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ECOLOGY AND MANAGEMENT OF D. SUZUKII

Review

Drosophila suzukii in Argentina: State of the Art and Further Perspectives

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Abstract

Drosophila suzukii (Matsumura) (Diptera: Drosophilidae), commonly known as spotted-wing drosophila or SWD, is an invasive, severe, and damaging pest, which is able to inflict huge economic losses on soft thin-skinned fruits worldwide. Argentina was not excluded from the rapid invasion of this new and aggressive pest. Berries and cherries are among the most economically important fruits, showing an increasing demand from both domestic and export markets, which make necessary the application of effective and early protection measures. Although SWD is currently established almost everywhere in Argentina, the scarcity of research on and rapid regulatory actions against this pest have probably contributed to its fast spread throughout the country. In view of that, the article reviews first the current threat status of SWD in Argentina, provides summarized information on crop and non-crop host fruits, seasonal variation and population dynamics, resident natural enemy assemblages, and describes control actions implemented to date. Finally, the need to focus local control actions within an integrated national SWD management program is emphasized. The development and application of complementary eco-friendly strategies, such as Sterile Insect Technique, biological control, mass trapping, and the use of innovative lactone-derived synthetic insecticides with extremely low toxicity for SWD parasitoids, in environmentally distinguishable Argentinian regions is also highlighted.

Keywords Spotted wing Drosophila · Area-wide integrated pest management · Host range · Pest control · Seasonal biology · Natural enemies

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Introduction

Drosophila suzukii (Matsumura) (Diptera: Drosophilidae) is an insect native to Eastern and Southeastern Asia that has rapidly invaded fruit-growing regions of Europe and the American continent (Asplen et al. 2015). Currently, this invasive dipterous species is widely distributed in Latin America (Garcia et al. 2022). This fly is commonly known as the spotted-wing Drosophila (SWD). The SWD is a worldwide pest that mainly infests small, soft, and thin-skinned healthy commercial fruits, such as berries and cherries (Lee et al. 2011). This is because in marked contrast to saprophytic drosophilids, SWD has a serrated and strongly sclerotized ovipositor which enables to lay eggs into fresh, healthy, ripening fruit (Atallah et al. 2014). Therefore, larval feeding causes unmarketable fruits whereby soft fruit production may suffer millionaire losses (De Ros et al. 2020). The distinctive serrated ovipositor, associated with its high population growth due to a high fecundity rate and a fast developmental cycle, as well with its high thermal plasticity and broad host range (Kirschbaum et al. 2020), make SWD a significant risk to Argentina's soft fruit industry. Furthermore, the lack of both registered pesticides for SWD control and regulatory measures to prevent its spread, increase the potential risk that SWD represents for southern Neotropical region´s fruit industry (Andreazza et al. 2017). In this sense, soft fruits comprise one of the main groups of high commercial value fruits to strengthen their production in different Argentinean fruit-growing regions, and therefore soft fruit crop protection is required against this novel invasive pest. Soft fruits grown in Argentina are mainly berries, such as *Rubus idaeus* L. (raspberry), *R. fruticosus* L. and *R. ulmifolius* Schott (blackberries), *Fragaria × ananassa* Duch. (strawberry) (Rosaceae), *Vaccinium corymbosum* L. (blueberry) (Ericaceae), and cherries such as *Prunus avium* L. (cherry) (Rosaceae). Additionally, other berries such as currant *Ribes rubrum* L. (red currant), *R. uva-crispa* L. (white currant), and *R. nigrum* L. (black currant) are also grown in Argentina, but only with a limited regional importance to Patagonia (Kirschbaum 2017). In Argentina, berries and cherries are produced for export and domestic markets, either fresh or frozen, and its social and economic importance are very significant (Kirschbaum 2017). Thus, this article provides an overview of the following issues regarding SWD in Argentina: (1) pest status; (2) current spreading; (3) crop and non-crop host fruit range; (4) seasonal variation and population dynamics in fruit-growing regions; (5) resident natural enemies; and (6) control actions implemented to date. Finally, local control actions within an integrated national SWD management program, emphasizing the development and application of complementary eco-friendly strategies in environmentally distinguishable regions, are discussed.

SWD pest status

The SWD is a novel pest species in Argentina first recorded in 2014 simultaneously in four Argentinean provinces with highly contrasting climatic conditions. In both Buenos Aires and Río Negro provinces (central-eastern Argentina and northern Patagonia, respectively), SWD was found infesting blueberries and strawberries (Santadino et al. 2015; Dettler et al. 2017) and raspberries (Cichón et al. 2015; Lavagnino et al. 2018), respectively. At the same time, in both Entre Ríos and Tucumán provinces (northeastern and northwestern Argentina, respectively) SWD was recorded in liquid traps placed on both wild and fruit crop plants (Lavagnino et al. 2018; Funes et al. 2023a). Shortly after the first SWD record, the National Plant Protection Directorate (DNPV, Spanish acronym), carried out the first country-wide SWD monitoring actions between 2014 and 2015 (SENASA 2016). Consequently, a trapping network and a fruit crop sampling were performed mainly in raspberry, cherry, blueberry, strawberry and grape (*Vitis vinifera* L:) crops from the major Argentinian fruit-producing regions, namely Patagonia (southern Argentina), Cuyo (central-western Argentina), Pampean (central Argentina), Northeastern Argentina (henceforth: NEA, Spanish acronym), and Northwestern Argentina (henceforth: NOA, Spanish acronym). In NOA, SWD monitoring was carried out in highlands Calchaquíes valleys from both Salta and Tucumán provinces, as well as in foothill berry growing areas of western Tucumán. Such extensive monitoring revealed the broad distribution of SWD throughout Argentina due to the high dispersal capacity of this invasive dipteran species. Thus, high numbers of SWD adults were caught at different locations, such as General Roca (Alto Valle de Río Negro), Choele Choel, Luis Beltrán, Lamarque (Valle Medio de Río Negro), Viedma and Carmen de Patagones (Valle Inferior de Río Negro and southeastern Buenos Aires), Trelew, Gaiman, El Hoyo, Esquel, Trevelin (Chubut), Los Antiguos (Santa Cruz), Monte Caseros (Corrientes), Concordia (Entre Ríos), Lobos (northeastern Buenos Aires), Cafayate (Salta), Chicligasta and Monteros (Tucumán), Rivadavia and Maipú (Mendoza), and Sarmiento (San Juan) (SENASA 2016; Garavelli 2017). In addition to trap catches, SWD puparia from blueberry crops collected in Lobos, Concordia, and Monte Caseros from NEA region (SENASA 2016) plus SWD-infested raspberry, cherry, strawberry, blueberry, grape, fig (*Ficus carica* L.), and black mulberry (*Morus nigra* L.) fruits from Patagonia, Cuyo, and NOA regions were also recorded (Garavelli 2017). Among all infested fruit crops, in a decreasing order, raspberry, blackberry, strawberry, blueberry, and cherry were the most affected (Garavelli 2017), which have a high social and economic significance in Argentina (Kirschbaum 2017). Due to its broad dispersion and economic implications, SWD was classified as novel pest under monitoring and surveillance in Argentina (SENASA 2016).

