the *Tospoviridae* family (Order: *Bunyavirales*) and genus *Orthotospovirus* (Adams *et al.,* 2017). Its genome consists of three RNA segments: Small-**S** (2.9 kb), Medium-**M** (4.8 kb) and Large-**L** (8.9 kb) (Cortês *et al.,* 1998). The long RNA contains 8,880 nucleotides, with an Open Reading Frame (ORF) in the complementary viral chain (vc). The RNA codifies for the polymerase RNA protein of the dependent RNA (RdRp) of 331.17 kDa in the negative direction (Figure 1) (Bag *et al*., 2010). The 5' and 3' termini of the L RNA (vc) contain two untranslated regions with 33 and 226 nucleotides, with both ends having conserved terminal nucleotides (a common characteristic of the genus) (Bag *et al.,* 2010).

M RNA consists of 4,817 nucleotides with two Open Reading Frames (ORF) with ambisense arrangement, separated by an intergenic region (IGR) of 380 nucleotides (Bag *et al.,* 2009). The small ORF contains 935 nucleotides that codifies a protein with 311 amino acids and 34.7 kDa. This ORF codifies in a positive direction for the non-structural movement (NSm). The long ORF contains 3,410 nucleotides and codifies a protein with 1,136 amino acids and 128.84 kDa, where the precursory glycoprotein (Gn/Gc) is found, in a complementary viral direction. Both ORFs

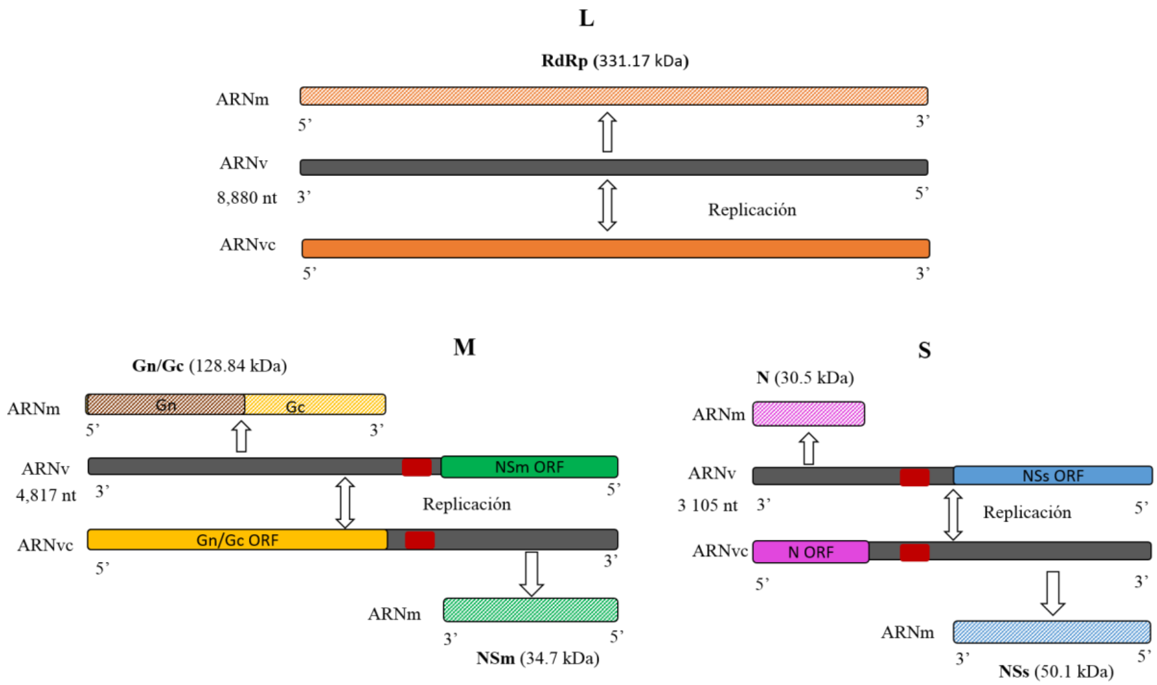

Figure 1. Representation of the segmented organization of the *Iris yellow spot orthotospovirus* RNA genome (L, M and S). Modified from Bag *et al.* (2015).

are separated by an intergenic region of 395 nucleotides (Bag *et al.,* 2009). Both S and M RNA are codified in both directions and both contain two ORFs (Granval de Millán and Gracia, 1999). Finally, S RNA consists of 3,105 nucleotides with two ORFs, one ORF with 1,329 nucleotides and codifies non-structural (NSs) protein in the positive direction, and another with 816 nucleotides that codifies the nucleoprotein (N) in the negative direction (Figure 1) (Cortês *et al.,* 1997; Cortês *et al.,* 1998).

