Egyptian Journal of Biological Pest Control

RESEARCH

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Comparative evaluation of biological control programs and chemical pesticides for managing insect and mite pests in cucumber greenhouses: a sustainable approach for enhanced pest control and yield

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Abstract

Background Cucumber plants are susceptible to several economically damaging pests, including whiteflies, aphids, thrips and spider mites. This study aimed to evaluate the efficacy of two biological control programs, utilizing different releases of bio-agents, in comparison with chemical control method. The bio-agents used were the aphid parasitoid *Aphelinus albipodus* Hayat and Fatima (Hymenoptera: Aphelinidae), the green lacewing *Chrysoperla carnea* (Steph.) (Neuroptera: Chrysopidae) and the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) in two release rates; low and high. Additionally, a chemical pesticides treatment was included for comparison in managing the pests in cucumber greenhouses during the winter seasons of 2022 and 2023, in Egypt. Abundances of whitefly, aphids, thrips and spider mites were recorded weekly throughout the study.

Results The aphid population in the greenhouse with high release rate (BIO 2) showed the highest reduction, with percentages of 84.55 and 89.88% in 2022 and 2023, respectively. Both greenhouse with low release rate (BIO 1) and BIO 2 exhibited significant reductions in the whitefly population, with proportions of 71.31 and 72.01% in 2022, and 82.05 and 85.94% in 2023, respectively. The thrips population also experienced notable reductions in both BIO 1 and BIO 2 greenhouses, with percentages of 72.08 and 75.71% in 2022, and 59.93 and 61.38% in 2023, respectively. However, the pesticide treatment demonstrated the lowest reduction in populations of aphids, whitefly and thrips in both seasons. Nevertheless, in all treatments in the two evaluated seasons, the high release rate of the predatory mite, *P. persimilis* (15 individuals/m^2), proved to be highly effective in maintaining the mite populations below the economic threshold level. However, the population density of the two-spotted spider mite, *Tetranychus urticae* Koch. (Acari: Tetranychidae), increased in the pesticide-treated greenhouse, indicating the development of resistance to pesticides. Although the tested programs resulted in similar yields, the biological control approach offered the advantage of pesticide-free produce and reduced production costs.

Conclusion For pest management in cucumber growing in greenhouses during winter, it is recommended to use biological control agents at a low release rate at the early occurrence of pests. This approach can help minimize pest populations effectively.

Keywords Cucumber, Protected cultivation, Winter season, Biocontrol agents, Pesticides, Evaluations

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Background

The global population is rapidly increasing, leading to a high demand for healthy fresh food (FAO et al. 2018). It is well known that the greenhouse industry plays a crucial role by providing high-quality fruits and vegetables rich in essential vitamins and minerals. Greenhouses offer several advantages, including high crop production per unit area and efficient water use (Stanghellini 2013). As a result, the global area dedicated to greenhouse production is expanding, with Egypt experiencing significant growth in protected cultivation, particularly in single-arch greenhouses, reaching approximately twenty thousand in number. Cucumber production accounts for around 60% of greenhouse cultivation in Egypt (El-Aidy et al. 2007).

However, the environmental conditions inside greenhouses, characterized by high temperature and humidity, create favorable conditions for various pests that can infest vegetable crops.

Cucumber plants are susceptible to infestation by wide range of pests, leading to a decrease in productivity and downgrade its quality. Several pests have been identified as having significant economic implications due to the direct and indirect damages they cause to cucumber. Among the pests that have been extensively studied and recognized as major threats to cucumber plants in Egypt are the whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), the cotton-melon aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae), the *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), the *Liriomyza bryoniae* (Kaitenbach) (Diptera: Agromyzidae), *Dacus ciliatus* (Loew) (Diptera: Tephritidae) and the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) (Emam et al. 2020).

Currently, chemical control methods, due to their fast results and hand liability, remain the primary approach for pest management in Egyptian greenhouse vegetables production. However, the use of pesticides presents several challenges, including negative impacts on human health, environmental pollution and the appearance of pesticide-resistant pest strains (Bernardes et al. 2015). Therefore, there is an increasing need to explore alternative pest control strategies, specifically biological control, as an integral part of integrated pest management (IPM) programs (van Lenteren 2020). Biological control offers a promising solution, especially in situations where the reliance on chemical control alone is undesirable, and it can often be cost-effective or even more economical than chemical methods (Bolckmans 1999).

Among the potential biological control agents, the aphid parasitoid *Aphelinus albipodus* Hayat and Fatima (Hymenoptera: Aphelinidae) has shown high efficiency in controlling the cotton-melon aphid, *A. gossypii*, which is a major pest of cultivated plants (Zamani et al. 2006).

