Persian J. Acarol., 15(2): 150210.

https://www.persianacarology.org

Research Article https://biotaxa.org/pja https://doi.org/10.22073/ pja.150210

Manipulating concentration of bifenazate and release time of *Phytoseiulus persimilis* (Acari: Phytoseiidae) maximizes their compatibility for integrated management of *Tetranychus urticae* (Acari: Tetranychidae)

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Received:
02 February, 2026
Accepted:
21 March, 2026
Published:
15 April, 2026

Subject Editor:
A. Farazmand

ABSTRACT

Investigating the potential effects of chemical pesticides on the biological performance of natural enemies is crucial for the successful implementation of integrated pest management programs. In the present study, the effects of low concentrations (LC_{10} = 5.14, LC_{20} = 12.55, and LC_{30} = 23.89 mg a.i./L) of bifenazate (Floramite® 24% SC) on the predation parameters of *Phytoseiulus persimilis* Athias-Henriot feeding on larvae and protonymphs of *Tetranychus urticae* Koch were investigated under laboratory conditions. The results indicated that the appropriate time interval for releasing the predator after the application of bifenazate (LC_{30} = 23.89 mg a.i./L) was at least 48 hours, as no obvious effects on its survival and predation parameters were detected. Furthermore, exposure to the low concentrations had no carryover effects on the predation performance of the offsprings. The age-stage specific predation rate (c_{xj}) increased with increasing age and stage of individuals and had the highest value for adult females, although its peak value decreased with increasing concentration. The values of net predation rate (C_0), finite predation rate (ω), transformation rate (Q_p), and stable predation rate (ψ) in the subsequent generation were not significantly affected when the female predators were exposed to the different concentrations. These results indicate that the different low concentrations of bifenazate had no negative effects on the predation performance of *P. persimilis* and its offspring. Therefore, their combination may play an important role in the sustainable management of *T. urticae*.

KEYWORDS

Acaricides, predation rate, predatory mites, sublethal effects, two-spotted spider mite

CITE: Rezaei, E. & Sedaratian-Jahromi, A. (2026) Manipulating concentration of bifenazate and release time of *Phytoseiulus persimilis* (Acari: Phytoseiidae) maximizes their compatibility for integrated management of *Tetranychus urticae* (Acari: Tetranychidae). *Persian Journal of Acarology*, 15(2): 150210.
https://doi.org/10.22073/pja.150210

INTRODUCTION

The two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), is a key phytophagous pest in both greenhouse and outdoor crops (Sedaratian *et al.* 2009). The control of TSSM is notoriously difficult and synthetic acaricides are considered as the main method for its management program. The high reliance on these chemicals causes several problems such as the development of resistant populations, environmental pollution, negative effects on non-target organisms and risks to human health (Sedaratian *et al.* 2011; Asadi *et al.* 2019; Khanamani *et al.* 2021). Therefore, there is great interest in effective and safe alternatives, especially biocontrol agents (Dalir *et al.* 2021; Kadkhodazadeh *et al.* 2021), selective acaricides (Rezaei *et al.* 2024) and the simultaneous application of acaricides and natural enemies (Azadi-Qoort *et al.* 2019). Integrated programs which emphasis on simultaneous application of biocontrol agents and acaricides have been noted as one of the most efficient strategies for sustainable management of populations of the TSSM (Jones *et al.* 2010). This approach could reduce

both the use of pesticides and their negative effects, which is one of the main objectives of IPM programs (Nicetic *et al.* 2001).

A fundamental component of any IPM program is understanding the compatibility of different strategies during their simultaneous application (Guedes *et al.* 2016). Regarding numerous reports addressing deleterious effects of chemicals on natural enemies of spider mites (*e.g.,* Schmidt-Jeffris *et al.* 2021; Rajaee *et al.* 2022; Mousavi *et al.* 2023; Rezaei *et al.* 2024), more attention should be devoted to finding safe compounds for successful implementation of integrated management programs (Saenz-de-Cabezon Irigaray *et al.* 2007). Accordingly, it is crucial to investigate all possible effects of pesticides on both behavioral and biological attributes of biocontrol agents (Desneux *et al.* 2007; Sedaratian *et al.* 2014). Phytoseiid mites (Acari; Mesostigmata; Phytoseiidae) are widely used worldwide in IPM to manage populations of different phytophagous mites and other pest arthropods (McMurtry *et al.* 2013). One of them, *Phytoseiulus persimilis* Athias-Henriot, is a specialist predator that controls web-spinning mites, especially *Tetranychus* species (McMurtry *et al.* 2013).

