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**ПИЩЕВОЕ ПОВЕДЕНИЕ И ФУНКЦИОНАЛЬНАЯ РЕАКЦИЯ ХИЩНОГО КЛЕЩА *PHYTOSEIULUS PERSIMILIS* НА РАЗНЫЕ СТАДИИ РАЗВИТИЯ ОБЫКНОВЕННОГО ПАУТИННОГО КЛЕЩА *TETRANYCHUS URTICAE***

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Результаты представленного исследования показали, что хищный клещ *Ph. persimilis* проявлял высокую пищевую предпочтитель-ность личиночной стадии (30,2% от общего числа потребляемых), по сравнению с яйцами (20,5%), нимфами (13,4%) и взрослыми особями (10,1%) паутинного клеща *T. urticae*. Функциональная реакция *Ph. persimilis*, питающегося яйцами и взрослыми особями *T. urticae* описывается кривой типа II. При максимальной плотности 60 жертв на листовой диск *Ph. persimilis* потреблял в среднем 22,8 яйца и 3,2 взрослых *T. urticae* в течение 8 часов. Расчетное время обработки добычи *Ph.persimilis* было в среднем 0,074 часа (4,4 минуты) и 3,2 часа для яиц и взрослых *T. urticae* соответствен-но. Среднее число яиц *T. urticae*, потребляемых *Ph. persimilis*, с увеличением плотности жертвы постепенно возрастало, но степень истребления (количество потребляемых яиц / плотность добычи) снижалась с 0,5 до 0,3. Среднее число взрослых *T. urticae*, потребляемых *Ph. persimilis* при плотностях 20, 40 и 60 на листовой диск, оставалось относительно постоянным, в то время как степень истребления снижалась с 0,09 до 0,04 при увеличении плотности добычи. Эксперименты показали, что, независимо от стратегии, используемой хищником, он использует ту, которая эффективна для его выживания

Ключевые слова: ОГУРЕЦ, ВРЕДИТЕЛЬ, ХИЩНИК, ДОБЫЧА, ПЛОТНОСТЬ, СТЕПЕНЬ ИСТРЕБЛЕНИЯ, ПОТРЕБЛЕНИЕ, ВЗРОСЛАЯ ОСОБЬ, ЛИЧИНКА, НИМФА

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Biological Sciences

**THE FEEDING BEHAVIOR AND FUNCTIONAL RESPONSE OF THE PREDATORY MITE *PHYTOSEIULUS PERSIMILIS* ON DIFFERENT DEVELOPENTAL STAGES OF TWO-SPOTTED SPIDER MITE *TETRANYCHUS URTICAE***

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The results of the study presented showed that predator mite *Ph. persimilis* exhibited high food preference of the larval stage (30,2% of the total number consumed) compared to the egg (20,5%), nymph (13,4%) and adult (10,1%) stages of two spotted spider mite *T. urticae*. The functional response of *Ph. persimilis* feeding on eggs and adults of *T. urticae* was described by the Type II curve. At a maximum density of 60 prey per leaf disc, *Ph. persimilis* consumed an average of 22.8 eggs and 3.2 adults over an eight-hour period. Calculated time for handling of the prey by *Ph. persimilis* was on the average 0.074 hours (4.4 minutes) and 3.2 hours for *T. urticae* eggs and adults respectively. The mean number of *T. urticae* eggs consumed by *Ph. persimilis* progressively increased with the increase of the prey density, but the rate of predation (number of eggs consumed/prey density) decreased from 0.5 to 0.3 with the increasing of prey density. The mean number of adult *T. urticae* consumed by *Ph. persimilis* at densities of 20, 40 and 60 per leaf disk remained relatively constant. But the rate of predation decreased from 0.09 to 0.04 with increasing of prey density. The experiments showed that regardless of the strategy utilized by the predator it was the one that was efficient for the predator survival

Keywords: CUCUMBER, PEST, PREDATOR, PREY, DENSITY, RATE OF PREDATION, CONSUMPTION, ADULT, LARVA, NYMPH

## Introduction

Two-spotted spider mite *Tetranychus urticae* Koch (Acari: Tetranychidae) is an important economic pest of a cucumber (*Cucumis sativus* L.) in greenhouses, which causes significant damage to the crop greatly reducing its quality and amount (Hussey, Parr, 1963; Hussey, Scope, 1985; Brandenburg, Kennedy, 1987 et al.).

