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Comparative evaluation of different control strategies for managing two-spotted spider mite, *Tetranychus urticae* Koch in cucumber greenhouse

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Abstract

The two-spotted spider mite (TSSM) *Tetranychus urticae* Koch is one of the most economically damaging pests in commercial Iranian greenhouse, where pest management has traditionally relied on synthetic acaricides. The experiment was conducted using a randomized complete block design (RCBD) with six treatments and three replicates. To ensure the reliability of the results, the experiment was repeated across three different time periods. The treatments included two biological control agents, *Phytoseiulus persimilis* Athias-Henriot and *Amblyseius swirskii* Athias-Henriot, two silicon-based fertilizers (Fermolife Silicon® and Silica Prime®), and one chemical acaricide Etoxazole (Baroque®, SC 10%), compared with an untreated control. Analysis of variance (ANOVA) revealed a significant difference in mortality percentage among treatments at different days after treatment (DAT) ($P < 0.01$). The highest mortality rate (92.91%) was observed in plots treated with *P. persimilis* at 50 DAT, followed by Etoxazole (82.13%) and Silica Prime (78.41%). F. Silicon and *A. swirskii* treatments also resulted in 67.27% and 53.92% mortality, respectively, with significant differences among treatments. Additionally, the lowest leaf damage index (LDI) was recorded for *P. persimilis* (0.60), followed by Silica Prime (1.27), *A. swirskii* (1.73), F. Silicon (1.87), and Etoxazole (2.87). These findings indicate that TSSM can be effectively managed on greenhouse cucumbers using *P. persimilis*, in combination with silicon-based fertilizers, demonstrating the superior efficacy of biological control compared to chemical control. This integrated approach not only reduces the reliance on chemical acaricides but also contributes to environmental protection and the safety of the final product.

Keywords: Biological control, Silicon-based fertilizers, Phytoseiid mites, Tetranychidae

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ارزیابی مقایسه‌ای راهبردهای مختلف کنترل کنه تارتن دولکه‌ای *Tetranychus urticae* Koch در کشت خیار گلخانه‌ای

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چکیده

کنه تارتن دولکه‌ای، *Tetranychus urticae* Koch یکی از مهم‌ترین و زیان‌بارترین آفات اقتصادی در گلخانه‌های تجاری ایران به شمار می‌رود که مدیریت آن به‌طور سنتی عمدتاً بر پایه استفاده از کنه‌کش‌های شیمیایی استوار بوده است. این تحقیق در قالب طرح بلوک‌های کامل تصادفی با شش تیمار و سه تکرار اجرا شد. به‌منظور اطمینان از صحت نتایج، آزمایش در سه بازه زمانی مجزا تکرار شد. تیمارها شامل دو عامل کنترل بیولوژیک *Phytoseiulus persimilis* Athias-Henriot و *Amblyseius swirskii* Athias-Henriot ، دو نوع کود سیلیکونی (سیلیکاپرایم و فرمولایف سیلیکون) و یک کنه‌کش شیمیایی (اتوکسازول SC10%) بود که با تیمار شاهد مقایسه شدند. نتایج تجزیه و تحلیل واریانس (ANOVA) نشان داد که بین تیمارها از نظر درصد تلفات در روزهای مختلف پس از تیمار (DAT) تفاوت معنی‌داری در سطح یک درصد وجود داشت. بیشترین میزان تلفات (۹۳ درصد) در تیمار *P. persimilis* در ۵۰ روز پس از تیمار مشاهده شد و پس از آن تیمارهای اتوگزازول (۸۲ درصد) و سیلیکاپرایم (۷۸ درصد) قرار گرفتند. همچنین تیمارهای فرمولایف‌سیلیکون و *A. swirskii* به‌ترتیب منجر به ٦٧ و ٥٤ درصد تلفات شدند که این تفاوت‌ها از نظر آماری معنی‌دار بود. علاوه بر این، کمترین شاخص خسارت برگی (LDI) در تیمار *P. persimilis* (۰/٦۰) ثبت شد و پس از آن به ترتیب تیمارهای سیلیکاپرایم (۱/۲۷)، *A. swirskii* (۱/۷۳)، فرمولایف سیلیکون (۱/۸۷) و اتوگزازول (۲/۸۷) قرار گرفتند و بالاترین میزان خسارت (٤/٨٨) در تیمار شاهد مشاهده شد. این نتایج نشان می‌دهد که می‌توان کنه تارتن دولکه‌ای را در گلخانه‌های خیار با استفاده از کنه شکارگر *P. persimilis* به‌همراه کودهای سیلیکاتی، به‌طور مؤثر مدیریت کرد و کارایی بالاتر کنترل بیولوژیک نسبت به مبارزه شیمیایی را اثبات نمود. این روش نه تنها موجب کاهش نیاز به کنه‌کش‌های شیمیایی می‌شود، بلکه به حفظ محیط زیست و سلامت محصول نهایی نیز کمک می‌کند.