Description and importance of crop species attacked by the SWD

Raspberry and Blackberries

The main Argentinian raspberry- and blackberry-growing areas are located in the southern Andean Region of Parallel 42, known locally as "Comarca Andina del paralelo 42," which covers both southwestern Rio Negro and northwestern Chubut (southern Patagonia), and in the "Alto Valle del Río Negro and Neuquén" (northern Patagonia) (Gomez Riera et al. 2014). The total Argentinian production of those fruits is about 1500 and 350 tons of raspberries and blackberries, respectively (Kirschbaum 2017). More than 70% of the total raspberry and blackberry farmed area (~ 300 ha) is localized in the Patagonian region, including the northwestern of Santa Cruz (southern Patagonia), with a gross output value close to USD 6,656,428.57 (De la Vega et al. 2017). The remaining crops of both berry species are distributed mainly in northeastern Buenos Aires (Pampean region) and barely in both Santa Fe (Pampean region) and Tucumán (NOA region) (Gomez Riera et al. 2014). Most of the raspberry and blackberry production is marketed as frozen fruit to make commercial jellies, jams, sauces, juices, and liqueurs. The first records of SWD on raspberries in March 2014 in northern Patagonia (Cichón et al. 2015, 2016; Lavagnino et al. 2018) only indicated larval infestation in the fruit, e.g., SWD accounted for 68 and 83% of the total drosophilid specimens recovered from raspberry samples at Choele Choel and General Roca (northern Patagonia) (Lavagnino et al. 2018). Subsequent evaluations between December 2016 and January 2017 in northeastern Buenos Aires provided information on both crop damage incidence (= DI), calculated as the percentage of fruits with at least one larva, and crop damage severity (= DS), measured as the average number of SWD larvae per fruit (Riquelme-Virgala et al. 2017). These authors revealed DS and DI of 3.1–7.4 larvae/fruit and 50–100% of total sampled fruit on raspberry cv. Autum Bliss, and 4.0–19.0 larvae/fruit and 50–100% on raspberry cv. Himbo Top. In addition, blackberry crops of northeastern Buenos Aires had DS and DI of 8.5 larvae/fruit and 83% of total tested fruit, respectively. Recently, in raspberry crops from Buenos Aires, the DI was 61% of the total sampled fruit (Dettler et al. 2021). Similarly, in raspberry orchards in different locations of Buenos Aires, the SWD larvae damage incidence in fruits was usually around of 44% (Gallardo et al. 2022a). Although raspberry and blackberry are small-scale production crops compared to blueberry and strawberry crops in Tucumán, both berry species are currently expanding in the province, mostly as organic farming (Funes et al. 2022a). The incidence of SWD on both *Rubus* L. crops is a potential constraint to further commercial yields. In this context, recent studies on the incidence of SWD in the raspberry cv. Heritage in Tucumán recorded 74% infested fruit (Funes et al. 2022a), which means a yield loss of 5180 kg ha^{-1}. In field surveys throughout berry crop areas of Tucumán, *R. idaeus* proved to be much more attractive to SWD than *R. fruticosus* (Funes et al. 2018a). All reported data verifies the relevance of raspberry as one of the SWD's primary hosts.

Strawberry

Strawberries are the most popular soft fruit in Argentina as they are grown almost everywhere in the country. Due to the wide range of climates which strawberries are grown, Argentina produces year-round. With 1300 ha farmed and 45,500 t yielded, Argentina is the third largest strawberry-producing country in South America, after Brazil and Chile (Kirschbaum 2017). About 70% of the country's total production occurs in three provinces: Santa Fe, Tucumán, Buenos Aires. Approximately 60% of the production is consumed as fresh fruit and the remaining 40% as processed fruit, while 1300 t are exported, mainly to the USA. The most popular cultivars in Argentina are Camino Real, San Andreas, Benicia, Festival, and Sabrina (Kirschbaum 2017). The first data on DI in strawberry at national level between 2015 and 2016 indicated 27% of damaged fruit (Garavelli 2017). Likewise, records in Neuquén (Northern Patagonia) in March 2016 indicated 89% DI in strawberry cv Albion (Lochbaum 2017). Even though strawberry acreage in Patagonia is small (40 ha), the gross output value is a bit more than USD 1,700,000.00 (De la Vega et al. 2017), so the high incidence of SWD in this crop may affect the regional economy. Approximately 14% of strawberry fields surveyed in Tucumán were infested with SWD (Funes et al. 2018a, 2021a). Comparative studies on strawberry crops in northwestern Argentina (Famaillá, Tucumán) and northern Patagonia (Plottier, Neuquén) (2022b showed high DI by SWD in overripe fruit and low DI in commercially ripe fruit (Funes et al. 2022b). Recent surveys in strawberry crops in Buenos Aires recorded low DI levels, which were 11% of the total recovered fruit (Gallardo et al. 2022a).

Blueberry

Blueberry crops are distributed in 61% of the national territory, which involves 14 provinces, but Tucumán (NOA), Entre Ríos (NEA), and Buenos Aires (Pampeana) are the most relevant in acreage and production. These three provinces account for around 47%, 28%, and 15% of Argentina's overall output, respectively (Rivadeneira and Kirschbaum 2011; Kirschbaum 2017; Funes et al. 2023a). The estimated production of blueberries in Argentina is 22,000 t, of which 17,100 t of fresh blueberries are exported mainly between September and December (spring and early summer). The NOA, NEA, and the Pampena regions account for 50, 39, and 11%, respectively, of the total exported, with an overall value of USD $ 110 million. Tucumán is the major Argentinian blueberry-producing area, as well the main exporter province, with 1384 ha, which involves ~ 46% of the total blueberry crop area in Argentina (Dell'Acqua et al. 2019; Funes et al. 2023a). Organic blueberry crops are expanding in the country. In this regard, fresh organic blueberries are ~ 19% of the total volume of fresh blueberries exported by Argentina, mainly to Europe (56%), North America (39%), and South-East Asia (5%), which reached 10,500 t in 2020 (Funes et al. 2023a). The most important blueberry cultivars in Argentina are Emerald, Snowchaser, and Jewel (Kirschbaum 2017). Regarding blueberry damage, records are highly variable based on fruit-growing regions and cultivated varieties. For instance, in November 2014, infested fruits from both O'Neil and Star blueberry early varieties were detected in crops of the northeastern Buenos Aires. The DI was close to 60% and the DS averaged 2.6 larvae/fruit (Santadino et al. 2015). Subsequent evaluations between December 2016 and January 2017 in the same fruit-growing region recorded DS and DI levels of 0.28 SWD larvae/fruit and 28% for the O'Neil variety, and 0.06–0.11 and 6–28%, and 0.11–0.17 and 17% for Briguita and Duke late varieties, respectively (Riquelme-Virgala et al. 2017). In contrast, blueberry SWD infestation levels between 2016 and 2017 in Tucumán were rather low. The DI was 2.3% over 4239 fruits, i.e., about 12 SWD individuals per kilogram of harvested blueberries, and the DS reached up to 0.1 larvae/fruit (Funes et al. 2017, 2023a).