Toxicological studies that only evaluate lethality may underestimate the total effects of pesticides on pests and their natural enemies. Desneux *et al.* (2007) stated that the effects of low concentrations should also be considered to estimate overall impacts of pesticides. Even at low concentrations, pesticides may affect the survivorship, growth, development, reproduction, and behavioral parameters of natural enemies (Ibrahim and Yee 2000; Chen *et al.* 2003; Bernard 2004; Galvan *et al.* 2005; Teodoro *et al.* 2005; Hamedi *et al.* 2010, 2011; Alinejad *et al.* 2014, 2016; Monjaras-Barrera *et al.* 2019; Rajaee *et al.* 2022; Rezaei *et al.* 2024). Although the application of low concentrations of pesticides can reduce their acute toxicity to the biological performance of natural enemies, the reports mentioned above have shown that this strategy may also has some detrimental effects. Accordingly, there is a critical need to investigate the overall impact of pesticides on pests and their natural enemies. Despite the widespread application of bifenazate for controlling TSSM in different cropping systems (Rezaei *et al.* 2018), our current knowledge about the effects of its low concentrations on the biological performance of *P. persimilis* remains very limited. As a new selective carbazate acaricide, bifenazate is being globally used for controlling spider mites in different cropping systems at the recommended concentration of 100 ml/100 liters of water (van Leeuwen *et al.* 2015). This acaricide primarily acts on the mitochondria and inhibits the Qo site of cytochrome *b* within complex III (Bilbo and Walgenbach 2020). We hypothesized that considering a reasonable time interval for the release of *P. persimilis* after pesticide treatment and application of low concentrations will improve the ultimate efficiency of integrated management of the TSSM. Accordingly, the present study was designed to determine an appropriate interval for releasing predatory mite *P. persimilis* after spraying bifenazate. After determining the appropriate time, possible effects of low concentrations of bifenazate on consumption rate and predation parameters of *P. persimilis* were investigated.

MATERIALS AND METHODS

Host plant cultivation

Certified seeds of cucumber (*Cucumis sativus* var. Y-TOP) were sown into plastic pots (25 cm height and 18 cm diameter) filled with fertilized field soil typically used by commercial growers (1:1:1 mix of sand, clay, and sheep manure). The plants were grown under greenhouse conditions (25 ± 5 °C, 65 ± 10 % R.H., and a mean light period of 13 hours). During the experiments, all plants were irrigated every other day. No additional fertilizers or pesticides were used. The same-aged plants (≈ 6-8 true leaf stages) were selected for both rearing *T. urticae* and experimentations.

Preparing leaf discs

To evaluate the sublethal effects of bifenazate on the predation parameters of *P. persimilis*, a leaf disc method was used (Azadi-Qoort *et al.* 2025). The cucumber leaves were cut into 5.5 cm diameter and placed upside down on a thin layer of water-soaked cotton. Each leaf disc was placed in a Petri dish (6 cm diameter and 1.5 cm height) and surrounded by a strip of cotton. The prepared disc was put inside the larger ones (8 cm diameter and 1.5 cm height) which had a ventilation hole in the center of its door

(1.5 cm diameter). This hole was covered by a fine mesh net. In order to keep the freshness of cucumber leaf, distilled water was daily added into the larger disc.

Rearing mites

A colony of TSSM was built up from greenhouse specimens on cucumber plants, collected in Yasouj, Iran (30° 37' 58.8" N, 51° 38' 11.1" E). The collected leaves were placed in plastic bags and transferred into laboratory for removing unwanted organisms (other pests and natural enemies). *Tetranychus* species was identified according to the characters of the male aedeagus. After this, the leaves infested with different life stages of *T. urticae* were transferred into greenhouse conditions (25 ± 5 °C, 75 ± 10 % R.H., and a mean light period of 13 hours) and put on the cucumber plants. The plants infected with these samples were kept in fine mesh cages (150 × 90 × 90 cm). Ten healthy plants were weekly added to the mesh cages and the dead ones were removed. To minimize inbreeding effects, the mites collected from the same regions were periodically added to the stock colony.

A colony of *P. persimilis* was established with specimens (at least 500 mites) obtained from the Koppert Biological Systems (SPIDEX®). They were reared according to the method described by Asadi *et al.* (2019). Rearing units were prepared by putting a piece of green plastic sheet (20 × 15 × 0.1 cm) on a wet sponge inside a water-containing container (30 × 20 × 15 cm). Strips of tissue paper immersed in the water of the container were used to cover all edges of the sheet for providing water supply and avoid predator escape. After releasing the predators on the sheet, the cucumber leaves infested with eggs, larvae and protonymphs of *T. urticae* (≈ 150-200 per leaf) were daily added into this arena as a food source. Before introduction, the leaves were carefully checked, and deutonymph and adult prey were eliminated. To prevent any pollution, the old leaves were removed weekly from the rearing arena. The rearing protocol was conducted in a growth chamber at 25 ± 1 °C, 60 ± 5 % R.H., and a photoperiod of 16: 8 (L: D) hours.

Experimental conditions

All experiments were performed in a growth chamber at 25 ± 1 °C, 60 ± 5 % R.H., and a photoperiod of 16: 8 (L: D) hours.