***کلید واژه‌ها:** کنترل بیولوژیک، کودهای سیلیکونی، کنه‌های شکارگر فیتوزئید، کنه‌های تترانیکید*

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Introduction

Today, greenhouses play a crucial role in crop production, particularly for vegetables, fruits, and ornamental plants, where a large number of economically valuable plants, including vegetables and ornamental plants, are grown (Romero-Aranda et al., 2022; Gruda et al., 2025). The cultivation area of greenhouse vegetables in the world in 2019 was approximately 5.6 million hectares (Hickman, 2019). In Iran, the total area under greenhouse cultivation reached 13,540 hectares in 2023 (Ministry of Agriculture-Jahad, 2023). Cucumber is one of the most popular greenhouse vegetables worldwide (Pal, 2020). Among vegetable and summer crops, cucumber has the largest area of cultivation and production in all greenhouse products, with the share of this product in the area of cultivation and production of greenhouse crops in the country being 63.48% and 62.68%, respectively (Salehi & Javanpour, 2008; Bayat et al., 2023).

The two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae) is one of the most destructive invasive pests that attacks and damages more than 1000 plant species belonging to more than 140 plant genera (Kumral et al., 2017; Zélé et al., 2020). This mite is a major pest of greenhouse crops and affects most annual and perennial plants, such as tomatoes, peppers, cucumbers, strawberries, apples, grapes, and citrus fruits causing economic damage as well (Islam et al., 2017; Urbaneja-Bernat & Jaques, 2022). TSSM can affect the physiological processes of plants, reduce the level of photosynthetic activity, and cause severe leaf fall (Rincón et al., 2019). Pest control in greenhouse cultivation presents many challenges due to the stable and favorable conditions. Pests in greenhouses have a short generation period and a high reproduction rate compared to those in open fields (Arbabi & Baniameri, 2016; Alsendi et al., 2021). Pesticides are the main weapon used in the control of agricultural pests, despite the serious threats related to food safety and the environment (Zélé et al., 2020). The intensive use of insecticides and acaricides has led to resistance in many insect and mite species (Van Leeuwen et al., 2010; Alpkent et al., 2020). The prevalence and rapid spread of pesticide resistance in many pests have significantly reduced their effectiveness. These conditions lead to increased pesticide use and higher residue levels in agricultural products (Arbabi & Baniameri, 2016; Hanash et al., 2020). It has been estimated that the spider mite, *T. urticae* has evolved resistance to more than 80 acaricides to date (Knowles, 1997; Devine et al., 2001; Choi et al., 2004; Van Pottelberge et al., 2009). Therefore, alternative control strategies must be explored and evaluated as part of integrated pest management (IPM) programs to manage TSSM and other greenhouse pests (Attia et al., 2013; Adly & Sanad, 2024).

The integrated pest management (IPM) programs focus on the long-term protection of plants from pests and their damage through the combination and integration of various techniques such as biological control, crop rotation, habitat manipulation, using resistant cultivars while also minimizing the use of pesticides (Abdallah et al., 2014; Hooman, 2017). Induced resistance in plants is considered as part of the IPM system and a suitable option for pest and disease control (Warabieda & Oszak, 2010). Some natural or chemical compounds, including food elements, can induce defense responses in plants (Hosseini et al., 2020). Among all the nutrient elements, the most important element that affects plant diseases and pests is potassium (Amtmann et al., 2008). Potassium deficiency makes the cell wall leaky to the release of hydrocarbon materials and thus provides suitable conditions for pest attack (Malakouti, 2005). According to the studies of the last two decades, silicon (Si)

also plays an effective role in controlling pests and diseases; based on the revised definition of essential elements, silicon is now considered as a semi-essential element for organic plants (Epstein & Bloom, 2005; Ghasemi Negad Rayeni et al., 2024).

