

## Predation and oviposition rates of *Phytoseiulus persimilis* Athias-Henriot on *Tetranychus urticae* Koch (Acari: Phytoseiidae, Tetranychidae) on different tomato hybrids

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### ABSTRACT

*Tetranychus urticae*, a prominent pest of tomatoes, is typically managed through various control measures such as chemical pesticides; however, the use of predatory mites like *Phytoseiulus persimilis* has emerged as an effective and environmentally friendly method for controlling its population. This study investigated the impact of prey stage, prey stage density, and tomato host plant characteristics on the predation and oviposition rates of the predatory mite, *Phytoseiulus persimilis* females on *Tetranychus urticae*, alone and their interaction. The results showed that the predation performance of *P. persimilis* was significantly ( $p < 0.01$ ) affected by these factors. Predator predation and oviposition rates were highly dependent on tomato cultivars, likely due to the adverse effects of trichome density on the predator. Plants of the Redjayda hybrid had the highest trichome density (105.7 glandular and non-glandular trichomes/mm<sup>2</sup>), while Miranda hybrid exhibited the lowest density (47.3 trichomes/mm<sup>2</sup>). Daily predation and fecundity rates were highest on Miranda and lowest on Redjayda hybrid. Interactions of factors significantly influenced prey consumption rates; notably, the highest daily predation rate was observed on nymphs (12.2 individuals) at a density of 60 individuals/leaflet of the Miranda hybrid. Conversely, this rate decreased when consuming adult stages at a density of 5 individuals/leaflet on Redjayda tomato hybrid. Further investigations into the interplay among host plants, mite herbivores, and predator systems, particularly the processes underlying the adverse impacts on *P. persimilis* as well as on *T. urticae*, are necessary to devise effective biological control strategies against *T. urticae* on various plants.

**Keywords:** Biological performance; consumption rate; leaf trichomes; phytoseiid; pest management; reproduction rate.

### INTRODUCTION

The two-spotted spider mite, *Tetranychus urticae* Koch is a significant pest of many economically important crops including tomatoes, in Egypt and many other countries. *T. urticae* exhibits rapid population growth due to its high reproductive capacity. This leads to substantial population levels in a short time, causing significant economic damage and yield losses, sometimes reaching up to 90% (Azandémè-Hounmalon et al. 2014). In tomato crops, it can cause qualitative and quantitative yield losses (Assouguem et al. 2022). Historically, conventional acaricides have been used to control *T. urticae* but with the growing popularity of organic farming and environmentally friendly practices, researchers are exploring non-chemical control methods that include using predatory mites.

Numerous predatory mites of the family Phytoseiidae hold significant economic importance

for serving as biocontrol agents of mite and insect pests. They constitute essential components of integrated pest management (IPM) programs, as underscored by numerous studies (McMurtry et al. 2013; Ghazi et al. 2016; Zhang 2017; Çobanoğlu et al. 2018; Bajda et al. 2022). Approximately 30 species, including *Phytoseiulus persimilis* Athias-Henriot, *Neoseiulus cucumeris* (Oudemans), *Neoseiulus californicus* (McGregor) and *Amblyseius swirskii* Athias-Henriot, are commercially produced as biocontrol agents and have been effectively used in various countries (van Lenteren 2012; Liu et al. 2017). Among these, *P. persimilis* categorized as a Type-I specialist predator, has been predominantly utilized for controlling spider mites (*Tetranychus* spp.) over several decades (McMurtry et al. 2013; Bajda et al. 2022). *Phytoseiulus* species exhibit a higher dependency on tetranychid mites for sustenance and reproduction compared to phytoseiids of other genera (McMurtry et al. 2013).

The adoption of biocontrol agent based IPM techniques has gained prominence as a comprehensive strategy for effective mite management, particularly with the increasing demand for safe food (Fathipour and Maleknia 2016). Predatory mites, employed in preventive management strategies, can curtail pest damage below economically detrimental levels (Afifi et al. 2015a; Chong 2022). Thus, it is imperative to understand the dynamics of interactions among plant hosts, predators and their prey before using such agents. Host plant characteristics significantly influence the efficacy of natural enemy (Gulati 2014).

The morphological and chemical attributes of plants not only impact the herbivores they host but also affect the performance of their natural enemies, directly and indirectly (Seelmann et al. 2007). Leaf hairiness density of host plants, temperature, prey type and density, host plant defenses, pesticides, among other factors, can impede the operational efficiency of predator mites (Skirvin and De Courcy Williams 1999; Cakmak et al. 2005, 2009). *P. persimilis* demonstrates high efficacy against *T. urticae* on cucumber plants but shows less efficient control over spider mites on eggplants, seemingly due to the presence of hairy leaves. Likewise, *P. persimilis* exhibits reduced performance on tomato varieties with densely trichome-covered leaves (Helle and Sabelis 1985).

Tomatoes may directly affect predators through physical characteristics and/or trichome exudates. Various glandular and non-glandular trichomes exist in tomatoes (Simmons & Gurr 2005). Non-glandular trichomes may physically impede predator movement, lengthening search periods and reducing prey encounter rates (Krips et al. 1999; Stavrinides and Skirvin 2003). Furthermore, the release of sticky and poisonous exudates by glandular tomato trichomes may hinder the activity of natural enemies, such as the predatory mite *P. persimilis* (Simmons & Gurr 2005). Compounds found in tomato trichome exudates, such as methyl ketones and zingiberene, are poisonous to both spider mites (Maluf et al. 2001) and *P. persimilis* (Gillespie and Quiring 1994). The indirect effects of tomatoes on predators are mediated by herbivores that accumulate harmful plant components, rendering

them unsuitable as prey (Koller et al. 2007). Tomato leaves include many phenolic compounds known to be toxic to *T. urticae* (Afifi et al. 2015b; Ali et al. 2015), although evidence of indirect, prey-mediated impacts on predatory mites remains inconclusive.