Bioassay procedure

To accomplish the experiments, a commercial formulation of bifenazate (Floramite® SC 24%, Chemtura AgroSolutions, Philadelphia, Pennsylvania, USA), was used. A contact toxicity bioassay was conducted on deutonymphs of *T. urticae*, recommended target of bifenazate, using concentrations of 2.4, 4.8, 9.6, 19.2, 84, and 180 mg a.i./L, which were selected based on their activity in initial dose-setting tests. Five replications were considered for each concentration with twenty deutonymphs (< 24 hours old) in each one. Before the treatment, deutonymphs were transferred into the experimental arenas using a fine camel-hair brush. Cucumber leaf discs were similarly sprayed using a manual sprinkler (≈ 40 µL/cm^2). The control individuals were sprayed with distilled water. The mortality was recorded after 48 hours. The bioassay was repeated three times under the same conditions (Robertson *et al.* 2007).

Time-dependent toxicity

A completely randomized design (CRD) was used to evaluate the contact toxicity of bifenazate to the female predators. Thirty cucumber leaf discs (5.5 cm diameter) were prepared and sprayed with LC_{30} (23.89 mg a.i./L) of bifenazate using a manual sprinkler (≈ 40 µL/cm^2). After spraying, five arenas were randomly selected, and 10 unmated female predators (< 24 hours old) were immediately introduced into each (*i.e.*, time interval = 0). In addition, a mixture of larval and protonymph stages of the TSSM (≈ 200) was brushed into each arena as prey. The same procedures were repeated at 12, 24, 48, 72, and 96 hours after spraying (five arenas per interval). All experimental discs were maintained in a growth chamber for 48 hours, after which mortality was recorded. Distilled water was served as the control.

Contact effects of low concentrations of bifenazate on female predators

A set of 50 leaf discs was prepared for each treatment (low concentrations and control). The discs were sprayed with different low concentrations (LC_{10}, LC_{20}, and LC_{30}) and distilled water and kept in a growth chamber for 48 hours. After this time period, one female predator (< 24 hours old) was

transferred into each arena. A male predator was also added to each one. Forty newly emerged larva and protonymph of *T. urticae* were daily transferred into arenas as prey. Experimental arenas were daily checked and the number of preys eaten was recorded. Eaten prey was replaced in each unit. The experiments lasted until the death of all individuals.

Carryover effects on predation performance of offspring

On the 3rd day of oviposition, to evaluate carryover activity of different concentrations on the predation performance of the offspring from treated females, 60 eggs (< 24 hours old) were randomly selected from each treatment and individually placed into an untreated disc. The same procedure was also conducted for untreated females as control. The leaf discs were kept in a growth chamber. After the emergence of larvae, the experimental discs were daily supplied with 20 preys (larvae and protonymphs). The units were checked once a day and the number of preys consumed by predators was counted. With adult emergence, the males and females were coupled and supplied with 40 preys. The number of preys consumed was daily recorded and replaced until the death of both predators. Prey consumption of adult predators was related to the male and female together and share of each individual was considered to be 50/50 (Khanamani *et al.* 2015). The predation parameters were acquired based on the information of all individuals tested (including immature stages, females, males, and individuals who died during the pre-adult development), as suggested by Chi and Yang (2003).

Data analysis

Unbalanced one-way ANOVA was used to compare total and daily predation of adult females at different treatments (PROC GLM, SAS ver. 9.1.3). Mean grouping was performed using a Student-Newman-Keuls test (SNK) at a significant level of 0.05. Prior to the ANOVA, the normality of data was tested by the Kolmogorov-Smirnov assay (MINITAB ver. 14) and it was determined that the data were normally distributed.

Probit analysis was performed using the statistical package of SPSS (ver. 18) to determine the concentrations of bifenazate that kill 10, 20, and 30% of the deutonymphs of *T. urticae* (*ie.*, LC_{10}, LC_{20}, and LC_{30}).

The daily consumption of all stages and individuals was used to calculate the age-stage specific consumption rate (c_{xj}), the age-specific predation rate (k_x), the age-specific net predation rate (q_x), the net predation rate (C_0), the transformation rate (Q_p), the stable predation rate (ψ), and the finite predation rate (ω). All individuals' predation data were analyzed using the computer program CONSUME-MSChart (Chi 2018a). The standard errors of predation parameters were estimated using the bootstrap procedure using 100,000 resamples. The differences of predation bootstrap-values among the treatments were compared using the paired bootstrap test based on the confidence interval of the difference by the computer program TWOSEX MSChart (Chi 2018b). Figures and box plots were drawn by Excel (Microsoft Office, ver. 2016) and R (ver. 3.6.0), respectively.

RESULTS

Bioassay procedure

The results of the bioassay with bifenazate for the deutonymphs of *T. urticae* are presented in Table 1. The estimated value of LC_{50} after two days was 69.23 mg a.i./L (95% FL = 54.50–91.44), while no mortality was recorded in controls. Based on data from this assay, we calculated the low concentrations of LC_{10}, LC_{20}, and LC_{30} (Table 1).

Table 1. Toxicity of bifenazate on the deutonymphs of *Tetranychus urticae*.

