

# Effect of prey and pollen on interactions between *Typhlodromus bagdasarjani* and *Phytoseiulus persimilis* (Acari: Phytoseiidae) on cucumber (Cucurbitaceae)

Mona Moghadasi, Hossein Allahyari<sup>1</sup>

**Abstract**—Intraguild predation is a notable factor to proper application of biocontrol agents to reduce pest populations. Intraguild predation was studied between *Typhlodromus bagdasarjani* Wainstein and Arutunjan (Acari: Phytoseiidae) and *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) in presence and absence of *Tetranychus urticae* Koch (Acari: Tetranychidae) as well as pollen. Intraguild predation between two predators was bidirectional. The highest and the lowest predation rates of both predators in absence and presence of *T. urticae* as well as in the pollen treatments were on heterospecific eggs and deutonymphs, respectively. *Typhlodromus bagdasarjani* consumed more heterospecific eggs compared with *P. persimilis*. When pollen was added, predation of *T. bagdasarjani* significantly reduced on heterospecific eggs and deutonymphs in absence and presence of *T. urticae* treatments, respectively. However, predation rate of *P. persimilis* on heterospecific stages was not significantly affected by pollen addition. Oviposition of both predators was higher in presence of *T. urticae* than in its absence and oviposition of *P. persimilis* was significantly higher on heterospecific stages than *T. bagdasarjani*. Pollen addition had a significant effect on increasing the oviposition rate of *T. bagdasarjani*. Extraguild prey presence had a nonsignificant effect on the consumption rate of intraguild prey by the intraguild predators. However, presence of extraguild prey led to a significant increase in oviposition rate of both predators.

## Introduction

Tetranychid mite, particularly *Tetranychus urticae* Koch (Acari: Tetranychidae), are serious pests on many commercial crops worldwide and phytoseiid mites (Acari: Phytoseiidae) are the main biocontrol agents of the tetranychid mites in commercial greenhouses (McMurtry and Croft 1997; Schausberger 1997; Hatherly *et al.* 2005; Cakmak *et al.* 2006, 2009; Abad-Moyano *et al.* 2010; McMurtry *et al.* 2013). *Phytoseiulus persimilis* Athias-Henriot (Acari: Phytoseiidae) is a highly specialised tetranychids predator (McMurtry and Croft 1997; Walzer *et al.* 2001; McMurtry *et al.* 2013) and *Typhlodromus bagdasarjani* Wainstein and Arutunjan (Acari: Phytoseiidae) is a generalist indigenous widespread predator in the orchards of Iran (Daneshvar 1993; Kamali *et al.* 2001; Faraji *et al.* 2007; McMurtry *et al.* 2013). Both of the above-mentioned phytoseiid mites are known to

have an important role in control of *T. urticae* populations in laboratory and greenhouse conditions (Walzer and Schausberger 1999a, 1999b; Schausberger and Croft 2000a, 2000b; Cakmak *et al.* 2006, 2009; Ganjisaffar *et al.* 2011a, 2011b; Moghadasi *et al.* 2013, 2014; Daneshmandi *et al.* 2014; Farazmand *et al.* 2015a, 2015b). It has been known that *P. persimilis* is sensitive to high temperatures and low humidity but *T. bagdasarjani* is well adapted to such conditions (Skirvin and Fenlon 2003; Ganjisaffar *et al.* 2011a, 2011b). Moreover, *T. bagdasarjani* is a generalist predator that can feed and reproduce on pollen, plant exudates, honeydew, and fungi and can maintain its populations in conditions without prey (McMurtry and Croft 1997; McMurtry *et al.* 2013).

Several researches have reported that simultaneous release of various predator species could be more effective in reducing pest populations than release of a single species of predator (Schausberger

Received 13 December 2016. Accepted 20 April 2017. First published online 8 August 2017.

M. Moghadasi, H. Allahyari,<sup>1</sup> Department of Plant Protection, College of Agriculture and Natural Resources, University of Tehran, Karaj 3158711167, Iran

<sup>1</sup>Corresponding author (e-mail: allahyar@ut.ac.ir).  
Subject editor: David Sjaussat  
doi:10.4039/tce.2017.28

and Croft 2000a, 2000b; Schausberger and Walzer 2001; Walzer *et al.* 2001; Hatherly *et al.* 2005; Cakmak *et al.* 2006, 2009; Lucas and Rosenheim 2011). Therefore, knowledge of interactions within a predator complex is indispensable and intraguild predation is one of the most notable factors in such considerations. In planning a biological control programme it should be considered that predator interactions could be complementary and increase suppression of a pest population. In contrast, predator intraguild interactions may cause interference and lessen the rate of prey reduction (Rosenheim *et al.* 1995; Holt and Polis 1997; Walzer *et al.* 2001; Hatherly *et al.* 2005; Negloh *et al.* 2012).

Competition and predation/parasitism are both types of species interactions and intraguild predation is a combination of these (Polis *et al.* 1989). This widespread interaction occurs among species with shared resources and influences abundance and distribution of communities used as biocontrol agents. Intraguild predation has been extensively documented for communities of natural enemies associated with arthropods (Polis *et al.* 1989; Rosenheim *et al.* 1995). In terms of intraguild predation, the predator is defined as the intraguild predator and the competitor as intraguild prey and their shared food as extraguild prey (Polis *et al.* 1989; Lucas *et al.* 1998; Lucas 2005; Negloh *et al.* 2012). Intraguild predation occurs predominantly in generalist predator communities that attack smaller conspecific and heterospecific individuals (Polis *et al.* 1989). Based on Rosenheim *et al.* (1995), generalist predators in the Acari are well represented in terms of intraguild interactions. Several studies have indicated that intraguild predation is usual existent among predator communities of phytoseiid mites (Schausberger 1997; Walzer and Schausberger 1999a, 1999b; Schausberger and Croft 2000a, 2000b; Hatherly *et al.* 2005; Cakmak *et al.* 2006, 2009; Momen and Abdel-Khalek 2009; Lucas and Rosenheim 2011; Walzer and Schausberger 2011; Guzman *et al.* 2016).