Additionally, lacewing species belonging to the genus *Chrysoperla* (Neuroptera: Chrysopidae) have long been recognized as important predator in various cropping systems, including vegetables, fruits, nuts, fiber, forage crops, ornamentals, greenhouse crops and forests. It is widely used and commercially available natural enemy, with its larval capable of consuming a range of insect pests such as aphids, thrips, mealybugs, immature whiteflies, small caterpillars, insect eggs and mites (Tauber et al. 2000). The specialist predator, *Phytoseiulus persimilis* Athis-Henriot (Acari: Phytoseiidae), has demonstrated effectiveness in controlling the two-spotted mite, *T. urticae*, in greenhouse environments (Adly 2015).

Numerous studies have been conducted to compare the efficacy of biological control agents and pesticide application against pests infested cucumber in greenhouses (Nomikou, et al. 2002; Ibrahim, et al. 2006; Messelink et al. 2006; Adly 2015; Eleawa and Waked 2016; Abou-Haidar et al. 2021).

However, further research is needed to determine the optimal release rates and cost benefits of biological control agents in comparison with the use of pesticide applications, which remains the predominant method of pest control in many countries.

This study aimed to address this gap by evaluating the effectiveness of two biological control programs, each employ the different release rates of bio-agents and compare them to chemical control methods. The evaluation focused on managing specific pests in cucumber cultivation within commercial greenhouses during the winter season. The assessment involves monitoring the target pests' abundance, assessing the crop yields obtained and evaluating the relative costs associated with each control method.

Methods

Study site

The experiments were conducted in commercial greenhouses located at Giza, Egypt. Four commercial plastic greenhouses, each measuring 480 m^2 (30 m × 16 m), were used for the experiment. Each greenhouse consisted 10 rows of 60 cucumber plants (*Cucumis sativus* L.), variety Paracoda, resulting into a total of 600 plants per greenhouse. Transplanting took place on December 17, 2022 and December 10, 2023. Traditional farming practices, including agricultural methods, irrigation and fertilization, were implemented according to the recommendations of the Ministry of Agriculture of Egypt. Daily temperatures and relative humidity data for this region were obtained from the Central Laboratory for Agriculture Climate (CLAC), Dokki, Egypt.

Source of natural enemies used

The parasitoid *A. albipodus*, predator, *C. carnea* and the predatory mite, *P. persimilis* used in the field trials were obtained from the Plant Protection Research Institute (PPRI), Agriculture Research Center (ARC), Giza, Egypt.

Experimental design

Treatments

Three treatments were assessed to determine their effectiveness against specific pests in the cucumber greenhouses. The first treatment (BIO 1) and second treatment (BIO 2) involved the release of the three natural enemies at two different release rates as shown in Table 1. These included; 1) mummies of the parasitoid *A. albipodus* that target aphids, 2) the second instar larvae of the predator *C. carnea* that target whitefly and thrips and 3) the predatory mite, *P. persimilis*, that target spider mites. The third treatment (conventional method) consisted of the application of recommended pesticides, following the recommended application time and rates by the grower (Table 1). The release of biological agents in the greenhouses BIO 1 & BIO 2 was started immediately on sight of the pests and the number of releases depended on the pest infestation level. Additionally, a control treatment was included in the greenhouse trials, free of biological agents or pesticides were applied.

Assessment of the effectiveness of treatments

To evaluate the effectiveness of the treatments, data were randomly collected by inspecting 25 plants chosen from each treatment (five plants per row) weekly, starting from seedling until harvest (about 3 months). The population density of pests was determined by counting the number of pests on three leaves that randomly selected and inspected from the top, middle and lower levels of each plant (75 leaves per treatment) in the greenhouse using square-inch hand-lens with 10× magnification for inspection. The recorded pests included all stages of *A. gossypii*, nymphs of *B. tabaci*, nymphs *Thrips* spp. and all mobile stages of spider mite *T. urticae*.

Cucumber yield estimation

Total cucumbers' yield in all treatments of different greenhouses was estimated during the two winter seasons of 2022 and 2023.

Data analysis

The data obtained were analyzed using analysis of variance method (ANOVA) using Proc. ANOVA in SAS (Anonymus 2003). Both mean counts of pest data obtained and inspection dates were considered, as factors for the two-way analysis model used. Variance due inspection dates was ignored. Mean separation between treatments was conducted using Tukey's honestly significant difference test at a significance level of $P=0.05$, within the SAS program. The data were statistically analyzed by correlation analysis between weather parameters and pest populations.

Results

Weather data

In 2022, the recorded weather data in the greenhouses showed maximum temperature ranges of 16.76–26.37 °C, minimum temperatures of 4.91–11.9 °C and relative

Table 1 Rates, concentrations and application time of the bio-agents and pesticides in the two seasons 2022–2023