Cherry

The current Argentinean fresh cherry production is ~ 11,000 t grown in ~ 2600 ha located mostly in the south of the country (Fernández-Lozano and Budde 2018; SAGP 2022). The main producing provinces are Mendoza (southern Cuyo), Río Negro, Neuquén (Northern Patagonia), Chubut, and Santa Cruz (southern Patagonia). Small-scale farming also occurs in Buenos Aires, Córdoba, and San Juan. Close to 80% of total cherry production is exported (Fernández-Lozano and Budde 2018). Currently, the sector is oriented to strengthen itself in the Chinese market, the main cherry importer. Argentina is the 20th largest cherry exporting country, with 5000 and 7000 tons exported between 2020 and 2021 (SAGP 2022). There are few published records of cherry damage by SWD for Argentina. National data from 2015 to 2016 indicate a DI close to 2% (Garavelli 2017). However, in cherry crops of the northeastern Buenos Aires, both DS and DI were particularly high, with values 28 larvae/fruit and 100% of the infested fruit (Detller et al. 2017). In contrast, cultivated cherries in different farms of Buenos Aires showed a 3% of DI over total tested fruit (Gallardo et al. 2022a).

Current SWD distribution in Argentina

The SWD is currently distributed in five fruit-growing regions of Argentina, from the warm and humid subtropics (Northwestern and Northeastern regions) to cold and arid southern Patagonia, and from the steep Andean valleys (Cuyo region) to the fertile Pampean lowlands in central region (Pampeana region). Therefore, the SWD broad distribution range covers 15 provinces over 23. The SWD spans from 23°34′S and 65°22′W at an altitude of 2461 m, in the city of Tilcara, Jujuy province (northwestern Argentina) (Gandini et al. 2023), to 46°55′S and 71°61′W at an altitude of 248 m in the Los Antiguos locality to the northwest of the Santa Cruz province (southern Patagonia), which is the SWD southernmost record (De la Vega and Corley 2019). The SWD has been found in diverse crop and wild environments with different climatic conditions throughout Argentina. Therefore, SWD adults can thrive in subtropical, temperate, and hot and cold semi-arid and cold arid climates of the country in an altitudinal range approximately between 10 and 2500 m (Table 1). Most likely, the origin of the SWD invasion in Argentina was due to two events, both originating in previously invaded areas, such as North America and Brazil (De la Vega et al. 2020). The SWD is a cold-tolerant species (De Vega and Corley 2019), and therefore has the ability to overwinter locally, as it can develop winter morphotypes adapted for absorbing and retaining heat throughout the winter (Kirschbaum et al. 2020). Since 2014 to date, SWD adults have been caught throughout crop and non-crop areas from Argentina by using different types of traps with different attractants, but the most common traps were plastic bottles or modified McPhail traps with liquid apple cider vinegar (Garavelli 2017; De la Vega et al. 2017; Lavagnino et al. 2018; Funes et al. 2017, 2018a, b, 2020, 2023a; Garrido et al. 2018; De Vega and Corley 2019; Gonsebatt et al. 2020; Dettler et al. 2021; Gómez Segade et al. 2021; Bennardo et al. 2021; Gallardo et al. 2022a; IFAB 2022). Chromatic yellow traps with soapy water were also used (Lue et al. 2017). Interestingly, numerous SWD adults were caught in several soft and stone fruit crops in the Patagonian Andean region of Parallel 42, which mainly involves the towns of El Bolsón (southern Rio Negro), Lago Puelo, El Hoyo, and Epuyén (northern Chubut) (IFAB 2022). In addition, SWD adults were also caught in cherry crops grown in the north of Santa Cruz (southern Patagonia) (De Vega and Corley 2019). At the beginning of 2020, SWD adults were caught in traps placed on plants of the genus *Opuntia* (Cactaceae) in the Martín García Island wildlife refuge, a small island in the Río de la Plata estuary, Northwestern Argentina (Bennardo et al. 2021).

Verified SWD host plants

In only 9 years from the first record of the SWD in Argentina, SWD has naturally infested 24 crop and non-crop fruit species, belonging to seven plant families (Table 2). Most SWD host species (~ 65%) belong to Rosaceae as it also occurs throughout the rest of Latin America (Garcia et al. 2022) and globally as well (Kirschbaum et al. 2020). Both Ericaceae and Moraceae including berries accounted for 12.5% of the total SWD host fruit species. Twenty host species (83%) are economically important crops, from which both *Prunus persica* (L.) Batsch and *R. ulmifolius* also occur as feral species in non-crop areas. Four host species (~ 17%) are wild (Table 2), occurring naturally in forested areas. Both *Solanum aligerum* Schltdl (Rull et al. 2023) and *Solanum betaceum* Cav. (Funes et al. 2021b; Garcia et al. 2022)

Table 1 Localities from different fruit-growing regions of Argentina, with their geographical coordinates, altitude, and climate at which *Drosophila suzukii* was recorded in a chronological order from it first collecting year in the country

Fruit-growing region and provinces	Collecting year	Locality	Geographical coordinates and altitude (m)	Climate	References[1]
Southern Argentina (Patagonia)					
Río Negro:	2014	Choele Choel	39°16′S–65°41′W (118)	Arid, cold, wet summer	[6, 9, 13, 19, 36–38, 51]
	2014	General Roca	39°02′S–67°35′W (240)	Arid, cold, wet summer	[6, 10, 32, 33, 37, 38, 51]
	2016	Luis Beltrán	39°19′S–65°46′W (129)	Arid, cold, wet summer	[51]
	2016	Lamarque	39°25′S–65°42′W (118)	Arid, cold, wet summer	[51]
	2016	Viedma	40°48′S–63°00′W (12)	Semiarid, dry, cold	[51]
	2017–2018	Contr. Martin Guerrico	39°01′S–67°43′W (252)	Arid, cold, wet summer	[33–35]
	2018	Allen	38°58′S–67°49′W (256)	Arid, cold, wet summer	[30, 32–35]
	2019–2021	El Bolsón	41°58′S–71°32′W (420)	Temperate, dry summer	[8, 12, 20, 41–42]
	2022	San Antonio Oeste	40°43′S–64°55′W (188)	Semiarid, dry, cold	[43]
Neuquén:	2016–2021	Plottier	38°56′S–68°15′W (283)	Arid, cold, wet summer	[13, 24, 30, 32–39, 44]
	2017	San Martín de los Andes	40°15′S–71°35′W (640)	Temperate-cold	[12]
Chubut:	2016–2021	El Hoyo	42°03′S–71°31′W (226)	Temperate-cold	[8, 20, 31, 41–42]
	2016	Trelew	43°15′S–65°18′W (11)	Temperate-dry, cold,	[31]
	2016	Gaiman	43°28′S–65°48′W (24)	Temperate-dry, cold,	[31]
	2016	Esquel	42°54′S–71°18′W (563)	Temperate-wet, cold	[31]
	2016	Trevelin	43°05′S–71°28′W (385)	Temperate-wet, cold	[31]
	2019–2021	Lago Puelo	42°04′S–71°37′W (230)	Temperate-wet, cold	[8, 20, 41]
	2021–2022	Epuyén	42°14′S–71°21′W (625)	Temperate-cold	[8]
Santa Cruz:	2017	Los Antiguos	46°55′S–71°61′W (248)	Temperate-humid, warm	[12, 13]
Central-western (Cuyo)					
Mendoza:	2015–2016	Capital	32°53′S–68°49′W (746)	Semiarid, dry-cold winter	[13]
	2016	Rivadavia	33°11′S–68°28′W (658)	Semiarid, dry-cold winter	[31]
	2016	Maipú	32°58′S–68°46′W (663)	Semiarid, dry-cold winter	[31]
	2018	San Carlos	33°46′S–69°02′W (1175)	Cold steppe	[11, 37]
	2021–2022	Tunuyán	33°34′S–69°01′W (875)	Temperate-warm, wet	[7]
	2021–2022	Tupungato	32°89′S–68°83′W (1603)	Semiarid, dry-cold winter	[7, 13]
	2022	La Consulta	33°43′S–69°07′W (1050)	Temperate-warm, dry	[30]
San Juan:	2015–2016	Zonda	31°54′S–68°54′W (640)	Semiarid, dry-cold winter	[13]
	2016	Sarmiento	31°58′S–68°25′W (547)	Semiarid, dry-cold winter	[31]
Central (Pampeana)					
Buenos Aires:	2014–2021	Lobos	35°11′S–59°05′W (23)	Temperate-wet, warm summer	[6, 14–19, 29, 36–37, 47–49, 51]
	2015–2016	Moreno	34°39′S–58°47′W (14)	Temperate-wet, warm summer	[47]
	2016	Carmen de Patagones	40°47′S–62°58′W (15)	Arid-cold, dry summer	[31, 51]
	2016–2017	Exaltación de la Cruz	34°17′S–59°05′W (37)	Temperate-wet, warm summer	[14, 15]
	2016–2019	Mercedes	34°39′S–59°26′W (38)	Temperate-wet, warm summer	[14–16, 29]
	2016–2021	Luján	34°34′S–59°06′W (21)	Temperate-wet, warm summer	[14, 15, 29, 47, 49]
	2020	San Pedro	33°40′S–59°40′W (31)	Temperate-wet, warm summer	[50]

