Journal of Integrated Pest Management, (2023) 14(1): 20; 1–10
https://doi.org/10.1093/jipm/pmad018
Profile

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Meet *Amblyseius swirskii* (Acari: Phytoseiidae): a commonly used predatory mite in vegetable crops

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Subject Editor: Donald Weber

Received 25 May 2023; Editorial decision 30 August 2023

The predatory mite, *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae), is a generalist predator feeding on multiple soft-bodied insects and mite pest species. It is a biological control agent commercially available since 2005 that has become one of the top 3 most released biocontrol predators worldwide. It is commonly used to suppress whitefly populations (Hemiptera: Aleyrodidae), thrips (Thysanoptera), and spider mites (Acari: Tetranychidae) to a lesser degree. This predatory mite has been used as part of Integrated Pest Management (IPM) programs for vegetable (e.g., peppers, eggplants, cucumbers, squash) and ornamental (e.g., roses, chrysanthemums) crops in open fields and greenhouses, and some field crops such as cotton, but it has been demonstrated to be more successful at establishing reproductive populations and suppressing pests under protected structures. *Amblyseius swirskii* can feed on various food resources besides prey, including pollen or honeydew. It is successful at suppressing pests when used together with low-risk pesticides, when multiple prey are available, when prey and pollen are available naturally (neighboring flowering or companion plants present), or when pollen is supplemented in the field. This predator is a good option to control pests early in the season if shelter and food resources are available for its establishment.

Key words: biological control, predatory mite, natural enemy, Phytoseiidae

The predatory mite, *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae), belongs to the subfamily Amblyseiinae, the largest subfamily in the family Phytoseiidae with 1,478 nominal species (Chant and McMurtry 2007). This species is native to the Mediterranean region (Goleva and Zebitz 2013). Since it was commercially available in 2005, *A. swirskii* has been released in more than 50 countries in the world to feed on soft-bodied pests such as whiteflies, thrips, spider mites, and other pests of vegetables, fruits, and ornamental plants grown under protected structures (e.g., greenhouses, high tunnels) or in open fields (Nomikou et al. 2003, Calvo et al. 2015). The wide prey range of *A. swirskii* and its ability to feed on the pollen of various plant species make it a good predator for early-season establishment and is considered one of the most used predatory mites in the world.

Life Cycle

The life cycle of phytoseiid mites, including *A. swirskii*, typically comprises 5 developmental stages: egg, larva, protonymph, deutonymph, and adult females and males. *Amblyseius swirskii* develops from egg to adult within a week at 25 °C and 70% ± 5% relative humidity (RH) and, unlike some pest mites (e.g., tetranychids), females must mate to produce eggs (Woolley 1988, Hoy 2011). Eggs are oval-shaped, translucent, and ~0.20 × 0.15 mm (Fig. 1). Eggs are usually laid on the underside of leaves individually or in clusters around the intersection of the main and lateral veins. If present, females prefer to lay their eggs on non-glandular leaf trichomes or in clusters inside domatia (i.e., small pockets of nonglandular trichomes found commonly in some pepper plants and other plant species) to protect them from predators (Hoy 2011). Eggs last for approximately 1–2 days, during which time the egg develops into a 6-legged larva.

The larvae are small (~0.22 × 0.16 mm), white to translucent in color, slow moving, and oval shaped (Fig. 2). This stage typically lasts for about 1–2 days. Larvae undergo one molt to develop into protonymphs that develop into deutonymphs after a second molt. Protonymphs and deutonymphs of *A. swirskii* have 8 legs, are orange colored, and are slightly larger than the larvae (Fig. 2). Each nymphal stage usually lasts for 1–2 days and feeds on insect pests such as first-instar thrips, first-instar whitefly immatures or whitefly eggs, and eggs or immature spider mites. After a short quiescent period, deutonymphs develop into adults (Hoy 2011, Calvo et al. 2015).

