Persian J. Acarol., 14(4): 140407.

Research Article https://biotaxa.org/pja https://doi.org/10.22073/pja.v14i4.87354

Biological performance and predation capacity of *Neoseiulus californicus* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae) and pollens of sunflower, tamarix, and common mallow

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Received:
08 June, 2025
Accepted:
31 August, 2025
Published:
15 October, 2025

Subject Editor:
M. Seiedy

ABSTRACT

The supply of pollens as an alternative food can enhance the performance of phytoseiid predatory mites. The study determined the effects of three different pollens (sunflower, tamarix, and common mallow) as supplementary diets on the life table parameters and predation rate of *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) in the absence and presence of *Tetranychus urticae* Koch (Acari: Tetranychidae) eggs. The chemical compositions of the pollens were also analyzed. The results showed that the fecundity of *N. californicus* on *T. urticae* in the presence of pollen was significantly higher than that on pollen alone. The intrinsic rate of increase (r) on *T. urticae* in the presence of tamarix and common mallow pollens (0.131 and 0.132 day^{-1}, respectively) was significantly higher than those recorded on the other diets. The net reproductive rate (R_0) varied from 0.585 offspring (on sunflower pollen) to 8.465 offspring (on tamarix pollen + *T. urticae*). The cohort reared on common mallow pollen + *T. urticae* had the highest values of both intrinsic rate and the finite rate of increase, followed by tamarix pollen + *T. urticae*. The predation rate of *T. urticae* by *N. californicus* fed on tamarix pollen was the highest compared to other pollens. Tamarix pollen had the highest protein content, while sunflower pollen contained higher levels of lipid, phenol, and flavonoid compounds. Due to its higher protein content, tamarix pollen had favorable effects on the survival, development, fecundity, and predation rate of *N. californicus*. Tamarix pollen can be used as a supplementary medium alongside *T. urticae*, since the treatment with tamarix pollen + *T. urticae* eggs showed most of the superior parameters. Therefore, *N. californicus* reared on tamarix pollen can be helpful in controlling *T. urticae*.

KEYWORDS

Biological control, fecundity, intrinsic rate of increase, pollen feeding, predation rate, survival rate

CITE: Dahmardeh, A., Mirshekar, A., Rezaei, M. & Ramroodi, S. (2025) Biological performance and predation capacity of *Neoseiulus californicus* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae) and pollens of sunflower, tamarix, and common mallow. *Persian Journal of Acarology*, 14(4): 140407.
https://doi.org/10.22073/pja.v14i4.87354

INTRODUCTION

The increasing demand for food due to global population growth makes crop protection a major concern in agriculture (Rodrigues *et al.* 2023). One significant threat is the two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), a destructive pest in both greenhouse and field crops. Its high reproductive rate and resistance to acaricides have reduced the effectiveness of chemical control and disrupted the balance with natural enemies (Khanamani *et al.* 2017a; Havasi *et al.* 2020). As a result, biological control using predatory mites, such as *Neoseiulus californicus* (McGregor), an important species of the Phytoseiidae family, has gained interest as an eco-friendly and sustainable alternative (Fathipour and Maleknia 2016; Havasi *et al.* 2020). This species feeds on spider mites from the Tetranychidae and Tarsonemidae families and successfully controls mite populations in fields and greenhouses (Havasi *et al.* 2020). This predatory mite is one of the natural enemies of the two-spotted spider mite, which is suitable for biological control of this pest in various climatic conditions (Khanamani *et al.* 2017a). In addition, this predator has a broader diet and can feed on various preys, such as thrips and alternative food sources, including plant pollens. In times of scarcity of its main prey, it can survive and reproduce by feeding on other alternative food sources, such as plant pollens (Gugole Ottaviano *et al.* 2015). The possibility of mass rearing of this predatory mite on a pollen-containing diet has gained increased interest in using this predator as a biological control agent (Khanamani *et al.* 2017a).

Pollen grains can be used as an available food source for the mass rearing of phytoseiid mites. Using them is specifically important when the population of natural prey (e.g., two-spotted spider mites) is low and leads to reduced rearing costs (McMurtry *et al.* 2013). In addition to increasing the efficiency of mass-rearing of predatory mites, identifying and using available plant pollens with high nutritional value can improve their efficiency as biological control agents and reduce prey populations (Hashemi *et al.* 2021). Pollen offers a significant source of nutrients essential for phytoseiid mites; however, the nutritional value of pollen from various plants varies, resulting in differing impacts on the life stages of predatory mites (Khanamani *et al.* 2017c; Pascua *et al.* 2020). Some phytoseiid species gain higher reproductive ability by feeding on plant pollens, and the survival and viability of their embryonic stages increase (Khanmani *et al.* 2017b; Soltaniyan *et al.* 2018).

To mass rear predatory mites, examining life table parameters is a useful tool for determining survival, developmental duration, and reproduction. This identifies the most vulnerable age and developmental stage with high mortality rates and predicts population growth (Carey 1993). Few studies have compared the effects of different pollens on the survival, growth period, and reproduction of *N. californicus* (Khanamani *et al.* 2017c; Eini *et al.* 2022). Also, researchers reported that *N. californicus* shows the highest total fecundity when feeding on pistachio pollen (Soltaniyan *et al.* 2018). Predatory mite *N. californicus* is reported to have the longest adult longevity by feeding on almond pollen (Khanmani *et al.* 2017b). Laboratory studies can provide valuable information for mass production programs of pollen-feeding natural enemies and biological pest control projects. Therefore, this study investigated the life table parameters and the predation rate of *N. californicus* reared on common mallow (*Malva sylvestris* L.), tamarix (*Tamarix aphylla* L.), and sunflower (*Helianthus annuus* L.) pollens, alone and in the presence of two-spotted spider mite eggs and evaluated the best pollen for feeding predatory mites. Also, the compositions of common mallow, tamarix, and sunflower pollens were studied.

MATERIAL AND METHODS

Host plant cultivation

The seeds of bean (*Phaseolus vulgaris* L., cv. Khomein), used as a host plant, were soaked in plastic containers for three days to allow germination. Then, five to six germinated seeds were transferred to the plastic pots (8 cm in diameter and 12 cm in height) filled with a mixture of perlite and peat moss (2:1 ratio). The plants were kept in a room under a photoperiod of 16:8 h (light:dark) and temperature of 25 °C. The pots were irrigated daily as needed. Plants showing signs of pest infestation or disease infection were removed from the growing area daily.

Rearing of two-spotted spider mite

The two-spotted spider mite was collected from infested bean plants in the University of Zabol's research greenhouse. The mites were reared in the laboratory on detached bean leaves placed on wet cotton wool in plastic containers. The containers were maintained in a growth chamber at 25 ± 2 °C with a 16:8 (light: dark) photoperiod, and 60 ± 5% RH. Fresh bean leaves were provided three times a week to ensure a continuous and stable supply of healthy mites for experimental purposes. After rearing three generations, the resulting colony was used for the experiment.

Rearing of predatory mite

The predatory mite *N. californicus* was purchased from Koppert (The Netherlands) and reared under controlled conditions (27 ± 1 °C, 60 ± 5% RH, and 16:8 h light:dark). A novel rearing setup was employed, consisting of a plastic plate (talc) placed on a water-saturated sponge within a water-filled container, with wet paper towel strips along the edges to prevent mite escape. Different biological stages of two-spotted spider mites and corn pollen were used to rear this predatory mite. Pollen was applied every three days onto bean leaf substrates using a fine brush, while spider mites of varying developmental stages were introduced as live prey. Adults of *N. californicus* were transferred using a moistened brush. This optimized method improved rearing efficiency compared to conventional protocols (Hatherly *et al.* 2005).

Preparing plant pollens

In this research, pollens of common mallow (*Malva sylvestris* L.), tamarix (*Tamarix aphylla* L.), and sunflower (*Helianthus annuus* L.) were collected from their natural habitats in Sistan and Baluchestan Province, Iran, on a sunny day. Common mallow and sunflower pollens were gathered from flowering plants growing in rangelands and agricultural margins. Tamarix pollen was collected from mature trees in arid regions near Zabol. Then, the cleaned pollen was oven-dried at 37 °C for 48 hours to reduce moisture content and prevent microbial contamination. For long-term storage, the pollen was frozen at −20 °C. For short-term use, pollen was stored in airtight containers at 4 °C for up to 2 weeks during the experiments.

Experimental unit

Leaf discs were prepared following the methods described by Kostiainen and Hoy (1994). Freshly excised bean leaf discs (variety Khomein), each measuring 1.5 × 1.5 cm, were placed upside down in Petri dishes (6 cm in diameter) on a cotton layer saturated with water, in which a 5 mm diameter hole was drilled. This also prevented the mites from leaving the arenas and drowning. Cotton threads, 0.5 cm thick, were arranged in circular barriers to prevent predators from escaping and maintain humidity. The prepared Petri dishes were placed inside larger dishes with a diameter of 8 cm. Water was added daily to the larger dishes to keep the leaves fresh. The mixture of pollen and spider mite eggs was replaced daily during both the immature development and adult stages of mites. All experimental units were kept in a growth chamber at 25 ± 1 °C, 75 ± 5% RH, and photoperiod of 16:8 h (light:dark).

Life history study of the predatory mite

In this study, 5 mg of pollen from the tested plant species and 20 eggs of *T. urticae* were provided daily to the larvae and nymphs of predatory mite in each Petri dish. A total of six treatments were evaluated, including pollen from common mallow, tamarix, and sunflower, as well as combinations of these pollen sources with kidney bean leaves containing *T. urticae* eggs. For treatments involving natural prey, 20 eggs of the two-spotted spider mite (*T. urticae*) along with leaf discs were added to the experimental arenas daily. To minimize fungal contamination, the leaf discs inside the Petri dishes were replaced every 24 h. Food availability and moisture levels were carefully monitored and adjusted as needed. To obtain same-aged eggs of *N. californicus* for the life table study, 40 male-female pairs of the predator were transferred onto a plastic sheet. After 24h, newly laid eggs (< 24h old) were collected and individually transferred to experimental units, yielding 60 replicates per treatment (six treatments total). Upon hatching, the respective test diet was immediately provided as food. The egg incubation period of *N. californicus* was recorded by measuring the time from oviposition to hatching. Egg mortality rates were calculated as the proportion of unhatched eggs to the total number of eggs. Petri dishes containing predatory mites were inspected at 24-hour intervals to determine mortality rates during the larval and nymphal stages, based on the number of dead larvae and nymphs observed. The developmental duration of both the larval and nymphal stages was recorded daily. Upon reaching maturity, the numbers of males and females were counted to establish the sex ratio in each treatment. Male mites were subsequently introduced into Petri dishes containing adult females for further observations. Daily oviposition rates were recorded and monitored until the death of all individuals. Additionally, the lifespan of adult mites, along with pre-oviposition and post-oviposition periods, was documented for each treatment group.

