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Drosophila suzukii Management in Latin America: Current Status and Perspectives

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Abstract

Spotted-wing drosophila, *Drosophila suzukii* Matsumura, was first established in Latin America in Mexico in 2011. The vinegar fly has since been detected in 296 municipalities in Argentina, Brazil, Chile, Mexico, and Uruguay. *Drosophila suzukii* is polyphagous and is found on 64 host plants in 25 families in Latin America, with most hosts also exotic species. In Latin America, *D. suzukii* is attacked by 14 species of parasitoid wasps in the families Diapriidae, Figitidae, and Pteromalidae, which are promising native parasitoids for control of the pest. This article analyzes results from studies on monitoring, biological, chemical, and cultural control, and sterile insect techniques to provide a basis for the development of area-wide and sustainable *D. suzukii* management programs in Latin America. The review examines how *D. suzukii* has been managed in Latin America and how research conducted in this region can contribute to management of the species in other parts of the world.

Key words: area-wide management, integrated pest management, neotropical region, areawide management, sustainable pest management

The spotted-wing drosophila *Drosophila suzukii* (Matsumura) is one of the most important invasive agricultural species (Garcia 2020a). The vinegar fly is a polyphagous pest that prefers hosts with thin epicarps, such as strawberry (*Fragaria* spp.) (Rosaceae), blackberry (*Rubus* spp.) (Rosaceae), blueberry (*Vaccinium* spp.) (Ericaceae), and raspberry (*Rubus* spp.) (Rosaceae) (Wollmann et al. 2020).

Native to Asia, *D. suzukii* was first detected outside its area of origin in Hawaii, although without any record of causing economic damage (O'Grady et al. 2002). In 2008, *D. suzukii* was detected simultaneously in the continental United States (Hauser 2011) and Europe (Calabria et al. 2012). The species is currently distributed in Asia, America, Europe, and Africa (Garcia 2020a). It has rarely been detected in Oceania, with two specimens found in French Polynesia in 2017 (EPPO 2021), even though the region has areas suitable for its establishment following invasion (dos Santos et al. 2017).

Rapid dispersion among countries and subsequent large agricultural losses demonstrate *D. suzukii* adapts easily to newly invaded areas (De Ros et al. 2013). Human activity is largely responsible for dispersion and colonization of *D. suzukii*, and the international trade of infested fruits is the primary means of fruit fly dispersion across continents (Westphal et al. 2008). Compared with native pests, natural enemies are less effective in controlling an exotic species invading a new territory, which leads to increases in populations and expanded distribution of the exotic (Keane and Crawley 2002, Roy et al. 2011). Currently, *D. suzukii* inhabits agroecosystems, native forests, and urban areas of Latin America (Garcia 2020a).

Latin America is a major fruit-exporting region, with an annual production of approximately 54 million tonnes of fruits and estimated total export value of US$11 billion (FAO 2019). Mexico has 44,000 ha cultivated with berries and produces approximately 800,000 tonnes/yr, with production of the soft fruits mainly in the states of Jalisco, Michoacán, Guanajuato, and Baja California, generating an export value of US$241 million and more than 350,000 jobs (Huerta 2019). Brazil is the third largest fruit-producing country in the world, with the production of 40 million tonnes/yr that generates 5 million jobs (ABRAFRUTAS 2021). Argentina has 4,203 ha of cultivated berries (Fagherazzi et al. 2017), reaching a total volume of 10,000 tonnes exported in 2020 (Agricultural Market 2021). Several provinces produce raspberry and blackberry, blueberry, strawberry, and cherry (Sánchez 2020). Chile has approximately 22,000 ha of cultivated berries, with approximately 180,000 tonnes exported in 2020 (USS 2021). Uruguay exported 95 tonnes of fruits, valued at more than US$72 million (Granja 2020).

The introduction of *D. suzukii* is a major threat to Latin American production and export of soft fruits (Garcia 2020a). However, the total economic impact of *D. suzukii* on different crops in Latin America has not been evaluated. Because most berries are produced for export, they must meet the high-quality standards required for commercialization, and therefore, economic losses extend beyond direct damage to fruits caused by the pest. Additional costs of materials, infrastructure, and personnel needed to implement surveillance and sanitization and control measures are difficult to measure, because they vary depending on pest status in a specific region, berry crop value, and the target market. In Chile, *D. suzukii* is estimated to cause average direct losses per year between 1.2 and 2.7 tonnes/ha of cherries, equivalent to 5,000 to 17,550 US$/ha, whereas in blueberries, losses are between 1 and 1.5 tonnes/ha, equivalent to 4,000 US$/ha (Buzzetti 2020). In Brazil, Benito et al. (2016) estimated average economic losses per year of US$ 21.4 million for peaches and US$7.8 million for figs. In Argentina, larvae in cherries, although not economically evaluated, cause problems in exporting those fruits to Australia and New Zealand because of quarantine restrictions (Cichón et al. 2019). This article provides an overview of *D. suzukii* introduction and establishment, its hosts and the damage it causes, and research on management in Latin America in order to determine future key strategies to mitigate economic impacts of the pest.

Historical Account of *D. suzukii* Invasion in Latin America

The first reports of *D. suzukii* in Latin America were in Costa Rica in 1997 and Ecuador in 1998, but it did not become established (Hauser 2011). Later, in 2011, *D. suzukii* was detected and became established in Mexico (SENASICA 2013), followed by Brazil in 2013 (Deprá et al. 2014), Uruguay in 2014 (González et al. 2015), Argentina in 2015 (Cichón et al. 2016), and Chile in 2017 (SAG 2017) (Fig. 1).

Drosophila suzukii was detected in the municipality of Los Reyes, Michoacán, in 2011. Subsequently, between 2012 and 2014, it was found in the nearby states of Colima, Jalisco, Guanajuato, Aguascalientes, and Querétaro, the state of Mexico, and the northern state of Baja California (SENASICA 2019). In 2015 and 2017, *D. suzukii* was discovered in Veracruz and Morelos (Lasa and Tadeo 2015, Bautista-Martinez et al. 2017). In 2015, *D. suzukii* was also trapped in Saltillo in the northern state of Coahuila. Owing to its status as a quarantine species, the Mexican government maintains an important monitoring program to prevent its possible spread, especially to the grape-producing region of the state of Sonora. To date, *D. suzukii* has not been detected in some Mexican states with favorable hosts and climatic conditions, including Puebla, Guerrero, Oaxaca, Tlaxcala, Hidalgo, and Chiapas (SENASICA 2019).

In Brazil, *D. suzukii* is currently found in eight states. The first records were in the states of Rio Grande do Sul and Santa Catarina (Deprá et al. 2014, Zazycki et al. 2019), which were followed by records in Paraná (Geisler et al. 2015), the Federal District (Paula et al. 2014), Rio de Janeiro (Bitner-Mathé et al. 2014), São Paulo (Vilela and Mori 2014), Minas Gerais (Andreazza et al. 2016), and Espirito Santo (Zanúncio Júnior et al. 2018). The species has not yet been registered in the state of Goiás, as was reported by Andreazza et al. (2016), because the area mentioned by the authors was actually in the Federal District (Paula et al. 2014). Southern Brazil is the most climatically favorable area for *D. suzukii* development and where potential economic losses are expected to be the highest (Benito et al. 2016, dos Santos et al. 2017). Moreover, *D. suzukii* is more likely to use areas with native vegetation than other exotic drosophilid species (Mendes et al. 2021).