The presence of shared prey (extraguild prey) can influence the nature of intraguild predation, for example when the common prey is rare or nonexistent the predator may extend its diet to new food resources such as other predator species in the same guild (Polis *et al.* 1989; Lucas *et al.* 1998; Guzman *et al.* 2016).

The purpose of this research was to assess presence and absence of shared prey, *T. urticae*, as

well as pollen on intraguild interactions between *T. bagdasarjani* and *P. persimilis* adult females and heterospecific immature stages under laboratory conditions. Comparison of prey consumption and fecundity of these predatory mites in presence and absence of shared prey conditions could lead to proper prediction of their predation potential in order to apply them together to control of *T. urticae* populations in greenhouses.

## Material and methods

### Plant species

Cucumber plants (*Cucumis sativus* Linnaeus cultivar Sultan; Cucurbitaceae) were planted in plastic pots filled with mixture of cocopeat: perlite (40:60 ratio) under greenhouse conditions ( $25 \pm 5^\circ\text{C}$ ,  $50 \pm 20\%$  relative humidity and natural light duration).

### Insect collection and rearing

*Tetranychus urticae* was originally collected from infested lima bean (*Phaseolus lunatus* Linnaeus; Fabaceae) leaves in the insect population ecology laboratory at the Department of Plant Protection, University of Tehran in Karaj, Iran and reared on cucumber plants in a growth chamber at  $25 \pm 2^\circ\text{C}$ ,  $50 \pm 10\%$  relative humidity and 16:8 light:dark hour photoperiod. *Phytoseiulus persimilis* was initially obtained from laboratory stock culture reared in population ecology laboratory at the Department of Plant Protection, University of Tehran in Karaj, Iran. *Typhlodromus bagdasarjani* was originally collected from black mulberry (*Morus nigra* Linnaeus; Moraceae) trees in the Faculty of Agriculture campus, Tarbiat Modares University, Tehran, Iran. The phytoseiid mites were reared on arenas consisting of a piece of green plastic on a water-saturated sponge in a plastic container ( $26 \times 16 \times 7$  cm) maintained at  $25 \pm 1^\circ\text{C}$ ,  $75 \pm 5\%$  relative humidity and 16:8 light:dark hour photoperiod in a growth chamber. The plastic piece margins were covered with moistened tissue paper to supply water to the predators and to prevent their escape (Overmeer 1985). The *T. urticae*-infested cucumber leaves were added to the arenas three times a week. In addition, some maize (*Zea mays* Linnaeus; Poaceae) pollen was added to *T. bagdasarjani* arenas as supplementary food two times a week.

## Experimental unit

The cucumber leaves were cut into circular shaped discs and placed upside down on water-saturated sponge in 9-cm-diameter Petri dishes. The leaf disc margins were surrounded with circular wet tissue paper strips to provide a 5-cm-diameter arena on leaf discs to serve as an experimental unit and prevent the predators from escape. The lid of each Petri dish had a 1-cm-diameter hole covered with a fine mesh net. Additional water was added to the units, daily. The experimental units were kept at the same laboratory conditions as the predator rearing units.

## Experimental procedure

A single one-day-old mated *T. bagdasarjani* and *P. persimilis* female were placed on each leaf disc. The predation and oviposition rate of each predator female (*T. bagdasarjani* and *P. persimilis*) as intraguild predator on eggs, larvae, protonymphs, and deutonymphs of heterospecific predator as intraguild prey was assayed in the absence and presence of *T. urticae* protonymphs as extraguild prey with and without maize pollen as supplementary food. Two basic experiments were prepared. In the first experiment, eight treatments were arranged as follows. Four treatments to investigate predation and oviposition of both phytoseiid species on each other in absence of *T. urticae*: (a) one phytoseiid adult female plus seven heterospecific eggs (<24-hour old), (b) one phytoseiid adult female plus seven heterospecific larvae (newly hatched), (c) one phytoseiid adult female plus five heterospecific protonymph (newly hatched), (d) one phytoseiid

adult female plus five heterospecific deutonymph (newly hatched). In the other four treatments, 30 *T. urticae* protonymphs were added to each of the above-mentioned treatments to examine the presence of extraguild prey on intraguild predation. Eight treatments were applied in the second experiment as follows. Four treatments were set up to investigate intraguild predation of predators in absence of *T. urticae* and presence of pollen: (a) one phytoseiid adult female, seven heterospecific eggs (less than 24 hour old) plus maize pollen, (b) one phytoseiid adult female, seven heterospecific larvae (newly hatched) plus maize pollen, (c) one phytoseiid adult female, five heterospecific protonymph (newly hatched) plus maize pollen, (d) one phytoseiid adult female, five heterospecific deutonymph (newly hatched) plus maize pollen. In the other four treatments, 30 *T. urticae* protonymphs were added to each of the above-mentioned treatments to evaluate the presence of *T. urticae* and pollen on intraguild predation of the two predators.

Each treatment was replicated 15 times. Evaluations were examined every 24 hours in five days to record the number of prey consumed and eggs laid by the female predators. Consumed and survived individuals were replaced by new ones, daily.

## Statistical analysis

All data were tested for normality with MINITAB 17 using the Ryan-Joiner method. The number of daily consumed prey and laid eggs by per female predators were analysed by one-way analysis of variance and differences

**Table 1.** Predation and oviposition (mean  $\pm$  standard error) of female adult *Phytoseiulus persimilis* when provided with different stages of *Typhlodromus bagdasarjani* in the presence or absence of *Tetranychus urticae*.