At this stage, adult females and males of *A. swirskii* are close to reaching their full size and are ready to mate. Adult females are about twice the size of the males and have pear-shaped bodies (Fig. 3). Adult females have a higher rate of predation to support the production of eggs. Adult males have oval bodies, usually move faster than females, and typically reach adulthood in a shorter time compared with *A. swirskii* females (Hoy 2011). The male guards a deutonymph female entering the quiescent stage and mates with the

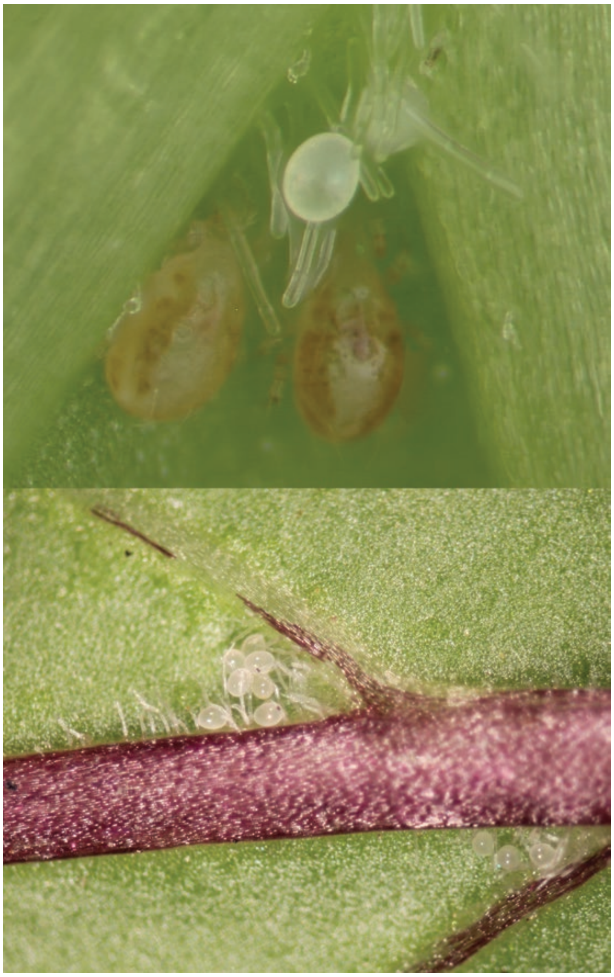

Fig. 1. Two eggs of *Amblyseius swirskii* laid on the domatia of a bell pepper leaf accompanied by adult females (top) and cluster of eggs on the domatia of an ornamental pepper leaf (bottom).

female immediately after she molts into an adult by placing himself venter to venter with the female. Once in this position, the male transfers a sperm packet with his modified chelicerae to the female's spermatheca. One female can lay 1.5–2 eggs per day and between 30 and 40 eggs in her life span. Mature eggs occupy most of the female's body cavity, giving her a characteristic pear-shaped body when reaching full body size (Figs. 1 and 3) (Hoy 2011, Lopez and Liburd, unpublished data).

Optimal Environmental Conditions

Amblyseius swirskii can develop and reproduce successfully over a range of temperatures from 15 to 36 °C, but its reproduction and survival are greatest at 25 °C. Adults can live for several weeks under favorable environmental conditions (22 ± 3 °C, 55%–85% RH), with access to shelter, water, and food resources (Abou-Awad et al. 2014, Al-Azzazy and Alhewairini 2020). Their survival, reproduction, and pest suppression ability are sensitive to temperature and RH and will decrease outside their optimal conditions (22–32 °C and 55–85% RH). It has been reported that *A. swirskii* population growth and development below 20 °C or above 38 °C could be slow and negatively impact their survival and ability to seek out prey (Ali and Zaher 2007, Lee and Gillespie 2011). Similarly, *A. swirskii* life stages are susceptible to changes in RH, resulting in long nymphal developmental periods, low female fecundity, and low egg survival when RH is below 50%, compared with mite populations exposed to RH levels above 55% (Al-Azzazy and Alhewairini 2020, San et al. 2021). While nymphs and adults can drink water and feed on prey or plant exudates to compensate for water loss at low RH (<40%), eggs are susceptible to desiccation and reduced hatchability (San et al. 2021).

The surface of most host plant leaves has a unique microclimate thanks to gas interchange processes. The increased RH and temperatures on the surface of leaves can promote predatory mite survival when they are directly released on top of the plants. Similarly, enclosed release methods such as sachets create a microclimate with a higher RH, temperature, and water content to maintain *A. swirskii* optimal conditions for weeks and promote their establishment in the released crop (Solano-Rojas et al. 2022). Despite the advantages of microclimates within sachets or plants, it is vital for mites to have access to water. Moreover, the overall environmental conditions of the geographic location where these predatory mites are released must fall within the optimal ranges for *A. swirskii* to successfully establish and provide biocontrol services (San et al. 2021, Solano-Rojas et al. 2022).