Treatments	Rates and concentrations		Week of application	
	*BIO 1	*BIO 2	2022	2023
Bio-agents				
Chrysoperla carnea	5 individuals 2nd larval instar/m^2	10 individuals 2nd larval instar/m^2	6th, 7th, 8th	2nd, 4th, 6th, 8th
Aphelinus albipodus	4 mummies/m^2	8 mummies/m^2	4th, 6th, 8th	4th, 6th, 8th
Phytoseiulus persimilis	5 individuals/m^2	15 individuals/m^2	7th, 8th, 10th	7th, 10th
Pesticides				
Acetamiprid (Mosiplan 20% SP)	(25 gm/100 l)		5th, 9th	2nd, 3rd, 6th
Abamectin (Vertimec 1.8% EC)	(50 gm/100 l)		6th, 10th, 11th, 12th	4th
Malathion (Malatox 57% EC)	(150 lm/100 l)		7th	–
Sulfur Makrony	(250 gm/100 l)		7th, 8th	8th
Imidacloprid (Mallet 35%SC)	(30 cm/100 l)		–	2nd, 3rd
Mineral oil	(250ml/100 l)		–	8th
Acrobat Copper 46% WP	(250 gm/100 l)		3rd, 7th	6th, 10th, 14th
Kernoex 50% WP	(250 gm/100 l)		4th, 8th, 12th	5th, 9th, 14th

*BIO 1, First treatment using bio-agents with low release rate; BIO 2, Second treatment using bio-agents with high release rate humidity of 49.75–84.29%. In 2023, the maximum temperature ranges were 17.72–25.14 °C, minimum temperatures were 8.32–9.87 °C and relative humidity of 51.37–87.58%.

The data underwent statistical analysis to examine the relationship between weather parameters and pest populations. In 2022, the populations of aphid and thrips showed a positive correlation with maximum temperature (r=0.8 and 0.68), minimum temperature (r=0.14 and 0.21) and relative humidity (r =0.09 and 0.15), respectively. On the other hand, the populations of whitefly and mite exhibited a negative correlation with maximum temperature (r=−0.55 and −0.58), minimum temperature (r = −0.21 and −0.6) and positive correlation with relative humidity (r = 0.17 and 0.18), respectively.

In 2023, the populations of aphid and thrips also demonstrated a positive correlation with maximum temperature (r=0.8 and 0.64), minimum temperature (r =0.81 and 0.23) and relative humidity (r= 0.07 and 0.18), respectively. Conversely, the populations of whitefly and mite displayed a negative correlation with maximum temperature (r=−0.45 and −0.59), minimum temperature (r =−0.22 and −0.38) and positive correlation with relative humidity (r=0.07 and 0.5), respectively.

Pest infested cucumber plants

Four prevalent pests were observed on cucumber plants growing in the greenhouses; the cotton-melon aphid, *A. gossypii*, the whitefly, *B. tabaci*, the thrips, *Thrips* spp., and the two-spotted mite, *T. urticae.*

Effects of aphid parasitoid Aphelinus albipodus and pesticides on the aphid, Aphis gossypii population

In 2022, the aphid population started to occur during the 1st week after transplanting with densities of 0.23 ± 0.63, 0.28 ± 0.5, 0.36 ± 0.66 and 0.35 ± 0.54 individuals/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively (Fig. 1). The aphid population density gradually increased and reached its peak during the 7th week in the control greenhouse (12.69 ± 1.23 individuals/leaf). Three applications of releasing aphid parasitoid *A. albipodus* were used on the 4th, 6th and 8th weeks after planting. However, by the 12th week, after three releases of the aphid parasitoid in BIO1 and BIO2 greenhouses and nine applications of the pesticides in the pesticide greenhouse (Table 1), the aphid population significantly declined to 1.41 ± 0.68, 1.86 ± 035 and 0.99 ± 0.32 individuals/leaf in BIO 1, BIO 2 and pesticides greenhouses, respectively. In contrast, the aphid population increased to 14.9 ± 0.54 individuals/leaf in control greenhouse (Fig. 1).

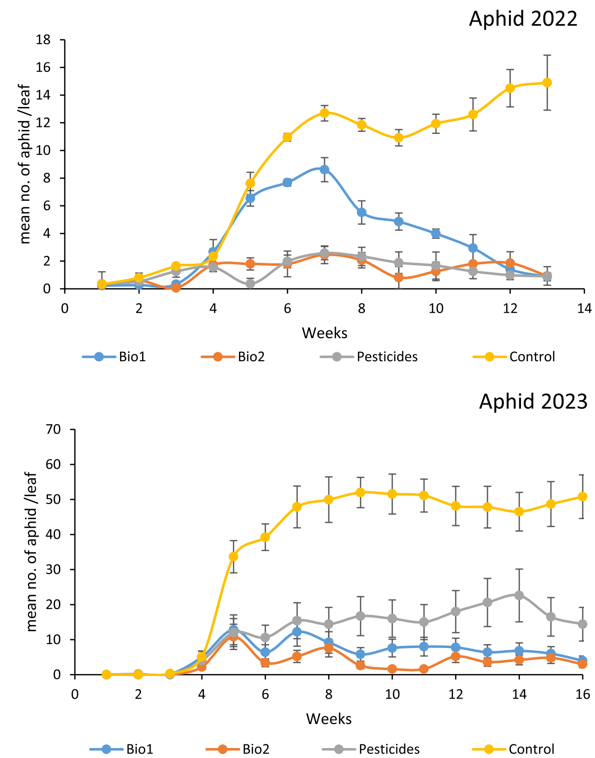

Fig. 1 Effect of different treatments on weekly average number of aphids per leaf in cucumber greenhouses at the two seasons 2022 and 2023

The BIO 1 greenhouse showed the lowest reduction in the aphid population reaching (59.39%). The highest reduction in the aphid population was observed in BIO 2 and pesticides greenhouses, with both achieving similar proportions of reduction 84.55 and 84.35%, respectively.

