Persian J. Acarol., 2024, Vol. 13, No. 2, pp. 265–282.
https://doi.org/10.22073/pja.v13i2.83614
Journal homepage: http://www.biotaxa.org/pja

Article

Life table parameters and predation rate of *Neoseiulus californicus* (Acari: Phytoseiidae) feeding on *Panonychus citri* and *Eutetranychus orientalis* (Acari: Tetranychidae)

Aya H. Gazoly, Abd-Allah M. Afifi, Fatma S. Ali and Mahmoud M. Ahmed*

Zoology and Agricultural Nematology Department, Faculty of Agriculture, Cairo University, Giza, Egypt; E-mails: Gazolyaya@yahoo.com, amafifi@agr.cu.edu.eg, famasamir@hotmail.com, mahmoudmonir@agr.cu.edu.eg

* Corresponding author

ABSTRACT

This study aimed 1) to investigate the effect of two citrus mites, *Panonychus citri* (McGregor) and *Eutetranychus orientalis* (Klein) as food on the biological parameters of *Neoseiulus californicus* (McGregor), and 2) to evaluate the effect of three factors (temperature with two levels (T), diet type with four levels (P) and density of diet with five levels (D)) on predation and reproduction rate of *N. californicus* alone, as well as the interactions between them, using factorial design with general linear model. From the results, feeding the predatory mite, *N. californicus* on mobile stages of *P. citri* caused a significant reduction in the pre-adult and adult longevity periods of females (4.96 and 24.22 days), respectively. Significant increase in the total fecundity (34 eggs/female) over an oviposition period of 14 days compared to feeding on *E. orientalis* was observed. Also, the values of the intrinsic rate of increase (r_m) and the finite rate of increase (λ) parameters were higher, and at the same time, the generation time (*T*) and doubling time (*DT*) were shorter when the predator fed on *P. citri* mobile stages than *E. orientalis.* Using a factorial design with general linear model, the predation rate of *N. californicus* and the daily number of eggs deposited by female were significantly ($p < 0.01$) affected by the three factors: temperature (T), diet type (P), and density of diet (D) alone, and with interaction between them. The high fecundity, short generation time, and moderate r_m of population of *N. californicus* in addition to being better adapted to high temperatures indicate significant potential as an effective biological control agent for the two citrus mites, *P. citri* and *E. orientalis* attacking citrus orchards. Results are necessarily being considered in pest management decisions.

KEYWORDS: Biocontrol, citrus mites, life table parameters, *Neoseiulus californicus*, predation efficiency.

PAPER INFO.: Received: 1 October 2023, Accepted by: *A. Farazmand*, 22 January 2024, Published: 15 April 2024

INTRODUCTION

Plant-feeding mites are among the most common in agricultural ecosystems and the most serious pests that cause economic damage to their host plants. Among them, the species belonging to the Tetranychidae family are considered one of the most important economic pests as they greatly affect various crops worldwide (Jeppson *et al*. 1975). These include citrus mites, specifically *Panonychus citri* (McGregor) and *Eutetranychus orientalis* (Klein) which are pest species in citrus orchards. These mites feed on the epidermis and parenchyma cells of leaves and fruits, reducing the photosynthetic capacity of leaves, and changing the quality of fruits, causing a significant decrease in market value (Vacante 2010). The tetranychid mites are difficult to manage because of their high reproduction

How to cite: Gazoly, A.H., Afifi, A.M., Ali, F.S. & Ahmed, M.M. (2024) Life table parameters and predation rate of *Neoseiulus californicus* (Acari: Phytoseiidae) feeding on *Panonychus citri* and *Eutetranychus orientalis* (Acari: Tetranychidae). *Persian Journal of Acarology*, 13(2): 265–282.

capacity along with high propensity to develop pesticide resistance (Navia *et al*. 2010; Zein *et al*. 2022). In this regard, biological control is one of the most cost-effective and environmentally friendly pest control methods available to farmers (Cock *et al*. 2010).