Predation rate study

In the predation rate study, *N. californicus* was reared on a mixed diet comprising all developmental stages of *T. urticae* (egg, larva, protonymph, deutonymph, and adult), supplemented with corn pollen. To prepare prey eggs for the predation rate experiment, the adult females of two-spotted spider mite were placed in each experimental unit to lay eggs daily. The same types of experimental arenas were used for the predation rate study. After each day, the females were removed without removing their web, and the eggs were reduced to the needed density. To assess the prey (*T. urticae* eggs) consumption by *N. californicus*, 20 eggs of *T. urticae* were added daily to discs. The experimental units were monitored daily, and the number of consumed prey (*T. urticae* eggs) was recorded. The same number of new eggs was added to each experimental unit. After adult emergence and pairing males and females, each pair was given 75 eggs of *T. urticae*, and the number of consumed eggs was recorded until the predators died. To separate the predation rate of males from that of females, the consumption prey rate of 20 single males was determined under similar conditions. To specify the daily consumption rate of females, the average male consumption was subtracted from the consumption of pairs (Farhadi *et al.* 2011; Moghadasi *et al.* 2014).

Determination of pollen chemical compositions

The chemical compositions (total carbohydrate, total lipid, and total protein) of pollens were determined as follows:

For protein extraction, pollen samples were homogenized in a 50 mM potassium phosphate buffer (pH 7.2). The homogenate was centrifuged at 14,000×g for 30 min at 4 °C. The supernatant (25 µl) was collected for protein assay and Bradford solution (250 µl) was added to it. Then, the mixture absorbance was measured at 595 nm by a spectrophotometer (Elisa Microplate Reader, BioTek 800TS) according to the method described by Bradford (1976). Finally, the total protein content was reported as mg g^{-1} using an equation obtained from the bovine serum albumin calibration curve. Total lipid content in the studied pollens was extracted by Soxhlet method using the solvent n-hexane, and the extract weight was determined by gravimetric analysis as crude lipid (Khanamani *et al.* 2017c).

To measure the sugar content of various pollens, high-performance liquid chromatography (HPLC) (Waters, Milford, MA) equipped with a supelcogel carbohydrate column of 300 by 7.8 mm (Supelco, Bellefonte, PA) was used, as shown by Qian *et al.* (2008). The mobile phase used was HPLC-grade water at a flow rate of 0.5 ml $\min^{-1}$. Before running samples, sugar standard solutions (5–1000 ppm for sucrose, glucose, and fructose) were injected into HPLC. Sugars were identified according to the retention time of standards and the peaks appearing at each retention time in injected samples. Total flavonoid content was measured by a colorimetric method at 415 nm, described by Bonvehi *et al.* (2001). The total phenolic content was measured using the Folin-Ciocalteu method (Bonvehi *et al.* 2001).

Statistical analysis

Before analysis, the normality of all data was tested with Mintab software. The biological parameters of predatory mites were calculated based on the age-stage, two-sex life table theory, which considers both sexes (male and female) and variable development between individuals and sex (Chi and Liu 1985; Chi, 1988). Population parameters including the intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T) were calculated according to the Goodman (1982) method. Age-stage specific survival rate (s_{xj}) (where x is age and j are stage), age specific survival rate (l_x), age-stage specific fecundity (f_{xj}), age-specific fecundity (m_x), β which is the number of stages, and population parameters were estimated using TWO SEX-MS Chart software (Chi 2025a) as below:

$$l_x = \sum_{j=1}^{\beta} Sxj$$

$$m_x = \frac{\sum_{j=1}^{\beta} Sxjfxj}{\sum_{j=1}^{\beta} Sxj}$$

Intrinsic rate of increase (r) was estimated using the iterative bisection method and Euler-Lotka Equation (x started from 0) as below (Goodman 1982):

$$\sum_{x=0}^{\infty} e^{-r(x+1)}\, lxmx = 1$$

$$\lambda = e^{r}$$

$$R_0 = \sum_{x=0}^{\infty} lxmx$$

$$T = \frac{ln\,(R0)}{r}$$

Variance and standard error for life table statistics and population growth parameters were estimated by the bootstrap method and compared using the paired bootstrap test based on confidence interval (95%) with a sample size of 10000 (Huang and Chi 2013). The graphs were depicted using SigmaPlot software (Sigmaplot 2011).

Raw data of daily predation for all individuals were analyzed to calculate the predation rate according to Chi and Yang (2003) by CONSUME-MSChart software (Chi 2025b). The age-specific predation rate (k_x, the average number of consumed preys per predator of age x) could be determined by the following formula (Chi and Yang 2003):

$$k_x = \frac{\sum_{j=1}^{\beta} SxjCxj}{\sum_{j=1}^{\beta} Sxj}$$

Where, β is the number of stages and c_{xj} is the age-stage specific consumption rate of individuals at age x and stage j.

The age-specific net predation rate (q_x, the weighted number of consumed preys by a predator of age x) showed the survival rate and was calculated as below (Chi and Yang 2003):

$$q_x = l_x k_x$$

The net predation rate (C_0) indicates the average number of preys consumed by a predator during its life span that was estimated as below:

$$C_0 = \sum_{x=0}^{\infty} lxkx = \sum_{x=0}^{\infty} qx$$

The ratio of the net predation rate to the net reproductive rate gives the transformation rate from prey population to predator offspring, which was defined as Q_p and calculated as below Chi and Yang (2003):

$$Q_p = \frac{C0}{R0}$$

This rate indicates the average number of prey required for a predator to produce an egg. Standard errors of predation parameters were also calculated by the paired Bootstrap test.

In this research, one-way analysis of variance was performed using SPSS version 16 statistical software. Statistical differences between means were estimated based on the Tukey test (*a* = 5%).

RESULTS

Life history

The average period of different life stages for *N. californicus* feeding on the studied pollens as well as on the two-spotted spider mite along with pollens is shown in Table 1. Variations in the egg, larval, or other developmental stages of *N. californicus* reared on plant pollens-based diets can significantly impact its biological role, particularly in biological control of spider mites. The results indicated that tamarix pollen increased the development time and survival rates (e.g. protonymph period, larval period, male longevity, female longevity, total life span, and oviposition period) of *N. californicus* compared to other pollens. The longest incubation period (3.7 days) and the shortest larval period (1.92 days) in *N. californicus* were obtained by feeding on sunflower pollen + *T. urticae*, which did not differ significantly from feeding on common mallow pollen + *T. urticae*. When exclusively feeding on each of the studied pollens, the shortest incubation period and the longest larval period were observed. The longest larval period of *N. californicus* (2.62 days) was associated with exclusive feeding on tamarix pollen (Table 1).

Table 1. Developmental biology (Mean ± *SE*) of *Neoseiulus californicus* fed on different plant pollens and *Tetranychus urticae* eggs.

Parameter	**Sunflower**	**Tamarix**	**Common mallow**	**Sunflower + *T. urticae***	**Tamarix + *T. urticae***	**Common mallow + *T. urticae***
Egg (days)	1.67 ± 0.07^{c}	1.52 ± 0.07^{c}	1.59 ± 0.08^{c}	3.7 ± 0.07^{a}	2.58 ± 0.07^{b}	3.36 ± 0.08^{a}
Larva (days)	2.55 ± 0.09^{a}	2.62 ± 0.07^{a}	2.55 ± 0.07^{a}	1.92 ± 0.19^{c}	2.3 ± 0.09^{b}	1.96 ± 0.14^{c}
Protonymph (days)	2.43 ± 0.11^{ab}	2.55 ± 0.08^{a}	2.47 ± 0.32^{ab}	2.11 ± 0.23^{c}	2.57 ± 0.11^{a}	1.72 ± 0.15^{d}
Deutonymph (days)	2.44 ± 0.18^{c}	2.76 ± 0.08^{b}	2.62 ± 0.39^{b}	1.59 ± 0.15^{d}	2.9 ± 0.19^{a}	1.74 ± 0.17^{d}
Male longevity (days)	13 ± 1^{c}	17.5 ± 0.50^{a}	14.70 ± 1.75^{b}	15.67 ± 0.88^{ab}	17.4 ± 1.5^{a}	15 ± 1^{b}
Female longevity (days)	13.14 ± 0.63^{d}	16.77 ± 1.38^{b}	15 ± 2^{c}	17.86 ± 1.02^{b}	19.29 ± 0.44^{a}	15.66 ± 0.43^{c}
Total life span (days)	7.16 ± 0.48^{e}	13.86 ± 0.62^{b}	11.14 ± 0.64^{d}	11.22 ± 0.73^{d}	17.08 ± 0.66^{a}	14.08 ± 0.51^{c}
APOP* (days)	2 ± 0.266^{c}	2.80 ± 0.09^{a}	2.52 ± 0.26^{b}	0.14 ± 0.14^{d}	1.2 ± 0.12^{d}	1.41 ± 0.13^{d}
TPOP* (days)	11.16 ± 0.31^{c}	12.07 ± 0.14^{b}	11.14 ± 0.89^{c}	8.64 ± 0.86^{d}	13.68 ± 0.32^{a}	10.88 ± 0.33^{c}
Oviposition days	9 ± 0.5^{b}	9.27 ± 0.12^{b}	9.31 ± 0.15^{b}	8.59 ± 0.21^{c}	10.38 ± 0.25^{a}	8.63 ± 0.25^{c}
Fecundity (eggs/female)	7 ± 1.01^{d}	8.52 ± 0.55^{d}	5.26 ± 0.43^{d}	15.14 ± 1.74^{a}	12.09 ± 0.88^{b}	8.11 ± 0.57^{c}

Means within a row with the same letter are not significantly different based on the Tukey test (*a* = 5%).
* APOP: Adult preoviposition period; TPOP: Total preoviposition period of female counted from birth.