It is no doubt that chemical pesticides are the preferred choice of farmers for control of *T. urticae* due to their ease of use and high effectiveness (Dobrynin, Mohammadali, 2014), but many factors limit their efficiency. Increasing public concern about pesticide applications and the widely–occurring problem of pesticide resistance justifies the need for alternative strategies for mite control (Keena, Granett, 1990; Stumpf, Nauen, 2002; Ruder, Benson, Kayser, 1991).

These limitations have led many growers to attempt to use biological control measures as an alternative to numerous acaricide applications. Among the native enemies of *T. urticae*, the predatory mite *Phytoseiulus persimilis* Athias-Henriot (Phytoseiidae, Parasitiformes) has appeared to be the most efficient in the biological control of *T. urticae* (Hussey, Scope, 1985; Opit, Nechols, Margolies, 2004), because *Ph. persimilis* is a specialist predator of the mite.

The efficiency of *Ph. persimilis* using for biological control of *T. urticae*, i.e. the number of preys consumed by the predator, depends on several factors, such as density and developmental stage of the prey and the predator, food preference of the predator, etc. (Wratten, 1987).

Generally, Solomon (1949) divided the responses of consumers (predators), into the functional and numerical ones. The functional response describes the change in the numbers of prey consumed by one predator at different prey density (Wratten, 1987), while numerical response describes the change in the numbers of natural enemy (reproduction rate) in response to the prey density (Pedigo, 1999). As Oaten and Murdoch (1975) believe the functional response is an essential component of relationships between predator and prey and significant in determining the stability of the system.

Holling (1959a; 1959b) described three models of the functional response: I – the linear, in which the number of individuals consumed by the predator increases linearly with increasing density of prey up to the certain value when a consumer is satiated, but the rate of predation = attack rate (number of preys consumed / prey density) remain constant; II – the cyrtoid, in which the number of individuals consumed increases at low prey density until it reaches the consistency at full saturation of a predator, herewith the rate of predation decrease with increasing prey density, and III – the sigmoid, in which the predation rate increases at first and then decreases at the satiation of a predator.

It is believed that the natural enemy that has the functional response of the type II may not have the ability to implement the complete lesion of the pest population, while the natural enemy with functional response of the type III are preferred from the standpoint of successful biological control.

The choose of a prey or a specific stage of a prey may be performed by a predator on the base of variation in the quality of food that contains the prey or the latest stage of prey development in comparison with the amount of energy consumed for attack. The preferred stage of a prey may be chosen instead of the last stage because it may contain the largest additional mass of food and take less energy consumed by the predator while attacking a prey, digesting its food content and destruction of toxic compounds (Sabelis, 1985). Van De Vrie (1985) pointed out that the attractiveness of prey for predator depends not only on the stage of prey development but by the level of predator satiation, the amount of adult females of predator, etc.

Considering the above, the objective of our study was to examine the feeding behavior and functional response of the predatory mite *Ph. persimilis* on different developmental stages of two-spotted spider mite *T. urticae*.

## Materials and Methods

### ***The Prey Stage Preference Study***

Two-spotted spider mite *T. urticae* colonies were maintained on cucumber plants in the conditions of experimental greenhouse in Iraq. Preference tests were conducted in modified Huffaker cells (Huffaker, 1948). The cells were made from three 7.6 x 7.6 x 0.6 cm Plexiglas pieces held together with four bolts and nuts. A 4.5-cm diameter hole was made in the middle Plexiglas piece to create a small chamber in which the assay was performed.

Twenty 10 $cm^2$ leaf disks were cut from cucumber plants grown in the laboratory under high intensity discharge mercury vapor lights at 14:10 (light : dark) photoperiod. Leaf disks were placed in the experimental cells to prevent desiccation until prey was introduced. Ten *T. urticae* eggs in a single patch and ten *T. urticae* adults were placed on each leaf disk with a help of a fine sable hair paintbrush. Predatory mites *Ph. persimilis* obtained from commercially available populations were acclimated to room temperature and then one predator was released into each cell directly from the shipping container. The cells were then sealed and the number of prey in each cell was counted before the observations began. Cells were left undisturbed for 10-15 minutes to allow predators to settle before initial observations were made.

