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***Original article (Orijinal araştırma)***

# Functional response and egg production of a native *Typhlodromus recki* Wainstein, 1958 (Acari: Phytoseiidae) population to *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae)[1]

*Typhlodromus recki* Wainstein, 1958 (Acari: Phytoseiidae)'nin yerli popülasyonunun *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae) üzerinde işlevsel tepkisi ve yumurta verimi

**Firdevs ERSİN[2*]**

## Abstract

In this study, which was conducted to determine predation potential of *Typhlodromus recki* Wainstein, 1958 (Acari: Phytoseiidae) at Ege University, Faculty of Agriculture, Department of Plant Protection in 2018-2019. Functional response and egg production of the predatory mite, *T. recki* fed on different biological stages (egg, larva, protonymph, deutonymph and adult male) of the two-spotted spider mite (green form), *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae) were studied under laboratory conditions (25±1°C, 60±10% RH and 16:8 h L:D photoperiod). In the experiments, seven prey densities (2, 4, 8, 16, 32, 64 and 128) for each biological stage of the prey were offered daily to the predatory mite. The results of logistic regression analysis indicated that *T. recki* had a Type II functional response on each developmental stage of its prey according to Holling's models. The attack rate (α) and the handling time ($T_h$) varied based on the biological stages of the prey. The highest *α* and the lowest $T_h$ values were determined as 1.035 and 0.001 when the predator fed on larvae and eggs of its prey, respectively. The highest average daily mean number of the eggs consumed by *T. recki* was 111 at 128 prey densities. The highest average daily mean number of eggs deposited by the predator were found to be 1.05 when it fed on the eight-prey density of *T. urticae* protonymphs. In addition, the lowest average daily mean number of eggs deposited by the predator was 0.15 when fed on the two-prey density with *T. urticae* adult males. The study indicates that *T. recki* could be effective and promising biological control agent for *T. urticae.*

**Keywords:** Biological control, fecundity, Phytoseiidae, predatory mite, *Tetranychus urticae*

## Öz

Bu çalışma 2018-2019 yıllarında Ege Üniversitesi Ziraat Fakültesi, Bitki Koruma Bölümü'nde avcı akar, *Typhlodromus recki* Wainstein, 1958 (Acari: Phytoseiidae)'nin besin tüketim potansiyelini belirlemek için gerçekleştirilmiştir. Avcı akar, *T. recki*'nin iki noktalı kırmızıörümcek (yeşil formu), *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae)'nin farklı biyolojik dönemleri (yumurta, larva, protonimf, deutonimf ve ergin erkek) üzerinde işlevsel tepkisi ve yumurta verimi laboratuvar koşulları altında (25±1°C, %60±10 RH and 16:8 L:D) çalışılmıştır. Denemelerde, avcı akara avın her bir biyolojik dönemi için günlük yedi farklı (2, 4, 8, 16, 32, 64 ve 128) besin yoğunluğu verilmiştir. Regresyan analizi sonuçlarına göre, *T. recki* avının bütün gelişme dönemlerinde Holling modeline göre Tip II işlevsel tepki gösterdiği belirlenmiştir. Avcı akarın arama (*α*) ve avlanma kapasiteleri ($T_h$) av biyolojik dönemlerine bağlı olarak değişkenlik göstermiştir. Avcı akara ait en yüksek *α* değeri ve en düşük $T_h$ değeri, avının larva ve yumurtası ile beslendiğinde sırası ile 1.035 ve 0.001 olarak belirlenmiştir. Avcı akar tarafından tüketilen günlük en yüksek yumurta dönemi 128 av yoğunluğunda 111 olmuştur. Avcı akar tarafından bırakılan günlük en yüksek yumurta sayısı ise, *T. urticae*'nin 8 protonimf yoğunluğunda 1.05 bulunmuştur. Ayrıca, *T. recki*'nin günlük bıraktığı en düşük yumurta sayısı ise 2 av yoğunluğunda 0.15 olarak *T. urticae*'nin ergin erkekleri ile beslendiğinde saptanmıştır. Bu çalışma *T. recki*'nin, *T. urticae*'nin mücadelesinde kullanılmak üzere etkili ve ümit var bir biyolojik savaş etmeni olabileceğini göstermiştir.

**Anahtar sözcükler:** Biyolojik savaş, üreme, Phytoseiidae, Predatör akar, *Tetranychus urticae*

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[2] Ege University, Agricultural Faculty, Department of Plant Protection, Izmir, Turkey
* Corresponding author (Sorumlu yazar) e-mail: firdevs.ersin@ege.edu.tr
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## Introduction

Two-spotted spider mite, *Tetranychus urticae* Koch, 1836 (Acari: Tetranychidae), is a generalist herbivore known to feed on more than 1200 plant species in 140 different plant families that damages both field and greenhouse crops worldwide (Zhang, 2003; Migeon & Dorkeld, 2021). *Tetranychus urticae* is a notorious pest due to its ability to develop resistance due to extensive use of insecticides/acaricides combined with its short life cycle and high fecundity (Stumpf et al., 2001; Yorulmaz & Ay, 2009; Migeon et al., 2010). Also, insecticides/acaricides usage has affected not only the pest species but also environment, human health and non-target organisms, such predators and parasitoids (Sánchez-Bayo, 2011). Nowadays, augmentative release of biological control agents such as predatory mites has become important for managing spider mite outbreaks. Phytoseiid mites are mostly effective and eco-friendly biological control agents to be used in biological control programs as some of them are easily mass-reared and available commercially all over the world. Although, there are some commercially produced predatory mites, the potential of many species is virtually unknown.