Statistical analysis of aphid populations indicated that there was nonsignificant difference observed among BIO1, BIO 2 and pesticides. However, there was significant difference among control and BIO 1, BIO 2 and pesticides (Table 2).

In 2023, the aphid population started at the 4th week after transplanting with the densities of 5.23 ± 0.54, 2.2 ± 0.87, 4.3 ± 0.53 and 5.07 ± 0.24 individuals/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively (Fig. 1). Three applications of releasing aphid parasitoid *A. albipodus* were used on the 4th, 6th and 8th weeks after planting. After the third release, during the 13th week after planting, the aphid population reached 6.4 ± 0.33, 3.6 ± 0.12 individuals/leaf in BIO 1 and BIO 2, respectively. However, in the pesticides greenhouse, where eight pesticides applied, the aphid population reached 20.6 ± 0.64 individuals/leaf as compared to 47.8 ± 0.45 individuals/leaf in control

Table 2 Comparison of the mean numbers of pests between biological control programs and chemical pesticides in Cucumber Greenhouses during 2022–2023

Year	Treatment	Mean no. of collected pests/no. of samples			
		Aphid	Whitefly	Thrips	Mite
2022	Bio 1*	3.53[b]	3.56[b]	1.20[b]	6.18[bc]
	Bio 2*	1.34[b]	3.48[b]	1.04[b]	1.31[c]
	Pesticides	1.36[b]	5.16[b]	1.64[b]	23.75[ab]
	Control	8.69[a]	12.43[a]	4.31[a]	32.33[a]
	F	21.15	31.88	29.71	7.66
	P	< .0001	< .0001	< .0001	0.0006
	LSD	2.87	2.89	1.07	20.27
2023	*Bio 1	7.53[c]	7.17[b]	1.80[b]	11.76[bc]
	*Bio 2	4.29[c]	5.53[b]	1.78[b]	5.67[c]
	Pesticides	15.09[b]	10.02[b]	2.30[b]	30.95[ab]
	Control	44.03[a]	40.64[a]	4.46[a]	44.67[a]
	F	103.93	191	28.18	10.14
	P	< .0001	< .0001	< .0001	< .0001
	LSD	6.76	4.58	0.91	21.38

Means with the same letter are nonsignificantly different. Means with different letters are significantly different

BIO 1, First treatment using bio-agents with low release rate; BIO 2, Second treatment using bio-agents with high release rate

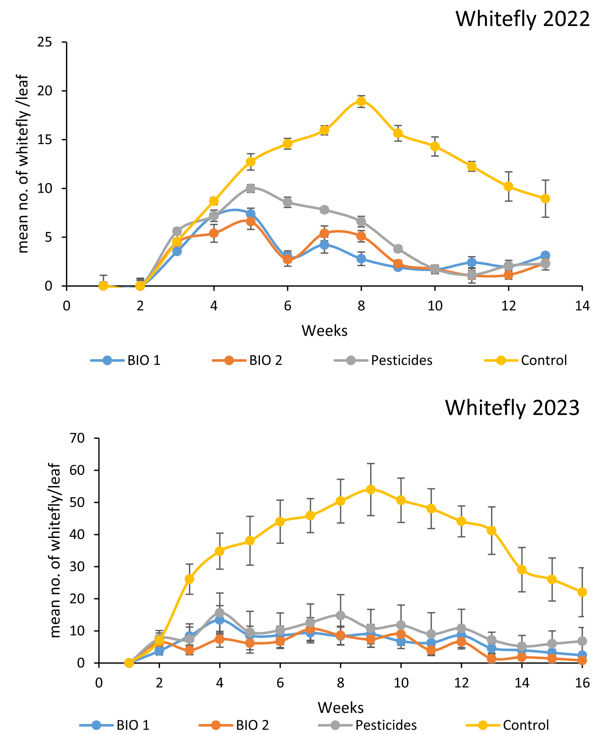

Fig. 2 Effect of different treatments on weekly average number of whitefly per leaf in cucumber greenhouses at the two seasons 2022 and 2023

greenhouse (Table 1 and Fig. 1). The pesticides greenhouse resulted in the lowest reduction in the aphid population reaching (65.15%). The highest in the aphid population was observed in the BIO 2 greenhouse reaching (89.88%) followed closely by BIO 1 greenhouse (81.98%).

There was nonsignificant difference between (BIO 1 and BIO 2), but there was a significant difference between BIO 1, BIO 2 and pesticides. Furthermore, there was a significant difference between control and treated greenhouses (BIO 1, BIO 2 and pesticides) (Table 2).

