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Article

Efficacy of phytoseiid mites and pesticides to control *Bemisia tabaci*, *Thrips tabaci* and *Tetranychus urticae* on *Capsicum annuum*

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ABSTRACT

Four predatory mites including *Amblyseius swirskii*, *Cydnoseius negevi*, *Neoseiulus cucumeris*, and *Phytoseiulus persimilis*, as well as mixture of commercial pesticides named Actara® and Egyxide® (Emulsified vegetable oil) were used to manage the population of *Bemisia tabaci*, *Thrips tabaci*, and *Tetranychus urticae* on red delta star pepper cultivar of *Capsicum annuum*. All treatments were applied separately and in combination on pepper cultivar grown in a high plastic-net tunnel. The results showed that *A. swirskii* released separately or combined with other treatments significantly suppressed the population of *B. tabaci* and *T. tabaci* to 0.00 and 0.04–2.10 individual/leaf, respectively. *Cydnoseius negevi* and *N. cucumeris* significantly reduced *B. tabaci* population. However, the latter was the most effective against *T. tabaci*. The numerical densities of movable and egg stages of *T. urticae* reduced significantly by *P. persimilis* alone or along with *A. swirskii*, followed by the release of *A. swirskii* with *N. cucumeris* and reached 0.00 individual/leaf. The most effective treatments for *T. tabaci* with percent reduction ranging from 94.53% to 100% were *A. swirskii*, *N. cucumeris*, and all combined treatments. Treatments with pesticides, *C. negevi*, and *A. swirskii* + pesticides exhibited less efficiency in controlling *B. tabaci*, *T. tabaci*, and *T. urticae*, respectively. Our findings indicated that the applied bio-agents were efficient, and the inclusion of *A. swirskii* in programs of integrated pest management is advisable for controlling *B. tabaci*, *T. tabaci*, and *T. urticae* on the pepper cultivar.

KEY WORDS: *Amblyseius swirskii*; biological control; *Cydnoseius negevi*; *Neoseiulus cucumeris*; pest management; *Phytoseiulus persimilis*.

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INTRODUCTION

Pepper, *Capsicum annuum* L. (Solanales: Solanaceae) has been one of the most economical and pharmacological important crops worldwide. Estimated average production in Egypt increased from 121,000 to 764,292 tons from 1970 to 2019, at a 4.50 percent annual rate and made Egypt one of the top 10 producers of pepper in the world (FAO 2021). Pepper cultivation, like other vegetable crops, has been attacked by various pests, resulting in a significant reduction in quality and yield of crops especially under controlled conditions. Whitefly, *Bemisia tabaci* (Gennadius) (Aleyrodidae: Hemiptera), onion thrips, *Thrips tabaci* Lindeman (Thripidae: Thysanoptera), and the two spotted spider mite, *Tetranychus urticae* Koch (Trombidiformes: Tetranychidae) have been the major economically important pests of pepper crop (Zhang 2003; El-laithy *et al.* 2013). The sucking insect

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pests viz., *B. tabaci* and *T. tabaci* were extremely injurious to many crops grown worldwide (Qari *et al.* 2020), causing direct and indirect damage to plants via sucking and destroying them, as well as transmitting plant viruses (Breene *et al.* 1992). Furthermore, *T. urticae* had a high reproductive capacity, causing significant economic damage and yield losses of up to 90%, and they could rapidly develop to very large populations under favorable conditions resulting in serious crop loss (Ginette *et al.* 2014).

Using chemical pesticides as a major and conventional method for controlling pests in Egypt has not always been effective enough. Synthetic pesticides had serious ecological issues including the emergence of pest resistance, pest outbreak, and effect on non-target organisms as well (Gorman *et al.* 2002). These concerns have greatly increased interest to use important agents of integrated plant protection procedures for safe production of vegetables (Al-Ani *et al.* 2020). Predatory phytoseiid mites are highly efficient biological control agents against other destructive mite groups (van Houten *et al.* 2007a; Fatnassi *et al.* 2015), as well as thrips and whiteflies (Calvo *et al.* 2006; Messelink *et al.* 2006). Most crops are infested by a variety of pests; thus, the use of generalist natural enemies has received much interest, whereas the use of specialist natural enemies was a good conventional choice in previous decades for each pest species (Fathipour and Maleknia 2016).

Several species of predatory mites are used widely in greenhouses as integral components of integrated pest management (IPM) (Dalir *et al.* 2021), for example, *Amblyseius swirskii* Athias-Henriot (Acari: Phytoseiidae) has been used as a generalist predator in over 50 countries (Calvo *et al.* 2015). It has proved its ability to restrict the population density of whiteflies, thrips, and the two spotted spider mite in greenhouses (Calvo *et al.* 2011; Lopez *et al.* 2017; Fathipour *et al.* 2020). In addition, *Neoseiulus cucumeris* Oudemans is one of the most effective generalist predators and showed efficiency against various pests (Williams 2001; Yazdanpanah *et al.* 2022). Moreover, *Cydnoseius negevi* (Swirskii & Amitai) was found to utilize *Frankliniella occidentalis* Pergande (Momen *et al.* 2009; El-laithy *et al.* 2021). Also, a well-known specialist predator, *Phytoseiulus persimilis* Athias-Henriot, is commercially available and widely used in controlling *T. urticae* in greenhouses and fields (Yanar *et al.* 2019). On the other hand, it has been reported that a combination of natural enemies and pesticides can be used to ensure a more effective IPM strategy (Sato *et al.* 2011; Lima *et al.* 2013; Bordini *et al.* 2021; Cheng *et al.* 2021).

Incorporation of economical and helpful natural enemies into IPM is a good choice and is required more than pesticides to suppress pest population below economic damage. Therefore, this study aims to evaluate the efficiency of two different programs of IPM strategies for controlling *B. tabaci*, *T. tabaci*, and *T. urticae* pests on red delta star pepper cultivar. The management tools basically depend on: (1) the release of four predatory phytoseiid mites, *A. swirskii*, *C. negevi*, *N. cucumeris*, and *P. persimilis*, (2) the application of a mixture of commercial pesticides named Actara and Egyxide oil, and (3) all applied as single or combined treatments. Experiments were carried out under high tunnel of plastic-net condition.

MATERIALS AND METHODS

Control agents used in the study

The four biological control agents used in this study were *Amblyseius swirskii*, *Cydnoseius negevi*, *Neoseiulus cucumeris*, and *Phytoseiulus persimilis*. In addition to a mixture of commercial pesticides composed of Actara (Thiamethoxam 25% WS WG) produced by Syngenta Agro, Egypt, and Egyxide (Natural emulsified vegetable oils 10%, glue 2%) produced by ROYAL for Agricultural Development, Egypt. A mixture of both commercial products (AE) was prepared to be used in ratio of 2.5 mL/L:2.5 mL/L. These control agents were applied separately and in combinations.