*Typhlodromus recki* Wainstein, 1958 (Acari: Phytoseiidae), for instance, is one of the most commonly found predatory mites in some areas of Europe and the Middle East (Tixier et al., 2020), where it was found on a wide range of plants, especially non-cultivated species but occasionally it is also found on crops such as aubergine, citrus, grapevines, potato, olive, orchard trees, strawberry and tomato (Swirski & Amitai, 1982; Şekeroğlu, 1984; Papaioannou-Souliotis et al., 1994; Tixier et al., 2003; Kumral, 2005; Rahmani et al., 2010; İnak & Çobanoğlu, 2018; Kreiter et al., 2020; Ersin et al., 2021). Therefore, it is expected that it may have great potential for biological control of mites. *Typhlodromus recki* is considered to be a generalist predator that is likely to feed on a wide range of pestiferous mites and arthropods. It can also reproduce on pollen, fungi and plant exudates in the absence of its main prey (McMurtry & Croft, 1997; McMurtry et al., 2013).

Before starting biological control studies, it is necessary to understand foraging behavior and predation capacity of natural enemies. Functional and numerical responses are among the most important characteristics and foraging behavior to understand the capacity and potential of predators on their prey (Fathipour & Maleknia, 2016). Predator and prey interactions are analyzed using functional response which determined consumption rates as function of prey densities. Holling's (1959) models include three types of functional responses: Type I, predator consumption rate increases linearly as density of prey increases, Type II response that a hyperbolic relationship in the predator consumption rate with increasing prey density, and Type III responses are sigmoidal, where the maximum consumption rate is reached at intermediate prey densities, before decreasing at higher densities (Soria-Díaz et al., 2018). Type II functional response, however, are the most common among phytoseiid mites. The functional responses of predators are usually influenced by temperature, relative humidity, host plant, prey stage, age and pesticide application (Escudero & Ferragut, 2005; Döker et al., 2016; Sousa Neto et al., 2020; Dalir et al., 2021). However, there have been no published studies on the functional response of *T. recki* to *T. urticae*.

Therefore, this study aimed to determine the functional response and fecundity of *T. recki* on different biological stages of *T. urticae*. The results obtained from the study will help to obtain detailed knowledge with regard to predation potential of *T. recki* on *T. urticae.*

## Materials and Methods

### Plant production, prey and predator culture

Barbunia plants (*Phaseolus vurgaris* cv. Barbunia supplied by Bursa Seeds, Bursa, Turkey) were grown in plastic pots in a climate room (25±1°C, 60±10% RH and 16:8 h L:D photoperiod). *Tetranychus urticae* (green form) collected from tomato plants in a greenhouse in Izmir was used for experimental studies and feeding *T. recki* colonies. They were reared on barbunia plants in the laboratory for more than 6 years and kept at 25±1°C, 60±10% RH and 16:8 h L:D photoperiod in the climate room. *Typhlodromus* *recki* was collected from vegetable garden in Denizli, Turkey (Ersin et al., 2021), and it was reared on black plastic arenas (80 x 150 mm) on top of wet sponge in a plastic tray filled with tap water. The edges of arenas were sealed with tissue paper immersed in the water to provide moisture and prevent the mites from escaping (Overmeer, 1985). Mixed stages of *T. urticae* and Cattail pollen were offered as a food source for the predatory mite every 2 days at 25±1°C, 60±10% RH and 16:8 h L:D photoperiod in a controlled-climate room. Cattail pollen collected from *Typha latifiola* L. in Denizli, Turkey was dried in air for 24 h in the laboratory under low humidity conditions, then sieved and stored in the refrigerator at -20°C.

**Functional response and egg production of *Typhlodromus recki***

Functional response and egg production of *T. recki* adult females to different stages of *T. urticae* were studied by modified Munger cells at 25±1°C, 60±10% RH and 16:8 h L:D photoperiod in an incubator (Sanyo, MLR 351H). A modified Munger cell (60 x 45 mm) that consisted of a stack containing three plates: base acrylic plate (2 mm thick), moistened filter paper, clean bean leaf; middle acrylic plate (5 mm thick and a central 23-mm diameter hole) and top covered with transparent acetate sheet (0.1 mm thick), respectively. Clean bean leaves obtained from the culture was placed abaxial side up on the filter paper. About 100 holes were punched into the transparent acetate sheet with an insect pin for ventilation. All layers were held together with two large binder clips (32 mm) (Kustutan & Cakmak, 2009; Kamburgil & Cakmak, 2014). To obtain prey stages of the same age (eggs, larvae, protonymphs, deutonymphs and adult males) for *T. recki*, adult females of *T. urticae* (about 40-50) from the stock culture were transferred onto clean leaf disc with a fine brush and allowed to deposit eggs for 24 h. Then, *T. urticae* females were removed from the leaf disc. Coeval eggs, larvae, protonymphs, deutonymphs and adult males of *T. urticae* transferred to experimental units with a fine brush. Seven different prey densities (2, 4, 8, 16, 32, 64 and 128) for each biological stage (eggs, larvae, protonymphs, deutonymphs and adult males) were offered to *T. recki* females per experimental unit. Prior to the experiments, gravid adult females of the predator obtained from culture were separately starved for 16 h in Eppendorf tubes. Then, the predatory mite was released individually onto the leaf discs and it was removed from the leaf disc after 24 h. The number of prey consumed and the eggs deposited by *T. recki* were recorded. Each prey density was repeated 20 times with different predatory mite individuals.

**Statistical analysis**

The functional responses of the predatory mite *T. recki* were determined after two-step data analysis (Juliano, 2001). The data of functional response were initially determined by a logistic regression the number of prey consumed ($N_a/N_0$) as a function of initial number of prey ($N_a/N_0$) (Juliano, 2001).

Equation 1 is used to determine the type of the functional response curve of the predatory mite, and $P_0$, (intercept), $P_1$ (linear), $P_2$ (quadratic) and $P_3$ (cubic coefficient) the respective coefficients.