Understanding the biological dynamics between pests and their predators is crucial for developing effective integrated pest management strategies (Koller et al. 2007; Naseri et al. 2010; Farazmand et al. 2012; Fathipour et al. 2018; Ahmed et al. 2021; Fahim and El-Saiedy 2021; Abdelwines and Ahmed 2022; Sulek et al. 2023). Hence, this study aimed to evaluate the effects of prey stage, prey density and tomato hybrids (host plants), individually and their interaction on predation and oviposition rates of *P. persimilis* under laboratory conditions. The understanding of the interplay between predatory mites and their prey across different host plants is pivotal for informed pest management decisions.

## MATERIALS AND METHODS

### Experimental procedures

This study utilized a factorial design, where the main variables included the prey stages, the prey density, and the variety of the host plant. The prey stage (S) of *T. urticae* was with two levels (adults and nymphs), density (D) of the prey stage was with five levels (5, 10, 20, 40 and 60 individual/leaflet) and tomato hybrid (H) leaf substrate was with four levels (Redjayda, Roufan, Nawara and Miranda). These are some of the most popular tomato hybrids that are cultivated in Egypt. The effects of individual variables and their interaction on predation and oviposition rates of *P. persimilis* within controlled laboratory conditions were studied.

Seeds of Redjayda, Roufan, Nawara, and Miranda tomato cultivars were obtained from Agrimatco for Agriculture, Technogreen, Kanza Group Companies in Egypt. They were germinated in seedling trays containing a mixture of peat moss and vermiculite (1:1 v/v) enriched with macro- and microelements under net-house conditions. Healthy 4–5-week-old seedlings were transplanted into plastic pots to ensure a constant supply of fresh leaves for both prey and predators throughout the experiment. The plants were protected from pest

infestations and subjected to standard agricultural practices without insecticide applications.

### **Mite colonies**

Both predators and prey were sourced from different vegetable crops at the Faculty of Agriculture, Cairo University. The prey was reared on the abaxial surface of the leaflets of each of the four tomato hybrids separately to serve as a food source for the predator during the experimental period. The leaflets obtained from two-month-old plants were nearly the same size ( $4.4 \pm 1 \text{ cm}^2$ ). They were placed on water-saturated cotton pads in Petri dishes, with water-saturated absorbent cotton strips lining their edges to prevent mites from escaping. Likewise, predators to be tested were reared on tomato leaflets of each hybrid to be tested and fed on either adults or nymphs of the prey separately.

Colonies of predators and prey were maintained in an incubator ( $30 \pm 1^\circ\text{C}$ ,  $65 \pm 5\%$  RH, and 16L:8D photoperiod) to ensure a continuous supply of mites for experimentation. Cotton beds were moistened daily, and the mite colonies were left undisturbed for at least three generations before commencing the experiments. Leaflets were replaced every five days, with mites transferred using a fine paintbrush from old to new leaflets.

### **Predation and oviposition rates**

Five replicates, 40 experimental units each, were used. Ten predatory female deutonymphs of similar ages were selected from colonies reared on each tested tomato hybrid. Each of them was transferred to a tomato leaflet with a size of  $4.4 \pm 1 \text{ cm}^2$  obtained from a two-month-old plant and allowed to mate with a one-day-old male for 24 hours, for later evaluations of predation and oviposition rates. After mating, the male was removed, and the female remained confined to the leaflet. Each female was provided with either prey nymphs or adults as a food source at each evaluated prey density. The number of prey attacked and eggs laid per predator was recorded every 24 hours during the oviposition period. Attacked prey individuals and eggs laid by each predator were removed every observation period, and the number of prey stages was replenished to its original count by adding new ones from the mite colonies. The experiments were conducted under laboratory conditions in an incubator set at  $30 \pm 1^\circ\text{C}$ ,  $65 \pm 5\%$  RH %, and 16L:8D photoperiod.

### **Estimation of leaf trichomes using a scanning electron microscope**

Leaf samples of tomato hybrids were collected from the upper third of plants when they were about two months old and prepared for scanning electron microscope (SEM) imaging to estimate trichome density (Joel jsm.6390LA) according to (Karnowsky 1965 and Fischer et al. 2012). The density of trichomes (numbers/ $\text{mm}^2$ ) on both leaf surfaces was determined from ten spots per leaf using the Compu Eye, Leaf, and Symptom Area program techniques (Bakr 2005).

### **Statistical analysis**

The data on the effects of prey stage (S), prey density (D), and tomato hybrid (H) leaf substrate on the predation and oviposition rates of the predator were analyzed for normality using the Shapiro–Wilk test (Shapiro and Wilk 1965). Subsequently, a factorial design of variance (ANOVA) with three factors was performed using MSTAT-C v.2.1 software (Michigan State University, Michigan, USA). Statistically significant means were compared using Tukey's Honestly Significant Difference test at the 1% probability level (Wickens and Keppel 2004), and t-test were also conducted where applicable.

## **RESULTS AND DISCUSSION**

The morphological distinctions among the leaf structures of the four tomato hybrids and their impact on the predation and oviposition rates of the predator are presented in Tables 1 and 2. These findings underscore significant variations in its biological performance when preying on *T. urticae* on tomato plants.

### **Tomato leaf morphological traits and its influence on the predator**

Significant differences ( $P < 0.05$ ) were observed in the number of trichomes/leaflet of the four hybrids (Table 1; Figures. 1, 2). The hybrid with the lowest trichome density seems to have facilitated the predator mobility and agility on the leaf surface, resulting in enhanced predation rates.

The Redjayda hybrid exhibited the highest density of non-glandular trichomes ( $103.3$ ,  $15.9$  trichomes/ $\text{mm}^2$ ) on the lower and upper leaf

surfaces, respectively. The same hybrid displayed the fewest density of glandular trichomes (2.4) on the lower surface, but the highest density (13.8, together with Nawara, 15.3) on the upper surface. Conversely, Miranda featured the lowest density of non-glandular trichomes (40.8) on the lower surface, whereas it had a moderate non-glandular trichome density (11.2) on the upper surface. As for glandular trichomes, Miranda had a relatively high density of glandular trichomes (in comparison with Redjayda), but a low density of this type of trichomes (4.1) on the upper surface. Meanwhile, Roufan and Nawara had moderate densities of non-glandular and glandular trichomes on the lower leaf surface. Consequently, the Redjayda hybrid leaf exhibited the highest total trichome densities (105.7, 29.6) across both surfaces, while the Miranda hybrid presented the lowest densities (47.3, 15.2, respectively).