Symptoms in onion. In onion, symptoms are usually specific (Weilner and Bedlan, 2013), and consist of elongated or diamond-shaped lesions, chlorotic or light brown to white, and with the presence or absence of a green island in the center of the lesions on the leaves (Figures 2 A-D) and floral stems (Gent *et al.,* 2006). At the onset of infection, symptoms may be confused with lesions caused by thrips or other pathogens (fungi or bacteria) (Weilner and Bedlan, 2013). However, these lesions are observed on the inner part of the leaves near the bulb, where thrips prefer to feed (Figures 2 E-F). When the virus lesions coalesce, the leaves collapse and the photosynthetic area is reduced (Kritzman *et al.,* 2001), affecting bulb formation (Gent *et al.,* 2006) and even causes the death of the plant when the damage is severe

(Weilner and Bedlan 2013). The symptoms are most frequent at an advanced age of the plant, or during the formation of the bulb (Weilner and Bedlan, 2013). The symptoms reported in the onion crop in Mexico are similar to those reported in other countries, chlorotic, yellowish or white, dry and elongated lesions (Figure 2A and 2B) (Ramírez-Rojas *et al*., 2016), and occasionally, a green island is observed in the center of the lesion (Figure 2 C and D) (Ávila-Alistac *et al*., 2017).

In other hosts such as *N. benthaminana*, IYSV causes mosaics and deformation of leaves (Ghotbi *et al.,* 2005; Ávila-Alistac *et al*., 2017; Ornelas-Ocampo *et al.,* 2018). In Mexican husk tomato (*Physalis ixocarpa*), symptoms are related to a yellowing and necrosis of the plant (Ríos-Domínguez *et al.,* 2017). Despite similar symptomatologic reports in Mexico and other countries, the genetic diversity of the

Figure 2. **A** and **B)** symptoms associated with the *Iris yellow spot orthotospovirus* infection, consisting of pale straw-colored chlorotic lesions with an elongated shape. **C** and **D)** pale straw-colored chlorotic lesions with a green island in the center of the lesion **E-G)** presence of large *T. tabaci* populations (immature and adult) in the onion crop.

IYSV populations may generate a diversity of symptoms (Iftikhar *et al.,* 2014). In Mexico, information on the diversity of IYSV is limited; there is only the report by Ornelas-Ocampo and collaborators (2018), who observe a variability of symptoms in onions infected with IYSV, and classify them as typical and severe symptoms. Nevertheless, there were no genomic differences between the analyzed fragments of the IYSV genome. In spite of this, the probability of variability in onion-producing areas is not ruled out, considering the presence of other *Orthotospoviruses* in agricultural areas.

National distribution and alternate IYSV hosts. IYSV is distributed in most of onion-producing areas of the world (Gent *et al.,* 2006). In Mexico, it was reported in 2010, in Delicias, Chihuahua, with severe economic losses in the crop (Velásquez-Valle *et al.,* 2010). It was also reported in Zacatecas in the same year (Velásquez-Valle and Reveles-Hernández, 2011). Later, in 2012, an incidence of 100% was reported in 2,500 ha planted with onion in Morelos (Ramírez-Rojas *et al*., 2016), and in 2013, in Vista Hermosa and Tanhuato, Michoacán (Ávila-Alistac *et al.,* 2017). These reports were registered for onion, and in Guanajuato alone, its presence was reported in garlic (*Allium sativum*) (Pérez-Moreno *et al.,* 2010), where the presence of the vector (*Thrips tabaci*) was confirmed, along with the virus in the insect (García-Rodríguez *et al.,* 2014).

In addition, IYSV has been detected in tomato husk in Malinalco and Tonatico, State of Mexico (Ríos-Domínguez *et al*., 2017; Ríos-Domínguez *et al.,* 2018), and tomato (*Solanum lycopersicum*) in Coatepec Harinas, State of Mexico (Ríos-Domínguez *et al.,* 2018). The infection in other hosts different to *Allium* display the ability of the virus to infect other economically important families in the country. Hence, the probability of the virus being distributed in other species is not ruled out.

For example, the IYSV host range was initially limited (Kritzman *et al.*, 2001), although in time, the range of hosts has been diversified in several ornamental plants (Jones, 2005), crops and weeds worldwide (Table 1) (Hsu *et al.,* 2011; Sampangi *et al.,* 2007; Schwartz *et al.,* 2014; Weilner and Bedlan, 2013; Szostek and Schwartz, 2015). The study of the role of the alternate hosts and secondary vectors (Schoonhoven *et al.,* 2005) is crucial to understand the IYSV-Vector-Host-Weed pathosystem to implement assertive strategies for holistic and systemic management. In Zacatecas, Mexico, Velásquez-Valle *et al*. (2013) highlights the importance of *Amaranthus* spp., *Bidens odorata*, *Brassica campestris*, *Chenopodium* spp., *Eruca sativa*, *Malva parviflora*, *Medicago sativa*, *Sisymbrium* spp. and *Sonchus oleraceus* as IYSV hosts. Interestingly, IYSV has been found in at least 20 plant families with a predominance in *Asteraceae*, abundant weeds in the country (Table 1).

