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Efficacy of two predatory phytoseiid mites in controlling the western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) on cherry tomato grown in a hydroponic system

Nevin Ahmed[1,2*] and Ming Lou[3]

Abstract

Thrips is one of the most harmful insect groups attacking many field and vegetable crops. Predatory mites, especially those in family Phytoseiidae, are considered as good bioagents to control thrips where application of chemical pesticides can be decreased. This work was conducted to evaluate the efficacy of the two phytoseiid mites, *Amblyseius swirskii* (Athias-Henriot) and *Neoseiulus cucumeris* (Oudemans), in controlling the western flower thrips (*Frankliniella occidentalis*, Pergande) on cherry tomato plants in a hydroponic system. The results indicated that both predatory mites were effective in decreasing populations of adults and larvae of *F. occidentalis* at all of the chosen periods. The mixed effect of *A. swirskii* plus *N. cucumeris* (AS + NC) was higher in reducing thrips populations than that when each of them was used alone. Larvae of *F. occidentalis* were decreased on leaves of tomato plants from 11.2 and 14.5/leaf in the control treatment (no predatory mites) to 4.27 and 3.73/leaf due to the combination of AS and NC after 7 and 15 days, respectively. On the other hand, larvae of *F. occidentalis* attained levels of 8.75 and 12.83/five flowers when no predatory mites were applied compared to 2.46 and 1.20/five flowers when adults of AS plus NC were used after 50 and 60 days of releasing, respectively. This study demonstrated that the combination of AS and NC resulted in higher reductions in *F. occidentalis* without any competition between them.

Keywords: Biological control, *Frankliniella occidentalis*, Predatory phytoseiid mites, Greenhouse, Hydroponic conditions

Background

Tomato is one of the most important vegetable crops and its fruit production reaches about 164×10^6 million tons from 4.7×10^6 ha around the world (FAOSTAT, 2015). Using chemical methods for controlling pests such as western flower thrips *Frankliniella occidentalis* (Pergande) is not sustainable because of their high costs and risks on non-target organisms and environmental systems (Herron et al., 2007). *F. occidentalis* is one of the serious polyphagous and cosmopolitan insect pests with marked harmful and adverse effects on flowers and fruits to over 200 host plants (Yang et al., 2015). It has also a high resistance to insecticides (about 163 cases) among more than 26 active chemical ingredients around the world (Bielza et al., 2007 and Wang et al., 2011). Larvae and adults of *F. occidentalis* have a high affinity level to attack aboveground organs of crops, especially buds, fruits, and young leaves (Venette and Davis, 2004). *F. occidental* injury can range from deformation and shifting for plant colors from bronze to black to heavy infections with lessening, dwarfed and defoliation of leaves, and detached petioles from the plant stem. Moreover, *F. occidentalis* is a vector of many plant viruses such as maize chlorotic mottle virus, impatiens necrotic spot virus, and tomato spotted wilt virus (Webster et al., 2011 and Zhao et al., 2014). Populations

* Correspondence: nevin.ahmed@fagr.bu.edu.eg
[1]Department of Plant Protection, Faculty of Agriculture, Benha University, Benha, Egypt
[2]Department of Plant Protection, Huazhong Agricultural University, Wuhan, Hubei, China
Full list of author information is available at the end of the article

of *F. occidentalis* can rapidly rebound from insecticide applications due to its high fecundity, haplotype genetics, and short generation time (Gao et al., 2012). It is difficult to control *F. occidentalis* with insecticides because it deposits its eggs inside plant tissues and the adults and larvae feed in concealed locations such as flower buds, which protected them from insecticide effects (Brodsgaard, 2004). Thus, an urgent requirement is strongly needed for the biological control strategy.