These morphological variations among the hybrids resulted in discernible differences in predator performance. Consequently, it exhibited significantly higher predation and oviposition rates on Miranda hybrid leaves compared to Redjayda hybrid. These results align with Fahim and El-Saiedy (2021) observations regarding the effect of two strawberry cultivars (029 and Wanter star) on the biological parameters of *A. swirskii* and *N. californicus* on *T. urticae*. The trichome number and length varied between the two tested cultivars, being longer on Wanter star leaves, on which significantly lower predator fecundity was observed. On that same crop, Rezaie et al. (2017)

determined the highest fecundity rate (13.29 eggs/female/oviposition period) on ‘Chandler’ among seven evaluated cultivars, attributing it to the superior nutritional quality of *T. urticae* as prey or to the lower trichome density of that cultivar. Zhang et al. (2016) reported the reproduction rate of *Neoseiulus bicaudus* (Wainstein) feeding on *T. turkestanii* Ugarov & Nikolskii to be highest on green bean (42.4 eggs /female) due to its lower trichome density (58 /cm<sup>2</sup>) and shorter trichome length (0.14 mm) compared to cucumber, cotton, eggplant and tomato plants. The morphological characteristics of the host plants were mentioned by Sarwar (2014) to affect fecundity, searching efficiency and abundance of *Neoseiulus pseudolongispinosus* (Xin, Liang and Ke).

### Predation and oviposition rates of the predator

The consumption rate of the predator was significantly ( $p < 0.01$ ) higher on nymphs (7.1 individuals per day) than adults (4.1). Consequently, the daily oviposition was significantly higher (1.5 eggs/female) when the predator was feeding on nymphs than on adults (1.2 eggs/ female) (Table 2, Figure 3).

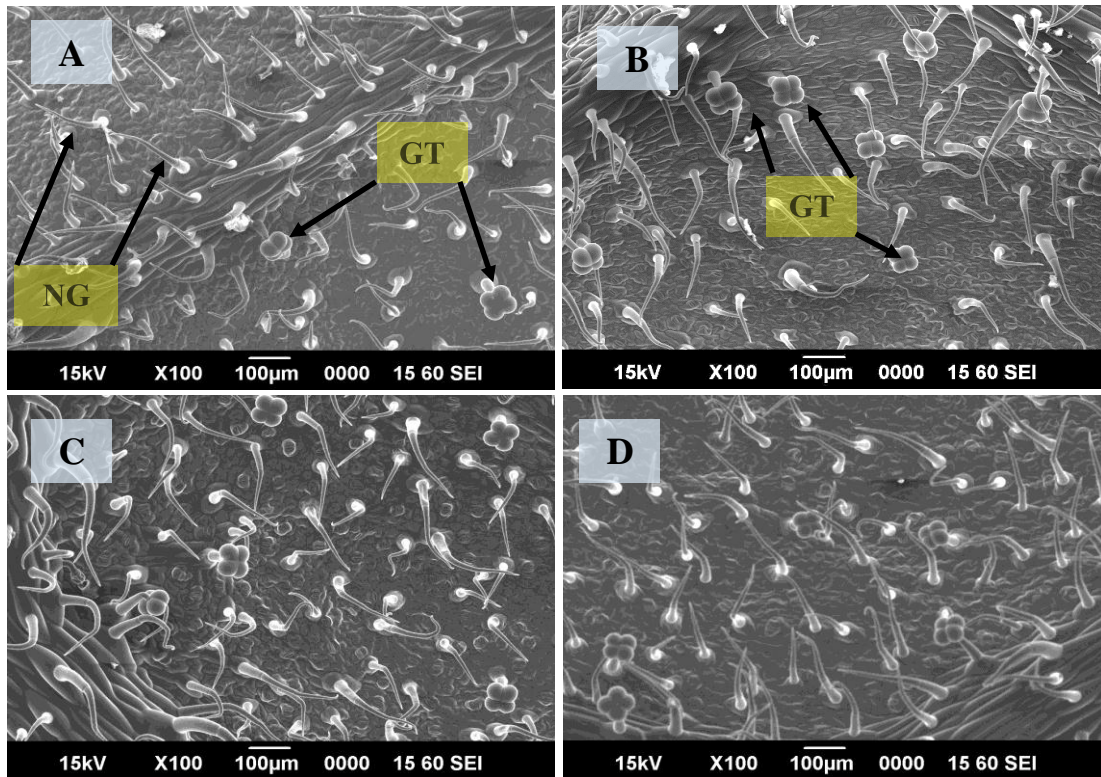
With the increase of prey density from 5 to 60 individuals per leaflet (each about  $4.4 \pm 1$  cm<sup>2</sup>), the predation rate of the predator increased about uniformly from 2.6 to 8.2 individuals, peaking at the density of 60 individuals (Figure 4). Likewise, the daily oviposition rate increased from 0.9 to 1.8 eggs/female at those respective extreme densities.

**Table 1.** Density of glandular and non-glandular trichomes on the upper and lower leaf surfaces of four tomato hybrids.