Among the six studied treatments, the tamarix + *T. urticae* treatment showed the longest protonymph period (2.57 days), which was not significantly different from the tamarix pollen treatment (2.55 days). The longest deutonymph period (2.9 days) was achieved by feeding on tamarix pollen + *T. urticae*. The shortest deutonymph period (1.59 days) was related to feeding on sunflower pollen + *T. urticae*, which did not show a significant difference with the common mallow pollen + *T. urticae* treatment (Table 1). Exclusive feeding on tamarix pollen resulted in the highest male longevity (17.5 days), which was not significantly different from the feeding on tamarix + *T. urticae* (17.4 days). The longest female longevity and total life span in the predatory mite *N. californicus* were related to feeding on tamarix pollen + *T. urticae* (19.29 days and 17.08 days, respectively) and their shortest periods (13.14 days and 7.16 days, respectively) were achieved through exclusive feeding on sunflower pollen (Table 1).

The longest oviposition period of the female (2.80 days) was obtained with exclusive feeding on tamarix pollen and the shortest was related to the feeding on sunflower + *T. urticae* (0.14 day). The longest total oviposition period of the female counted from birth (13.68 days) was related to feeding on tamarix pollen + *T. urticae* and the shortest (8.64 days) was obtained in the treatment feeding on sunflower pollen + *T. urticae* (Table 1). The longest oviposition period (10.38 days) was observed with feeding on tamarix pollen + *T. urticae*, and the shortest period (8.59 days) was associated with feeding on sunflower pollen + *T. urticae*. Among the six studied treatments, the sunflower pollen + *T. urticae* treatment showed the highest fecundity (15.14 eggs/female) and the lowest value (5.26 eggs/female) was related to the exclusive feeding on common mallow pollen (Table 1).

Population parameters

The investigation of population parameters in *N. californicus* (Table 2) showed that the highest intrinsic rate of increase (r = 0.132 day^{-1}) was obtained when fed on common mallow pollen + *T. urticae*, which did not differ significantly from tamarix pollen + *T. urticae* (0.131 day^{-1}). The lowest r (0.041 day^{-1}) was recorded under exclusive feeding on sunflower pollen (Table 2).

Table 2. Population growth parameters (Mean ± SE) of *Neoseiulus californicus* fed on different plant pollens and *Tetranychus urticae* eggs.

Life table parameters	**Sunflower**	**Tamarix**	**Common mallow**	**Sunflower + *T. urticae***	**Tamarix + *T. urticae***	**Common mallow + *T. urticae***
***r* (day^{-1})**	0.041 ± 0.039^{d}	0.112 ± 0.009^{b}	0.075 ± 0.011^{c}	0.117 ± 0.020^{b}	0.131 ± 0.008^{a}	0.132 ± 0.009^{a}
λ (day^{-1})	0.959 ± 0.036^{d}	1.119 ± 0.009^{b}	1.078 ± 0.012^{c}	1.123 ± 0.020^{b}	1.131 ± 0.009^{a}	1.142 ± 0.010^{a}
R_0* *(offspring/ individual)	0.585 ± 0.242^{c}	5.286 ± 0.675^{b}	2.845 ± 0.434^{d}	4.240 ± 1.071^{c}	8.465 ± 0.990^{a}	5.685 ± 0.658^{b}
***T* (day)**	13.01 ± 1.447^{b}	14.807 ± 0.144^{b}	13.864 ± 0.167^{b}	12.382 ± 0.34^{c}	16.348 ± 0.330^{a}	13.115 ± 0.303^{b}

Means within a row with the same letter are not significantly different based on the Tukey test ($a = 5\%$). *r*: Intrinsic rate of increase; λ: Finite rate of increase; R_0: Net reproductive rate; *T*: Mean generation time

The highest finite rate of increase (λ = 0.142 day^{-1}) was recorded when fed on common mallow pollen + *T. urticae*, which did not differ significantly from tamarix pollen + *T. urticae* (0.131 day^{-1}). The lowest λ (0.959 day^{-1}) was related to the exclusive feeding on sunflower pollen (Table 2).

The investigation of population parameters in *N. californicus* (Table 2) showed that the highest intrinsic rate of increase (r = 0.132 day^{-1}) and finite rate of increase (λ = 0.142 day^{-1}) were obtained when fed on common mallow pollen + *T. urticae*, which did not differ significantly from tamarix pollen + *T. urticae* (0.131 day^{-1} and 0.131 day^{-1}, respectively). The lowest values in r (0.041 day^{-1}) and λ (0.959 day^{-1}) were recorded under exclusive feeding on sunflower pollen (Table 2).

The highest net reproductive rate (8.465) of *N. californicus* was obtained by feeding on tamarix pollen + *T. urticae*, and the lowest value (0.585) was related to exclusive feeding on sunflower pollen. Exclusive feeding on tamarix pollen and the treatment of common mallow pollen + *T. urticae* did not show significant differences in net reproductive rate (Table 2).

The results of mean generation time among the six studied treatments indicated that the average period of one generation when fed on tamarix pollen + *T. urticae* was longer (16.348 days) than other tested treatments. The lowest mean generation time (12.382 days) was obtained by feeding on sunflower pollen + *T. urticae*. Other treatments showed no significant differences in mean generation time compared to one another (Table 2).

Predation parameters

Predation parameters of *N. californicus* fed on different plant pollen are presented in Table 3. The net predation rate showed that the mean number of consumed prey (*T. urticae* eggs) by the average individual *N. californicus* fed on the combination treatments of *T. urticae* eggs + common mallow, tamarix, and sunflower pollens during its life span was 57.804, 81.605, and 26.525 prey, respectively (P = 0.95).

The highest finite predation rate of *N. californicus* (3.215 day^{-1}) was related to the diet of *T. urticae* eggs + tamarix pollen (Table 3). The transformation rate of *N. californicus* fed on *T. urticae* eggs + common mallow pollen, *T. urticae* eggs + tamarix pollen, and *T. urticae* eggs + sunflower pollen was 10.27, 9.727, and 6.24 preys, respectively. These results showed that *N. californicus* fed on *T. urticae* eggs along with common mallow, tamarix, and sunflower pollen required 10.27, 9.727, and 6.24 *T. urticae*, respectively, to produce each egg, among which the lowest value was related to the diet of *T. urticae* eggs + sunflower pollen (Table 3). The stable predation rate of *N. californicus* was the highest (2.821 Prey/predator) on diet of *T. urticae* eggs + tamarix pollen (Table 3).

Table 3. Predation rates (Mean ± SE) of *Neoseiulus californicus* fed on *Tetranychus urticae* eggs under different pollen-based diets.

Parameters	Sunflower	Tamarix	Common mallow
C_0 (Prey)	26.525 ± 5.220^{c}	81.605 ± 6.809^{a}	57.804 ± 4.837^{b}
ω (day^{-1})	1.605 ± 0.272^{c}	3.215 ± 0.201^{a}	2.766 ± 0.205^{b}
Q_p (Prey/ offspring)	6.240 ± 1.027^{b}	9.727 ± 0.901^{a}	10.270 ± 0.725^{a}
Ψ (Prey/ predator)	1.429 ± 0.220^{b}	2.821 ± 0.163^{a}	2.423 ± 0.161^{a}

Means within a row with the same letter are not significantly different based on the Tukey test (a = 5%).
C_0: Net predation rate; ω: Finite predation rate; Q_p: Transformation rate; Ψ: Stable predation rate.

The age-stage predation rate (*cxj*, the age-stage specific consumption rate of individuals at age *x* and stage *j*) of *N. californicus* fed on sunflower, tamarix, common mallow pollen along with *T. urticae* eggs is shown in Figure 1 illustrating the average number of consumed prey (*T. urticae* eggs) by a predator with age *x* in stage *j*. The curve related to predation rate in each age group-life stage indicates the different life stages separately and the overlap between these stages. The age-stage predation rate was greatly influenced by pollen diet. In feeding on each of the studied pollens, the adult female exhibited the highest age-stage predation rate compared to other developmental stages. The highest age-stage predation rate (15) was associated with 6-day-old female of *N. californicus* fed on *T. urticae* eggs + tamarix pollen. However, as the female age increased, the age-stage predation rate decreased. In females that had fed on tamarix and common mallow pollens with the *T. urticae* eggs, the age-stage predation rate started at age of 5 days, but in females that had fed on *T. urticae* eggs + sunflower pollen, it started at age of 6 days (Fig. 1). Male adults fed on *T. urticae* eggs + tamarix pollen could show a higher age-stage predation rate than those fed on other pollens, whereas when fed on *T. urticae* eggs + common mallow pollen, their age-stage predation rate was zero compared to other growth stages. In total, the highest number of prey eaten by males (10 prey) was obtained when feeding on a *T. urticae* eggs + tamarix pollen at 17 days of age (Fig. 1). Only under the *T. urticae* eggs + tamarix pollen diet, the age-stage predation rate of *N. californicus* raised with increasing predator stage for *T. urticae* eggs. Therefore, under these conditions, adults consumed more *T. urticae* eggs compared to immature stages (Fig. 1). At *T. urticae* eggs + sunflower pollen diet, immature stages showed the highest number of eaten prey (8 preys) at 5 and 6 days of age (Fig. 1).

The age-specific survival rate (*lx*, the probability that a newborn will survive to age *x*), the age-specific predation rate (*kx*, the average number of consumed prey per predator of age *x*), and age-specific net predation rate (*qx*, the weighted number of consumed prey by a predator of age *x*) of *N. californicus* fed on sunflower, tamarix, and common mallow pollens along with *T. urticae* were combined for all stages and are plotted in Figure 2. The highest age-specific survival rate was observed at 5 and 6 days of age while feeding on *T. urticae* eggs + tamarix pollen. Predatory mite *N. californicus* that fed on *T. urticae* eggs + tamarix pollen had a higher age-specific survival rate with increasing age and also in adults compared to the other pollens (Fig. 2). In *T. urticae* eggs + sunflower pollen, the age-specific survival rate reduced rapidly to 37% from 0 to 10 days and then slowly decreased to 0% at the age of 28 days. In *T. urticae* eggs + tamarix pollen, it diminished slowly to 78% from 0 to 12 days and then rapidly decreased to 0% at the age of 23 days. In *T. urticae* eggs + common mallow pollen, survival rate reduced slowly to 91% from 0 to 8 days and then rapidly diminished to 0% at the age of 21 days (Fig. 2).