Heavy rain events can also limit the establishment of *A. swirskii* in the open field. Thus, this predatory mite is most successfully used under protected structures where the desired average daily temperature throughout the year is between 20 and 30 °C and high RH is common (Lee and Gillespie 2011, Lopez and Liburd 2022).

Mite Biology

Dispersal Capacity

The ability of a predatory mite to suppress pests is strongly influenced by its capacity to disperse from the release site and seek prey throughout the crop (Pratt and Croft 2000, Buitenhuis et al. 2010, Parolin et al. 2014). Like most predatory mite species, *A. swirskii* disperses by walking through plants, soil, and planting material. They are highly mobile and can move from plant to plant using any bridges between the leaves (e.g., leaf bridges, pot surfaces, plastic or living mulch, and irrigation lines, to name a few) traveling at least 1 m within 24 h in high tunnel-grown pepper plants (Lopez et al. 2017) and at least 17 m within a week in open field-grown squash plants (Lopez and Liburd 2022). This is considered a high dispersal capacity for nonflying arthropods. Ambulatory dispersal is the main mode of dispersal for most predatory mites, followed by aerial dispersal. *Amblyseius swirskii* can disperse aerially, especially gravid females in search of prey, new oviposition sites, or alternative food sources. Females will not move far unless prey is scarce, or shelter is limited due to increasing predatory mite populations. Predatory mites can detect chemical cues released by the host plants, such as organic volatiles that indicate when the plant is infected by a pathogen (i.e., insect-transmitted pathogens), interacting with symbiotic microorganisms, or being fed on by herbivore arthropods (Schausberger et al. 2012). Similarly, they can estimate shelter and food availability based on encounters or interactions with other mites or based on chemical signals from other *A. swirskii* mites nearby or from other predatory mite species (e.g., webbing, molting sheds, among others) (Schausberger et al. 2012). These limiting situations may be disadvantageous for females' progeny; thus, females disperse to find new oviposition sites to secure food and shelter for their progeny and avoid cannibalism due to the increase in the population (Hoy 2011). When there is open space between plants, crops, or otherwise, females can use air currents to colonize new areas or

Fig. 2. *Amblyseius swirskii* larvae (top) and deutonymph (bottom).

Fig. 3. Adult female of *Amblyseius swirskii.*

crops. Because mites cannot decide where to fall but reach other places haphazardly, the presence of windbreakers, shrubs, and forest patches near neighboring crops plays an important role in their dispersal. Immature stages rarely move beyond one or a couple of leaves unless no food (prey or pollen) is available (Pratt and Croft 2000, Lopez et al. 2017). In addition, predatory mites can probably hitchhike on farm equipment, worker clothes, or greenhouse materials to colonize new plants or areas.

Promoting Establishment

Companion planting or intercropping has been used as a diversification tactic mostly to promote biocontrol services by beneficial arthropods (Pratt and Croft 2000, Parolin et al. 2014). It involves growing other crop or noncrop plants with the cash crop. Insectary plants are often used as companion plants within vegetable crops to provide alternative shelter and food items to beneficial arthropods such as *A. swirskii,* promoting their establishment and dispersal toward the cropping system (Parolin et al. 2014). Examples of insectary plants used to encourage *A. swirskii* include sweet alyssum (*Lobularia maritima* (L.) Desv., Brassicales: Brassicaceae), buckwheat (*Fagopyrum esculentum* Moench, Caryophyllales: Polygonaceae), pinto bean (*Phaseolus vulgaris* L., Fabales: Fabaceae), sweet, chili, and ornamental peppers (*Capsicum annum* l., Solanaceae) (Fig. 4) (Xu and Enkegaard 2010, Calvo et al. 2011, Lopez et al. 2017).

Food Resources

Phytoseiid mites are classified into 4 groups based on their lifestyles (McMurtry et al. 2013). *Amblyseius swirskii* is categorized as a subtype III-b species consisting of mites that prefer to live on glabrous leaves (with little or no trichomes) and are generalist predators that feed on multiple insect and mite species. They can feed and reproduce on mites of families Eriophyidae (russet or gall mites), Tarsonemidae (e.g., broad mites), Tetranychidae (spider mites), Tenuipalpidae (false spider mites), and Tydeidae, as well as other soft-bodied organisms such as thrips (first-instar thrips), whiteflies (whitefly eggs and first and second instars), mealybugs, and nematodes, to name a few (McMurtry et al. 2013, Soleymani et al. 2016). In addition, they have been reported to feed and maintain themselves on microcrustacean species *Artemia franciscana* Kelogg (Crustacea: Artemiidae) as factitious food (i.e., a food source that the predator would not normally encounter in its natural habitat but on which the predatory mite can be reared for mass production) (Nguyen et al. 2013, Liburd et al. 2020).

