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Article

Efficacy of *Amblyseius swirskii*, *Neoseiulus californicus* (Acari: Phytoseiidae), and acaricides in controlling some pests on sweet pepper in greenhouses

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ABSTRACT

In Egypt, serious piercing-sucking pests such as the western flower thrips, *Frankliniella occidentalis*, white fly, *Bemisia tabaci*, the broad mite, *Polyphagotarsonemus latus*, and the two-spotted spider mite, *Tetranychus urticae* cause significant yield losses in sweet pepper crop grown in greenhouses. The purpose of this research is to assess the effectiveness of two phytoseiid mites, *Amblyseius swirskii* and *Neoseiulus californicus*, as biological control agents for piercing-sucking pests on sweet pepper in greenhouses, compared with chemical acaricides. Three release rates were assessed: 10 adults of *A. swirskii*/plant, 10 adults of *N. californicus*/plant, and 7 adults of *A. swirskii* + 7 adults of *N. californicus* combined. The highest population density of *B. tabaci* and *F. occidentalis* was on yellow 'Qiuda' followed by significant damage with *T. urticae*. Red 'Grand bell', on the contrary, was consistently more susceptible to *T. urticae* and moderately prone to whitefly infestation. Both biological and chemical pest control were efficient in reducing pest populations on sweet pepper in greenhouses. The results indicated that *A. swirskii*, alone or in combination with *N. californicus*, was more effective against *F. occidentalis*, *B. tabaci*, and *P. latus* on both pepper cultivars than acaricides sprayed under the same conditions. Moreover, the predatory mite, *N. californicus*, outperformed *A. swirskii* and acaricides against *T. urticae*. Together, the predatory mites, *A. swirskii* and *N. californicus* can improve biological control of piercing-sucking pests. The yield increased by 37.4 to 40.0% over the control treatment using the biological control candidates. Furthermore, biological control program resulted in the highest cost reductions for sweet pepper production (35.7–40.7 and 16.2–27.2%) compared to the control and acaricides treatments, as well as a safe yield free of chemical residues.

KEYWORDS: Biological control, broad mite, IPM, phytoseiid mites, spider mite, thrips, whitefly.

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INTRODUCTION

Sweet pepper, *Capsicum annuum* L. (Solanaceae), is one of the important economic vegetable crops worldwide, due to the nutritional content of its fruits and its economic significance (Howard *et al.* 2000).

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In Egypt, sweet pepper crops are attacked by several piercing-sucking pests causing significant yield losses due to malformation of leaves, flower and fruits under protected cultivation, e.g., the western flower thrips, *Frankliniella occidentalis* Pergande (Thripidae); white fly, *Bemisia tabaci* (Gennadius) (Aleyrodidae); the broad mite, *Polyphagotarsonemus latus* (Banks) (Tarsonemidae); and the two-spotted spider mite, *Tetranychus urticae* Koch (Tetranychidae) (Ellaithy *et al.* 2015; Ibrahim 2017; Sanad and Hassan 2019). Both nymphs and adults of such pests feed on the cell sap of the pepper leaves and delicate portions, causing aging prematurely.

Frankliniella occidentalis is one of the more dangerous polyphagous and widespread insect pests, causing noticeable harm and severe effects on the flowers and fruits of over 200 host plants (Yang *et al.* 2015). Because it lays the eggs inside plant tissues and feeds in more hidden sites like flower buds, where it is shielded from insecticide effects, it is challenging to control it using insecticides (Brodsgaard 2004). It is a primary pest of sweet peppers infesting flowers, feeding on pollen and leaves.

Bemisia tabaci is also a serious pest on vegetables in greenhouses causing great damages by feeding and transmitting viruses, due to its pesticide resistance and effectiveness as a vector for many plant viruses (Gerling 1990). *Bemisia tabaci* causes economic damage ranging from minor to devastating, with yearly worldwide losses in several crops exceeding billions of dollars (Hasan *et al.* 2019).

Polyphagotarsonemus latus is a serious mite pest of greenhouse crops like pepper, cucumber, and eggplant; attacking young, growing parts and causing lower fruit weight in young plants (Gerson 1992; Weintraub 2003; Jovicich *et al.* 2009). *Tetranychus urticae* is one of the most important mite pests feeding on about 1161 host plant species worldwide including vegetables, fruits, crops, and ornamentals (Migeon and Dorkeld 2023). Spider mite density should not exceed three mobile stages per leaf; they can rapidly grow and cause significant economic damages (yield losses reach 90%) (Warabieda 2015).

Biological control is a key component of environmentally sustainable integrated crop protection systems. The benefits of local natural enemies and controlling pests prone to pesticide resistance with low-cost sustainable treatments and minimal risks to the environment are the main advantages of such an approach.

Phytoseiid mites are widely used in biological control operations to eradicate pests of field crops and greenhouse plants around the world (Hajiqanbar and Farazmand 2021). Highly effective biological control agents for thrips, whiteflies, broad mites, and spider mites have been described for ornamental plants and vegetable crops, e.g., *Amblyseius swirskii* Athias-Henriot, *Neoseiulus californicus* (McGregor), *N. barkeri* Hughes, and *N. cucumeris* (Oudemans) (Fan and Petitt 1994; Weintraub *et al.* 2003; Calvo *et al.* 2009, 2011; van Maanen *et al.* 2010; Yari *et al*. 2023).

The generalist predatory mite, *A. swirskii* is a primary agent used in the biocontrol of thrips larvae and whitefly eggs and crawlers in sweet pepper crops (van Maanen *et al.* 2010; Barghout *et al.* 2022; Perera and Senanayake 2023). This mite is frequently used in biological control strategies for ornamental and vegetable crops (solanaceous and cucurbit). The efficacy of *A. swirskii* population management of sucking pests in commercial paper production in greenhouses in Egypt is rare.

Neoseiulus californicus is one of the major and selective predators that feed on many species of tetranychids [type II according to McMurtry *et al.* (2013)]. It is an economical biological control candidate for phytophagous mites and insect pests in many countries worldwide in the integrated pest management (IPM) programs (Hoddle *et al.* 2000; Rhodes and Liburd 2006; Monteiro *et al.* 2008; Jovicich *et al.* 2009; Ibrahim *et al.* 2010; Farazmand *et al*. 2012; El-Saiedy and Fahim 2021). Thus, the objective of the present study is to evaluate the release rates of two phytoseiid mites, *A. swirskii* and *N. californicus* in controlling piercing-sucking pests on two sweet pepper cultivars in greenhouses.

MATERIAL AND METHODS

Experimental site

Experiments were carried out at Ghita village (31° 31' 51.33" E, 30° 22' 20.43" N), Bilbis district, Sharkia governorate, Egypt, during 2022/2023, under natural infestation conditions. Daily temperature (°C) and relative humidity (%) were obtained from the Central Laboratory for Agriculture Climate, Dokii, Giza, Egypt.

Source of predatory mites

Both predatory mites, *A. swirskii* and *N. californicus* colonies were collected from sweet pepper plants at Ghita village, Bilbis district, Sharkia governorate, Egypt on March 2021. The colonies of *N. californicus* were reared in plastic pots planted with *Phaseolus vulgaris* (L.) (Fabaceae) infested with *T. urticae*. The mass-rearing method followed that of Ibrahim *et al.* (2010). However, *A. swirskii* was reared and maintained on *Carpoglyphus lactis* (L.) (Carpoglyphidae) and *Tyrophagus putrescentiae* (Schrank) (Acaridae) as a food source in an environmental chamber at 25 ± 2 °C and 65 ± 5% RH and photoperiod of L16:D8 h according to Elhalawany *et al.* (2023).