After the release of the aphid parasitoid *A. albipodus* in the BIO1 and BIO 2 greenhouses, the presence of mummies was noticed on the leaves and the number of mummies increased up to the end of the two seasons. In both seasons, releases of aphid parasitoid, *A. albipodus* successfully decreased the aphid population under the economic threshold (7 *A. gossypii*/cm^2 of cucumber leaf). In contrast, in the pesticide greenhouse, the aphid population was higher than the economic threshold level.

Although the predator *C. carnea* being released initially for whitefly control, the subsequent release of the aphid parasitoid *A. albipodus* proved to be highly effective in controlling aphid. The effectiveness was evident from the presence aphid parasitoid mummies and the significant increase in their numbers, indicating successful aphid control primarily attributed to the parasitoid.

Effects of the predator Chrysoperla carnea and pesticides on the whitefly Bemisia tabaci and thrips, Thrips spp. populations

In 2022, the whitefly population started to appear during the 3rd week after cucumber transplanting with densities of 3.54 ± 0.32, 4.47 ± 0.38, 5.61 ± 0.12 and 4.56 ± 0.33 nymphs/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively. However, during the 11th week after three releases of the predator *C. carnea* and nine applications of pesticides in greenhouses, the whitefly population decreased to 2.01 ± 0.54, 1.14 ± 0.27 and 2.07 ± 0.48 nymphs/leaf in BIO 1, BIO 2 and pesticides greenhouses, respectively (Table 1). In contrast, the whitefly increased to10.2 ± 0.29 nymphs/leaf in a control greenhouse (Fig. 2). The pesticides treatment had the lowest reduction in the whitefly population, reaching (58.46%). The whitefly population reduction was the highest in BIO 1 and BIO 2 greenhouses, with their proportions being close to each other, reaching (71.31 and 72.01%), respectively.

Similarly, the thrips population also started to appear during the 3rd week after transplanting with population densities of 2.61 ± 0.57, 1.5 ± 0.63, 1.92 ± 0.24 and 1.77 ± 0.85 nymphs/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively. During the 11th week after the three releases of the predator *C. carnea* the thrips population decreased to less than 1 nymph/leaf, 0.54 ± 0.12 and 0.93 ± 0.22 nymphs/leaf in BIO 1 and BIO 2, respectively. However, following nine applications of the pesticides the thrips population reached 2.61 ± 0.74 nymphs/leaf in pesticides greenhouse as compared to 4.22 ± 0.68 nymphs/leaf in a control greenhouse (Table 1, Fig. 3). The pesticides treatment caused the lowest reduction in the thrips population, reaching (61.79%). The thrips population reduction was the highest in BIO 1 and BIO 2 greenhouses, with their proportions being close to each other, reaching (72.08 and 75.71%), respectively.

In 2023, similar trends were observed. The whitefly population started to appear during the 2nd week after cucumber transplanting with a population of 3.79 ± 0.53, 6.39 ± 0.85, 7.59 ± 0.81 and 7.02 ± 0.33 nymphs/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively. Four releases of *C. carnea* in the 2nd, 4th, 6th and 8th weeks after planting were applied. It was also noticed that by the 11th week, after the fourth release of the predator the whitefly population reached 6.3 ± 0.72 and 3.9 ± 0.36 nymphs/leaf in BIO 1 and BIO 2, respectively. However, following nine applications of the tested pesticides, the whitefly population recorded 8.9 ± 0.68 nymphs/leaf in pesticides greenhouse as compared to 48.06 ± 0.42 nymphs/leaf in control greenhouse (Table 1, Fig. 2). The pesticides treatment had the lowest reduction in the whitefly population, reaching (75.59%). The whitefly population reduction was the highest in BIO 1 and BIO 2 greenhouses, with their proportions being close to each other, reaching (82.05 and 85.94%), respectively.

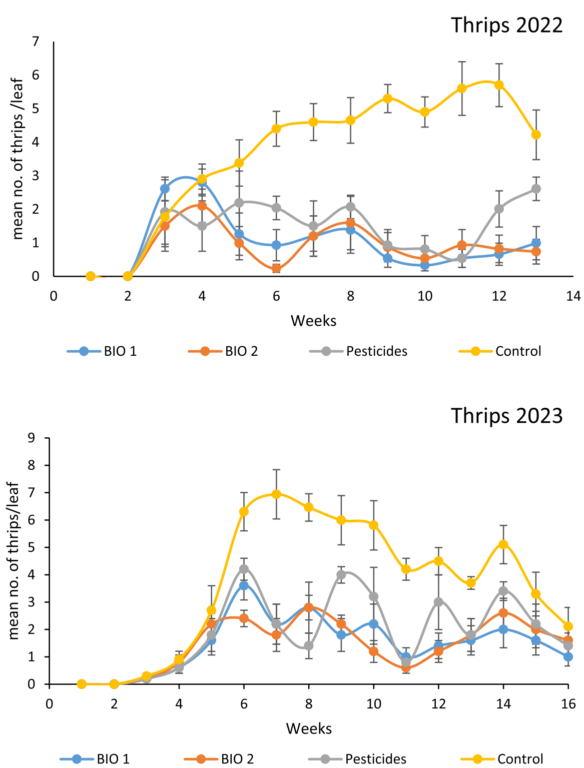

Fig. 3 Effect of different treatments on weekly average number of thrips per leaf in cucumber greenhouses at the two seasons 2022 and 2023