In Argentina, *D. suzukii* was first recorded in 2014. The species is currently in the following provinces: Río Negro (Cichón et al. 2015), Buenos Aires (Santadino et al. 2015), Entre Ríos (Dìaz et al. 2015), Neuquén (Lochbaum et al. 2017), La Rioja (Lue et al. 2017), Tucumán (Funes et al. 2018a, b; Lavagnino et al. 2018), Santa Fé (Gonsebatt et al. 2017), and Mendoza (Dagatti et al. 2018). *Drosophila suzukii* was first detected in Uruguay in 2014 in damaged blueberries in Canelones and in banana-baited traps in Montevideo in the south of the country (González et al. 2015), from where it expanded to San José and Salto (Ferronato et al. 2019). In Chile, the pest was first detected in 2017 in adult traps placed along the Pucón-Villarrica Road in the Araucanía region (Bizama 2020).

The *D. suzukii* routes of invasion in Latin America are not clearly established. The introduction to Mexico, although not confirmed, was possibly from the United States considering the intense trade between countries and the great expansion of the pest in the United States beginning in 2008. In the years before South America was invaded, Brazil imported large volumes of potential host fruits from previously invaded countries, which may have been the main source of entry to Brazil and thereafter to Argentina. The invasion from Brazil to Argentina is supported because the two countries share *D. suzukii* haplotypes (de La Vega et al. 2020). In Brazil, the *D. suzukii* population originated from a genetic mixture of individuals from southwestern and eastern regions of the United States (Fraimout et al. 2017). Expansion of *D. suzukii* distribution from southern to southeastern Brazil was aided by human-mediated transport of fruits from region to region (Ferronato et al. 2019). Andreazza et al. (2017a) suggest there were two potential routes of *D. suzukii* invasion in southern parts of the Neotropical Region. One route was possibly from the southern region of Brazil, which had the first documented report of the pest in South America. The other possible route was along the Pacific coast of Chile, where the species was collected in the port of Valparaíso, which imports a variety of soft fruits from Asia. The invasion of Uruguay may have occurred from Brazilian populations. In Chile, in addition to detection in the port of Valparaiso, *D. suzukii* could have also arrived in contaminated fruits that entered by a tourist route from Argentina (González 2017).

In Latin America, as in other invaded regions, *D. suzukii* shows wide plasticity in adapting to different climates and environments. In South America, records mainly show niche expansion into areas with climatic conditions that are different from those in the native area of *D. suzukii*, including semiarid and cold climates in Argentina, hot temperate weather and with winter rains in Chile, and tropical ecosystems with well-defined dry and rainy periods in the central region of Brazil (dos Santos 2017). Similarly, in Mexico, *D. suzukii* is found in both the arid region of Baja California and the mesophilic cloud forest of Veracruz (Lasa and Tadeo 2015, SENASICA 2019). This high adaptability has led to large increases in the last four years in the number of municipalities with the pest in all countries invaded by *D. suzukii* (Fig. 2). Thus, the species is able to expand its distribution and rapidly colonize invaded regions. *Drosophila suzukii* dispersed very quickly in Chile, and detections increased from one municipality in 2017 to 184 in 2021 (Fig. 2). In the same period, the number of records almost doubled in Brazil, and in Argentina,

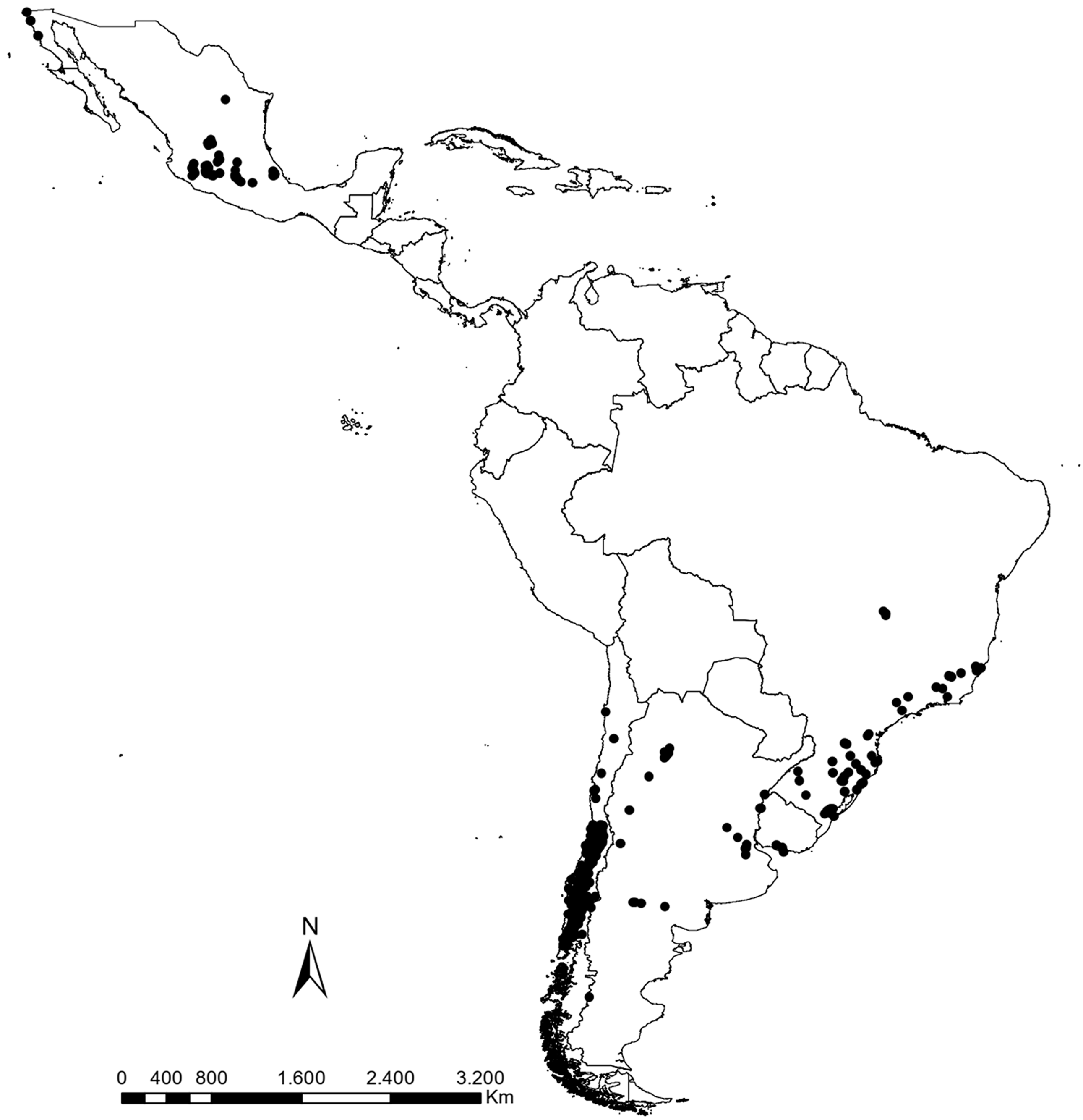

Fig. 1. Map of the current geographic distribution of *Drosophila suzukii* in Latin America.

it quadrupled. By contrast, dispersion rates in Mexico and Uruguay were much lower between 2017 and 2021 (Fig. 2).