Few reports of *A. swirskii* surviving on aphid honeydew exist, and it was reported as a poor food source for these predators (Ragusa and Swirski 1977). There are fewer reports of *A. swirskii* feeding on aphids. When *A. swirskii* was fed adult stages of *Aphis durantae* Theo (Hemiptera: Aphididae), long periods of nymphal development and low female fecundity were recorded indicating that these aphids were not an ideal food source for the mites (Ragusa and Swirski 1977, Ali and Zaher 2007).

As a generalist predatory mite, *A. swirskii* feeds not only on various prey but also on other food sources such as pollen, nectar, plant exudates, honeydew, and pycnial fluid from fungi in the absence of prey or as complementary food when prey is available (Nomikou et al. 2003, Goleva and Zebitz 2013). The combination of prey + alternative food resources (i.e., pollen) increases their reproductive capacity and the likelihood of establishment at early stages of the crop when pest abundance is low but flowering plants are present (McMurtry and Croft 1997, Calvo et al. 2015, Lopez et al. 2017) (Fig. 5). Therefore, supplementing pollen when releasing *A. swirskii* could reduce or eliminate the need for multiple releases during the growing season and the cost minimized when pollen or multiple prey are present. Pollen subsidies and non-living factitious foods such as dry *Artemia* or *Ephestia* eggs can be purchased from multiple biological companies as a resource to promote predatory mite establishment, including *A. swirskii*.

No negative effects on biological control services have been reported associated with pollen supplementation for *A. swirskii* when prey is available. In contrast, pest control is improved when prey (e.g., twospotted spider mites, whiteflies, or thrips) is available, and pollen is supplemented, probably due to the increase in reproductive capacity caused by the presence of pollen (Nomikou et al. 2010, Schuldiner-Harpaz et al. 2016). *Amblyseius swirskii* populations can grow rapidly when fed only pollen, at a comparable rate to feeding on prey (Nomikou et al. 2010, Riahi et al. 2017). However, not all types of pollen are suitable for *A. swirskii* survival. Cattail (*Typha* spp.), pepper (*Capsicum* spp.), alyssum (*Lobularia* spp.), corn (*Zea mays* L.), and almond (*Prunus dulcis* Mill.) pollen are some of the pollen types that have been reported as suitable for development and population growth of *A. swirskii* (Henry et al. 2011, Schuldiner-Harpaz et al. 2016, Riahi et al. 2017). In contrast, some cucurbit pollen (i.e., squash pollen) does not seem like a preferred or even suitable food source for these mites (Lopez and Liburd 2022). *Amblyseius swirskii* has been reported feeding on extrafloral nectaries but their importance on population growth and survival is yet unknown (Henry et al. 2011).

Distribution

Amblyseius swirskii is a predatory mite widely distributed in many parts of the world. It has been reported in Europe in many countries, including Spain, Italy, France, Greece, Turkey, Bulgaria, and the Netherlands. *Amblyseius swirskii* was originally described in 1962 from almond trees (*P. dulcis*) in Israel, where it naturally occurs on citrus, grapes, vegetables, and cotton (Swirski and Amitai 1997). In Spain, it is currently one of the most used predators in greenhouse crops, especially in pepper production, and it has also been found in citrus orchards and other outdoor crops (Bouagga et al. 2018). In Asia, *A. swirskii* has been reported in several countries, including Israel, Iran, and China. Similarly, this predatory mite has been reported in many African countries, including Egypt, South Africa, and Morocco. In all these countries, *A. swirskii* has been used as a biological control agent mostly in greenhouses and some open field crops for the control of whiteflies, thrips, and occasionally spider mites (Bouagga et al. 2018).

In North and South America, *A. swirskii* has been reported in the United States, Canada, Mexico, Brazil, and Chile. In the United States, it has been used in greenhouse crops, including tomatoes, cucumbers, and peppers, to control spider mites and thrips (Gerson et al. 2008, Calvo et al. 2015). *Amblyseius swirskii* is commonly found in Florida, where it was first discovered in the late 1990s and it is known to be established in many states since then, including California, Arizona, Georgia, Texas, Ohio, and Michigan (Gerson et al. 2008). The distribution of *A. swirskii* in the United States is influenced by various factors, including the introduction and spread of the mite by commercial growers for pest control purposes. However, despite its widespread use, the effectiveness of *A. swirskii* as a biological control agent can vary depending on the environmental conditions and the type of pest present (Gerson et al. 2008, Bouagga et al. 2018). Therefore, the distribution of this predatory mite may continue to evolve as vegetable, fruit, and ornamental growers seek effective pest control options that are sustainable and environmentally friendly.