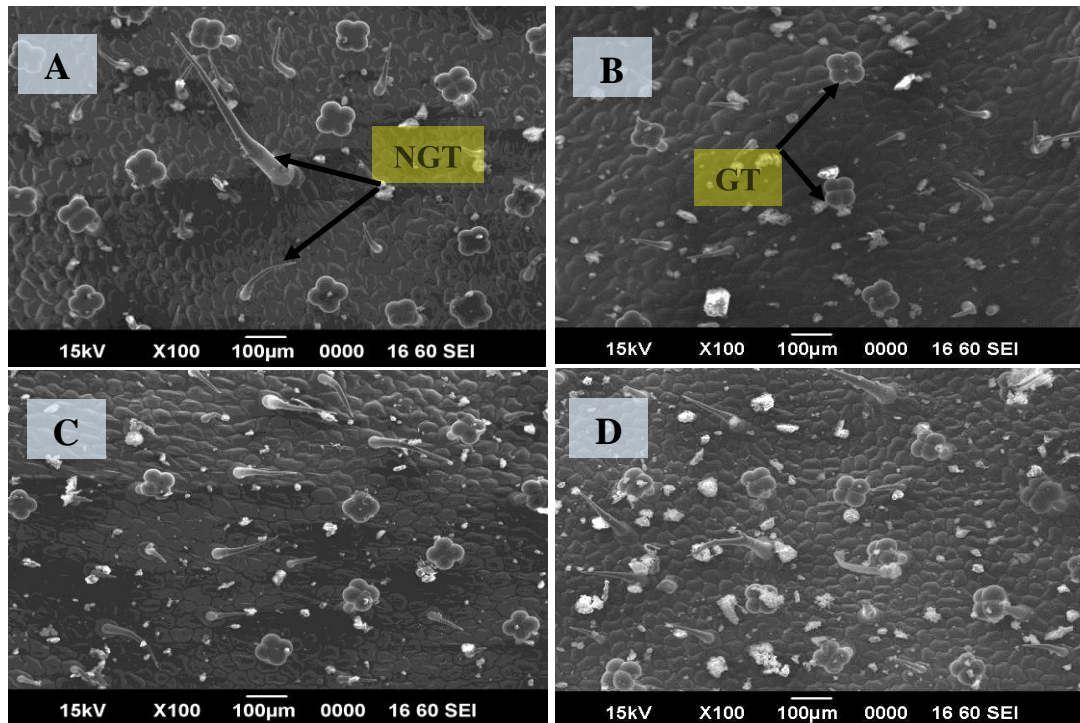
Tomato hybrids	Non-glandular trichomes (mm <sup>-2</sup> )		Glandular trichomes (mm <sup>-2</sup> )		Total number of trichomes (mm <sup>-2</sup> )	
	Lower surfaces	Upper surface	Lower surfaces	Upper surface	Lower surfaces	Upper surface
Redjayda	103.29±2.27 <sup>A</sup>	15.85±0.54 <sup>A</sup>	2.40±0.17 <sup>C</sup>	13.78±0.56 <sup>A</sup>	105.69±2.34 <sup>A</sup>	29.63±0.92 <sup>A</sup>
Miranda	40.75±1.13 <sup>C</sup>	11.16±0.39 <sup>B</sup>	6.53±0.17 <sup>AB</sup>	4.06±0.12 <sup>C</sup>	47.28±1.10 <sup>C</sup>	15.22±0.49 <sup>D</sup>
Roufan	64.76±1.71 <sup>B</sup>	9.47±0.37 <sup>C</sup>	5.92±0.20 <sup>B</sup>	11.47±0.40 <sup>B</sup>	70.67±1.74 <sup>B</sup>	20.94±0.24 <sup>C</sup>
Nawara	65.58±1.93 <sup>B</sup>	10.33±0.20 <sup>BC</sup>	7.12±0.23 <sup>A</sup>	15.29±0.65 <sup>A</sup>	72.69±2.07 <sup>B</sup>	25.62±0.55 <sup>B</sup>

Means in each column with the different letters are significantly different according to Tukey's test ( $p < 0.05$ ).





**Figure 1.** Scanning Electron Microscopy (SEM) images of the lower leaf surfaces of four tomato hybrids; Redjayda (A), Miranda (B), Roufan (C), and Nawara (D) to visualize the diversity of trichome types (glandular: GT and non-glandular: NGT) and densities.



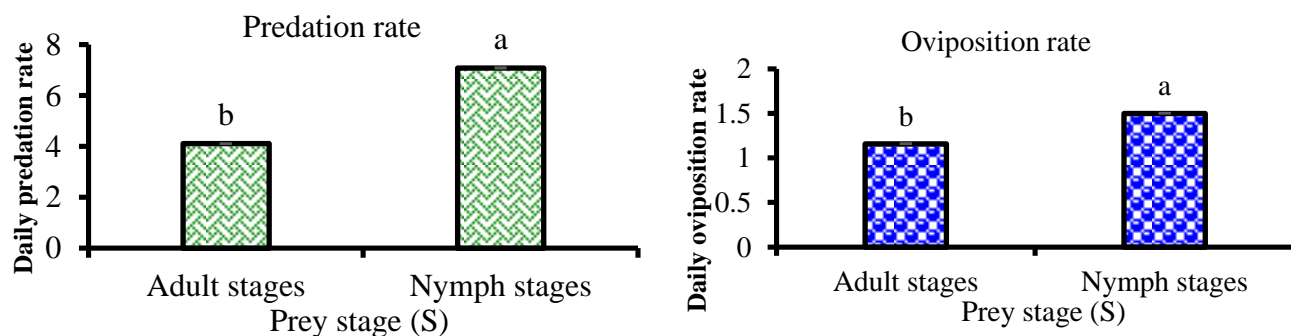
**Figure 2.** Scanning Electron Microscopy (SEM) images of the upper leaf surfaces of four tomato hybrids; Redjayda (A), Miranda (B), Roufan (C), and Nawara (D) to visualize the diversity of trichome types (glandular: GT and non-glandular: NGT) and densities.

**Table 2.** Analysis of variance (ANOVA) in a factorial design for the effects of prey stage (S) with two levels, density (D) with five levels, tomato hybrid (H) with four levels, and the interaction between them on daily predation and oviposition rates of *Phytoseiulus persimilis*.