Table 1. Range of *Iris yellow spot orthotospovirus* hosts.

Family	Scientific name	Common name	References
Alliaceae	*Allium tuberosum*	Garlic chives	Gawande *et al.*, 2014
	A. fistulosum	Green onion	Tabassum *et al.,* 2016
Amaranthaceae	*Amaranthus retroflexus*	Redroot pigweed	Gent *et al.,* 2006; Sampangi *et al.,* 2007; Schwartz *et al.,* 2014; Birithia *et al.,* 2018
	A. hybridus	Smooth pigweed	Karavina y Gubba, 2017
	A. spinosus	Spiny amaranth	Karavina y Gubba, 2017
	Amaranthus spp.[z]	Amaranth	Velásquez-Valle *et al.,* 2013
	Atriplex micranth	Small-leaved saltbush	Evans *et al.,* 2009[a]
Asteraceae	*Arctium minus*	Common burdock	Hsu *et al.*, 2011; Smith *et al*., 2012
	Tripleurospermum inodorum	Scentless false mayweed	Weilner y Bedlan, 2013
	Artemisia vulgaris	Common mugwort	Weilner y Bedlan, 2013
	Arctium tomentosum	Downy burdock	
	Cichorium intybus	Common chicory	Hsu *et al*., 2011; Smith *et al*., 2012; Weilner y Bedlan, 2013
	Taraxicum officinale	Dandelion	Hsu *et al.,* 2011; Smith *et al.,* 2012; Schwartz *et al.,* 2014; Szostek y Schwartz, 2015
	Sonchus asper	Prickly sowthistle	Nischwitz *et al.,* 2007
	Lactuca serriola	Prickly lettuce	Sampangi *et al.,* 2007; Schwartz *et al.,* 2014; Szostek y Schwartz, 2015
	S. oleraceus[z]	Annual sowthistle	Schwartz *et al.,* 2014; Velásquez-Valle *et al.,* 2013
	Senecio vulgaris	Common groundsel	Schwartz *et al*., 2014
	Bidens odorata[z]	Tall beggarticks	Velásquez-Valle *et al.,* 2013
	Chrysothamnus nauseosus	Rubber rabbitbrush	Schwartz *et al*., 2014
	Conyza canadensis	Canadian horseweed	Schwartz *et al*., 2014
	Tragopogon dubius	Yellow salsify	Schwartz *et al*., 2014; Szostek y Schwartz, 2015
Amaryllidaceae	*Bessera elegans*	Coral drops	CABI, 2015
Brassicaceae	*Chorispora tenella*	Blue mustard	Schwartz *et al.,* 2014
	Descurainia sophia	Flixweed	Schwartz *et al.,* 2014; Szostek y Schwartz, 2015
	Capsella bursapastoris	Shepherd's purse	Weilner y Bedlan, 2013
	Eruca sativa[z]	Arugula	Velásquez-Valle *et al.,* 2013
	Brassica campestris[z]	Field mustard	Velásquez-Valle *et al.,* 2013
	Sisymbrium spp[z]	Hedge mustard	Velásquez-Valle *et al.,* 2013
	B. kaber	Wild mustard	Schwartz *et al.,* 2014
Convolvulaceae	*Convolvulus arvensis*	Field bindweed	Schwartz *et al.,* 2014; Weilner y Bedlan, 2013
Chenopodiaceae	*Kochia scoparia*	Kochia	Sampangi *et al*., 2007; Schwartz *et al.,* 2014
	C. album	White goosefoot	Sampangi *et al*., 2007; Schwartz *et al.,* 2014; Birithia *et al.,* 2018
	Chenopodium spp.[z]	Goosefoot	Velásquez-Valle *et al.,* 2013
	Salsola iberica	Iberian saltwort	Schwartz *et al*., 2014
Euphorbiaceae	*Ricinus communis*	Castor oil plant	Schwartz *et al*., 2014
	Euphorbia dentata	Toothed spurge	Schwartz *et al.,* 2014
Fabaceae	*Medicago sativa*[z]	Alfalfa	Velásquez-Valle *et al.,* 2013

Table 1. Continue...