Another effective strategy is biological control agents which play an important role as one of the components of IPM. Among the natural enemies used to control TSSM, predatory mites, especially those from the Phytoseiidae family, receive special attention (Arbabi, 2007; Heydari et al., 2016). The use of predatory mites for the biological control of TSSMs began in the 1960s. Their applied studies have shown that only a small percentage of them, perhaps less than 5%, can effectively control harmful mites biologically (Arbabi & Singh, 1996). The phytoseiid mite, *Phytoseiulus persimilis* is a specialist predator feeding on *Tetranychus* species (McMurtry & Croft, 1997). It is considered the most frequently used biological control agent, especially in greenhouses (van Lenteren & Woets, 1988). Predatory mite *P. persimilis* receives special attention due to its high reproductive power, short growth period, and the ability to feed on all life stages of the spider mites (Arbabi, 2007). Today, this predator is used against damaging mites, especially TSSMs, in more than 85 countries of the world, including European countries, America, Canada, Brazil, Australia, New Zealand, China, Japan, Turkey, Russia, Egypt, and South Africa (Van de Vire, 1985; Van Lenteren & Van Woets, 1988); 60 to 90% of TSSM infestations in greenhouse environments are controlled by this predatory mite (Zhang, 2003). Also, the predatory mite *Amblyseius swirskii* Athias-Henriot from the Phytoseiidae family, as a generalist predator, can feed on various insects and mites as well as plant pollen. This predator can control a large number of pests in the greenhouse similar to other general predators (Symondson et al., 2002).

Foliar sprays of pesticides are frequently used to control two-spotted mites (TSSM) in Iranian greenhouses, but these also destroy natural enemies and pose a high risk to humans and the environment. Moreover, the application of pesticides has led to resistance in populations of TSSM in most of the locations where collections and resistance monitoring has occurred (Van Pottelberge et al., 2009; Ahmed et al., 2021). Furthermore, the use of chemical pesticides can adversely affect natural enemies, such as phytoseiid mites, which are generally more sensitive to pesticides than other mites (Abdelwines & Ahmed, 2022). To minimize the negative effects of chemical control, a more rational form of pest management can be provided by evaluating and combining safer alternative strategies (Kogan, 1998).

Due to the high consumption of fresh cucumber products in Iran, the use of chemical pesticides for pest control is limited (Amrollahi et al., 2018). Thus, the use of alternative safe and low-risk methods, including biological control agents, is unavoidable. The present study aims to control the phytophagous mite, *T. urticae* in cucumber greenhouses and compare the effectiveness of two predatory mite species (*P. persimilis* and *A. swirskii*), potassium silicate compounds, as well as the acaricide Etoxazole.

Materials and Methods

Cultivation of cucumber as host plant

This research was carried out in a 300 square meter greenhouse located in Qaemshahr city with the physical characteristics of a standard arched metal structure (area of 300 m², 30 m in length, 10 m in width, and a sidewall height of 4.5 m, equipped with drip irrigation, side and roof ventilation), during the months of April to August 2023 (Figure 1). Following the

method of Modarres-Najafabadi et al. (2019), cucumber plants (Victor variety: Seminis Company) was planted as a pest host. After selecting the seeds, they were planted in pots containing peat moss to grow seedlings for cultivation in the greenhouse. Then, the pots were placed at 30°C with 16L: 8D photoperiod and over 70% relative humidity (RH). They germinated after 7 days, and cucumber seedlings were transferred to the greenhouse after reaching the true leaf stage. For this purpose, the greenhouse bed was prepared in the form of stream and stack. The width of the stream was 50 cm and the width of the stack was 100 cm, and the bushes were planted on both sides of the stream 5 cm away from the edge of the stream. The distance between the rows was 50 cm on both sides of the ridge and 90 cm on the other, and the distance within each row was 40 cm. Irrigation of seedlings in the greenhouse was carried out in the form of drip irrigation.

Rearing of TSSM and contamination of cucumber plants

Before applying the treatments, a colony of *T. urticae* was reared. According to the method of Bahari et al. (2018), the primary mite colony was collected from the surrounding cucumber fields or bean plants and reared in the growth room of the botanical department on bean plants under controlled conditions of 25 ± 2°C, 65 ± 5% relative humidity and 16L: 8D photoperiod. After a few weeks, when the mite population had sufficiently increased, adult female mites were used to infest the cucumber plants. In this regard, 20 adult TSSM females were removed from the base colony and placed on the youngest fully expanded leaf for each plant.

Implementation of the pilot project

A randomized complete block design (RCBD) with six treatments in three blocks was implemented in the greenhouse. The treatments included two silicon-based fertilizers, two predatory mite species released at different rates and frequencies, a chemical acaricide (Etoxazole), and an untreated control. Detailed descriptions of the treatments and their application rates are provided in Table 1. The entire experiment was conducted in three independent trials to ensure reproducibility and reliability of the results. Each trial followed the same experimental design and conditions.



Figure 1. The greenhouse (300 square meter; 4.5 m height) for the cultivation of cucumber as host plant for two-spotted spider mite (TSSM), *Tetranychus urticae* Koch located in Qaemshahr city, Mazandaran province.

Table 1. The characteristics of the treatments used for controlling TSSM in cucumber greenhouse.