Sublethal concentrations (mg a.i./L)*				
LC_{10} (95% FL)	**LC_{20} (95% FL)**	**LC_{30} (95% FL)**	**Slope ± SE**	**χ^2 (*df*)**
5.14 (3.36–7.15)	12.55 (9.29–16.13)	23.89 (18.76–29.92)	1.135 ± 0.092	7.763 (4)

* Different low concentrations and 95% fiducial limits (FL) were estimated using Probit analysis.

Time-dependent toxicity

The results revealed a time-dependent mortality in female predators released into the LC_{30}-treated discs ($F_{5, 28} = 32.67$; $P < 0.001$). Female predators were released into the treated arenas after 0, 12, and 24 hours. had suffered a mortality percentage of 26, 20, and 10, respectively. No mortality was recorded at 48 hours' time interval and higher ones.

Predation parameters of the treated females

Figure 1 exhibits that releasing the predators into arenas treated with different concentrations of bifenazate had no detectable effects on the total ($F = 0.42$; $df = 3, 171$; $P = 0.7423$) and daily ($F = 0.34$; $df = 3, 171$; $P = 0.7953$) consumption of this predaceous mite when predating larva and protonymph of *T. urticae*.

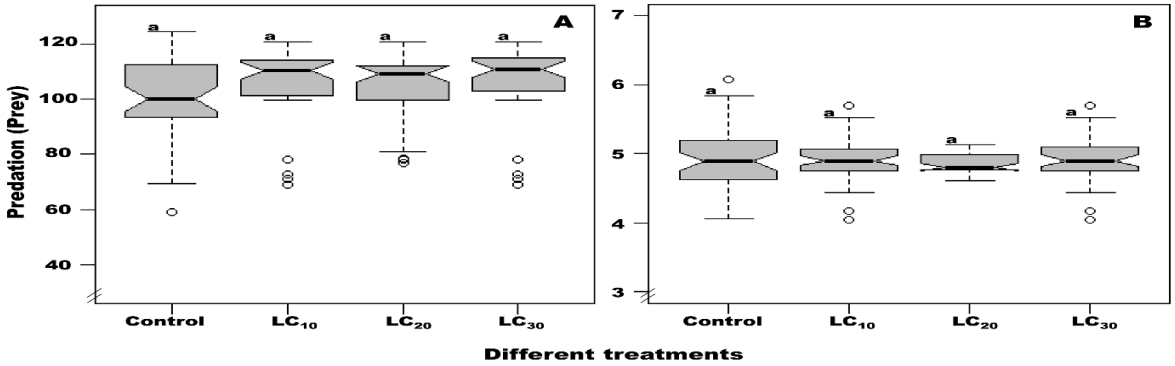

Figure 1. Total (A) and daily (B) predation (mean ± SE) of adult females of *Phytoseiulus persimilis* fed on *Tetranychus urticae* on treated arenas with different concentrations of bifenazate. The boxes represent 50% of the variation, whiskers the other 50% and the line indicates the median.

Carryover effects on the predation performance of offspring

The age-stage-specific predation rate (c_{xj}) illustrates the mean number of preys consumed by the immature and adult stages of the predator of age x and stage j at different concentrations of bifenazate (Fig. 2). The trend of c_{xj} values for *P. persimilis* at different treatments followed a similar pattern. In other words, different concentrations tested had no obvious effects on the trend of this parameter.

