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Ziad Barbar, Margaret Skinner, Bruce L. Parker, Serge Kreiter. Species of Phytoseiidae (Acari: Mesostigmata) predators of thrips and whiteflies: a review. *Acarologia*, 2024, 64 (3), pp.745-767. 10.24349/alf8-2ujo . hal-04593993

**HAL Id: hal-04593993**

**<https://institut-agro-montpellier.hal.science/hal-04593993>**

Submitted on 30 May 2024

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# Species of Phytoseiidae (Acari: Mesostigmata) predators of thrips and whiteflies: a review

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## Original research

### ABSTRACT

The biological control of thrips and whiteflies, major pests of crops in greenhouses, is mainly based on the use of hymenopteran parasitoids and many predatory species. Several species of the family Phytoseiidae are natural enemies of these pests. Although several phytoseiid species have been commercially available in the last two decades, more and more research on their efficiency has been accumulated. Data on many additional species as potential predators has been published but research is still limited. This manuscript aims to present the results of relatively recent research about each phytoseiid species studied/commercialized to control whiteflies and thrips. The phytoseiid mite species are divided into three groups: predators that prey on whiteflies and thrips with a preference for phytophagous mites, those commercially produced for managing whiteflies and thrips, and those needing further research to clarify their potential. Available information about the efficacy and limitations of each species is provided and future perspectives for their use are proposed.

**Keywords** predatory mites; biological control; Aleyrodidae; Thripidae

## Introduction

Families Aleyrodidae (Hemiptera) and Thripidae (Thysanoptera) constitute two major groups of insects with piercing-sucking mouthparts. They have an economic importance and worldwide distribution (Nakahara 1994; Evans 2007). In the first group, the tobacco whitefly, *Bemisia tabaci* (Gennadius) and the greenhouse whitefly *Trialetrodes vaporariorum* (Westwood), are among the most serious pests. They infest more than 800 plant species in the greenhouse and the field. They infest bean, pepper, eggplant, cucumber, tomato and a large number of ornamentals, including species of chrysanthemum, fuchsia, gerbera, poinsettia and rose (Evans 2007; Lee and Zhang 2018; CABI 2023). Their impacts on host plants are significant causing major economic damage. They have also shown a high level of resistance to several insecticides and can act as vectors of plant viruses (Navas-Castillo *et al.* 2011; Reliy *et al.* 2011).

Several species in the second group include *Frankliniella bispinosa* (Morgan), *Frankliniella occidentalis* (Pergande), *Frankliniella schultzei* Trybom, *Heliethrips haemorrhoidalis* (Bouché), *Scirtothrips dorsalis* Hood, *Thrips flavidulus* (Bagnall), *Thrips palmi* Karny, and *Thrips tabaci* Lindeman. All are among the most important pests of crops and ornamentals throughout the world. They cause direct damage through feeding and sucking out the contents of plant cells (flowers, young foliage, and buds) and indirect damage as vectors of destructive plant viruses in greenhouse and field crops. The most damaging species are *F. occidentalis*, *T.*

Received 03 April 2024

Accepted 23 May 2024

Published 29 May 2024

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Academic editor

Tsolakis, Haralabos

<https://doi.org/10.24349/alf8-2ujo>

ISSN 0044-586X (print)

ISSN 2107-7207 (electronic)



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**How to cite this article** Barbar Z. *et al.* (2024), Species of Phytoseiidae (Acari: Mesostigmata) predators of thrips and whiteflies: a review. *Acarologia* 64(3): 745-767. <https://doi.org/10.24349/alf8-2ujo>

*tabaci*, *T. palmi* and *S. dorsalis* (Nakahara 1994; Jenser and Szenasi 2004; Seal *et al.* 2006; Cannon *et al.* 2007; Reitz 2009).

The biological control of whiteflies and thrips is a successful and sustainable approach within IPM (Integrated Pest Management) as it is considered as a permanent and durable method and help to prevent the development of insecticide resistance. IPM provides long-term management by regulating thrips and whitefly populations over time and it is an alternative to insecticides. It reduces the need for repeated pesticide applications that can have negative impacts on non-target organisms, the environment and workers and consumers (Cock *et al.* 2010; Van Lenteren *et al.* 2017). With biological control, many parasitoids and predators can be efficient and regulate pest populations. Evans (2007) reported in his catalog more than 50 Aphelinidae (Hymenoptera) parasitoid species of *B. tabaci* and most of them belong to the genera *Encarsia* and *Eretmocerus* (39 and 14 species, respectively). He also reported more than 300 species of insect predators of the families Coccinellidae and Miridae. Aphelinidae, Coccinellidae and Miridae are natural enemies of *T. vaporariorum* with about 50 total species in these families (Evans 2007). Among these natural enemies, the aphelinid parasitoids *Encarsia formosa* Gahan, *Eretmocerus eremicus* (Rose & Zolnerowich), *Eretmocerus mundus* Mercet and the mirid predators *Macrolophus pygmaeus* Rambur and *Nesidiocoris tenuis* (Reuter) are widely used worldwide in the augmentative biological control of whiteflies (Van Lenteren 2012; Gullino *et al.* 2020).

Regarding predatory insects used as biological control agents of thrips, several species such as *Franklinothrips vespiformis* (Crawford) (Aeolothripidae), *Scolothrips sexmaculatus* (Pergande) (Thripidae), the generalist predator *Mallada signata* (Schneider) (Neuroptera, Chrysopidae), and many species of the genus *Orius*, such as *Orius insidiosus* (Say) and *Orius laevigatus* (Fieber) (Hemiptera, Anthocoridae) are important (Van Lenteren 2012; Gullino *et al.* 2020).

Many predacious mite species of the family Phytoseiidae (Mesostigmata) can also feed and reproduce on whiteflies and thrips (Gerson *et al.* 2003; McMurtry *et al.* 2013). Currently, this family contains about 2,557 valid species (Demite *et al.* 2024). The well-known species were classified according to their feeding habits and habitats, biological traits, and morphological characteristics in four major types (and several sub-types) of predators (specialized mite predators, selective predators of tetranychid mites, generalist predators, and polliniphagous generalist predators) (McMurtry *et al.* 2013). Most species of Phytoseiidae are generalist predators (Type III) that feed and reproduce on a wide range of prey including phytophagous mites, thrips, whiteflies, as well as pollen and fungi (McMurtry and Croft 1997; McMurtry *et al.* 2013). Despite the high number of described species of this family, less than thirty species are practically involved as biological control agents, of which only eleven are used to control whiteflies and/or thrips (Van Lenteren *et al.* 2017). This could be explained by the little knowledge of their biological features, ability to predation and feeding habits, and lifestyles (McMurtry *et al.* 2013; Tixier *et al.* 2020). However, more research has been done since 2000 on additional predacious mites and their potential to control these pests, especially thrips.

This review aims to present data on the phytoseiid species studied under laboratory conditions and in greenhouse crops to manage whiteflies and thrips, to provide information about their efficacy and limitations, and to present future perspectives for their use.

Literature was electronically collected from the Google Scholar internet browser, CABI Abstracts, Science Direct sources, and Semantic Scholar AI research tool, using the search terms 'Phytoseiidae', 'phytoseiid', or phytoseiid species name in combination with 'whitefly-whiteflies or whitefly species name', and 'thrips or thrips species name'. We focused on the references published after 2000. According to data from the literature, phytoseiid species were divided into three groups: (i) species predate whiteflies and/or thrips but prefer phytophagous mites, (ii) species used as biological control agents of whiteflies and thrips, and (iii) species need further research for exploration as biological control agents of whiteflies and thrips. They were tabulated according to the pests on which they were tested (whitefly and/or thrips). The names of phytoseiid genera and species in this review follow those used in the taxonomic

system summarized in Chant and McMurtry (2007) and in the Phytoseiidae database (Demite *et al.* 2024), in which other species names and synonyms can be consulted.