When determining the functional response type; if the linear $P_1$ parameter is significantly negative, it shows that the predator has a Type II functional response (Juliano, 2001).

$$\frac{Na}{No} = \frac{exp\left(P_0+P_1N_0+P_2N_0^2+P_3N_0^3\right)}{1+exp\ (P_0+P_1N_0+P_2N_0^2+P_3N_0^3} \quad (1)$$

Given that Type II functional response were determined for all biological stages of the prey, the handling time and the attack rate were determined using the Holling's disc equation (Equation 2) (Holling, 1959). where, $N$ is the initial number of prey offered, $P$ is the number of predators, $N_a$ is the number of prey consumed, $a$ is the attack rate, $T_h$ is the handling time (h), $T$ is the experimental time.

$$\frac{N_a}{p} = \frac{aTN}{(1+aT_hN)} \quad (2)$$

The difference between the food consumption and the number of eggs deposited by the predatory mite fed on different biological stages of *T. urticae* was determined by one-way ANOVA, and means were subsequently separated by Student-Newman-Keuls test ($P < 0.05$). Before the analysis, the homogeneity of variances was checked using the Levene test, and when the test was significant, logarithmic transformation was applied to the data. In order to compare α and $T_h$ values at different stages of food, pseudo-values (*rj*) for 20 replicates were produced using jackknife resampling method and Equation 3 was applied to the data (Efron, 1982).

$$rj = (20 * r) - [\,(20 - 1) * re] \quad (3)$$

The differences between α and $T_h$ values were also determined using one-way ANOVA, followed by Student-Newman-Keuls test ($P < 0.05$). All analyses were conducted in SPSS version 25.0.

## Results

All linear coefficients ($P_1$) are significantly negative for all of prey stages (Table 1). The proportion of the prey consumed decreased with increasing prey densities for all prey stages (Figure 1). The significantly negative $P_1$ values and the functional response curves clearly indicated that adult female *T. recki* had a Type II functional response to all biological stages of *T. urticae*. The attack rate and the handling time of *T. recki* on different biological stages of *T. urticae* were estimated by using Holling's disc equation. The highest numerically attack rate was found on larvae (1.04±0.147), followed by eggs (0.98±0.048), adult male (0.72±0.072), protonymph (0.64±0.078) and deutonymph (0.53±0.062) (Table 2). However, the attack rate is not significantly different between larvae and eggs. The shortest handling time was found on eggs (0.001±0.000) followed by protonymphs (0.012±0.002), larvae (0.018±0.001), adult males (0.022±0.001) and deutonymphs (0.062±0.004). There was a statistically significant difference between eggs, larvae, protonymphs, deutonymphs and adult males. However, no significant differences were observed between larvae, protonymphs and adult males. The daily mean number of the prey consumed by *T. recki* increased with increasing prey densities (Table 3). The highest number of eggs, larvae, protonymphs, deutonymphs and adult males consumed by *T. recki* was 111, 40.6, 42.0, 15.0 and 31.4 at 128 prey densities, respectively. In contrast, the lowest number of the prey consumed by the predator was 1.85 eggs, 1.90 larvae, 2.00 protonymphs, 1.75 deutonymphs and 1.95 adult males at two prey densities. The number of deutonymphs consumed by *T. recki* was the lowest at all prey densities except for two prey densities (Table 3; $P < 0.001$). The average number of eggs deposited by *T. recki* per day also increased with increasing prey densities (Table 4). The highest mean number of eggs (1.05 females/day) deposited by *T. recki* was determined at eight protonymphs prey densities. This value was not significantly different between all protonymphs prey densities. In contrast, the lowest oviposition rate (0.15 females/day) was found at the two adult males prey density.

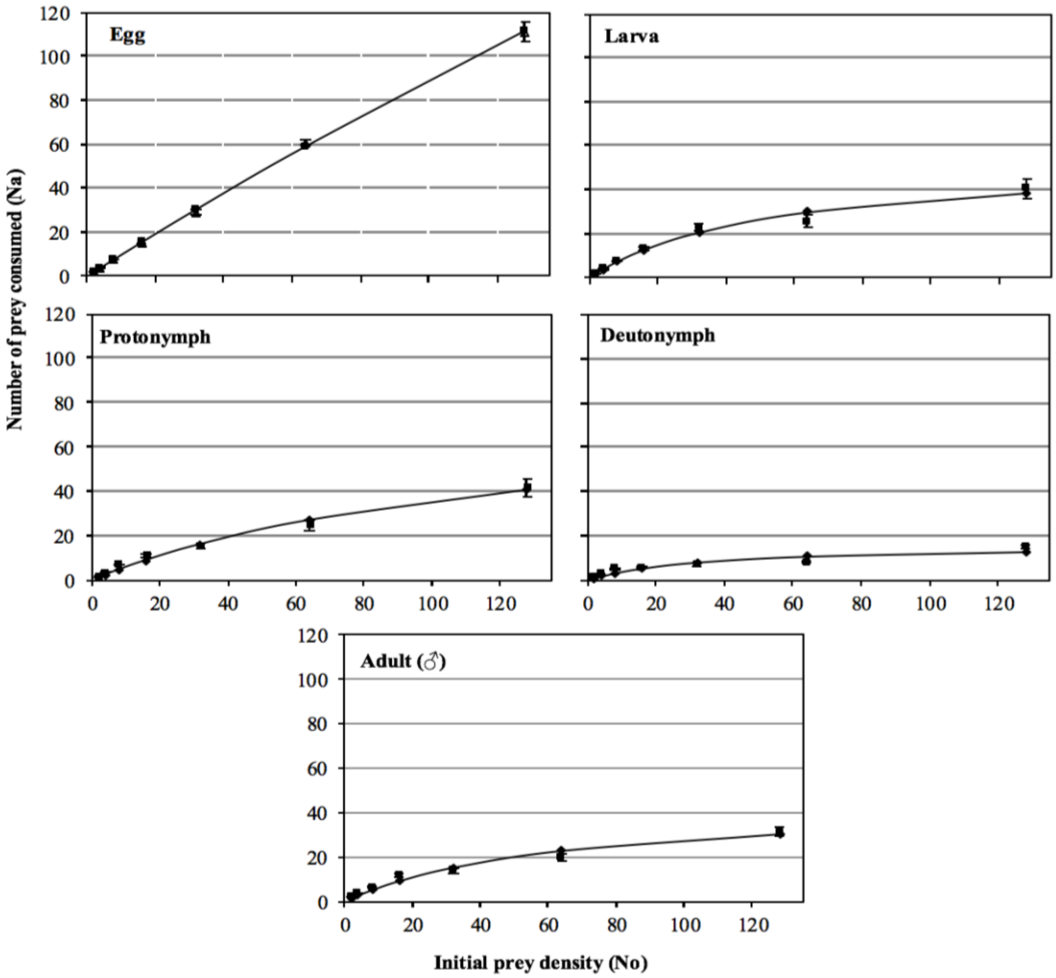


Figure 1. Functional response curves of *Typhlodromus recki* on fedd on egg, larva, protonymph, deutonymph and adult male at seven densities of *Tetranychus urticae*.