Phytoseiid mites (Acarina: Phytoseiidae) are vital polyphagous predators and have got a great attention to be applied as bio-control agents or as alternative approaches to pesticides against *F. occidentalis* on different plants such as vegetable, fruit, and ornamental crops under both greenhouse and field conditions (Jacobson et al., 2001; van Houten et al., 2005 and Messelink et al., 2006). These predatory mites have been successfully used against several pests, including spider mites, whitefly, and thrips (Chow et al., 2010; Fouly et al., 2011 and Kakkar et al., 2016) but their beneficial effects in managing *F. occidentalis* (Thysanoptera: Thripidae) on tomato plants have not been evaluated thoroughly and are needed to be reported. Therefore, this study aimed to evaluate the efficacy of the two phytoseiid predatory *Typhlodromips* (*Amblyseius*) *swirskii* and *Neoseiulus cucumeris* in controlling *F. occidentalis* on cherry tomato plants grown under a hydroponic system.

Materials and methods

Cultures of mites and thrips

Both predatory mite colonies were obtained from a citrus orchard located at Huazhong Agricultural University, Wuhan, Hubei, China, in February 2015. Both mites were reared and maintained on *Tyrophagus putrescentiae* (Schrank) as a food source in an environmental chamber at 25 ± 1 °C and 70 ± 5% RH and photoperiod of L16:D8 h. *F. occidentalis* was obtained from a commercial tomato field and then maintained on pods and leaves of kidney beans (*Phaseolus vulgaris* L.) in sterilized glass jars according to Arthurs and Heinz (2002). The jars were closed by plastic films which contained 2–3-cm holes covered with fine meshes for ventilation. The rearing jars were placed in an environmental chamber at 26 ± 2 °C, 65 ± 5% RH and photoperiod of L13:D11 h ± 1.

Experimental design

The experiments were conducted at Hubei Academy of Agricultural Sciences, Wuhan, Hubei Province, China, from March 1, 2015, to May 15, 2015, in cages (0.5 m length × 0.5 m width × 1.5 m height) covered with nylon mesh under greenhouse conditions using cherry tomato (*Solanum lycopersicum*) as an indicator plant. Strong tomato seedlings at age of 15 days were prepared, transferred, and then grown in a hydroponic system. Each cage contained five pots and each pot had two tomato seedlings. Hoagland's solution was used in the current experiment as a nutrient source for tomato plants.

First experiment

This experiment had four treatments with five replicates each: T1 (control without predatory mites), T2 (adults of *A. swirskii*), T3 (adults of *N. cucumeris*), and T4 (adults of *A. swirskii* plus *N. cucumeris*). The experimental cages were arranged in blocks and randomly assigned. The released numbers of predatory mites were 30 (10 males + 20 females) per plant, while the initial numbers of *F. occidentalis* for each plant were 60 adults. Both thrips and predatory mites were released one time at the beginning of the experiment. Predatory mites were released onto plants after 24 h from adding adults of thrips. Leaves of tomato plants were checked six times (after 7, 15, 30, 45, 60, and 75 days), while their flowers were only examined two times (after 50 and 60 days) from the transporting of tomato seedlings. Leaves (2–5) and flowers (5–8) of tomato were collected from each plant in separate Ziploc bags (17 × 22 cm) from each plant and then transferred to the laboratory. The leaves and flowers of tomato were placed in a plastic cup with ethanol (75%: diluted from analytical ethanol grade 99%) for 30 min to displace the different stages of thrips. Numbers of thrips (larvae and adults) per leaf and per five flowers were counted using a magnifier lens.

Second experiment

This experiment was conducted under the same conditions as described above with two treatments in five replicates for each one, T1 (*A. swirskii*) and T2 (*N. cucumeris*), to evaluate densities of their different stages (egg, immature, and adult) on leaves and flowers of cherry tomato infested by *F. occidentalis*. The initial numbers of *F. occidentalis* for each plant were 60 adults. The released numbers of these predatory mites were 30 (10 males + 20 females). Numbers of eggs, immature stages, and adults for *A. swirskii* and *N. cucumeris* were counted six times as mentioned above on each leaf and only two times for every five flowers after their release by a dissecting microscope.