Family	Scientific name	Common name	References
Geraniaceae	*Erodium cicutarium*	Redstem filaree	Schwartz *et al.,* 2014
Polygonaceae	*Rumex crispus*	Curled dock	Hsu *et al.,* 2011; Smith *et al.,* 2012; Weilner y Bedlan, 2013
Portulacaceae	*Portulaca oleracea*	Purslane	Cosmi *et al.,* 2003; Schwartz *et al.,* 2014
Plantaginaceae	*Linaria canadensis*	Blue toadflax	CABI, 2015
	Plantago lanceolata	Ribwort plantain	Schwartz *et al.,* 2014
Poaceae	*Setaria viridis*	Green foxtail	Evans *et al.,* 2009b
	Aegilops cylindrica	Jointed goatgrass	Schwartz *et al.,* 2014
	Dactylis glomerata	Orchard grass	Weilner y Bedlan, 2013
	Eleusine indica	Goosegrass	Karavina y Gubba, 2017
	Poa sp.	Bluegrass	Weilner y Bedlan, 2013
Polygonaceae	*Polygonum lapathifolium*	Pale smartweed	Schwartz *et al.,* 2014
Malvaceae	*Hibiscus trionum*	Flower-of-an-hour	Schwartz *et al.,* 2014
	Malva palviflora[z]	Cheeseweed	Velásquez-Valle *et al.,* 2013
	M. neglecta	Common mallow	Szostek y Schwartz, 2015
Solanaceae	*Solanum nigrum*	Black nightshade	Schwartz *et al.,* 2014; Birithia *et al.,* 2018
	S. sarrachoides	Potato vine	Schwartz *et al.,* 2014
	Datura stramonium	Jimsonweed	Birithia *et al.,* 2018
	S. lycopersicum[y]	Tomate	Ríos-Domínguez *et al.,* 2018
	Physalis minima	Pygmy groundcherry	Birithia *et al.,* 2018
	P. ixocarpa[y]	Mexican husk tomato	Ríos-Domínguez *et al.,* 2017; Ríos-Domínguez *et al.,* 2018
Zygophyllaceae	*Tribulus terrestres*	Puncturevine	Sampangi *et al.,* 2007
Geraniaceae	*Pelargonium hortorum*	Geranium	Ghotbi *et al.,* 2005
Cycadaceae	*Cycas* sp.	Cycad	Ghotbi *et al.,* 2005
Rosaceae	*Rosa* sp.	Rose	Ghotbi *et al.,* 2005
Araceae	*Scindapsus* sp.	Pothos	Ghotbi *et al.,* 2005
Gentianaceae	*Eustoma russellianum*	Lisianthus	Kritzman *et al.,* 2000
	E. grandiflorum	Lisianthus	Mumford *et al.,* 2008
	chrysanthemum	Crysanthemum	Rafizadeh *et al.,* 2013

[y]Detected by RT-PCR.

[z]Detected by ELISA.

Forms of transmission and IYSV vectors. To date there is no evidence of the transmission of the virus via seeds (Kritzman *et al.,* 2001) and under controlled conditions, the mechanical transmission in onion plants is lower than 30% (Bag *et al.,* 2015). The main vector is *T. tabaci* (Terebrantia: Thripidae) (Cortês *et al.,* 1998), also known as “onion thrips”, which transmits to the virus in a persistent and propagative manner (Diaz-Montano *et al*., 2011). It was also shown that *Frankliniella fusca*, under greenhouse conditions, has the ability to transmit the virus at a low percentage (Srinivasan *et al*., 2012). Species of *Orthotospovirus* are naturally transmitted by thrips in a persistent manner (Bag *et al.*, 2015); that is, once the virus infects the insect, it will be able to transmit it for the rest of its life.

Onion thrips is an important pest in this crop (Diaz-Montano *et al*., 2011), and in a large number of economically important plants, such as vegetables and ornamental plants (Schoonhoven *et al.,* 2005; Alford, 1999; Gent *et al.,* 2004). This vector becomes more relevant since it not only transmits IYSV, but also the *Tomato spotted wilt orthotospovirus* (TSWV) (Jenser *et al*., 2011) and the *Impatiens necrotic spot orthotospovirus* (INSV) (Ghotbi *et al.,* 2005). It is Cosmopolitan and polyphagous pest, which can easily survive in alternate plants as weeds, particularly in the absence of the crop (Schoonhoven *et al.,* 2005). Both INSV and TSWV are found in vegetable crops in Mexico; INSV has been reported in *P. ixocarpa*, *Capsicum* spp. and tomato (Torre-Almaraz *et al.,* 1998; González-Pacheco and Silva-Rosales, 2013; Zuñiga-Romano *et al*., 2019) and TSWV, in several vegetable and ornamental plant crops in the country, and even in onion crops (Torre-Almaraz *et al.,* 1998; Holguín-Peña and Rueda-Puente, 2007; Morales-Díaz *et al.,* 2008; Velásquez-Valle *et al.,* 2009; Velásquez-Valle *et al.,* 2012).