Treatment	Compound/product name	Application rate	Composition	Produced company
Fertilizer	FERMOLIFE Silicon	2 ml/l of water	12% K_2O + 25% SiO_2	Baharan Co.
Fertilizer	SILICA PRIME	2 ml/l of water	20% K_2O + 32% SiO_2	Sevin Chemical
Bio-agent	*Phytoseiulus persimilis*	10 mites/m^2	2000 mites/bottle	Mahargar Insectarium
Bio-agent	*Amblyseius swirskii*	100 mites/m^2	2000 mites/bottle	Mahargar Insectarium
Pesticide	Etoxazole (Baroque)	0.25 ml/l of water	Baroque® (SC 10%)	Kavosh Kimia Kerman Co.
Control	No treatment			

Each treatment was applied on an eight-meter planting line. In order to avoid the effect of mixing treatments with each other, a distance of 1.5 meters was considered between the treatments in each block, as well as a distance of 3 meters between the blocks. For each replication of each treatment, five plants were considered. Foliar spraying of fertilizers was done according to the instructions on the fertilizer in the morning and at five times after the two-leaf stage of the plant. Repetitions of fertilizer treatments (based on the container label) and Etoxazole acaricide (based on the container label) were carried out every 10 days with the respective concentrations and applied by dissolving the compound in water and using a 20-liter electric knapsack sprayer with a four-hole lance in Greenhouse. The predatory mite *P. persimilis* was released in three times with two-week intervals, and *A. swirskii* was released once, following established practices of augmentative biological control (Liang et al., 2013; Lemaire et al., 2025). All three trials were conducted separately, maintaining identical treatment applications and environmental conditions.

Sampling and data collection

In order to evaluate the population reduction of the active stages of the TSSM, every 10 days after spraying, five leaves from each treatment and each replication were collected, and the number of live mites (adults and nymphs) was counted under a stereomicroscope in the laboratory. The interval between sampling and counting was as short as possible to prevent changes between blocks due to sampling. The desired criterion for distinguishing the living from the dead was observing their movement. This sampling procedure was consistently followed across all three experimental trials.

Calculating the percentage of mortality

The loss percentage was calculated using the Henderson-Tilton formula (Henderson & Tilton, 1955):

$$\text{Mortality}\ (\%) = (1 - \frac{T_a \times C_b}{T_b \times C_a}) \times 100$$

T_a: the number of live individuals after treatment, T_b: the number of live individuals before treatment, C_a: the number of live individuals in the control (untreated check) after treatment and C_b: the number of live individuals in the control (untreated check) before treatment.

Calculation of leaf damage index

The leaf damage index was assessed based on a scoring system modified from Meyer (1996). Each leaf was assigned a score from 0 to 5 according to the percentage of the damaged leaf area, as detailed below:

Damage score	0	1	2	3	4	5
Leaf damage	No damage	1–20%	21–40%	41–60%	61–80%	More than 80%

Statistical Analysis

Data analysis was performed by one-way analysis of variance (ANOVA) using SAS software (version 9.4). Mean comparisons were performed using Duncan's multiple range test at a 1% significance level. Data from the three independent trials were analyzed separately to confirm consistency, and then combined for final statistical analysis.

Results

Comparison of treatment effectiveness

The analysis of variance revealed that the highest (97.08%) and lowest (54.97) of mortality percentage at 10 DAT (days after treatments) were observed in the plots treated with *P. persimilis* and F. Silicon, respectively (Table 2; Figure 2). The highest efficiency by *P. persimilis* (97.08%) had no significant difference with plots treated with Etoxazole (91.26%). Following, the plots treated with predatory mite, *A. swirskii* resulted the efficiency percentage of an average of 72.88% which was significantly lower than *P. persimilis* and Etoxazole but higher than Silica Prime and F. Silicon. The results indicated that Silica Prime (59.84%) and F. Silicon (54.97%) treatments showed no significant difference from each other. At 20 DAT, the highest mortality (95.50%) was observed in the plots treated with Etoxazole which was significantly higher than other treatments. The next highest mortality rate was recorded in the plots treated with the predatory mite *P. persimilis* (87.66%) mortality. Further, the application of Silica Prime resulted in a mortality rate of 80.86%. The results also showed that while the application of F. Silicon (74.82%) and the predatory mite *A. swirskii* (63.95%) led to significant reductions in TSSM populations, their effects were lower compared to the aforementioned treatments at 20 DAT (Figure 2).