Data analysis

The statistical analysis of experimental data was performed with one-way ANOVA using SPSS 18.0 followed by Tukey's test to evaluate the significant differences between treatments at $P < 0.05$.

Results and discussion

Controlling *F. occidentalis* with the predatory mites

Data in Table 1 showed that numbers of *F. occidentalis* larvae and adults on tomato leaves were highly affected

Table 1 Mean numbers (±SE) of *Frankliniella occidentalis* per leaf of tomato after releasing adults of *Amblyseius swirskii* and *Neoseiulus cucumeris* at different periods (days)

		Experimental intervals (days)					
Treatments		7	15	30	45	60	75
CK	Larvae	11.2 ± 2.03a	14.5 ± 1.98 a	19.6 ± 3.15 a	12.3 ± 2.83 a	9.93 ± 1.87 a	5.47 ± 1.01 a
AS		7.09 ± 0.97 c	6.16 ± 1.13 b	5.58 ± 0.65 b	4.81 ± 0.29 b	3.95 ± 0.45 c	2.70 ± 0.23 b
NC		8.14 ± 0.88 b	7.69 ± 1.34 b	6.04 ± 0.58 b	5.48 ± 0.47 b	4.93 ± 0.38 b	3.58 ± 0.54 b
AS + NC		4.27 ± 0.56 d	3.73 ± 0.67 d	3.11 ± 0.45 c	2.34 ± 0.32 c	1.86 ± 0.23 d	1.24 ± 0.28 e
CK	Adults	5.41 ± 0.72 a	6.27 ± .68 a	7.97 ± 1.01 a	7.03 ± 0.81 a	6.25 ± 0.76 a	4.09 ± 0.61 a
AS		4.09 ± 0.35 b	2.74 ± 0.26 b	2.28 ± 0.35 c	1.86 ± 0.24 c	1.49 ± 0.34 c	1.15 ± 0.16 c
NC		4.28 ± 0.41 b	3.04 ± 0.44 b	2.86 ± 0.47 b	2.56 ± 0.39b	2.19 ± 0.32 b	1.77 ± 0.22 b
AS + NC		3.67 ± 0.52 b	2.16 ± 0.31 c	1.73 ± 0.29 d	1.21 ± 0.24 d	1.00 ± 0.18 d	0.85 ± 0.11 c

Means followed by same letters within columns are not significantly different ($P < 0.05$, Tukey's HSD)
CK control, *AS Amblyseius swirskii*, *NC Neoseiulus cucumeris*, *AS + NC Amblyseius swirskii + Neoseiulus cucumeris* and *SE* standard error

by the presence of both *A. swirskii* and *N. cucumeris* mites after different exposure periods. It was clear from these results that using *A. swirskii* and *N. cucumeris* caused higher reductions in *F. occidentalis* larvae and adults than in control treatments (no mites). By increasing experimental times, larvae and adults of *F. occidentalis* declined, while their lowest values were observed after 60 and 70 days of transferring tomato seedlings in the hydroponic pots. Using *A. swirskii* in combination with *N. cucumeris* led to greater reductions in *F. occidentalis* larvae and adults than single applications. The effect of *A. swirskii* was higher than that of *N. cucumeris*. At 7 days, larvae of *F. occidentalis* decreased from 11.2/leaf in the control to 4.27, 7.09, and 8.14 individuals/leaf in the *A. swirskii* plus *N. cucumeris*, *A. swirskii*, and *N. cucumeris* treatments, respectively. Thrips adults (at 7 days from transferring the tomato seedlings to the cages) were decreased from 5.41/leaf under no mite present to 3.67, 4.09, and 4.28 individuals/leaf after using adults of *A. swirskii* plus *N. cucumeris*, *A. swirskii*, and *N. cucumeris*, respectively. At the end of the experimental study, numbers of larvae and adults of *F. occidentalis* were obviously decreased from 5.47 and 4.09/leaf in the control to 1.24 and 0.85, to 2.70 and 1.15/ leaf, and to 3.58 and 1.77/ leaf in the *A. swirskii* plus *N. cucumeris*, each of *A. swirskii* and *N. cucumeris* treatments, respectively.