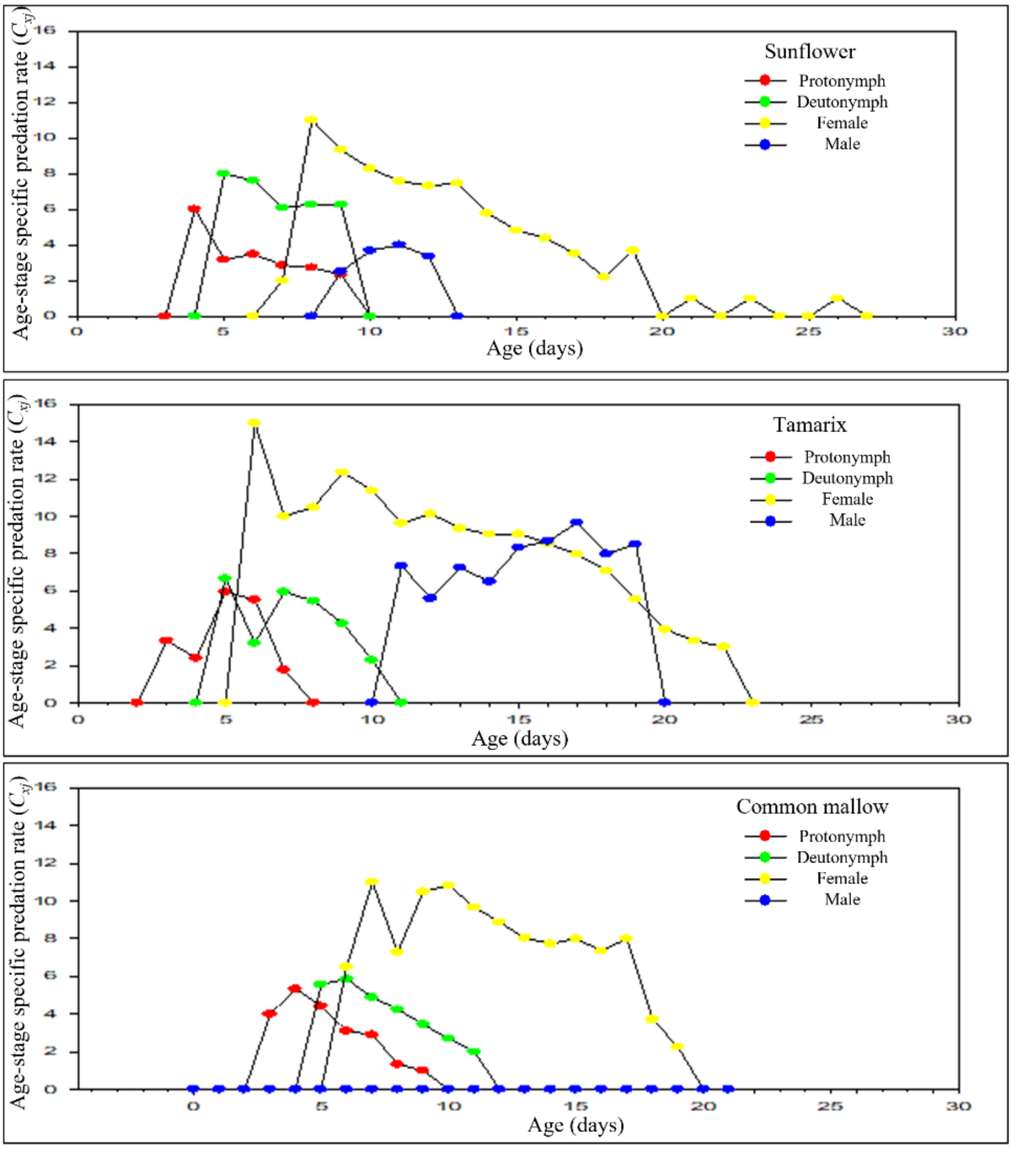

Figure 1. Age-stage specific predation rate (*Cxj*) of *Neoseiulus californicus* fed on *T. urticae* eggs supplemented separately with sunflower, tamarix, or common mallow pollen.

The age-specific predation rate showed the average number of *T. urticae* eggs consumed by the predator at age *x*. In this study, the age-specific predation rate refers to the average number of *T. urticae* eggs consumed by *N. californicus* at age *x*, which was examined by feeding separately on sunflower, tamarix, and common mallow pollens. Under *T. urticae* eggs + tamarix pollen diet, the highest age-specific predation rate (0.8) was obtained at the age of 12 days, followed by the ages of 13, 14, and 15 days, respectively. Under *T. urticae* eggs + common mallow pollen diet, the highest age-specific predation rate (0.7) was observed at the age of 10 days, followed by the ages of 9, 11, and 12 days, respectively. Under *T. urticae* eggs + sunflower pollen diet, the highest age-specific predation rate (0.6) was at the age of 10 days, followed by the ages of 9, 11, 12, and 13 days, respectively. In terms of pollen type, the age-specific predation rate of *N. californicus* was in *T. urticae* eggs + tamarix > *T. urticae* eggs + common mallow > *T. urticae* eggs + sunflower (Fig. 2). The age-specific predation rate curve is a simplified version of the age-stage specific predation rate curves, and by considering survivorship, the age-specific net predation rate can be specified. Under *T. urticae* eggs + tamarix pollen diet, the highest age-specific net predation rate of *N. californicus* (0.7) was obtained at the age of 12 days. Under *T. urticae* eggs + common mallow pollen diet, the highest age-specific net predation rate (0.6) was at the age of 10 days and under *T. urticae* eggs + sunflower pollen diet, its maximum amount (0.3) was observed at the age of 8 days. Predatory mite *N. californicus* that fed on *T. urticae* eggs + tamarix pollen had a higher age-specific net predation rate compared to those feeding on the other two pollens, even at older ages (Fig. 2).

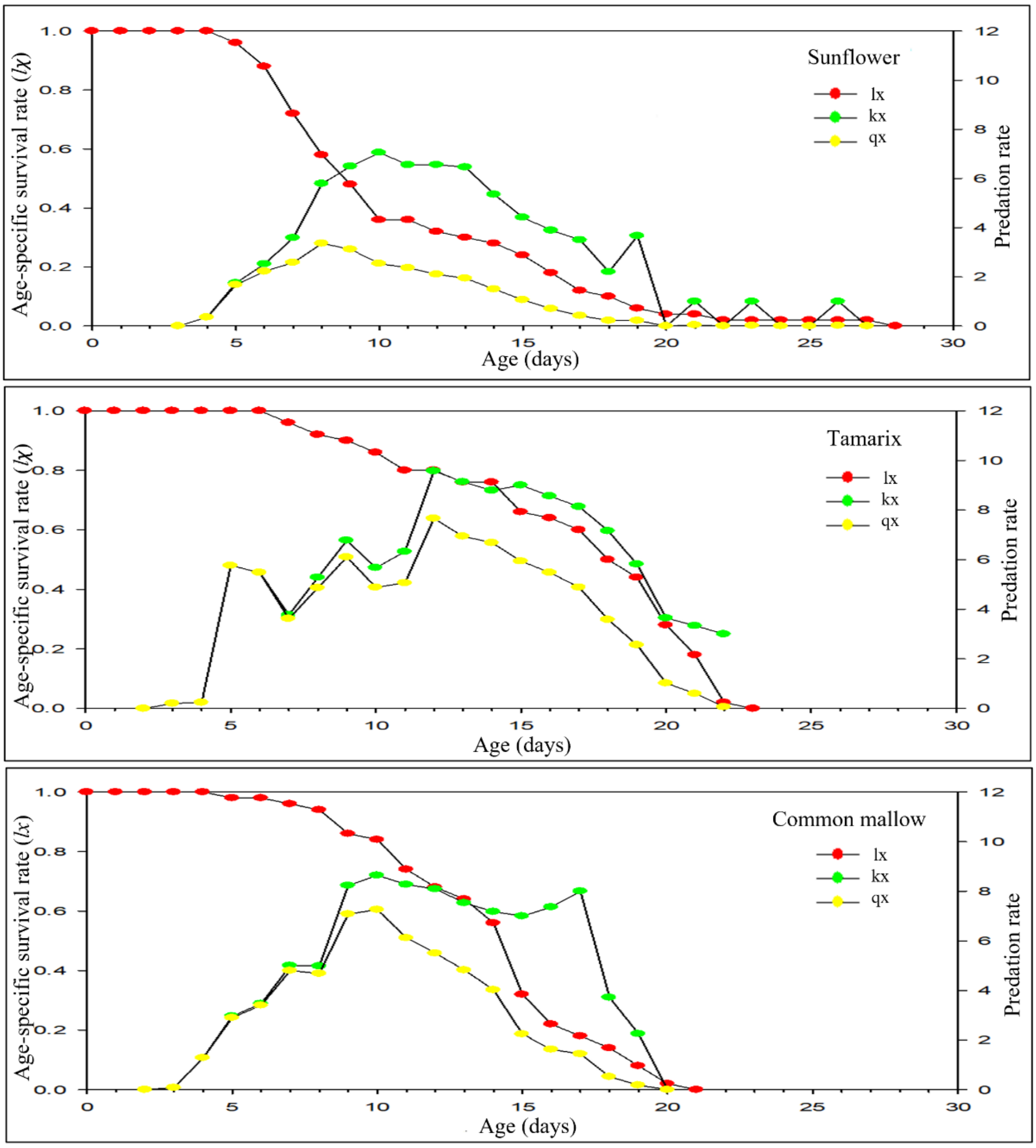

Figure 2. Age-specific survival rate (l_x), age-specific predation rate (k_x), and age-specific net predation rate (q_x) of *Neoseiulus californicus* fed on *T. urticae* eggs supplemented separately with sunflower, tamarix, or common mallow pollen.

The results of the total age-stage predation rate for the *N. californicus* (Fig. 3) indicated that all developmental stages responded more to feeding on *T. urticae* eggs + tamarix pollen. Under conditions of feeding on all three pollens, female adults had a higher total age-stage predation rate compared to other developmental stages, and male adults had a lower value. The lowest total age-stage predation rate across all ages was for adult males feeding on *T. urticae* eggs + common mallow pollen. Under *T. urticae* eggs + tamarix pollen diet, the highest total age-stage predation rate (360) was observed for adult females at the age of 12 days and under *T. urticae* eggs + common mallow pollen diet, the highest value (340) was for adult females at the age of 10 days. Under *T. urticae* eggs + sunflower pollen diet, the highest total age-stage predation rate (120) was obtained for female adults at the ages of 9 and 10 days. After the age of 12 days, the total age-stage predation rate of female adults at all ages was higher in *T. urticae* eggs + tamarix pollen than in *T. urticae* eggs + common mallow pollen and in *T. urticae* eggs + common mallow pollen than in *T. urticae* eggs + sunflower pollen (Fig. 3).