## Early and current research on Phytoseiidae predators of whiteflies and thrips

From 1960 to about the beginning of 2000, moderate numbers of research (~150) were done and dealt with the biology, ecology and potential use of Phytoseiidae as natural enemies of whiteflies and thrips. The bibliography of Phytoseiidae by Kostianen and Hoy (1996), showed that *Amblyseius swirskii* Athias-Henriot, *Euseius scutalis* (Athias-Henriot) and *Phytoseiulus persimilis* Athias-Henriot, were the first species tested for their potential as predators of *B. tabaci* and *T. vaporariorum* (Teich 1966; Vogel 1969). *Amblyseius swirskii* and *Neoseiulus cucumeris* (Oudemans) were also the first two phytoseiid species tested as predators of *T. tabaci* and *F. occidentalis*, respectively (Vartapetov and Vasilev 1971; Castagnoli *et al.* 1990). Later, other phytoseiid predators were examined and involved in the control of further species of whiteflies and thrips (as *Heliothrips sylvanus* Faure, *Scirtothrips aurantii* Faure, *Scirtothrips citri* (Moulton), *Scolothrips longicornis* Priesner, *S. dorsalis*, *Taeniothrips simplex* (Morison), *Thrips palmi*, and *Parabemisia myricae* (Kuwana)). Only the three phytoseiid mites, *Iphiseius degenerans* (Berlese), *N. cucumeris* and *Neoseiulus barkeri* Hughes have demonstrated good performances as biological control agents and became commercially available before 2000 to manage thrips in Europe, North America and other areas (Van Lenteren 2012; Knapp *et al.* 2013; Van Lenteren *et al.* 2017).

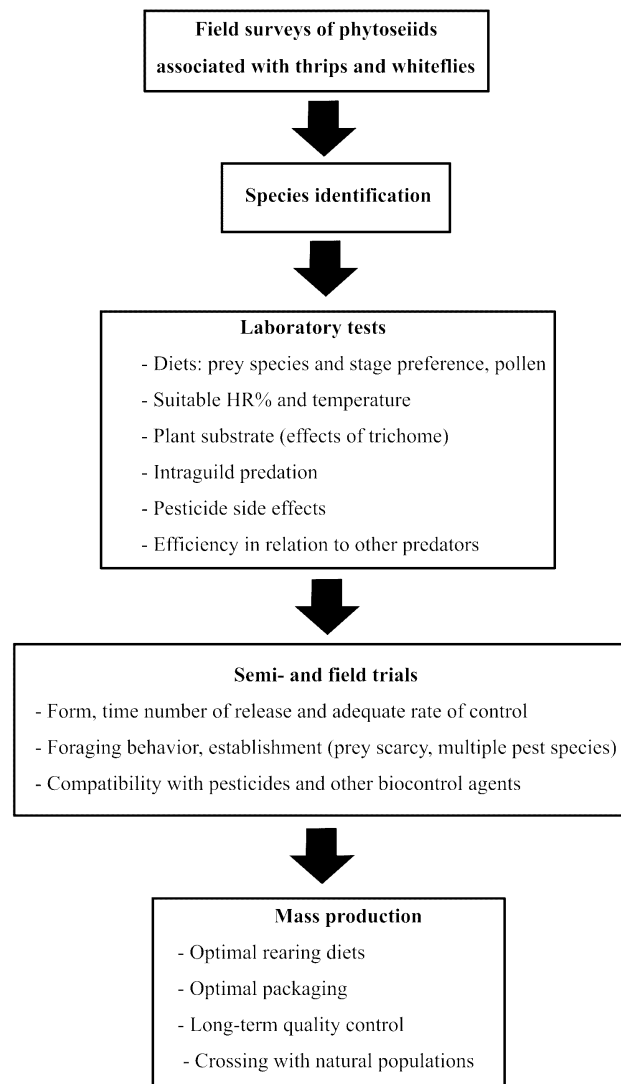
After 2000 and to date, a significant increase in research on the biological control of whiteflies and thrips by Phytoseiidae occurred. The ability of predation and factors affecting the performance of 40 phytoseiid species were examined/re-examined on several whiteflies and thrips taxa under laboratory, semi-field conditions and/or in greenhouses of several crops or ornamental plants like cucumber, sweet pepper, eggplant, bean, tomatoes, roses, chrysanthemum, etc. (Supplementary Table 1, Figure 1). The most targeted pests were *F. occidentalis* (by 23 tested phytoseiid species) *B. tabaci* (by 18 species), *T. vaporariorum* (12 species), *T. tabaci* (by 11 species), and *T. palmi* (by 10 species), and *S. dorsalis* (by six species).

The number of phytoseiid species evaluated against these pests mostly belong to the subfamily Amblyseiinae in particular to three main genera: *Euseius* (nine species), *Amblyseius* and *Neoseiulus* (eight species of each). However, only three species of the subfamily Typhlodrominae [*Typhlodromus* (*Typhlodromus*) *athiasae* Porath and Swirski, *Typhlodromus* (*Typhlodromus*) *pyri* Scheuten and *Cydnoseius negevi* (Swirski & Amitai)] and one of Phytoseiinae (*Phytoseius finitimus* Ribaga) have been the subject of studies mentioned above. Most studies involving phytoseiid species were either pollen-feeding generalist predators (type IV) of *Euseius* and *Iphiseius* genera, for which pollen constitute an important part of their diet, or generalist predators (type III) living in various habitats [on pubescent leaves (III-a) like *Typhlodromalus aripo* De Leon and *T. pyri*, on glabrous leaves (III-b) like *A. swirskii* and *Transeius montdorensis* (Schicha), in confined space on dicotyledonous plants (III-c) as *Amblyseius herbicolus* (Chant), and predators from soil/litter habitats (III-e) like *N. barkeri* and *N. cucumeris*] (McMurtry *et al.* 2013).

## Phytoseiid species predate whiteflies and/or thrips but prefer phytophagous mites

This group of mites includes eleven phytoseiid species that are specialized on the *Tetranychus* genus, in the Tetranychidae or prefer to feed on members of other phytophagous mite families such as Eriophyidae, Tarsonemidae and/or Tenuipalpidae. They are alphabetically presented.

*Amblyseius andersoni* (Chant) was described based on the specimens collected from prune (Rosaceae) from Canada. It is a generalist predator living on glabrous



**Figure 1** Schema representing the main objectives of literature research on Phytoseiidae predators of thrips and whiteflies.

leaves (type III-b) and widely distributed particularly in Europe (Demite *et al.* 2024). It has been reared on a commercial scale since 1995 and utilized to control several mite species such as the two-spotted spider mite *Tetranychus urticae* Koch, the apple rust mite *Aculus schlechtendali* (Nalepa), the European red mite *Panonychus ulmi* (Koch), the western flower thrips *F. occidentalis* and the tomato russet mite *Aculops lycopersici* (Masse) (Knapp *et al.* 2018). It was commercially available to control mites in Europe, North America, and Asia (Van Lenteren 2012). It was used in conservation and augmentation biological control and its releases were suggested as a preventive measure to slow the increase of *T. urticae* (McMurtry and Croft 1997; Van Lenteren 2012). However, the results of Sengonca and Dreischer (2001) showed its best performance was on *T. tabaci* as prey with regard to developmental time, longevity and predation compared with its use on *T. urticae* control.