The features of *Ph. persimilis* were registered at 0, 30, 60, 90 and 120 minute intervals after initiation of the experiment. Observations were not taken after 120 minutes because there was a high probability of egg laying by the prey and egg hatching, which could change prey age structure.

Proportional data of all observed behaviors were analyzed by the contingency table analysis; the mean numbers of behavior events observed were analyzed by ANOVA.

***The Functional Response Study***

The populations of *T. urticae* were reared on cucumber plants grown as previously described. Experimental devices were constructed by placing a 10 $cm^2$ cucumber leaf disk excised from uninfested cucumber plants on the top of a small piece of clay in the bottom of a Petri dish filled with enough tap water to float the disk.

*T. uritcae* eggs or adults were placed on leaf disks at densities of 5, 10, 20, 40 and 60 per disk. Adult individuals of *T. urticae* were transferred directly to leaf disks from the colonies on the day of the experiment. Eggs were obtained by placing 25 *T. urticae* adults on each of five pest free leaves inside a Petri dish for two days at 30°C prior to the experiment. On the day of the experiment, eggs were transferred from leaves inside the Petri dish into the experimental devices. At least ten replications were conducted for each variant of prey density. The experimental devices were left undisturbed for one hour and then inspected to see if any *T. urticae* eggs had hatched or adults had laid eggs.

*Ph. persimilis* adults were removed from the shipping container, placed by one in the center of each leaf disk and allowed to feed for eight hours. *T. urticae* eggs were removed from devices with adults every hour for the duration of the experiment. Devices with *T. urticae* eggs were inspected hourly for the presence of newly hatched mobile forms, which were removed from the disks and replaced with the eggs. After eight hours, the number of adult *T. urticae* cadavers in the devices with adults and the number of viable eggs in the devices with eggs were counted to determine the number of preys that had been consumed.

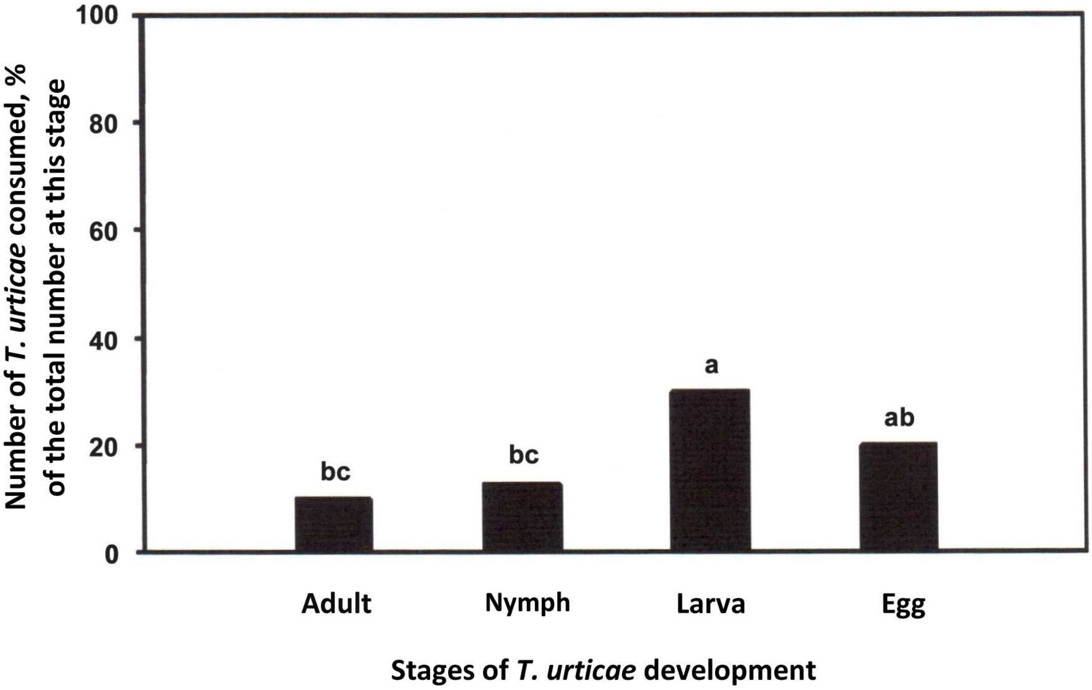
Data obtained were analyzed using the least squares regression by fitting a line through the data points predicted by the descriptive functional response equation as described by Fujii, Holling and Mace (1986). The same equation was used to determine the type of functional response curve. The calculations were performed by fitting Holding's disk equation for type II functional response (Holling, 1959b): $\mathbf{Na = a\ T\ N / 1 + a\ T_h\ N}$ (where **Na** is the number of prey attacked, **a** is the attack rate = rate of predation, **T** is the total time, **N** is the prey density, and $T_h$ is the handling time) to the data points to derive the attack rate and handling time.