Pollen chemical compositions

The results of pollen composition showed that the amount of total carbohydrates, fructose, sucrose, and glucose was higher in common mallow pollen (238, 3.81, 2.86, and 2.85 mg g^{-1}, respectively) than other pollens (Table 4). The highest protein content (33 mg g^{-1}) was observed in tamarix pollen, while the lowest was found in common mallow pollen (Table 4). Sunflower pollen contained the highest lipid content (5.1%) and the lowest content was recorded in common mallow pollen (Table 4). Sunflower pollen had the highest amount of phenols and flavonoids (155 mg g^{-1} and 96 mg g^{-1}, respectively), and tamarix pollen contained the lowest amount of these compounds (Table 4).

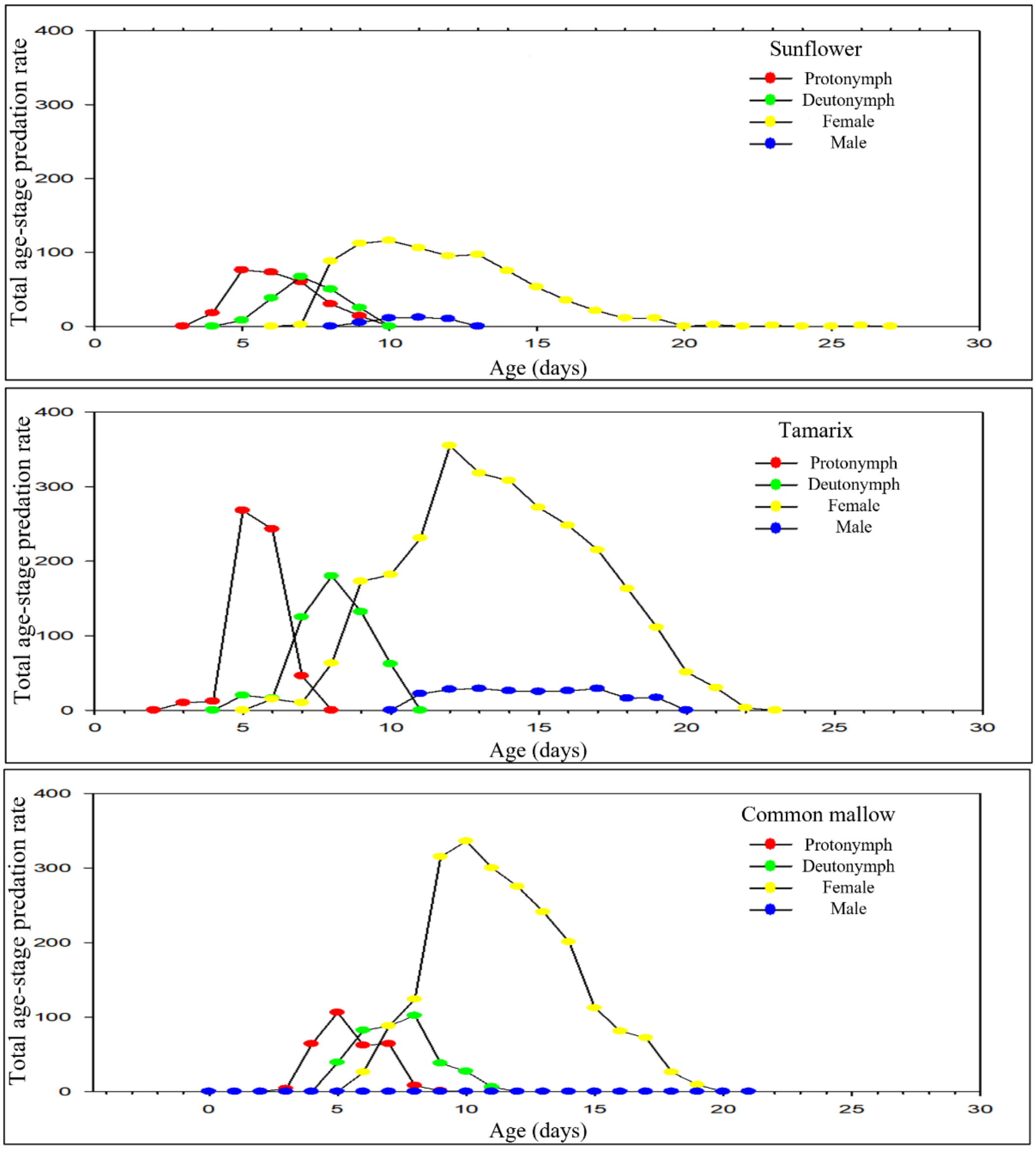

Figure 3. Total age-stage predation rate of *Neoseiulus californicus* fed on *T. urticae* eggs supplemented separately with sunflower, tamarix, or common mallow pollen.

Table 4. Chemical compositions of common mallow, tamarix, and sunflower pollens.

Pollen	Total carbohydrate (mg g^{-1})	Fructose (% w/w)	Sucrose (% w/w)	Glucose (% w/w)	Total protein (mg g^{-1})	Lipid (% w/w)	Total phenol (mg g^{-1})	Total flavonoid (mg g^{-1})
Sunflower	150 ± 0.92^{b}	2.40 ± 0.01^{b}	1.80 ± 0.01^{b}	1.79 ± 0.01^{b}	32 ± 0.11^{b}	5.1 ± 0.3^{a}	155 ± 0.97^{a}	96 ± 0.22^{a}
Common mallow	238 ± 0.49^{a}	3.81 ± 0.01^{a}	2.86 ± 0.01^{a}	2.85 ± 0.01^{a}	30 ± 0.34^{c}	3.2 ± 0.25^{c}	106 ± 0.32^{b}	44 ± 0.15^{b}
Tamarix	91 ± 0.66^{c}	1.46 ± 0.01^{c}	1.09 ± 0.01^{c}	1.08 ± 0.01^{c}	33 ± 0.25^{a}	4 ± 0.28^{b}	85 ± 0.19^{c}	36 ± 0.33^{c}

Means within a column with the same alphabetical superscript were not significantly different based on the Tukey test (α=5%).

DISCUSSION

In greenhouses and/or fields experiencing a shortage or absence of natural prey, the survival, growth, and reproduction of predatory mites on alternative foods, such as plant pollen, is essential for the successful biological control strategies (McMurtry *et al.* 2013; Hashemi *et al.* 2021). In this study, the suitability of common mallow, tamarix, and sunflower pollen as a sole or supplementary food sources for the predatory mite *N. californicus* was evaluated by determining life table parameters and comparing them with the biological parameters of *N. californicus* fed on *T. urticae* and these pollens. By investigating six diets having the pollen, this study improved the knowledge of the food source spectrum for rearing *N. californicus*. Our findings indicated that *N. californicus* can feed and develop into adults on all tested diets. Exclusive feeding of *N. californicus* with tested pollen types showed that the completion of the predatory mite life cycle took a longer time by exclusive feeding on tamarix pollen. *N. californicus* has a greater potential to survive, lay eggs, and complete its life cycle when fed on the tamarix pollen + *T. urticae* eggs, which could be due to the high protein content in tamarix pollen (Table 4). In this regard, it has been reported that pollen protein content has an important role in nutritive value and predator performance (Roulston and Cane 2000). Also, differences in the nutritional value and morphological characteristics of pollen from various plants can affect the food supply required by mites, which in turn may lead to variations in the period of developmental stages and egg-laying rates in predatory mites tested on pollen (Goleva and Zebitz 2013; Khanamani *et al.* 2017c; Pascua *et al.* 2020). Various studies have been conducted about the effect of plant pollen on the biological characteristics of phytoseiid predatory mites (Riahi *et al.* 2017; Rezaie 2019). Other researchers have also studied the effect of pollen types and quality on the biological characteristics of the predatory mite *N. californicus* (Khanamani *et al.* 2017c; Soltaniyan *et al.* 2018). Rezaie (2019) stated that sunflower pollen is not suitable for completing the life cycle of the predatory mite *Neoseiulus barkeri* (Acari: Phytoseiidae).

The egg stage duration of *N. californicus*, when fed on various pollen diets either alone or combined with *T. urticae*, ranged from 1.52 to 3.7 days. Meanwhile, the larval stage lasted between 1.92 and 2.62 days. The egg stage of *N. californicus* lasts 2.7 days when consuming date palm pollen and 2.68 days when feeding on corn pollen (Khanamani *et al.* 2017b). The larval stage of *N. californicus*, when fed on *T. urticae* + *Typha angustifolia* has been noted to last 0.5 day (Pascua *et al.* 2020). The differences in the present research compared to the mentioned studies can be attributed to variations in temperature, data analysis methods, test accuracy, pollen type, prey type, and predation rate (Rezaie 2019). In this study, longevity of *N. californicus* ranged from 13.14 to 19.29 days (sunflower pollen and tamarix pollen + *T. urticae* eggs, respectively) for females and 13 to 17.5 days (sunflower pollen and tamarix pollen, respectively) for males. These values are notably shorter than reported in other studies. The lifespan of *N. californicus* females was recorded at 37 days when consuming date palm pollen and 36 days with corn pollen (Khanamani *et al.* 2017b). In contrast, their longevity extended to 52.38 days, 43.88 days, and 41.14 days when fed on pistachio, date palm, and pomegranate pollens, respectively (Hashemi *et al.* 2021). The lifespan of *N. californicus* males was determined to be 35.61 days when fed on date palm pollen and 35.29 days when consuming corn pollen (Khanamani *et al.* 2017b). In a different study, their longevity was 40.36, 38.7, and 36.12 days when fed on pistachio, date palm, and pomegranate pollens, respectively (Hashemi *et al.* 2021). The shorter longevity of adults in this study compared to the mentioned studies can be attributed to variations in experimental temperatures, pollen types, prey types, and data analysis methods, as reported in another research (Rezaie 2019). In another study, the longest mean longevity (89.73 days) of *N. californicus* females was recorded when they continuously utilized maize pollen, while the shortest (35.09 days) was noted when continuously consumed *T. urticae* eggs. The same previous trend was also observed for the life span of females (Saber 2012). Another study demonstrated the longest mean longevity of *N. californicus* females when continuously consumed plant pollen including sunflower, in comparison to *T. urticae* eggs (Sazo *et al.* 2006).