*Amblyseius orientalis* (Ehara) was described based on the specimens collected from *Quercus crispula* Blume (Fagaceae) from Japan. It has been recorded from China, Hawaii, India, Japan, Russia and South Korea (Demite *et al.* 2024) and has been applied in orange and apple orchards for biological control of spider mites (Zhang *et al.* 2015). This predator was

also able to complete its development on *B. tabaci* eggs. However, developmental duration was longer and fecundity was lower when reared on *T. urticae* protonymphs, or a mix of both preys. Thus, *A. orientalis* could be considered as a potential biological control agent of *B. tabaci*, when it co-occurs with *T. urticae* (Zhang *et al.* 2015). It has been mass-produced and Wei *et al.* (2023) showed that rearing on *Carpoglyphus lactis* (L.) (Acari: Carpoglyphidae) deutonymphs resulted in lower fecundity than when reared on eggs. This can significantly improve *A. orientalis* production on a large scale.

***Euseius finlandicus* (Oudemans)** was described based on the specimens collected from *Salix caprea* L. (Salicaceae) from Finland. It is a pollen feeding generalist predator (type IV) widely distributed in Europe and Asia (Demite *et al.* 2024). It is used in conservation biological control of mites on deciduous fruits and can be important in control of *P. ulmi*. It has been commercially available to control mites in Europe since 2000 (Van Lenteren 2012). *Euseius finlandicus* was more effective in controlling spider mite in cucumber greenhouses and can predate on *F. occidentalis* and *T. vaporariorum*. It did not establish better than other predacious species such as *N. cucumeris* (Messelink *et al.* 2006; Sarwar *et al.* 2011).

***Neoseiulus californicus* (McGregor)** was described based on the specimens collected from lemon (Rutaceae) from USA. It has been reported from more than 30 countries particularly in Americas and Europe (Demite *et al.* 2024). It is a selective predator of tetranychid mites (type II) and particularly associated with species that produce heavy webbing (McMurtry *et al.* 2013). It is commercially available to control spider mites in Europe, Africa North and South, North and Latin America, and Asia since 1985 (Van Lenteren 2012). First instars of *F. occidentalis* are aggressively attacked and provide enough nutrients for egg production of *N. californicus* but its predation rates were low compared with the specialized thrips predator *N. cucumeris* (Walzer *et al.* 2004). It can also predate and oviposit on the first instar *T. tabaci* larvae but juvenile mortalities were very high (only about 16% of newly hatched larvae reached maturity) and seems to be less advantageous than *I. degenerans* for biological control of this pest (Rahmani *et al.* 2009, 2016).

***Neoseiulus fallacis* (Garman)** was described based on the specimens collected from apple (Rosaceae) from USA. It has been reported from 18 countries in Americas, Europe, Africa and Australia (Demite *et al.* 2024). It is a selective predator of tetranychid mites (type II) and was reported to feed on a wide range of mite pests of deciduous fruit orchards and ornamentals (McMurtry *et al.* 2013). It has been commercially available to control mites in Europe and North America since 1997 (Van Lenteren 2012). Studies showed that females consumed and deposited eggs on *T. tabaci* nymphs (Abdel-Karim and Abd EL-Wareth 2012) and on first instars of *F. occidentalis* and *T. vaporariorum*. Survival and fecundity were low compared to *T. urticae* (Pratt *et al.* 1999).

***Neoseiulus womersleyi* (Schicha)** was described based on the specimens collected from strawberry (Rosaceae) from Australia. It has been reported from China, Japan, South Korea and Taiwan (Demite *et al.* 2024). It is a selective predator of tetranychid mites (type II). It has been commercially available in Asia to control mites since 2005 (Van Lenteren 2012). It was the most efficient predator in controlling *F. occidentalis* and *T. vaporariorum* populations on greenhouse cucumber compared with *Euseius castaneae* (Wang & Xu), *Euseius utilis* (Liang & Ke) and *E. finlandicus* (Sarwar *et al.* 2011).

***Phytoseiulus persimilis* Athias-Henriot** was described based on the specimens collected from *Rosa* spp. (Rosaceae) from Algeria. It has been reported from more than 40 countries, especially in Europe, northern Africa and Middle East (Demite *et al.* 2024). It is one of the most comprehensively studied species and commercially used for the control of *Tetranychus* mites, especially *T. urticae* (specialized of *Tetranychus* genus; type I-a). Females of this predator did not attack *F. occidentalis* larvae and cannot produce eggs. These larvae can be an alternative prey for its immatures, enabling them to develop to adulthood but developmental times prolonged and mortality increased as compared to spider mite prey (Walzer *et al.* 2004).

***Phytoseiulus finitimus* Ribaga** was described based on the specimens collected from *Buddleja madagascariensis* Lamarck (Buddlejaceae) from Italy. It has been reported many times from

the Mediterranean region (Demite *et al.* 2024). This generalist predator lives on plants with pubescent leaves (type III-a) usually found in association with eriophyid and tetranychid mites. It has been commercially available in Europe to control mites since 1990 (Van Lenteren 2012). It has a low impact on whitefly populations (no or very low oviposition on *B. tabaci* of many tested strains) (Nomikou *et al.* 2001). Its predation on spider mite eggs and larvae, and on *T. vaporariorum* crawlers was higher than this on *F. occidentalis* larvae. The mixed diets of pollen with each of those preys reduced consumption but increased the predator's egg production (Pappas *et al.* 2013).

***Typhlodromalus aripo* De Leon** was described based on the specimens collected from *Solanum stramonifolium* Jacquin (Solanaceae) from Trinidad. It has been reported from many countries in South America and Africa (Demite *et al.* 2024). It is a generalist predator living on pubescent leaves (type III-a). It can develop and reproduce on *B. tabaci* crawlers but consumption and fecundity were lower than when feeding on the cassava green mite *Mononychellus progresivus* Doreste. It is sensitive to extreme low humidity and temperatures compared to other phytoseiids (the optimal conditions for survival were 75% RH and 27 °C) (Mutisya *et al.* 2014).

***Typhlodromus (Typhlodromus) pyri* Scheuten** was described based on the specimens collected from *Pyrus communis* L. (Rosaceae) from Germany and widely distributed in Europe and the Middle East (Demite *et al.* 2024). It is a generalist predator living on pubescent leaves (type III-a). It is known to feed on mites, eggs and larvae of insects, on pollen, fungal spores and hyphae, honeydew and plant saps. It seems to prefer *P. ulmi* (McMurtry and Croft 1997; Zemek and Prenerova 1997). It has been commercially available in Europe to control mites since 1990 (Van Lenteren 2012). Its ability to control *F. occidentalis* was studied in cucumber greenhouses but it did not establish better than *N. cucumeris* (Messelink *et al.* 2006).

***Typhlodromus (Typhlodromus) athiasae* Porath** and Swirski was described based on the specimens collected from *Citrus* sp. (Rutaceae) from Israel and has been reported from Azerbaijan, Cyprus, Egypt, France, Greece, Iran, Jordan, Lebanon, Syria, and Turkey (Demite *et al.* 2024). It has been commercially available in Europe to control mites since 1995 (Van Lenteren 2012). This generalist predator has a significantly lower peak oviposition rate on *B. tabaci* and pollen than other species as *A. swirskii* and *E. scutalis* (Athias-Henriot) (Nomikou *et al.* 2001).

## Phytoseiid species used as biological control agents of whiteflies and thrips

In total, eleven phytoseiid species are biological control agents and commercially available for whitefly and thrips management (Van Lenteren 2012; Van Lenteren *et al.* 2017).

These species are *N. barkeri*, *N. cucumeris*, *I. degenerans*, *E. scutalis*, *T. montdorensis*, *A. swirskii*, *Euseius ovalis* (Evans), *Amblydromalus limonicus* (Garman and McGregor), *Euseius amissibilis* Meshkov, *Gynaeseius liturivorus* (Ehara) and *Amblyseius tamatavensis* Blommers. They are discussed according to their date of commercialization.