Acaricide/Insecticide used

Three acaricides were used in the current study, Abamectin (Gold 1.8% EC) at the rate of 450 ml per ha, Chlorfenapyr (Challenger Super 24% SC) at the rate of 600 ml per ha, and Spirodiclofen (Concor 24% SC) at rate of 300 ml per ha. The three acaricides had 17 applications during the experiment (Table 1).

Experimental design and sampling

After a month and half of germination, the two sweet pepper cultivars: red ‘Grand bell’ and yellow ‘Qiuda’ seedlings were transplanted to one acre of net greenhouse. The two net greenhouses were planted with 1350 sweet pepper seedlings on 15 August 2022. Each variety was planted in a separate greenhouse. The experimental area for each sweet paper variety consisted of five equal plots of 100 m^2 (5 × 20 m) each. Each plot contained three double row beds of sweet pepper, where each bed contained 100 plants (totally 270 plants/plot). The experiments were arranged in a randomized complete block design (RCBD) with three replications. To avoid pest transmission between plots, each plot was completely separated using a vertical polyethylene sheet. The growing season extended from August 2022 to June 2023. Plants were fertilized and irrigated by a drip irrigation system. The recommended agricultural process was performed.

The two predatory mites were released three times after plantation (four, eight, and 16 weeks). This experiment had five treatments with three replicates each: T1 (10 adults of *A. swirskii*/plant), T2 (10 adults of *N. californicus*/plant), T3 (7 adults of *A. swirskii* + 7 adults of *N. californicus* combined), T4 (Abamectin/Chlorfenapyr or Spirodiclofen), and T5 (untreated plot served as control). The infestation by pests occurred naturally. Release of two predatory mites was done using 100 ml plastic bottles that contained predatory mites and carrier (a mixture of wheat bran and vermiculate material by 1:1 ratio). In each greenhouse, the application of acaricides/pesticides on the two sweet paper cultivars was alternated biweekly.

Plants were monitored at weekly intervals for 43 weeks after plantation, beginning on 22 August 2022. Population densities of the targeted pests, *F. occidentalis*, *B. tabaci*, *P. latus*, and *T. urticae* were estimated weekly throughout the plant growing season. Thirty randomly selected leaves and 10 randomly selected flowers from each treatment were picked from the top, middle, and bottom levels of the plant. Samples were maintained in coolers and brought to the laboratory for inspection using a stereo-microscope (BS-3030B, China). All motile stages of each pest found on sweet pepper leaves were counted along with the number of two predatory mites.

At the end of the growing season, the sweet pepper production yields from the two greenhouses were calculated. Additionally, cost-benefit analyses of the outcomes of applying biological and chemical control were conducted (EL-Halawany *et al.* 2000; Adly 2015; El Arnaouty *et al.* 2020) as follows: Cost-benefit = costs of yield production − control costs. The reduction percentage in yield was calculated according to Abbott's formula (1925) as follows: Reduction % = 100 × [(Ta-Tc)/ Ta] where: Ta = total yield in biological treatment, Tc = total yield in control (untreated) treatment.

Statistical analysis

The effects of the predatory mites on thrips, whitefly, broad mite, and spider mite populations were compared to the pest populations in the control greenhouses on the mean week until the end of the experiment after 43 weeks. Reduction percentages were calculated according to Henderson and Tilton (1955) as follows:

Reduction % = 1 − (Number of pests in control before application × Number of pests in treatment after application)/(Number of pests in control after application × Number of pests in treatment before application) × 100.

For each cultivar, the overall mean of percent reduction of sucking-pests (during the period from the first sample after treatment to the last sample of the study, the weekly values of percent reduction of mite were averaged over this period to obtain the overall mean of reduction percentages of sucking-pests on each treatment) were also calculated at the end of study. The obtained results in this study were statistically analyzed using (SAS Institute 2003) software. Two-way analysis of variance (ANOVA) was performed and the differences among the means were uncovered using Tukey's HSD test at α = 0.05.

RESULTS

Weather conditions

The mean weekly temperature varied from 16.2 to 29.9 °C. The minimum and maximum temperatures varied in the range of 8.7–25.6 and 16.2–34.9 °C, respectively. The average relative humidity ranged from 41.7 to 66.9% (Fig. 1). The three acaricides (Gold 1.8% EC, Challenger Super 24% SC, and Concor 24% SC) were applied alternately biweekly in the current study 17 times for control piercing-sucking pests on the two sweet pepper cultivars. In the biological control trend, the two predatory mites *A. swirskii* and *N. californicus* were released three times on the 4th, 8th and 16th weeks after cultivation (Table 1).

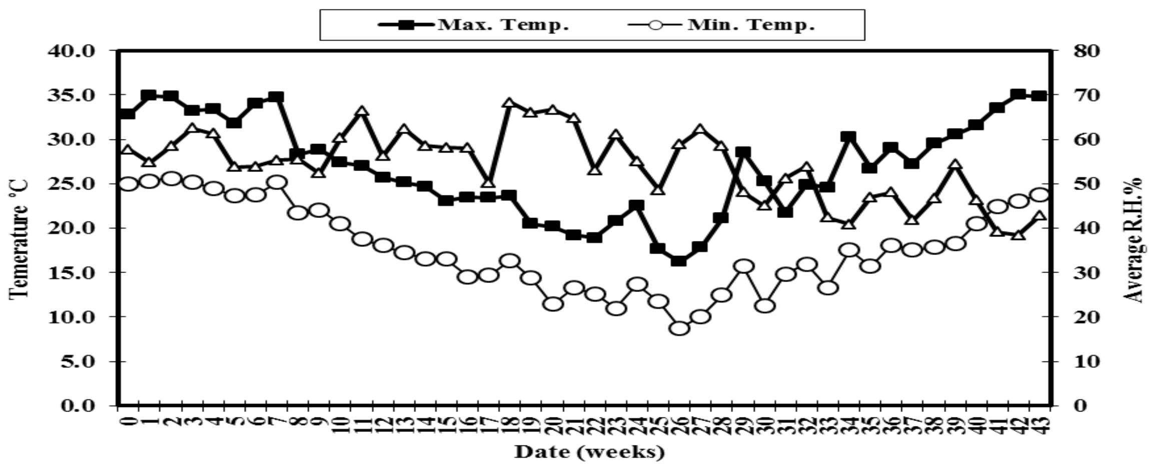


Figure 1. Minimum and maximum temperatures (°C) and mean relative humidity (%) per week from mid-Aug. 2022 until 12th June 2023 under IPM conditions in greenhouses.

Table 1. Release date of two predatory mites, *Amblyseius swirskii* and *Neoseiulus californicus* and three acaricides on sweet pepper in greenhouses.