The distribution of *D. suzukii* in the region may be greater than that currently recorded. The discrepancy is suspected because monitoring networks and entomologists trained in the identification of the species are lacking in some countries, pest density is low at the beginning of an invasion, and the species often inhabits areas of natural forests or agroecosystems that are rarely monitored for *D. suzukii* because the economic impact of the pest is low (Garcia 2020b). According to modeling, regions in South America where *D. suzukii* could potentially occur include the central region of southern Brazil, the southern half of Paraguay, all regions of Uruguay, East and South Argentina, the Pacific coast, and all regions of Chile. Among those potential regions, the most environmentally suitable areas for *D. suzukii* populations are in southern Chile and Uruguay, on the southern coasts of Brazil, and along the northern coast of Argentina (dos Santos et al. 2017). Models of distribution have also been developed for Mexico (Castro-Sosa et al. 2017), Argentina (de la Vega and Corley 2019), Brazil (Benito et al. 2016, dos Santos et al. 2017, Ferronato et al. 2019), and Chile (Bizama 2020).

Hosts of *D. suzukii* in Latin America

In Latin America, *D. suzukii* has been recorded in 64 species of host plants in 25 families (Table 1). The fruit fly attacks berries, stone fruits, and tropical fruits. The family Rosaceae has the most hosts with 21 species, followed by Myrtaceae with 10 species. *Drosophila suzukii* has more exotic hosts (60.9%) than native hosts in Latin

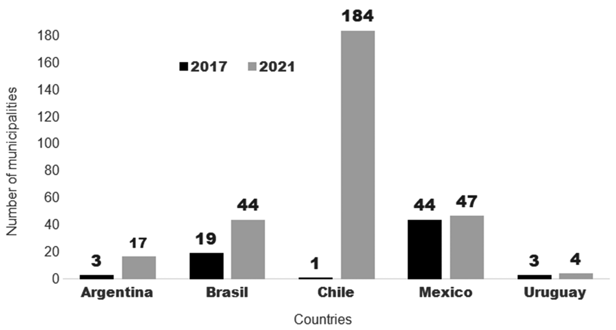

Fig. 2. Numbers of municipalities with records of *Drosophila suzukii* in Latin America. Information extracted from Andreazza et al. (2017a), SENASICA (2019), Bächli (2022).

America. Although most host plants are commonly distributed in countries of Latin America, *Vaccinium corymbosum* L. (northern highbush blueberry) and *Rubus idaeus* L. (raspberry) are the only *D. suzukii* hosts reported in all five countries where *D. suzukii* occurs (Table 1).

Most host plant species infested by *D. suzukii* also occur in the other countries of South and Central America that have not yet been invaded. Therefore, because of the many areas environmentally suitable for pest colonization (Santos et al. 2017), it is extremely important for governments of those countries not yet invaded to take phytosanitary measures to prevent *D. suzukii* entry.

Owing to its polyphagous nature and the great diversity of hosts in Latin America, *D. suzukii* populations can maintain high densities throughout the year. For example, Cattley guava (*Psidium cattleianum* Sabine) and Surinam cherry (*Eugenia uniflora* L.) serve as hosts of *D. suzukii* in off-season periods in Brazil (Wollmann et al. 2020). In Mexico, common guava (*Psidium guajava* L.), not previously reported as a *D. suzukii* host, can be heavily infested (Lasa et al. 2017a), and it has become an alternative host and reservoir for the pest. Other noncrop hosts such as loquat [*Eriobotrya jaonica* (Thunb.)] and wild black cherry (*Prunus serotina* Ehrh var. Capulli) are often near orchards and also provide shade and resting areas for the pest. Notably, *D. suzukii* also dominates the emergence from guava fruits infested with other drosophilid species in Argentina (Escobar et al. 2018) and Brazil (Mendes et al. 2019).

In Brazil, *D. suzukii* infestations are high in blackberry (40–65% damaged fruits) and strawberry (approximately 30% damaged fruits), but infestation in blueberry is significantly less (<7% damaged fruits) (Wollmann et al. 2020). In Argentina, the range of hosts for *D. suzukii* recently expanded, with the pest recorded in 14% of strawberry fields (Lochbaum 2017; Funes et al. 2021a, b) and also in mulberry and loquat fruits, with the latter on the edges of blueberry farms (Funes et al. 2021a). *Drosophila suzukii* has also been found in 64% of backyard fruit trees, which include persimmon, fig, apple, European and Asian pear, common plum, peach, and quince (Dettler et al. 2017, Segade 2020, Funes et al. 2021a). It was also collected from tree tomato (*Solanum betaceum* Cav.), with 8% of fruits damaged. The collection was the first record of *D. suzukii* on this Argentine native species (Funes et al. 2021a) (Table 1).

In Mexico, the economic impact of *D. suzukii* is primarily limited to blackberry and raspberry crops and to a lesser extent, blueberry and strawberry crops. Raspberry is the most damaged crop (20–40% damaged fruits). The high level of damage is most likely because the berries are highly attractive to *D. suzukii* and because it is the only berry crop that fruits during the entire summer season. By contrast, strawberry is the least damaged crop with approximately 2–5% infested fruits. However, when growers fail to remove overripe fruit in an effort to obtain better prices, damage can increase significantly in strawberries to 25–30% (Abraham et al. 2015). Loss of flesh firmness and reduction in force required to penetrate the skin combined with some attractive volatiles of ripe fruits may explain the increase in the level of damage at this stage (Lee et al. 2016). In Mexico, damage has not been reported in other susceptible crops, such as cherries and grapes, apparently because the pest is absent in the main production areas of those types of fruit.

Monitoring and Population Dynamics of *D. suzukii* in Latin America

Population dynamics of *D. suzukii* are variable in invaded areas of Latin America. Regardless of the type of trap and attractant used to capture these flies, densities of *D. suzukii* are highest from late spring to mid-fall in southern Brazil (Wollmann et al. 2019b). Temperature is the factor that most influences the seasonality of populations in the field and explains low numbers of catches during winter (Wollmann et al. 2019b).

In northwest and northeast regions of Argentina, the highest incidence of *D. suzukii* on blueberry is from November to December, with a second peak from April to May, primarily in regions approximately 2,200 m above sea level (e.g., Tafi del Valle, Tucuman). Santadino et al. (2015) also detected *D. suzukii* in blueberry fruits from November to December in the province of Buenos Aires, indicating that females prefer spring conditions to infest the crop. There were also some early captures of *D. suzukii* from September to November in baited traps, but no fruit damage was recorded in that period. The winters morphotype of *D. suzukii* females, i.e., those that mated in the fall and hibernated, may have mature eggs in early spring and infest earlier maturing berries as well as any other suitable uncultivated fruit produced at the same time. Such early infestation facilitates development of the first generation of the summer *D. suzukii* morphotype and increases the pest population in late spring (Panel et al. 2018).

In Mexico, population dynamics of *D. suzukii* vary depending on region, predominant berry crops, pest management practices, and climatic conditions, among other factors. However, in general, populations of *D. suzukii* in the main berry-growing region are stable and relatively low between September and January, but numbers begin to increase significantly from January to February. The increase is concurrent with warmer temperatures and the start of the fruiting season and coincides with the end of blackberry and strawberry harvests. Populations increase from April to May at the beginning of the rainy season and the final harvests of blackberry and strawberry. From May to June, when strawberry and blackberry production has ended, *D. suzukii* infests raspberry, a crop that can have year-round production and in which *D. suzukii* reaches its maximal population levels between July and August (Saide Aguas, pers. comm.). The main production of berries in the region occurs between 1,300 and 1,700 m above sea level, although some crops, particularly blueberry, are produced at higher altitudes. Notably, significant populations of *D. suzukii* have not been observed in berry crops above 1,800 m above sea level in Mexico (R. Hernández-Toledo, pers. comm.), which is an observation that deserves further investigation because of the possible influence of atmospheric pressure.