There is the possibility of *T. tabaci* having the ability of transmitting the three *Orthotospoviruses* in viral mixtures, since there is evidence that two or more viruses can complement to infect their host. Bag *et al.* (2012a) claims this by highlighting that TSWV facilitated the movement of the viral IYSV protein from the area of inoculation to the young *Datura* leaves, becoming a systemic infection. In other words, the double infection of IYSV and TSWV in *Datura* increased the severity of the symptoms in inoculated plants, as well as in young leaves (systemic infection), producing a synergism. It is worth mentioning that the behavior of TSWV and IYSV in *Datura* plants is different: TSWV infects systemically and IYSV is localized (infection limited in inoculated areas). The redistribution and/or the genetic complementation among the genomic segments of the viruses could contribute to greater variability, which is not limiting the infection of two or more *Orthotospoviruses* in nature (Bag *et al.,* 2012a). This reinforces the theory that the vector insect has the ability to transmit viruses individually and in viral mixtures.

Alternate hosts of *Thrips tabaci*. *T. tabaci* host plants include, not only economically important crops, but also a diversity of weeds that, when they die or are eliminated, can favor the dispersion of viruliferous insects to crops of interest (Doederlein and Sites, 1993; Ghotbi *et al*., 2005). In Mexico, studies have been conducted on the role of weeds of the *Cucurbitaceae* and *Solanaceae* families as potential sources of inoculum for the development of the *Tomato apex necrosis virus* (ToANV), the *Zucchini yellow mosaic virus* (ZYMV), the *Watermelon mosaic virus* (WMV), the *Papaya ring spot virus* (PRSV-W) and the *Cucumber mosaic virus* (CMV) in crops of agronomic importance (Félix-Gastélum *et al*., 2023). The information on onion regarding weeds is limited; only in Morelos and Michoacán was there a study of the presence of IYSV in weeds related to the crop (Ramírez-Rojas *et al*., 2016; Ávila-Alistac *et al.,* 2017). However, only the presence of *T. tabaci* was registered in crops related to the crop, without evaluating the presence of the virus in the insect (Table 2). Nevertheless, the weeds reported in other countries and which tested positive for IYSV are found in Mexico and they interact with the onion crop

Table 2. Alternate *Thrips tabaci* and *Iris yellow spot orthotospovirus* hosts in Mexico and the world.

Species	*T. tabaci* host in Mexico	National/Global IYSV host	References
Amaranthaceae			
Chenopodium spp	+	+/+	Velásquez-Valle *et al*., 2013; Sampangi *et al*., 2007; Schwartz *et al.,* 2014
Amaranthus spp.	+	+/-	Velásquez-Valle *et al*., 2013
A. hybridus	+	-/+	Ávila-Alistac *et al.,* 2017
A. spinosus	+	-/+	Ávila-Alistac *et al.,* 2017; Karavina y Gubba, 2017
Solanaceae			
Solanum eleagnifolium	+	-/-	Velásquez-Valle *et al*., 2013
Solanum tuberosum	+	-/-	Velásquez-Valle *et al*., 2013
Capsicum annumm	+	-/-	Beltran *et al.,* 2011; Velásquez-Valle *et al.,* 2009.
Asteraceae			
Sonchus spp.	+	-/+	Velásquez-Valle *et al*., 2013; Nischwitz *et al.,* 2007
Sonchus oleraceus	+	-/+	Ávila-Alistac *et al.,* 2017; Schwartz *et al.,* 2014
Parthenium hysterophorus	+	-/-	Ávila-Alistac *et al.,* 2017
Tithonia tubiformis	+	-/-	Ávila-Alistac *et al.,* 2017
Lactuca serriola	+	-/-	Ávila-Alistac *et al.,* 2017
Bidens odorata	-	+/-	Velásquez-Valle *et al*., 2013
Fabaceae			
Phaseolus vulgaris	+	-/-	Velásquez-Valle *et al*., 2013
Medicago sativa	-	+/-	Velásquez-Valle *et al*., 2013
Brassicaceae			
Brassica spp.	+	-/-	Velásquez-Valle *et al*., 2013
Sisymbrium spp.	+	+/-	Velásquez-Valle *et al*., 2013
Lepidium virginicum	+	-/-	Ávila-Alistac *et al.,* 2017
Brassica campestris	-	+/-	Velásquez-Valle *et al*., 2013
Eruca sativa	-	+/-	Velásquez-Valle *et al*., 2013
Liliaceae			
A. cepa	+	-/-	Magos, 2011; Velásquez-Valle *et al*., 2013; Ávila-Alistac *et al.,* 2017

Table 2. Continue...