Data presented in Table 2 showed the effect of different treatments on populations of larvae and adults of *F. occidentalis* on flowers of cherry tomato after 50 days from its transfer to the hydroponic containers. The results indicated the positive role of predatory mites (*A. swirskii* plus *N. cucumeris*, each of *A. swirskii* and *N. cucumeris*) in controlling *F. occidentalis*. Also, using both showed better patterns in reducing the populations of larvae and adults of *F. occidentalis* than using either *A. swirskii* or *N. cucumeris* alone. At 50 days (when flowers of tomato appeared or opened), the highest values of larvae and adults of *F. occidentalis* (8.75 and 4.19 individuals/ five flowers) were recorded in the control treatments (no predatory mites). In contrast, the lowest populations of larvae and adults of *F. occidentalis* (2.46 and 1.68 individuals/five flowers) were found when adults of *A. swirskii* plus *N. cucumeris* were released. After 60 days, larvae and adults of *F. occidentalis* averaged 12.83 and 7.11 individuals/five flowers, respectively, and then reached their lowest values (1.21 and 0.89 individuals/five flowers) after releasing adults of *A. swirskii* plus *N. cucumeris*.

The current study showed marked reductions in populations of larvae and adults of western flower thrips due to using predatory mites at different intervals. Shipp and Wang (2003) found that populations of *F. occidentalis* after the release of *A. cucumeris* under greenhouse conditions were significantly decreased to lower values (63.6 thrips per plant as a result of *A. cucumeris* releasing) compared to the control. (averaged 283.8 thrips per plant). Therefore, it can be easily noted that the decrease in thrips numbers could coincide with the presence of this predatory mite.

It was clear from the current investigation that *A. swirskii* and *N. cucumeris* were differed in their

Table 2 Mean numbers (±SE) of *Frankliniella occidentalis* per five flowers of tomato after releasing adults of *Amblyseius swirskii* and *Neoseiulus cucumeris* at different periods (days)

Treatments	Larvae		Adults	
	50 days	60 days	50 days	60 days
CK	8.75 ± 1.89 a	12.83 ± 2.34 a	4.19 ± 0.33 a	7.11 ± 0.79 a
AS	3.15 ± 0.54 c	2.10 ± 0.31 c	1.94 ± 0.42 b	1.36 ± 0.11 b
NC	4.07 ± 0.46 b	3.24 ± 0.57 b	2.21 ± 0.26 b	1.85 ± 0.18 b
AS + NC	2.46 ± 0.23 c	1.20 ± 0.24 d	1.68 ± 0.17 b	0.89 ± 0.10 b

Means followed by same letters within columns are not significantly different ($P < 0.05$, Tukey's HSD)
CK control, *AS Amblyseius swirskii*, *NC Neoseiulus cucumeris*, *AS + NC Amblyseius swirskii + Neoseiulus cucumeris* and *SE* standard error