Use of baited traps is an essential strategy to monitor flies before decisions are made regarding control. For example, in Mexico, one to two monitoring traps per hectare are commonly placed during the vegetative phase of a crop, but trap numbers typically increase to five to six traps/ha during fruiting season. Although

Table 1. Host plants of *Drosophila suzukii* in invaded countries of Latin America. Host plant origin: E, exotic; N, native. Country: A, Argentina; B, Brazil; C, Chile; M, Mexico; U, Uruguay[a]

Host Plant	Common name	Origin	Countries	References
Actinidiaceae				
Actinidia chinensis Planch	Kiwi	E	B	Andreazza et al. (2017a), Garcia (2020)
Actinidia arguta (Siebold & Zucc.) Planch	Hardy kiwi	E	C	SAG (2021)
Aquifoliaceae				
Ilex aquifolium L.	Holly	E	C	SAG (2020)
Anacardiaceae				
Spondias mombin L.	Yellow mombin, tropical plum	N	M	Castro-Sosa et al. (2017)
Araliaceae				
Fatsia japonica (Thunb.)	Glossy-leaf paper plant	E	C	SAG (2020)
Hedera helix L.	Common ivy	E	C	SAG (2020)
Hedera rhombea Siebold and Zucc.	Japanese ivy	E	C	SAG (2020)
Arecaceae				
Butia capitata (Mart.)	Butia	N	U	Garcia (2020), B. Goñi personal information
Butia yatay (Mart.)	Butia	N	U	Garcia (2020), B. Goñi personal information
Caricaceae				
Carica papaya L.	Papaya	N	B	Zanúncio Júnior et al. (2018)
Cornaceae				
Cornus sp.	Dogwood	E	C	SAG (2020)
Ebenaceae				
Dispyro kaki Thunberg	Kaki	E	A, B, U	Andreazza et al. (2017a), Lauyé (2017), Funes et al. (2021a)
Elaeocarpaceae				
Aristotelia chilensis (Molina)	Chilean wineberry	N	C	Buzzetti (2020)
Ericaceae				
Vaccinium ashei Reade	Rabbiteye blueberry	E	U	González et al. (2015)
Vaccinium corymbosum L.	Northern highbush blueberry	E	A, B, C, M, U	Vilela and Mori (2014); Santadino et al. (2015); Lauyé (2017); Funes et al. (2018a,Funes et al. 2018b, Funes et al. 2019); Buzzetti (2020); Segade (2020) ; Toledo-Hernández et al. (2021)
Ginkgoaceae				
Ginkgo biloba L.	Ginkgo	E	U	Garcia (2020), B. Goñi personal information
Loranthaceae				
Notanthera heterophylla Ruiz and Pav.	Quintral del boldo	N	C	SAG (2020)
Lythraceae				
Punica granatum L.	Pomegranate	E	U	Garcia (2020), B. Goñi personal information
Malpighiaceae				
Malpighia emarginata DC.	Barbados cherry	N	B	Louzeiro et al. (2019, 2020); Mendonça et al. (2019)
Byrsonima crassifolia (L.) Kunth	Nance	N	M	Castro-Sosa et al. (2017)
Melastomataceae				
Miconia albicans (Sw.)	Elder's shin	N	B	Ramos et al. (2017)
Miconia fallax DC.	–	N	B	Ramos et al. (2017)
Monimiaceae				
Peumus boldus Molina	Boldo	N	C	SAG (2020)

Table 1. Continued

Host Plant	Common name	Origin	Countries	References
Moraceae				
Morus nigra L.	Mulberry	E	A, U	Garcia (2020), B. Goñi personal information, Funes et al. (2021a)
Ficus carica L.	Figs	E	A, C, M, U	Lauyé (2017), Bautista-Martínez et al. (2017), Dettler et al. (2017), Segade (2020), SAG (2021), Funes et al. (2021a)
Myrtaceae				
Acca sellowiana Burret	Feijoa	N	B, U	Andreazza et al. (2017a), Lauyé (2017), Souza et al. (2017)
Blepharocalyx salicifolius (Kunth)	Arrayán	N	B	Ramos et al. (2017)
Eugenia involucrata DC.	Cherry of Rio Grande	N	B	Geisler et al. (2015)
Eugenia uniflora L.	Surinam cherry	N	B	Geisler et al. (2015)
Luma apiculata DC.	Chilean myrtle	N	C	SAG (2020)
Myrceugenia planipes (Hook. et Harn.)	Valdivia's patagua	N	C	SAG (2020)
Psidium cattleianum Sabine	Cattley guava	N	A, B, M, U	Andreazza et al. (2017a), Lauyé (2017), Zanúncio Júnior et al. (2018), Wollmann et al. (2020), R. Lasa personal information
Psidium guajava L.	Common guava	N	A, B, M	Andreazza et al. (2017a), Lasa et al. (2017b), Escobar et al. (2018), Mendes et al.(2019), Funes et al. (2021a)
Syzygium cumini (L.) Skeels	Jambul	E	B	Rampasso and Vilela (2017)
Ugni molinae Turcz.	Chilean guava	N	C	SAG (2020)
Passifloraceae				
Passiflora caerulea L.	Passion fruit	N	U	Garcia (2020), B. Goñi personal information
Rosaceae				
Cotoneaster franchetii Bois	Cotoneaster	E	C	SAG (2021)
Cydonia oblonga Mill.	Quince	E	A	Segade (2020), Funes et al. (2021a)
Eriobotrya japonica (Thunb.)	Loquat	E	A, B, M	Geisler et al. (2015), Funes et al. (2021a), R. Lasa personal information
Fragaria × ananassa Duch.	Strawberry	E	A, B, C, M	Andeazza et al. (2017a); Schlesener et al. (2017a); Zanúncio Júnior et al. (2018); Wollmann et al. (2020); SAG (2020); Lochbaum (2017); Funes et al. (2021a,Funes et al. 2021b)
Malus domestica L.	Apple	E	A, B	Andreazza et al. (2017a), Funes et al. (2021a)
Prunus armeniaca L.	Apricot	E	A, B	Andreazza et al. (2017a), Dettler et al. (2017)
Prunus avium L.	Sweet cherry	E	A, B, C	Andreazza et al. (2017a), Lochbaum (2017), Dettler et al. (2017), Buzzetti (2020), Gómez-Segade et al.(2021)
Prunus cerasifera Ehrh	Cherry Plum	E	C	Buzzetti (2020)
Prunus cerasus L.	Sour cherry	E	A, C	Buzzetti (2020), Dettler et al. (2017)
Prunus domestica L.	Common plum	E	A, B, C	Andreazza et al. (2017a), Dettler et al. (2017), Segade (2020), Funes et al. (2021a)
Prunus persica L.	Peach	E	A, B, C	Geisler et al. (2015), Dettler et al. (2017), Foppa et al.(2018), SAG (2020)
Prunus persica var. nectarina	Nectarine	E	A	Gómez-Segade et al. (2021)
Pyrus communis L.	European pear	E	A, B, U	Andreazza et al. (2017a), Lauyé (2017), Funes et al.(2021a)
Prunus serotina var. Capuli	Wild black cherry	E	M	Rebollar-Alviter personal information