Week	Date	Predatory mite	Rate	Acaricides	Rate
4	12 Sep. 2022	*A. swirskii* *N. californicus* *A. swirskii* + *N. californicus*	10 pred./plant 10 pred./plant 7 + 7 pred./plant	Abamectin	40 ml^{-100L}
6				Chlorfenapyr	60 ml^{-100L}
8	10 Oct. 2022	*A. swirskii* *N. californicus* *A. swirskii* + *N. californicus*	10 pred./plant 10 pred./plant 7 + 7 pred./plant	Spirodiclofen	30 ml^{-100L}
10				Abamectin	40 ml^{-100L}
12	7 Nov. 2022	–		Chlorfenapyr	60 ml^{-100L}
14				Spirodiclofen	30 ml^{-100L}
16	5 Dec. 2022	*A. swirskii* *N. californicus* *A. swirskii* + *N. californicus*	10 pred./plant 10 pred./plant 7 + 7 pred./plant	Abamectin	40 ml^{-100L}
18				Chlorfenapyr	60 ml^{-100L}
20	2 Jan. 2023	–		Spirodiclofen	30 ml^{-100L}
22				Abamectin	40 ml^{-100L}
24	30 Jan. 2023	–		Chlorfenapyr	60 ml^{-100L}
26				Spirodiclofen	30 ml^{-100L}
28	27 Feb. 2023	–		Abamectin	40 ml^{-100L}
30				Chlorfenapyr	60 ml^{-100L}
32	27 Mar 2023	–		Spirodiclofen	30 ml^{-100L}
34				Abamectin	40 ml^{-100L}
36	24 Apr. 2023	–		Chlorfenapyr	60 ml^{-100L}

Thrips management

Frankliniella occidentalis population remained significantly lower in all treatments where predatory mites were released and acaricides applied than in the control treatment (Fig. 2). The population appeared on leaves and flowers of the two pepper cultivars after eight weeks of cultivation (Oct. 10, 2022). Then, the thrips gradually increased in number and reached its highest in late December "16 weeks (Dec. 26, 2022)" and late May "40 weeks (May 22, 2023)" (15.4 and 42.0 individuals/leaf on yellow 'Qiuda', respectively). Red 'Grand bell' it had one peak in late May "40 weeks (May 22, 2023)" (recorded 36.5 individuals/leaf in control) (Fig. 2).

The population density of *F. occidentalis* on 'Qiuda' and 'Grand bell' pepper differed significantly after application than in the control treatment during 43 weeks. The biweekly treatment of acaricides significantly decreased the population of *F. occidentalis* immediately, and then the population increased gradually during the season. It was observed after six weeks of release that the two predatory mites, *A. swirskii* and *N. californicus*, and their combination exhibited a similar significant efficacy on *F. occidentalis* control compared to control treatment until the end of experiment. The mean numbers of thrips per pepper leaf and flower in biological control treatment and acaricides were significantly lower than in the control treatment ($F = 57.72$, $P < 0.0001$; $F = 54.28$, $P = 0.001$; on 'Qiuda' and 'Grand bell' pepper, respectively).

Whitefly management

Few *B. tabaci* appeared in the first week post cultivation August 22, 2022, then increased gradually to reach its peak in the "15 weeks (Nov. 28, 2022)"and "29 weeks (Mar. 6, 2023)" on 'Qiuda' (17.2 and 24.5 individuals/leaf in control). However, on 'Grand bell', the population was

(8.8 and 9.0 individuals/leaf), in the "18 weeks (Dec. 19, 2022)" and "26 weeks (Feb. 13, 2023)" (Fig. 3).

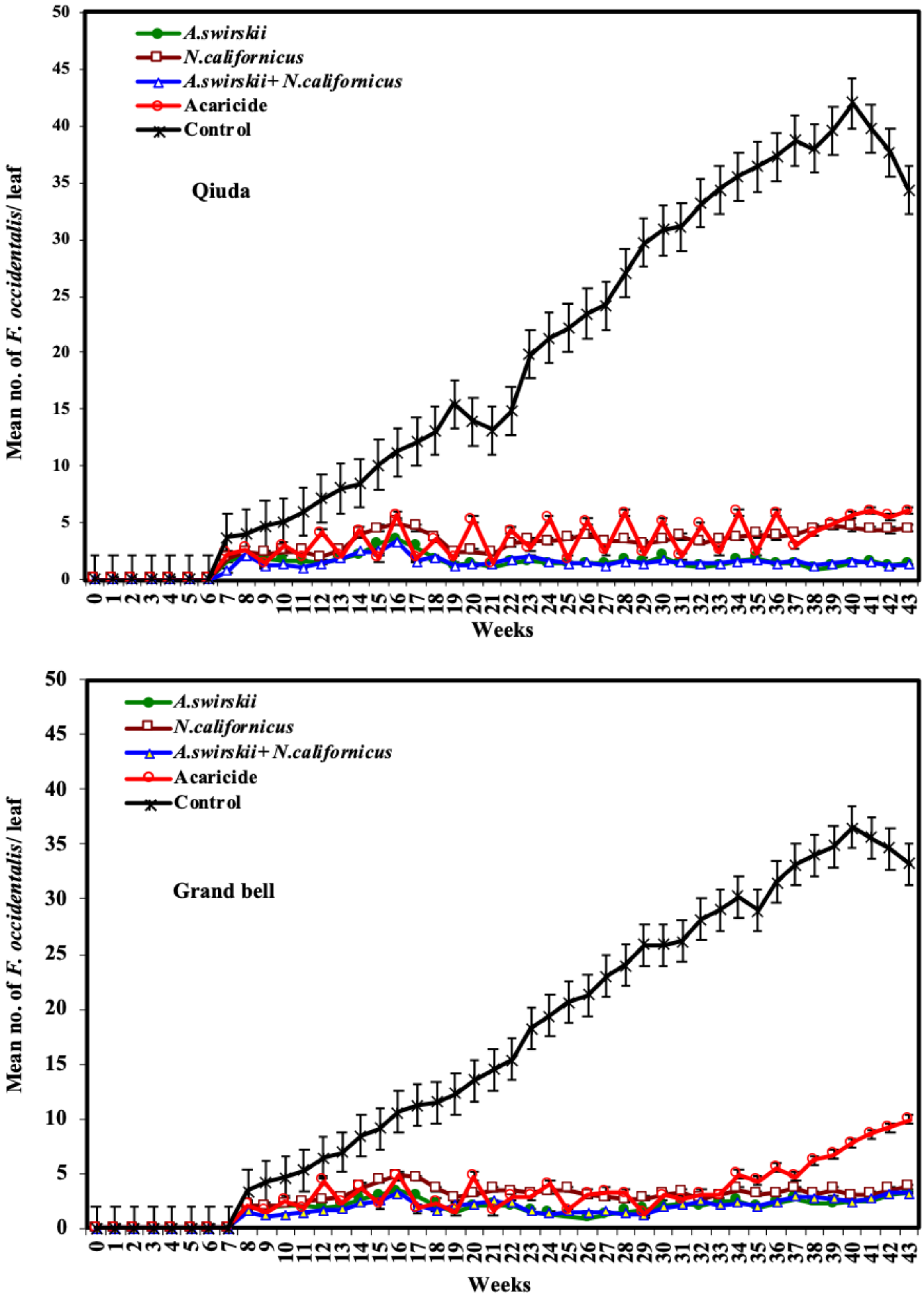


Figure 2. Mean numbers/leaf (± SE) of *Frankliniella occidentalis* motile stages recorded weekly after application on red 'Grand bell' and yellow 'Qiuda' pepper at Sharkia governorate, Egypt during 2022–2023.