Successful management of mites requires an integrated approach. Crop production has shifted in recent decades from yield to quality, safety, and sustainability. To that end, the concept of integrated pest management (IPM) strategies based on biocontrol agents has gained importance. Based on the high demand for safe food, the use of biocontrol agents is expected to be in high demand in the future (Fathipour and Maleknia 2016). Preventive management using predatory mites and other biological control agents can be quite effective when done correctly to reduce pest damage below the level of economic injury (Afifi *et al*. 2015; Chong 2022). Mite predators play an important role in mite pest control, especially the species belonging to the family Phytoseiidae (Moraes *et al*. 2004; Tixier 2018). Over the last 50 years, global interest in phytoseiid mites research has significantly expanded (McMurtry *et al*. 2015). Predatory mites of this group are considered important biological control agents and are currently essential elements in integrated pest management programs, having great relevance, especially in the management of phytophagous mites and a wide range of agricultural pests (Moraes *et al*. 2004; Ghazi *et al*. 2016; Çobanoğlu *et al*. 2018). There are about 30 species of predatory mites commercially produced as biological control agents such as *Phytoseiulus persimilis* Athias-Henriot, *Neoseiulus cucumeris* (Oudemans), *N. californicus* (McGregor) and *Amblyseius swirskii* Athias-Henriot that have been successfully applied in many countries (van Lenteren 2012; Liu *et al*. 2017).

The predatory mites, *N. californicus* was collected from lemon trees associated with *P. citri* (Moraes *et al*. 2004). This predator has a wide geographical range and seems to be tightly associated with *P. ulmi* (Taj and Jung 2012). As a Type II selective predator (McMurtry *et al*. 2013), in apple orchards, *N. californicus* has proven its ability to suppress several mites, notably *P. ulmi* (Koch) (Monetti and Fernandez 1995). Its adaptability as a predator has been noted not just because it preys on *Tetranychus urticae* Koch, but also other tetranychid mites, and insects, and can even subsist on pollen (Castagnoli and Liguori 1991; McMurtry and Croft 1997; Croft *et al*. 1998). Having adequate information about a biological control agent is essential before selecting a species for use in a pest management system.

A major factor affecting the dispersal of agricultural pests and their natural enemies is climate change and extreme weather events (Skendžić *et al*. 2021). Temperature is a crucial factor for invertebrate survival, reproduction, and development (Bale and Walters 2001). The performance of natural enemies is influenced by host plant characteristics and environmental conditions (Gulati 2014). Given that temperature stands as the primary environmental determinant influencing pest populations, the warming global climate is anticipated to prompt the enlargement of their geographical range, increased overwintering survival, reproduction, spread, and population dynamics as well as the relationships between pests, the environment, and natural enemies (Prakash *et al*. 2014; Skendžić *et al*. 2021). There is a strong demand to improve pest management practices as the pest problem is made worse by climate change. As a result, climate and pest population monitoring, as well as upgrading integrated pest control programs, can be helpful (Prakash *et al*. 2014; Skendžić *et al*. 2021). Therefore, this study aimed to evaluate the effect of two citrus mites, *P. citri* and *E. orientalis* on the biological parameters of the selected predator, *N. californicus,* and the effect of their density on its predation and reproduction rate under different temperatures. The information availability about predatory mites is necessarily being considered in pest management decisions.

MATERIALS AND METHODS

Mite colonies

The predator (*N. californicus*) and its prey (*P. citri* and *E. orientalis*) were all collected from citrus trees grown on the farm of the Faculty of Agriculture, Cairo University, and identified by Dr.

Reham Abo-Shnaf (Gazoly *et al*. 2023). *Panonychus citri* and *E. orientalis* were reared on the adaxial surface of sweet orange (*Citrus sinensis* (L.) Osbeck, Rutaceae) leaves separately as a food source for the predator during the trial period. Leaves were placed on water-saturated cotton pads in dishes, and a water-saturated, absorbent cotton strip was placed around the edge of the leaves to prevent the escaping of mites. Likewise, *N. californicus* was reared on the sweet orange leaves with each tested prey, it was fed on the movable stages of both *P. citri* and *E. orientalis* separately.