***Neoseiulus barkeri* Hughes** based on the specimens collected from germinating barley from England. It has a worldwide distribution (Demite *et al.* 2024). It is a generalist predator (type III-e) collected mainly from soil or litter habitats and can predate on several phytophagous mite species, thrips and whiteflies (El-Banhawy *et al.* 2001; Nomikou *et al.* 2001; McMurtry *et al.* 2013). It has commercially been used for the biological control of thrips since 1981 (Van Lenteren 2012). Under laboratory conditions, high rates of consumption and fecundity of this predator were observed on the 1<sup>st</sup> instar *T. tabaci* (Jafari *et al.* 2013) and *T. flavidulus* (Yao *et al.* 2014) but they were lower on the 1<sup>st</sup> instar *T. palmi* than those of *N. cucumeris* (Komi *et al.* 2008). In greenhouses with cucumber, the release of *N. barkeri* at the density of 250 mites/m<sup>2</sup> reduced the population of *T. tabaci* and *F. occidentalis* by 76% and 41% in six

weeks, respectively (Wu *et al.* 2014). However, it did not establish better than *N. cucumeris* (Messelink *et al.* 2006).

***Neoseiulus cucumeris* (Oudemans)** was described based on the specimens collected from *Cucumis melo* L. (Cucurbitaceae) from France. It is a generalist predator (type III-e) collected mainly from soil or litter habitats and has a wide distribution especially in Europe (Demite *et al.* 2024). It can predate on many pests including mites, whiteflies and thrips (McMurtry *et al.* 2013; Li *et al.* 2017). It has been used commercially for the biological control of mites and thrips since 1985 in Europe, Africa North and South, North and Latin America, Asia, Australia and New Zealand (Van Lenteren 2012). It is now become one of the top four phytoseiid mites used as biological control agents (Knapp *et al.* 2018). This predator was released in many greenhouse crops and ornamentals. In greenhouses with cucumber, placement of *N. cucumeris* sachets on plants immediately after planting entirely suppressed populations of *F. occidentalis* and the damage was reduced (Jacobson *et al.* 2001). In greenhouse tomatoes, the curatively inundative introductions of this predator at the rate of one sachet (1000 predatory mites per sachet) per plant significantly reduced *F. occidentalis* populations to low levels (Shipp and Wang 2003). In cyclamen, at the 200 and 350 mites/m<sup>2</sup> released rates of *N. cucumeris* resulted in a rapid decline of *F. occidentalis* populations (De Courcy Williams 2001). When comparing the efficiency of *N. cucumeris* with *A. limonicus*, *A. swirskii* and *E. ovalis*, much higher population levels and better control of *F. occidentalis* in greenhouses cucumber was obtained by these species (Messelink *et al.* 2006). Moreover, *N. cucumeris* was found to perform optimally at relatively higher *F. occidentalis* densities contrarily to *A. swirskii* which was found to perform better at lower densities and can be released preventively when the crop is flowering and remains present in the crop throughout the entire growing season (Bolckmanns *et al.* 2005; Dalir *et al.* 2021). The same results were obtained in greenhouse with pepper in which, both *N. cucumeris* and *A. swirskii* were established and reduced numbers of chili thrips *S. dorsalis* following a single release (30 mites/plant). However, *A. swirskii* was a more effective predator compared with *N. cucumeris* (Arthurs *et al.* 2009). Other biotic and abiotic factors can affect the performance of this predator such as prey species and stages, duration of light, intraguild predation, and application of pesticides, etc. For example, its daily fecundity was slightly higher (2.6 eggs/female/day) on 1<sup>st</sup> instar of *T. flavidulus* (Yao *et al.* 2014) than on 1<sup>st</sup> instar of *T. palmi* (2.2 eggs/female/day) (Komi *et al.* 2008). Furthermore, this predator was not effective for controlling of *T. palmi* and *F. schultzei* on blooms of cucumber in the field (Kakkar *et al.* 2016). Zilahi-Balogh *et al.* (2007) demonstrated that the use supplemental lighting in greenhouses in northern temperate zones would increase its oviposition and thus improve the biological control of *F. occidentalis*. Combinations of *N. cucumeris* with other natural enemies or pesticides would assure sufficiently high control levels of thrips. For example, the introduction of ten *N. cucumeris* adults per plant (*Phaseolus vulgaris* L.) and applications of 200 infective juveniles/cm<sup>2</sup> of entomopathogenic nematodes (*Heterorhabditis bacteriophora* Poinar or *H. indica* Poinar, Karunakar, & David) significantly reduced *F. occidentalis* populations compared with individual applications of each natural enemy (Ebssa *et al.* 2006). The same results were obtained with the combination of NeemAzal-U (17% azadirachtin), a formulation developed for root uptake, with *N. cucumeris* and the soil dwelling mites *Hypoaspis aculeifer* Canestrini (Acari, Laelapidae) (Thoming and Poehling 2006). Ahmed and Lou (2018) demonstrated that combined use of *N. cucumeris* and *A. swirskii* was responsible for the highest positive effect in controlling *F. occidentalis* on cherry tomato grown compared with the use of each of them alone. However, previous studies (Madadi *et al.* 2009; Buitenhuis *et al.* 2010) showed a significant reduction in number of this predator in the presence of minute pirate bugs, *Orius albidipennis* (Reuter) when used to control *T. tabaci*. Negative interactions (intraguild predation) between *N. cucumeris* and *A. swirskii* also occurred when used together in biological control of *F. occidentalis*. Side effects of some pesticides used in many agrosystems on *N. cucumeris* were also tested. For example, the use of Spinosad was not toxic to motile stages of this predator two hours after treatment but female oviposition was reduced by 76% after three days, which indicates that the use of this compound may not be compatible with releases of this



predacious mite for controlling of *F. occidentalis* (Van Dreische *et al.* 2006). Relatively high mortality of *N. cucumeris* was observed following exposure to both direct applications and dry residues of Spinosad (Conserve®) and abamectin (Dynamec®) but good survival was recorded for thiacloprid (Calypso®), pymetrozine (Chess®), and dry residues of imazalil (Fungaflor®) (Cuthbertson *et al.* 2012). In contrast, no effects on this predacious mite were observed when Spinosad was used. The release of this predator in combination with *T. montdorensis* and *Hypoaspis miles* (Berlese) (Acari, Laelapidae) together with Spinosad to control *F. occidentalis* on strawberry was more effective than single species releases (Rahmani *et al.* 2011).

***Iphiseius degenerans* (Berlese)** was described based on the specimens collected from herb and moss from Italy and has been reported from more than 35 countries particularly in Africa and the Middle East (Demite *et al.* 2024). It is important to note that the genus *Iphiseius* does not seem a valid one as its single species is included within the *Euseius* clade based on a molecular work by Vicente and Tixier (2018). It is a pollen feeding generalist predator (type IV). It was commercialized for thrips control in 1993 (Van Lenteren 2012). This species was reported to feed and oviposit on pollen, *T. urticae*, larvae of *T. tabaci*, *T. palmi*, *F. occidentalis* or eggs of *Ephesthia kuehniella* (Zeller) (Vantornhout *et al.* 2005; Cuthbertson *et al.* 2012). It was unable to develop beyond the protonymph stage when it fed on *T. tabaci* (Sengonca and Dreischer 2001). Although it is adapted to the Mediterranean region and effectively controls thrips in greenhouses in Northern Europe, its mass production is difficult (Bolckmans *et al.* 2005). Its establishment was more successful than *N. cucumeris* on sweet pepper for controlling *F. occidentalis* but not on cucumber plants (Bolckmans *et al.* 2005; Messelink *et al.* 2006). In greenhouses, the releases of *I. degenerans* in combination with the anthocorid predator, *O. insidiosus* (a commercial natural enemy of *F. occidentalis*) did not enhance thrips control on roses (Chow *et al.* 2008). The application of the insecticide Teflubenzuron (of the benzoyl-phenyl urea group) could be considered harmless on the survival of *I. degenerans* adults on some plants despite its effectiveness to control *F. occidentalis* and *H. haemorrhoidalis* was reduced (Scott Brown *et al.* 2003). However, the use of spinosad (an insecticide based on chemical compounds found in the bacterial species *Saccharopolyspora spinosa* Mertz and Yao) may not be compatible with releases of *I. degenerans* to control *F. occidentalis* due to its negative effects on its survival and fecundity (Van Dreische *et al.* 2006; Cuthbertson *et al.* 2012). Moreover, the insecticides acetamiprid, metaflumizone, spinetoram and thiamethoxam should be used with caution in greenhouses where *I. degenerans* was introduced as they highly decreased the fecundity of this predator compared with other insecticides such as lubendiamide, chlorantraniliprole and methoxyfenozide (Döker *et al.* 2015).