At 30 DAT, the highest mortality (90.20%) was related to the plots treated by the predatory mite *P. persimilis* which had significant difference compared to other treatments. Silica Prime (81.09%) and Etoxazole (78.53%) showed no significant difference from each other but were both significantly higher than F. Silicon (72.09%). The predatory mite *A. swirskii* resulted in the lowest mortality (29.83%), which was significantly different from all other treatments. Additionally, no significant difference was observed between F. Silicon and Etoxazole. At 40 DAT, the highest mortality (96.28%) was observed in *P. persimilis*, which was significantly higher than all other treatments. Silica Prime (86.82%) showed significantly higher mortality than Etoxazole (73.21%) and F. Silicon (68.72%). There was no significant difference between Etoxazole and F. Silicon at 40 DAT. *A. swirskii* had the lowest recorded mortality (44.48%), which was significantly different from all other treatments (Figure 2). At 50 DAT, the highest mortality percentage (93.36%) was recorded in the plots treated with *P. persimilis* followed by Silica Prime (83.46%) which had no significant difference with each other. There was not significant difference among the plots treated with Etoxazole (72.15%), F. silicon (65.77%) and *A. swirskii* (58.44%). Based on the results of comparing the average value of treatments during the sampling period, the highest efficiency (92.91%) was obtained for *P. persimilis* treatment, which had a significant difference with other treatments. This was followed by foliar spraying with Etoxazole acaricide, which caused 82.13% mortality. The use of Silica Prime recorded an average mortality of 78.41%. The application of F. Silicon fertilizer and the predatory mite *A. swirskii* also recorded average mortality of 67.27% and 53.92%, respectively, with significantly differences compared to each other and other treatments (Table 2).

Temporal variation in treatment effectiveness

The highest efficiency of F. Silicon was observed at 20 DAT (74.82%), with no significant difference from 30 DAT, while the lowest efficiency (54.97%) occurred at 10 DAT. The trend indicated an initial increase in efficacy up to 20 DAT, followed by a decline, although mortality at 50 DAT remained significantly higher than at 10 DAT. Silica Prim demonstrated the highest efficiency at 40 DAT (86.82%), with a slight but non-significant decline at 50 DAT, while the lowest mortality rate (59.84%) was recorded at 10 DAT. The trend showed a gradual increase up to 40 DAT, followed by a minor reduction. *P. persimilis* exhibited its highest mortality effect (97.08%) at 10 DAT, while the lowest (87.66%) was recorded at 20 DAT, with fluctuations in efficiency observed over the 50-day period. Similarly, *A. swirskii* achieved the highest mortality at 10 DAT (72.88%), but efficiency significantly declined at 30 DAT (29.83%) before recovering in the final 20 days. Etoxazole displayed an increasing trend in efficiency during the first 20 days, reaching a peak of 95.50% at 20 DAT. However, over the remaining 30 days, efficiency gradually declined by approximately 23%, reaching the lowest level (72.15%) at 50 DAT despite multiple applications. It is important to note that these variations in mortality rates, particularly the declines observed at later time points for some treatments, may be attributed to the fact that results represent the mean of three independent experimental replications, which could introduce variability in recorded efficiencies over time (Table 2).

Comparison of leaf damage index

The analysis of variance revealed that the average LDI at 10 DAT showed that the lowest leaf damage index was 0.73 and 0.87 in the plots treated with *P. persimilis* and Etoxazole, respectively, with non-significant difference. The plots treated with the predatory mite, *A. swirskii* showed an LDI of 1.67, which was higher than that of the plots treated with *P. persimilis* and Etoxazole. The evaluated LDI for Silica Prime and F. Silicon treatments were 2.20 and 2.33, respectively. At 10 DAT, the highest LDI was determined with an average of 4.80, which had a significant difference and was related to the control treatment. The results at 20 DAT

Table 2. The percentage of mortality of different treatments on two-spotted spider mite (TSSM), *Tetranychus urticae* controlling at 10 to 50 days after treatments (DAT).

Treatments	Mean ± SE**					
	10 DAT‡	20 DAT	30 DAT	40 DAT	50 DAT	Mean (%)
F. Silicon	54.97±2.12D(c)	74.82±1.34A(c)	72.09±2.59AB(c)	68.72±1.41BC(c)	65.77±2.40C(c)	67.27±1.97
Silica Prime	59.84±1.55C(c)	80.86±1.39B(bc)	81.09±1.24B(b)	86.82±1.54A(b)	83.46±1.11AB(ab)	78.41±1.37
P. persimilis	97.08±2.06A(a)	87.66±2.33C(b)	90.20±1.25BC(a)	96.28±1.39A(a)	93.36±1.72AB(a)	92.91±1.75
A. swirskii	72.88±2.14A(b)	63.95±2.34B(d)	29.83±2.05E(e)	44.48±2.91D(d)	58.44±2.97C(d)	53.92±2.47
Etoxazole	91.26±2.81A(a)	95.50±2.12A(a)	78.53±2.84B(bc)	73.21±2.11BC(c)	72.15±1.17C(bc)	82.13±2.21