Table 1. Estimated coefficients from logistic regression of the different stages of *Tetranychus urticae* consumed by *Typhlodromus recki* as a function of initial prey density in 24 h

| Prey stage | Parameters* | Estimate (±SE) | $X^2$ | *P* |
|---|---|---|---|---|
| Egg | $P_0$ | 3.8667 (±0.2906) | 177.023 | <0.0001 |
| | $P_1$ | -0.1142 (±0.0203) | 31.5494 | <0.0001 |
| | $P_2$ | 0.0023 (±0.0003) | 39.2415 | <0.0001 |
| Larva | $P_0$ | 3.0618 (±0.1567) | 381.4086 | <0.0001 |
| | $P_1$ | -0.0786 (±0.0046) | 291.5870 | <0.0001 |
| | $P_2$ | 0.0003 (±0.0000) | 189.4967 | <0.0001 |
| Protonymph | $P_0$ | 3.5635 (±0.2757) | 167.0422 | <0.0001 |
| | $P_1$ | -0.1953 (±0.0187) | 109.0868 | <0.0001 |
| | $P_2$ | 0.0028 (±0.0003) | 74.3136 | <0.0001 |
| Deutonymph | $P_0$ | 1.4965 (±0.1856) | 65.0054 | <0.0001 |
| | $P_1$ | -0.1398 (±0.0152) | 83.8422 | <0.0001 |
| | $P_2$ | 0.0018 (±0.0003) | 37.3923 | <0.0001 |
| Adult (male) | $P_0$ | 2.8602 (±0.2393) | 142.8469 | <0.0001 |
| | $P_1$ | -0.1548 (±0.0168) | 84.3527 | <0.0001 |
| | $P_2$ | 0.0020 (±0.0003) | 45.4799 | <0.0001 |

*$P_0$, $P_1$ and $P_2$ are intercept, linear and quadric, respectively.

Table 2. Attack rate (*a*) and handling time ($T_h$) of the Holling's disc equation for *Typhlodromus recki* preying on *Tetranychus urticae* different prey stages (mean ± SE)

| Prey Stage | *a* ± SE | | $T_h$ ± SE | | $R^2$ |
|---|---|---|---|---|---|
| Egg | 0.983±0.048 | ab* | 0.001±0.000 | c | 0.872 |
| Larva | 1.035±0.147 | a | 0.018±0.001 | b | 0.958 |
| Protonymph | 0.639±0.078 | b | 0.012±0.002 | b | 0.931 |
| Deutonymph | 0.531±0.062 | b | 0.062±0.004 | a | 0.665 |
| Adult (male) | 0.723±0.072 | b | 0.022±0.001 | b | 0.899 |

* Means within columns following by the same letter are not significantly different according to Student-Newman-Keuls Test ($F$ = 4.03 $P$ < 0.005 for *a*; $F$ = 35.5 $P$ < 0.001 for *Th*).

Table 3. Average daily number of different stages of *Tetranychus urticae* consumed by *Typhlodromus recki (*mean ± SE)

| Prey density | Egg | | Larva | | Protonymph | | Deutonymph | | Adult (Male) | | F | *P* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1.85±0.07 | a* | 1.90±0.10 | a | 2.00±0.00 | a | 1.75±0.09 | a | 1.95±0.05 | a | 2.083 | >0.05 |
| 4 | 3.92±0.04 | a | 3.95±0.05 | a | 3.90±0.06 | a | 2.85±0.22 | b | 3.70±0.12 | a | 17.584 | <0.001 |
| 8 | 7.62±0.21 | a | 7.80±0.15 | a | 7.30±0.23 | a | 5.15±0.31 | c | 6.35±0.32 | b | 16.922 | <0.001 |
| 16 | 14.65±0.50 | a | 12.95±0.77 | ab | 11.35±0.80 | b | 5.80±0.35 | c | 11.75±0.63 | b | 28.736 | <0.001 |
| 32 | 28.97±1.02 | a | 30.15±0.55 | a | 15.35±1.22 | b | 7.20±0.54 | c | 13.85±0.95 | b | 99.335 | <0.001 |
| 64 | 60.85±1.00 | a | 25.75±2.88 | b | 25.0±2.39 | b | 8.25±0.59 | d | 19.75±1.37 | c | 181.336 | <0.001 |
| 128 | 111.32±4.68 | a | 40.55±4.33 | b | 41.95±3.95 | b | 14.95±0.82 | c | 31.40±2.22 | b | 102.340 | <0.001 |

* Means within same row with different letters are not significantly different according to *****Student-Newman-Keuls test or **†**Kruskal Wallis test.

Table 4. Average daily number of eggs deposited by *Typhlodromus recki* when fed with different stages densities of *Tetranychus urticae (*mean ± SE)

| Prey density | Egg | | Larva | | Protonymph | | Deutonymph | | Adult (Male) | | F | *P* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.40±0.07 | ab* | 0.30±0.10 | b | 0.75±0.12 | a | 0.50±0.11 | ab | 0.15±0.08 | b | 4.314 | <0.05 |
| 4 | 0.37±0.08 | b | 0.45±0.11 | ab | 0.75±0.14 | a | 0.20±0.09 | b | 0.20±0.09 | b | 3.884 | <0.05 |
| 8 | 0.32±0.07 | b | 0.45±0.11 | b | 1.05±0.11 | a | 0.40±0.11 | b | 0.25±0.09 | b | 9.126 | <0.001 |
| 16 | 0.25±0.06 | b | 0.55±0.13 | ab | 0.75±0.12 | a | 0.50±0.11 | ab | 0.30±0.10 | b | 4.267 | <0.05 |
| 32 | 0.40±0.08 | b | 0.65±0.13 | ab | 0.90±0.14 | a | 0.45±0.11 | b | 0.40±0.11 | b | 3.356 | <0.05 |
| 64 | 0.52±0.08 | a | 0.70±0.14 | a | 0.95±0.13 | a | 0.70±0.10 | a | 0.60±0.11 | a | 2.023 | >0.05 |
| 128 | 0.74±0.10 | a | 0.70±0.12 | a | 0.95±0.11 | a | 0.45±0.11 | a | 0.70±0.10 | a | 2.061 | >0.05 |

* Means within a row followed by the same letter are not significantly different according to *****Student-Newman-Keuls test or **†**Kruskal Wallis test.