The total pre-ovipositional period (TPOP) varied significantly among diets, with the longest periods observed for tamarix pollen + *T. urticae*. The shortest mean preoviposition period (2.55 days) of *N. californicus* was recorded when continuously reared on *T. urticae* eggs (control) (Saber 2012). Lower protein content in sunflower and common mallow pollens may explain the relatively shorter TPOP and reduced fecundity under those diets. Although the diets varied, they all facilitated egg-laying; however, the highest fecundity occurred with sunflower + *T. urticae*, followed by tamarix + *T. urticae*. Deficiency or absence of primary essential nutrients (especially protein) in pollens for fecundity may be the source of such differences (Khanamani *et al.* 2017c). In this study, the protein content in sunflower and common mallow pollens was lower than that of tamarix pollen (Table 4). The presence of *T. urticae* shortened total pre-ovipositional period of *N. californicus* on the sunflower pollen (and after that the common mallow pollen). Female phytoseiid mites lay eggs only when there is enough food for their offspring (Tsolakis and Chiara 1994). All diets in this study were able to support *N. californicus* fecundity. The highest average fecundity of *N. californicus* was obtained by feeding on sunflower + *T. urticae* (after that on tamarix + *T. urticae*). Exclusive pollen feeding did not make a difference in the fecundity of this mite; however, the fecundity was higher in exclusive feeding on tamarix pollen than in exclusive feeding on the other two pollens. The fecundity of *N. californicus* was the highest (53.91 eggs/female) in females continuously fed on *T. urticae* eggs, while it was the lowest (27.91 eggs/female) in those continuously reared on maize pollen (Saber 2012). The average fecundity of *N. californicus* feeding on *T. urticae* and cedar, pear, apricot and pistachio pollens was reported to be 25.11%, 2.58, 2.82, 13.44, and 30.24 eggs per female, respectively (Soltaniyan *et al.* 2018). Researchers stated that *N. californicus* fecundity was higher when feeding on *T. urticae* and pollens (corn, date palm, and bee) than when the predatory mite fed only on pollens (Khanamani *et al.* 2017b). The results of the present study also showed the same result. Pollens from sunflower and hazelnut were less suitable as food sources, leading to the poor performance of *Amblyseius swirskii* (Goleva and Zebitz 2013). Although the reproductive performance of the predator on the sunflower and common mallow pollens (in the absence of *T. urticae*) was low, because of their fitness for the retention of predator adults they can be used as a food source supplied during mass production of *N. californicus*. In the absence of natural prey, an alternative food source must be able to retain predatory mites over the long term rather than raise the capacity for producing eggs, because their over-abundance can cause the over-consumption of food resources and an increment in cannibalism frequency (Schausberger 2003). Therefore, sunflower and common mallow pollens may be appropriate for promoting the retention of *N. californicus* populations during periods when natural prey is lacking in plants.

The most preferred food source results in a higher intrinsic rate of increase and greater population growth. Under conditions of exclusive feeding on pollens in the present study, the intrinsic rate of increase for *N. californicus* was high only in tamarix pollen (0.112 day^{-1}), indicating the suitability of this pollen as an exclusive food for this predatory mite. However, adding the tested pollen to natural prey (*T. urticae* eggs) increased the intrinsic rate of increase more. Therefore, the intrinsic rate of increase in the diets of common mallow + *T. urticae* and tamarix + *T. urticae* (0.132 and 0.131 day^{-1}, respectively) was higher than that of the other tested treatments. Similarly, *Neoseiulus cucumeris* (Oudemans) fed, developed, and reproduced better when it was provided with pollen (maize, sweet pepper, mungbean, cucumber, tomato, and rose) in combination with the prey (mold mite), compared to pollens offered alone (Sarwar 2016). Plant pollens, as appropriate supplementary food sources, can positively influence the growth statistics of phytoseiid predatory mites. For example, the intrinsic rate of increase for *N. californicus* feeding on almond, date palm, sunflower, and castor bean pollens was reported to be 0.129, 0.152, 0.123, and 0.146 day^{-1}, respectively (Yazdanpanah *et al.* 2021). In another study, the intrinsic rate of increase for *N. californicus* feeding on pistachio, date palm, and pomegranate pollens was estimated to be 0.190, 0.184, and 0.168 day^{-1}, respectively, which was higher compared to other tested pollens. Also, pistachio and date palm pollens resulted in high finite rate of increase and net reproductive rate for *N. californicus* (Hashemi *et al.* 2021). The intrinsic rate of increase, finite rate of increase, and net reproductive rate of *N. californicus* feeding on corn pollen in the presence of *T. urticae* (0.1409 day^{-1}, 1.1513 day^{-1}, and 27.73 offspring/individual, respectively) were higher than when the predatory mite fed on corn pollen and *T. urticae* separately (Khanamani *et al.* 2017b). These values in the above study were higher than the intrinsic rate of increase and net reproductive rate in all six diets in our study, which could be due to the pollen type and quality, rearing techniques, laboratory conditions, host plant used for rearing *T. urticae*, and data analysis method (Soltaniyan *et al.* 2018; Hashemi *et al.* 2021). The shortest mean generation time and the highest net reproductive rate (15.33 days and 34.08 offspring/individual, respectively) of *N. californicus* occurred when continuously fed on *T. urticae* eggs, while the longest mean generation time (16.90 days) and the lowest net reproductive rate (19.07 offspring/individual) were recorded when continuously reared on maize pollen. Also, the finite rate of increase was the highest (1.26) when *N. californicus* females continuously consumed *T. urticae* eggs (control), whereas it was the lowest (1.19) when continuously maize pollen (Saber 2012). The finite rate of increase in all six treatments was lower than the control of the above study. The intrinsic rate of increase and net reproductive rate for the predatory mite *A. swirskii* were higher when feeding on almond pollen than on other pollens, and chemical analysis of pollens showed a higher nutritional value of almond pollen (Riahi *et al.* 2017). Peach pollen diet produced the lowest intrinsic rate of increase, finite rate of increase, and net reproductive rate and the longest oviposition period of female; hence, an inappropriate pollen for *N. californicus* (Hashemi *et al.* 2021). Taking only the three pollens tested in the present study into consideration, it is indicated that tamarix pollen due to its higher protein content was of higher nutritional value for *N. californicus* than the other pollens. This pollen resulted in shortest pre-adult development and oviposition period of female, and the highest net reproductive rate, oviposition duration, fecundity, intrinsic rate of increase, and finite rate of increase, both in the absence and presence of *T. urticae*. Similar results were reported for *N. californicus* fed on date palm and pistachio pollens (Hashemi *et al.* 2021). Soltaniyan *et al.* (2018) stated that the shortest oviposition period, longest oviposition period, and fecundity, as well as the highest intrinsic rate of increase, finite rate of increase, and net reproductive rate were on pistachio pollen, followed by apricot pollen, which was related to the higher nutritional value of these pollens for *N. californicus*. The sunflower pollen diet produced the lowest intrinsic rate of increase, finite rate of increase, net reproductive rate, and fecundity (despite the shortest oviposition period of female) than the other two pollens in the absence of *T. urticae*, which indicated that this pollen was unsuitable for *N. californicus*. Similar results were reported for *N. californicus* fed on peach pollen (Hashemi *et al.* 2021). These differences may be related to pollen nutritional composition, pollen surface physiology (either by an impervious thick exine and/or by the very long spines of the pollen surface), adaptation of mite mouthpart morphology to pollen morphology, and mite digestive metabolism (Khanamani *et al.* 2017b; Soltaniyan *et al.* 2018). In sunflower + *T. urticae* diet, shortest oviposition period and highest fecundity were observed, while intrinsic rate of increase, finite rate of increase, and net reproductive rate had lower values in comparison to tamarix + *T. urticae* diet. On the other hand, higher fecundity compensated for longest oviposition period in tamarix + *T. urticae* diet. In addition, intrinsic rate of increase, finite rate of increase, and net reproductive rate were higher in tamarix + *T. urticae* diet. Therefore, it is difficult to resist the result that tamarix pollen could be a more suitable food source for the growth and reproduction of *N. californicus* both in absence and presence of *T. urticae*.

Predation capacity of predatory mites may change with pollen availability (Rezaie and Montazerie 2018). This study investigated the predation rate of *N. californicus* with the availability of common mallow, tamarix, and sunflower pollens. The ability *of N. californicus* to suppress *T. urticae* varied depending on the pollen type, and the predation rate of *T. urticae* by *N. californicus* fed on tamarix pollen was the highest value compared to other pollens. In this regard, it has been reported that plant pollens can increase the efficiency of phytoseiid predatory mites to suppress the density of natural prey (e.g., *T. urticae*), which varies depending on the pollen type and phytoseiid species (Khanamani *et al.* 2017b). According to our results, under conditions of feeding on all three pollens (especially, tamarix pollen), *N. californicus* female adults had a higher predation rate than other growth stages. In fact, tamarix pollen enhanced the ability of *N. californicus* to reduce *T. urticae* populations. In this regard, Rezaie and Montazerie (2018) stated that the predation rate of *N. californicus* females on various growth stages of *T. urticae* was different among the predatory mite reared on corn, walnut, and date pollens and *T. urticae* eggs and the highest predation rate was related to *N. californicus* reared on date pollen. When *A. swirskii* was reared on almond pollen, the net predation rate, transformation rate, and finite predation rate were significantly higher (Ansari-Shiri *et al.* 2022). In another study, a diet consisting of *T. latifolia* pollen supported the development and reproduction of *N. cucumeris* for 25 consecutive generations without diminishing its predation capacity, making it an appropriate diet for the long-term rearing of *N. cucumeris* in augmentative biological control of tetranychid mites (Gravandian *et al.* 2022). The age-specific survival rate shows the survival of various development periods without considering the individuals differentiation. Predatory mite *N. californicus* that fed on tamarix pollen had a higher age-specific survival rate with increasing age and in adults compared to the other two pollens. In other words, in tamarix pollen, age-specific survival rate decreased slowly to 78% from 0 to 12 days. This could be due to the high protein content of tamarix pollen. It has been reported that the age-specific survival rate of *N. californicus* slowly decreased to 0% in pistachio and date palm pollens (Hashemi *et al.* 2021). The highest survival rate of *N. californicus* after the emergence of adult insects was observed on the diet of pomegranate, walnut, corn, saffron and olive pollens (Eini *et al.* 2022). Survival of *A. swirskii* was increased by feeding on a diet of apricot, soybean, sesame, and date palm pollens and was much more efficient than feeding on pest eggs alone (Fadaei *et al.* 2018).