Species	*T. tabaci* host in Mexico	National/Global IYSV host	References
Acanthaceae			
Dicliptera peduncularis	+	-/-	Ávila-Alistac *et al.,* 2017
Convolvulaceae			
Ipomoea purpurea	+	-/-	Ávila-Alistac *et al.,* 2017
Euphorbiaceae			
Acalypha ostryifolia	+	-/-	Ávila-Alistac *et al.,* 2017
Ricinnus comunis	+	-/+	Ávila-Alistac *et al.,* 2017; Schwartz *et al*., 2014
Acalypha arvensis	+	-/-	Ávila-Alistac *et al.,* 2017
Malvaceae			
Malva parviflora	+	+/-	Velásquez-Valle *et al.*, 2013; Ávila-Alistac *et al.,* 2017
Anoda cristata	+	-/-	Ávila-Alistac *et al.,* 2017
Malvastrum coromandelianum	+	-/-	Ávila-Alistac *et al.,* 2017
Portulacaceae			
Portulaca oleracea	+	-/+	Ávila-Alistac *et al.,* 2017; Cosmi *et al.,* 2003; Schwartz *et al.,* 2014

[+] *T. tabaci* and/or IYSV host.

and are also hosts of the vector (Beltran *et al.,* 2011; Velásquez-Valle *et al.*, 2013; Ávila-Alistac *et al.,* 2017). These weeds have been reported in large populations, as well as *T. tabaci*; *e.g.*, *Portulaca oleracea* has been reported as the host of IYSV (Cosmi *et al*., 2023; Schwartz *et al*., 2014), a widely distributed weed in onion-producing areas (Figure 3) (Ávila-Alistac *et al.,* 2017). The frequency of the weeds inside and outside of onion fields are the main cause for the prevalence of *T. tabaci*, potential vectors in productive areas, without the presence of IYSV (Gent *et al.,* 2006; Tanveer *et al.,* 2015). Therefore, the presence of IYSV is not ruled out in weeds found in the country, such as those reported by Velásquez-Valle *et al.* (2013) (Table 2). In Mexico, at least 14 weed species are *T. tabaci* hosts and they have been reported as IYSV hosts in Mexico and areas outside the country (Table 2).

Epidemiology and management of IYSV. IYSV, like the rest of the viruses of the same genus, require the interaction of basic factors to cause an epidemic: the vector, host, alternate host, and virus (Ullman *et al.,* 2002). Alongside these, the weather conditions can condition the epidemic in a particular area (German *et al.,* 1992). These viruses have the capability of using the vector insect to infect new

Figure 3. Weeds interacting inside and outside of the onion (*Allium cepa*) crop. **A)** Parthenium weed (*Parthenium hysterophorus*); **B)** Purslane (*Portulaca oleracea*); **C)** Pineland threesed mercury (*Acalypha ostryifolia*); **D)** Mexican sunflower (*Tithonia tubiformis*) on the edge of an onion crop.

hosts, broadening their adaptability when carrying the virus; exerting an influence on its incidence and distribution under different environmental conditions and new hosts (Jones, 2005).

The severity of IYSV in the onion crop is complex and will depend on the population of healthy and infected thrips and on the number of healthy and infected plants, as well as on asymptomatic plants. Once the plant is infected by the virus, there is no treatment to control it, although these plants can become a food source for healthy thrips, and these can infect healthy plants. Additionally, the population density in the field of both thrips and IYSV host plants depend on biotic and abiotic factors, as well as on agronomic management (Figure 4). The impact of IYSV has been observed to depend on the phenological stage in which the first symptoms appear. If the symptoms appear when the bulbs are still developing, the size and quality of the bulbs will be affected (Drost *et al*., 2019).