** Different uppercase letters in each row indicate significant differences ($P < 0.01$) between treatment efficiencies over time, while lowercase letters in each column show differences among treatments on the same time

‡ DAT = Days after treatment

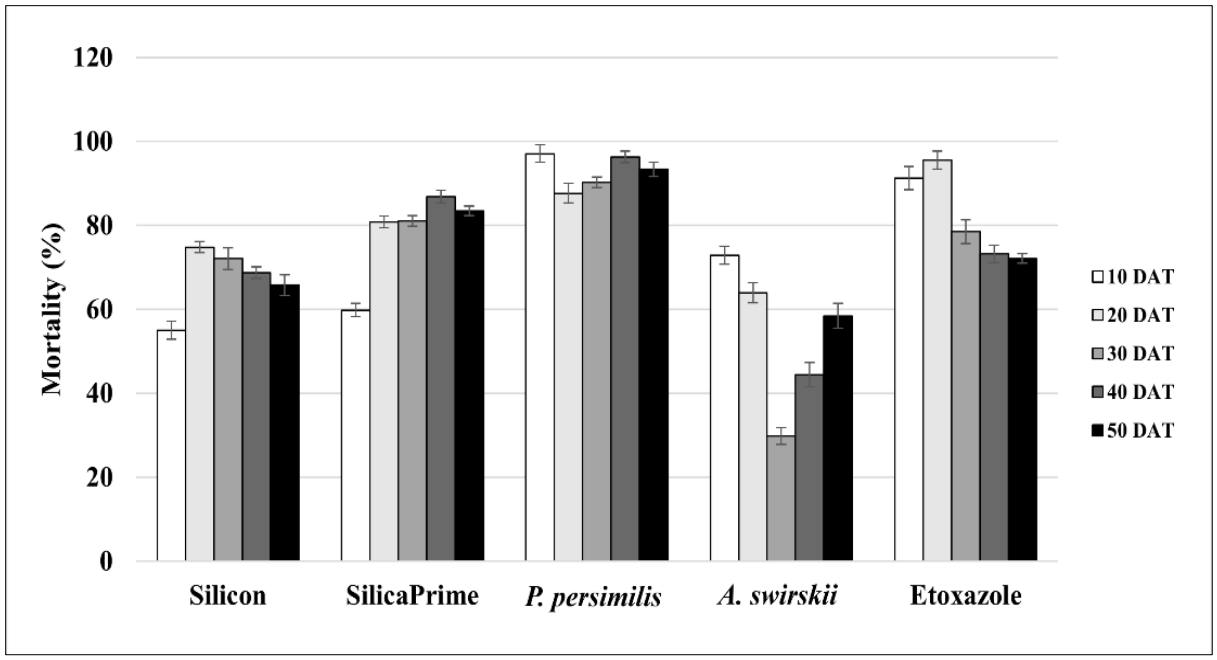


Figure 2. The percentage of the mortality of two-spotted spider mite (TSSM), *Tetranychus urticae* affected by different treatments at 10 to 50 days after treatments (DAT).

revealed that the lowest LDI, 0.40, was related to the Etoxazole treatment, with a significant difference compared to other treatments. The plots treated with *P. persimilis* and Silica Prime had LDI values of 0.73 and 1.20, respectively, and were ranked after Etoxazole, with a significant difference. The highest LDI (4.53) was recorded in the non-treated control, followed by *A. swirskii* (1.47) and F. Silicon (1.67). The results at 30 DAT revealed that the lowest LDI, 0.53, was related to the plots treated with *P. persimilis*, with a significant difference compared to other treatments. The plots treated with Silica Prime, Etoxazole, and F. Silicon had LDI values of 1.20, 1.33, and 1.40, respectively, and were placed after the plots treated with *P. persimilis*, with no significant difference. The highest LDI (4.13) was recorded in the non-treated control, with a significant difference, followed by *A. swirskii* (2.33) (Table 3).