Fig. 4. Adult females (bottom), immature (top), and egg (bottom) stages of *Amblyseius swirskii* in a bell pepper flower.

Economic Importance

Mass Rearing Methods

The most common methods of mass-rearing for phytoseiid mites around the world, including *A. swirskii*, are tri-trophic rearing systems. These consist of growing a plant host under greenhouses to rear prey, which will serve as food to sustain predatory mite populations. Commercial mass-rearing facilities often use bean plants as the foundation of their rearing systems due to the ease of cultivation and fast development into full-grown plants. Similarly, spider mites (*Tetranychus* spp., Tetranychidae) are typically chosen as prey because of their fast reproductive ability and population growth.

Most commercially available predatory mites (*A. swirskii, Neoseiulus californicus*, and *N. cucumeris*) are mass-reared only on factitious foods (i.e., a food source that the predator would not normally encounter in its natural habitat) (Hoy 2011, Bouagga et al. 2018). The ability of *A. swirskii* to develop and reproduce factitious foods is a huge benefit in establishing mass-rearing systems (Barbosa and de Moraes 2015) at a relatively low cost. The mold mite *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) and the dried fruit mite *Carpoglyphus lactis* L. (Acari: Carpoglyphidae) are factitious prey used successfully in the commercial rearing of *A. swirskii* around the world (Barbosa and de Moraes 2015, Pirayeshfar et al. 2020). Mass-produced *A. swirskii* are then distributed in various substrates consisting of bran, rice flakes, or both mixed with prey in bottle shakers, paper or plastic sachets, or releasing capsules.

Populations of *A. swirskii* can vary genetically among commercial biocontrol product providers. Because genetic variations are linked to resilience and predator performance when biocontrol

Fig. 5. Adult females of *Amblyseius swirskii* on ornamental pepper flower.

agents are released into crops, there may be performance benefits from using various providers when purchasing *A. swirskii* for biological control purposes (Paspati et al. 2019). In addition, the host plant and diet used to rear *A. swirskii* populations can significantly influence the behavior of the mites (Buitenhuis et al. 2014, Calvo et al. 2015). Various mass-reared predatory mites, including *A. swirskii*, have shown different performance levels (i.e., biocontrol services) based on the crop/plant where they are released and the pests they encounter. It has been demonstrated that releasing these commercial biocontrol agents in crops with different conditions from the ones they were reared on may harm their establishment and population growth (Buitenhuis et al. 2014). This is probably because the mites are accustomed to a plant structure and morphology type, diet, and environmental conditions different from those they encounter once released (Calvo and Knapp 2019). This is probably due to the predatory mite learning behavior when multiple generations have been reared on the same host plant or diet for long periods of time (Schausberger et al. 2020), as well as the species' genetically predetermined preferences. For instance, it is well known that *A. swirskii* avoids tomato and squash plants due to the glandular trichomes and may perform poorly in this crop or not establish at all. On the other hand, they thrive in pepper plants even when plants are not often used as rearing hosts in commercial rearing facilities. Therefore, early establishment of *A. swirskii* and/or pollen supplements, as well as the use of flowering plants can be advantageous to enhance their performance (Xiao et al. 2012). Moreover, release rates of *A. swirskii* may need to be adjusted depending on the crop in which it is used (Buitenhuis et al. 2014).

Biocontrol Potential

Amblyseius swirskii quickly became one of the most successful biocontrol agents after its introduction into the market in 2005 and is now released in more than 50 countries (Calvo et al. 2015, 2019). It is an effective predator of major pests found in vegetable production, such as the sweetpotato whitefly (*Bemisia tabaci*), the greenhouse whitefly (*Trialeurodes vaporariorum* Westwood, Hemiptera: Aleyrodidae), western flower thrips (Frankliniella *occidentalis*), melon thrips (*Thrips palmi*), and common blossom thrips (Frankliniella *schultzei*) (Xu and Enkegard 2010, McMurtry et al. 2013, Buitenhuis et al. 2015, Kutuk et al. 2016).