Mite cultures

The four tested predatory phytoseiid mites were maintained at 28 ± 2 °C and 70 ± 5% R.H. for six months and reared for 4–5 generations in the Acarology laboratory at National Research Centre (NRC), Cairo, Egypt. *Tetranychus urticae* was used as prey; it was reared at the same conditions on lima bean plant, *Phaseolus vulgaris* L. (Fabaceae) and kept under muslin cage to prevent any infestation. The culture was supplied continuously by cleaned developed lima bean plants which were preserved in a different muslin cage.

The stock of each predator was maintained separately in rearing units, each unit consisted of large trays (26 × 15 × 10 cm). The lima bean leaves infested with *T. urticae* were placed upside-down on moist cotton wool in each tray. Sufficient food of *T. urticae* was introduced continuously in order to preserve the culture, and predators were transferred to fresh leaves when the old substrate deteriorated. Moreover, water was added daily to maintain cotton wet and to prevent tested predacious mites from escaping. For mass rearing, a greenhouse in NRC experimental farm at Imam Malik village, Nubaria, Egypt was used. At temperature of 28 ± 2 °C and 70 ± 5% R.H., lima bean plant was served as the host plant, and the greenhouse was divided into six isolated chambers; one contained clean lima bean plants, another with lima bean plants infested by *T. urticae*, and the remaining four champers included infested lima bean plants with *T. urticae* in which the tested predatory mites were released.

Experimental design

The field experiment was conducted at Om Saber village, Tahrir province, El-Beheira Governorate, Egypt during 2019–2020 season. Red delta star cultivar of *Capsicum annuum* was transplanted on April 1st 2019 under high tunnel of plastic-net conditions in area size of 525 m^2 for the experiment. There were 10 equal plots including nine plots for treatments; *A. swirskii*, *C. negevi*, *N. cucumeris*, *P. persimilis*, AE, *A. swirskii* + *P. persimilis*, *A. swirskii* + *C. negevi*, *A. swirskii* + *N. cucumeris*, and *A. swirskii* + AE, and one untreated plot served as control. The size area of each plot was about 52.5 m^2, and the plots were completely separated by plastic sheets covered with paraffin wax to prevent the predatory mites from escaping and mixing. Each treatment consisted of three 30 m rows and the distance between two plants was 40 cm. Each row represented one replicate and contained 75 plants. The infestation by tested pests occurred naturally, and plants were observed daily and watered on a regular basis following all recommended agricultural practices.

The adult females of predatory mites were first released once on May 15th, 2019 at a predatory:prey ratio of 1:10 (Heikal and Fawzy 2003) during the flowering stage of the plant, as the population density of investigated pests built up on pepper cultivar. Whereas, mixture of Actara and Egyxide treatment (AE) (75mL/100L) was sprayed five times on May15th, 2019 (w 0), July 15th, 2019 (w 8), September 30th, 2019 (w 18), November 30th, 2019 (w 26), and January 30th, 2020 (w 34). For combined treatment of *A. swirskii* + AE, the AE was sprayed first then after 48 h the predatory mite was released using the technique mentioned previously.

Sampling technique

Sampling initiated from May15th, 2019, the date of pre-treatment count, and continued for additional 42 weeks after the first treatment. The population of sucking pests viz., *B. tabaci*, *T. tabaci*, and *T. urticae* were weekly recorded. Thirty leaves were randomly collected (10 per replicate) from top, middle and lower parts of the plant in each plot. The collected leaves were placed in polyethylene bags inside ice box, and then transferred to the laboratory. The numbers of *B. tabaci* (nymphs and eggs), *T. tabaci* and *T. urticae* (all stages) on each leaf were counted under a stereomicroscope. Prepared samples of pests were classified and identified in Department of Pests and Plant Protection, NRC, Cairo, Egypt.

Data analysis

For each replicate in treated and untreated plots, the mean number of observed pests was summed every two weeks and mean number was calculated. The experiments were arranged in a randomized complete block design (RCBD) with three replications. To determine the influence of different treatments on pepper at equal intervals (two weeks), the mean number of individuals in three replicates of all treatments were compared with that of control group using one way analysis of variance ANOVA by Duncan tests ($P < 0.05$). The percent reduction of pests in treated plots was calculated according to Henderson and Tilton equation (Henderson and Tilton 1955) as follows:

$$\%Reduction = \left(1 - \frac{n\ in\ C\ before\ treatment\ x\ n\ in\ T\ after\ treatment}{n\ in\ C\ after\ treatment\ x\ n\ in\ T\ before\ treatment}\right) x\ 100$$

Where: n = pest population, T = treated, C = control
All statistical analyses were performed using SPSS version 14.0.

RESULTS

Efficacy of different treatments on insect and mite pests infested Capsicum annum *L.*

Bemisia tabaci

Data presented in Figure 1a showed that the population density of *B. tabaci* (eggs and nymphs) on red delta star pepper cultivar differed significantly after application of separated treatments during 42 weeks. *Phytoseius persimilis* is a specialist predator mite of *T. urticae* therefore, on tested cultivar the mean number of *B. tabaci* increased gradually after its release with mean number similar to that of control plot. Also, the application of AE on weeks 8, 18, 26, and 34 significantly reduced the population of *B. tabaci* directly after its application, then the population increased gradually during the season. As shown in Figure 1a, the lowest population counts of *B. tabaci* after AE application were 2.90 ± 0.10, 3.20 ± 0.46, 4.50 ± 0.75, and 5.10 ± 0.32 individuals/leaf (F = 88.466, 124.305, 754.476, and 493.083; *P* = 0.000) on weeks 10, 20, 28, and 36, respectively. After two weeks of separated application, the recorded population of *B. tabaci* after the release of *C. negevi* and *N. cucumeris* did not differ significantly and was similar to that recorded in untreated plot. However, it can be noticed that *A. swirskii* proved to be the most effective treatment in reducing *B. tabaci* population on tested cultivar where no eggs and/or nymphs were observed from week 24 until the end of experiment. The data obtained revealed that the release of *C. negevi* and *N. cucumeris* had a similar effect on the population of *B. tabaci* during the 42-week experiment.