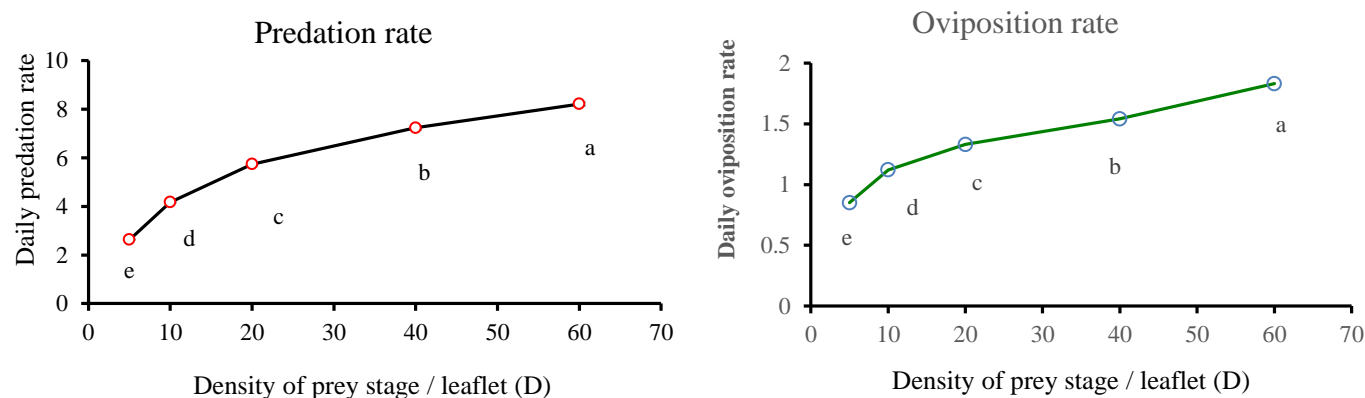
Source of variance	Df	Predation rate			Oviposition rate		
		MS <sup>y</sup>	F-value	P-value	MS <sup>y</sup>	F-value	P-value
Prey stage (S)	1	441.64	3837.01	0.000	5.78	274.91	0.000
Density of stage (D)	4	203.90	1771.54	0.000	5.66	269.09	0.000
Tomato hybrid (H)	3	79.33	689.21	0.000	5.15	244.99	0.000
S × D	4	32.88	285.66	0.000	0.03	1.55	0.192 <sup>ns</sup>
S × H	3	5.36	46.55	0.000	0.04	1.87	0.137 <sup>ns</sup>
D × H	12	2.15	18.68	0.000	0.06	2.77	0.002
S × D × H	12	1.61	14.01	0.000	0.03	1.64	0.09 <sup>ns</sup>
Error	160	0.115			0.021		
Total	199						

S: adults and nymphs; D: 5, 10, 20, 40 and 60 individual/leaflet; H: Redjayda, Roufan, Nawara and Miranda.

<sup>y</sup>MS: Mean square. ns = non-significant ( $p > 0.01$ ).



**Figure 3.** Effect of prey stage (S) with two levels (adults and nymphs of *Tetranychus urticae*) on the daily predation and oviposition rates of *Phytoseiulus persimilis* females.



**Figure 4.** Effect of density of prey stage/ leaflet with five levels (D) on the daily predation and oviposition rates of *Phytoseiulus persimilis* females.

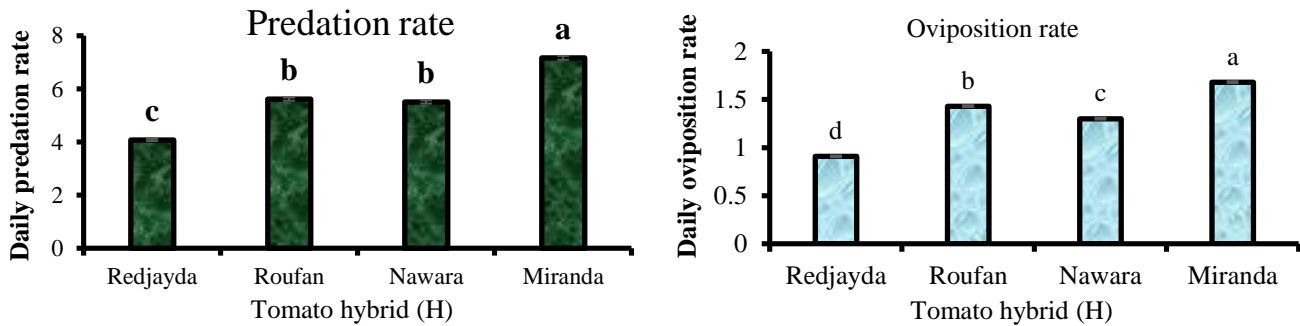
Also, significant differences were observed in daily predation and oviposition of each predator preying on *T. urticae* nymphs and adults across the four tomato hybrids. The highest rates were on Miranda hybrid (7.2 individuals and 1.7 eggs). In contrast, the lowest rates were observed on Redjayda hybrid (4.1 and 0.9). These findings

suggest that the Miranda hybrid is more favorable for the predator (Figure 5), likely due to its lower trichome density.

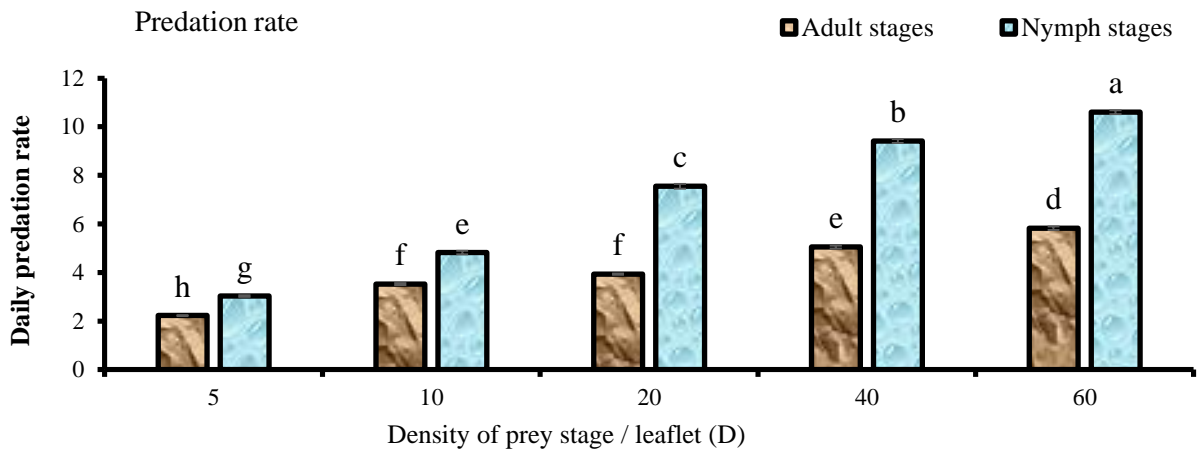
The predation rate of *P. persimilis* was significantly influenced ( $p < 0.01$ ) by two-way interactions between the factors mentioned above, namely (S×D), (S×H) and (D×H) (Table 2 and