Amblyseius swirskii is well adapted to several vegetable crop hosts including cucumber, pepper, and eggplant (Nomikou et al. 2002, Stansly and Castillo 2009, Onzo et al. 2012, Farkas et al. 2016). This predatory mite effectively suppresses the sweetpotato whitefly and *F. occidentalis* populations in greenhouse-grown cucumber plants, suppressing up to 99% of whitefly nymphs compared to an exponential increase of more than 200 nymphs per leaf when

A. swirskii was absent (Calvo et al. 2011). Moreover, the presence of *A. swirskii* resulted in significant thrips suppression of more than 98% irrespective of the presence of whiteflies. The authors of this study also reported that predatory mite abundance was highest in the treatment combining *A. swirskii*, whitefly, and thrips. The option of targeting 2 pests with a single natural enemy has positive implications for biocontrol and resembles pest-predator complexes in field conditions (Messelink et al. 2010). In addition, it has been demonstrated that when multiple prey or food sources (prey + pollen) are available, *A. swirskii* survival is increased and populations are larger (Lopez et al. 2017).

In experiments to compare the effectiveness of several predatory mite species, Messelink et al. (2006) found that *A. swirskii* performed better suppressing *F. occidentalis* in cucumber compared with *Euseius scutalis* Athias-Henriot (Acari: Phytoseiidae) and *N. cucumeris*, the latter being the predatory mite commonly used for augmentative biological control of thrips in cucumber and other vegetable crops. In another study conducted on cucumber crops, Kakkar et al. (2016) demonstrated that *A. swirskii* provided effective control of *T. palmi* and *F. schultzei* under laboratory and semi-field conditions (shade house), and field trials. Their results demonstrated that *A. swirskii* may rival the effectiveness of chemical control strategies generally used for the management of these pests.

Few studies have reported the establishment of reproductive populations of *A. swirskii* in cucurbit crops such as squash (Kakkar et al. 2016, Lopez and Liburd 2022). This is probably because *A. swirskii* are more likely to establish in crops with glabrous leaves, such as peppers or cucumbers, than in leaves with abundant glandular trichomes such as some squash and tomato leaves (Xiao et al. 2012, Calvo et al. 2015). For instance, *A. swirskii* can be established in squash but prefers mature leaves that have fewer glandular trichomes. This predatory mite was rarely observed in younger leaves where these trichomes are most abundant (Lopez and Liburd 2022). Likewise, *A. swirskii* avoid tomato plants due to the presence of glandular trichomes consistent with this species' behavioral preference for glabrous leaves. The glandular trichomes on tomato leaves and stems not only limit *A. swirskii* movement but also have toxic effects on the nymphs and adult stages that are in contact with the secondary metabolites secreted in the tomato trichomes (Paspati et al. 2019). Thus, *A. swirskii* populations are often unsuccessful at establishing this crop.

Amblyseius swirskii has the ability to establish reproductive populations on other cucurbit crops besides cucumbers, such as summer squash in open fields and greenhouses. Companion plants serve as refugia by offering shelter, oviposition sites, and alternative food sources to support *A. swirskii* in times of prey (pest) scarcity (Xiao et al. 2012), given that this predatory mite is not likely to feed on squash pollen. Furthermore, parasitoids and larger predators that are also attracted to the companion plants, such as hoverflies (Syrphidae), big-eyed bugs (*Geocoris* spp.), and minute pirate bugs (*Orius* spp.), could feed on other pests in the system, such as aphids, while *A. swirskii* seeks out sweetpotato whiteflies and establishes earlier in the season by feeding on pollen or alternative prey.

In European countries, *A. swirskii* demonstrated its potential to suppress thrips and whiteflies in sweet peppers under protected structures in combination with *N. cucumeris*, and the minute pirate bug (*Orius laevigatus* Fieber, Hemiptera: Anthocoridae) (Van Maanen et al. 2010). *Amblyseius swirskii* use in sweet peppers expanded throughout the world soon after it was successfully used in Spain under greenhouse production (Van Maanen et al. 2010, Calvo et al. 2019). In addition, *A. swirskii* showed potential to be established in banker plant systems (i.e., open-rearing systems consisting of banker plant, alternative food, and predatory mites used to maintain and disperse beneficial populations) and disperse from banker plants into pepper plants to successfully suppress populations of sweetpotato whiteflies, western flower thrips, and chilli thrips under laboratory and greenhouse conditions (Pratt and Croft 2000, Huang et al. 2011, Xiao et al. 2012). *Amblyseius swirskii* maintained low levels of the 3 pests for most of the experimental cycle (90 days) in laboratory conditions and more than 10 weeks under high tunnels (Lopez et al. 2017). Providing pollen (e.g., *Typha* pollen) to this predator may enhance its establishment and efficiency in controlling pests (Nomikou et al. 2010, Kutuk and Yigit 2011).