The results of combined treatments on the red delta star cultivar are shown in Figure 1b. It was observed that, till six weeks post-initial treatment, all combined treatments exhibited a similar significant efficacy on controlling *B. tabaci* in comparison to control. Releasing of *A. swirskii* in combined treatment with *C. negevi* and *N. cucumeris* showed the most potent effect that resulted in a complete control (0.00 population) of *B. tabaci* after eight weeks of application until the end of experiment. From two weeks post-initial treatment to the week 22, both combined treatments of *A. swirskii* + *P. persimilis* and *A. swirskii* + AE exhibited similar effects on number of *B. tabaci* recorded ranging from 4.20 ± 0.95 to 1.36 ± 0.29 and from 2.23 ± 0.67 to 2.20 ± 0.86 individuals/leaf, respectively, compared to control (6.30 ± 0.11–38.93 ± 0.14 individuals/leaf). Moreover, *A. swirskii* + *P. persimilis* and *A. swirskii* + AE caused complete reduction (~0.00) in *B. tabaci* population in weeks 26 and 36 after application (F = 5,013.739 and 29,227.885; *P* = 0.000), respectively.

Thrips tabaci

The population density of *T. tabaci* (all stages) was affected significantly by separated treatments of predatory mites and AE spray over time on tested cultivar. Data obtained in Figure 2a show that, throughout the experiment in plot where *P. persimilis* was released, the population density of *T. tabaci* was similar to that in control plot. In plot sprayed with AE on weeks 8, 18, 26, and 34 the population of *T. tabaci* significantly reduced particularly after repeating the treatment to reach 1.48 ± 0.32, 1.93 ± 0.34, 2.90 ± 0.51, and 2.93 ± 0.37 individuals/leaf on weeks 10, 20, 28, and 36 (F = 149.934, 481.629, 200.651, and 578.824; P = 0.000), respectively compared to predatory mites' treatments and control. It was obvious that *A. swirskii* and *N. cucumeris* exhibited similar effects during 42 weeks; both predatory mites significantly lowered the population of *T. tabaci* on tested cultivar. During the experiment, the release of *C. negevi* was less effective on controlling *T. tabaci* compared to control population. By the end of the experiment time, on week 42 the most effective treatments were *A. swirskii* and *N. cucumeris*, followed by AE then *C. negevi* (F = 147.644; P = 0.000).

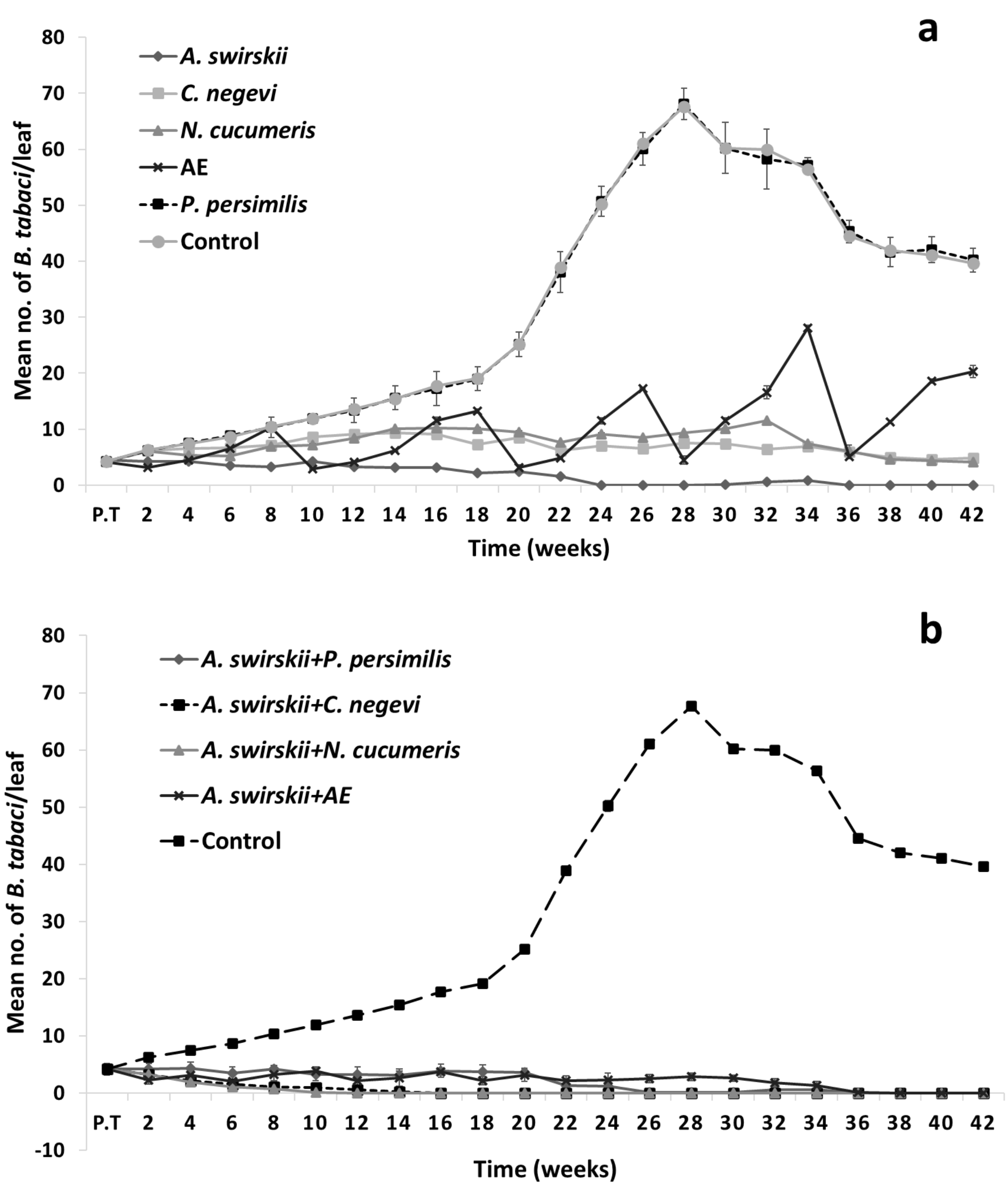

Figure 1. The average densities of *Bemisia tabaci* (nymphs and eggs) on red delta star pepper cultivar during 42-weeks after: **(a)** separated treatments, and **(b)** combined treatments. Mean (± SE) values compared using ANOVA by Duncan tests (P < 0.05), P.T: Pre-treatment count.

Data displayed in Figure 2b confirm that the combined treatments significantly affected the population density of thrips on red delta star pepper cultivar during the experiment. A combined release of *A. swirskii* + *N. cucumeris* was most effective and resulted in ~0.00 count of *T. tabaci* on week 14 (F = 120.506; *P* = 0.000) until the end of the experiment. Whereas, *A. swirskii* + *P. persimilis* and *A. swirskii* + *C. negevi* resulted in ~0.00 population on week 40 (F = 1,273.198; *P* = 0.000). By the end of the experiment, the highest count of *T. tabaci* was observed in plot treated with *A. swirskii* + AE reaching to 2.10 ± 0.51 individuals/leaf compared to the untreated plot with 43.19 ± 1.19 individuals/leaf (F = 1,074.248; *P* = 0.000).