Predator species	Prey			
	Species	Stage	Predation rate	Oviposition rate
<i>P. persimilis</i>	<i>T. bagdasarjani</i>	Egg	0.85 $\pm$ 0.07d	2.13 $\pm$ 0.07a
	<i>T. bagdasarjani</i>	Larva	0.65 $\pm$ 0.05cd	2.16 $\pm$ 0.06a
	<i>T. bagdasarjani</i>	Protonymph	0.28 $\pm$ 0.03ab	2.01 $\pm$ 0.07a
	<i>T. bagdasarjani</i>	Deutonymph	0.16 $\pm$ 0.03a	1.93 $\pm$ 0.06a
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i>	Egg	0.85 $\pm$ 0.04d	4.41 $\pm$ 0.09b
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i>	Larva	0.48 $\pm$ 0.06bc	4.20 $\pm$ 0.08b
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i>	Protonymph	0.36 $\pm$ 0.04ab	4.15 $\pm$ 0.1b
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i>	Deutonymph	0.16 $\pm$ 0.03a	4.21 $\pm$ 0.08b

**Note:** Means followed by the same letters in each column are not significantly different ( $P < 0.05$ , Tukey's multiple range test).

**Table 2.** Predation and oviposition (mean  $\pm$  standard error) of female adult *Typhlodromus bagdasarjani* when provided with different stages of *Phytoseiulus persimilis* in the presence or absence of *Tetranychus urticae*.

Predator species	Prey		Predation rate	Oviposition rate
	Species	Stage		
<i>T. bagdasarjani</i>	<i>P. persimilis</i>	Egg	1.17 $\pm$ 0.07c	1.00 $\pm$ 0.03ab
	<i>P. persimilis</i>	Larva	0.60 $\pm$ 0.03b	1.01 $\pm$ 0.04ab
	<i>P. persimilis</i>	Protonymph	0.31 $\pm$ 0.04a	0.99 $\pm$ 0.04ab
	<i>P. persimilis</i>	Deutonymph	0.09 $\pm$ 0.03a	0.95 $\pm$ 0.04a
	<i>P. persimilis</i> + <i>T. urticae</i>	Egg	1.23 $\pm$ 0.09c	1.48 $\pm$ 0.09d
	<i>P. persimilis</i> + <i>T. urticae</i>	Larva	0.71 $\pm$ 0.11b	1.37 $\pm$ 0.07d
	<i>P. persimilis</i> + <i>T. urticae</i>	Protonymph	0.31 $\pm$ 0.05a	1.25 $\pm$ 0.07cd
	<i>P. persimilis</i> + <i>T. urticae</i>	Deutonymph	0.17 $\pm$ 0.03a	1.24 $\pm$ 0.07cd

**Note:** Means followed by the same letters in each column are not significantly different ( $P < 0.05$ , Tukey's multiple range test).

**Table 3.** Predation (mean  $\pm$  standard error) of an intraguild adult predator (*Phytoseiulus persimilis*/*Typhlodromus bagdasarjani*) on immature stages of intraguild prey (*Phytoseiulus persimilis*/*Typhlodromus bagdasarjani*) in the absence and presence of *Tetranychus urticae*.

Intraguild predator (intraguild prey)	Intraguild prey stages			
	Egg	Larva	Protonymph	Deutonymph
<b>Absence of <i>T. urticae</i></b>				
<i>P. persimilis</i> ( <i>T. bagdasarjani</i> )	0.85 $\pm$ 0.07	0.65 $\pm$ 0.05	0.28 $\pm$ 0.03	0.16 $\pm$ 0.03
<i>T. bagdasarjani</i> ( <i>P. persimilis</i> )	1.17 $\pm$ 0.07	0.6 $\pm$ 0.03	0.31 $\pm$ 0.04	0.09 $\pm$ 0.03
<i>P</i>	0.004**	0.382	0.626	0.10
<b>Presence of <i>T. urticae</i></b>				
<i>P. persimilis</i> ( <i>T. bagdasarjani</i> )	0.85 $\pm$ 0.04	0.48 $\pm$ 0.06	0.36 $\pm$ 0.04	0.16 $\pm$ 0.03
<i>T. bagdasarjani</i> ( <i>P. persimilis</i> )	1.23 $\pm$ 0.09	0.71 $\pm$ 0.11	0.31 $\pm$ 0.05	0.17 $\pm$ 0.03
<i>P</i>	0.002	0.097	0.418	0.737

among means were compared by Tukey's multiple range test in SPSS 16. Comparison between predation and oviposition rates of predators in treatments was conducted using the *t*-test in SPSS 16.

## Results

### Effect of the absence or presence of *Tetranychus urticae* on the intraguild interaction between *Phytoseiulus persimilis* and *Typhlodromus bagdasarjani*

Females of both phytoseiid species fed on different stages of the other species both in absence and presence of *T. urticae* as extraguild prey (Tables 1–2). Based on results of one-way analysis of variance, the highest and least

predation rates of both predators were on heterospecific eggs and deutonymphs, respectively in both absence and presence of *T. urticae* treatments ( $F(7,119) = 36.554$ ,  $P < 0.0001$ , Table 1;  $F(7,119) = 43.129$ ,  $P < 0.0001$ , Table 2). The *t*-test results showed that females of *T. bagdasarjani* consumed significantly more heterospecific eggs than *P. persimilis* both in the absence and presence of *T. urticae* (Table 3). The oviposition of both predators was higher in the presence of *T. urticae* than in its absence ( $F(7,119) = 217.716$ ,  $P < 0.0001$ , Table 1;  $F(7,119) = 11.316$ ,  $P < 0.0001$ , Table 2). Based on results of *t*-test, oviposition of *P. persimilis* was significantly higher on heterospecific different stages than *T. bagdasarjani* both in absence and presence of *T. urticae* (Table 4).

**Table 4.** Oviposition (mean  $\pm$  standard error) of an intraguild adult predator (*Phytoseiulus persimilis*/*Typhlodromus bagdasarjani*) on immature stages of intraguild prey (*Phytoseiulus persimilis*/*Typhlodromus bagdasarjani*) in the absence and presence of *Tetranychus urticae*.