At 40 DAT, the plots treated with *P. persimilis*, Silica Prime, and F. Silicon indicated LDI of 0.40, 1.07 and 1.67, respectively with a significant difference. Followed by *A. swirskii* (2.13) and Etoxazole (2.20), with non-significant differences. The highest LDI (4.47) was recorded in the Non-Treated Control with significant difference. Finally, the analysis of variance revealed that the LDI at 50 DAT was found to be significant. At 50 DAT, the lowest (0.60) and highest (4.88) LDI were observed in the plots treated with *P. persimilis* and Non-Treated Control plots respectively. Additionally, the plots treated by Silica Prime, *A. swirskii*, F. Silicon and Etoxazole showed and averages of 1.27, and 1.73, 1.87, 1.87 and 2.87 of LDI, respectively. But at 50 DAT, LDI was found non-significant difference between *A. swirskii* and F. Silicon treatments. Overall, the application of *P. persimilis* predatory mite in three times, Silica Prime in five times, *A. swirskii* predatory mite in one time, F. Silicon in five times, and Etoxazole acaricide in five times caused an average leaf damage index (LDI) of 0.60, 1.39, 1.87, 1.79 and 1.53 by TSSM, respectively (Table 3).

Table 3. Leaf damage index (LDI) of greenhouse cucumber plants at different days after treatment.

Treatments	Mean ± SE**					
	10 DAT‡	20 DAT	30 DAT	40 DAT	50 DAT	Mean ± SE
F. Silicon	2.33±0.08B	1.67±0.13B	1.40±0.11C	1.67±0.14C	1.87±0.13C	1.79±0.12
Silica Prime	2.20±0.12B	1.20±0.10C	1.20±0.05C	1.07±0.11D	1.27±0.15D	1.39±0.11
P. persimilis	0.73±0.06D	0.73±0.07D	0.53±0.04D	0.40±±0.06E	0.60±0.08E	0.60±0.06
A. swirskii	1.67±0.07C	1.47±0.05B	2.33±0.08B	2.13±0.10B	1.73±0.07C	1.87±0.07
Etoxazole	0.87±0.06D	0.40±0.01E	1.33±0.07C	2.20±0.12B	2.87±0.18B	1.53±0.09
Control	4.80±0.12A	4.53±0.17A	4.13±0.18A	4.47±0.23A	4.88±0.26A	4.56±0.19

** Different letters in each column indicates a significant difference between the treatments ($P < 0.01$).
‡ DAT = Days after treatment.

Discussion

The present study focused on evaluating the effectiveness of different safer control methods including using two predatory species, *P. persimilis* and *A. swirskii* and the two fertilizers compared to chemical control for managing two-spotted spider mite (TSSM) in a cucumber commercial greenhouse during April to August 2023. The results of the study significantly indicated that the application of bio-agents has higher or even equal effectiveness compare to the use of the pesticide in controlling of TSSM. However, the three-time releases of the predatory mite *P. persimilis*, at 50 days after treatment (DAT) resulted in an average mortality of 92.92%, whereas, the one-time release of another phytoseiid mite, *A. swirskii*, caused 53.92% mortality on the TSSM population. This shows that the predatory mite, *P. persimilis* led to significant reductions in pest populations compared to *A. swirskii*. These findings agree with Arbabi (2007) who reported the effectiveness of the *P. persimilis* predatory mite in controlling TSSM in wooden and metal frame cucumber greenhouses in Varamin region at three times of release. Other studies have indicated the possibility of using *P. persimilis* to efficiently control TSSM on various vegetable crops in greenhouses across different provinces of Iran. The study of different predator: prey release ratios to suppress the population of TSSM on cucumber plants indicated that the greatest suppression of the population was found at the predator to prey release ratio of 4:1 for both predators; *P. persimilis* and *A. swirskii* (Moghadasi & Allahyari, 2018). Ahmadi et al. (2020) studied the biological control of TSSM using phytoseiid predatory mites, *P. persimilis* and *A. swirskii* on four rose cultivars in a commercial rose greenhouse. They found that *P. persimilis* had the ability to reduce the density of spider mites, but *A. swirskii* had no obvious effect on reducing the density of TSSM. The results of an investigation into the efficiency of *P. persimilis* in controlling TSSM on pepper plants indicated that it had higher activity than other predators, especially *A. swirskii* predatory mite (Barghout et al., 2022). The present study also confirmed that the efficiency of the *P. persimilis* was significantly higher than that of *A. swirskii*.

The results of the present study also indicated that the release of predatory mites fewer times compared to foliar spraying with Etoxazole achieved an acceptable efficiency for TSSM control. The results agree with Abou-Haidar et al. (2021) who also found that in integrated pest management programs, the release of biological control agents, *A. swirskii* and *P. persimilis* effectively maintains the cucumber pest population below the economic threshold. In addition, they found that biological control agents were equally or more effective in suppressing pest populations compared to several insecticides and acaricides applied to control

TSSM in cucumber greenhouses which was confirmed by the present study.