Figs. 6-8). The consumption rate reached its peak at a density of 60 nymphs in the interactions between the prey stage and density of prey stage (S×D). As the density increased, more nymph stages were consumed compared to adult stages. Specifically, in the case of (S×D), the highest consumption rate was observed on nymphs of *T. urticae* (10.6 individuals) when the density reached 60 individuals, while the lowest

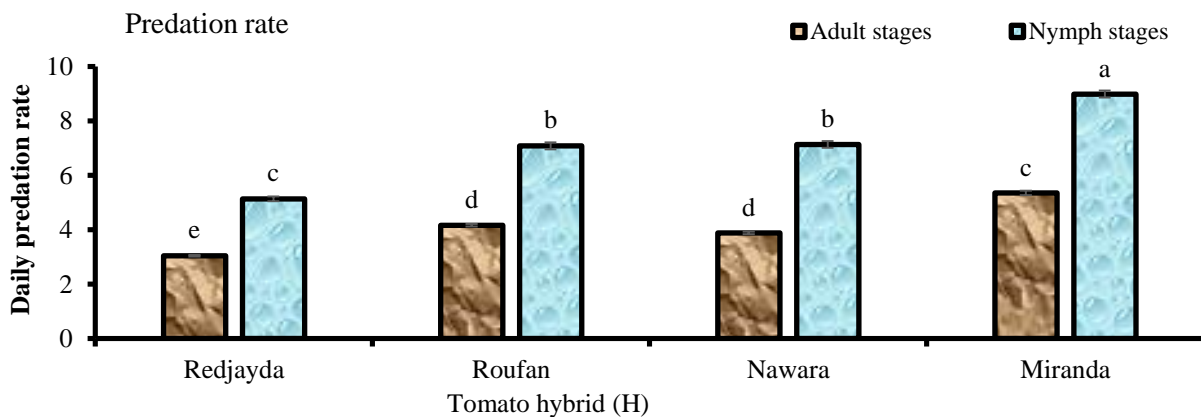
consumption rate was on adults of the prey (3.0 individuals) when the density was 5 individuals (Figure 6). Likewise, in the interactions between (S×H), the highest consumption rate was on the Miranda cultivar with nymphs of *T. urticae* (9.0 individuals), while the lowest was on leaves of Redjayda hybrid (3.0 individuals) with adults (Figure 7).



**Figure 5.** Effect of leaf substrate of tomato hybrid (H) with four levels on the daily predation and oviposition rates of *Phytoseiulus persimilis* females.



**Figure 6.** Effect of the interactions between prey stage (S) with two levels and density of prey stage/leaflet (D) with five levels on the daily predation rate of *Phytoseiulus persimilis* female.



**Figure 7.** Effect of the interactions between prey stage (S) with two levels and tomato hybrid (H) with four levels on the daily predation rate of *Phytoseiulus persimilis* female.

In the interactions between (D×H), predation and oviposition rates of the predator gradually increased with increasing prey density, peaking at a density of 60 individuals on all tomato hybrids. The highest predation rate was on Miranda hybrid (10.5 individuals), with a significantly higher daily oviposition of 2.2 eggs per female. In contrast, the Redjayda hybrid had the lowest predation rate, related to a lower oviposition rate. The lowest oviposition rate of the predator was observed when the density of the prey was 5 individuals/leaflet on Redjayda hybrid, associated with the low predation rate on this hybrid (Figs. 8, 9). Sato et al. (2011) revealed that *P. macropilis* and *P. longipes* predators were negatively affected by trichomes, which hindered their movement and reduced their prey consumption and oviposition rates. However, the presence of webbing was found to increase both prey consumption and oviposition rates of the predators. The webbing, that increases as density increases, mitigated the adverse effects of trichomes on the predators.

The interaction among the three factors (S×D×H) showed a significant effect on prey consumption rate (Tables 2, 3). The highest consumption rate by a predator female occurred with nymph stages of *T. urticae* (12.20 individuals) at a density of 60 individuals per leaf on Miranda tomato hybrid. This rate decreased when the predator consumed the adult stages at a density of 5 individuals per leaflet on Redjayda tomato hybrid.

The independent or combined influence of the three factors on increasing the predation rate of the female predator also impacted its oviposition rate. The oviposition rate was significantly ( $p < 0.01$ ) affected by the prey stage (S), density of the prey stage (D), and tomato hybrid as a substrate (H) individually. Additionally, when the two interactions between (D×H) were combined, this effect remained significant. However, this effect was not significant ( $p > 0.01$ ) with the other two or three-way interaction combinations of the three factors (S×D), (S×H), and (S×D×H) (Table 2).

Our findings suggest that the tomato hybrids had a direct effect on the predation and oviposition rates of *P. persimilis* females, likely due to the trichome density, which negatively affected the performance of the predator. The Redjayda hybrid had the greatest trichome density

(105.69 trichomes/mm<sup>2</sup>), while the Miranda hybrid leaves had the least density (47.28 trichomes/mm<sup>2</sup>). As a result, the daily consumption and fecundity rates were highest on the Miranda hybrid and lowest on Redjayda hybrid. These results can be of practical use to growers in their efforts to control *T. urticae*. By selecting tomato hybrids with lower trichome densities, such as the Miranda hybrid, growers may be able to enhance the effectiveness of *P. persimilis* as a biological control agent. This could potentially lead to improved pest management strategies. The trichomes on the tomato hybrids appear to play a significant role in the interaction between the predator *P. persimilis* and the pest *T. urticae*. On the other hand, these trichomes could potentially have a favorable effect on *T. urticae*. A higher trichome density might make it more difficult for *P. persimilis* to access and control *T. urticae*, thereby favoring its survival and proliferation. The negative effect of trichomes on predation and oviposition rate of *P. persimilis* was also reported by Sarwar (2014); Zhang et al. (2016); Rezaie et al. (2017); Fahim and El-Saiedy (2021).