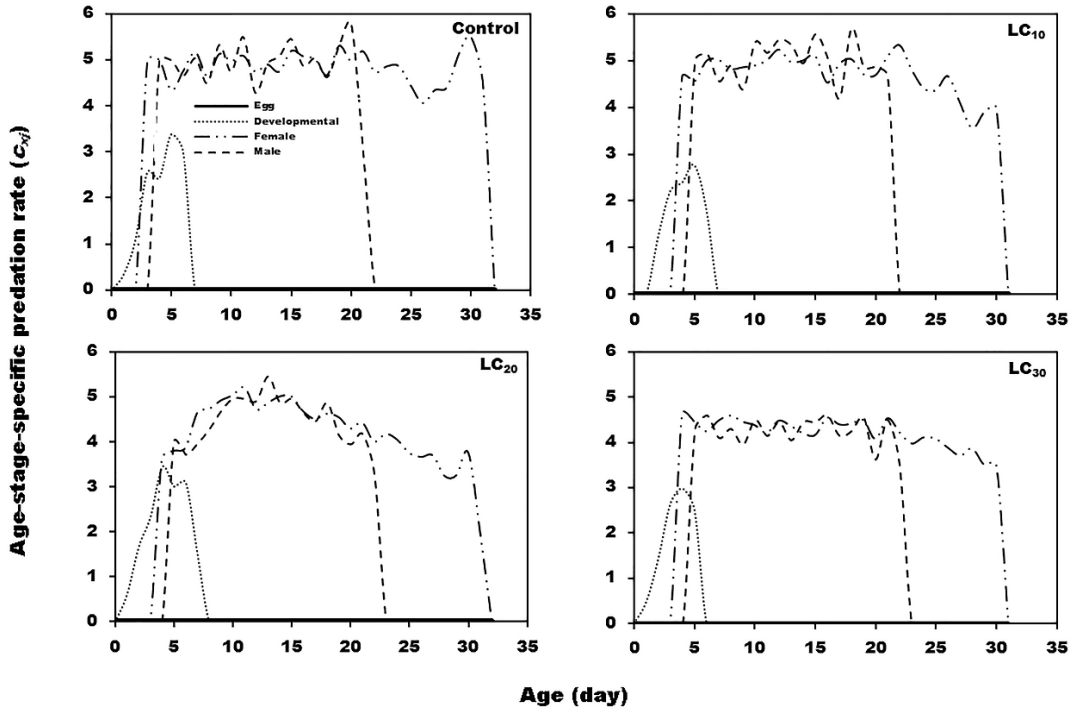

Figure 2. Age-stage-specific predation rate (c_{xj}) of offsprings from treated females of *Phytoseiulus persimilis* by different concentrations of bifenazate on *Tetranychus urticae*.

As illustrated in Figure 2, the value of age-stage-specific consumed preys was increased by developing new stages. Based on the results obtained, the highest value of this parameter for immature stages of *P. persimilis* was recorded in the treatment LC_{20}, while female and male individuals had the highest value in control. The highest number of preys consumed at the control, LC_{10}, LC_{20}, and LC_{30} was recorded for the female predators (24.00, 22.68, 22.07, and 21.90 preys) at the ages of 4, 5, 5, and 5 days, respectively. The adult males had the lowest value of this parameter (16.50, 15.55, 16.72, and 16.20 prey at the ages of 5, 6, 6, and 6 days, respectively) (Fig. 2).

The age-specific predation rate (k_x), and the age-specific net predation rate (q_x) of both treated and untreated individuals of *P. persimilis* are shown in Figure 3. The value recorded for k_x, which presents the mean number of preys consumed by the predators at age x, was gradually increased to its peak and then decreased by raising the predator's age in all treatments tested. From this figure, it is clearly realized that the highest value of k_x was obtained at the age of 31, 23, 12, and 17 days in the control (5.50 preys), LC_{10} (5.34 preys), LC_{20} (5.14 preys), and LC_{30} (4.55 preys), respectively. The maximum value for the q_x was estimated at the age of 16, 13, 12, and 9 days, respectively (control = 4.78; LC_{10} = 4.98; LC_{20} = 4.77; LC_{30} = 4.19 preys). The highest values of both k_x and q_x parameters occurred at the same age (day 12) when predators were exposed to the LC_{20}, where the value of l_x was 0.927 (Fig. 3). In the other treatments, however, the peak of q_x was observed at the earlier ages than k_x. This can be explained by the higher value of l_x at earlier ages compared with later ones. Figure 3 also shows that the values of k_x and q_x were identical until the age of 4 (control), 4 (LC_{10}), 6 (LC_{20}), and 5 (LC_{30}) days, where the first mortality was recorded and the age-specific survival rate (l_x) initiated to decrease from 1.