Intraguild predator (IG prey)	Intraguild prey stages			
	Egg	Larva	Protonymph	Deutonymph
<i>Absence of T. urticae</i>				
<i>P. persimilis</i> ( <i>T. bagdasarjani</i> )	2.13 $\pm$ 0.06	2.16 $\pm$ 0.06	2.01 $\pm$ 0.07	1.93 $\pm$ 0.06
<i>T. bagdasarjani</i> ( <i>P. persimilis</i> )	1.00 $\pm$ 0.03	1.01 $\pm$ 0.04	0.99 $\pm$ 0.04	0.95 $\pm$ 0.04
<i>P</i>	0.00	0.00	0.00	0.00
<i>Presence of T. urticae</i>				
<i>P. persimilis</i> ( <i>T. bagdasarjani</i> )	4.41 $\pm$ 0.09	4.2 $\pm$ 0.09	4.15 $\pm$ 0.1	4.21 $\pm$ 0.08
<i>T. bagdasarjani</i> ( <i>P. persimilis</i> )	1.48 $\pm$ 0.09	1.37 $\pm$ 0.07	1.25 $\pm$ 0.07	1.24 $\pm$ 0.07
<i>P</i>	0.00	0.00	0.00	0.00

**Table 5.** Predation and oviposition (mean  $\pm$  standard error) of female adult *Phytoseiulus persimilis* when provided with different stages of *Typhlodromus bagdasarjani* in the presence or absence of *Tetranychus urticae* with pollen.

Predator species	Prey		Predation rate	Oviposition rate
	Species	Stage		
<i>P. persimilis</i>	<i>T. bagdasarjani</i> $\pm$ pollen	Egg	0.81 $\pm$ 0.06e	2.11 $\pm$ 0.05a
	<i>T. bagdasarjani</i> $\pm$ pollen	Larva	0.61 $\pm$ 0.04d	2.12 $\pm$ 0.06a
	<i>T. bagdasarjani</i> $\pm$ pollen	Protonymph	0.29 $\pm$ 0.03ab	1.97 $\pm$ 0.07a
	<i>T. bagdasarjani</i> $\pm$ pollen	Deutonymph	0.13 $\pm$ 0.02a	1.95 $\pm$ 0.06a
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Egg	0.80 $\pm$ 0.03e	4.45 $\pm$ 0.08c
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Larva	0.48 $\pm$ 0.04cd	4.28 $\pm$ 0.06bc
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Protonymph	0.35 $\pm$ 0.04bc	4.13 $\pm$ 0.09b
	<i>T. bagdasarjani</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Deutonymph	0.13 $\pm$ 0.02a	4.19 $\pm$ 0.06bc

**Note:** Means followed by the same letters in each column are not significantly different ( $P < 0.05$ , Tukey's multiple range test).

### Effect of pollen in the absence or presence of *Tetranychus urticae* on the intraguild interaction between *Phytoseiulus persimilis* and *Typhlodromus bagdasarjani*

When pollen was added to treatments with and without *T. urticae*, the intraguild predation on heterospecific different stages was observed between both phytoseiid predators (Tables 5–6). Such as the experiments without pollen, the highest and least consumption rate of both phytoseiid predators were on heterospecific eggs and deutonymphs, respectively in both absence and presence of *T. urticae* treatments ( $F(7,119) = 47.949$ ,  $P < 0.0001$ , Table 5;  $F(7,119) = 56.903$ ,  $P < 0.0001$ , Table 6). According to *t*-test results, pollen addition caused significant reduction in *T. bagdasarjani* predation on heterospecific eggs and deutonymphs in absence and presence of

*T. urticae* treatments, respectively (Table 7). However, predation rate of *P. persimilis* on heterospecific stages was not significantly affected by pollen addition either in presence or in absence of *T. urticae* (Table 8). In treatments with and without pollen, oviposition of both predators was higher in presence of *T. urticae* than in its absence ( $F(7,119) = 292.945$ ,  $P < 0.0001$ , Table 5;  $F(7,119) = 19.261$ ,  $P < 0.0001$ , Table 6). The *t*-test analysis of *T. bagdasarjani* oviposition indicated the significant effect of pollen addition on increasing the rate of oviposition in absence of *T. urticae* (Table 9). However, *T. bagdasarjani* oviposition was not affected by pollen addition in presence of *T. urticae* (Table 9). Moreover, pollen addition had a nonsignificant effect on the oviposition of *P. persimilis* either in presence or in absence of *T. urticae* (Table 10).

**Table 6.** Predation and oviposition (mean  $\pm$  standard error) of female adult *Typhlodromus bagdasarjani* when provided with different stages of *Phytoseiulus persimilis* in the presence or absence of *Tetranychus urticae* with pollen.

Predator species	Prey		Predation rate	Oviposition rate
	Species	Stage		
<i>T. bagdasarjani</i>	<i>P. persimilis</i> $\pm$ pollen	Egg	0.89 $\pm$ 0.04c	1.13 $\pm$ 0.04a
	<i>P. persimilis</i> $\pm$ pollen	Larva	0.51 $\pm$ 0.03b	1.19 $\pm$ 0.04a
	<i>P. persimilis</i> $\pm$ pollen	Protonymph	0.27 $\pm$ 0.04a	1.09 $\pm$ 0.04a
	<i>P. persimilis</i> $\pm$ pollen	Deutonymph	0.07 $\pm$ 0.02a	1.09 $\pm$ 0.04a
	<i>P. persimilis</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Egg	1.07 $\pm$ 0.09c	1.59 $\pm$ 0.06b
	<i>P. persimilis</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Larva	0.52 $\pm$ 0.07b	1.51 $\pm$ 0.04b
	<i>P. persimilis</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Protonymph	0.23 $\pm$ 0.03a	1.4 $\pm$ 0.04b
	<i>P. persimilis</i> $\pm$ <i>T. urticae</i> $\pm$ pollen	Deutonymph	0.08 $\pm$ 0.03a	1.4 $\pm$ 0.04b

**Note:** Means followed by the same letters in each column are not significantly different ( $P < 0.05$ , Tukey's multiple range test).

**Table 7.** Predation (mean  $\pm$  standard error) of *Typhlodromus bagdasarjani* on immature stages of *Phytoseiulus persimilis* in the absence and presence of *Tetranychus urticae* with and without pollen.