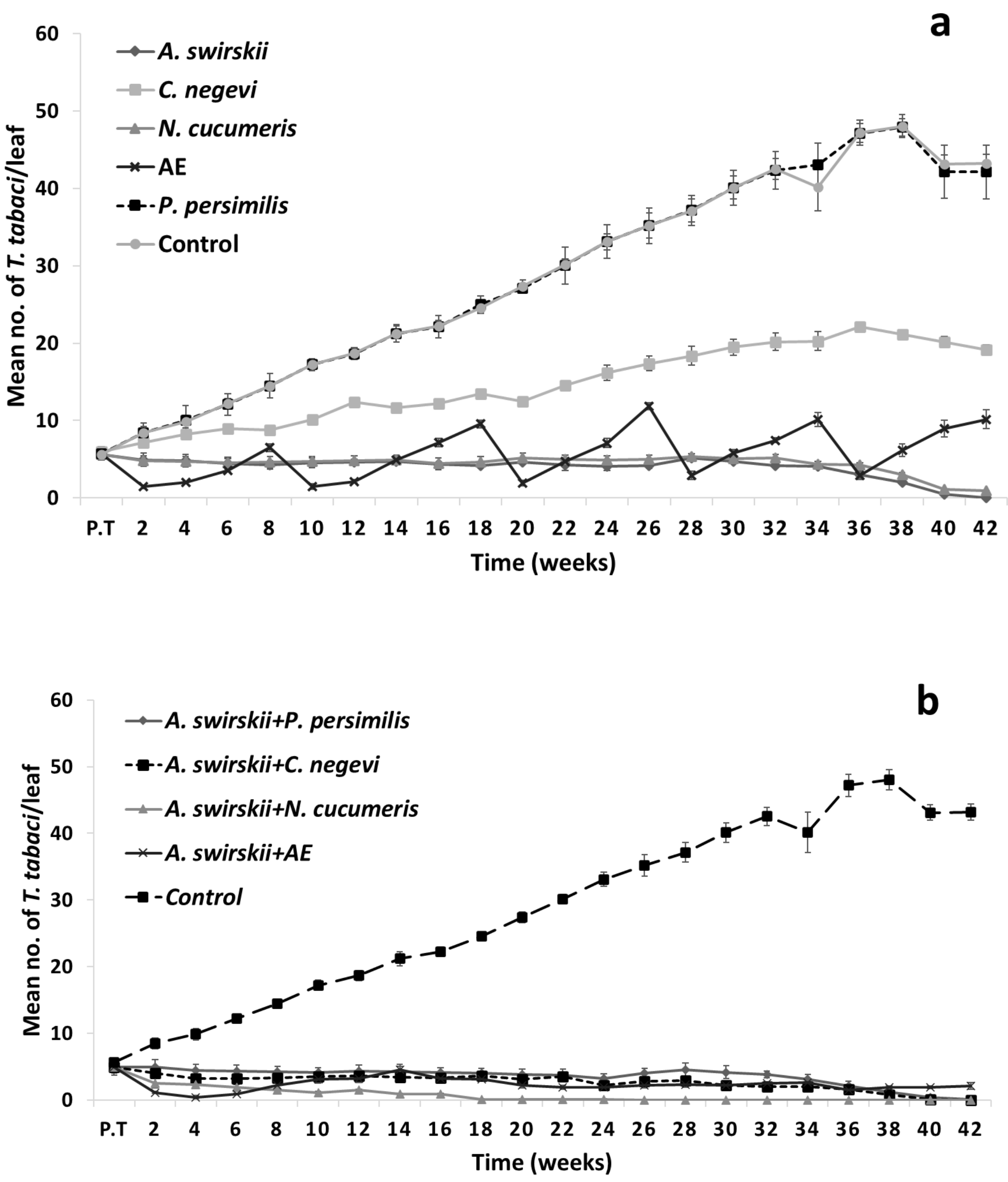

Figure 2. The average densities of *Thrips tabaci* (all stages) on red delta star pepper cultivar during 42-weeks after: **(a)** separated treatments, and **(b)** combined treatments. Mean (± SE) values compared using ANOVA by Duncan tests (*P* < 0.05), P.T: Pre-treatment count.

Tetranychus urticae

Results in Figure 3a, b displayed the population density of *T. urticae* movable and egg stages on tested cultivar after separated treatments. It was initially observed that the population density of *T. urticae* tested stages in control plot increased till week 26 then decreased sharply. A significant reduction in the numerical density of *T. urticae* tested stages was observed by the action of all tested treatments compared to that of the control. The data in Figure 3a indicated that *P. persimilis* achieved the highest decrease rate in the population density of *T. urticae* movable stages especially after 20 weeks post-initial treatments (F = 78.25; *P* = 0.000), and the mean number of individuals/leaf was zero compared to that of control (108.7 ± 7.66 individual/leaf). Also, the treatment of AE showed a remarkable decrease rate at 2, 10, 20, 28, and 36 weeks post-repeated pointed time application (F = 22.25, 67.94, 78.25, 132.30, and 146.61; *P* = 0.000). Other than the indicated weeks, the population density of *T. urticae* movable stages increased gradually by AE treatment as time pass away. Data showed no significant difference between the efficacy of *A. swirskii* and *N. cucumeris*. Both treatments decreased the density of *T. urticae* movable stages per leaf at the final week to 43.61 ± 3.01 and 49.30 ± 3.99 individual/leaf, respectively compared to that of control (129.09 ± 4.94 individual/leaf). On the other hand, *C. negevi* treatment was the least effective on movable stages among treatments compared to control.

Regarding the efficacy of tested treatments on *T. urticae* egg stage (Fig. 3b); *P. persimilis* was the most effective treatment on the egg stage compared to that of control especially after week 18 (F = 34.38; *P* = 0.000) followed by *A. swirskii*, *N. cucumeris*, and *C. negevi* treatments which show insignificant differences among their efficacy over the most tested time. Treatment with AE showed oscillation effect in the population density of eggs which was significantly decreased especially after each repeated application. Then, the population density of eggs increased sharply but less than in control plot, and reached 27.33 ± 2.50 eggs/leaf at the last week compared to that of control (62.14 ± 4.00 eggs/leaf).

The data presented in Figure 4a, b clarified that combined treatments showed a significant reduction in densities of all tested stages. The release of *A. swirskii* + *P. persimilis* was the most potent treatment, and the population density significantly decreased to zero especially at weeks 16 and 12 for movable stages (Fig. 4a) and egg stage (Fig. 4b) (F = 76.77, 54.11; *P* = 0.000), respectively. Concerning with movable stages, *A. swirskii* with *N. cucumeris* showed a considerable decrease equal or more than it was observed with *C. negevi* in most times. There was no significant difference between *A. swirskii* + *N. cucumeris* and *A. swirskii* + *C. negevi* treatments in their efficacy on the population density during all weeks. Regarding the egg stage, all treatments in most determined weeks were closely the same, and there was no significant difference in numerical density between *A. swirskii* with *P. persimilis* and with *N. cucumeris* at weeks 30, 34, 36, and 38.