In this study, two fertilizer treatments, Silica Prime and F. Silicon, were evaluated to control mite populations, and results indicated the effectiveness of the examined potassium silicate compounds in reducing the pest population. The effectiveness of the examined potassium silicate compounds, Silica Prime and F. Silicon was recorded as 78.41 and 67.27% mortality, respectively, during the 50 days after treatment application. The role of potassium silicate compounds in inducing resistance in the host plant against harmful mites, especially TSSM, has been proven by several studies (Afifi et al., 2015; Catalani et al., 2016). These compounds have both the effect of inducing the defensive reaction of the plant host, which results in less damage to the plant, and in some cases, they control and suppress the pest population with their acaricidal effect (Alzoubi & Çobanoğlu, 2010; De Toledo & Reis, 2018; Emam et al., 2021; Abdelwines & Ahmed, 2022; Ali et al., 2022). Khodayari and Abedini (2019) studied the possibility of creating resistance in cucumber against TSSM through foliar spraying of the two elements potassium and phosphorus, by studying the life table of this mite on the Kish variety cucumber plant. They reported that Phosphate-Ka compounds which contained both elements of potassium and phosphorus, at a concentration of 10 ml/liter with three foliar spraying, caused a significant decline in some parameters of the life table of TSSM compared to the control. Therefore, they concluded that foliar spraying of cucumber plants with Phosphate-Ka fertilizers can reduce the survival and reproduction of the spider mite. Additionally, Rezaei et al. (2020) examined the effect of fertilizers based on silicon (Si) such as potassium silicate and calcium silicate, on the biological parameters and density of TSSM on five varieties of beans. They reported that liquid potassium silicate and powdered calcium silicate, respectively, caused the greatest reduction in survival rate and life expectancy, as well as the reduction in the egg-to-larvae, larva-to-nymph, and nymph-to-mite transition rates. Hosseini et al. (2020) also evaluated the effect of a potassium silicate protective fertilizer on the control of TSSM. They observed the highest percentage of mite mortality (79.2%) in the treatment combining protective fertilizer and pesticides in both stages of application, before and after the plant was infected with mites. Furthermore, the application of fertilizer treatments before and after infecting the plant with mites caused 53 and 72% mortality, respectively. Additionally, Liu et al. (2020) conducted an experiment to assess the effects of silicon application as fertilizer on strawberry plants against TSSM. The silicon treatments reduced the severity of pest damage in two consecutive years across different strawberry cultivars. Ismail et al. (2022) examined the effect of silicon in the form of oligomeric silicic acid and potassium silicate in inducing resistance in eggplant against TSSM infestation under field conditions. They reported that both forms of silicon at high concentration (4 ml/l) significantly reduced the number of mites in treated eggplant plants. Gatarayiha et al. (2010) also found that the application of potassium silicate at a ratio of 0.08% (volume/volume) caused a reduction of 32.6, 35.7, and 52.1% of leaf damage by TSSM in eggplant, bean, and cucumber plants, respectively. This finding aligns with the present study, confirming the positive effect of potassium silicate compounds in reducing leaf damage. The findings of the present study also indicated that five applications of the chemical acaricide Etoxazole achieving an 82.13% control efficiency in controlling this pest which was lower than the effect of the predatory mite *P. persimilis* and close to that of potassium silicate compounds. Also,

in the present study, the lowest leaf damage index (LDI) was reduced in the *P. persimilis* treatment compared to *A. swirskii*, Silica Prime, F. Silicon and Etoxazole, confirming the role of *P. persimilis* in controlling TSSM. These findings suggested that an integrated approach utilizing Etoxazole in conjunction with biological agent especially *P. persimilis* and potassium silicate compounds can be an effective alternative for TSSM management in greenhouse cucumber production in Iran.

Conclusion

In the present study, we developed an integrated strategy incorporating two biological agents (*P. persimilis* and *A. swirskii*), two potassium silicate compounds (FERMOLIFE Silicon and Silica Prime), and Etoxazole to control TSSM on cucumber in greenhouses. The selection of Etoxazole as the chemical agent in the integrated strategy was based on its relative toxicity level and safety profile. The results demonstrated the success of this integrated strategy in controlling TSSM populations. The introduction of the predatory mite, especially *P. persimilis*, effectively reduced mite populations and leaf damage in cucumber greenhouses. Leaf damage was also effectively reduced by integrating the release of phytoseiid predatory mites with foliar spraying of potassium silicate compounds as a safer alternative. Therefore, for integrated pest management in Iranian greenhouse cucumber production, it is recommended to use biological control agents, silicon-based fertilizers, and a low-risk pesticide at minimal application rates. This approach can help effectively suppress pest populations. All tested programs provided comparable levels of pest control. However, the advantage of biological control is that it ensures pesticide residue-free yields, presenting a promising alternative for managing TSSM infestations in the future.

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