	Intraguild prey stages			
	Egg	Larva	Protonymph	Deutonymph
Absence of <i>T. urticae</i>				
Without pollen	1.17 $\pm$ 0.07	0.6 $\pm$ 0.03	0.31 $\pm$ 0.04	0.09 $\pm$ 0.03
With pollen	0.89 $\pm$ 0.04	0.51 $\pm$ 0.03	0.27 $\pm$ 0.04	0.07 $\pm$ 0.02
<i>P</i>	0.003	0.058	0.489	0.473
Presence of <i>T. urticae</i>				
Without pollen	1.23 $\pm$ 0.09	0.71 $\pm$ 0.11	0.31 $\pm$ 0.05	0.17 $\pm$ 0.03
With pollen	1.07 $\pm$ 0.09	0.52 $\pm$ 0.07	0.23 $\pm$ 0.03	0.08 $\pm$ 0.03
<i>P</i>	0.230	0.181	0.176	0.019

**Table 8.** Predation (mean  $\pm$  standard error) of *Phytoseiulus persimilis* on immature stages of *Typhlodromus bagdasarjani* in the absence of *Tetranychus urticae* with and without pollen.

	Intraguild prey stages			
	Egg	Larva	Protonymph	Deutonymph
Absence of <i>T. urticae</i>				
Without pollen	0.85 $\pm$ 0.07	0.65 $\pm$ 0.05	0.28 $\pm$ 0.03	0.16 $\pm$ 0.03
With pollen	0.81 $\pm$ 0.06	0.61 $\pm$ 0.04	0.29 $\pm$ 0.03	0.13 $\pm$ 0.02
<i>P</i>	0.665	0.558	0.776	0.493
Presence of <i>T. urticae</i>				
Without pollen	0.85 $\pm$ 0.04	0.48 $\pm$ 0.06	0.36 $\pm$ 0.04	0.16 $\pm$ 0.03
With pollen	0.80 $\pm$ 0.03	0.48 $\pm$ 0.04	0.35 $\pm$ 0.04	0.13 $\pm$ 0.02
<i>P</i>	0.356	1	0.807	0.493

## Discussion

This project studied the predation capacity and fecundity of phytoseiid mites, *P. persimilis* and

*T. bagdasarjani*, on each other's immature stages in the absence and presence of shared prey, *T. urticae*, as well as pollen addition. Tests were done under laboratory conditions. According to

**Table 9.** Oviposition (mean  $\pm$  standard error) of *Typhlodromus bagdasarjani* on immature stages of *Phytoseiulus persimilis* in the absence of *Tetranychus urticae* with and without pollen.

	Intraguild prey stages			
	Egg	Larva	Protonymph	Deutonymph
Absence of <i>T. urticae</i>				
Without pollen	1 $\pm$ 0.03	1.01 $\pm$ 0.04	0.99 $\pm$ 0.04	0.95 $\pm$ 0.04
With pollen	1.13 $\pm$ 0.04	1.19 $\pm$ 0.04	1.09 $\pm$ 0.04	1.09 $\pm$ 0.04
<i>P</i>	0.020	0.004	0.049	0.020
Presence of <i>T. urticae</i>				
Without pollen	1.48 $\pm$ 0.09	1.37 $\pm$ 0.07	1.25 $\pm$ 0.07	1.24 $\pm$ 0.07
With pollen	1.59 $\pm$ 0.06	1.51 $\pm$ 0.04	1.40 $\pm$ 0.04	1.40 $\pm$ 0.04
<i>P</i>	0.321	0.126	0.083	0.072

**Table 10.** Oviposition (mean  $\pm$  standard error) of *Phytoseiulus persimilis* on immature stages of *Typhlodromus bagdasarjani* in the absence of *Tetranychus urticae* with and without pollen.

	Intraguild prey stages			
	Egg	Larva	Protonymph	Deutonymph
Absence of <i>T. urticae</i>				
Without pollen	2.13 $\pm$ 0.07	2.16 $\pm$ 0.06	2.01 $\pm$ 0.07	1.93 $\pm$ 0.06
With pollen	2.11 $\pm$ 0.05	2.12 $\pm$ 0.06	1.97 $\pm$ 0.07	1.95 $\pm$ 0.06
<i>P</i>	0.760	0.658	0.693	0.877
Presence of <i>T. urticae</i>				
Without pollen	4.41 $\pm$ 0.09	4.2 $\pm$ 0.08	4.15 $\pm$ 0.10	4.21 $\pm$ 0.08
With pollen	4.45 $\pm$ 0.08	4.28 $\pm$ 0.06	4.13 $\pm$ 0.09	4.19 $\pm$ 0.06
<i>P</i>	0.754	0.459	0.924	0.794

Lucas (2005), intraguild predation can be unidirectional when one of the predator species is always intraguild prey and the other is always intraguild predator; it is bidirectional (mutual) when both predator species prey on each other and each predator is also prey and vice versa. The current research implies that predation occurred by two predator female species on all stages of the other species (bidirectional) not only in absence of *T. urticae* as food but also in its presence. Bidirectional intraguild predation between *P. persimilis* and *T. bagdasarjani* has also been reported by Ghasemloo *et al.* (2016), in absence of *T. urticae*. Nevertheless, *P. persimilis* did not feed on the heterospecific nymph stages in interactions among *P. persimilis*, *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae), and *Neoseiulus barkeri* (Hughes) (Acari: Phytoseiidae) (Maleknia *et al.* 2016).