## Discussion

The results of this study demonstrated the predation potential of *T. recki* on different stages of *T. urticae*. This appears to be the first study to evaluate the predation potential of *T. recki* when offered *T. urticae* as prey. The functional response of *T. recki* was Type II (convex) indicating that the number of prey consumed increased with prey availability and then began to decrease when a maximum point was reached. Many predators with the Type II functional response model have been successfully used as biological control agents (Hughes et al., 1992; Fernandez-Arhex & Corley, 2003; Xiao & Fadamiro, 2010). The Type II functional response is also common among phytoseiid species such as *Neoseiulus cucumeris (*Oudemans, 1930) (Zheng et al., 2017), *Neoseiulus womersleyi* (Schicha, 1975) (Ali et al., 2011), *Galendromus occidentalis* (Nesbitt, 1951) (Xiao & Fadamiro, 2010), *Neoseiulus californicus (*McGregor, 1954) (Castagnoli & Simoni, 1999; Gotoh et al., 2004; Kustutan & Cakmak, 2009; Xiao & Fadamiro, 2010), *Euseius finlandicus (*Oudemans, 1915) (Shirdel, 2003), *Euseius hibisci (*Chant, 1959) (Badii et al., 2004), *Iphiseius degenerans (*Berlese, 1889) (Fantinou et al., 2012), *Typhlodromus bagdasarjani* Wainstein & Arutunjan, 1967 (Farazmand et al., 2012) and *Kampimodromus aberrans (*Oudemans, 1930) (Kasap & Atlihan, 2011).

The attack rate refers to the time spend by a predator to searching for prey (Fatipour & Maleknia, 2016). In addition, the handling time describes the duration between first predator-prey encounter and end of feeding (Veeravel & Baskaran, 1997). These two parameters are used to determine the magnitude of functional response of the predators (Pervez & Omkar, 2005). The predators exhibited higher attack rate and shorter handling time are considered to have better potential as biological control agent. In this study, the highest numerical attack rate was found on larvae (1.035) while the shortest handling time was determined on eggs (0.001). Similarly, Song et al. (2016) reported that the highest attack rate of *N. californicus* was found on larvae (0.25) of *T. urticae*. The attack rate obtained on the larvae in the current study is close to that determined by Ali et al. (2011) for *N. womersleyi* (1.133) fed on larvae of *Tetranychus macfarlanei* Baker & Pritchard, 1960. These results clearly showed that the larvae may be the most preferred stage of the prey by phytoseiid mites. This can be explained by its smaller size and less mobile when compared to other mobile stages such as nymphs and adults. In addition, predators may also need to attack more prey due to their nutrition needs as already explained by Li & Zhang (2020).

The handling time also varied depending on the biological stage of the prey. The shortest handling time with eggs clearly indicated that *T. recki* spent less time to fed on eggs than the other biological stages, most probably due to its smaller size and inactivity. The handling time of *T. recki* in this study is shorter than those of *Amblyseius swirskii* Athias-Henriot, 1962 (0.518), *N. californicus* (1.732) and *N. womersleyi* (0.056) fed on *T. urticae* eggs (Xiao et al., 2013; Sugawara et al., 2018). Döker et al. (2016) studied functional response of *N. californicus* with *T. urticae* eggs under different humidity conditions and they found that the handling time at 50-70% RH was 0.037 and 0.031, respectively. Fathipour et al. (2020) reported that the estimated minimum handling time of *A. swirskii* was 0.706 with *T. urticae* eggs close to that estimated by Xiao et al. (2013). The shortest handling time (0.153) of *Metaseiulus flumenis* (Chant, 1957) (Acari: Phytoseiidae) was found with *Oligonychus pratensis* (Banks, 1912) (Acari: Tetranychidae) eggs (Ganjisaffar & Perring, 2015). Different factors are likely to affect the handling time of predatory species such as prey movement, subduing, speed of predator (Hassell, 1978). In contrast, current results also show that the longest handling time for *T. recki* were found with deutonymph stage. This result is in agreement with findings of Li & Zhang (2020) who detected that the longest handling time for *N. cucumeris* was with deutonymphs of *T. urticae* compared to those obtained with other biological stages. The reason for a longer handling time with the deutonymph stage may also be related by the size of prey as discussed by Hassell (1978).

The result of this study showed that *T. recki* consumed more eggs of *T. urticae* than the other biological stages. McMurtry & Croft (1997) reported that life styles and feeding habits of phytoseiid mites, generalist predator species showed no prey preference or preferred larvae. However, *T. recki* did not fit into this classification because of more consumed or damaged eggs in this study. Kasap & Atlihan (2011) reported that generalist *K. aberrans* consumed more larvae than eggs. Prey preference of phytoseiid mites can vary according to the prey species. Similarly, Ganjisaffar & Perring (2015) reported that *M. flumenis* prefers *O. pratensis* eggs to other stages of its prey. Higher consumption of eggs in this study can be explained by the following reasons: (1) *T. recki* may prefer to feed on small prey; (2) high nutritional value of eggs (Burnett, 1971); (3) stages of eggs are immobile and easier to catch them; and (4) it can be penetrated to egg chorion instead of cuticle of other stages (Sabelis, 1985).