Table 1. Continued

Host Plant	Common name	Origin	Countries	References
Pyrus pyrifolia (Burm.) Nak	Asian pear	E	A, B	Andreazza et al. (2017a), Dettler et al. (2017)
Rosa moschata Herm.	Musk rose	E	C	SAG (2020)
Rubus fruticosus L.	Blackberry	E	A, B, M	Andreazza et al. (2017a), Lasa et al. (2017b), Lochbaum (2017), Dettler et al. (2017), Funes (2018a), Funes et al. (2019)
Rubus idaeus L.	Raspberry	E	A, B, C, U, M	Santadino et al. (2015); Alexandre (2016); Cichón et al. (2016); Lauyé (2017); Andreazza et al. (2017a); Escobar et al. (2018); Funes et al. (2019); Lasa et al. (2019); SAG (2020); Gómez-Segade et al. (2021), Cichón et al. (2016); Escobar et al. (2018); Lochbaum (2017); Funes et al. (2018a, b); Lavagnino et al. (2018)
Rubus ulmifolius Schott	Elmleaf blackberry	E	C, U	Lauyé (2017), Buzzetti (2020)
Rubus adenotrichus Schltd	Wine blackberry	N	M	Castro-Sosa et al. (2017)
Rubus L. subgen. *Rubus* Watson	Blackberry	E	A	Dagatti et al. (2018)
Rubiaceae				
Psychotria suterella Muell.	–	N	B	Conde et al. (2019)
Rutaceae				
Citrus sinensis L.	Orange	E	U	Lauyé (2017)
Sapindaceae				
Allophylus edulis (ASt.Hil)	Chal-chal	N	U	Garcia (2020), B. Goñi personal information
Smilacaceae				
Smilax aspera L.	Zarzaparilla	E	C	SAG (2021)
Solanaceae				
Solanum betaceum Cav	Tomato tree Tamarillo	N	A	Funes et al. (2021a)
Vitaceae				
Vitis labrusca L.	Fox grape	E	B	Andreazza et al. (2017a)
Vitis vinifera L.	Grape vine	E	B, C, U	Andreazza et al. (2017a), Lauyé (2017), SAG (2021)

[a]Modified and updated table from Garcia (2020b).

there is no specific consensus among Mexican growers, the treatment threshold is usually considered to be approximately two flies per trap per day in at least two traps, or when one of the traps has two flies per trap per day in two consecutive weeks (R. Lasa, pers. observation).

In Mexico, 0.5–1-liter transparent traps baited with apple cider vinegar are recommended (SENASICA 2014). However, traps constructed using plastic bottles (Ibarra-Bautista et al. 2014) or opaque, red polyethylene cups (Lasa et al. 2017b), both modified with different access holes and with red–black visual stimuli, are increasingly used by growers to reduce costs and improve *D. suzukii* captures. In Brazil, use of SWDTRAP model traps (Wollmann et al. 2017) is suggested to standardize research and monitoring.

The attractiveness of apple cider vinegar is similar in several commercial brands in Mexico and is similar to that of wine vinegar. However, apple cider vinegar is significantly more effective in capturing *D. suzukii* than other apple-flavored vinegars that have a lower cost, because they are formulated with cane vinegar and added colorants and flavors (Lasa et al. 2020). Among vinegars evaluated in Mexico, an agricultural-grade apple cider vinegar that contained high amounts of apple debris and fermentation products was significantly more effective than commercial apple vinegars and Droskidrink, a mixture of apple cider vinegar, wine, and cane sugar that is widely used in Europe (Lasa et al. 2020). Yeast–sugar–water mixtures and other actively fermenting attractants generate higher capture levels than apple vinegar or other commercial attractants such as SuzukiiTrap (Bioibérica, Barcelona, Spain), Suzukii Trap Max Capture (Bioibérica), Z-kinol (Squid Biological and Pheromones, Texcoco, Mexico), and Pherocon SWD (Trécé Inc., Adair, OK) (Lasa et al. 2017b, Toledo-Hernández et al. 2021). In Brazilian field conditions, Droskidrink had higher captures of *D. suzukii* females than those with CeraTrap, Torula, Biofruit, SuzukiiTrap, and apple cider vinegar but was not selective in the capture of nontarget insects (Wollmann et al. 2019a, Brilinger et al. 2021). Fermenting attractants have less selectivity for *D. suzukii* than most commercial attractants (Iglesias et al. 2014; Lasa et al. 2017b, Lasa et al. 2019), although the specificity of attractants for *D. suzukii* is variable between crops and trials and can vary with type of crop management (Lasa et al. 2019, Toledo-Hernández et al. 2021). Natural fermentation of noncommercial raspberry fruits mixed with sugar and water is as effective as apple cider vinegar, although the mixture is less effective than a two-component trap that combines apple cider vinegar plus ethanol and a mixture of active yeasts with sugar (Lasa et al. 2019). Uncollected fruits on the ground in late crop periods strongly favor the presence of other drosophilids that tend to reduce trap specificity (Lasa et al. 2017a, Toledo-Hernández et al. 2021).

Biological Control of *D. suzukii* in Latin America

Biological control of *D. suzukii* in Latin America has focused mainly on the use of parasitoids, although nematodes, predators, and fungal entomopathogens have also been explored as biological control agents.

Parasitoids

In Latin America, parasitoid wasps of *D. suzukii* include 14 species in the families Diapriidae, Figitidae, and Pteromalidae (Hymenoptera) (Table 2). Figitids are larval parasitoids, whereas the other two families are pupal parasitoids (Garcia et al. 2020). Figitidae has the highest richness of parasitoid species of *D. suzukii* in the Neotropics with eight species in five genera. In Diapriidae, there are three species in one genus, and in Pteromalidae, there are three species in two genera. Parasitoids of *D. suzukii* have been recorded in Argentina, Brazil, Mexico, and Uruguay but not in Chile.

Argentina has the highest richness of parasitoid species (71.4%), followed by Mexico with 35.7% (Table 2). In addition to the parasitoids associated with *D. suzukii* reported by Kirschbaum et al. (2020), other species have recently been identified: *Dieucoila octoflagella* Reche (Figitidae), *Dicerataspis* sp. (Figitidae), *Ganaspis brasiliensis* Ihering (Figitidae) (Fig. 3A), *Pachycrepoideus vindemmiae* Rondani (Pteromalidae) (Fig. 3C), and *Spalangia endius* Walker (Pteromalidae) (Fig. 3D) (Funes et al. 2020, Gallardo et al. 2021, Gomez-Segade et al. 2021, Reche et al. 2021).

Trichopria anastrephae Lima (Fig. 3E) was first observed parasitizing pupae of *D. suzukii* in the state of Rio Grande do Sul (Brazil) (Garcia et al. 2017). This parasitoid is less sensitive to insecticides (Schlesener et al. 2019) and has a competitive advantage over *P. vindemmiae* (da Costa Oliveira et al. 2021). In Brazil, *T. anastrephae* is reared in the laboratory with adults fed either pure honey (100%) or honey diluted to 50% in water (Vieira et al. 2020). Competition among females of this parasitoid does not impair offspring viability, and host deprivation for up to 7 days does not influence parasitism capacity, indicating *T. anastrephae* can be used as a pre-release strategy (Krüger et al. 2019a). *Trichopria anastrephae* is found only in South America, where it commonly parasitizes pupae of the genus *Anastrepha* (Diptera: Tephritidae) in Argentina, Brazil (Goiás, Minas Gerais, Rio de Janeiro, Rio Grande do Sul, and Santa Catarina), and Venezuela (Garcia and Corseuil 2004, Cruz et al. 2011, Garcia and Ricalde 2013).

Trichopria drosophiliae Perkins (Hymenoptera: Daipriidade) (Fig. 3F) seems to be cosmopolitan with a wide distribution and attacks pupae of *D. suzukii* in Europe, North America, and Asia (Yi et al. 2020). In a study in Mexico on releases of *T. drosophiliae* and *Leptopilina boulardi* Barbotin, Carton, and Kelner-Pillault (Hymenoptera: Figitidae) (Fig. 3B), individually or combined, González-Cabrera et al. (2019) observed a 50% reduction in *D. suzukii* populations in areas with individual releases and a 55% reduction in areas with releases of both species. Those results indicate that releases of *T. drosophilae* alone may be a more economical option to reduce *D. suzukii* populations (González-Cabrera et al. 2019). Parasitoids *T. anastrephae* in Brazil (Fig. 4A) and *T. drosophiliae* in Mexico (Fig. 4B) have been reared in *D. suzukii* pupae.