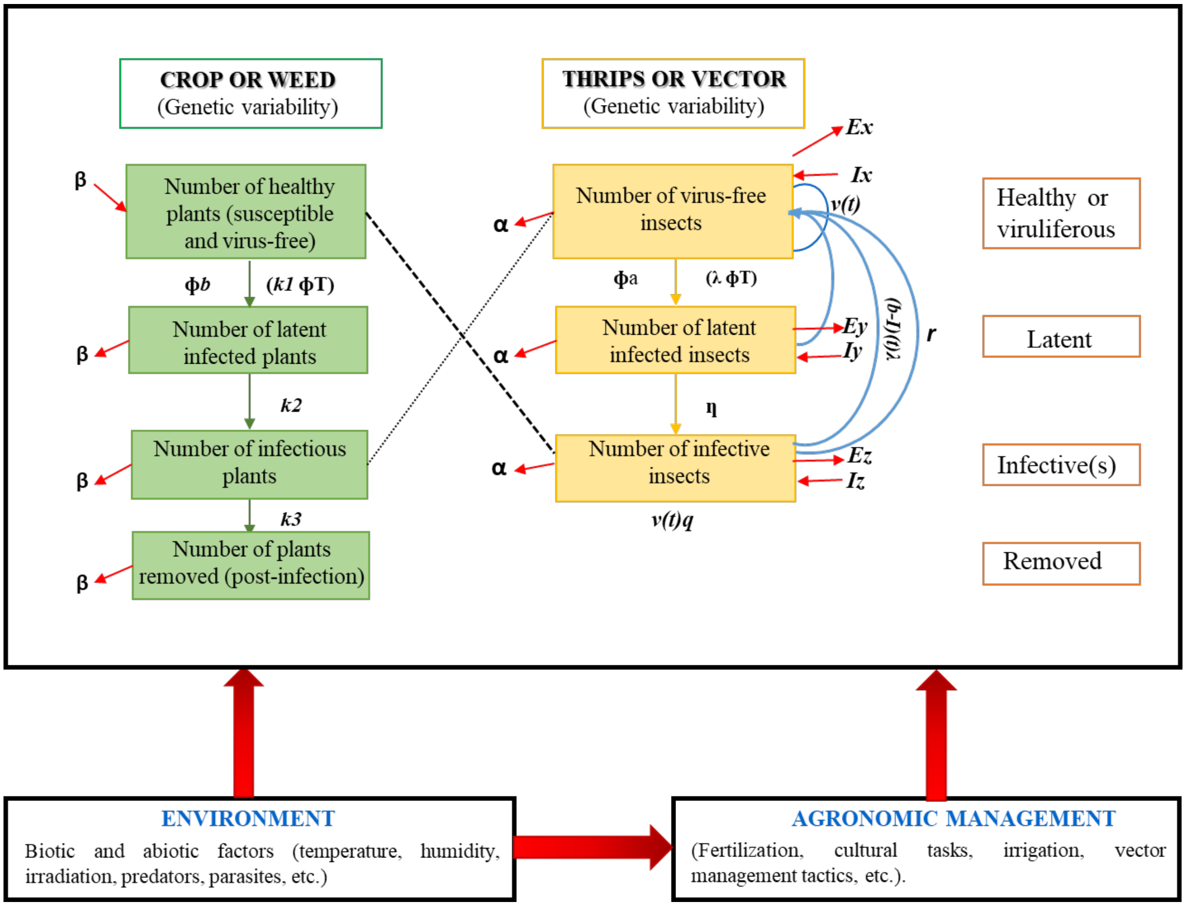

Figure 4. Epidemiological system of a viral pathosystem focused on *Iris yellow spot orthotospovirus* (based on and modified from Madden *et al*., 2000). Notes used: *v(t)*= Total fertility rate of the insect population per day within the crop. ***I*****=** Virus incubation time within the vector. ***q***= Probability that the offspring of the vector will be viruliferous. **β**= Plant mortality and recovery rate (replanting). **α**= Insect mortality and birth rate. **ϕ***b*= (Plants visited by insects per day) (Probability that the viruliferous insect inoculates the virus in a plant per visit). 1/k1= Time taken for the vector to inoculate the plant. 1/k2= Virus latency period in the plant. 1/k3= Infectious period of the virus in the plant. **ϕ**T= (Plants visited by insects per day) (Time taken for the insect to sample the plant in one visit). *Ex*= Rate of emigration of virus-free insects. *Ix*= Rate of emigration of virus-free insects. *Ey*= Rate of emigration of latent insects. *Ez*= Rate of emigration of infective insects. *Iy*= Rate of emigration of latent insects. *Iz*= Rate of immigration of infective insects. **1/λ =** Vector acquisition time. **ϕ***a*= (Plants visited by insects per day) (Probability that an insect will acquire the virus with a single visit to the infected plant). *1/η*= Time taken for the virus to transition from latent to infective within the vector (latency period). For further information, refer to Madden *et al*. (2000).

On the other hand, the presence of *T. tabaci* in vegetable is an important phytosanitary problem in Mexico (Palomo *et al*., 2015), since they are virus vectors and due to the direct damage they cause when feeding off the host causing premature wilting, a delay in leaf development and a distortion in vegetative sprouts (Aguilar *et al.,* 2017). In both immature and adult stages, they puncture the cells with their mouth apparatus and draw out the sap (Jones, 2005). Of the six life stages of the insect (egg, two larval instars, prepupa, pupa and adult) (Jones, 2005; Pourian *et al.,* 2009), the larvae of the first and second instar can acquire the virus through feeding, but only the larva from the second instar and adults transmit it (Sastry, 2013; Hull, 2001; Chatzivassiliou *et al.,* 2002). If the insect acquires the virus in an adult stage, it will not be able to transmit it (Jones, 2005; Whitfield *et al.,* 2005). It is imminent that, once the insect acquires the virus, it will reproduce and move efficiently through the midgut and the salivary glands of the thrips, without affecting the development, fertility and mortality of the insect upon virus infection (Inoue *et al.,* 2010). This insect is prolific, recording up to six generations in the crop cycle without being affected by rainfall (Palomo *et al*., 2015).