***Euseius scutalis* (Athias-Henriot)** was described based on the specimens collected from *Ceratonia siliqua* L. (Fabaceae) from Algeria. It has been recorded from many countries in North Africa, Middle-East and Southern Europe (Demite *et al.* 2024). It is a pollen feeding generalist predator (type IV) (McMurtry *et al.* 2013) and frequently found in humid climates and seems to be tolerant to hot and dry ones (30 °C was the most favourable temperature for the population increase) (Bounfour and McMurtry 1987; Kasap and Şekerçlı 2004). It is an important predator of tetranychid mites, scale insects and became a commercial biocontrol agent of whiteflies in 2001 (Nomikou *et al.* 2001; Gerson *et al.* 2003; Abdelgayed *et al.* 2020; Zergani *et al.* 2023). This predator has a high oviposition rate on many plant with pollen (i.e. cattail, alfalfa, broad bean, castor bean and date palm) which could be a suitable alternative food source for their survival and egg reproduction (Nomikou *et al.* 2001; Nomikou *et al.* 2003b; Al-Shemmary, 2011; Fouly *et al.* 2013). Oviposition on *B. tabaci* immatures was equal to that of *A. swirskii* and they were able to suppress whitefly populations on cucumber in a greenhouse (Nomikou *et al.* 2001). However, an unequal distribution of this predator on cucumber plants (more abundant on the lowest leaves) resulted in insufficient controlling of *F. occidentalis* (abundant on the upper leaves) (Messelink *et al.* 2006).

***Transeius montdorensis* (Schicha)** was described based on the specimens collected from *Datura* sp. (Solanaceae) from New Caledonia and was recorded from Australia, Fidji, Tahiti and Vanuatu (Demite *et al.* 2024). It is a generalist predator found on plants with glabrous leaves

(type III-b). This species became commercially available in Europe in 2004 for controlling thrips, whiteflies and tarsonemid mites (Van Lenteren *et al.* 2017). It is a good predator of *F. schultzei*, *F. occidentalis* and *T. palmi* in strawberry, cucumber, and pepper greenhouses (Steiner *et al.* 2003; Rahmani *et al.* 2011; Cuthbertson *et al.* 2012; Labbé *et al.* 2019; Téllez *et al.* 2020). It is an effective control agent of *B. tabaci* and *T. vaporariorum* in poinsettia and cucumber in greenhouses and exhibited higher populations than *A. swirskii*, specifically when climatic conditions were cold. Therefore, its releasing in winter, followed with releases of *A. swirskii* in spring, may be a good control strategy for greenhouse grown cucumbers (Richter 2017; Téllez *et al.* 2020).

*Amblyseius swirskii* Athias-Henriot was described based on the specimens collected from *Prunus dulcis* (Miller) Webb (Rosaceae) from Israel and found in many countries of the Mediterranean, African subtropical and tropical areas on wild and cultivated plants having glabrous leaves (generalist predator of type III-b), (Zannou and Hanna 2011; McMurtry *et al.* 2013; Döker *et al.* 2020; Zahidi *et al.* 2023). More than 100 papers have been published on biology, behaviour, predation and feeding habits of this species under laboratory, semi-field or field conditions of various crops such as cucumber, sweet pepper, eggplant, bean, tomatoes, and ornamental plants chrysanthemum, roses and poinsettia. Calvo *et al.* (2015) listed 36 pest species on which *A. swirskii* has been reported to develop and/or oviposit in laboratory experiments: 18 phytophagous mite species, five thrips species, two species of whiteflies, and the remaining taxa of other insect families. The results of these various research proved the value of *A. swirskii* that became a successful biological control agent since 2006 and it has been used in augmentative biological control of thrips and whiteflies in more than 50 countries. Furthermore, factors such as feeding on various pests and controlling them simultaneously, its capacity to multiply on pollen in the absence or scarcity of pests and its easy and cheap production on stored product mites are thought to be the main reasons for its worldwide use (Calvo *et al.* 2015; Knapp *et al.* 2018). More recently, *A. swirskii* demonstrated its effectiveness on *T. palmi*, in commercial open fields of cucumber (Kakkar *et al.* 2016) and significantly reduced poinsettia thrips (*Echinothrips americanus* Morgan) densities in greenhouse sweet pepper particularly when cattail pollen was also applied (Ghasemzadeh *et al.* 2017). However, it was revealed that *A. swirskii* preferred *T. urticae* rather than *B. tabaci* and *T. vaporariorum* (Heydari *et al.* 2016; Asadi *et al.* 2019; Hosseininia *et al.* 2020). Additional studies showed the impact of several factors on this predacious mite. The acarid mite, *C. lactis* is the best prey for mass production of this predator (Hosseininia *et al.* 2020). Furthermore, using living mites of *Thyreophagus entomophagus* (Laboulbène) as a food source greatly increased its density compared with the use of cattail pollen, a commonly used supplemental food, supporting biological control of thrips and other pests in greenhouse chrysanthemum (Pirayeshfar *et al.* 2021). The provision of *Pinus brutia* Tenore pollen also did not result in an effective management of *F. occidentalis* despite significant increase of its population in greenhouse eggplants and pepper. Thus, thought to be the presence of trichomes on eggplant leaves or the pine pollen was an unsuitable food source for this predator (Kütük 2017, 2018). Combination of *A. swirskii* with other natural enemies were also examined. Under laboratory conditions, *A. swirskii* was a stronger competitor compared to *A. orientalis* or *N. californicus* even in the presence of *B. tabaci* eggs (an extra-guild prey) (Guo *et al.* 2016). On the contrary, it has a higher oviposition rate and a faster development time on an extra-guild prey (*B. tabaci* eggs) than on intra-guild prey (eggs, larvae and protonymphs of *T. negevi*) (Momen *et al.* 2013). In greenhouse conditions, *A. swirskii* can interfere with the phytoseiid *Neoseiulus longispinosus* (Evans) and disrupt biological control of *T. urticae* on papaya plants (Döker *et al.* 2021). The release of *A. swirskii* and *P. persimilis* were highly effective in suppressing *B. tabaci*, *F. occidentalis*, and *T. urticae* populations on cucumber and more effective than many insecticidal and acaricidal sprays in the control greenhouse (Abou-Haidar *et al.* 2021). The combinations of predatory mirids *N. tenuis*, *M. pygmaeus* or predatory anthocorid *O. laevigatus* with *A. swirskii* significantly reduced *F. occidentalis* and *B. tabaci* populations on sweet pepper (Bouagga *et al.* 2018). Using the parasitoid *E. eremicus* and *A. swirskii* was a feasible strategy for management

of *B. tabaci* on poinsettia and reduced insecticide applications by 25–78% (Vafaie *et al.* 2021). The application of the entomopathogenic fungus *Lecanicillium muscarium* R. Zare & W. Gams conidia followed by the release of *A. swirskii* suppressed *T. vaporariorum* on roses and was more effective than an application of the control agents separately (Mitina *et al.* 2021).