The thrips population started during the 3rd week after transplanting with population densities 0.198 ± 0.47, 0.2 ± 0.11, 0.19 ± 0.21 and 0.29 ± 0.13 nymphs/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively. During the 11th week, after the fourth release of the predator, the thrips population reached 0.99 ± 0.12 and 0.63 ± 0.46 nymphs/leaf in BIO 1 and BIO 2 greenhouses, respectively. However, after nine applications of the pesticides, it was noticed that, the thrips population reached 0.81 ± 0.6 nymphs/leaf in pesticides greenhouse as compared to 4.22 ± 0.7 nymphs/leaf in control greenhouse, respectively (Table 1 and Fig. 3). The pesticides treatment had the lowest reduction in the thrips population, reaching (48.84%). The thrips population reduction was the highest in BIO 1 and BIO 2 greenhouses, with their proportions being close to each other, reaching (59.93 and 61.38%), respectively.

Statistical analysis indicated that nonsignificant difference among BIO1, BIO 2 and pesticides treatments for both whitefly and thrips in the two seasons. However, there was a significant difference among control and BIO 1, BIO 2 and pesticides (Table 2).

The results of this study demonstrate that the release of the predator *C. carnea* was more effective in controlling the population of whitefly and thrips in cucumber greenhouses compared to the application of pesticides. Both methods achieved pest populations below the economic threshold (18.4 adults/plant, or 4.6 adults/leaf for whitefly on cucumber and 1.3 adult thrips/cucumber leaf). However, the biocontrol agents approach exhibited higher reduction in pest populations compared to pesticide application.

Effects of the predator mite, Phytoseiulus persimilis and pesticides on the two-spotted mite, Tetranychus urticae population

In 2022, the two-spotted mite population observed during the 3rd week after transplanting cucumber, with densities of 0.22 ± 0.35, 0.38 ± 0.34, 0.21 ± 0.22 and 0.35 ± 0.42 individuals/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively. The spider mite population continued to increase gradually in all greenhouses. Three releases of predator mite *P. persimilis* in the 7th, 8th and 10th weeks after planting were applied. After the third release of predatory mite in 11th week, the spider mite population decreased to 9.19 ± 1.5 and 0.96 ± 0.43

individuals/leaf in BIO 1 and BIO 2 greenhouses, respectively (Fig. 4). However, in the pesticides greenhouse, despite nine applications of the pesticides, the spider mite population increased to 39.12 ± 5.66 individuals/leaf, while its population increased to 58.68 ± 7.65 individuals/leaf in the control greenhouse (Table 1 and Fig. 4). The highest reduction in mite population was observed in BIO 2 greenhouse (95.92%) following by BIO 1 greenhouse (80.87%) and pesticides greenhouse (26.54%).

In 2023, a similar trend was observed. The two-spotted mite population started during the 4th week after transplanting with densities of 0.53 ± 0.41, 0.66 ± 0.19, 0.63 ± 0.64 and 0.54 ± 0.53 individuals/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively. The spider mite population continued to increase gradually in all greenhouses and reached 17.86 ± 2.74, 7.14 ± 1.99, 40.54 ± 3.66 and 42.84 ± 4.32 individuals/leaf in BIO 1, BIO 2, pesticides and control greenhouses, respectively.

After the second release of the predatory mite *P. persimilis*, the population of spider mite decreased gradually to reach 4.53 ± 1.3 and 0.74 ± 0.93 individuals/leaf in BIO 1 and BIO 2, respectively. However, in pesticides greenhouse, despite eight applications of the pesticides the spider mite population increased to 49.92 ± 3.96 individuals/leaf and in control greenhouse, it increased even more to 114.81 ± 4.77 individuals/leaf (Table 1 and Fig. 4). The highest reduction in mite population was observed in BIO 2 greenhouse (83.95%) following by BIO 1 greenhouse (67.42%) and pesticides greenhouse (25.63%).