Both in absence and presence of *T. urticae* treatments, with no significant difference, the highest predation rate of both phytoseiid predators was on heterospecific eggs such that the greatest tendency to interspecific predation on eggs was by *T. bagdasarjani* females compared with *P. persimilis*. Therefore, *T. bagdasarjani* seems to be a stronger intraguild predator of heterospecific eggs than *P. persimilis*. Intraguild predation is particularly common in generalist predators as they consume other natural enemies as well as their main prey. In fact, generalist species in predator-predator interactions have greater tendency to interspecific predation than the specialist types (McMurtry and Croft 1997; Schausberger 1997; Janssen *et al.* 1998; Schausberger and Croft 2000a; Cakmak *et al.* 2006; Meszaros *et al.* 2007; Momen and Abdel-Khalek 2009). In this regard, studies have shown that intraguild predation between the specialist

*P. persimilis* and the generalist *Neoseiulus californicus* (McGregor) was strongly asymmetric in favour of the generalist (Walzer and Schausberger 1999a, 1999b; Walzer *et al.* 2001; Cakmak *et al.* 2006). Walzer *et al.* (2001) explained that in predator combination systems including *P. persimilis* and *N. californicus* with abundant prey (*T. urticae*), *N. californicus* displaced *P. persimilis*. Also, *N. californicus* persisted three to five times longer after prey depletion than did *P. persimilis*. In their opinion, intraguild predation was a stronger force than food competition in predator–predator interactions. Research by Abad-Moyano *et al.* (2010) demonstrated the generalist *Euseius stipulatus* (Athias-Henriot) (Acari: Phytoseiidae) as the stronger intraguild predator compared with *P. persimilis* and *N. californicus*.

The high predation rate of phytoseiid females on heterospecific eggs in this study was probably because eggs are immobile and unable to escape so they were more accessible to the predator at that stage than during the active stages. As a result, consumption of eggs required less time than other stages. Reports have indicated that the nutritional requirements of intraguild predator and the body size of intraguild prey were determining factors in intraguild predation (Polis *et al.* 1989; Holt and Polis 1997; Schausberger 1997; Schausberger and Croft 2000a; Walzer and Schausberger 2011; Negloh *et al.* 2012). Farazmand *et al.* (2015b) reported the highest consumption of *N. californicus* and *T. bagdasarjani* on each other's larvae compared with heterospecific eggs and protonymphs and they considered *N. californicus* as the more prone predator to intraguild predation than *T. bagdasarjani*. According to Ghasemloo *et al.* (2016), in the absence of *T. urticae*, both *P. persimilis* and *T. bagdasarjani* had a higher predation rate on the heterospecific larvae compared to eggs and protonymphs. The more feeding on heterospecific larvae compared with other stages in *P. persimilis*, *A. swirskii*, and *N. barkeri* was presented by Maleknia *et al.* (2016). Such more predation on heterospecific larvae by *P. persimilis* and *N. californicus* was reported by Walzer and Schausberger (1999a). However, the study by Abad-Moyano *et al.* (2010) supports our results that determined more intense predation of *P. persimilis* females on heterospecific eggs.

The lowest predation of *T. bagdasarjani* and *P. persimilis*, in absence and presence of *T. urticae*, with no significant difference, was observed on heterospecific deutonymphs. This may be due to bigger body size of deutonymphs and better ability of defense or escape at that stage compared with other stages, as well as it being a more active stage making them more difficult to catch (Holt and Polis 1997; Schausberger 1997; Schausberger and Croft 2000a; Momen and Abdel-Khalek 2009; Walzer and Schausberger 2011).

Investigation of the effect of pollen addition on interactions between two predators, in absence and presence of *T. urticae*, indicated similar results as treatments without pollen. The consumption rate of *T. bagdasarjani*, as a generalist phytoseiid mite, was significantly affected by presence of pollen, as pollen addition reduced predation on heterospecific eggs and deutonymphs in absence and presence of *T. urticae* treatments, respectively. Pollen is an important supplementary food for generalist predators and it has an effective role in reduced intensity predation on alternative prey (McMurtry and Croft 1997; McMurtry *et al.* 2013; Guzman *et al.* 2016; Maleknia *et al.* 2016). However, when pollen was offered to *T. bagdasarjani*, the feeding rate on heterospecifics was not significantly different between presence and absence of *T. urticae* treatments.

In contrast, predation of *P. persimilis*, as a specialist phytoseiid mite, was not affected by pollen presence. A specialist predator has provided appropriate short time for prey suppression and a generalist predator had more ability to stand at low prey density, even with a lack of prey; that is, at the beginning and the end of the growth season (McMurtry and Croft 1997; Hatherly *et al.* 2005; McMurtry *et al.* 2013).

According to our results, *P. persimilis* and *T. bagdasarjani* could lay eggs when provided with heterospecifics, both in presence and absence of shared prey. Some studies showed that *P. persimilis* was unable to produce eggs on some stages of intraguild prey (Walzer and Schausberger 1999a; Ghasemloo *et al.* 2016) but in agreement with our results, Farazmand *et al.* (2015b) and Ghasemloo *et al.* (2016) reported oviposition by *T. bagdasarjani* on intraguild prey stages. Research has reported that a generalist predator was able to



sustain oviposition on heterospecifics (Schausberger 1997; Walzer and Schausberger 1999a; Hatherly *et al.* 2005; Meszaros *et al.* 2007; Momen and Abdel-Khalek 2009; Negloh *et al.* 2012).

The oviposition rates of both predators in presence of *T. urticae* were significantly higher than in its absence with no significant difference among heterospecific stages treatments in *P. persimilis*. The specialist predators such as *P. persimilis* were more prone to cannibalism than intraguild predation in view of aggressiveness and nutritional benefits (Walzer and Schausberger 1999a, 1999b; Schausberger and Croft 2000a, 2000b; Meszaros *et al.* 2007). It can be concluded that the nutritional value of conspecifics for *P. persimilis* was more than that of heterospecifics, and as a result, in intraguild predation case, the presence of main food (*T. urticae*) will be more affective on fecundity of *P. persimilis* adult females than heterospecifics.

In presence of *T. urticae*, number of eggs laid by *T. bagdasarjani* fed on heterospecific eggs and larvae was significantly more than that of on heterospecific protonymphs and deutonymphs. It is possible that *T. bagdasarjani* had more nutritional benefit from heterospecific eggs and larvae than two other heterospecific stages.