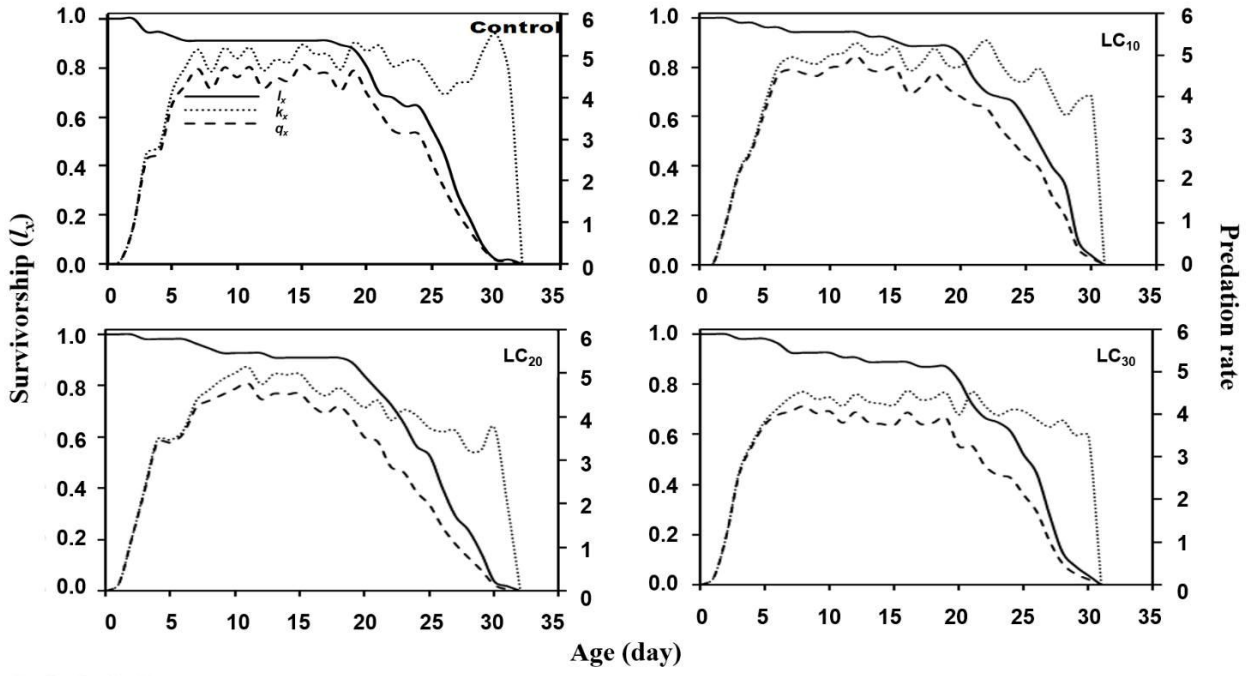

Figure 3. Age-specific survival rate (l_x), age-specific predation rate (k_x), and age-specific net predation rate (q_x) of offspring from treated females of *Phytoseiulus persimilis* by different concentrations of bifenazate on *Tetranychus urticae*.

Total prey consumption displays the total amount of consumed prey at each life stage of the predatory mite as long as the mite is alive (Fig. 4). In other words, it represents the total capacity of the cohort at age x and stage j. Regarding Figure 4, the values recorded for this parameter in different treatments fluctuated with similar trends, indicating no detectable effects of different concentrations. The highest amount of prey consumption in male (66.00 preys) and female (201.50 preys) individuals was observed in the control, and the highest amount of this parameter for immature stages was related to those evaluated at the LC_{20} (141.00 preys). For both immature and adult individuals, the lowest value of total consumption was observed in the LC_{30} treatment.

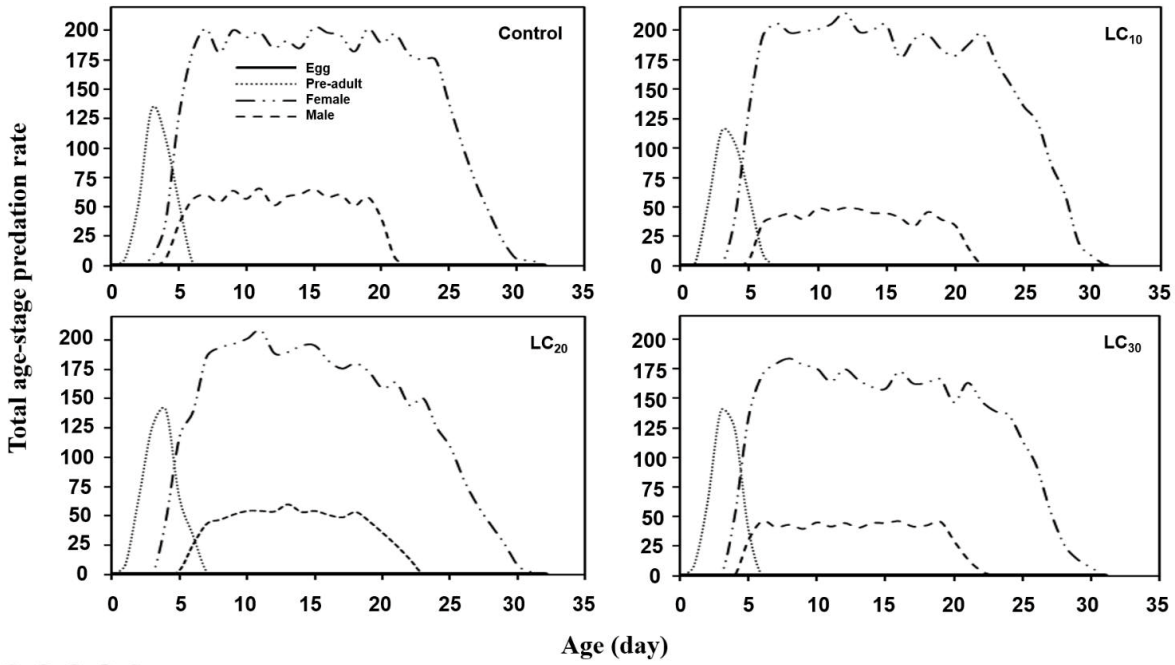

Figure 4. Total prey (*Tetranychus urticae*) consumption of different life stages of offspring from treated females of *Phytoseiulus persimilis* by different concentrations of bifenazate.

Predation parameters of the offspring from treated females of *P. persimilis* by different concentrations of bifenazate in comparison to the control group are presented in Table 2. Surprisingly, the outcomes reflected that exposing the female predators to the low concentrations of bifenazate had no significant effects on the mean number of preys consumed by a predator during its life span (C_0). Similarly, no significant differences were observed when comparing the finite predation rate (ω) and stable predation rate (ψ) of *P. persimilis* among different treatments. The transformation rate (Q_p) was not significantly affected by different concentrations of bifenazate (Table 2).

Table 2. Predation parameters (mean ± SE) of offspring from treated females of *Phytoseiulus persimilis* by different concentrations of bifenazate compared with control.