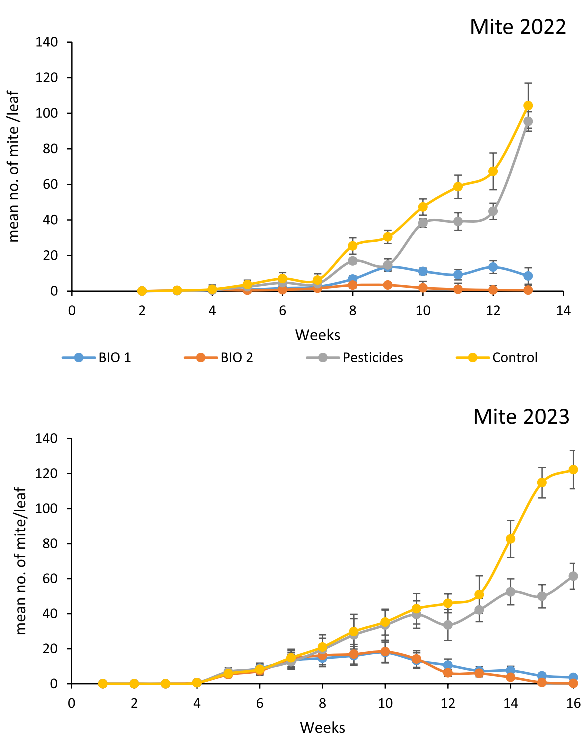

Fig. 4 Effect of different treatments on weekly average number of mite per leaf in cucumber greenhouses at the two seasons 2022 and 2023

Statistical analysis of mite populations revealed that nonsignificant difference between (BIO1 and BIO 2), (BIO1 and pesticides) and (control and pesticides) treatments in both seasons. However, significant differences were observed among control and BIO 1, BIO 2 (Table 2).

Among the different tested treatments, it was observed that the spider mite population remained above the economic threshold level (less than1 mite/cm^2 cucumber leaf) in both the BIO 1 (5 individuals/m^2) greenhouse and the pesticide greenhouse during the two successive seasons. The highest release rate of the predatory mite, *P. persimilis* (15 individuals/m^2) proved to be highly effective in maintaining the mite populations below the economic threshold level.

Yields and cost benefit of control strategies

In 2022, the cucumber yields produced were 311, 311, 315 and 68 kg in BIO 1, BIO 2, pesticides and control greenhouses, respectively. In 2023, the yields were 289, 294, 283 and 52 kg in BIO 1, BIO 2, pesticides and control greenhouses, respectively.

Data proved that there were nonsignificant yield differences observed among the BIO 1, BIO 2 and pesticides greenhouses in season of 2022 and 2023.

Yield data indicate that all treatments have a positive impact on the crop compared to non-treated, with values that ranged four times in 2022, while these values reached approximately five times in 2023.

The costs of all agricultural practices were equal in the three greenhouses, except for the cost of pest control. The highest cost of pest control was observed in BIO 2 greenhouse with 481.8LE (15.59$) in 2022 and 286.8 LE (9.28$) in 2023, respectively. The BIO 2 greenhouse had a high rate of biological control agent release. This was followed by the pesticides greenhouse, with cost of 253.5 LE (8.2$) and 163.5LE (5.29$) in 2022 and 2023, respectively. The lowest cost of pest control was observed in BIO 1 greenhouse with 218.4LE (7.07$) and 129.4 (4.19$) LE in 2022 and 2023, respectively.

Discussion

The present study focused on evaluating the effectiveness of different rates of biocontrol agents' release compared to chemical control for managing aphid, whitefly, thrips and two-spotted spider mite in cucumber commercial greenhouses during winter seasons of 2022–2023. Several pest species were recorded in cucumber greenhouses including; *A. gossypii*, *B. tabaci*, *Thrips* spp., jassids and *T. urticae* (Güncan et al. 2006; Saleh et al. 2017).

The study's results indicated that both the application of two rates of release bio-agents and the use of pesticides were equally effective in controlling aphids, whiteflies, and thrips. The aphid parasitoid, *A. albipodus* successfully controlled aphids in the greenhouse of vegetable crops (Takada 2002).

It was also found that initiating the release of parasitoids and predators immediately after the first appearance of pests and multiple releases led to significant reductions in pest populations. These findings agree with Campbell and Lilley (1999) who suggested that early-season releases of natural enemies in low pest density, are more effective than late-season releases when pest density is high. However, it remains uncertain whether increasing the release rate of natural enemies can achieve successful pest control as its population density increases. Both release rates of aphid parasitoid (4 and 8 mummies/m^2) effectively maintained the aphid populations below the economic threshold level of 7 *A. gossypii* individuals/cm^2 of cucumber leaf (Hussey 1985). Both release rates of the predator *C. carnea* (5 and 10 individuals 2nd larval instar/m^2) and pesticides effectively maintained the whitefly and thrips, population below the economic thresholds of 18.4 adults/plant, or 4.6 adults/leaf for whitefly on cucumber (Shen et al. 2005) and 1.3 adult thrips/cucumber leaf (Steiner 1990).

Previous studies have indicated the possibility of using *C. carnea* to efficiently control whitefly and thrips on various vegetable crops in greenhouses. For instance, Ahmadzadeh and Hatami (2006) investigated the integrated use of insecticide (Confidor) and *C. carnea* against different nymphal instars of whitefly on tomato plant. They found that the integrated treatments were equally effective in pest control. Similarly, Rehman et al. (2020), released different rates of larvae of *C. carnea* on tomato plants to control whitefly *B. tabaci*. They found that all release rates successfully decreased the whitefly nymph population. Additionally, Pijnakker et al. (2019) reported significant control of Japanese flower thrips, *Thrips setosus* by repeatedly releasing of the green lacewings alone or in combination with predatory thrips. Their study demonstrated a substantial reduction in thrips populations and minimal leaf and flower damage, which supports our observations of the effectiveness of biocontrol methods against thrips. Furthermore, Maisonneuve and Marrec (1999) reported the efficacy of the predator, *Chrysoperla lucasina* (Lacroix) against *T. tabaci* in cut flowers and in seedling leek, adding to the body of evidence supporting the potential of bio-agents for pest management.