Overall reduction

It can be noticed that the efficacy of separated and combined treatments on the population of three pests; *B. tabaci*, *T. tabaci*, and *T. urticae* on red delta star pepper cultivar varied significantly. As presented in Table 1, by the end of experiment a complete control of *B. tabaci* (zero population density) and maximum reduction percentage (100%) caused by separated release of *A. swirskii* and all combined treatments was achieved. Also, *C. negevi* and *N. cucumeris* showed a significant similar reduction effect and reduced the final numerical densities of *B. tabaci* to 4.90 ± 0.28 and 4.10 ± 0.17 individual/ leaf respectively. The overall mean reduction percentages caused by *C. negevi* and *N. cucumeris* were 87.73 ± 1.20 and 89.81 ± 0.08%, respectively. Although the significant reduction in *B. tabaci* population after AE treatment during the experiment time, at the end of the season it showed less effectiveness and reduced the population to 20.30 ± 1.08 individuals/leaf compared to control (39.63 ± 0.42 individual/leaf). The reduction percentage at the end of season after AE treatment was only 47.51 ± 1.93. The results also showed that *P. persimilis* had no effect for controlling *B. tabaci*.

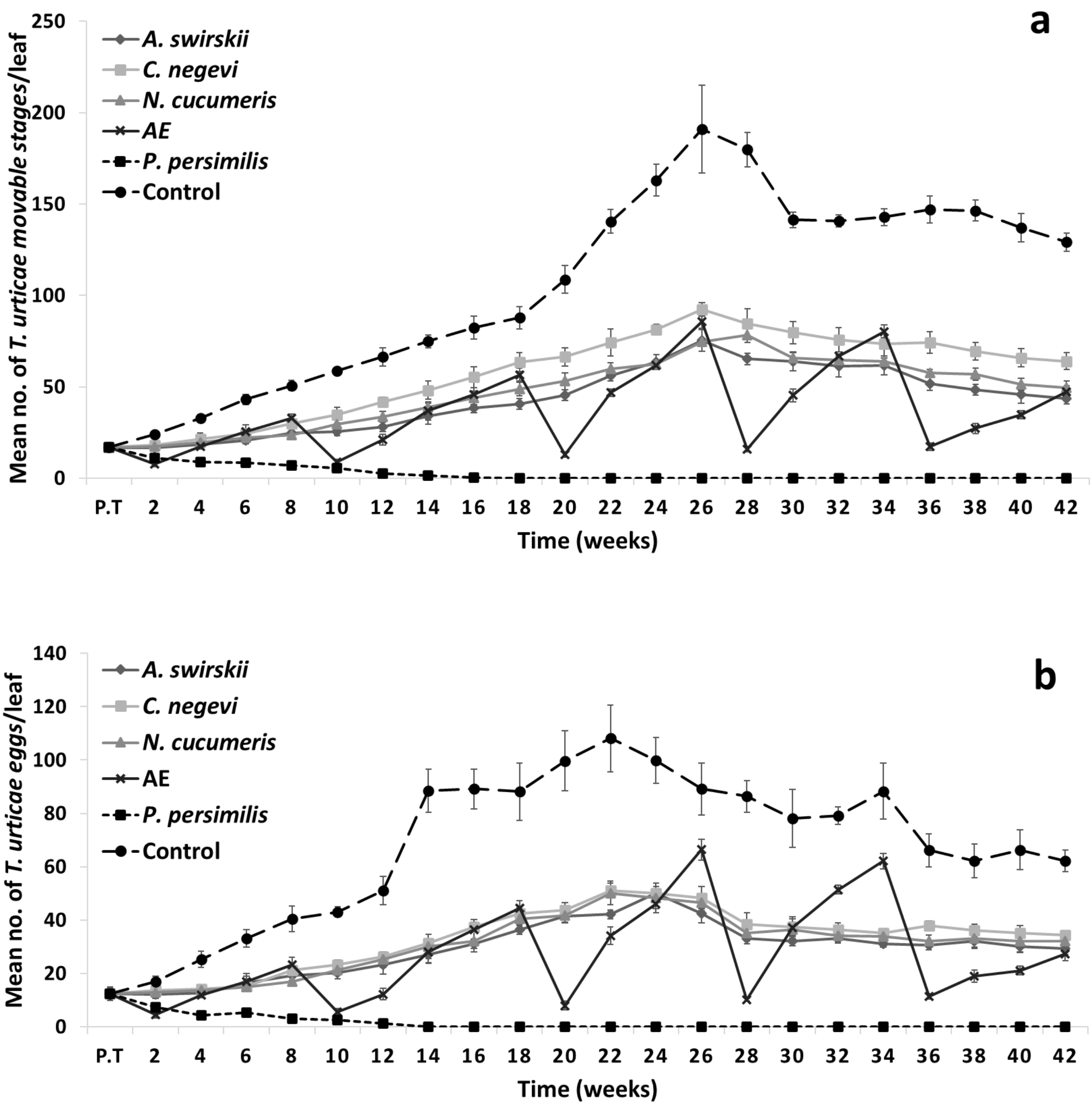

Figure 3. The average densities of *Tetranychus urticae* **(a)** movable stages and **(b)** eggs on red delta star pepper cultivar during 42-weeks after separated treatments. Mean (± SE) values compared using ANOVA by Duncan tests ($P < 0.05$), P.T: Pre-treatment count.

Data in Table 1 also confirm that, *A. swirskii*, *N. cucumeris*, and all combined treatments were not statistically different. They were the most effective treatments for *T. tabaci* control with final count of 0.00–2.10 individuals/leaf and reduction percentages ranged from 94.53 ± 0.92 to 100% in the tested cultivar. Likewise, AE treatment showed a significant effect which was more than that caused by the release of *C. negevi*. The mean number of *T. tabaci* counted after AE treatment was 10.17 ± 1.18 individuals/leaf compared to control (43.19 ± 1.19 individuals/leaf); whereas, 19.11 ± 0.66 individuals/leaf were counted after the release of *C. negevi*. The overall mean reduction percentage caused by AE treatment was 76.89 ± 1.43%. While, *C. negevi* released in tested cultivar resulted in reduction percentage of 57.63 ± 3.75%. The numerical density of *T. tabaci* was increased significantly in the plot treated with *P. persimilis* to 42.11 ± 3.47 individuals/leaf, and it was similar to the population density of the insects in control plot.

Table 1. Mean number and percent reduction of *Bemisia tabaci* (eggs and nymphs) and *Thrips tabaci* (all stages) on pepper plant at the end of crop season.