Ganaspis brasiliensis was identified as a parasitoid of *D. suzukii* in Mexico, and although not parasitizing *D. suzukii*, the species has also been found in Brazil and Panama (González-Cabrera et al. 2020). Differences in hosts should be investigated further with this species, because *G. brasilensis* has recently been reported to include at least two cryptic species with marked differences in suitability as biological control agents (Seehausen et al. 2020).

Pachycrepoideus vindemmiae is not considered to be a promising parasitoid for use in augmentative biological control programs. The parasitoid has low specificity (Garcia et al. 2017), is susceptible to insecticides (Schelesener et al. 2019), and is a facultative hyperparasitoid of parasitoids of the tephritid fruit flies *Anastrepha* spp. and *Ceratitis capitata* (Wied.) (Garcia et al. 2020b).

Other Biological Control Agents

Among entomopathogenic nematodes evaluated, *Heterorhabditis indica* Poinar, Karunakar & David IBCBn 05; *H. amazonensis* Andaló et al. IBCBn 24; *Steinernema carpocapsae* Weiser IBCBn 02; and *S. feltiae* (Filipjev) IBCBn 47 infected pupae of *D. suzukii*, with 35, 16, 13, and 43% becoming nonviable, respectively, and also adults, with 47, 80, 84, and 57% mortality, respectively (Brida et al. 2019). Adults of *D. suzukii* infected with *S. rarum* PAM 25 had a significant reduction in longevity (dos Santos et al. 2022). The predatory mites *Stratiolaelaps scimitus* Berlese (Mesostigmata: Laelapidae) and *Macrocheles muscaedomesticae* (Scopoli) (Mesostigmata: Macrochhelidae) can be effective predators of *D. suzukii* eggs. In the laboratory, *S. scimitus* consumed from 5 to 14 eggs per day and *M. muscaedomesticae* consumed from 3 to 17 eggs per day (Silva et al. 2018). In Argentina, *Chrysoperla externa* (Hagen) (Neuroptera, Chrysopidae) was evaluated as potential predators of *D. suzukii* under laboratory conditions. Third instar larvae consumed both larvae and pupae of *D. suzukii* (Dettler et al. 2017).

Entomopathogenic fungi from the collection of the National Reference Center of Biological Control (CNRCB) in Mexico, including *Isaria fumosorosea* Wize, *Metarhizium anisopliae* (Metchnikoff), and *Cordyceps bassiana* Li et al., have been explored for control of *D. suzukii*. They appear to be promising agents that can contribute to future *D. suzukii* control by incorporating them into area-wide management programs (Naranjo-Lázaro et al. 2014, Peralta-Manzo et al. 2014). Recently, a new isolate of *Isaria javanica*, also from the CNRCB collection, caused rapid mortality of *D. suzukii* adults under laboratory conditions, making it a good candidate for future field experiments (Gutierrez-Palomares et al. 2021).

Chemical Control of *D. suzukii* in Latin America

Among the countries in Latin America, Chile has the largest list of authorized active ingredients (13 products) for control of *D. suzukii*, which includes chemicals such as avermectin, neonicotinoids, organophosphates, and pyrethroids and also two essential plant oils. By contrast, there are no specific insecticides currently registered

Table 2. Parasitoids of *Drosophila suzukii* in invaded countries of Latin America, with evaluation of their efficiency in the laboratory or field. Country: A, Argentina; B, Brazil; M, Mexico; U, Uruguay. RP, rate of parasitism; E, emergence; H, high; L, low; N, none[a]

Type of parasitoid	Countries	RP[b]	E[b]	References
Larval parasitoids				
Figitidae				
*Dicerataspis*sp.	A	–	–	Buonocore-Biancheri et al. (2021)
Dieucoila octoflagella Reche et al.	A	–	–	Reche et al. (2021)
Ganaspis brasiliensis Ihering	M	H	H	González-Cabrera et al. (2020); Wang et al. (2018, Wang et al. 2019, Wang et al. 2020b); Toledo-Hernández et al. (2021)
Ganaspis hookeri Crawford	A	–	–	Lue et al. (2017)
Ganaspis sp.	A	–	–	Funes et al. (2019)
Leptopilina boulardi Barbotin, Carton and Kelner-Pillault	A, B, M	L	N	Chabert et al. (2012); Kacsoh and Schlenke (2012); García-Cancino et al. (2015); Garrido et al. (2018); González-Cabrera et al. (2019, 2020); Mazzetto et al.(2016); Wollmann et al. (2016)
Leptopilina clavipes (Hartig)	A	L	N	Kacsoh and Schlenke (2012), Lue et al. (2017)
Hexacola sp.	A	–	–	Funes et al. (2019)
Pupal parasitoids				
Diapriidae				
Trichopria anastrephae Lima	B, U	H	H	Wollmann et al. (2016), Krüger et al.(2019a), Schlesener et al. (2019), Vieira et al. (2020)
Trichopria drosophilae Perkins	M	H	H	García-Cancino et al. (2015); Gonzalez-Cabrera et al. (2019, 2020); Rossi-Stacconi et al. (2015, Rossi-Stacconi et al. 2017, Rossi-Stacconi et al. 2018, Rossi-Stacconi et al. 2019); Wang et al. (2016a, Wang et al. 2016b, Wang et al. 2018b); Kaçar et al. (2017); Knoll et al.(2017); Wolf et al. (2019); Yi et al. (2020)
Trichopria sp.	A	–	–	Funes et al. (2019)
Pteromalidae				
Pachycrepoideus vindemmiae Rondani	A, B, M	H	H	Chabert et al. (2012); Gabarra et al. (2015); García-Cancino et al. (2015); Moreno-Carrillo et al. (2015); Rossi-Stacconi et al. (2015); Kaçar et al.(2017); Wang et al.(2016a,Wang et al. 2016b,Wang et al. 2018); Knoll et al.(2017); Zhu et al.(2017); Bonneau et al. (2019); Da Silva et al. (2019a,Da Silva et al. (2019b); Funes et al. (2019); Schlesener et al. (2019)
Spalangia endius Walker	A	–	–	Gómez-Segade et al. (2021)
Spalangia simplex Perkins	M	–	–	García-Cancino et al. (2015)

[a]Modified and updated table from Garcia (2020b) and Wang et al. (2020a).
[b]Studies were conducted with *D. suzukii* larvae or pupae presented either in artificial diet or contained fruit.

for *D. suzukii* control in Uruguay. In Argentina, the insecticides chlorantraniliprole, lambda-cyhalothrin, and spinetoram were recently authorized for *D. suzukii* control in blueberry, raspberry, and cherry crops, and abamectin and cyantraniliprole were also authorized for control in tomato tree (SENASA, personal communication). The insecticides abamectin, spirotetramat, emamectin benzoate, and methomyl are candidates for registration against *D. suzukii* in Argentina (Cichón et al. 2019). In Brazil, the only insecticide authorized for *D. suzukii* control is spinetoram, for use in blackberry, blueberry, raspberry, and grape (AGROFIT 2021). Although the pest causes losses that can reach 30% of production in strawberry in Brazil (Santos 2014), spinetoram has not been registered for that crop, most likely because of the risk of contamination from chemical residues during pre-harvest or ripening periods, which is also when the likelihood of *D. suzukii* infestation increases (Andreazza et al. 2017b). In México, spinosyns are the most widely used and best performing insecticides against *D. suzukii* in the field. However, other pesticides recommended for control of other berry pests (e.g., thrips, whiteflies, and mites), such as pyrethroids, carbamates, and neem extracts, also affect *D. suzukii* populations and are sometimes integrated for its control.