Table 1 (continued)

Fruit-growing region and provinces	Collecting year	Locality	Geographical coordinates and altitude (m)	Climate	References[1]
	2020	Baradero	33°48′S–59°30′W (41)	Temperate-wet, warm summer	[50]
	2020	Isla Martín García	34°11′S–58°15′W (27)	Temperate-wet, warm summer	[1]
	2021–2022	Azul	36°47′S–59°51′W (137)	Temperate-wet, warm summer	[30]
	2021–2022	Pereyra Iraola	34°50′S–58°09′W (11)	Temperate-wet, warm summer	[44]
	2021–2022	Bavio	35°05′S–57°44′W (22)	Temperate-wet, warm summer	[44]
Santa Fe:	2016–2018	Rosario	32°57′S–60°38′W (25)	Temperate-wet, warm summer	[36]
	2016–2018	Zavalla	33°01′S–60°53′W (41)	Temperate-wet, warm summer	[36]
	2016–2018	Piñero	33°06′S–60°48′W (50)	Temperate-wet, warm summer	[36]
Córdoba:	2022	Colonia Caroya	31°02′S–64°05′W (491)	Temperate-dry	[30]
Northeastern Argentina (NEA)					
Entre Ríos:	2014, 2017–2018	Concordia	31°54′S–58°38′W (21)	Subtropical, wet-winter	[6, 13, 17, 19, 36–38, 46, 51]
Corrientes:	2016	Monte Caseros	30°15′S–57°39′W (70)	Subtropical, wet-winter	[51]
Northwestern Argentina (NOA)					
La Rioja:	2015	Anillaco	28°8′S–66°93′W (1325)	Semiarid-warm,	[6, 13, 19, 40]
Tucumán:	2015	Ticucho	26°31′S–65°15′W (610)	Semiarid-	[6, 38]
	2015–2017	Lules	26°55′S–65°20′W (382)	Subtropical, dry-winter	[3, 21–25, 27, 37]
	2016–2017	Yerba Buena	26°55′S–65°05′W (660)	Subtropical, dry-winter	[2, 4, 5, 18, 35, 37]
	2016–2017	Tafi Viejo	26°43′S– 65°15′W (591)	Subtropical, dry-winter	[2, 4, 18, 35, 37]
	2016–2018	Chicligasta	27°20′S–65°35′W(379)	Subtropical, dry-winter	[3, 21–25, 27, 37]
	2016–2018	Monteros	27°10′S–65°29′W (393)	Subtropical, dry-winter	[3, 21–25, 27, 37]
	2016–2022	Tafi del Valle	26°52′S–65°41′W (2014)	Temperate-wet, cold	[3, 18, 23, 28, 30, 37]
	2022	Famaillá	27°01′S–65°22′W (363)	Subtropical, dry-winter	[25–27]
	2022	Amaicha del Valle	26°36′S–65°55′W (2000)	Arid-dry, warm summer	[30]
Salta:	2016	Cafayate	26° 21′S–65°38′W (1683)	Dry-temperate, warm summer	[31]
	2021–2022	Valle de Lerma	25°20′S–65°26′W (1200)	Subtropical, dry-winter	[52]
Jujuy:	2022	San Salvador de Jujuy	24°11′S–65°17′W (1259)	Subtropical, dry-winter	[30]
	2022	Tilcara	23°34′S–65°23′W (2465)	Arid-dry, warm summer	[30]

[1] [1] Bennardo et al. (2021), [2]–[5] Buonocore Biancheri et al. (2021a, b, 2022, 2023), [6] CABI (2016), [7] Chiandussi et al. (2022), [8] Chillo et al. (2022), [9]–[10] Cichón et al. (2015, 2016), [11] Dagatti et al. (2018), [12] De la Vega and Corley (2019), [13] De la Vega et al. (2020), [14]–[16] Dettler et al. (2017, 2018, 2021), [17] Díaz et al. (2015), [18] Escobar et al. (2018), [19] EPPO (2022), [20] Fischbein et al. (2022), [21]–[28] Funes et al. (2018a, 2018b, 2018c, 2021a, b, 2022a, 2022b, 2023a, 2023b), [29] Gallardo et al. (2022a), [30] Gandini et al. (2023), [31] Garavelli (2017) [32] Garrido et al. (2018), [33]–[35] Gómez Segade et al. (2021, 2022a, 2022b), [36] Gonsebatt et al. (2020), [37] Kirschbaum et al. (2020), [38] Lavagnino et al. (2018), [39] Lochbaum et al. (2018), [40] Lue et al. (2017), [41]–[42] Martínez et al. (2022a, b), [43] MINAGRI (2023), [44] Morelli et al. (2022), [45] Moreno et al. (2018), [46] Mousques (2017), [47] Riquelme-Virgala (2016), [48]–[49] Santadino et al. (2015, 2017), [50] Segade (2020), [51] SENASA (2016), [52]Socías (2022)

have been collected from low-disturbance environments in wild vegetation areas of the subtropical mountain rainforest, locally known as Yungas, in Tucumán, northwestern Argentina. However, infestation levels in those native fruits have been low, ranging from less than 1 to 8% (Funes et al. 2021b; Rull et al. 2023). In addition to those native host species, two exotic feral fruit species, such as *Morus nigra* L. and *Psidium guajava* L., were also recorded as SWD hosts. Both host feral fruit species are commonly found in highly disturbed sectors at the foothills of the Yungas rainforest in Tucumán, which border with soft fruit commercial crops, such as strawberry, blueberry, blackberry, and raspberry.