In this study, the numerically highest egg deposited by *T. recki* was determined when fed on protonymph. However, the predatory mite consumed more eggs than the other biological stages, and if the predator consumes more prey, it is expected to deposit more eggs. The possible reason is that the predatory mite may try to consume or puncture the eggs with their mouthparts and damaged the eggs. If they are unsuccessful, they stop feeding. However, when feeding on protonymph, the predator may take high nutritional value. Blackwood et al. (2001) reported that generalist species may have mouthparts that are not as effective in piercing the egg chorion of *T. urticae* as mouthparts of more specialized species. For generalist predator species, there is some evidence that suggests *T. urticae* larvae may be more favorable than eggs with respect to both nutritional benefits. Zaher & Shehata (1971) found that *Typhlodromus pyri* Scheuten, 1857 feeding on mobile stages of *Tetranychus cinnabarinus* (Boisduval, 1867) were more fecundity than on eggs of the same species.

In order to find an effective predator in biological control programs, it is necessary to perform experiments on the characteristics of the predator including predation and oviposition activities. Although, many new phytoseiid mite species have been identified by researchers, information about their potential as biological control agents is limited (Helle & Sabelis, 1985; Kuştutan & Cakmak, 2009; Kamburgil & Cakmak, 2014). In addition, the potential of some species described many years ago, that are common in a diverse range of habitats (cultivated and uncultivated plants), also remains unknown. Among them, *T. recki* is known as one of the most common species in many European and West Asian countries as it was determined on a series of cultivated and uncultivated plants (Swirski & Amitai, 1982; Şekeroğlu, 1984; Papaioannou-Souliotis et al., 1994; Tixier et al., 2003; Kumral, 2005; Rahmani et al., 2010; İnak & Çobanoğlu, 2018; Tixier et al., 2020). However, information on the biological control potential of *T. recki* is limited with only a few recent studies (Tixier et al., 2020; Ersin et al., 2021). Tixier et al. (2020) reported that *T. recki* is a generalist predator and its biological characteristics are close to some other generalist predators such as *K. aberrans*, *T. pyri* and *N. californicus*. Tixier et al. (2020) tested this species for the first time against to *Tetranychus evansi* Baker & Pritchard, 1960 and *T. urticae* and concluded that *T. recki* preferred *T. urticae* over *T. evansi.* Ersin et al. (2021) also showed the feeding and reproduction ability of *T. recki* on *T. urticae* at five temperatures under laboratory conditions.

In conclusion, the results presented here demonstrate for the first time the ability of *T. recki* to control populations of *T. urticae*. The native population of *T. recki* has the potential to be a biological control agent of *T. urticae* due to its ability to feed and reproduce at all biological stages of its prey. Field and greenhouse experiments are needed to determine if the biocontrol potential of *T. recki* on *T. urticae* can be realized on different host plants under production conditions. As predator-prey release ratio is also important for the success of biological control, the most effective ratio should also be determined for *T. recki* to provide effective control for *T. urticae* (Cakmak et al., 2009; Kazak et al., 2015; Kasap, 2019).

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## References

Ali, M. P., A. A. Naif & D. Huang, 2011. Prey consumption and functional response of a phytoseiid predator, *Neoseiulus womersleyi*, feeding on spider mite, *Tetranychus macfarlanei.* Journal of Insect Science, 11 (167): 1-11.

Badii, M. H., E. Hernández-Ortiz, A. E. Flores & J. Landeros, 2004. Prey stage preference and functional response of *Euseius hibisci* to *Tetranychus urticae* (Acari: Tetranychidae). Experimental and Applied Acarology, 34 (2-3): 263-273.

Blackwood, J. S., P. Schausberger & B. A. Croft, 2001. Prey-stage preference in generalist and specialist phytoseiid mites (Acari: Phytoseiidae) when offered *Tetranychus urticae* (Acari: Tetranychidae) eggs and larvae. Environmental Entomology, 30 (6): 1103-1111.

Burnett, T., 1971. Prey consumption in acarine predator prey populations reared in the greenhouse. Canadian Journal Zoology, 49 (6): 903-913.

Cakmak, I., A. Janssen, M. W. Sabelis & H. Baspinar, 2009. Biological control of an acarine pest by single and multiple natural enemies. Biological Control, 50 (1): 60-65.

Castagnoli, M. & S. Simoni, 1999. Effect of long-term feeding history on functional and numerical response of *Neoseiulus californicus* (Acari: Phytoseiidae). Experimental and Applied Acarology, 23 (3): 217-234.

Dalir, S., H. Hajiqanbar, Y. Fathipour & M. Khanamani, 2021. Age-Dependent functional and numerical responses of *Neoseiulus cucumeris* (Acari: Phytoseiidae) on two-Spotted spider mite (Acari: Tetranychidae). Journal of Economic Entomology, 114 (1): 50-61.

Döker, İ., C. Kazak & K. Karut, 2016. Functional response and fecundity of a native *Neoseiulus californicus* population to *Tetranychus urticae (*Acari: Phytoseiidae, Tetranychidae) at extreme humidity conditions. Systematic & Applied Acarology, 21 (11): 1463-1472.

Efron, B., 1982. The Jackknife, the Bootstrap, and Other Resampling Plans. Society for Industrial & Applied Mathematics, Philadelphia, 92 pp.

Ersin, F., F. Turanlı & I. Cakmak, 2021. Development and life history parameters of *Typhlodromus recki* (Acari: Phytoseiidae) feeding on *Tetranychus urticae* (Acari: Tetranychidae) at different temperatures. Systematic & Applied Acarology, 26 (2): 496-508.

Escudero, L. A. & F. Ferragut, 2005. Life-history of predatory mites *Neoseiulus californicus* and *Phytoseiulus persimilis* (Acari: Phytoseiidae) on four spider mite species as prey, with special reference to *Tetranychus evansi* (Acari: Tetranychidae). Biological Control, 32 (3): 378-384.

Fantinou, A. A., A. Baxevani, F. Drizou, P. Labropoulos, D. Perdikis & G. Papadoulis, 2012. Consumption rate, functional response and preference of the predaceous mite *Iphiseius degenerans* to *Tetranychus urticae* and *Eutetranychus orientalis*. Experimental and Applied Acarology, 58 (2): 133-144.