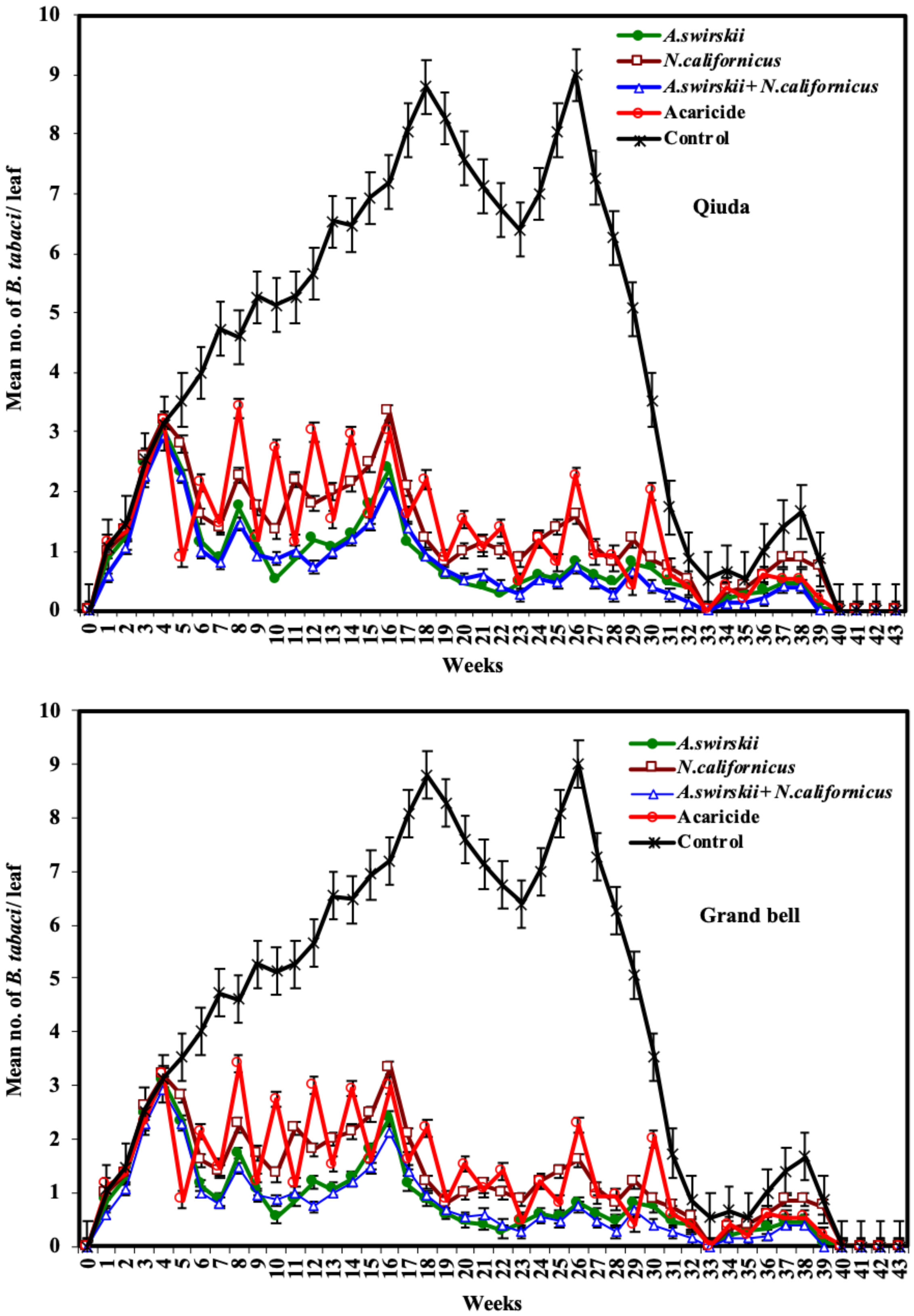


Figure 3. Mean numbers/leaf (± SE) of *Bemisia tabaci* motile stages recorded weekly after application on red 'Grand bell' and yellow 'Qiuda' pepper at Sharkia governorate, Egypt during 2022–2023.

The two predatory mites release and acaricides treatments significantly decreased *B. tabaci* population than in the control treatment. The mean numbers were 1.0, 1.7, 0.9, and 1.9 individuals/leaf on 'Qiuda' pepper, and 0.8, 1.2, 0.7, and 1.2 individuals/leaf on 'Grand bell' respectively for *A. swirskii*, *N. californicus*, *A. swirskii* + *N. californicus* combined, and acaricides compared with 10.4 and 4.1 in the control (Table 2). There were significant differences among the population of *B. tabaci* in the biological and chemical control treatments compared with control ($F = 54.24$, $P_{0.05} = 0.0001$ and $F = 38.66$, $P_{0.05} = 0.0001$ on 'Qiuda' and 'Grand bell' pepper, respectively). It was clear that all treatments exhibited similar effects during the 43 weeks; both predatory mites significantly reduced the population of *B. tabaci* on both tested cultivars.

Table 2. Yield production and cost benefits of sweet pepper after using predatory mites and acaricides for controlling some piercing-sucking pests in greenhouses.

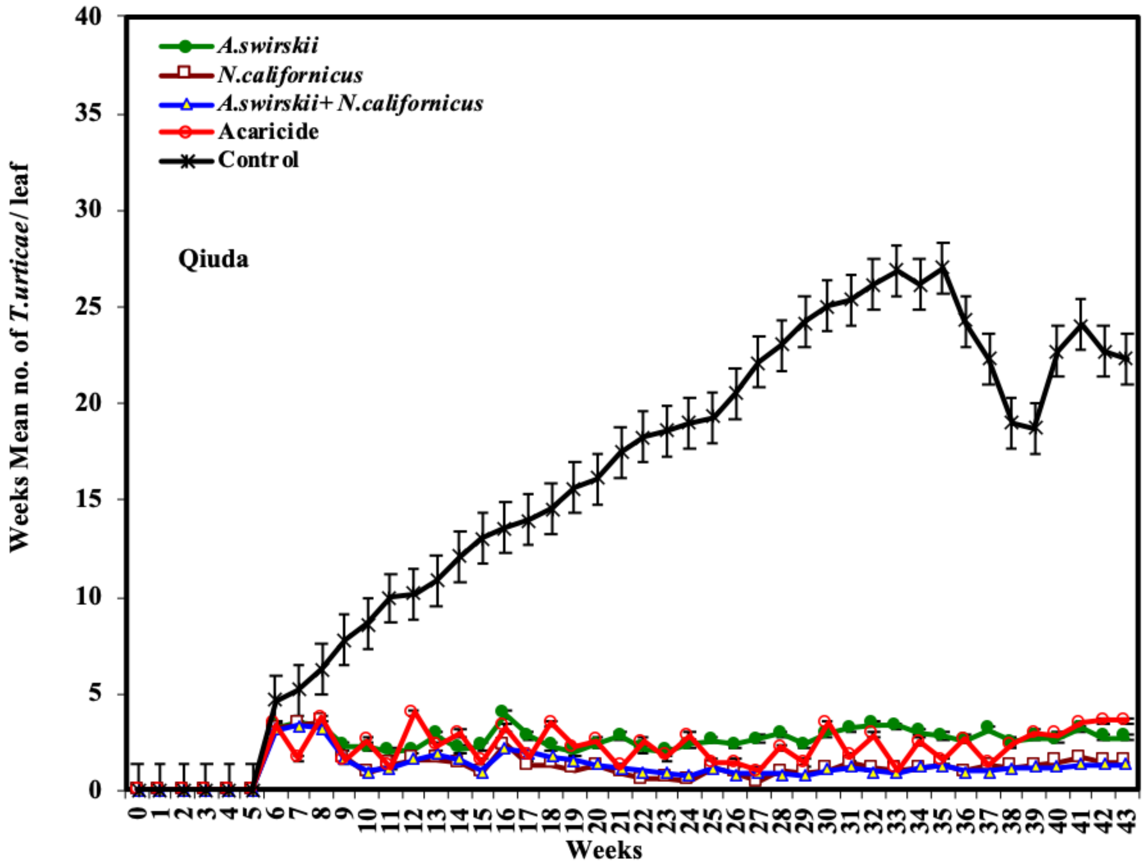
Treatments	Yield/treatment (Kg)	Yield price (LE)	Control cost (LE)	Cost benefits (LE)	Increase yield (%)
Qiuda cultivar					
A. swirskii	1104.03	22080.6	405	21675.6	37.5
N. californicus	1119.74	22394.7	405	21989.7	38.4
A. swirskii + *N. californicus*	1099.76	21995.1	567	21428.1	37.3
Acaricides	803.61	16072.2	472.5	15599.7	14.2
Control	689.09	13781.7	-	13781.7	-
Grand bell cultivar					
A. swirskii	1058.90	21177.9	405	20772.9	40.0
N. californicus	1054.35	21087	405	20682.0	39.7
A. swirskii + *N. californicus*	1049.31	20986.2	567	20419.2	39.4
Acaricides	921.56	18431.1	472.5	17958.6	31.1
Control	635.04	12700.8	-	12700.8	-