## Results and Discussion

### ***The Prey Stage Preference Study***

In our study the predator *Ph. persimilis* showed high food preference of the larvae stage compared to the nymph and adult stages of the two-spotted spider mite *T. urticae*. The consumption rate accounted for 30,2% of the total number of *T. urticae* larvae for the duration of the experiment (8 hours), which was significantly higher compared to 13,4% and 10,1% for each of the nymph and adult stages, respectively, but did not statistically differed from 20,5% for egg stage (Fig. 1).

Some authors conducting their experiments in a similar manner to compare consumption of larval, nymph and adult stages of prey also revealed that the highest percentage of predation occurred on larvae prey (Burnett, 1971).




The averages in columns marked with the same letter did not significantly differ at P = 0.05 by Duncan's test

Fig. 1 - Food preference of *Ph. persimilis* feeding on various stages of *T. urticae*

In other studies conducted by Takafuji and Chant (1976) it was demonstrated that adult *Ph. persimilis* attacked larvae and protonymphs of *T. pacificus*, but preferred the eggs even when the mobile prey stages were abundant, while in more earlier study Chant (1961) observed that *Ph. persimilis* feeding on *T. telarius* dispersed from prey patches once active prey forms were consumed, leaving the eggs uneaten. The research of Fernando and Hassel (1980) illustrated that *Ph. persimilis* protonymphs prefer larval *T. urticae* to its deutonymphs, while adult *Ph. persimilis* prefer deutonymphs to larvae.

So, it is obvious that the feeding behavior of *Ph. persimilis* is plastic and foraging strategies used by the predator may vary in a course of time (Campbell and Gaugler, 1997), depending on the age of a predator (Popov, Kondryakov, 2008), the level of its satiety, the type of a habitat (Ennis, Dillon, Griffin, 2010; Ecology and Evolution…, 2012) etc.

***The Functional Response Study***

Processing of the data obtained by means of the functional response equation (Fujii, Holling, Mace, 1986) showed the functional response of *Ph. persimilis* feeding on eggs and adults of *T. urticae* was described by the type II curve (Fig. 2, 3). As an indicator of the correct alignment of the regression lines, the coefficient of determination between the empirical (observed) and aligned (predicted) values of traits was used. The high values of the obtained coefficient of determination: $R^2 = 0{,}964$ and $R^2 = 0{,}979$ indicate that the alignment of regression lines was produced very qualitatively, i.e. the found models describe the relationships between the factors X and Y by 96-98%.