Additional studies have also reported good pest suppression by *A. swirskii* in onions and ornamentals such as roses and chrysanthemums (Onzo et al. 2012, Parolin et al. 2014, Calvo et al. 2015, Kumar et al. 2015). Similarly, cotton fields in Egypt have been reported as rich in *A. swirskii* individuals with abundant mites at the pleats of the lower surfaces of the leaves located in the middle part of cotton plants during the warm months of the season (Elshazly 2022).

Chemical Control Compatibility

The effects of various insecticides used in vegetable production on *A. swirskii* have been evaluated. Most of the assessed products are limited to conventional cropping systems, including abamectin, metaflumizone, chlorantraniliprole, emamectin benzoate, fenpyroximate, methoxyfenozide, and flonicamid, to name a few (Colomer et al. 2011, Gradish et al. 2011, Amor et al. 2012, Lopez et al. 2015, Fernandez et al. 2017). The susceptibility of phytoseiid mites to plant protection products varies among developmental stages, with immature stages more susceptible to most pesticides than adult mites (Capinera 2008). Research has demonstrated that emamectin benzoate, milbectin, cyhexatin, fenpyroximate, and pyridaben have more negative impacts on phytoseiid adults and most also cause reduced fecundity (Amor et al. 2012, Lopez et al. 2015, Schmidt-Jeffris et al. 2021). While most also cause detrimental effects on immature stages, it has been shown that populations exposed to fenpyroximate treatments causing immature mortality below 50% can recover within a couple of weeks under optimal conditions (Lopez et al. 2015). Thus, the negative effects of even some harmful pesticides can be mitigated when well-timed applications are implemented.

Despite being considered a selective miticide in the past, studies testing the side effects of abamectin on phytoseiids have shown significant harm to predatory mites, and it is no longer considered selective (Gradish et al. 2011, Fernandez et al. 2017, Schmidt-Jeffris et al. 2021). Similarly, broad-spectrum pesticides such as etoxazole and most mitochondrial complex electron transport inhibitors (METI) are known to be harmful to predatory mites. However, some new METI pesticides such as bifenazate and acequinocyl are currently known as the least harmful products to predatory mites, together with hexythiazox, spiromesifen, and cyflumetofen (Fernandez et al. 2017, Schmidt-Jeffris et al. 2021), and some organic and reduce risk pesticides.

Exposure to reduce-risk pesticides such as potassium salts of fatty acids residues (e.g., M-Pede or Safer, also known as pesticidal soaps or soap salts) had minimal detrimental effects on all stages of the predatory mites (Lopez and Liburd, unpublished data). Reports of low *A. swirskii* mortality in M-Pede-treated squash may be related to the short persistence of its active ingredient. Similar findings were reported by Stanyard et al. (1998), who evaluated the toxicity of M-Pede on the predatory mite *Amblyseius fallacis* Garman (Acari: Phytoseiidae). This phytoseiid mite is used in apple trees for the control of the European red mite (*Panonychus ulmi* Koch, Acari: Tetranychidae), and direct single applications of M-Pede showed little if any detrimental effects to the predatory mite. Potassium salts of fatty acids, as various other organic and/or reduce-risk pesticides, are known for their short persistence in the environment and often have a soil half-life of 1 day or less. However, when the frequency of M-Pede applications increased due to red mite outbreaks to more than 2 consecutive applications, *A. fallacis* populations were severely affected (Stanyard et al. 1998). Susceptibility to these potassium salts of fatty acids may vary depending on the predatory mite species.

Not all reduced-risk pesticides can be safely integrated with *A. swirskii* releases unless modifications on release schedules are enforced. For example, residues of azadirachtin + pyrethrins had detrimental effects on all stages of *A. swirskii*, with larvae being more negatively affected (49–73% mortality) than females and nymphs in laboratory experiments (Liburd et al. 2020). The pyrethrin component is a broad-spectrum chemical that targets the nervous system of insects and mites; it is very fast-acting and causes immediate paralysis. Azadirachtin has molting disruption properties (Yu 2008); thus, the larval stage was more susceptible to insecticide toxicity due to lower body sclerotization (Capinera 2008).