capabilities to control *F. occidentalis* on tomato plants, where *A. swirskii* was more efficient as a bioagent than *N. cucumeris*. These findings are similar to those obtained by van Houten et al. (2005) who found that the release of *A. swirskii* led to a better establishment and superior for *F. occidentalis* control on sweet pepper over 6 weeks compared with *N. cucumeris*. Arthurs et al. (2009) also showed that *A. swirskii* and *N. cucumeris* were good and effective predators for *Scirtothrips dorsalis* on sweet pepper but the efficiency of *N. cucumeris* was less than *A. swirskii*. Similarly, Stansly and Castillo (2010) observed low efficiency in controlling whiteflies and broad mites by *N. cucumeris* as compared with *A. swirskii* on eggplant and pepper under field conditions in south Florida. Moreover, Lee and Gillespie (2011) demonstrated that *A. swirskii* in the Mediterranean region with an optimum temperature for survival and growth might have better adaptation to this local temperature than *N. cucumeris*. Kakkar et al. (2016) found that *A. swirskii* was more effective in diminishing *Thrips palmi* (Karny) populations than *N. cucumeris* on cucumber leaves. So, we could suggest that *A. swirskii* had a higher adaption for the greenhouse conditions than *N. cucumeris* under the hydroponic system. However, some other studies showed different patterns than the current results. Arevalo et al. (2009) found that *N. cucumeris* or *A. swirskii* were not efficient in controlling *F. schultzei* (Trybom) that attacked pepper and blueberry flowers. They explained the low inability of *N. cucumeris* or *A. swirskii* to control *F. schultzei* by the low presence of mites on flowers of the infested plants. Also, Kakkar et al. (2016) showed that *N. cucumeris* and *A. swirskii* were effective under shade house and field trial against *T. palmi* on cucumber leaves, but failed to control *F. schultzei* in its flowers.

Combination of the used predatory mites (*A. swirskii* and *N. cucumeris*) showed large reductions in population of larvae and adults of *F. occidentalis* on leaves and flowers of tomato plants that were grown in hydroponic conditions. These findings are in harmony with the results of Chow et al. (2010) who recorded that mixing predators led to higher enhancements in controlling different species of thrips on many crops.

Populations of predatory mites preying on *F. occidentalis*

The presented results showed that numbers of eggs, immature stages, and adults of *A. swirskii* and *N. cucumeris* were highly enhanced with the increase of the experimental periods to 45 days. Numbers of *A. swirskii* were higher than those of *N. cucumeris* on both leaves and flowers of cherry tomato plants that were attacked by adults of *F. occidentalis* (Tables 3 and 4). Numbers of *A. swirskii* and *N. cucumeris* on leaves of tomato plants were greater than those on their flowers. On the leaves of tomato, counts of eggs, immature stages, and adults for *A. swirskii* ranged from 0.83, 2.13, and 2.61/ leaf to 5.09, 9.51, and 10.75/ leaf, respectively, while stages of *N. cucumeris* varied from 0.61, 1.76, and 2.14/leaf to 4.18, 7.42, and 9.26/leaf, respectively, when the experimental period increased from 7 to 75 days. Data in Table 5 showed that feeding of *A. swirskii* on *F. occidentalis* that attacked flowers of tomato plants caused marked enhancements in the numbers of its eggs, immature stages, and adults from 0.89, 2.03, and 2.69/five flowers after 50 days to 1.40, 3.71, and 5.80/five flowers after 60 days, respectively. Moreover, noticeable increases were recorded in eggs, immature stages, and adults of *N. cucumeris* from 0.78, 1.63, and 2.37/five flowers after 50 days to 1.26, 2.84, and 4.60/five flowers after 60 days, respectively, after using *F. occidentalis* as a prey.

The current investigation clearly showed that counts of eggs, immature stages, and adults of *A. swirskii* and *N. cucumeris* after attacking *F. occidentalis* on leaves and flowers of tomato were highly enhanced and they were higher for *A. swirskii* than for *N. cucumeris* at the chosen experimental periods from 7 to 75 days on leaves and from 50 to 60 days on flowers after transferring seedlings of tomato to the hydroponic containers. The higher increases in populations of *A. swirskii* than *N. cucumeris* might be related to its better adaptation under

Table 3 Density of different stages (±SE) of *Amblyseius swirskii* per leaf of tomato after feeding on *Frankliniella occidentalis* at different periods (days)

Experimental days	Egg	Immature	Adults
7	0.83 ± 0.07 f	2.13 ± 0.25 e	2.61 ± 0.31 d
15	1.79 ± 0.21 e	5.37 ± 0.61 d	6.21 ± 0.59 c
30	4.83 ± 0.48 d	7.98 ± 0.76 c	10.84 ± 2.45 b
45	6.91 ± 0.69 a	12.07 ± 3.10 a	14.16 ± 3.56 a
60	5.65 ± 0.71 b	11.22 ± 2.34 a	13.00 ± 3.27 a
75	5.09 ± 0.46 c	9.51 ± 2.15 b	10.75 ± 2.78 b