In this respect, pollen addition led to increased oviposition rate of the generalist predator, *T. bagdasarjani*, in an absence of *T. urticae*. As previously mentioned, pollen was an optimised alternative food source for generalist phytoseiids with an important effect on reproductive capacity, particularly in conditions that lacked main prey (McMurtry and Croft 1997; McMurtry *et al.* 2013; Guzman *et al.* 2016). However, in presence of prey, pollen addition had a neutral effect on fecundity of *T. bagdasarjani*.

Results of this research revealed that intraguild predation between the specialist *P. persimilis* and generalist *T. bagdasarjani* was affected by presence and absence of shared prey, *T. urticae* as well as pollen addition with influence on predation and oviposition rates in treatments with different heterospecific stages.

## Conclusion

In the current research, intraguild predation between two predator species was bidirectional not only in absence of *T. urticae* but also in its presence.

Both in absence and presence of *T. urticae* treatments, with no significant difference, the highest and the lowest predation rates of both predators were observed on heterospecific eggs and deutonymphs, respectively. Based on results, *T. bagdasarjani* seems to be a stronger intraguild predator of heterospecific eggs than *P. persimilis*.

Effect of pollen addition on interactions between two predators, in absence and presence of *T. urticae*, was similar to results of treatments without pollen. The consumption rate of generalist predator, *T. bagdasarjani*, was significantly affected by presence of pollen, as pollen addition reduced predation on heterospecific eggs and deutonymphs in absence and presence of *T. urticae*, respectively. Moreover, *P. persimilis* and *T. bagdasarjani* could lay eggs when offered heterospecifics, both in presence and absence of shared prey and the oviposition rates of both predators in presence of *T. urticae* were significantly higher than in its absence.

Assessment of feeding and reproduction of intraguild predator species on heterospecific different stages with and without shared prey as well as alternative foods could present valuable information about co-occurrence qualifications of these predators to successful suppression of pest populations. For this reason, current study was done to address the effects of different food sources on interactions between *P. persimilis* and *T. bagdasarjani* – as two effective natural enemies of *T. urticae* – in laboratory conditions. On the other hand, the generalisation of laboratory experiment results to natural conditions is difficult because of their small scales and eventually, the possibility of changing behaviour of predators compared to the natural environment. Proper application of these predators together with correct management of *T. urticae* populations in the greenhouse and in the field, additional experiments in natural conditions with more detailed investigations are needed.

## Acknowledgements

The project was supported by the Iran National Science Foundation and the Center of Excellence of Biological Control of Pests, Department of Plant Protection, College of Agriculture, University of Tehran, Karaj, Iran under Grant by project number 92025486, which is greatly appreciated.

## References

- Abad-Moyano, R., Urbaneja, A., and Schausberger, P. 2010. Intraguild interactions between *Euseius stipulatus* and the candidate biocontrol agents of *Tetranychus urticae* in Spanish clementine orchards: *Phytoseiulus persimilis* and *Neoseiulus californicus*. *Experimental and Applied Acarology*, **50**: 23–34.
- Cakmak, I., Janssen, A., and Sabelis, M. 2006. Intraguild interactions between the predatory mites *Neoseiulus californicus* and *Phytoseiulus persimilis*. *Experimental and Applied Acarology*, **38**: 33–46.
- Cakmak, I., Janssen, A., Sabelis, M.W., and Baspinar, H. 2009. Biological control of an acarine pest by single and multiple natural enemies. *Biological Control*, **50**: 60–65.
- Daneshmandi, A., Rahmani, H., Walzer, A., and Jalaeian, M. 2014. Intraguild predation among three phytoseiid species in the absence of *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae). *In Proceedings of the 3rd Integrated Pest Management Conference*. Shahid Bahonar University of Kerman, Kerman, Iran. Pp. 57–62.
- Daneshvar, H. 1993. Distribution of two predatory mite *Amblydromella kettanehi* and *Euseius libanesi* (Acari: Phytoseiidae) in Iran. *In Proceedings of the 11th Iranian Plant Protection Congress*. University of Guilan, Rasht, Iran. Pp. 260.
- Faraji, F., Hajizadeh, J., Ueckermann, E.A., Kamali, K., and McMurtry, J.A. 2007. Two new records for Iranian phytoseiid mites with synonymy and keys to the species of *Typhloseiulus* Chant and McMurtry and Phytoseiidae in Iran (Acari: Mesostigmata). *International Journal of Acarology*, **33**: 231–239.
- Farazmand, A., Fathipour, Y., and Kamali, K. 2015a. Control of the spider mite *Tetranychus urticae* using phytoseiid and thrips predators under microcosm conditions: single-predator versus combined-predators release. *Systematic & Applied Acarology*, **20**: 162–170.
- Farazmand, A., Fathipour, Y., and Kamali, K. 2015b. Intraguild predation among *Scolothrips longicornis* (Thysanoptera: Thripidae), *Neoseiulus californicus* and *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) under laboratory conditions. *Insect Science*, **22**: 263–272.
- Ganjisaffar, F., Fathipour, Y., and Kamali, K. 2011a. Effect of temperature on prey consumption of *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae) conditions. *International Journal of Acarology*, **37**: 556–560.
- Ganjisaffar, F., Fathipour, Y., and Kamali, K. 2011b. Temperature-dependent development and life table parameters of *Typhlodromus bagdasarjani* (Phytoseiidae) fed on two-spotted spider mite. *Experimental and Applied Acarology*, **55**: 259–272.
- Ghasemloo, Z., Pakyari, H., and Arbab, A. 2016. Cannibalism and intraguild predation in the phytoseiid mites *Phytoseiulus persimilis* and *Typhlodromus bagdasarjani* (Acari: Phytoseiidae). *International Journal of Acarology*, **42**: 149–152.
- Guzman, C., Sahun, R.M., and Montserrat, M. 2016. Intraguild predation between phytoseiid mite species might not be so common. *Experimental and Applied Acarology*, **68**: 441–453.
- Hatherly, I.S., Bale, J.S., and Walters, K.F.A. 2005. Intraguild predation and feeding preferences in three species of phytoseiid mite used for biological control. *Experimental and Applied Acarology*, **37**: 43–55.
- Holt, R.D. and Polis, G.A. 1997. A theoretical framework for intraguild predation. *The American Naturalist*, **149**: 745–764.
- Janssen, A., Pallini, A., Venzon, M., and Sabelis, M.W. 1998. Behaviour and indirect interactions in food webs of plant-inhabiting arthropods. *Experimental and Applied Acarology*, **22**: 497–521.
- Kamali, K., Ostovan, H., and Atamehr, A. 2001. A catalog of mites and ticks (Acari) of Iran. Islamic Azad University Scientific Publication Center, Tehran, Iran.
- Lucas, É. 2005. Intraguild predation among aphidophagous predators. *European Journal of Entomology*, **102**: 351–364.
- Lucas, É., Coderre, D., and Brodeur, J. 1998. Intraguild predation among aphid predators: characterization and influence of extraguild prey density. *Ecology*, **79**: 1084–1092.
- Lucas, É. and Rosenheim, J.A. 2011. Influence of extraguild prey density on intraguild predation by heteropteran predators: a review of the evidence and a case study. *Biological Control*, **59**: 61–67.
- Maleknia, B., Fathipour, Y., and Soufbaf, M. 2016. Intraguild predation among three phytoseiid species, *Neoseiulus barkeri*, *Phytoseiulus persimilis* and *Amblyseius swirskii*. *Systematic & Applied Acarology*, **21**: 417–426.
- McMurtry, J.A. and Croft, B.A. 1997. Life-styles of phytoseiid mites and their roles in biological control. *Annual Review of Entomology*, **42**: 291–321.
- McMurtry, J.A., De Moraes, G.J., and Sourassou, N.F. 2013. Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. *Systematic & Applied Acarology*, **18**: 297–320.
- Meszaros, A., Tixier, M.S., Cheval, B., Barbar, Z., and Kreiter, S. 2007. Cannibalism and intraguild predation in *Typhlodromus exhilaratus* and *T. phialatus* (Acari: Phytoseiidae) under laboratory conditions. *Experimental and Applied Acarology*, **41**: 37–43.
- Moghadasi, M., Saboori, A., Allahyari, H., and Zahedi Golpayegani, A. 2013. Prey stages preference of different stages of *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) to *Tetranychus urticae* (Acari: Tetranychidae) on rose. *Persian Journal of Acarology*, **2**: 531–538.
- Moghadasi, M., Saboori, A., Allahyari, H., and Zahedi Golpayegani, A. 2014. Life table and predation capacity of *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) feeding on *Tetranychus urticae* (Acari: Tetranychidae) on rose. *International Journal of Acarology*, **40**: 501–508.