Farazmand, A., Y. Fathipour & K. Kamali, 2012. Functional response and mutual interference of *Neoseiulus californicus* and *Typhlodromus bagdasarjani (*Acari: Phytoseiidae) on *Tetranychus urticae (*Acari: Tetranychidae). International Journal of Acarology, 38 (5): 369-376.

Fathipour, Y. & B. Maleknia, 2016. “Mite Predators, 329-366”. In: Ecofriendly Pest Management for Food Security (Ed. Omkar). Elsevier, USA, 750 pp.

Fathipour, Y., B. Maleknia, A. Bagheri, M. Soufbaf & G. V. P. Reddy, 2020. Functional and numerical responses, mutual interference, and resource switching of *Amblyseius swirskii* on two-spotted spider mite. Biological Control, 146: 104266 (1-10).

Fernandez-Arhex, V. & J. C. Corley, 2003. The functional response of parasitoids and its implications for biological control. Biocontrol Science and Technology, 13 (4): 403-413.

Ganjisaffar, F. & T. M. Perring, 2015. Prey stage preference and functional response of the predatory mite *Galendromus flumenis* to *Oligonychus pratensis*. Biological Control, 82: 40-45.

Gotoh, T., K. Yamaguchi & K. Mori, 2004. Effect of temperature on life history of the predatory mite *Amblyseius (Neoseiulus) californicus* (Acari: Phytoseiidae). Experimental and Applied Acarology, 32 (1-2): 15-30.

Hassell, M. P., 1978. The Dynamics of Arthropod Predator-prey Systems. Princeton University Press, 248 pp.

Helle, W. & M. W. Sabelis, 1985. Spider Mites, Their Biology, Natural Enemies and Control Vol. 1A. Elsevier, Amsterdam, New York, 455 pp.

Holling, C. S., 1959. Some characteristics of simple types of predation and parasitism. The Canadian Entomologist, 91 (7): 385-398.

Hughes, R. D., L. T. Woolcok, M. A. Hughes, 1992. Laboratory evaluation of the parasitic Hymenoptera used in attempts to biologically control aphid pests of crops in Australia. Entomologia Experimentalis et Applicata, 63 (2): 177-185.

İnak, E. & S. Çobanoğlu, 2018. Determination of mite species on vineyards of Ankara, Turkey. Fresenius Environmental Bulletin, 27 (2): 1232-1239.

Juliano, S. A., 2001. “Non-Linear Curve Fitting: Predation and Functional Response Curves, 178-196”. In: Design and Analysis of Ecological Experiments (Eds. S. M. Schneider & J. Gurevitch). Oxford University Press, 432pp.

Kamburgil, S. & I. Cakmak, 2014. Biological parameters of the predatory mite *Cheletomimus bakeri* (Acari: Cheyletidae) feeding on *Tetranychus cinnabarinus* (Acari: Tetranychidae). Biocontrol Science and Technology, 24 (12): 1339-1348.

Kasap, I., 2019. Effect of pollen with different predator release ratios on biological control of *Tetranychus urticae* by the predaceous mite *Kampimodromus aberrans.* Systematic & Applied Acarology, 24 (7): 1310-1318.

Kasap, I. & R. Atlihan, 2011. Consumption rate and functional response of the predaceous mite *Kampimodromus aberrans* to two-spotted spider mite *Tetranychus urticae* in the laboratory. Experimental and Applied Acarology, 53 (3): 253-261.

Kazak, C., K. Karut & İ. Döker, 2015. Indigenous populations of *Neoseiulus californicus* and *Phytoseiulus persimilis* (Acari: Phytoseiidae): single and combined releases against Tetranychus urticae (Acari: Tetranychidae) on greenhouse eggplant. International Journal of Acarology, 41 (2): 108-114.

Kreiter, S., K. Amiri, M. Douin, T. Bohinc, S. Trdan & M. S. Tixier, 2020. Phytoseiid mites of Slovenia (Acari: Mesostigmata): new records and first description of the male of *Amblyseius microorientalis*. Acarologia, 60 (2): 203-242.

Kumral, N. A., 2005. Investigations on Determination of Pest and Natural Enemy Mites in Temperate Zone Fruit of Bursa Province and Sensitivity of *Panonychus ulmi* (Koch) Against Some Pesticides. Uludağ University, Natural and Applied Sciences, (Unpublished) PhD Thesis, Bursa, 159 pp (in Turkish with abstract in English).

Kustutan, O. & I. Cakmak, 2009. Development, fecundity, and prey consumption of *Neoseiulus californicus* (McGregor) fed *Tetranychus cinnabarinus* Boisduval. Turkish Journal Agriculture and Forestry, 33 (1): 19-28.

Li, G. Y. & Z. Q. Zhang, 2020. Can supplementary food (pollen) modulate the functional response of a generalist predatory mite (*Neoseiulus cucumeris*) to its prey (*Tetranychus urticae*)? BioControl, 65 (2): 165-174.

McMurtry, J. A. & B. A. Croft, 1997. Life-styles of phytoseiid mites and their roles in biological control. Annual Review Entomology, 42: 291-321.

McMurtry, J. A., G. J. Moraes & N. F. Sourassou, 2013. Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. Systematic and Applied Acarology, 18 (4): 297-320.

Migeon, A. & F. Dorkeld, 2021. Spider Mites Web. (Web page: http://www.montpellier.inra.fr/CBGP/spmweb) (Date accessed: May 2021).

Migeon, A., E. Nouguier & F. Dorkeld, 2010. “Spider Mites Web: A Comprehensive Database for the Tetranychidae, 557-560”. In: Trends in Acarology (Eds. M. W. Sabelis & J. Bruin). Springer, Dordrecht, Heidelberg, London, New York, 561 pp.

Overmeer, W. P. J., 1985. “Rearing and Handling, 161-169”. In: Spider Mites, Their Biology, Natural Enemies and Control (Eds. W. Helle & M. W. Sabelis). Elsevier, Amsterdam, 455 pp.

Papaioannou-Souliotis, P., S. Ragusa di Chiara & C. Tsolakis, 1994. Phytophagous mites and their predators observed on cultivated plants in Greece during 1975-1990. Annales Institut Phytopathologique Benaki, 17: 35-86.