Table 2 Crop and non-crop fruit species naturally infested by SWD larvae in Argentina

Host plant family and species plus (common name)	Origin[a]	Host fruit status[b]	Fruit collection sites (provinces and fruit-growing regions)[c]	References[d]
Ebenaceae:				
Diospyro kaki L.f (Japanese persimmon)	E	C	T (NOA)	[12]
Ericaceae:				
Vaccinium corymbosum L. (Blueberry)	E	C	BA (Pam), ER, C (NEA), T (NOA)	[8], [9], [10], [13], [16]-[18]
Moraceae:				
Ficus carica L (Fig)	E	C	BS (Pam), T (NOA)	[5], [10], [12], [17]
Morus nigra L (Black mulberry)	E	W	T (NOA), BS (Pam),	[12], [13]
Myrtaceae:				
Psidium guajava L (Common guava)	E	W	T (NOA)	[6], [12]
Rosaceae:				
Cydonia oblonga Mill (Quince)	E	C	BS (Pam), T (NOA)	[12], [18]
Eriobotrya japonica (Thunb.) Loquat	E	C	T (NOA)	[12]
Fragaria × ananassa Duch. Strawberry)	E	C	N, RN (Pat.), T (NOA), BS (Pam)	[9], [11]-[13], [19]
Malus domestica L (Apple)	E	C	T (NOA)	[12]
Prunus armeniaca L (Apricot)	E	C		[4], [9]
Prunus avium L (Sweet cherry)	E	C	N, RN (Pat), BS (Pam)	[4], [13], [14]
Prunus cerasus L (Sour cherry)	E	C		[14]
Prunus domestica L (Common plum)	E	C	BS (Pam), T (NOA)	[4], [12], [14], [17]
Prunus persica (L.) Batsch (Peach)	E	C	BS (Pam)	[4], [13]
		W	T (NOA)	[1]
Pyrus communis L (European pear)	E	C	T (NOA)	[12]
Pyrus pyrifolia (Burm.) Nak (Asian pear)	E	C	BS (Pam)	[4], [14]
Rubus fruticosus L (European Blackberry)	E	C	N (Pat), BS (Pam), T (NOA)	[4], [8], [10]
Rubus idaeus L (Raspberry)	E	C	N, RN, Ch (Pat), BS (Pam), T (NOA)	[2], [4]-[8], [10], [13]-[16]
Rubus L. subgen. *Rubus* Watson (Blackberry?)	E	C	M (Cu)	[3]
Rubus ulmifolius Schott (Elmleaf Blackberry)	E	C	BS (Pam), RN, Ch (Pat)	[7], [13]
		W	Ch (Pat)	[7]
Solanaceae:				
Lycopersicon esculentum P. Mill cv cerasiforme (Dinal) A.Gray (Tomato cherry)	E	C	BS (Pam)	[19]
Solanum aligerum Schltdl (?)	N	W	T (NOA)	[20]
Solanum betaceum Cav (Tomato tree)	N	W	T (NOA)	[12]

Table 2 (continued)

Host plant family and species plus (common name)	Origin[a]	Host fruit status[b]	Fruit collection sites (provinces and fruit-growing regions)[c]	References[d]
Vitaceae:				
Vitis vinifera L (Grape)	E	C	?	[15]

[a]*E* exotic, *N* native

[b]*C* cultivated, *W* wild

[c]Provinces: *BA* Buenos Aires, *C* Corrientes, *Ch* Chubut, *ER* Entre Ríos, *M* Mendoza, *N* Neuquén, *RN* Río Negro, *T* Tucumán; fruit-growing regions: *Cu* Cuyo (central-western Argentina), *NEA* Noreste (northeastern Argentina), *NOA* Noroeste (northwestern Argentina), *Pam* Pampeana (central Argentina), and *Pat* Patagonia (southern Argentina)

[d]References: [1] Buonocore Biancheri et al. (2022), [2] Cichón et al. (2015), [3] Dagatti et al. (2018), [4]–[5] Dettler et al. (2017, 2021), [6] Escobar et al. (2018), [7] Fischbein et al. (2022), [8]–[12] Funes et al. (2018a,b, 2019, 2021a,b), [13] Gallardo et al. (2022a), [14] Garcia et al. (2022), [15] Garavelli (2017), [16] Lavagnino et al. (2018), [17] Santadino et al. (2015), [18] Segade (2020), [19] Riquelme-Virgala et al. (2016), [20] Rull et al. (2023)

The widespread occurrence of those both feral fruit species in wildlife environments is mainly due to dispersal by birds and mammals (Ovruski et al. 2003). Natural infestation levels of *D. suzukii* in feral guava and peach ranged between 0.3 and 0.8 SWD puparia per sampled fruit (Escobar et al. 2018; Buonocore Biancheri et al. 2022). Among the economically valuable soft fruit species, *R. idaeus*, *R. fruticosus*, *R. ulmifolius*, *V. corymbosum*, and *F. ananassa* are primary SWD hosts throughout Argentina (Lavagnino et al. 2018; Funes et al. 2018a,b, 2019, 2021a,b; Dettler et al. 2017, 2021; Garcia et al. 2022; Gallardo et al. 2022a; Fischbein et al. 2022). In *Vitis vinefera* L., an economically valuable crop species, a small number of fruits were affected, e.g., 2% of all fruit sampled (Garavelli 2017). In *Ficus carica* L. crops in northeastern Buenos Aires, the DI was ~ 10% of the total tested fruit (Dettler et al. 2021), whereas in *P. persica* crops the DI was only 3% (Gallardo et al. 2022a). In addition, 21% of the *M. nigra* fruit grown close to berry orchards were infested by SWD (Gallardo et al. 2022a). Other cultivated fruit species scattered in different fruit-growing regions, such as *Diospyro kaki* L.f.,. *F. carica*, *Cydonia oblonga* Mill. (Quince), *Eriobotrya japonica* (Thunb.), *Malus domestica* L., *Prunus armeniaca* L., *P. domestica* L., *P. persica*, *Pyrus communis* L., and *P. pyrifolia* (Burm.) Nak., are rather secondary hosts, and were mainly affected by SWD in family orchards, and disused crops and backyards where no phytosanitary measures were taken (Dettler et al. 2017, 2021; Segade 2020; Funes et al. 2021a; Garcia et al. 2022). Reports of damage to some of those fruit species were provided by Dettler el al. (2017) between 2016 and 2017 for farmed areas in the northeastern Buenos Aires. Thus, both DS and DI were 0.2 and 6% in fig, 10.3 and 100% in apricot, 0.1 and 7% in peach, 10.4 and 78% in plum, and 0.3 and 17% in Asian pear. Such fruit species, jointly with exotic feral host species or even native host species, may act as reservoirs, which allow the pest to multiply and overcome times when their main hosts are scarce. In turn, there is a wide variety of wild plant species in the southern Patagonian Andean Region of Parallel 42 (southwestern Rio Negro and northwestern Chubut) whose small, soft-skinned fruits could be used as alternative hosts for SWD throughout the year, especially when there are no primary crop hosts, such as cherries and berries (IFAB 2022). Some of these wild species include *Aristotelis chilensis* (Molina) Stuntz (Elaeocarpaceae), *Berberis* spp. (Berberidaceae), *Cotoneaster* spp., *Crataegus* sp., *Prunus laurocerasus* L., *Rosa rubiginosa* L., *Rubus ulmifolius* Schott, *Sorbus aucuparia* L. (Rosaceae), *Luma apiculata* (DC.) Burret, and *Myrceugenia exsucca* O.Berg (Myrtaceae) (IFAB 2022). Naturally occurring *R. ulmifolius* plants have recently been recorded as SWD host (Fischbein et al. 2022). In addition to all those wild plant species, farmed berry species such as *Sambucus nigra* L. (Elderberry) and *Ribes* spp. (Currants) are highly potential host plants for SWD in Patagonia (IFAB 2022).