The two-spotted spider mite management

As shown in (Fig. 4), at the beginning of the experiment, the mean number of *T. urticae* per leaf was similar in all treatments. In the control, the number of *T. urticae* increased in "6 weeks (Sep. 26, 2022)" on 'Qiuda' and in the "7 weeks (Oct. 3, 2022)" on 'Grand bell' and continued until the end of the season. Then, the population density increased gradually and reached the highest (27.7 and 24.1 individuals/leaf) at the "35 weeks (Apr. 17, 2023)" and "41 weeks (May 29, 2023)" on 'Qiuda', while on 'Grand bell' it was 33.1 individuals/leaf in the "34 weeks (Apr. 10, 2023)". There were significant differences among the population of *T. urticae* in the biological and chemical control compared with control ($F = 104.8$, $P_{0.05} = 0.0001$ and $F = 105.2$, $P_{0.05} = 0.0001$ on 'Qiuda' and 'Grand bell' pepper, respectively).

Broad mite management

In all treatments, the broad mite appeared in the "4 weeks (Sep. 12, 2022)" with low numbers. In control, the population had two peaks in "11 weeks (Oct. 31, 2022)" and "32 weeks (Mar. 27, 2023)" on the two pepper cultivars and gradually declined thereafter. Sweet pepper plants in the control had significantly more mites than those treated with acaricides and predatory mites ($F = 15.62$, $P = 0.0001$) on 'Qiuda' and ($F = 13.07$, $P = 0.0001$) on 'Grand bell'. The acaricides treatment always caused a rapid decline in broad mite population after application. The release of predatory mites and acaricides resulted in successful control of broad mites on leaves and flowers and reduced the density significantly until the end of the experiment (Fig. 5).



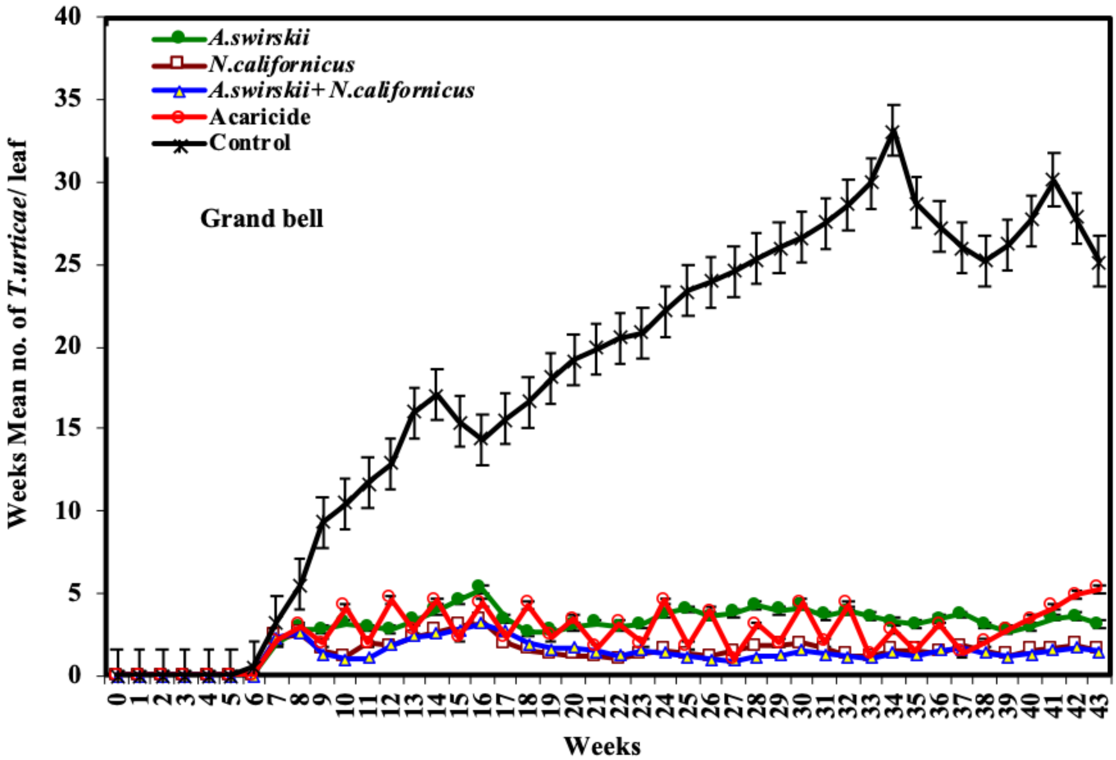
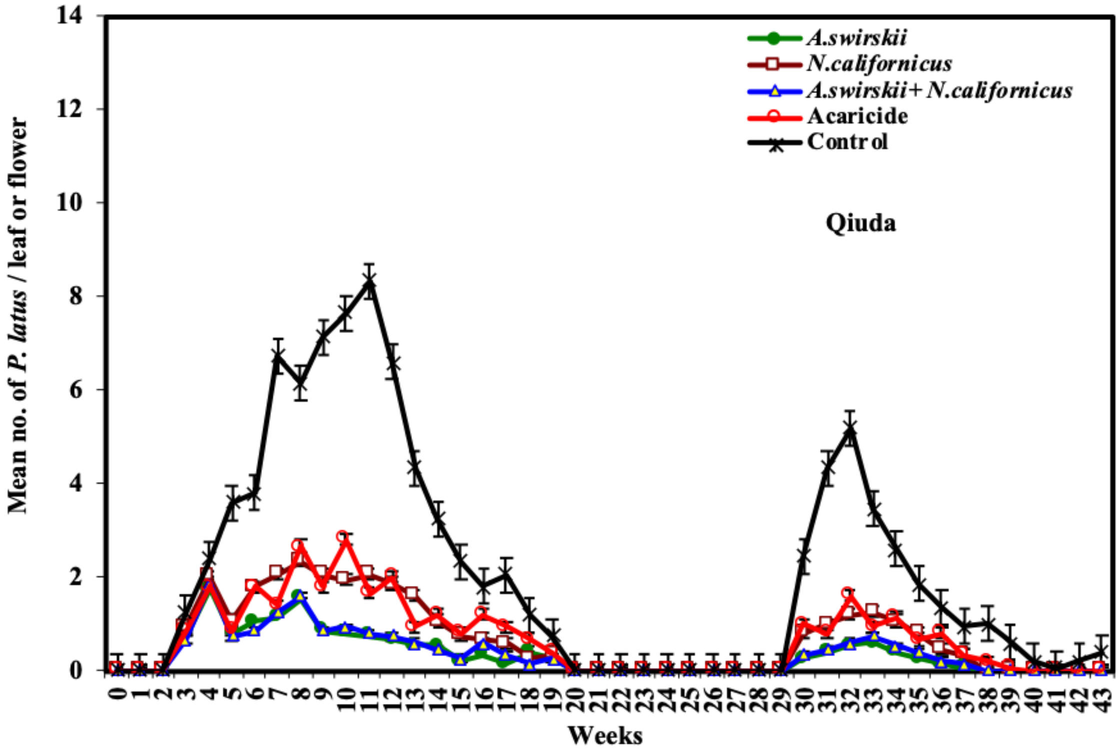


Figure 4. Mean numbers/leaf (± SE) of *Tetranychus urticae* motile stages recorded weekly after application on red 'Grand bell' and yellow 'Qiuda' pepper at Sharkia governorate, Egypt during 2022–2023.