Although chemical control has successfully controlled aphid and whitefly, intensive use of insecticides has led to an increase in insecticide resistance (Sun et al. 1994). In this study, various treatments evaluated to control mite populations, and among them, the highest release rate of the predatory mite, *P. persimilis* (15 individuals/m^2) proved to be highly effective in maintaining mite populations below the economic threshold level of less than1 mite/cm^2 cucumber leaf (Park and Lee 2007 and Tehri et al. 2014).

However, in the pesticide-treated greenhouse, the population density of the mite *T. urticae* continued to increase throughout the season. This development of resistance to spider mites could be attributed to extensive pesticide applications (Abamectin). Several studies have reported resistance of *T. urticae* populations to abamectin, emphasizing the urgent need for implementing integrated management programs to effectively control this pest (Díaz-Arias et al. 2019, Herron et al. 2021 and Martínez-Huasanche et al. 2021).

In protected agriculture, the recommended release rate of the predatory mite, *P. persimilis*, is generally (5 female/m^2), but this rate may vary between crops. Timing of introduction is crucial for *P. persimilis* survival, and the release should coincide with the presence of sufficient prey to ensure optimal control (Stavrinides 2010). The numbers of spider mites decreased when the prey/predator ratio reached approximately 10:1 (Campbell and Lilley 1999). Yanar et al. (2019) demonstrated the potential of *P. persimilis* to provide effective control of *T. urticae* populations in cucumber greenhouse.

Abou-Haidar et al. (2021) used IPM strategies, including the release of the biological control agents, *Amblyseius swirskii* Athias-Henriot (Mesostigmata: Phytoseiidae) and *P. persimilis* to control whitefly, thrips and two-spotted spider mite populations on cucumber greenhouse plants. They found that biological control effectively maintained pest populations below the economic threshold when combined with other IPM strategy. Biological control agents were equally or more effective in suppressing pest populations compared to insecticides performed in the greenhouses.

In terms of yields and costs, the three tested programs in this study resulted in similar yields, with the advantages of the biological control greenhouse being low in cost. Previous studies have also shown that using pesticides for whitefly and mite control can lead to yield reductions, while the use of biological control agents can increase crop yield (Edwards 1986; Shoeb et al. 2005; Atanassov 1997; Adly 2015). However, it is important to note that Eleawa and Waked (2016) reported significant differences in the total yield of cucumber. They found that the use of pesticides (Ortus 5% SC) resulted in the maximum yield of 10.51 tons/feddan (Feddan = 4200 m^2), followed by 7.53 tons/feddan for the release of predatory mite, *P. persimilis*, and 5.47 tons/feddan for the control group. These results indicate that there may be variations in yield outcomes depending on specific factors such as crop type, pest infestation and management practices.

Conclusions

In the present study, both high and low rates of the biological control agents (*A. albipodus* and *C. carnea*) as well as chemical control methods proved successful in controlling the population of aphid, whitefly and thrips. The introduction of the predatory mite, *P. persimilis*, at a rate of (15 individuals/m^2) effectively reduced mite populations in both seasons. However, it is worth noting that the population density of the mite *T. urticae* increased in the pesticide-treated greenhouse, indicating the development of resistance.

For pest management in cucumber greenhouses during winter, it is recommended to use biological control agents at a low rate in early occurrence of pests. This approach can help minimize pest populations effectively. All tested programs resulted in producing equal yields in the treatments, but the advantage of biological control is that it produced yield without pesticide residuals.

Abbreviations

BIO 1	First treatment using bio-agents with low release ate
BIO 2	Second treatment using bio-agents with high release rate
IPM	Integrated pest management

Acknowledgements
Not applicable.

Author contributions
Dalia Adly conceived research. Dalia Adly and Ahmad Said Sanad conducted experiments. Dalia Adly and Ahmad Said Sanad contributed material. Dalia Adly and Ahmad Said Sanad analyzed data and conducted statistical analyses. Dalia Adly and Ahmad Said Sanad wrote the manuscript. Dalia Adly and Ahmad Said Sanad secured funding. All authors read and approved the manuscript.

Funding
No funding was received.

Availability of data and materials
All data and materials are available.

Declarations

Ethics approval and consent to participate
Not applicable—the study was conducted on insect species that are abundant in the ecosystem and does not require ethical approval.

Consent for publication
The manuscript has not been published in completely or in part elsewhere.

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

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Received: 14 April 2024 Accepted: 10 July 2024
Published online: 14 July 2024

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