Pervez, A. & Omkar, 2005. Functional responses of coccinellid predators: An illustration of a logistic approach. Journal of Insect Science, 5 (5): 1-6.

Rahmani, H., K. Kamali & F. Faraji, 2010. Predatory mite fauna of Phytoseiidae of northwest Iran (Acari: Mesostigmata). Turkish Journal of Zoology, 34 (4): 497-508.

Sabelis, M. W., 1985. “Predator-Prey Interaction: Predation on Spider Mites, 103-127”. In: Spider Mites, Their Biology, Natural Enemies and Control (Eds. W. Helle & M. W. Sabelis). Elsevier, Amsterdam, 455 pp.

Sánchez-Bayo, F., 2011. “Ecological Impacts of Toxic Chemicals, 63-87”. In: Impacts of Agricultural Pesticides on Terrestrial Ecosystems (Eds. F. Sánchez-Bayo, P. J. van den Brink & R. M. Mann). Bentham e-Books, 281 pp.

Şekeroğlu, E., 1984. Phytoseiid mites (Acarina: Mesostigmata) of Southern Anatolia, their biology, and effectiveness as a biological control agent on strawberry plant. Doğa Bilim Dergisi, D2, 8: 320-336.

Shirdel, D., 2003. Species Diversity of Phytoseiidae (Acari: Mesostigmata) in East Azarbaijan, Iran and Comparison of Preying Efficiencies of Two Species on *Tetranychus urticae* Koch, 1836. Islamic Azad University, (Unpublished) Ph.D. Thesis, Tehran, 192 pp.

Song, Z. W., Y. Zheng, B. X. Zhang & D. S. Li, 2016. Prey consumption and functional response of *Neoseiulus californicus* and *Neoseiulus longispinosus (*Acari: Phytoseiidae) on *Tetranychus urticae* and *Tetranychus kanzawai* (Acari: Tetranychidae). Systematic & Applied Acarology, 21 (7): 936-946.

Soria-Díaz, L., M. S. Fowler, O. Monroy-Vilchis & D. Oro, 2018. Functional responses of cougars (*Puma concolor*) in a multiple prey-species system. Integrative Zoology, 13 (1): 84-93.

Sousa Neto, E. P., J. A. Mendes, R. M. C. Filgueiras, D. B. Lima, R. N. C. Guedes & J. W. S. Melo, 2020. Effects of acaricides on the functional and numerical responses of the phytoseid predator *Neoseiulus idaeus* (Acari: Phytoseiidae) to a spider mite eggs. Journal of Economic Entomology, 113 (4): 1804-1809.

Stumpf, N., C. P. W. Zebitz, W. Kraus, G. D. Moores & R. Nauen, 2001. Resistance to organophosphates and biochemical genotyping of acetylcholinesterases in *Tetranychus urticae* (Acari: Tetranychidae). Pesticide Biochemistry Physiology, 69 (2): 131-142.

Sugawara, R., M. S. Ullah, C. C. Hob, T. Gotoh, 2018. Impact of temperature-mediated functional responses of *Neoseiulus womersleyi* and *N. longispinosus* (Acari: Phytoseiidae) on *Tetranychus urticae (*Acari: Tetranychidae). Biological Control, 126: 26-35.

Swirski, E. & S. Amitai, 1982. Notes on predacious mites (Acarina: Phytoseiidae) from Turkey, with description of the male of *Phytoseius echinus* Wainstein and Arutunian. Israel Journal of Entomology, 16: 55-62.

Tixier, M. S., M. Douin, O. Rocio, L. Gonzalez, B. Pount & S. Kreiter, 2020. Distribution and biological features of *Typhlodromus (Anthoseius) recki* (Acari: Phytoseiidae) on *Tetranychus urticae*, *T. evansi* (Acari: Tetranychidae) and *Aculops lycopersici* (Acari: Eriophyidae). Acarologia, 60 (4): 684-697.

Tixier, M. S., S. Kreiter, L. Allam, A. Ouahbi & M. Hmimina, 2003. Phytoseiid and tetranychid mites (Acari: Mesostigmata, Prostigmata) of some Moroccan crops. Acarologia, XLIII (1): 87-97.

Veeravel, R. & P. Baskaran, 1997. Functional and numerical responses of *Coccinella transversalis* Fab and *Cheilomenes sexmaculatus* Fab feeding on the Melon Aphid, *Aphis gossypii* Glov. International Journal of Tropical Insect Science, 17 (3-4): 335-339.

Xiao, Y. & H. Y. Fadamiro, 2010. Functional responses and prey-stage preferences of three species of predacious mites (Acari: Phytoseiidae) on citrus red mite, *Panonychus citri (*Acari: Tetranychidae). Biological Control, 53: 345-352.

Xiao, Y. F., L. S. Osborne, J. J. Chen & C. L. McKenzie, 2013. Functional responses and prey-stage preferences of a predatory gall midge and two predacious mites with twospotted spider mites, *Tetranychus urticae*, as host. Journal of Insect Science, 13 (1): 8 (1-12).

Yorulmaz, S. & R. Ay, 2009. Multiple resistance, detoxifying enzyme activity, and inheritance of abamectin resistance in *Tetranychus urticae* Koch (Acarina: Tetranychidae). Turkish Journal of Agriculture and Forestry, 33 (4): 393-402.

Zaher, M. A. & K. K. Shehata, 1971. Biological studies on the predator mite *Typhlodromus pyri* Sch. (Acarina: Phytoseiidae) with the effect of prey and non prey substances. Zeitschrift für Angewandte Entomologie, 67 (1-4): 389-394.

Zhang, Z., 2003. Mites of Greenhouses: Identification, Biology and Control. CABI Publishing, Wallingford. 244 pp.

Zheng, Y., P. De Clercq, Z. W. Song, D. S. Li & B. X. Zhang, 2017. Functional response of two *Neoseiulus* species preying on *Tetranychus urticae* Koch. Systematic & Applied Acarology, 22 (7): 1059-1068.