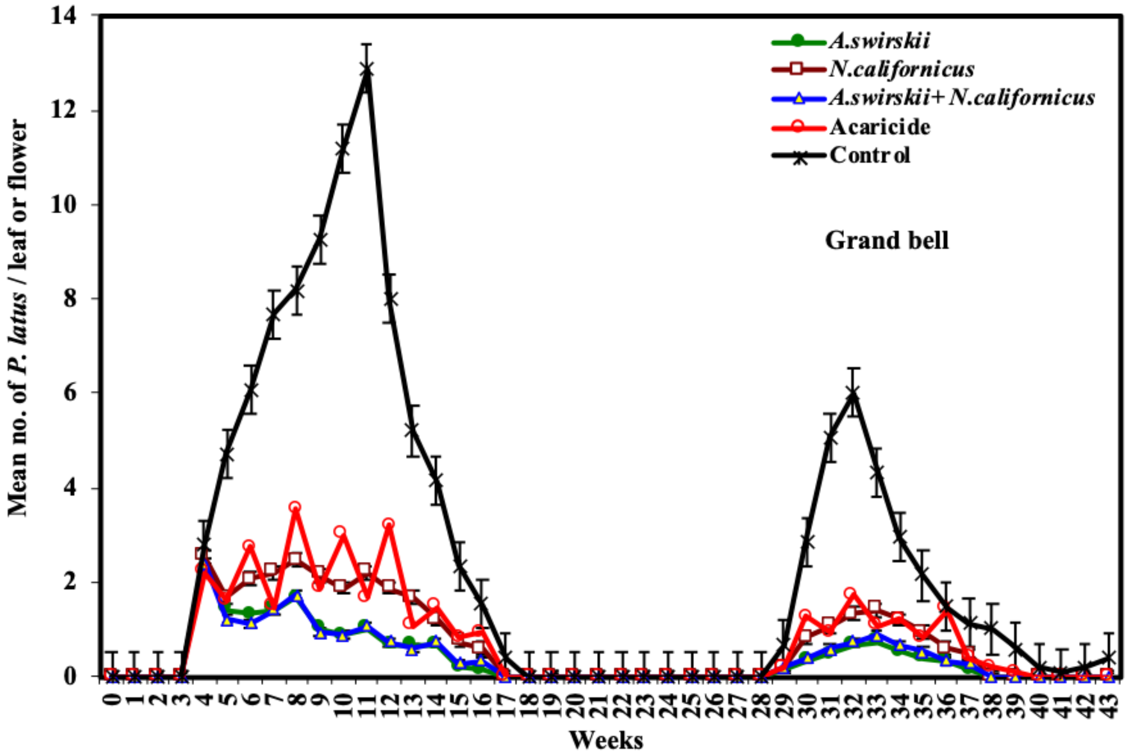
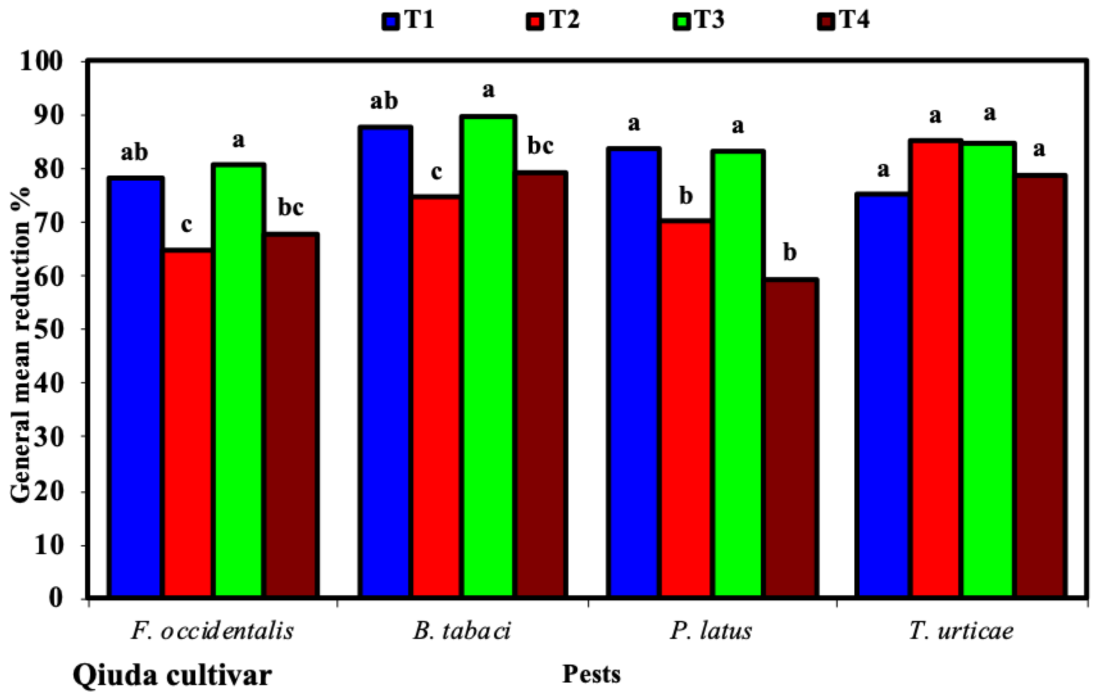


Figure 5. Mean numbers/leaf (± SE) of *Polyphagotarsonemus latus* motile stages recorded weekly after application on red 'Grand bell' and yellow 'Qiuda' pepper at Sharkia governorate, Egypt during 2022–2023.

Overall reduction percentage

In two pepper cultivars, the statistical analysis showed that the overall mean of reduction percentages of *F. occidentalis* varied significantly among treatments (F = 5.20, $P_{0.05}$ = 0.0020; F =

2.5, $P_{0.05}$ = 0.0624). The highest value was recorded with *A. swirskii* + *N. californicus* combined and *A. swirskii* alone, however, the lowest was recorded with *N. californicus* and acaricides treatments with no significant difference in each cultivar (Fig. 6).