SWD population seasonal variations

Studies on SWD seasonal dynamic in Argentina have evidenced a close relationship between pest presence and host fruiting seasons. However, weather conditions, such as air temperature and relative humidity, are still determining factors of the SWD population abundance (Kirschbaum et al. 2020). In Argentina, as a standard pattern for all invaded fruit-growing regions, SWD adult populations frequently reach peaks in spring and/or autumn, to decrease from early winter onward. In this regard, in berry-growing foothill areas from the NOA, most SWD adult incidence occurred during both blueberry and *Rubus* spp. fruiting periods covering late October to early January, with a first peak between late spring and early summer (November–December) (Funes et al. 2017, 2018a,b, 2022a, 2023a). A second peak of SWD adult catches, but with a lower capture level than that of late spring, was also recorded between April and May, e.g., mid-autumn (Funes et al. 2022a, b; Garcia et al. 2022). However, that last population peak most frequently appeared at high-altitude berry-growing areas, e.g., at 2000 m, such as the highlands of the Tafí valley, Tucumán (Funes et al. 2018c). Isolated SWD adult catches have been also recorded in August (winter) blueberry-growing lowland areas of Tucumán (Funes et al. 2023a). Regardless of the farmed fruits, a wide range of alternative non-crop fruit hosts, either growing in wild vegetation areas, family orchards or backyards surrounding crops, supports SWD populations throughout periods of commercial berry shortage in Tucumán. Among these non-crop hosts prevail feral guava and peach (Escobar et al. 2018; Buonocore Biancheri et al. 2022, 2023), in addition to other exotic species such as loquat and fig (Funes et al. 2021b; Garcia et al. 2022), and native solanaceous plants (Funes et al. 2021b; Rull et al. 2023). These alternative non-crop hosts may be available through November to June.

In fruit-growing areas of northwestern Buenos Aires province, Pampeana region, the highest SWD population peaks in blueberry, raspberry, and stone fruit crops also occurred between late spring and early summer (December–January) (Santadino et al. 2015; Riquelme-Virgala et al. 2017; Dettler et al. 2021; Gallardo et al. 2022a). However, a lower level of SWD catches occurred throughout raspberry-fruiting periods, which extends from late spring, e.g., December, to mid-autumn, e.g., April (Riquelme-Virgala et al. 2017). In addition, there was SWD adult catches throughout the year, mainly between September and October, e.g., early and mid-spring (Santadino et al. 2015; Dettler et al. 2021; Gallardo et al. 2022a).

In both northern and southern Patagonia, the SWD adult catches mainly in raspberry crops started at early summer (late December), peaked in April (mid-autumn), and then slowly decreased until mid-July (winter), but remained very low until mid-December (late spring) (Lochbaum 2017; IFAB 2022). In the Alto Valle de Rio Negro (northern Patagonia), the highest SWD adult trapping rate occurred between late summer and late autumn, e.g., March–May, covering raspberry and cherry fruiting seasons (Cichón et al. 2016). This SWD population pattern shows some difference from that of the northern and central fruit-growing regions.

Natural enemies

Several parasitoid species have been recorded as natural enemies of SWD up to date in different Argentinean fruit-growing regions. Thirteen hymenopterous parasitoid species were reported for Argentina, of which ten, two, and one parasitoid species belong to the families Figitidae (all larval parasitoids), Pteromalidae and Diapriidae (all pupal parasitoids), respectively. However, only five species (two figitids, two pteromalids, and one diaprid) were recovered directly from SWD puparia taken from both crop and non-crop fruits in Tucumán (NOA) (Table 3). A true host-parasitoid trophic relationship, e.g., a parasitoid specimen emerged from the puparium of the target host (Wharton et al. 1998), was established with five resident parasitoid species, such as *Dieucoila octofagella* Reche and *Ganaspis brasiliensis* Ihering (Hymenoptera: Figitidae), *Trichopria anastrephae* Lima (Hymenoptera: Diapriidae), *Pachycrepoideus vindemiae* Rondani, and *Spalangia* sp. cf. *S. endius* Walker (Hymenoptera: Pteromalidae). Those parasitoid species

Table 3 Parasitoid species found in a close trophic association with larvae or puparia of *Drosophila suzukii* in Argentina

Parasitoid family and species	Origin[a]	Host stage attacked	Associated crop and non-crop fruit species	Collection sites (province and locality)	References[b]
Diapriidae:					
Trichopria anastrephae Lima	Neo	Pupa	Peach and Guava (non-crop)	Tucuman (Horco Molle)	[1], [2]
Figitidae:					
Dieucoila octofagella Reche	Neo	Larva	Raspberry (crop)	Tucumán (Tafí del Valle)	[4]
Ganaspis brasiliensis Ihering	Neo	Larva	Raspberry (crop)	Tucumán (Tafí del Valle)	[3]
Pteromalidae:					
Pachycrepoideus vindemiae Rondani	Cos	Pupa	Peach and Guava (non-crop)	Tucuman (Horco Molle)	[1], [2]
Spalangia sp. cf. *S. endius* Walker	Cos	Pupa	Peach (non-crop)	Tucuman (Horco Molle)	[1]

[a]*C* Cosmopolite, *Neo* Neotropics

[b]References: [1]–[2] Buonocore Biancheri et al. (2022, 2023), [3] Gallardo et al. (2022b), [4]Reche et al. (2021)

belong to three different fruit fly parasitoid guilds categorized and detailed by Ovruski et al (2000) and Garcia et al. (2020). The two figitid species belong to guild "2," which includes solitary, koinobiont endoparasitoids that oviposit in the host larva but the adult emerges from the fly puparium; therefore, they are known as larval parasitoids. The diaprid species belongs to guild "3," which involve solitary, idiobiont endoparasitoids that oviposit inside the host pupa but the adult emerges from the fly puparium; hence, they are known as pupal parasitoids. The two pteromalid species belongs to guild "4" which involves solitary, pupal idiobiont ectoparasitoids, which oviposit in the space between the inner edge of the puparium and the host pupa, and the adult emerges from the fly puparium. Species from guilds "2" and "3" are native from the Neotropical region, while parasitoids from guild "4" are cosmopolitans. The remaining eight-figitid species were caught with SWD adults in liquid traps placed in fruit crops (Table 4). The three pupal parasitoid species, *T. anastrephae*, *P. vindemiae*, and *S. endius*, and one larval parasitoid species, *G. brasiliensis*, were also collected in liquid traps (Table 4).