***Euseius ovalis* (Evans)** was described based on the specimens collected from rubber plant from Malaysia. It is a pollen feeding generalist predator (type IV) widely distributed in eastern countries of Asia and was also found in Australia, New Zealand, and Mexico. It was very often confused with *Euseius ovaloides* (Blommers) (Liao *et al.* 2017). *Euseius ovalis* typically lives on plants with smooth leaves. (Liao *et al.* 2017; Demite *et al.* 2024). They became commercially available in Europe in 2008 and has good potential for the biological control of *F. occidentalis* and *T. vaporariorum* in greenhouse cucumbers (Messelink *et al.* 2006; Van Lenteren *et al.* 2017). It was also found to be the most effective control agent of *T. vaporariorum* in greenhouse roses compared to other phytoseiid species such as *A. swirskii*, *A. limonicus*, *N. californicus* and *N. cucumeris* (Pijnakker *et al.* 2007). It is also a better predator of the poinsettia thrips, *E. americanus* pupae on sweet pepper compared to *A. swirskii*, *A. limonicus*, and *E. amissibilis* (Ghasemzadeh *et al.* 2017).

***Amblydromalus limonicus* (Garman and McGregor)** was described based on the specimens collected from *Citrus* sp. (Rutaceae) from USA. It has been reported in many countries in Central and South America, Australia, New Zealand, and several European countries including Italy, Portugal, Spain, and Slovenia and Turkey (Tsolakis and Ragusa 2020; Bas *et al.* 2022; Demite *et al.* 2024;). It is a generalist predator living on plants with glabrous leaves (type III-b) (McMurtry *et al.* 2013) and became commercially available in 2012 (Knapp *et al.* 2013). It is a better predator of *F. occidentalis* in cucumber greenhouses compared to other species (Messelink *et al.* 2006) and its biology and predation on many pests (spider mites, *T. tabaci*, *F. occidentalis*, *B. tabaci* and *T. vaporariorum*) were reviewed by Knapp *et al.* (2013). Laboratory, semi-field and field trials demonstrated its excellent performance as a biological control agent of thrips and whiteflies in cucumber, gerbera, poinsettia and roses. High predation and reproduction rates were observed on 1<sup>st</sup> and 2<sup>nd</sup> instar *E. americanus* under laboratory conditions (Ghasemzadeh *et al.* 2017). It has also high potential to control outbreaks of *F. occidentalis* (Vangansbeke *et al.* 2014). The addition of *Typha angustifolia* L. pollen in mixed diets of this pest increases its populations and enhances their biological control capabilities even in the presence of low thrips densities (Samaras *et al.* 2021). This predator is also a promising candidate for the biological control of the invasive thrips *S. dorsalis* and may be as effective as *A. swirskii* in the field (Schoeller *et al.* 2020). However, its reproductive performance when with fed *T. vaporariorum* was significantly lower than when fed on *F. occidentalis* (Vangansbeke *et al.* 2014). Similar results were obtained in greenhouse cucumber. It was not a suitable candidate for treatment of high populations of *T. vaporariorum* despite its high level of predation (compared to *T. montdorensis* and *A. swirskii*) (Medd and GreatRex 2014). In contrast, releasing *A. limonicus* on poinsettia proved to be a good addition or alternative to the endoparasitism by the wasp *E. formosa* to control *T. vaporariorum* (as it is less susceptible to low temperature during autumn) but slightly less efficient for *B. tabaci* (Richter 2017).

***Euseius amissibilis* Meshkov** was described based on the specimens collected from *Platanus orientalis* L. (Platanaceae) from Tajikistan. It was also found in Iran. This species is actually the senior synonym of *Euseius gallicus* Kreiter and Tixier (Döker *et al.* 2024) which has been recorded from France (Tixier *et al.* 2009), Belgium, Germany, Italy, Mauritius, the Netherlands, Slovenia, Tunisia and Turkey (Demitte *et al.* 2024). It is a biocontrol agent of whiteflies and thrips and has been commercially available in Europe since 2013 (Van Houten *et al.* 2016; Van Lenteren *et al.* 2017). It has been shown to be a promising control agent of *F. occidentalis* in cut roses (Pijnakker *et al.* 2014). Laboratory and semi-field experiments demonstrated that the predator is a suitable biocontrol agent for *T. vaporariorum* on roses, but not for *F. occidentalis* (Van Houten *et al.* 2016), nor for *E. americanus* on sweet pepper plants even at high densities in the presence of *Typha latifolia* L. pollen as a supplementary food source (Ghasemzadeh *et al.* 2017).

***Gynaeseius liturivorus* (Ehara)** was described based on the specimens collected from soybean (Fabaceae) from southern Japan. It has been recorded from Philippines, Sri Lanka, Taiwan and Vietnam (Demites *et al.* 2024). It is a generalist predator (type-III) (Kreiter *et al.* 2020). It predaes on the eggs and larvae of *B. tabaci* and *T. vaporariorum*. It was considered of interest for control of *S. dorsalis*, *F. occidentalis* and *T. palmi*, on which the daily consumption average was 7.4-19.4 1<sup>st</sup> instar of these preys and laid an average of 1.6-6.8 eggs within 24-48 hours (Mochizuki, 2009). It became a commercially available biocontrol agent of whiteflies and thrips in Asia in 2013 (Van Lenteren *et al.* 2017).

***Amblyseius tamatavensis* Blommers** was described based on the specimens collected from *Citrus hystrix* de Candolle (Rutaceae) from Madagascar. This generalist predator (type III) has been reported from over 40 countries in central and South America, Africa, eastern Asia and Australia (Demite *et al.* 2024). Its females can consume eight *B. tabaci* eggs daily and has 3.5 times higher oviposition rate than those when fed on *T. urticae* (Cavalcante *et al.* 2015a). However, Massaro and Moraes (2019) observed differences in these parameters among different populations of this species and those having larger dorsal and ventrianal shields has the highest rates of daily predation and oviposition. Variations in predation of this pest were also observed according to leaf characteristics of host plants: higher on cotton, potato and bell pepper and lower on tomato and melon (Cavalcante *et al.* 2017; Barbosa *et al.* 2019). The acarid mite, *Aleuroglyphus ovatus* (Troupeau) (Acaridae), seems to be a suitable host for mass production of this predator (Cavalcante *et al.* 2015a). *Amblyseius tamatavensis* has been marketed in Brazil as a control agent of *B. tabaci* (releasing 15 adults per plant, suggests the high potential of this species to control *B. tabaci* in pepper plants) (Souza and Marucci, 2021). It was also observed to predate on the ficus whitefly *Singhiella simplex* (Singh) and on *F. occidentalis* under laboratory conditions (Döker *et al.* 2018; Jorge *et al.* 2021).

## Phytoseiid species that need further research for exploration as biological control agents of whiteflies and thrips

Eighteen species were studied in this group and many of them showed potential for biological control of thrips and whiteflies.

***Amblydromalus lailae* (Schicha)** was only found on papaw (Caricaceae) in Australia. It is a generalist predator living on glabrous leaves (type III-b) (McMurtry *et al.* 2013; Demite *et al.* 2024). It can feed on the broad mite, *Polyphagotarsonemus latus* (Banks) (Tarsonemidae) and tomato russet mite *Aculops lycopersici* (Massee) (Eriophyidae) in protected crops. It had an average of seven and two larvae consumption of the first and the second instar of *F. schultzei* per day, respectively, and thus it is a candidate for the biological control of this pest (Steiner *et al.* 2003). It is important to note that this species may be the junior synonym of *A. limonicus* according to Steiner and Goodwin (2005), Minor (2008), and Ma *et al.* (2018).