Parameters	Treatments			
	Control	LC_{10}	LC_{20}	LC_{30}
Net predation rate (C_0) (prey)	99.053 ± 4.59[a]	96.387 ± 4.461[a]	96.218 ± 3.963[a]	95.130 ± 4.065[a]
Finite predation rate (ω) (day^{-1})	2.151 ± 0.101[a]	2.097 ± 0.094[a]	2.165 ± 0.109[a]	2.162 ± 0.099[a]
Transformation rate (Q_p) (prey/offspring)	2.841 ± 0.184[a]	2.889 ± 0.159[a]	2.742 ± 0.187[a]	2.643 ± 0.164[a]
Stable predation rate (ψ) (prey/predator)	1.582 ± 0.060[a]	1.544 ± 0.050[a]	1.598 ± 0.070[a]	1.580 ± 0.060[a]

* Means followed by the same letters within the same row are not significantly different based on the paired bootstrap test with 100,000 resampling ($P < 0.05$).

DISCUSSION

One of the main concerns of integrated pest management programs is utilizing suitable techniques in a compatible manner (Kogan 1998; Koul *et al.* 2004; Fathipour and Sedaratian 2013). Minimizing the deleterious effects of chemical pesticides on the biological performance of natural enemies during their simultaneous application could promote the overall efficiency of such programs (Sedaratian-Jahromi 2021). In the current study, we hypothesized that increasing the time interval for releasing predatory mite *P. persimilis* after spraying low concentrations of bifenazate could minimize the possible deleterious effects

of this acaricide on the biological performance of the predator. Our findings show that bifenazate had no acute toxicity on *P. persimilis* after 48 hours and thus, this interval was selected for releasing predatory mites and investigating sublethal effects on the predation parameters. After this, predation parameters of *P. persimilis* predating *T. urticae* into the untreated and treated arenas were compared.

Consistent with Ochiai *et al.* (2007), our results indicate that bifenazate exerts no adverse effects on the biological performance of *P. persimilis*. While Ochiai *et al.* (2007) focused on biological parameters, this study provides the first comprehensive assessment of bifenazate's impacts on the predation parameters of *P. persimilis*, extending previous findings and confirming the compatibility of bifenazate with the predatory mite *P. persimilis*.

Our findings showed that female predators consumed more prey than other stages, which may be related to their larger size and higher energy requirements for reproduction. As previously mentioned, fecundity of female predators directly depends on their prey consumption (McMurtry *et al.* 1970). These evidences are in line with previous reports about the higher consumption rate of female predators during their oviposition period (*e.g.*, Pernando and Hassell 1980; Gutierrez *et al.* 1981; Hayes and McArdle 1987; Rasmy *et al.* 1991).

By considering the probability of survival of individuals (l_x) at the age-specific predation rate (k_{ex}), the net age-specific predation rate (q_x) was calculated ($q_x = l_x k_{ex}$). Accordingly, the values calculated for the net age-specific predation rate (q_x) in all treatments may be equal to or less than those estimated for the age-specific predation rate (k_{ex}), and the difference between these parameters is related to the effect of survival rate (l_x). From Figure 2, it is apparent that as long as the survival rate (l_x) was equal to 1, the values of parameters k_{ex} and q_x were identical. With decreasing survivorship, the difference between these parameters was observed.

According to the current study, the net predation rate (C_0) ranged from 95.13 to 99.05 prey, which was lower than what was estimated by Alipour *et al.* (2016) and Moghadasi *et al.* (2016), who reported that *P. persimilis* consumed 185.11–259 and 363.54 eggs of *T. urticae*, respectively. The lower biomass of tetranychid egg than its larva and protonymph explains the higher predation of *P. persimilis* in these studies than what was observed in the present study. The finite predation rate ($\omega = \lambda\psi$) is a standard parameter because it can help us to evaluate and compare the efficacy of the natural enemies used in the biocontrol programs by considering the finite rate of population increase (λ), the stable age-stage structure (a_{xj}), and the age-stage-specific predation rate (c_{xj}) (Safaeeniya *et al.* 2024). Our findings showed that *P. persimilis* needed an average of 2.64–2.89 prey to deposit one egg, which is substantially lower than previously reported for the transformation rate (Q_p) of this predator (Alipour *et al.* 2016; Moghadasi *et al.* 2016). Environmental conditions (Skirvin and Fenlon 2003), chemical acaricides (Kim and Yoo 2002), prey stage/species (Moghadasi *et al.* 2016), and host plant attributes (Krips *et al.* 1999) have been discussed as the most important factors causing such differences in the predation parameters of *P. persimilis*. According to our results, different concentrations of bifenazate did not have a considerable impact on the consumption rate of *P. persimilis*. This issue is in contrast with the earlier report published by Kim and Yoo (2002), who stated that exposure to chlorfenapyr and flufenoxuron had deleterious effects on the predation rate of *P. persimilis* on *T. urticae*. Undoubtedly, considering an appropriate interval for releasing predators in the present study had an incredible role in decreasing the deleterious effects of bifenazate on *P. persimilis* and its progeny.