Limited information is available on the natural incidence of resident parasitoid species over SWD population. Only one specimen of both *D. octofagella* and *G. brasiliensis* was recovered from numerous SWD puparia collected from raspberry (*R. idaeus* cv. "Heritage") organic crops in Tafi del Valle, Tucumán (Reche et al. 2021; Gallardo et al. 2022b). Field surveys recorded an average parasitism on SWD puparia recovered from fallen feral fruits ranging from 5 to 56% between early December (early summer) and late April (early autumn) at Horco Molle, Yerba Buena, Tucumán (Buonocore Biancheri et al. 2022, 2023). At the first survey (Buonocore Biancheri et al. 2022), which involved three feral peach fruiting seasons between 2014 and 2017, parasitism

Table 4 Parasitoid species caught with *Drosophila suzukii* adults using several types of baited traps placed on fruit trees in different Argentinean fruit-growing regions

Parasitoid family and species	Origin[a]	Host stage attacked	Type of traps and lure	Collection sites[b]	Reference[c]
Diapriidae:					
Trichopria anastrephae Lima	Neo	Pupa	Plastic bottle/water + apple vinegar	BA (Pam)	[4]
Figitidae:					
Euxestophaga argentinensis Gallardo	Neo	Larva	Plastic bottle/water + apple vinegar	BA (Pam)	[4]
Ganaspis brasiliensis Ihering	Neo	Larva	Plastic bottle/water + apple vinegar	RN, Ch (Pat)	[1]
Ganaspis hookeri Crawford	Neo	Larva	Yellow pan traps/water + detergent	LR (NOA)	[7]
Ganaspis pelleranoi (Brèthes)	Neo	Larva	Plastic bottle/water + apple vinegar	BA (Pam)	[4]
Hexacola bonaerensis Reche	Neo	Larva	Plastic bottle/water + apple vinegar	BA (Pam)	[4]
Hexacola cf *hexatoma* (Hartig)	Cos	Larva	Plastic bottle/water + apple vinegar	RN, Ch (Pat)	[1]
Leptopilina boulardi Barbotin, Carton and Kelner-Pillault	Cos	Larva	Plastic bottle/water + apple vinegar	N, RN (Pat)	[5]
			Plastic bottle/water + apple vinegar + PHEROCON® SWD Broad Spectrum Lure	N, RN (Pat)	[6]
			Plastic bottle/water + apple vinegar	BA (Pam)	[4]
Leptopilina clavipes (Hartig)	Nea-Neo	Larva	Yellow pan traps/water + detergent	LR (NOA)	[7]
Leptopilina heterotoma (Thomsom)	Cos	Larva	Plastic bottle/water + apple vinegar	RN, Ch (Pat)	[1]
Pteromalidae:					
Pachycrepoideus vindemiae Rondani	Cos	Pupa	Modified McPhail trap/water + apple vinegar	T (NOA)	[2], [3]
			Plastic bottle/water + apple vinegar + PHEROCON® SWD Broad Spectrum Lure	N, RN (Pat)	[4]
			Plastic bottle/water + apple vinegar	BA (Pam)	[3]
			Plastic bottle/water + apple vinegar	RN, Ch (Pat)	[1]
Spalangia endius Walker	Cos	Pupa	Plastic bottle/water + apple vinegar + PHEROCON® SWD Broad Spectrum Lure	N, RN (Pat)	[6]
			Plastic bottle/water + apple vinegar	RN, Ch (Pat)	[1]

[a] *C* Cosmopolite, *Nea* Neartic, *Neo* Neotropics

[b] Provinces: *BA* Buenos Aires, *Ch* Chubut, *N* Neuquén, *RN* Río Negro, *T* Tucumán; fruit-growing regions: *NEA* Noreste (northeastern Argentina), *NOA* Noroeste (northwestern Argentina), *Pan* Pampeana (central Argentina), *Pat* Patagonia (southern Argentina)

[c] References: [1] Fischbein et al. (2022), [2]–[3] Funes et al. (2020, 2023a), [4] Gallardo et al. (2022a), [5] Garrido et al. (2018), [6] Gómez Segade et al. (2021), [7]Lue et al. (2017)

was mainly exerted by *P. vindemiae* and to a lesser level by both *S. endius* and *T. anastrephae*. *Pachycrepoideus vindemiae* accounted for 93% of the total parasitoid specimens recovered from SWD puparia, while both *T. anastrephae* and *S. endius* accounted for 6% and 1%, respectively. In a second survey (Buonocore Biancheri et al. 2023) carried out between 2016 and 2017, *T. anastrephae* and *P. vindemiae* were once again recovered from SWD puparia, albeit from both feral peach and guava. The SWD parasitism percentages by *T. anastrephae* were 15 and 10% from infested feral peaches and guavas, respectively, whereas parasitisms by *P. vindemiae* were 20 and 9%, respectively.

There are few records of SWD predators in Argentina. Among them, Detller et al. (2017) recorded mature larvae of *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae) feeding on SWD larvae and pupae under lab conditions. Similarly, *Orius insidiosus* Say and *Anthocoris nemoralis* (Fabricius) (Hemiptera: Anthocoridae) prey on SWD larvae and adults, but no more than 12% under lab conditions (Escudero-Colomar 2014; Funes et al. 2018c). However, no field assessments were carried out with any of those three generalist predators, which are abundant and frequent in berry crops. Likewise, unidentified specimens of Thomisidae (Aranea) and from both Hemerobidae and Chrysopidae (Neuroptera) have been recorded attacking SWD in blueberry crops in Buenos Aires (Santadino et al. 2017). Regarding entomopathogenic fungi, the widely used *Beauveria bassiana* (Balsamo) Vuillemin (Ascomycete) was evaluated on SWD adults in lab tests, causing mortality rates of up to 44% (Escudero-Colomar 2016; Funes et al. 2018c).