***Amblyseiella setosa* Muma** was described based on the specimens collected from orange (Rutaceae) in USA. It was also recorded from Brazil, Peru, and many European and northern African countries (Demite *et al.* 2024). Very few studies have dealt with the biology of *A. setosa*. Muma (1971) showed that the tetranychid mite *Eutetranychus banksi* (McGregor) is an adequate food source of this predator but other species such as *Panonychus citri* (McGregor) and *Eotetranychus sexmaculatus* (Riley) were considered only as survival food. Momen *et al.* (2004) demonstrated the *A. setosa* had faster development and higher fecundity when fed on the eriophyid mites compared to its feeding on diets of *Phoenix dactylifera* L. pollen, the scale insect *Parlatoria ziziphus* (Lucas) (Hemiptera, Diaspididae) and *B. tabaci*.

***Amblyseius eharai* Amitai** and Swirski was described based on the specimens collected from *Dimocarpus longan* (Loureiro) (Sapindaceae) from Hong Kong. It was also recorded from China, Georgia, Japan, Malaysia, South Korea, Taiwan and Thailand (Demite *et al.* 2024). It is a generalist predator living on glabrous leaves (type III-b). Contrarily to *A. swirskii*, this species is susceptible to low humidity (most of its eggs would not hatch at relative humidities

lower than 60%) but they have a relatively low optimal temperature for population growth (Ji *et al.* 2013; Park *et al.* 2021). A study conducted by Komi *et al.* (2008) showed that this predator had higher prey consumption rate on *T. palmi* than *N. cucumeris* and was a promising candidate for the biological control of *T. palmi* in greenhouse vegetable. Side effects of > 50 insecticides, acaricides and fungicides were tested on this predator [also on *Amblyseius tsugawai* Ehara and *Euseius sojaensis* (Ehara)] and their effects ranged from harmless to harmful to the survival and fecundity of adult females and immatures (Kishimoto *et al.* 2018, 2020).

***Amblyseius herbicolus* (Chant)** was described based on the specimens collected from an unidentified Bromeliaceae from USA. It is widely distributed in the Americas and was also recorded from many African, European and Asian countries (Demite *et al.* 2024). It is a generalist predator living in confined spaces on dicotyledonous plants (type III-c) (McMurtry *et al.* 2013). Laboratory evaluation of this species as candidate for the control of *B. tabaci* has showed high levels of egg predation and oviposition (Cavalcante *et al.* 2015a). High oviposition rates and short developmental durations were also observed when its immatures and females fed on mixed diets of *T. vaporariorum* eggs and cattail pollen (*Typha orientalis* C. Presl). This latter seemed suitable as an alternative or additional food source with high nutritional value (Xin and Zhang, 2021). Finally, *Oulenziella bakeri* (Hughes) (Winterschmidtidae), *A. ovatus* and almond pollen could be potential alternative foods for mass rearing programs (Cavalcante *et al.* 2015a; Hou *et al.* 2022).

***Amblyseius largoensis* (Muma)** was described based on the specimens collected from Key lime (Rutaceae) from USA. It is widely distributed in Americas, in many African, Middle East, eastern Asian countries and Australia (Demite *et al.* 2024). It is a type III generalist predator. Under laboratory conditions, predation levels on eggs of *B. tabaci* were higher than *A. limonicus* (Cavalcante *et al.* 2015a) and even than *A. swirskii* (Fouly *et al.* 2011). The acarid mite *A. ovatus* is suitable for its mass production (Cavalcante *et al.* 2015a). This predator could also be effective for the controlling *Aleurodicus cocois* (Curtis) (Aleurodidae), a serious pest of cashew, *Anacardium occidentale* L. especially in low level of pest populations (Alfaia *et al.* 2018).

***Amblyseius tsugawai* Ehara** was described based on the specimens collected from apple (Rosaceae) in Japan. This generalist predator (type III) has been reported from China and South Korea (Demite *et al.* 2024). It is better adapted to herbaceous plants (Yang *et al.* 2019). Although the consumption and oviposition rates of this species on 1<sup>st</sup> instar of *T. palmi* were higher than those of *N. barkeri*, *E. sojaensis* and *Proprioseiopsis nemotoi* (Ehara and Amano), these parameters were lower compared to other predators such as *G. liturivorus* and *A. eharai* (Komi *et al.* 2008). Evaluation of this predator against *B. tabaci* showed its preference for eggs rather than 1<sup>st</sup> instar but the reproduction was very low suggesting low chance for population establishment (Yang *et al.* 2019).

***Cydnoseius negevi* (Swirski and Amitai)** was described based on the specimens collected from *P. dactylifera* from Israel. This generalist predator (type III) has been reported from Egypt, Morocco, Oman, Pakistan, Saudi Arabia, Sudan, and United Arab Emirates (Demite *et al.* 2024). Date palm pollen was a suitable food source for their mass production and an alternate food source in the field under arid environmental conditions (Alatawi *et al.* 2018). Similarly, Fouly *et al.* (2021) showed that eggs of *T. urticae* and pollen of date palm were the most favourable food for the development and reproduction of this predator compared with eggs of *Spodoptera littoralis* (Boisduval), *Trialeurodes ricini* (Misra), and *E. kuehniella*. A laboratory study by Momen *et al.* (2009) showed that the total egg reproduction of this predator was the highest on *Ricinus communis* L. pollen and eggs of *B. tabaci* compared to other hosts such as the maskell scale *Insulaspis pallidula* (Green) (Hemiptera: Diaspididae) and the red date scale *Phoenicoccus marlatti* Cockerell (Hemiptera: Phoenicoccidae) eggs. Female developmental time and longevity were shorter and fecundity was higher when this predator fed on an eriophid *A. lycopersici* rather than on *B. tabaci*. Its release reduced *B. tabaci* populations by 63-84% in open eggplants fields (Elkholy *et al.* 2022). Releasing this predator in combination with blue sticky traps reduced *F. occidentalis* about 45% in greenhouse pepper

(Sanad and Hassan 2019). In addition to the effects of feeding source, other factor seemed to affect this predator. Momen *et al.* (2013) showed a high predation rate by *A. swirskii* on *T. negevi* eggs (intra-guild prey). It was higher than on an extra-guild prey *B. tabaci* eggs. Negative effects of the entomopathogenic fungi, *Metarhizium anisopliae* (Metchnikoff), *Beauveria bassiana* (Balsamo), *Paceliomyces fumosoroseus* (Vassiljevsky) were observed on the mobile stages of this predator. *Paceliomyces fumosoroseus* had the highest rate of reduction in egg production followed by *B. bassiana* and *M. anisoplia* (Saad *et al.* 2021).

***Euseius castaneae* (Wang and Xu)** was described based on the specimens collected from *Castanea mollissima* Blume (Fagaceae) from China (Demite *et al.* 2024). Its release to control *F. occidentalis* and *T. vaporariorum* in a greenhouse of cucumber showed a reduction in the populations of these pests, but they were unable to develop successfully under greenhouse conditions (Sarwar *et al.* 2011).

***Euseius concordis* Chant** was described based on the specimens collected from *Citrus* sp. (Rutaceae) from Argentina and has been reported especially from Central and South America, USA, Montenegro, and Portugal (Demite *et al.* 2024). Several studies showed its ability to feed on pollen and several species of phytophagous mites. This indicates its use as a biological control agent of pests (De Figueiredo *et al.* 2018; Lopes *et al.* 2018; Silveira *et al.* 2020; Dameda *et al.* 2021). As *A. largoensis*, this predator could be effective in controlling the whitefly *A. cocois*, which attacks cashew, when its populations are low (Alfaia *et al.* 2018).

***Euseius nicholsi* (Ehara and Lee)** was described based on the specimens collected from grass (Poaceae) from Hong Kong. It has been reported from China, Taiwan, and Thailand (Demite *et al.* 2024). It has been used for reducing *T. urticae* populations on various crops (Zhang *et al.* 2018). This species can predate *T. flavidulus*. The female laid the maximum number of eggs (2.6) at a density of 25 first-instar thrips. The predation and successful attack rates increased with increasing temperatures up to 26 °C and attack rates were reduced afterward (Yao *et al.* 2014).