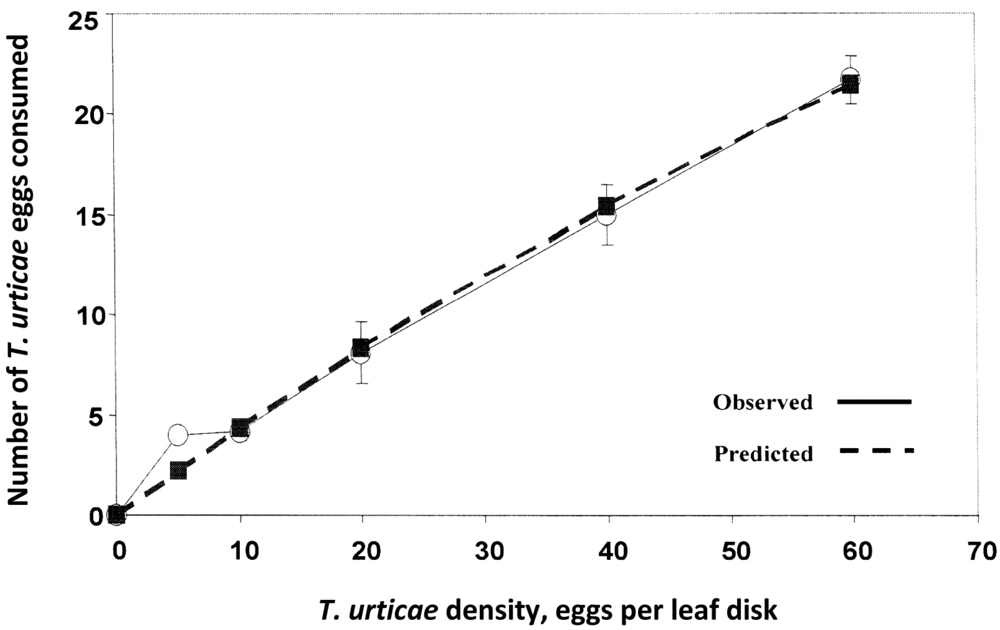



Figure 2 - The functional response of adult *Ph. persimilis* on *T. urticae* eggs

$T_h$ - handling time = 0.074 h; $R^2$= 0.979

As it follows from the figures 2 and 3, at a maximum density of 60 preys per leaf disc, *Ph. persimilis* consumed an average of 22.8 eggs and 3.2 adults over an eight-hour period. Calculated time for handling of the prey by *Ph. persimilis* was on the average 0.074 hours (4.4 minutes) and 3.2 hours for *T. urticae* eggs and adults respectively.

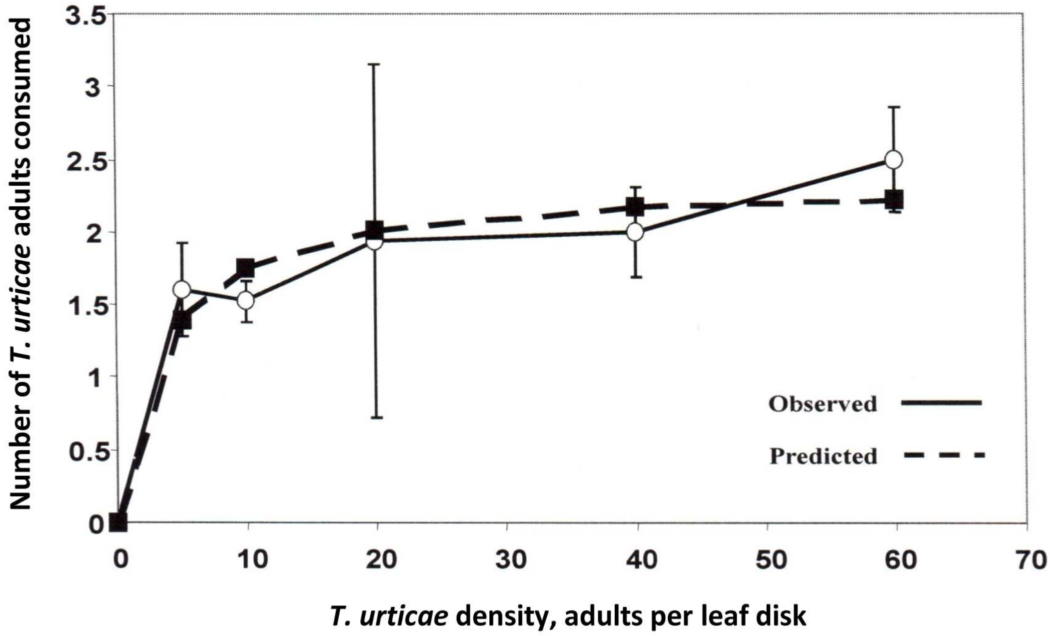



Figure 3 - The functional response of adult *Ph. persimilis* on *T. urticae* adults