Management strategies

Due to the fast spread of SWD throughout Argentina's fruit-growing regions, preventive mitigation procedures have been quickly adopted to minimize economic losses at the provincial or regional level, but without prior national coordination through a strategic SWD integrated management program . In this regard, and after monitoring SWD adults and infested fruits at a regional and national scale (Garavelli 2017), SWD mitigation strategies such as crop sanitation, chemical controls, exclusion nets, mass trapping supported by attractant-based traps, and postharvest phytosanitary quarantine treatments, such as methyl bromide, ionizing radiation, or fruit cooling application (Funes et al. 2018c), were initially implemented. At the same time, actions to implement complementary biological strategies such as the Sterile Insect Technique (=SIT) and biological control (=BC) using natural enemies are at an early phase of evaluation and development. Among the first defensive procedures implemented in Argentina, there were some cultural tactics, such as removing damaged fallen berries or injured fruit even on the plant (Lochbaum 2017), and the use of physical exclusion using fine mesh netting to protect cherry and berries crops (Cichón et al. 2016) in northern Patagonia. Implementation of other cultural controls, which included strategies to (1) reduce habitat favorability for both SWD adults and immature stages, such as pruning, mulching, and drip irrigation, and to (2) alter resource availability, such as higher harvest frequency, crop sanitation, and removal of alternative hosts surrounding the crops, were also carried out in southern Patagonia (IFAB 2022). Chemical control by spraying different insecticides to control SWD adults into host plant foliage, with mortality rates from 20 to 70% in 48 hs, have been used in toxicity tests in berries crops from the northeastern Buenos Aires (Riquelme-Virgala et al. 2017). Tested insecticides were Chlorantraniliprole, Lambda-Cyhalothrin, Spinosad, and Neemazal (Riquelme-Virgala et al. 2017). In turn, insecticides such as Abamectin, Spirotetramat, Emamectin benzoate, and Methomyl are suitable for use against SWD (Cichón et al. 2019). Currently, moderately dangerous pesticides, such as Chlorantraniliprole, Lambda-Cyhalothrin, and Spinetoram, were recently authorized to SWD control in berries and cherry crops, and both Abamectin and Cyantraniliprole were also authorized in tomato crops (Garcia et al. 2022). Mass trapping systems have been evaluated on raspberry and cherry crops grown at the Alto Valle de Río Negro and Neuquén (northern Patagonia). In this context, plastic bottles baited with apple vinegar plus water at a density of 200 traps/ha were extensively used in raspberry crops in Plottier (Neuquén) (Lochbaum 2017). A broad variety of traps with different attractants was tested on cherry and raspberry crops in Rio Negro for their use in mass trapping. Thus, bottles baited with apple vinegar plus water or with apple vinegar plus red wine, *SuzukiiTrap*®, bottle trap with apple vinegar + water plus a low specificity lure (Trécé® bait) or plus a high specificity lure (Trécé® bait) placed over the top of each trap were used (Cichón et al. 2016). The use of the SIT as an effective bio-rational control method within an area-wide integrated SWD management program framework is likely to be achieved within a short term (Sassù et al. 2020). For this purpose, the development of a mass-rearing system for SWD at ISCAMEN's km-8 Insect Mass Rearing biofactory, located in the Mendoza (Cuyo region), is in progress (Taret et al. 2017). Goals of developing the SWD SIT project involve local diet elaboration, puparia irradiation dosage and establishment of mass-rearing quality control parameters, sterile fly pre-release packaging and open-field release criteria, and post-release assesssment (Taret et al. 2017). With regard to BC, both resident pupal parasitoids, *T. anastrephae* and *P. vindemiae*, could be promising agents for use in SWD augmentative biological control programs in Argentina. This is based on the interesting natural parasitism rates on SWD puparia lately recorded in northwestern Argentina (Buonocore Biancheri et al. 2022, 2023). However, *P. vindemiae*, due to its low specificity, high sensitivity to insecticides, and its facultative hyperparasitoid status, would not be a recommended candidate for use as biocontrol agent (Garcia et al. 2022). Although both resident pupal parasitoid species are available, this does not exclude the possibility of importing a *G. brasiliensis* lineage more specialized on SWD, such as the Japanese one (Wang et al. 2020; Seehausen et al. 2020), which attacked SWD larvae in fresh fruits in the tree canopy, but rarely in fallen fruits (Matsuura et al. 2018). An important point to note is that the Argentinean specimens of *G. brasiliensis* found in Tucumán attacking SWD larvae belongs to a much more widespread, worldwide lineage in close association with different saprophytic drosophilid species (Gallardo et al. 2022b). Therefore, it is possible that the parasitism on SWD by *G. brasiliensis* recorded in Argentina could be casual, since one specimen (~ 0.5% parasitism) was recovered from numerous SWD puparia, and until now, it has not been found associated with this novel invasive pest again. However, a common issue to be addressed when including biological control within a pest control program is the costs related to the production and release of the natural enemy in comparison to chemical control, which is fast and effective. However, the contribution of biological control used conscientiously within an integrated pest management approach is unquestionable, particularly when the production of the agent is carried out in a framework associated with the development and application of SIT. Chemical control can be a technique with negative effects on the environment and with a very low valuation by people. Usually, costs of those negative impacts are difficult to quantify because they involve different variables and occur over the long-term. Biological control is known as an eco-friendly technique with both a low environmental impact and very good standing due to its high level of social acceptance (Wang et al. 2020).

Concluding remarks

Concisely, the SWD displayed biological traits which significantly facilitated its rapid spread throughout almost all of Argentina, from 23°34′S-65°22′W (northern Argentina) to 46°55'S-71°61'W (southern Argentina), which implies a distance of ~ 3300 km between both sampling sites. Similarly, SWD have been collected over a wide altitudinal range, covering altitudes between 2461 and 11 m. Thus, the establishment of this novel invasive pest species in Argentina across a diverse array of environments with very distinctive weather and geographical and ecological features has been undoubtedly documented. Among SWD biological traits can be highlighted the broad host range with alternative crop and non-crop host plants and high population growth rate in all invaded fruit-growing regions, and its seasonal phenotypic plasticity enabling it to adapt to adverse thermal periods, from extremely cold dry-arid to warm humid-subtropical climates. All aforementioned added to egg-laying preference for fresh healthy, ripening soft fruits by SWD females swiftly drove this exotic dipterous to damage mainly commercial berry crops, such as raspberry, blackberry, strawberry, blueberry, and small stone fruits, like cherries, in all those Argentinean fruit-producing areas. In view of this, and due to the fact that SWD was first detected in 2014 in the country, this invasive species was temporarily categorized as a novel pest under monitoring and surveillance at national level. However, damage incidence levels on raspberry and cherry crops grown in northeastern Buenos Aires reached 100% of the harvested fruit, while on blueberry crops was 28%. Such preliminary information provides evidence on the economic and social relevance of this invasive novel pest for commercially valuable soft fruit production in Argentina. Interestingly, two SWD population seasonal patterns between the northern and central fruit-growing regions and southern Argentina can be highlighted. The SWD mostly generate two main population peaks in the early regions, namely, in late spring-early summer (November–December) and mid-autumn (April–May), while in southern fruit-producing regions SWD mostly peaks in April (mid-autumn). These differences may be associated with both the extreme climatic conditions of the Patagonian region (dry, arid, cold) and berry fruiting periods, particularly raspberries. Mitigation strategies carried out so far against SWD, particularly by provincial or regional entities, have involved mainly mass trapping systems, chemical control, postharvest quarantine treatments, and cultural control practices to reduce the availability and suitability of crop habitats for this novel invasive pest. However, up to date none nationally coordinated SWD integrated management strategies have not yet been implemented. Regardless of that, interesting forthcoming scenarios arise in Argentina to develop and apply environmentally friendly methods, combining SIT and BC. Particularly, augmentative releases of parasitoids as a SWD biocontrol strategy may provide a more effective regulation of this invasive pest (Rossi Stacconi et al. 2019).

In view of the foregoing, there is a pressing need to incorporate those local SWD control actions into a national integrated area-wide pest management program. Such approach should involve provincial and regional operational systems for SWD control in all invaded fruit-growing regions through three major goals: (1) surveillance activities by monitoring, phytosanitary control, and producer outreach; (2) supervising control and regulatory operations; and (3) implementation of mitigating measures at ports of entry. Once the above has been undertaken, it is relevant to concentrate efforts on identifying ways to improve the efficiency of the actions undertaken at the provincial or regional level. In this way, it is essential to achieve the success of those operational programs, and at the same time optimize resources. In this framework, collaboration and communication between the different entities involved through control actions should be an overarching, nationally coordinated component. Looking ahead, successful large-scale integration of management strategies such as SIT, biological control, and mass trapping, among other complementary tactics (Garcia 2020), will require not only regional but also national coordination and consensus. Likewise, the use of alternative insecticides compatible with the conservation of natural enemies may be advisable from an ecological perspective for environmentally sound control of SWD. In this regard, macrocyclic lactones, e.g., avermectins and milbemycins, derived from naturally occurring compounds produced by soil-dwelling actinobacteria, such as *Streptomyces* Waksman & Henrici, are widely used as insecticides to control pests with low risk to non-target insects (Batiha et al. 2020). Interestingly, current research has shown innovative lactone-derived synthetic compounds to have selectivity for the parasitoid *T. anastrephae* when used against SWD (Mantilla-Afanador et al. 2023). Those novel lactone-based insecticides have the potential for use into an integrated SWD management program.

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Declarations

Conflict of Interest The authors declare no competing interests.

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