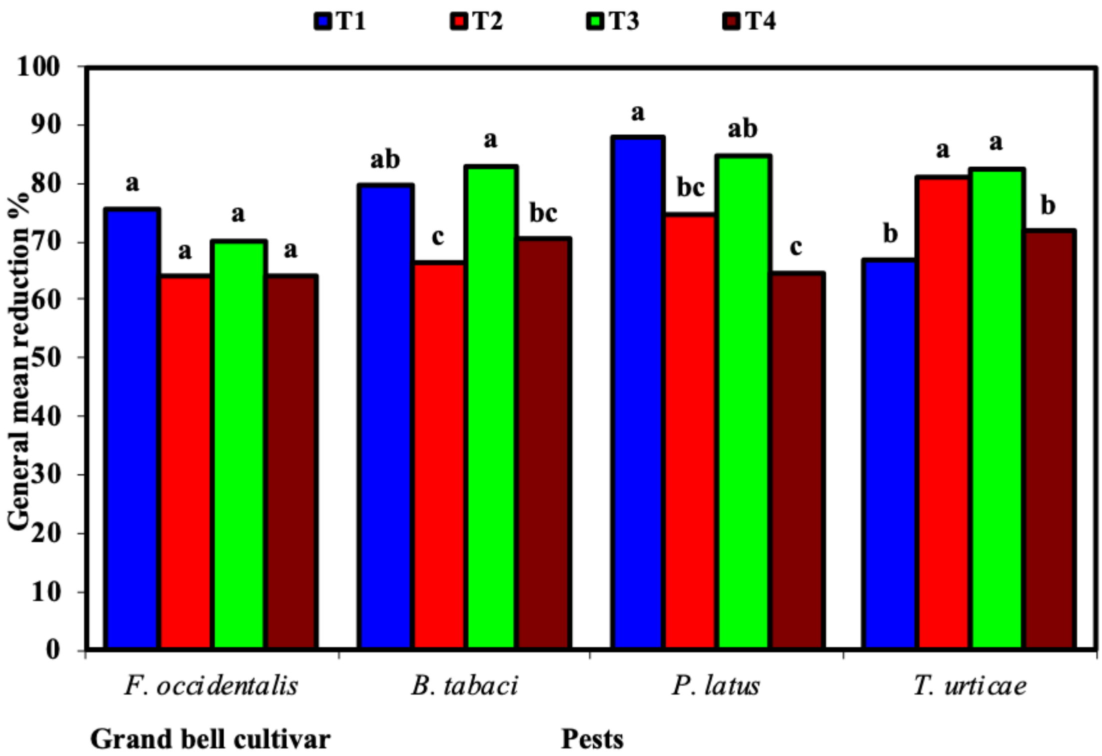


Figure 6. Reduction percentages of *Frankliniella occidentalis*, *Bemisia tabaci*, *Polyphagotarsonemus latus*, and *Tetranychus urticae* after 43 weeks of application on yellow 'Qiuda' and red 'Grand bell' pepper at Sharkia governorate, Egypt during 2022–2023. The same letter above column shows values are not significantly different, according to Tukey's HSD test at α = 0.05; T1 = *A. swirskii*, T2 = *N. californicus*, T3 = *A. swirskii* + *N. californicus*, T4 = acaricides.

It can be noticed that the reduction percentage of *B. tabaci* population on the two pepper cultivars varied in all treatments. The overall mean reduction percentages caused by *A. swirskii* alone and *A. swirskii* + *N. californicus* combined were 87.7 and 89.9% on 'Qiuda'; and 79.6 and 83.0% on 'Grand bell', respectively, with no significant differences, especially between *N. californicus* and acaricides treatments on each cultivar (Fig. 6).

The highest reduction percentage of *P. latus* was 83.6 and 83.3% for *A. swirskii* alone and *A. swirskii* + *N. californicus* combined on 'Qiuda', at the end of season, while the lowest (59.6%) was for acaricides with significant differences ($F = 12.03$, $P_{0.05} = 0.0001$). A similar result was recorded on 'Grand bell' with significant differences ($F = 10.37$, $P_{0.05} = 0.0001$) (Fig. 6).

The overall mean of reduction percentages of *T. urticae* caused by *N. californicus* and *A. swirskii* + *N. californicus* combined on the two pepper cultivars varied significantly among treatments ($F = 2.67$, $P_{0.05} = 0.0500$; $F = 12.79$, $P_{0.05} = 0.0001$). The lowest reduction percentage was recorded at the end of season after release of *A. swirskii* (75.1 and 66.8%) on 'Qiuda' and 'Grand bell', respectively (Fig. 6).

Pest control costs

The total cost of purchasing predators and chemical acaricides in both pepper cultivars was similar. The cost of releasing both *A. swirskii* and *N. californicus* is 405 LE per treatment, 567 LE for *A. swirskii* + *N. californicus* combined, and 472.5 for three acaricide applications 17 times (Table 2).

Cost benefits

The economic benefits of applying biological control (*A. swirskii*, *N. californicus*, and *A. swirskii* + *N. californicus* combined) on 'Qiuda' pepper were higher (31.6, 37.3, and 35.6%, respectively) than in the control treatment. These values were (38.8, 42.2, and 40.7%, respectively) on 'Grand bell' pepper. However, the cost benefits were (28.0, 29.0, and 27.2%, respectively) on 'Qiuda' pepper, higher than using acaricides. While those on 'Grand bell' pepper were (13.5, 18.3, and 16.2%, respectively) higher than acaricides; attaining a safe yield free of any residues was also a priority (Table 2).

Sweet pepper yield

When biological control agents were used, the highest yield production increase of 'Quida' pepper ranged from (37.3 to 38.4%) than in the control, while that of 'Grand bell' pepper ranged from (39.4 to 40.0%). Acaricide application increased yield from 14.2 to 31.1% compared to the control for 'Qiuda' and 'Grand bell' pepper (Table 2).

DISCUSSION

A few phytoseiid mite species have been released to control some of the most significant greenhouse pests. Growers would profit from more biological control agent alternatives because they would be able to select species that are better suited for use in diverse crop pest and environmental conditions. According to Ellaithy *et al.* (2013), depending on the color of the fruit, red pepper cultivar was more susceptible to *T. urticae* infestation; conversely, yellow fruit was more likely to be infested by *T. tabaci*. Our findings support this; the highest population density of *B. tabaci* and *F. occidentalis* was on yellow 'Qiuda', followed by moderate damage with *T. urticae*. On the contrary, red 'Grand bell' was consistently more susceptible.

The present study indicated that the predatory mites, *A. swirskii* and *N. californicus*, when combined, can decrease the population of *F. occidentalis*, *B. tabaci*, *T. urticae*, and *P. latus* on sweet pepper in greenhouses. Abou-Haidar *et al.* (2021) found that *A. swirskii* and *P. persimilis* are particularly successful in controlling whitefly, thrips, and two-spotted spider mite populations on cucumber in greenhouses when combined with other IPM strategies. They suggested that biologically based integrated pest management in the Mediterranean region could provide health benefits to consumers, farmworkers, and the environment by reducing the use of pesticides. However, crucial considerations include proper scouting, considering abiotic factors, choosing disease-resistant plant cultivars, and considering the high cost of international transport. Barghout *et al.* (2022), indicated that *A. swirskii* suppressed *B. tabaci* and *T. tabaci* populations, while *Cydnoseius negevi* (Swirski & Amitai) and *Neoseiulus cucumeris* reduced *B. tabaci* populations. *Tetranychus urticae* densities were decreased by *Phytoseiulus persimilis* Athias-Henriot with *A. swirskii* and *N. cucumeris*, all combined treatments being the most effective. *Amblyseius swirskii* has been considered as a potential whitefly and thrips control agent for sweet pepper (Bolckmans *et al.* 2005) and cucumber (Calvo *et al.* 2011). Furthermore, even at low pest levels, *A. swirskii* can be released preventively when the crop is flowering and persists in the crop throughout the growing season. Barghout *et al.* (2022) showed that all combined treatments, including *A. swirskii* as a shared predator, greatly reduced the populations of *B. tabaci*, *T. urticae*, and *T. tabaci* on the red delta star pepper cultivar.