Some insecticides have systemic activity and kill *D. suzukii* eggs and larvae inside fruits. The insecticides fenitrothion, malathion, and methidathion reduce the viability of *D. suzukii* eggs by 100% (Schlesener et al. 2017b), whereas cyantraniliprole, dimethoate, lambda-cyhalothrin, malathion, spinetoram, and spinosad have high larvicidal activity (Andreazza et al. 2017b).

The selectivity of insecticides to *D. suzukii* parasitoids was examined in Brazil. Spinosyns (spinosad and spinetoram) and abamectin caused high mortality rates in *P. vindemmiae* but were harmless to *T. anastrephae*. Neonicotinoids, organophosphates, and pyrethroids caused high mortality rates in *P. vindemmiae* compared with those in *T. anastraphae* (Schlesener et al. 2019). Exposure to sublethal concentrations of lambda-cyhalothrin led to a higher percentage of *D. suzukii* mating couples, whereas thiamethoxam exposure resulted in higher fecundity, and such stimulatory effects on *D. suzukii* can lead to outbreaks and insecticide resistance (Krüger et al. 2021a).

Insecticides can be applied in toxic baits to specifically target a pest, which reduces effects of insecticides on natural enemies and avoids chemical residues (Mangan et al. 2014). Mortality rates of *D. suzukii* adults reach 65% with the homemade formulation

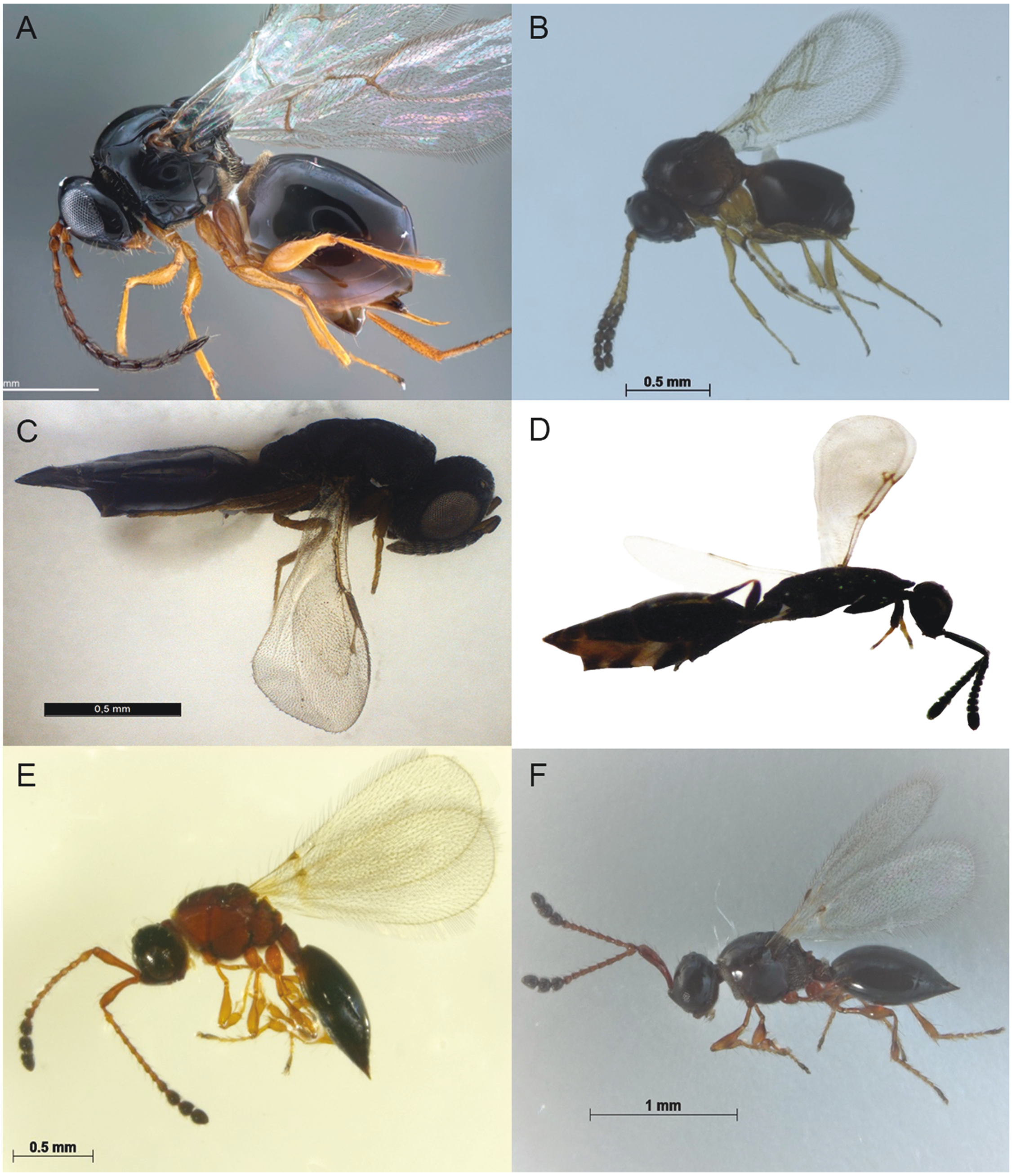

Fig. 3. Some parasitoids os *Drosphila suzukii* in LA; A) *Ganaspis brasiliensis*, (B) *Leptopilimia boulardii*, (C) *Pachycrepoideus vindemmiae*, (D). *Spanalgia endius*, (E) *Trichopria anastrephae*, (F) *Trichopria drosophiliae*.

of Droskidrink + 0.3% sugar + 0.15% malathion (Brilinger et al. 2021). Although a toxic bait containing a mixture of sucrose, invert sugar, glycerol, apple juice, and yeasts with spinosad was effective under laboratory conditions, promising results were not observed when it was applied directly to the crop (Aguas-Lanzagorta 2019).

Sterile Insect Technique as a Potential Management Tool for *D. suzukii* in Latin America

Sterile insect technique in *D. suzukii* management remains in the experimental phase. Research has focused on determining the appropriate radiation dose for sterilization; the best way to rear the pest in the laboratory; biology, behavior, and ecology of sterile insects; and compatibility of the technique with biological control.