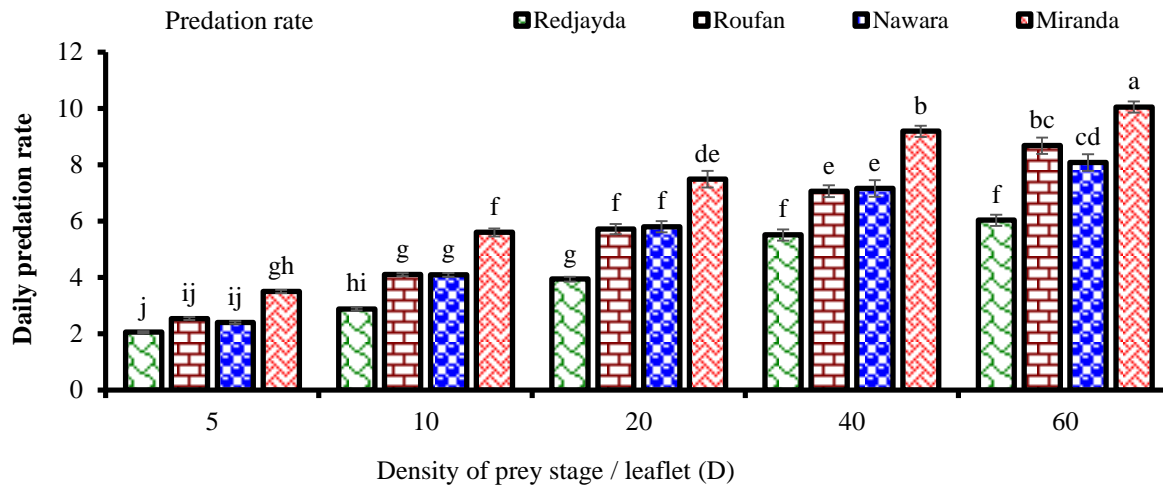
Additional investigation into the dynamics among the host plant, mite herbivore, and predator system, particularly the mechanisms causing the negative effects of the host plant on *P. persimilis* is necessary to develop a successful biological control strategy against *T. urticae* on various plants (Koller et al. 2007). It has been suggested that when the interaction among factors is statistically significant, prioritizing the examination of interaction effects holds greater importance than focusing solely on the main effects (Wickens and Keppel, 2004). In statistical analysis, the main effects of individual factors are often not enough to fully understand the behavior of a complex system. Especially, when the factors in the system interact with each other in a way that their combined effect is different from the sum of their individual effects. Prioritizing the examination of interaction effects in these situations allows for a more accurate and comprehensive understanding of the system. It can reveal complex relationships and dependencies between factors that would not be apparent when looking at the main effects alone.



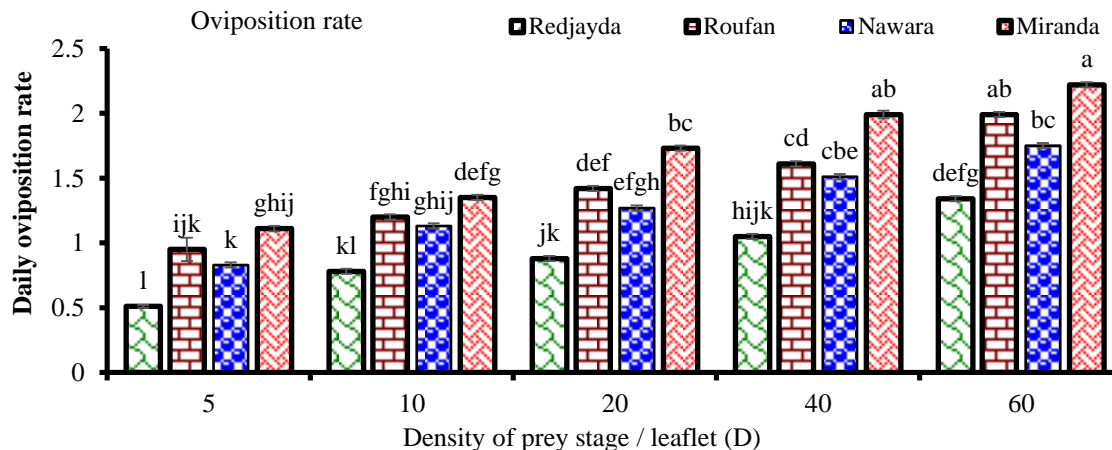
**Table 3.** Effect of the triple interaction between prey stage (S) with two levels, density of prey (D) with five levels and tomato hybrid (H) with four levels on the daily predation rate of *Phytoseiulus persimilis* female.

Prey stage (S)	Density of prey (D)	Tomato hybrid (H) with four levels			
		Redjayda	Roufan	Nawara	Miranda
Adult stages of <i>T. urticae</i>	5	1.78±0.02 <sup>T</sup>	2.12±0.04 <sup>RS</sup>	2.06±0.03 <sup>ST</sup>	2.94±0.03 <sup>NOP</sup>
	10	2.54±0.5 <sup>OR</sup>	3.72±0.10 <sup>LMN</sup>	3.54±0.12 <sup>MNO</sup>	4.28±0.07 <sup>JK</sup>
	20	3.14±0.04 <sup>NOP</sup>	4.02±0.07 <sup>KL</sup>	3.88±0.06 <sup>KLM</sup>	4.66±0.08 <sup>J</sup>
	40	3.64±0.06 <sup>LMN</sup>	5.04±0.05 <sup>I</sup>	4.56±0.07 <sup>J</sup>	6.96±0.05 <sup>G</sup>
	60	4.08±0.07 <sup>KL</sup>	5.92±0.10 <sup>H</sup>	5.38±0.07 <sup>HI</sup>	7.90±0.09 <sup>F</sup>
Nymph stages of <i>T. urticae</i>	5	2.34±0.04 <sup>QR</sup>	2.96±0.05 <sup>NOP</sup>	2.74±0.05 <sup>OPQ</sup>	4.06±0.05 <sup>KL</sup>
	10	3.22±0.09 <sup>MNO</sup>	4.48±0.06 <sup>JK</sup>	4.64±0.03 <sup>J</sup>	6.92±0.05 <sup>G</sup>
	20	4.74±0.08 <sup>IJ</sup>	7.42±0.08 <sup>FG</sup>	7.72±0.06 <sup>F</sup>	10.32±0.07 <sup>CD</sup>
	40	7.38±0.06 <sup>FG</sup>	9.08±0.07 <sup>E</sup>	9.76±0.07 <sup>D</sup>	11.42±0.10 <sup>AB</sup>
	60	7.98±0.06 <sup>F</sup>	11.44±0.08 <sup>AB</sup>	10.78±0.11 <sup>BC</sup>	12.20±0.08 <sup>A</sup>