Substantially, high mortality for all *A. swirskii* developmental stages has been observed when mites were released 1–3 days after pesticide treatment (Liburd et al. 2020). Females and nymphs of the predatory mite released 1 day after treatment with reduced-risk insecticides (i.e., potassium salts of fatty acids and azadirachtin + pyrethrins) showed higher mortality rates when exposed to residues compared to the control (water sprays) in greenhouse-grown squash (Liburd et al. 2020). Releases of *A. swirskii* within 3 days after insecticide treatment should be avoided, and insecticide treatment should be scheduled at least a week after releasing *A. swirskii* to allow the predators to acclimate and establish in the crop. In addition, a deep understanding of the *A. swirskii* life cycle and population growth within the crop is imperative to schedule accompanying pesticide applications that minimize the negative effects of the predators present. Proper implementation of the plant protection product label and understanding its mode of action will also contribute to mitigating detrimental effects on natural enemies and improving pest suppression.

Concluding Remarks

Amblyseius swirskii ranks in the top 3 of the most used commercially available predatory mites in the world. It is acclimated to multiple vegetable crops such as cucumbers, peppers, and eggplants, and can also be established in squash and cotton crops. It is known to prefer plant hosts with glabrous leaves or leaves that may offer specialized shelters like domatia. The presence of trichomes, particularly glandular trichomes, can limit the performance of some predatory mite species. The high density of glandular trichomes like the ones found on newly unfolded squash or tomato leaves are usually avoided by some generalist phytoseiids, including *A. swirskii*. *Amblyseius swirskii* is a generalist predatory mite species that can feed on a wide variety of insects and mites, but it is most successful at suppressing whiteflies, thrips, tarsonemids, and spider mites to a lesser degree. But it can also feed on a wide variety of alternative food items with some plant pollen at the top of the high-quality alternative foods comparable with some types of prey.

The main purpose of this article is not only to gather the most important aspects of *A. swirskii* biology but also to highlight the main components that must be considered for the successful use of *A. swirskii* in vegetable crops. These include, but are not limited to, the following:

- Identifying the pest or pests that need suppression and determining if *A. swirskii* is efficient at suppressing them.
- Considering if the plant morphology and fitness of the plant (e.g., presence of plant diseases, age of the crop, etc.) is suitable for the establishment and survival of *A. swirskii*.
- Examining environmental conditions within the target crop (e.g., temperature, RH, and water availability) to determine compatibility with the optimal conditions required for *A. swirskii*.
- Identifying trustworthy commercial providers where to acquire high-quality predatory mites. Guidelines to identify such providers are summarized by LeBeck and Leppla (2018) and more can be found at https://ipm.ifas.ufl.edu/applying/Biological_Control.shtml.
- Gathering information regarding the developmental stage of the pests' populations in the crop to schedule well-timed predator releases and/or pesticide applications. The performance of *A. swirskii* can be promoted when small populations of pests are present and *A. swirskii* is used as a preventive tactic.
- Availability of pollen from crop or noncrop plants or pollen supplements can enhance their performance, as well as implementing other suppression practices in combination (e.g., cultural practices such as sanitation, isolation, etc.).
- If pest populations are already high before the introduction of biocontrol agents, the performance of *A. swirskii* can be limited, and pesticide applications may need to be scheduled prior to *A. swirskii* release.
- Choosing reduce-risk pesticides that mitigate detrimental effects to natural enemies for use with *A. swirskii* can promote the survival of these predators in the crop.
- Releasing *A. swirskii* more than 3 days after pesticide treatments is ideal to avoid detrimental effects due to pesticide residues. Similarly, pesticide applications should be conducted at least 1 wk after *A. swirskii* release to allow predator establishment.

Even though these general considerations could be followed for most phytoseiid mites, multiple factors may vary greatly among predatory mite species, including diet specificity, optimal environmental conditions, and preferred host plants, among others. *Amblyseius swirskii* is one of the most researched predatory mites in the world, together with *Phytoseiulus persimilis*, and this article is a basic overview of the knowledge related to *A. swirskii*.

Acknowledgments

I thank all past and present members of the Small Fruit and Vegetable IPM Laboratory at the University of Florida for their help during field and lab work on the study of *A. swirskii* in cucurbits. I thank the staff and workers at the University of Florida's Plant Science, Research and Education Unit (PSREU) for their assistance in maintaining the plants for my research. Lastly, I thank Tom Kuhar from Virginia Tech for encouraging me to write this article.

Author Contributions

Lorena Lopez (Conceptualization [Lead], Investigation [Lead], Writing – original draft [Lead], Writing – review & editing [Lead])

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