High reliance on chemical pesticides for controlling phytophagous pests can't be considered a sustainable strategy, mainly in circumstances in which these compounds deleteriously impact the biological performance of natural enemies (Kaplan *et al.* 2012). As a selective acaricide, bifenazate has proven its performance for managing destructive populations of spider mites even at sublethal concentrations (Li *et al.* 2017; Rezaei *et al.* 2018). The information presented herein revealed that manipulating pesticide concentration and predator release time maximizes their compatibility for sustainable management of the TSSM. Our findings suggest that bifenazate can be safely integrated into spider mite management programs in which *P. persimilis* acts as the key biocontrol agent. Nevertheless,

further laboratory, semi-field, and field assessments are still needed to validate the efficacy of simultaneous application of bifenazate and *P. persimilis*.

Author contributions: Analyses and data curation: E.R., A.S.-J.; Writing–original draft preparation: E.R.; Writing – revisions and editing: A.S.-J.; Supervision: A.S.-J.; Funding acquisition: A.S.-J. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by the Yasouj University.

Availability of data and materials: Data are available upon request from the corresponding author.

Ethics approval and consent to participate: This study only included arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

Consent for publication: All participants in the study expressed their agreement with the publication.

Competing interests: The authors declare no conflict of interest.

Generative AI statement: The authors declare no use of Gen AI in the creation of this manuscript.

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افزایش میزان سازگاری بایفنازیت و کنهٔ شکارگر *Phytoseiulus persimilis* (Acari: Phytoseiidae) در برنامه مدیریت تلفیقی کنهٔ تارتن دولکه‌ای *Tetranychus urticae* (Acari: Tetranychidae) با دستکاری غلظت و زمان رهاسازی

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دریافت
۱۳ بهمن ۱۴۰۴
پذیرش
۱ فروردین ۱۴۰۵
انتشار
۲۶ فروردین ۱۴۰۵
دبیر تخصصی
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چکیده

بررسی اثرهای بالقوه آفت‌کش‌های شیمیایی بر کارایی زیستی دشمنان طبیعی برای اجرای موفقیت‌آمیز برنامه‌های مدیریت تلفیقی بسیار ضروری است. در مطالعه حاضر، اثرهای غلظت‌های کم (LC_{10} = 5.14، LC_{20} = 12.55 و LC_{30} = 23.89 میلی‌گرم ماده مؤثره بر لیتر) بایفنازیت (Floramite® 24% SC) بر پارامترهای شکارگری هرنای شکارگر *Phytoseiulus persimilis* Athias-Henriot با تغذیه از لارو و پورهٔ سن یکم هرنای تارتن دولکه‌ای در شرایط آزمایشگاهی مورد بررسی قرار گرفت. نتایج به‌دست آمده نشان داد که زمان مناسب رهاسازی هرنای شکارگر بعد از کاربرد بایفنازیت (LC_{30}) دست‌کم ۴۸ ساعت می‌باشد که پس از آن، هیچگونه اثرات منفی قابل ردیابی بر زنده‌مانی و پراسنجه‌های شکارگری مشاهده نشد. افزون بر این، مواجهه با غلظت‌های کم هیچگونه تأثیری بر کارایی شکارگری نتاج ماده‌های تیمار شده نیز نداشت. اگرچه حداکثر مقدار محاسبه شده میزان شکارگری ویژه سن–مرحله رشدی (e_{xj}) با افزایش غلظت مورد مطالعه کاهش یافت، اما مقادیر این پراسنجه در تیمارهای مختلف با افزایش سن و مرحله رشدی افراد مورد مطالعه افزایش یافت و بیشترین میزان آن در ماده‌های بالغ ثبت شد. مقادیر محاسبه شده میزان خالص شکارگری (C_0)، میزان متناهی شکارگری (ω)، میزان تبدیل (Q_b) و میزان پایدار شکارگری (ψ) در نتاج حاصل از ماده‌های تیمار شده، تحت تأثیر غلظت‌های مورد مطالعه قرار نگرفت. نتایج حاضر نشان داد که غلظت‌های کم مختلف بایفنازیت اثرهای منفی زیادی بر کارایی شکارگری هرنای شکارگر *P. persimilis* و نتاج آن ندارند. بنابراین، استفاده تلفیقی از آن‌ها می‌تواند نقش مهمی در مدیریت پایدار هرنای تارتن دولکه‌ای *T. urticae* داشته باشد.

واژگان کلیدی: کنه‌کش، هرناهای شکارگر، غلظت‌های زیرکشنده، میزان شکارگری، هرنای تارتن دولکه‌ای

CITE: Rezaei, E. & Sedaratian-Jahromi, A. (2026) Manipulating concentration of bifenazate and release time of *Phytoseiulus persimilis* (Acari: Phytoseiidae) maximizes their compatibility for integrated management of *Tetranychus urticae* (Acari: Tetranychidae). *Persian Journal of Acarology*, 15(2): 150210.
https://doi.org/10.22073/pja.150210