Pollen composition affects its suitability for predatory mites (Khanamani *et al.* 2017c). This study revealed that the amount of total carbohydrates, fructose, sucrose, and glucose in common mallow pollen was higher than that of other pollens. Protein seems to be the most effective nutrient for *N. californicus*, as the predatory mite, by exclusively feeding on tamarix pollen (having high protein), was able to complete its life stages and exhibited higher fecundity, net reproductive rate, finite rate of increase, and intrinsic rate of increase, while its performance was lower when feeding on sunflower pollen (having medium protein) and after that common mallow (lowest protein). Pollen protein content is one of the important indicators of nutritive quality as it is closely related to the performance of consumers (Roulston and Cane 2000). The high protein content may also indicate that pollen is a highly suitable food source (Stanley and Linskens 1974; Goleva *et al.* 2015). Riahi *et al.* (2016) reported that protein and sucrose play the most effective role in the nutritional value of food sources for *Typhlodromus bagdasarjani* Wainstein & Arutunjan. They also reported that almond pollen had the highest nutritional value for this predator due to its crude protein level above 25%, while corn pollen came in second place due to its moderate protein level (below 20%) and the highest sucrose content. The higher performance of predatory mites on pollens having greater protein content has been reported by Khanamani *et al.* (2017c). Studying the chemical compositions of 7 pollens (almond, corn, sunflower, date palm, bitter orange, bee pollen, and castor bean) showed that the highest lipid content was found in sunflower and castor bean pollens, while bee pollen had the highest amount of fructose and glucose (Riahi *et al.* 2016). In the present study, the highest amount of lipid was found in sunflower pollen, which was consistent with the above study. The lower performance of *N. californicus* on sunflower pollen can be due to the higher content of phenol and flavonoids. Whereas carbohydrates, proteins, lipids, and amino acids can be consumed as nutrients and digestion and metabolization should be unproblematic for phytoseiid mites, the detoxification of secondary compounds in pollen, like flavonoids, alkaloids, or saponins depends on the mite species mechanisms, such as metabolizing enzymes (Bonvehi *et al.* 2001; Goleva *et al.* 2015). Specifically, the esterases, multifunctional oxidases, or glutathione-S transferases, are responsible for food adaptations in herbivorous insects and detoxifying xenobiotics (Goleva *et al.* 2015). Additionally, certain pollens (e.g., maize pollen) may contain quercetin, a plant flavonoid and a potent protease inhibitor, that disrupts protein digestion and adversely impacts food conversion (Larson 1971; Goleva *et al.* 2015). Similarly, *Lilium martagon* pollen was called a toxic pollen because of its plant secondary compounds (Goleva and Zebitz 2013). To better understand the feeding of phytoseiid mites on plant materials, such as pollen, it is essential to know more about the chemical composition of pollen and the feeding physiology of these mites.

CONCLUSION

The most striking findings from this study were that 1) the nutritional value of different pollen varies, and 2) different pollens have different effects on biological parameters and predation rates of *N. californicus*. Among the tested pollens, tamarix resulted in the shortest pre-adult period and oviposition period of females, and the highest net reproductive rate, oviposition duration, fecundity, intrinsic rate of increase, and finite rate of increase for *N. californicus* compared to other pollens, both in the absence and presence of *T. urticae*. Also, the availability of tamarix pollen increased the predation rate of *N. californicus*, which is beneficial for the control of *T. urticae*. This was due to the high nutritional value (protein content) of tamarix pollen. Therefore, tamarix pollen is a very suitable diet for *N. californicus*. Under conditions of feeding on sunflower and common mallow pollens (in the absence of *T. urticae*), *N. californicus* performance, especially reproductive was lower, but their adults were maintained in the long term. Therefore, sunflower and common mallow pollens may be suitable as a food source during mass production of *N. californicus* and to promote population maintenance of this predator when natural prey (*T. urticae* eggs) is scarce in crops. Thus, our findings provide important information in designing a comprehensive program for the conservation or mass production of *N. californicus* to control *T. urticae*.

ACKNOWLEDGEMENTS

This research was conducted as part of the first authors master's thesis in Agricultural Entomology. The authors gratefully acknowledge the financial support provided by the Deputy of Research and Technology at the University of Zabol, Zabol, Iran (Grant No. IR-UOZ-GR-0821).

Author contributions: Conceptualization: A.M., M.R.; investigation: A.D., M.R.; methodology: M.R., S.R.; writing original draft: A.D.; analyses and data curation: A.D., M.R.; writing revisions & editing: A.M., M.R., S.R.; Supervision: A.M., M.R.; funding acquisition: A.M. All authors have read and agreed to the published version of the manuscript.

Funding: The research was funded by the Deputy of Research and Technology at the University of Zabol, Zabol, Iran (Grant No. IR-UOZ-GR-0821).

Data availability: Data are available upon request from the authors.

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

Conflict of interest: The authors declare no conflict of interest.

REFERENCES

Ansari-Shiri, H., Fathipour, Y., Hajiqanbar, H., Riahi, E.& Riddick, E. W. (2022) Quality control of the predatory mite *Amblyseius swirskii* during long-term rearing on almond *Prunus amygdalus* pollen. *Arthropod-Plant Interactions*, 16(6): 645–655. https://doi.org/10.1007/s11829-022-09929-6

Bonvehi, S.J., Torrento, M.S., & Lorente, E.G. (2001) Evaluation of polyphenolic and flavonoid compounds in honeybee-collected pollen produced in Spain. *Journal of Agricultural and Food Chemistry,* 49: 1848–1853. https://doi.org/10.1021/jf0012300

Bradford, M.M. (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. *Analytical Biochemistry*, 72: 248–254. https://doi.org/10.1016/0003-2697(76)90527-3

Carey, J.R. (1993) *Applied Demography for Biologists: Special Emphasis on Insects.* Oxford University Press, New York, 206 pp. https://doi.org/10.1093/oso/9780195066876.001.0001

Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. *Environmental Entomology*, 17: 26–34. https://doi.org/ 10.1093/ee/17.1.26

Chi, H. (2025a) TWOSEX-MSChart: A computer program for the age-stage, two-sex life table analysis. Available from: http://140.120.197.173/Ecology/Download/ TWOSEX-MSChart.rar

Chi, H. (2025b) CONSUME-MSChart: A computer program for consuming rate analysis based on the age stage, two-sex life table. Available from: http://140.120.197.173/Ecology/Download/CONSUME-MSChart.zip

Chi, H. & Liu, H. (1985) Two new methods for the study of insect population ecology. *Academia Sinica*, 24: 225–240.

Chi, H. & Yang, T.C. (2003) Two-sex life table and predation rate of *Propylaea japonica* Thunberg (Coleoptera: Coccinellidae) fed on *Myzus persicae* (Sulzer) (Homoptera: Aphididae). *Environmental Entomology*, 32: 327–333. https://doi.org/ 10.1603/0046-225X-32.2.327

Eini, N., Jafari, S., Fathipour, Y. & Zalucki, M. P. (2022) How pollen grains of 23 plant species affect performance of the predatory mite *Neoseiulus californicus*. BioControl, 67(2): 173–187. https://doi.org/10.22073/pja.v14i1.85955

Fadaei, E., Hakimitabar, M., Seiedy, M. & Sarraf Moaieri, H. (2018) Effects of different diets on biological parameters of the predatory mite *Amblyseius swirskii* (Acari: Phytoseiidae). *International Journal of Acarology*, 44(7): 341–346. https://doi.org/10.1080/01647954.2018.1525428

Farhadi, R., Allahyari, H. & Chi, H. (2011) Life table and predation capacity of *Hippodamia variegata* (Coleoptera: Coccinellidae) feeding on *Aphis fabae* (Hemiptera: Aphididae). *Biological Control*, 59: 83–89. https://doi.org/10.1016/j.biocontrol.2011.07.013

Fathipour, Y. & Maleknia, B. (2016) Mite predators. *In*: Omkar (Ed.), *Ecofriendly Pest Management for Food Security*. San Diego, USA, Elsevier, pp. 329–366. https://doi.org/10.1016/B978-0-12-803265-7.00011-7

Goleva, I., Rubio Cadena, E.C., Ranabhat, N.B., Beckereit, C. & Zebitz, C.P. (2015). Dietary effects on body weight of predatory mites (Acari, Phytoseiidae). *Experimental and Applied Acarology*, 66: 541–553. https://doi.org/10.1007/s10493-015-9920-5

Goleva, I. & Zebit, C.P.W. (2013) Suitability of different pollen as alternative food for the predatory mite *Amblyseius swirskii*. *Experimental and Applied Acarology*, 61: 259–283. https://doi.org/ 10.1007/s10493-013-9700-z

Goodman, D. (1982) Optimal life histories, optimal notation, and the value of reproductive value. *The American Naturalist*, 119: 803–823.

Gravandian, M., Fathipour, Y., Hajiqanbar, H., Riahi, E. & Riddick, E.W. (2022) Long-term effects of cattail *Typha latifolia* pollen on development, reproduction, and predation capacity of *Neoseiulus cucumeris*, a predator of *Tetranychus urticae*. *BioControl,* 67: 149–160. https://doi.org/10.1007/s10526-021-10116-4

Gugole Ottaviano, M.F., Cédola, C.V., Sánchez, N.E. & Greco, N.M. (2015) Conservation biological control in strawberry: effect of different pollen on development, survival, and reproduction of *Neoseiulus californicus* (Acari: Phytoseiidae). *Experimental and Applied Acarology*, 67: 507–521. https://doi.org/10.1007/s10493-015-9971-7

Hashemi, S., Asadi, M. & Khanamani, M. (2021) How does feeding on different diets affect the life history traits of *Neoseiulus californicus*? *International Journal of Acarology*, 47(5): 367–373. https://doi.org/10.1080/01647954.2021.1912175

Hatherly, L.S., Bale, J.S. & Walters, K.F. (2005) Intraguild predation and feeding preferences in three species of phytoseiid mite used for biological control. *Experimental and Applied Acarology*, 37(1): 43–55. https://doi.org/10.1007/s10493-005-0358-z

Havasi, M., Mosallanejad, H. & Fathipour, Y. (2020) Influence of low-lethal concentrations of thiamethoxam on biological characteristics of *Neoseiulus californicus* (Acari: Phytoseiidae). *Journal of Crop Protection*, 9(1): 41–55.