Treatments	*Bemisia tabaci*		*Thrips tabaci*	
	Mean number of prey/leaf (± SE)	%Reduction (± SE)	Mean number of prey/leaf (± SE)	%Reduction (± SE)
A. swirskii	0.00 ± 0.00d	100.00 ± 0.00a	0.03 ± 0.02d	99.91 ± 0.06a
C. negevi	4.90 ± 0.28c	87.73 ± 1.20b	19.11 ± 0.66b	57.63 ± 3.75c
N. cucumeris	4.10 ± 0.17c	89.81 ± 0.08ab	0.90 ± 0.05d	97.88 ± 0.14a
AE	20.30 ± 1.08b	47.51 ± 1.93c	10.17 ± 1.18c	76.89 ± 1.43b
P. persimilis	40.20 ± 2.15a	−0.57 ± 9.99d	42.11 ± 3.47a	1.62 ± 7.54d
A. swirskii* + *P. persimilis	0.00 ± 0.00d	100.00 ± 0.00a	0.13 ± 0.08d	99.72 ± 0.15a
A. swirskii* + *C. negevi	0.00 ± 0.00d	100.00 ± 0.00a	0.00 ± 0.00d	100.00 ± 0.00a
A. swirskii* + *N. cucumeris	0.00 ± 0.00d	100.00 ± 0.00a	0.00 ± 0.00d	100.00 ± 0.00a
***A. swirskii* + AE**	0.00 ± 0.00d	100.00 ± 0.00a	2.10 ± 0.51d	94.53 ± 0.92a
Control	39.63 ± 0.42a	-	43.19 ± 1.19a	-
F-value	445.469*	103.812*	194.363*	133.272*

The values with different letters within the same column are significantly different ($P < 0.05$) (ANOVA) (Duncan test).
* = Highly significant

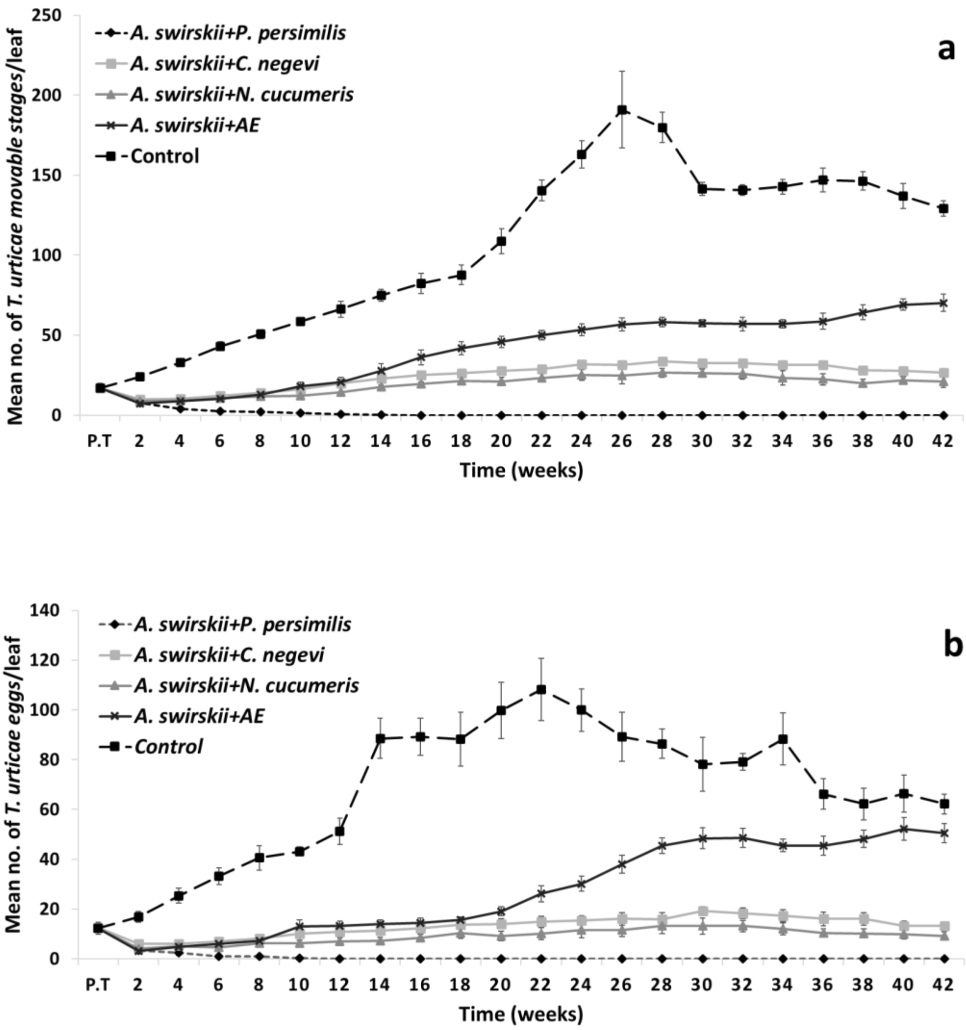

Figure 4. The average densities of *Tetranychus urticae* **(a)** movable stages and **(b)** eggs on red delta star pepper cultivar during 42-weeks after combined treatments. Mean (± SE) values compared using ANOVA by Duncan tests ($P < 0.05$), P.T: Pre-treatment count.

Data in Table 2 showed that, at the end of growing season both *P. persimilis* and *A. swirskii* + *P. persimilis* were the most potent treatments on movable stages of *T. urticae*. Both treatments suppressed the population densities of movable stages to zero with reduction percentage of 100%. Also, the combined release of *A. swirskii* with *N. cucumeris* significantly reduced the movable stages to 21.16 ± 3.68 individuals/leaf compared to 129.09 ± 4.93 individuals/leaf of movable stages in control plot. The data showed that *C. negevi* released separately and *A. swirskii* + AE treatments were the least effective and reduced the movable stages of *T. urticae* to only 64.04 ± 4.53 and 70.23 ± 5.27 individuals/leaf, respectively. It was observed that, *A. swirskii*, *N. cucumeris*, and AE treatments exhibited moderate and similar efficacy with reduction percentages ranging from 43.61 ± 3.01 to 49.30 ± 3.98%. Similar to reduction efficacy of *P. persimilis* and *A. swirskii* + *P. persimilis* on the population densities of movable stages, also the egg stage population was reduced significantly to zero after both treatments (Table 2). Likewise, the combined release of *A. swirskii* with *N. cucumeris* remarkably reduced the numerical densities of egg stage to 9.20 ± 1.52 individuals/leaf compared to 62.14 ± 3.99 individuals/leaf in control plot. The efficacy of *A. swirskii* + *N. cucumeris* did not differ significantly with *A. swirskii* + *C. negevi*. The less potent treatment was *A. swirskii* + AE; it reduced the numerical density of egg stage to 50.50 ± 3.75 individuals/leaf. Additionally, no significant difference was observed among *A. swirskii*, *C. negevi*, *N. cucumeris*, and AE treatments with reduction percentages ranging from 43.23 ± 5.9 to 53.64 ± 5.59%.