Alternate hosts are crucial for the IYSV epidemiology, particularly if *T. tabaci* finishes developing in the hosts (Hsu *et al.,* 2011). Due to this, the management of the alternate hosts are decisive for the comprehensive management of the disease (Schwartz *et al*., 2014; Wisler and Norris, 2005). This increases the interest in the study of the insect-IYSV-*Allium cepa*-alternate hosts (weeds), since these interactions tend to be complex. Rodríguez *et al.* (2007) emphasize the benefit of broadly understanding this relationship to optimize comprehensive management. These interactions can affect the appearance of new variants of the virus, a range of hosts and/or transmission frequency (Syller, 2012). Likewise, the capability of thrips to develop in other plants favors this type of interaction, since the absence of the main host incentivizes migration to other vegetative parts or the inflorescences of other plants (Milne and Walter, 1998).

In general, all IYSV management strategies have basically focused on precautionary activities that reduce *T. tabaci* populations and avoid the growth of weeds in the crop (Drost *et al*., 2019). The determination of vector and alternate host patterns of the virus and/or vector could help producers devise integrated management strategies in the crop (Birithia *et al.,* 2018).

However, the vector must not only be controlled chemically, but further research must be carried out to understand its behavior in the country. In Zacatecas, according to their needs, the behavior of the virus has been studied, and the presence of IYSV has been observed in onion seedlings in open field seedbeds, making it impossible for the vector to be present (Velásquez-Valle *et al.,* 2017). This type of problem leads to the belief that the sale of onion seedlings among onion-producing states increases the possibility of virus and vector movement. Faced with the possibility of a successful sale of their products, onion producers choose to abandon their plots, risking an increase of the virus and thrip populations (Velásquez-Valle *et al*., 2013). In many cases, management has been crucial to minimize the risks of viral infection of at least avoid severe damage to the crop. Turina *et al.* (2016) point out that, given the difficulty of combating thrips vectors with insecticides, the best way to mitigate or prevent diseases induced by *Orthotospoviruses* implies a strategy of virus-resistant seeds. Studies have been conducted in Mexico on 20 varieties regarding their performance against virus infection in Morelos. These results revealed that the varieties "Blanca Morelos," "Doña Blanca F1," "Línea INIFAP 19" and "Chona" have greater yields than the rest of the varieties in the presence of IYSV (Magos, 2011).

Conclusions

A comprehensive management should be considered that takes into account all factors that influence the IYSV epidemic into account in order to counteract the disease. Since its first report in the country (2010) onion cultivation has been a concern; despite its severity having decreased over time. A similar case occurred with the *Tomato brown rugose fruit virus* (ToBRFV), which was reported to cause severe damages to tomato and peppers in 2018 (Cambrón-Crisantos *et al.*, 2019); but currently, attenuated symptoms and the presence of haplotypes have been reported, which may be having an influence on the symptomatologic intensity on tomato and pepper plants (Ávila-Alistac *et al*., 2024). Early, accurate and efficient diagnose studies have been conducted on ToBRFV (Zamora-Macorra *et al*., 2023), as well as studies on the variability of the virus in different tomato and pepper varieties (Ávila-Alistac *et al*., 2024) and virus management alternatives (Ramos-Villanueva *et al*., 2023). However, little is known on its range of hosts and factors that influence the epidemiology of the virus. There is a greater knowledge of the host and vector of IYSV, although it is important to inquire with greater interest into this nationwide problem, since it has been reported in Solanaceae, which are of great economic importance in the country, as well as to consider the reemergence of the virus, according to crop management, genetic recombination among species of the same genus and even the influence of climate change, which has a bearing on the *T. tabaci* population dynamics.

Currently, information on weeds as IYSV and vector hosts provides a greater understanding of the disease, similarly to voluntary onion plants. Hence the importance of knowing these aspects, as well as the management carried out by the producers, since it is another crucial factor for the establishment of the vector and IYSV in the different phenological stages of the crop. There is evidently a complex relationship between IYSV- *T. tabaci –Allium cepa*-weeds and other *Orthotospoviruses* transmitted by *T. tabaci*; e.g., studying weeds as a plant trap can be beneficial, due to the feeding preference of *T. tabaci*, even in the presence of the crop. In addition, it should be considered that these weeds are not hosts of the virus, as they would be a problem by hosting the vector and the virus. In summary, knowledge of the virus, alternate hosts, and vector in the country will guide future research to help producers counteract this problem and minimize losses caused by the virus in onion and garlic crops, mainly.

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