- Momen, F.M. and Abdel-Khalek, A. 2009. Cannibalism and intraguild predation in the phytoseiid mites *Typhlodromus swirskii*, *Euseius scutalis* and *Typhlodromus athiasea* (Acari: Phytoseiidae). *Acarina*, **17**: 223–229.
- Negloh, K., Hanna, R., and Schausberger, P. 2012. Intraguild predation and cannibalism between the predatory mites *Neoseiulus neobaraki* and *N. paspalivorus*, natural enemies of the coconut mite *Aceria guerreronis*. *Experimental and Applied Acarology*, **58**: 235–246.
- Overmeer, W.P.J. 1985. Rearing and handling. In *Spider mites: their biology, natural enemies and control*. Volume 1B. *Edited by* W. Helle and M.W. Sabelis. Elsevier, Amsterdam, The Netherlands. Pp. 161–170.
- Polis, G.A., Myers, C.A., and Holt, R.D. 1989. The ecology and evolution of intraguild predation: potential competitors that eat each other. *Annual Review of Ecology Systematics*, **20**: 297–330.
- Rosenheim, J.A., Kaya, H.K., Ehler, L.E., Marois, J.J., and Jaffee, B.A. 1995. Intraguild predation among biological-control agents: theory and evidence. *Biological Control*, **5**: 303–335.
- Schausberger, P. 1997. Inter- and intraspecific predation on immatures by adult females in *Euseius finlandicus*, *Typhlodromus pyri* and *Kampimodromus aberrans* (Acari: Phytoseiidae). *Experimental and Applied Acarology*, **21**: 131–150.
- Schausberger, P. and Croft, B.A. 2000a. Cannibalism and intraguild predation among phytoseiid mites: are aggressiveness and prey preference related to diet specialization? *Experimental and Applied Acarology*, **24**: 709–725.
- Schausberger, P. and Croft, B.A. 2000b. Nutritional benefits of intraguild predation and cannibalism among generalist and specialist phytoseiid mites. *Ecological Entomology*, **25**: 473–480.
- Schausberger, P. and Walzer, A. 2001. Combined versus single species release of predaceous mites: predator–predator interactions and pest suppression. *Biological Control*, **20**: 269–278.
- Skirvin, D.J. and Fenlon, J.S. 2003. The effect of temperature on the functional response of *Phytoseiulus persimilis* (Acari: Phytoseiidae). *Experimental and Applied Acarology*, **31**: 37–49.
- Walzer, A., Blümel, S., and Schausberger, P. 2001. Population dynamics of interacting predatory mites, *Phytoseiulus persimilis* and *Neoseiulus californicus*, held on detached bean leaves. *Experimental and Applied Acarology*, **25**: 731–743.
- Walzer, A. and Schausberger, P. 1999a. Cannibalism and interspecific predation in the phytoseiid mites *Phytoseiulus persimilis* and *Neoseiulus californicus*: predation rates and effects on reproduction and juvenile development. *BioControl*, **43**: 457–468.
- Walzer, A. and Schausberger, P. 1999b. Predation preferences and discrimination between con- and heterospecific prey by the phytoseiid mites *Phytoseiulus persimilis* and *Neoseiulus californicus*. *BioControl*, **43**: 469–478.
- Walzer, A. and Schausberger, P. 2011. Threat-sensitive anti-intraguild predation behaviour: maternal strategies to reduce offspring predation risk in mites. *Animal Behaviour*, **81**: 177–184.