Table 2. Mean number and percent reduction of *T. urticae* movable and egg stages on pepper plant at the end of crop season.

Treatments	Movable stages		Egg stage	
	Mean number of prey/leaf (± SE)	%Reduction (± SE)	Mean number of prey/leaf (± SE)	%Reduction (± SE)
A. swirskii	43.61 ± 3.01c	72.64 ± 7.13c	29.20 ± 2.17c	52.81 ± 1.36c
C. negevi	64.04 ± 4.53b	50.32 ± 2.61e	34.41 ± 1.59c	43.23 ± 5.91c
N. cucumeris	49.30 ± 3.98c	61.34 ± 1.41d	32.16 ± 2.92c	46.29 ± 6.46c
AE	47.32 ± 3.22c	62.65 ± 2.53d	27.33 ± 2.49c	53.64 ± 5.59c
P. persimilis	0.00 ± 0.00e	100.00 ± 0.00a	0.00 ± 0.00e	100.00 ± 0.00a
A. swirskii* + *P. persimilis	0.00 ± 0.00e	100.00 ± 0.00a	0.00 ± 0.00e	100.00 ± 0.00a
A. swirskii* + *C. negevi	26.42 ± 2.24d	79.40 ± 0.68bc	13.13 ± 1.61d	79.05 ± 0.27b
A. swirskii* + *N. cucumeris	21.16 ± 3.68d	83.59 ± 0.14b	9.20 ± 1.52d	85.43 ± 0.89b
***A. swirskii* + AE**	70.23 ± 5.27b	45.14 ± 2.37e	50.50 ± 3.75b	14.87 ± 6.53d
Control	129.09 ± 4.93a	-	62.14 ± 3.99a	-
F-value	114.445*	49.016*	74.431*	48.927*

The values with different letters within the same column are significantly different ($P < 0.05$) (ANOVA) (Duncan test).
* = Highly significant

DISCUSSION

The present work aimed to evaluate the efficacy of two control strategies; four biological control agents separated and combined as well as a mixture of commercial pesticides (Actara and Egyxide) against *B. tabaci*, *T. tabaci*, and *T. urticae* pests on red delta star pepper cultivar. Our study showed that the predatory phytoseiid mites effectively suppressed the populations of studied pests. In addition, some tested bio-agents were comparable to or more potent than tested pesticides during growing season. Data in this work revealed that by the end of growing season, *A. swirskii* alone or combined with *N. cucumeris* and *C. negevi* treatments were significantly effective in reducing the population density of *B. tabaci* and *T. tabaci* on the studied cultivar. The same trend was observed by separated release of *N. cucumeris* and *C. negevi*, while the last treatment was the least potent on

T. tabaci. Although all treatments reduced the population of *T. urticae* in comparison to untreated plot, the treatments including *A. swirskii* performed better than others not including it. Similarly, it was reported that *B. tabaci* and thrips populations were significantly reduced on sweet pepper in response to release of *A. swirskii* (Calvo *et al.* 2012). Also, *A. swirskii* was found to feed and reproduce on *T. urticae* (Gerben *et al.* 2010; Xiao *et al.* 2012). Although all of them are generalist phytoseiid mites (McMurtry *et al.* 2013), their food preference, predation rate, as well as the relationship between them and their pests, along with climate conditions and plant architecture may explain the current result (Xu and Enkegaard 2010). It has been demonstrated that the presence of alternative prey for predators did not show a negative impact on the biological control, but rather improved it (Collyer 1964). In this study, different food sources for the predator might improve its survival. Therefore, control of *B. tabaci*, *T. tabaci*, and *T. urticae* with the same predator such as *A. swirskii* makes it a very interesting candidate as a new biological control agent. *Amblyseius swirskii* was reported as a predominant effective predator on a wide host range worldwide, and it was established in various crops including peppers, eggplants, and cucumber with no limited effects on *B. tabaci*, *T. tabaci*, and *T. urticae* pests (van Houten *et al.* 2007a; Messelink *et al.* 2010; Calvo *et al.* 2012, 2015; Mortazavi *et al.* 2019). In this study, *A. swirskii* performance on *T. urticae* could be related to the presence of more than one pest on the tested pepper cultivar; this result is in agreement with that reported previously (Messelink *et al.* 2008; Calvo *et al.* 2011). *Tetranychus urticae* produces heavy webbing that renders the predator to manage it, however in the presence of *Frankliniella occidentalis* and *Trialeurodes vaporariorum* insects, *A. swirskii* could manage *T. urticae* nearby webbing when consuming other pests (van Houten *et al.* 2007b; Messelink *et al.* 2010). Similar to our observation on the efficacy of *N. cucumeris* and *C. negevi* on all tested pests, a study by Gerson *et al*. (2003) who reported that *N. cucumeris* have been broadly used for the commercial biological control of various pest species especially thrips. On the other hand, *N. cucumeris* treatment recorded the lowest reduction percentage on *T. urticae* in eggplant cultivars (El-Saiedy *et al.* 2008). Also, in previous research *C. negevi* gave the lowest reduction percentage among tested predators on *T. urticae* in sweet pea cultivars (Kamel *et al.* 2018). Sometimes omnivorous predatory mites preferred insects over tetranychid mites (Muma 1971). It was found that some biological parameters of *C. negevi* on *T. urticae* eggs take long time, and *C. negevi* appeared to develop well on eggs of whiteflies more than eggs of scale insects and pollen (Momen 1999; Momen *et al*. 2009).