$T_h$ - handling time = 3.166 h; $R^2$= 0.964

It is known that preference can be affected by prey density, levels of gut fullness and predator motivational state (Mori and Chant (1965),

Although, the overall result of our experiment demonstrated strong preference of *Ph. persimilis* to larval stage of the prey - *T. urticae* (Fig. 1), in the beginning of experiment, we also observed *Ph. persimilis* adults aggressively attacking *T. urticae* adults. Similar behavior was also observed by Sabelis (1981).

He noted that adult *Ph. persimilis* females could consume mainly adults and larger nymphs of *T. urticae*, leaving some of the youngest individuals and eggs for feeding of their own offspring hatching from the eggs. After destroying the basic portion of the pest colony, adult predator mites migrate to other infested leaves (Bernstein, 1984). Such behavior may be instinctive, as Sabelis (1981) and Bernstein (1984) presumed in their studies, and may lead to appearance of the functional reaction of the type III (being described by sigmoid curve), which is more characteristic of generalists.

But *P. persimilis* is a specialist predator on spider mites, so *Ph. persimilis* exhibited the type II overall response for both egg and adult *T. urticae* in our experiments (Fig. 2 and 3). And the preference for adults occurred in only a few instances (more often in the beginning of *Ph. persimilis* release when they were hungry and need to be sated quickly). Only predators that were extremely hungry captured and fed on adult *T. urticae*, but this may not be an efficient long-term strategy, because adult preys are more difficult to capture and require a longer handling time, which was proved by our data mentioned above: 3.2 hours compared with 4.4 minutes for eggs. Although adults may possess a higher quantity of digestible material, it is more difficult for *Ph. persimilis* to extract those materials (Helle, Sabelis, 1985). If a predator can reach its desired gut fullness level with eggs, it would be inefficient for it to handle adults.

However adult prey has a larger food content compared to eggs, so predators have to eat more eggs than adults to survive and maintain a steady fecundity rate. It is known that *Ph. persimilis* must consume 6 prey eggs for every egg they lay and they can oviposit up to 4 eggs per day (Helle, Sabelis, 1985). Therefore, theoretically, *Ph. persimilis* individuals can consume 24 eggs per day. In our functional response experiments *Ph. persimilis* consumed an average of 22.8 eggs in an eight-hour period. This number may seem too high, but it could be due the temperature in our experiment averaged 28° C with relative humidity levels between 30 and 40%. And in low relative humidity situations predators have to feed more to acquire enough liquids (Helle, Sabelis, 1985), which leads to higher prey consumption rates (Mori, Chant, 1965).

As it is seen from the Fig. 2, the mean number of *T. urticae* eggs consumed by *Ph. persimilis* progressively increased with the increase of the prey density, but the rate of predation (attack rate) decreased from 0.5 to 0.3 with the increasing of prey density from 5 to 60 per leaf disk, which visually illustrates the functional response of the type II.

The mean number of adult *T. urticae* consumed by *Ph. persimilis* at densities of 20, 40 and 60 per leaf disk in our experiments remained relatively constant (Fig. 3). But the rate of predation decreased from 0.09 to 0.04 with increasing of prey density from 20 to 60 per leaf disk, the reason of what could be the interference of prey. Prey was seen bumping into predators that were attempting to eat them. This caused the predators to abandon the prey and move quickly to another area of the leaf disc. Disturbance has been observed by other researchers to cause the functional response curve to become sigmoid (Mori and Chant, 1965), although this did not occur over the densities tested in the present study, where the curve was cyrtoid or the type II (Fig. 3).

The additional cause for similar predation rates at the densities of 20, 40 and 60 *T. urticae* adults per leaf disc in our experiments could be considerable amounts of webbing which high-density populations of *T. urticae* usually produce. And it is known that webbing can negatively affect the capture success of phytoseiid mites (Sabelis, Bakker, 1992).

Anyway, our experiments showed that regardless of the strategy utilized by the predator it was the one that was efficient for the predator survival.

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