S: adults and nymphs; D: 5, 10, 20, 40 and 60 individual/leaflet. Notes: The means followed by different letters in the table are significantly different ( $p < 0.01$ , Tukey's HSD test after factorial design). The values are presented as mean ± SE.



**Figure 8.** Effect of the interactions between density of prey stage/ leaflet (D) with five levels and tomato hybrid (H) with four levels on the daily predation rate of *Phytoseiulus persimilis* female.



**Figure 9.** Effect of the interactions between density of prey stage / leaflet (D) with five levels and tomato hybrid (H) with four levels on the daily oviposition rate of *Phytoseiulus persimilis* female.

The increase in prey density corresponded to an increase in predation, consequently leading to a significant increase in the oviposition rate of *P. persimilis* female. That can be attributed to the functional response of predators to prey density. Predators, such as *P. persimilis*, often adjust their feeding rates based on the availability of prey, leading to an increase in predation as prey density increases. In turn, this increased food availability can also stimulate higher oviposition rates, as the predators have more resources for reproduction (Nawar 1992). However, if higher prey densities were used, it's possible that the predation and oviposition rates would continue to increase up to a certain point. As, at extremely high prey densities, the predation rate may plateau or even decrease due to factors such as predator satiation, limited predator mobility, or increased disturbance by the prey (Reis et al. 2003). This trend also parallels the findings observed with the predator *N. californicus* fed on *T. urticae* (Friese and Gilstrap 1982; Canlas et al. 2006; Marafeli et al. 2011; Farazmand et al. 2012; Song et al. 2016; Jahanbazi et al. 2021).

The interaction among the three factors (S×D×H); prey stage (S), density of prey (D) and tomato hybrid (H) showed a significant effect on the prey consumption and on the daily oviposition rate of *P. persimilis* females preying on *T. urticae*. Miranda hybrid emerged as a superior host plant for this predator seemingly due to its lower leaf trichomes density, consistent with Sulek et al. (2023), who found that *P. persimilis* attack rates were found to be similar overall among different cotton varieties when feeding on protonymphs of *T. urticae*, except for the Gloria and Lima types, which featured lower trichome densities. Furthermore, Koveos and Broufas (2000) noted lower attack rates of *Amblyseius andersoni* (Chant) and *Euseius finlandicus* (Oudemans) on the hairy surface of apple leaves compared to peaches.

In this study, higher prey consumption and oviposition rates of the predator were observed with nymphs of *T. urticae* compared to adults. Nymphs are smaller and less mobile than adults, making them easier targets for predators but adult

prey might pose a greater risk to the predator, either through physical defenses or by their ability to escape (Moghadas et al. 2013). Nymphs and adults of *T. urticae* represent active feeding stages that directly impact crop damage and reproduction. Studying predation rates on these stages may provide valuable insights into the ecological dynamics of pest control. Difference of *P. persimilis* predation and oviposition rates on different prey stages had also been reported by Sulek et al. (2023). Those authors observed higher attack rates of *P. persimilis* on protonymphs compared to eggs. Likewise, Krips et al. (1999) found that the consumption rate of *P. persimilis* fed on *T. urticae* eggs on low-high hairy gerbera plants was influenced by leaf hairiness. Nassar et al. (2010) found that the number of *T. urticae* nymphs devoured by *P. persimilis* across different plant species, reflecting the influence of leaf hairiness.

Despite the fact that a higher density of *T. urticae* eggs and protonymphs led to an increase in the fecundity of *P. persimilis*, the egg-laying behavior of *P. persimilis* did not show significant variation across different cotton varieties when preying on eggs or protonymphs of *T. urticae*, Sulek et al. (2023). This was also confirmed by the study's findings, indicating that the oviposition rate was not significantly ( $p > 0.01$ ) affected by three-way interactions among the three factors (S×D×H), prey stage (S), density of prey stage (D), and tomato hybrid as a substrate (H) (Table 2).

However, Nassar et al. (2010) found a statistically significant variations in the number of eggs laid by *P. persimilis* across different cultivated plants with varying levels of hairiness (bean, apple, fig, zucchini, cucumber, mango, and cotton), which resonates with the two-way interaction observed between density of prey stage/leaflet (D) and tomato hybrid (H) in this study on the daily oviposition rate of *P. persimilis* (Fig 9). In contrast, Ottaviano et al. (2013) observed that the number of eggs produced by *N.*

*californicus* did not vary across different strawberry varieties with different trichome densities. However, they noted that as the density of the prey increased, so did the proportion of eggs laid.

### CONCLUSION

In conclusion, this study highlights the profound influence of prey stage (S), prey density (D) and tomato hybrid (H), individually and in combination, on the performance of *P. persimilis*. The predation rate of *P. persimilis* and the daily egg deposition by females notably increased when feeding on nymph stages of *T. urticae* with a density of 60 individuals, indicating a preference for Miranda over Redjayda hybrid due to lower leaf trichome density. The ability of *P. persimilis* to consume *T. urticae* prey was influenced by the leaf trichome density on tomato plants. To address this issue comprehensively, further research is necessary, particularly to study the foraging behavior of *P. persimilis* in response to different prey stages and densities and the adverse effects of leaf trichomes on its performance.

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