Means followed by same letters within columns are not significantly different ($P < 0.05$, Tukey's HSD)
SE standard error

Table 4 Density of different stages (±SE) of *Neoseiulus cucumeris* per leaf of tomato after feeding on *Frankliniella occidentalis* at different periods (days)

Experimental days	Egg	Immature	Adults
7	0.61 ± 0.06 d	1.76 ± 0.26 e	2.14 ± 0.32 d
15	1.33 ± 0.11 c	4.83 ± 0.37 d	5.39 ± 0.71 c
30	3.70 ± 0.24 b	6.52 ± 0.84 c	9.40 ± 1.48 b
45	5.30 ± 0.56a	10.91 ± 1.87 a	12.08 ± 2.51 a
60	4.98 ± 0.63 a	9.34 ± 2.11 b	11.7 ± 1.93 a
75	4.18 ± 0.49 b	7.42 ± 0.86 c	9.26 ± 1.06 b

Means followed by same letters within columns are not significantly different ($P < 0.05$, Tukey's HSD)
SE standard error

Table 5 Density of different stages (±SE) of predatory mites per five flowers of tomato after their feeding on *Frankliniella occidentalis* at different experimental periods (days)

Experimental days	Predatory mites	Egg	Immature	Adults
50	*Amblyseius swirskii*	0.89 ± 0.04 b	2.03 ± 0.21 b	2.69 ± 0.31 b
60		1.40 ± 0.13 a	3.71 ± 0.35 a	5.80 ± 0.65 a
50	*Neoseiulus cucumeris*	0.78 ± 0.23 b	1.63 ± 0.15 b	2.37 ± 0.24 b
60		1.26 ± 0.11 a	2.84 ± 0.27 a	4.60 ± 0.51 a

Means followed by same letters within columns are not significantly different ($P < 0.05$, Tukey's HSD)
SE standard error

the experimental conditions. The results of the current experiment differed than the findings of Kakkar et al. (2016) who found that eggs and motile stages of *A. swirskii* were higher than those of *N. cucumeris* only on leaves of treated plants, while no eggs and motile stages were observed on flower samples.

Conclusions

This study shows the effective roles of *A. swirskii* and *N. cucumeris* in controlling western flower thrips that infests cherry tomato plants under a hydroponic system. Results clearly indicated that *A. swirskii* was more efficient than *N. cucumeris* as a bio-control agent against larvae and adults of *F. occidentalis*. Mixing *A. swirskii* and *N. cucumeris* was responsible for the highest governing effect on *F. occidentalis*. So, use of *A. swirskii* plus *N. cucumeris* to control thrips is highly recommended.

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Availability of data and materials
All data are available at the end of the article and the materials used in this work are of high quality and grade.

Significant statement
This study is very helpful for entomologist and acarologist researchers because it provides marked information about the control effect of *Amblyseius swirskii* and *Neoseiulus cucumeris* for *F. occidentalis* on cherry tomato grown under a hydroponic system.

Authors' contributions
NA designed and set up the experiments, and after that, she analyzed the data and wrote the article. ML conducted the experiment and wrote and revised the article. Both authors read and approved the final manuscript.

Ethics approval and consent to participate
All experimental works were approved by College of Plant Science and Technology at Huazhong Agricultural University, Wuhan, Hubei, China.

Consent for publication
The agreement of publication was taken, and as a corresponding author, I confirm that.

Competing interests
The authors declare that they have no competing interests.

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Author details
[1]Department of Plant Protection, Faculty of Agriculture, Benha University, Benha, Egypt. [2]Department of Plant Protection, Huazhong Agricultural University, Wuhan, Hubei, China. [3]Department of Vegetables Production, Hubei Academy of Agricultural Sciences, Wuhan, China.

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