At the Federal University of Pelotas in Brazil, development of an artificial diet (Schlesener et al. 2017a, Schlesener et al. 2018) and determination of the most suitable temperature to raise *D. suzukii* (Schlesener et al. 2020) led to several research projects on the species and its parasitoids, as well as testing of sterile insect technology (SIT) in South America. The first research project using SIT against *D. suzukii* in South America was 'Evaluating the use of sterile insects and pupal parasitoids to manage *Drosophila suzukii* in greenhouse' that began in 2017 in Brazil. The Insect Ecology Laboratory of the Biology Institute of Universidade Federal de Pelotas coordinated the project, and the International Atomic Energy Agency provided funds (Garcia 2020b). In addition to Brazil, SIT has been developed in Mexico

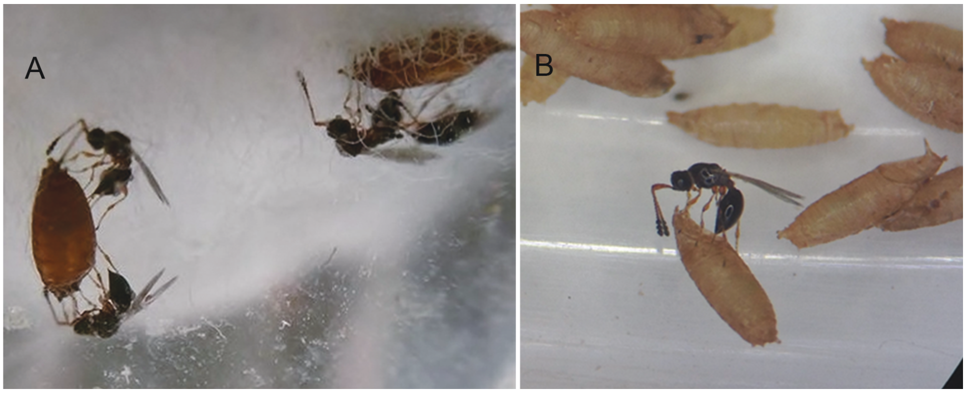

Fig. 4. Parasitoids being reared in *Drosophila suzukii* pupae; (A) *Trichopria anastrephae*, (B) *Trichopria drosophiliae*.

and is in the experimental stage in Argentina. In Mexico, *D. suzukii* adults are reared on a diet of coconut fiber + Brewer's yeast, because it produces the highest number of pupae per gram of diet and the maximum bioconversion (6%) (Aceituno-Medina et al. 202). In Plexiglas cages (30 × 40 × 30 cm) loaded with 5,000 adults and stocked with 500 g of coconut fiber and Brewer's yeast diet distributed in a 3-cm thick layer in 15 × 5 × 10-cm plastic trays, at least 84,000 *D. suzukii* pupae were produced per day (Aceituno-Medina et al. 2020).

Sterility in *D. suzukii* is achieved with gamma radiation at 75 Gy in females and 200 Gy in males (Krüger et al. 2018). Sterile males have shorter copulation times than those not exposed to radiation (Krüger et al. 2019b). Sterile *D. suzukii* flies perform better when provided with food and when exposed to temperatures between 15 and 25°C and relative humidity above 60% (Krüger et al. 2021b).

Other Control Methods

Some measures of cultural control can prevent *D. suzukii* populations from rapidly increasing and thus minimize chemical use for control. Measures have been described for different crops in Chile (SAG 2020), Argentina (Funes et al. 2018b), Brazil (Garcia 2020b), and Mexico (SENASICA 2014).

Growers use mass trapping primarily by distributing traps around the perimeter or at the entrance of polytunnels (large tunnel made of polythene). For example, some growers place five traps in two rows (staggered pattern, separated by approximately 1.5–2.0 m) at the entrance of each polytunnel (6.6 m wide) as a strategy to prevent the entry of *D. suzukii* flies. Conventional mass trapping systems, including traps distributed homogeneously within a crop, have not produced satisfactory results in Mexico when using 50 traps/ha baited with agricultural grade vinegar (R. Lasa, unpublished data). Some growers report good control using 300 traps/ha, but that number of traps is costly, and many growers prefer to control the pest by placing fewer traps along the perimeter or at the entrances of polytunnels. It is also essential to control *D. suzukii* in urban areas, such as in grocery stores, which can be achieved by eliminating infestations in residues of host fruits using solarization or freezing before they are discarded (Santos et al. 2017).

Insect nets for physical control (mesh size: 0.98 to 1 mm × 0.6 mm) have been recommended in Argentina to protect cherry and other small fruit crops (Cichón et al. 2016).

Future Perspectives

Implementation of additional and improved control strategies for *D. suzukii* in different berry crops is one of the primary demands of growers in Latin America. Increased understanding of crop damage, biology, and ecology of *D. suzukii* across different crops and seasons could lead to the development of multiple control tools that could reduce insecticide applications and associated environmental impacts (Schlesener et al. 2015, 2017c; Garcia 2020c). In general, there is a lack of insecticides registered to control this pest in almost all countries in Latin America, primarily due to organic production. Although spinosad and spinetoram are the most effective insecticides to control the pest, they are being used more frequently than recommended (Garcia F.RM and Lasa RL, pers. information), which may result in the development of resistance. The search for new insecticides that are safe and have a reduced postharvest interval should be one of the research priorities for the management of *D. suzukii*. As an example, a patent was submitted by the Universidade Federal de Pelotas of Brazil (Garcia et al. 2016) for a newly developed nontoxic insecticide to control *D. suzukii*, which could be an additional tool in the future management of this pest.

Although a few studies in Latin America have focused on developing toxic baits for *D. suzukii* control, to date, there have not been clear advances. Toxic baits provide effective control of tephritid fruit flies, and additional effort is needed to improve insecticide mixtures that, in addition to increasing attractiveness and ingestion, have a longer half-life when applied in the field. Toxic baits can be applied to specific areas (patches) or bait stations (Piñero et al. 2014, Rice et al. 2017), thereby avoiding direct contact with fruits but providing long-lasting control. As alternatives to chemical insecticides, several insects repellents have become widely used in organic production in Mexico. However, studies are required to determine their actual efficacy, appropriate application systems, and possible integration in 'push–pull' techniques by combining them with traps or bait stations inside or outside polytunnels.

Biological control with the parasitoids *T. anastrephae* and *G. brasiliensis* has been highly effective in recent studies, but additional studies are needed to determine approaches for convenient release and mass production. Exotic parasitoids that do not occur in Latin America, such as *Asobara japonica* Belokobylskij (Hymenoptera: Braconidae), *Leptopilina japonica* Belokobylskij (Hymenoptera: Braconidae), *Spalangia erythrotera* Forster (Hymenoptera: Pteromalidae), and *Muscidifurax raptorellus* Kogan & Legner (Hymenoptera: Pteromalidae), have high rates of parasitism and emergence in immature forms of *D. suzukii* (Wang et al. 2020a) and could be introduced. However, such a decision requires detailed knowledge of the potential risk of introduction and its feasibility depending on the agroecosystem, factors that vary among countries. Sterile insect technology is another tool that can improve *D. suzukii* control in an area-wide management approach, but many additional studies, mainly to improve mass production of males, pupae sterilization, and adult release, are needed to make SIT a cost-effective strategy in Latin America.

Although control methods for this pest are similar to those developed in other parts of the world, they must be adapted to specific crops and their phenologies, which vary between Latin American countries but especially between northern and southern hemispheres. Much can also be learned about control methods adopted by other countries that suffer from this pest, such as those in Europe or the USA. For example, rotational schemes of insecticides and plastic and natural mulches produce good results in Florida (Liburd and Rhodes 2020).

The actual economic damage caused by *D. suzukii* in different agroecosystems has been poorly researched in Latin America, even where the pest is established. There is also a lack of knowledge on pest expansion in the continent. South and Central America and the Caribbean, where *D. suzukii* is not yet established, should prevent invasions by using conventional monitoring surveys and strict protocols for importing soft fruits. Paraguay and Colombia have begun surveillance programs to prevent entry and establishment of *D. suzukii*, and Perú has established strict protocols for the importation of fresh fruits (SENAVE 2019, Agronegócio 2021).

Because the pest is already a problem, additional research should also focus on different postharvest treatments (Walse et al. 2020) in order to ensure fruits can be commercially supplied to the United States, Oceania, and Europe. Current investigations on precision agriculture, artificial intelligence, nanotechnology, remote sensing, and robotics, among other technologies, could lead to the integration of new approaches to manage this pest with greater precision and reduced costs and environmental impacts (Garcia 2020c).

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