***Euseius sojaensis* (Ehara)** was first described based on the specimens collected from mulberry (Moraceae) from Japan. It is a type IV predator and has been reported from Taiwan (Demite *et al.* 2024) and considered as an effective indigenous natural enemy of some eriophyid mites and spider mites in Japan (Kishimoto 2014; Tsuchida and Masui 2021). This predator affects the population density of *S. dorsalis* in vineyard and can consume 5.4 larvae/female/day of this pest (Shibao *et al.* 2004) and its effectiveness was higher on the less hairy grape cultivar 'Pione' than on the hairy one 'Shine Muscat' (Tsuchida and Masui 2023). The consumption and oviposition rates of this species on 1<sup>st</sup> instar of *T. palmi* were lower than those of *A. tsugawai* and *N. cucumeris* (Komi *et al.* 2008).

***Euseius utilis* (Liang and Ke)** was described based on the specimens collected from *Malus domestica* Borkhausen (Rosaceae) from China (Demite *et al.* 2024). As for the predator *E. castaneae*, releasing of *E. utilis* to control *F. occidentalis* and *T. vaporariorum* species in greenhouse cucumber showed a reduction in the populations of these pests compared to not releasing them in cucumber, but it seems unable to develop successfully under greenhouse conditions (Sarwar *et al.* 2011).

***Neoseiulus bicaudus* (Wainstein)** was described based on the specimens collected from grass (Poaceae) from Kazakhstan. It has been reported from 30 countries particularly in the Mediterranean and Middle of Asia (Demite *et al.* 2024). It can feed on spider mite (Li *et al.* 2015; Zhang *et al.* 2016) and prefers the 1<sup>st</sup> instar *T. tabaci* to adults of the tetranychid mite *Tetranychus turkestanii* Ugarov & Nikolski (Zhang *et al.* 2017). Releasing this predator in combination with blue sticky traps reduced *F. occidentalis* population about 57% in greenhouse pepper (Sanad and Hassan 2019).

***Neoseiulus tunus* (De Leon)** was described based on the specimens collected from *Psidium guajava* L. (Myrtaceae) from Trinidad. It has been reported from Argentina, Brazil, Colombia, Guadeloupe, Jamaica, Marie-Galante, Martinique, and Peru (Demite *et al.* 2024). High levels of predation on *B. tabaci* eggs were observed (Cavalcante *et al.* 2015a). It is promising for management of *B. tabaci*. The acarid mite *A. ovatus* seemed was a suitable host for the mass

production of *N. tunus* (Cavalcante *et al.* 2015a). It was synonymized with *N. neotunus* (Denmark and Muma) by Kreiter *et al.* (2018).

***Neoseiulus umbraticus* (Chant)** was described based on the specimens collected from *Rubus fruticosus* L. (Rosaceae) from England. It has been widely reported from Europe. It was also found in Iran, Morocco, Jamaica and USA (Demite *et al.* 2024). It was often associated with *T. tabaci*, *P. latus* and *T. urticae* on bean fields (Kazak *et al.* 2002). It can predate on *T. tabaci* larvae. However, its predation and oviposition period on this pest were lower than those on *T. urticae* (Sengonca and Dreischer 2001).

***Proprioseiopsis lenis* (Corpuz & Rimando)** was described based on the specimens collected from *Citrus reticulata* Blanco (Rutaceae) from Philippines. It has been reported from Thailand, Vietnam and Australia (Demite *et al.* 2024). The results of Nguyen *et al.* (2019) suggested that *P. lenis* may have a potential as a natural enemy and could be used in augmentative biological control of spider mites and thrips due to its high oviposition rates on *F. occidentalis* and *T. urticae*, and its ability to be reared on the storage mite *C. lactis*, and its high oviposition rate on *T. latifolia* pollen.

***Proprioseiopsis mexicanus* (Garman)** was first described based on the specimens collected from *Zinnia* sp. (Asteraceae) from USA. This generalist predator (type III) has been reported from Australia, Benin, Brazil, Colombia, Cuba, Ghana, Guadeloupe, Hawaii, Kenya, Martinique, New Zealand, and other countries (Demite *et al.* 2024). It is a generalist predator and can develop on tarsonemid and spider mites but may require pollen for survival and reproduction (Farfan *et al.* 2021a, b). This species has the characteristics of successful predator of *F. occidentalis* and its optimum development time at 35° C was above the temperature optimum of most phytoseiid mites (Emmert *et al.* 2008). In the same way, this predator could be a helpful biological control agent for *T. tabaci* and the results indicate its capability to develop and reproduce at a broad range of temperatures, especially above 25° C (Huang *et al.* 2014).

***Proprioseiopsis nemotoi* (Ehara and Amano)** was described based on the specimens collected from pear (Rosaceae) from Japan. It has been reported from South Korea and classified as a generalist predator from soil/litter habitats (type III-e) (Farfan and Schmidt-Jeffris 2019; Demite *et al.* 2024). It can predate on *T. palmi* larvae, but the prey consumption and oviposition rates were lower than those of other species such as *N. cucumeris* and *A. tsugawai* (Komi *et al.* 2008).

## Conclusions and future research

A total of 40 phytoseiid species have been shown their ability to predate, develop and reproduce on one or several species of thrips and whiteflies. Among them, 11 species are specialists and prefer feeding on Tetranychidae or other phytophagous mite family members (Eriophyidae, Tarsonemidae or Tenuipalpidae). Eleven species have shown good performance on thrips and whiteflies, and have already been commercially available as biological control agents, most of them on greenhouse crops. They all belong to the subfamily Amblyseiinae and are generalist predators most are found on plants with glabrous leaves, from soil/litter habitats, or are pollen-feeding predators. *Amblyseius swirskii* was the most studied and used for biological control of at least six thrips and two whiteflies species in greenhouses with bean, cucumber, sweet pepper, eggplant, tomatoes, chrysanthemum, roses and poinsettia. *Neoseiulus cucumeris*, was mainly used for controlling many thrips species. *Amblydromalus limonicus* was used for both thrips and whiteflies. The 18 remaining species mostly belong to the subfamily Amblyseiinae and nine of them originated from the oriental biogeographical zone. *Amblyseius eharai*, *P. lenis* and *P. mexicanus* were promising candidates for the biological control of thrips. However, additional studies (i.e. effects of abiotic factors, predation capacity, and ability to mass production) are needed to confirm their performance and potential establishment in the field. Similarly, *A. herbicolus*, *A. largoensis*, *E. concordis* and *N. tunus* could be promising control agents of whitefly species. However, evaluation of their biological traits, prey species

preference and their performances under semi-field and field conditions should essentially be examined and. Few data are available about the performance of the last 11 remaining species as predators of thrips and whiteflies. It is difficult to confirm their effectiveness since extensive future research (evaluation of life history traits, prey preference and alternative food, computability with pesticides, effects of abiotic factors, effects of host plant traits, intraguild predation, development of mass production) is necessary.

Future should be oriented toward surveying indigenous communities of phytoseiids not only in natural ecosystems but also in open-field agroecosystems. In addition, evaluation of the feasibility of their incorporation with exotic species should also be considered in integrated pest management programs. Examining of other species of *Amblyseius*, *Euseius*, *Neoseiulus*, and *Proprioseiopsis* genera that constitute about 50% of phytoseiids are also essential. More than 140 new phytoseiid species have been described in the last decade. Consideration should also be taken to the sub-genus *Typhlodromus* (*Anthoseius*) which contains approximately 400 species but nearly none of them have been examined against thrips and whiteflies. Finally, despite valuable research on phytoseiid biological control agents in some regions of the world such as China, Japan, occidental Europe and Brazil, it seems to be insufficient in other regions. Efforts and financial support should be available for training new taxonomists in collaboration with researchers and experts in systematic biology. The development of new technologies for phytoseiid mass production would increase their widespread use.

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