The release of *N. californicus* resulted in a considerable reduction in the number of piercing-sucking pests during the full growing season. Predator population densities are tracked closely with the density of all pests. Similarl to the findings of this study, several authors demonstrate the impact of inundative release of predatory mites in pest management. El-Saiedy and Fahim (2021) demonstrated that *N. californicus* with a rate of 1:7 predator:prey appears to be a more competent strategy for controlling *T. urticae* on strawberry than chemical control. The current study showed that *N. californicus* suppressed *T. urticae* populations better than *A. swirskii*, possibly due to different levels of phytoseiid specialization in terms of diet. Our results agreed with those of Elmoghazy *et al.* (2011), who showed that *N. californicus* reduced *T. urticae* populations by 87.22%, while *A. swirskii* reduced *T. urticae* numbers by 57.49% on *Vicia faba* L. (Fabaceae).

In this investigation, the population suppression of *B. tabaci*, *F. occidentalis*, and *P. latus* was lowest with *N. californicus* and acaricides. The highest suppression of these pests' populations was observed in the combination of *A. swirskii* + *N. californicus*, and *A. swirskii* alone. In greenhouses, *N. californicus* outperformed *A. swirskii* and acaricides in controlling *T. urticae*. According to Adly (2016), there was a substantial difference between biological control and pesticides for whitefly and mite populations on cucumbers in greenhouses. Ibrahim *et al.* (2010) found that releasing *N. californicus* at a rate of 30 predators/apple seedlings resulted in the greatest reduction (66.89% of the *T. urticae*). Elhalawany *et al.* (2019) showed that *N. californicus* had the highest reduction in *Thrips tabaci* Lindeman population (73.42%) on onion crops. According to El Arnaouty *et al.* (2020), the biological control approach was the most effective in managing the complex of sweet pepper pests.

Moreover, our findings support those of Abou-Haidar *et al.* (2021), who found that *A. swirskii* kept whitefly and thrips populations below the economic threshold of 4.6 whiteflies/cucumber leaf. Predatory mites are as effective as, if not more effective than, many insecticidal and acaricidal sprays. In this investigation, acaricide treatment was effective but not as effective as *A. swirskii* and *N. californicus* together on *B. tabaci* and *F. occidentalis*; nevertheless, it did not differ from *N. californicus* on *B. tabaci* and *F. occidentalis*. Shehawy *et al.* (2021) surmised that *A. swirskii*, *C. negevi*, and the Vertemic + Egyxide combination had the highest reduction percentage of *B. tabaci* infesting tomato crop, whilst *N. cucumeris* and *N. californicus* had more moderate reduction effects.

Using the biological control agents, we found that the yield increased over the control treatment. In addition, the application of the biological control candidates resulted in the biggest cost savings for sweet pepper production, higher than the control and acaricides treatments, as well as a safe yield free of any chemical residues. These results matched those of El-Halawany *et al.* (2000), who found that the cost of biological control by *P. persimilis* was 300 LE less than the cost of chemical control, which was 416 LE. Adly (2015) reported a 40% increase in cucumber yield when a biological management program was used on cucumber in greenhouses. In cucumber yield, Adly (2016) found that the biological control was (62.15%) greater than the chemical control. On pepper, the cost benefits of the biological control program were (31.61%) higher than the control treatment and (26.45%) higher than chemical treatment (El Arnaouty *et al.* 2020).

CONCLUSIONS

In conclusion, the results revealed that *A. swirskii*, alone or in combination with *N. californicus*, was significantly more effective against *F. occidentalis*, *B. tabaci*, and *P. latus* on two pepper cultivars than the chemical control under the same conditions. Moreover, the predatory mite, *N. californicus* outperformed *A. swirskii* and acaricides against *T. urticae*. Our findings suggest that combining the two predatory mites, *A. swirskii* and *N. californicus*, can improve biological control of piercing-sucking pests. The yield increased by around 37.4 to 40.0% over the control treatment using the biological control agents. Furthermore, the biological control led to the highest cost reductions for sweet pepper production (35.7–40.7 and 16.2–27.2%) compared to the control and acaricides treatments, and a safe yield free of residues as well.

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اثر *Amblyseius swirskii*، *Neoseiulus californicus* (Acari: Phytoseiidae)، و کنه‌کش‌ها در کنترل برخی آفات فلفل دلمه در گلخانه‌ها

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چکیده

در مصر آفات مهم زننده-مکنده مانند تریپس گل غربی، *Frankliniella occidentalis*، سفیدبالک، *Bemisia tabaci*، کنهٔ پهن، *Polyphagotarsonemus latus* و کنهٔ تارتن دو لکه‌ای، *Tetranychus urticae* باعث کاهش عملکرد فراوانی در گیاه فلفل شیرین در گلخانه‌ها می‌شود. هدف از این پژوهش، بررسی اثربخشی دو کنه فیتوزئید *Amblyseius swirskii* و *Neoseiulus californicus* به عنوان عوامل مهار زیستی برای آفات زننده-مکنده روی فلفل دلمه‌ای گلخانه‌ای در مقایسه با کنه‌کش‌های شیمیایی است. سه مقدار رهاسازی مورد بررسی قرار گرفت: ۱۰ کنهٔ کامل *A. swirskii*/گیاه، ۱۰ کنهٔ کامل *N. californicus*/گیاه، و ترکیب ۷ کنهٔ کامل *A. swirskii* + ۷ کنهٔ کامل *N. californicus*. بیشترین انبوهی جمعیت گونه های *B. tabaci* و *F. occidentalis* روی رقم «کیودا» زرد و به دنبال آن خسارت زیادی با *T. urticae* مشاهده شد. برعکس، رقم «گرند بل» قرمز به طور پیوسته بیشتر مستعد ابتلا به *T. urticae* و به نسبت مستعد ابتلا به سفیدبالک بود. هم مهار زیستی و هم مهار شیمیایی در کاهش جمعیت آفات روی فلفل دلمه‌ای در گلخانه ها کارآمد بودند. نتایج نشان داد که *A. swirskii*، به تنهایی یا در ترکیب با *N. californicus* عرضه شده، در برابر *F. occidentalis*، *B. tabaci* و *P. latus* بر روی هر دو رقم فلفل مؤثرتر از کنه‌کش‌هایی است که در شرایط یکسان پاشیده می‌شوند. افزون بر این، کنهٔ شکارگر، *N. californicus*، بهتر از *A. swirskii* و کنه‌کش‌ها در برابر *T. urticae* عمل کرد. کنه‌های شکارگر *A. swirskii* و *N. californicus* با هم می‌توانند مهار زیستی آفات زننده-مکنده را بهبود بخشند. عملکرد ۳۷/۴ تا ۴۰/۰ درصد نسبت به تیمار شاهد با استفاده از عوامل مهار زیستی افزایش یافت. افزون بر این، برنامه مهار زیستی منجر به بیشترین کاهش هزینه برای تولید فلفل شیرین (۳۵/۷-۴۰/۷ و ۱۶/۲-۲۷/۲٪) در مقایسه با تیمار شاهد و کنه‌کش‌ها و همچنین عملکرد ایمن عاری از باقیماندهٔ آفت‌کش‌ها شد.

واژگان کلیدی: مهار زیستی، کنهٔ فیتوزئید، تریپس، سفیدبالک، کنهٔ پهن، کنهٔ تارتن، مدیریت تلفیقی آفات.

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