The result of the current study indicated that *A. swirskii* with *N. cucumeris* was more effective than *A. swirskii* treatment alone, while the last statistically did not differ with *C. negevi* on *T. urticae* movable stages. The efficacy of combined biological treatments is complex; it can sometimes be useful but not always. Intra-guild predation between *A. swirskii* and other predators such as *N. cucumeris* and *C. negevi*, was reported in previous studies (Buitenhuis *et al.* 2008; Momen *et al.* 2013), where *A. swirskii* preferred *N. cucumeris* immatures and *C. negevi* eggs more than *F. occidentalis* and whitefly. The opposite was observed by Momen and Abdel-Khalek (2021) who found that introducing *T. urticae* to *A. swirskii* decreased the predation of *N. barkeri* and *N. californicus* intra-guild preys. Interestingly, the present data showed that *P. persimilis* alone and with *A. swirskii* were the most potent treatments in reducing the population density of *T. urticae* movable and egg stages. However, *P. persimilis* alone had no role in controlling neither *B. tabaci* nor *T. tabaci* in the tested cultivar. *Phytoseius persimilis* has been known as a specialist and effective predatory mite for controlling all stages of *T. urticae*, and can reproduce highly, make race through the dense webbing, tolerate temperature and humidity changes in a wide scale of agricultural crop systems (McMurtry *et al.* 2013). As shown in the present study, the presence of *A. swirskii* with *P. persimilis* did not hinder its impact on *T. urticae*. Similar results were found for introducing mix of these predatory mites successfully to control *T. urticae* on cucumber and sweet pepper plants in green houses (van Houten *et al*. 2007b; Abou-Haidar *et al.* 2021). Regarding to the efficacy of pesticides (AE) treatment in this work, it was potent but still less than what was recorded by separated phytoseiid mite treatments on *B. tabaci*; whereas, it did not differ from *C. negevi* on *T. tabaci* and *T. urticae*.

However, AE combined with the release of *A. swirskii* remarkably increased the control activity against *B. tabaci* and *T. tabaci*. Similarly, it was observed that the number of *B. tabaci* adults/leaf was lower in the treatment involving pesticide applications prior to the release of *A. swirskii* (Calvo *et al.* 2009). It has been known that many pesticides are compatible with *A. swirskii* (Calvo *et al.* 2015), therefore allowing the simultaneous control of pests and diseases that are difficult to be controlled biologically. Egyxide is a commercial product that has been used as green pesticide in a previous study against *T. urticae* and sucking insect pests (Zidan *et al.* 2022). A previous study conducted by Shehawy *et al.* (2021) revealed that the highest reduction percentage of *B. tabaci* infesting tomato crop was recorded by *A. swirskii* followed by *C. negevi* and Vertemic + Egyxide mixture, whereas *N. cucumeris* and *N. californicus* have moderate reduction effects. Moreover, they performed a combination treatment and concluded that (*Typhlodromips swirskii* + Vertemic) exhibited considerable effects for *B. tabaci* management, followed by (*T. swirskii* + *C. negevi*), (*T. swirskii* + *N. cucumeris*) and (*T. swirskii* + *N. californicus*). Chemical control is considered as the primary strategy for IPM programs. It was reported that, Azadirachtin + Thiamethoxam significantly lowered the population of red spider mites/leaf on brinjal (Shejulpatil *et al.* 2019). Also, low lethal concentrations of thiamethoxam, imidacloprid, and acetamiprid showed no significant effects on developmental time of immature stages of *N. californicus* and pre-adult duration of *N. fallacis* predatory mites (Villanueva Walgenbach 2005; Havasi *et al.* 2020). Likewise, four active neonicotinoids ingredients including thiamethoxam reduced the number of deposited eggs laid by treated *T. urticae* females (Ako *et al.* 2004). On the contrary, a negative effect was observed on *T. urticae* and *P. persimilis* after imidacloprid and thiamethoxam applications (Pozzebon *et al.* 2011). Low concentrations of pesticide can be used in combination with predatory mites in IPM programs (Dent 2000). The differences in the efficacy of pesticide treatments may be due to the variation of sensitivity and resistance of the pest or its predator to pesticides, which lead to a decrease or increase of densities.

CONCLUSION

In conclusion, *A. swirskii* showed a remarkable controlling efficacy against *B. tabaci*, *T. tabaci*, and *T. urticae* on red delta star pepper cultivar. Furthermore, predatory mites; *N. cucumeris* and *P. persimilis* were also most effective against *T. tabaci* and *T. urticae*, respectively. We observed that all combined treatments including *A. swirskii* as a shared predator, significantly reduced the populations of the three tested pests on tested cultivar. Our results suggest that the biological control of *B. tabaci*, *T. tabaci*, and *T. urticae* can be improved with a generalist predatory mite such as *A. swirskii*. Also, the compatibility of *A. swirskii* with other treatments encourages their combined application for controlling more than one pest simultaneously.

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اثربخشی کنه‌های فیتوزئید و آفت‌کش‌ها در کنترل *Bemisia tabaci*، *Thrips tabaci* و *Tetranychus urticae* روی *Capsicum annuum*

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چکیده

چهار کنهٔ شکارگر شامل *Amblyseius swirskii*، *Cydnoseius negevi*، *Neoseiulus cucumeris* و *Phytoseiulus persimilis* و همچنین مخلوطی از آفت‌کش‌های تجاری به نام های Actara® و Egyxide® (روغن گیاهی امولسیون شده) برای مدیریت جمعیت *Bemisia tabacii*، *Thrips tabaci* و *Tetranychus urticae* روی فلفل رقم ستاره دلتا قرمز *Capsicum annuum* استفاده شد. تمام تیمارها به طور جداگانه و به صورت ترکیبی روی رقم فلفل رشد کرده در یک تونل توری پلاستیکی مرتفع انجام شدند. نتایج نشان داد که *A. swirskii* به طور جداگانه یا همراه با سایر تیمارها به میزان زیادی جمعیت *B. tabaci* و *T. tabaci* را به ترتیب به ۰،۰۰ و ۰/۰٤–۲/۱۰ فرد در برگ محدود کرد. *Cydnoseius negevi* و *N. cucumeris* به میزان زیادی جمعیت *B. tabaci* را کاهش دادند. با این حال، دومی در برابر *T. tabaci* موثرترین بود. تراکم عددی مراحل متحرک و تخم *T. urticae* توسط *P. persimilis* به تنهایی یا همراه با *A. swirskii* به میزان زیادی کاهش یافت و به دنبال آن رهاسازی *A. swirskii* با *N. cucumeris* به ۰/۰۰ فرد در برگ رسید. موثرترین تیمارهای *T. tabaci* با درصد کاهش از ۹٤/۵۳٪ تا ۱۰۰٪ عبارت بودند از *A. swirskii*، *N. cucumeris* و تمام تیمارهای ترکیبی. تیمارهای با آفت‌کش‌ها، *C. negevi* و *A. swirskii* + آفت‌کش‌ها به ترتیب عملکرد کمتری در کنترل *B. tabaci*، *T. tabaci* و *T. urticae* نشان دادند. یافته‌های این پژوهش نشان داد که عوامل زیستی به کار رفته کارآمد بوده و گنجاندن *A. swirskii* در برنامه‌های مدیریت تلفیقی آفات برای کنترل *B. tabaci*، *T. tabaci* و *T. urticae* بر روی این رقم فلفل توصیه می‌شود.

واژگان کلیدی: *Amblyseius swirskii*؛ مهار زیستی؛ *Cydnoseius negevi*؛ *Neoseiulus cucumeris*؛ مدیریت آفات؛ *Phytoseiulus persimilis*.

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