Huang, Y.B. & Chi, H. (2013) Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. *Journal of Applied Entomology*, 137(5): 327–339. https://doi.org/10.1111/jen.12002

Khanamani, M., Fathipour, Y., Talebi, A.A. & Mehrabadi, M. (2017a) Evaluation of different artificial diets for rearing the predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae): diet-dependent life table studies. *Acarologia*, 57(2): 407–419. https://doi.org/10.1051/acarologia/20174165

Khanamani, M., Fathipour, Y., Talebi, A.A. & Mehrabadi, M. (2017b) How pollen supplementary diet affect life table and predation capacity of *Neoseiulus californicus* on two-spotted spider mite. *Systematic and Applied Acarology*, 22(1): 135–147. https://doi.org/10.11158/saa.22.1.14

Khanamani, M., Fathipour, Y., Talebi, A.A. & Mehrabadi, M. (2017c) Linking pollen quality and performance of *Neoseiulus californicus* (Acari: Phytoseiidae) in two-spotted spider mite management programs. *Pest Management Science*, 73(2): 452–461. https://doi.org/10.1002/ps.4305

Kostiainen, T. & Hoy, M.A. (1994) Variability in resistance to organophosphorus insecticides in field-collected colonies of *Amblyseius finlandicus* (Oudemans) (Acari, Phytoseiidae). *Journal of Applied Entomology*, 117(1–5): 370–379. https://doi.org/10.1111/j.1439-0418.1994.tb00748.x

Larson, R.L. (1971) Glucosylation of quercetin by a maize pollen enzyme. *Phytochemistry*, 10: 3073–3076. https://doi.org/10.1016/s0031-9422(00)97355-2

McMurtry, J.A., De Moraes, G.J. & Sourassou, N.F. (2013) Revision of the lifestyles of phytoseiid mites (Acari: Phytoseiidae) and implications for biological control strategies. *Systematic and Applied Acarology*, 18(4): 297–320. https://doi.org/10.11158/saa.18.4.1

Moghadasi, M., Saboori, A., Allahyari, H. & Zahedi Golpayegani, A. (2014) Life table and predation capacity of *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) feeding on *Tetranychus urticae* (Acari: Tetranychidae) on rose. *International Journal of Acarology*, 40: 501–508. https://doi.org/ 10.1080/01647954.2014.962084

Pascua, M.S., Rocca, M., Greco, N. & De Clercq, P. (2020) *Typha angustifolia* L. pollen as an alternative food for the predatory mite *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae). *Systematic and applied acarology*, 25(1): 51–62. https://doi.org/10.11158/saa.25.1.4

Qian, W.L., Khan, Z., Watson, D.G. & Fearnley, J. (2008) Analysis of sugars in bee pollen and propolis by ligand exchange chromatography in combination with pulsed amperometric detection and mass spectrometry. *Journal of Food Composition and Analysis*, 21(1): 78–83. https://doi.org/10.1016/j.jfca.2007.07.001

Rezaie, M. (2019) Suitability of different plant pollens as supplementary food source and natural prey for predatory mite, *Neoseiulus barkeri* Hughes (Acari: Phytoseiidae). *Plant Protection*, 41(4): 77–90. (In Persian with English abstract). https://doi.org/10.22055/ppr.2019.14155

Rezaie, M. & Montazerie, F. (2018) Influence of feeding with different plant pollens on prey-stage preference and predation rate of *Neoseiulus Californicus* (Mcgregor) (Acari: Phytoseiidae). *International Journal of Entomological Research*, 6(1): 1–6. https://doi.org/10.33687/entomol.006.01.2328

Riahi, E., Fathipour, Y., Talebi, A.A. & Mehrabadi, M. (2016) Pollen quality and predator viability: life table of *Typhlodromus bagdasarjani* on seven different plant pollens and two-spotted spider mite. *Systematic and Applied Acarology*, 21(10): 1399–1412. https://doi.org/10.11158/saa.21.10.10

Riahi, E., Fathipour, Y., Talebi, A.A. & Mehrabadi, M. (2017) Natural diets versus factitious prey: comparative effects on development, fecundity and life table of *Amblyseius swirskii* (Acari: Phytoseiidae). *Systematic and Applied Acarology*, 22(5): 711–723. https://doi.org/10.11158/saa.22.5.10

Rodrigues, L.C.C., Fortini, R.M. & Neves, M. (2023) Impacts of the use of biological pest control on the technical efficiency of the Brazilian agricultural sector. *International Journal of Environmental Science and Technology*, 20: 1–16. https://doi.org/10.1007/s13762-022-04032-y

Roulston, T.H. & Cane, J.H. (2000) Pollen nutritional content and digestibility for animals. *Plant Systematics and Evolution*, 222: 187–209. https://doi.org/10.1007/bf00984102

Saber, S.A. (2012) Biological aspects and life table parameters of the predacious mite, *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) consuming food types during immature stages and after adult emergence. *Archives of Phytopathology and Plant Protection*, 45(20): 2494-2501. https://doi.org/10.1080/03235408.2012.730887

Sarwar, M. (2016) Comparative life history characteristics of the mite predator *Neoseiulus cucumeris* (Oudemans) (Acari: Phytoseiidae) on mite and pollen diets. *International Journal of Pest Management*, 62(2): 140–148. https://doi.org/10.1080/09670874.2016.1146806

Sazo, L., Araya, J.E. & Iturriaga, P. (2006) Effect of the type of pollen on survival, fertility and viability of eggs of *Neoseiulus californicus* (McGregor) in the laboratory. *Boletin de Sanidad Vegetal Plagas*, 32: 3619–3623.

Schausberger, P. (2003) Cannibalism among phytoseiid mites: a review. *Experimental and Applied Acarology*, 29: 173–191. https://doi.org/10.1023/a:1025839206394

SigmaPlot (2011) SigmaPlot, version 12.0, Systat Software Inc.

Soltaniyan, A., Kheradmand, K., Fathipour, Y. & Shirdel, D. (2018) Suitability of pollen from different plant species as alternative food sources for *Neoseiulus californicus* (Acari: Phytoseiidae) in comparison with a natural prey. *Journal of Economic Entomology*, 111(5): 2046–2052. https://doi.org/10.1093/jee/toy172

Stanley, R.G. & Linskens, H.F. (1974) *Pollen: Biology Biochemistry and Management*. Springer, Berlin, 310 pp.

Tsolakis, H. & Chiara, S. (1994) Biological and life table parameters of *Amblyseius andersoni* (Chant) (Parasitiformes, Phytoseiidae) on different kinds of food substances. *Phytophaga*, 5: 21–28.

Yazdanpanah, S., Fathipour, Y. & Riahi, E. (2021) Pollen grains are suitable alternative food for rearing the commercially used predatory mite *Neoseiulus cucumeris* (Acari: Phytoseiidae). *Systematic and Applied Acarology*, 26(5): 1009–1020. https://doi.org/10.11158/saa.26.5.14

کارایی زیستی و ظرفیت شکارگری کنه *Neoseiulus californicus* (Acari: Phytoseiidae) روی *Tetranychus urticae* (Acari: Tetranychidae) و گرده‌های آفتابگردان، گز و پنیرک معمولی

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دریافت
۱۸ خرداد ۱۴۰۴

پذیرش
۹ شهریور ۱۴۰۴

انتشار
۲۳ مهر ۱۴۰۴

دبیر تخصصی
م. سیدی

چکیده

تأمین گرده به‌عنوان منبع غذایی جایگزین می‌تواند کارایی کنه‌های شکارگر خانواده Phytoseiidae را بهبود بخشد. در این پژوهش، تأثیر سه نوع گرده مختلف (آفتابگردان، گز و پنیرک معمولی) به‌عنوان رژیم‌های غذایی کمکی بر شاخص‌های جدول زندگی و میزان شکارگری کنهٔ شکارگر *Neoseiulus californicus* McGregor (Acari: Phytoseiidae) در حضور و غیاب تخم‌های کنهٔ تارتن دولکه‌ای *Tetranychus urticae* Koch (Acari: Tetranychidae) بررسی شد. همچنین ترکیب شیمیایی گرده‌ها مورد تجزیه و تحلیل قرار گرفت. نتایج نشان داد که باروری (تخم‌گذاری) *N. californicus* روی *T. urticae* در حضور گرده، به‌طور معنی‌داری بیشتر از حالتی بود که فقط از گرده تغذیه کرده بود. میزان ذاتی افزایش جمعیت (r) روی *T. urticae* در حضور گرده‌های گز و پنیرک معمولی (به‌ترتیب ۰/۱۳۱ و ۰/۱۳۲ بر روز) به‌طور معنی‌داری بیشتر از سایر رژیم‌های غذایی بود. میزان خالص تولیدمثل (R_0) از ۰/۵۸۵ (در گرده آفتابگردان) تا ۸/۴۶۵ نتاج/فرد/نسل (در تیمار گرده گز + *T. urticae*) متغیر بود. جمعیت پرورش‌یافته روی تیمار گرده پنیرک معمولی + *T. urticae* بیشترین میزان ذاتی افزایش جمعیت و میزان متناهی افزایش جمعیت را داشت و پس از آن تیمار گرده گز + *T. urticae* قرار گرفت. میزان شکار *T. urticae* توسط کنهٔ *N. californicus* که با گردهٔ گز تغذیه شده بود، در مقایسه با سایر گرده‌ها بیشترین مقدار را داشت. گردهٔ گز بیشترین مقدار پروتئین را داشت، در حالی‌که گردهٔ آفتابگردان حاوی مقدار بیشتری از ترکیبات چربی، فنول و فلاونوئید بود. به دلیل محتوای بیشتر پروتئین، گرده گز اثرات مطلوبی بر زنده‌مانی، نمو، باروری و میزان شکارگری *N. californicus* داشت. بنابراین، گرده گز می‌تواند به‌عنوان یک منبع تغذیه کمکی در کنار تخم‌های *T. urticae* مورد استفاده قرار گیرد، زیرا تیمار گرده گز + تخم *T. urticae* بیشترین مقادیر را در اغلب شاخص‌ها نشان داد. در نتیجه، پرورش *N. californicus* با گرده گز می‌تواند در کنترل کنهٔ تارتن دولکه‌ای *T. urticae* مفید و مؤثر واقع شود.

واژگان کلیدی: مهار زیستی، باروری، میزان ذاتی افزایش جمعیت، تغذیه از گرده، میزان شکارگری، میزان زنده‌مانی

CITE: Dahmardeh, A., Mirshekar, A., Rezaei, M. & Ramroodi, S. (2025) Biological performance and predation capacity of *Neoseiulus californicus* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae) and pollens of sunflower, tamarix, and common mallow. *Persian Journal of Acarology*, 14(4): 140407.

https://doi.org/10.22073/pja.v14i4.87354