The colonies of prey and predator were maintained in an incubator (28 ± 1 °C, 55 ± 5% RH, and 16L:8D photoperiod) to maintain a continuous source of mites to be used during the experiments. The cotton bed was soaked with water daily. The colonies of prey and predator were left for at least three generations before starting the experiments. Leaves were replaced every seven days. A fine paintbrush was used to transfer the mites from old leaves to new ones. The movable stages of *P. citri* and *E. orientalis* were introduced separately to the predator colonies as food.

Biological parameters of N. californicus *the two citrus mites*

The influence of prey type for the selected citrus mites (*P. citri* and *E. orientalis*) on the biology and life table parameters of the predator mite, *N. californicus* was evaluated under laboratory conditions. Forty mated females roughly the same age as the predator (obtained from the colonies reared on each tested prey) were separately transferred on sweet orange leaves which were placed on wet cotton pads in Petri dishes and left for oviposition. All Petri dishes were maintained in an incubator at 28 ± 1 °C, 55 ± 5 % R.H.%, and 16L:8D photoperiod. After oviposition, the female and all eggs except one were removed from every replicate. Forty eggs as replications per each tested prey were used. The eggs were observed daily until the larvae hatched. The period of each developmental stage was observed till all larvae became adults. During the experiment, leaves of replications were replaced every seven days. Newly emerged adults were separated by sex, paired into couples, and transferred to new leaves for evaluating the pre-oviposition and oviposition periods, fecundity, and adult longevity. In leaves where males died before females, new males were added from the stock colony to the relevant experimental units. However, the data from these males were not used in the analysis. The dead mites and the eggs laid by female individuals in each disc were counted and removed daily until the end of the experiment. During the experiment, the predator was provided with its prey from each of the colonies of *P. citri* and *E. orientalis* (more than thirty individuals in immature stages) as a source of food. The data analysis was done when all mites were dead.

Predation and reproduction rate

Female deutonymphs are roughly the same age as the predator from the colonies reared on each tested prey were moved separately to a sweet orange leaf and were allowed to mate with a one-day-old male for 24 hours to calculate the predation and reproduction rate of *N. californicus*. After mating, the male was removed and the female remained confined on the detached leaf and was provided with either the immature stage (larva + nymph), or adult stage (male + female) of *P. citri* and *E. orientalis* separately as a source of food at the density of 10, 20, 40, 60, and 80. The number of prey consumed, and eggs laid per female of *N. californicus* was recorded every 24 hours for the first three days of the oviposition period. Consumed prey and eggs laid by each female of *N. californicus* were removed every observation period and the number of prey was brought back to the original count by adding new ones from mite colonies. The experiments were replicated seven times and were conducted for three consecutive days, then the averages of the three days were taken. These experiments were carried out under laboratory conditions in an incubator at 25 and 30 ± 1 °C, 55 ± 5% RH, and 16L:8D photoperiod.

Statistical analysis

The data of life-history for the predatory mite was analyzed according to the age-stage, two-sex life table method (Chi and Liu 1985), and the method of Chi (1988) using the TWO SEX-MS Chart program (Chi 2023). The age-stage specific fecundity (f_{xj}), the age-specific survival rate (l_x), and the age-specific fecundity (m_x) were calculated. In addition, the population parameters, comprise the intrinsic rate of increase (r), the finite rate of increase (λ), the net reproductive rate (R_0), the mean generation time (T), doubling time (DT), and gross reproductive rate (GRR) were estimated consequently. The bootstrap technique was used to calculate the mean and standard errors of the population parameters, while paired bootstrap test was used to compare the means of life table parameters of predator fed on movable stages of both *P. citri* and *E. orientalis* (Wei *et al*. 2020).

Data collected from predation and reproduction rate of *N. californicus* were checked for normality using the Shapiro–Wilk test (Shapiro and Wilk 1965) and were subjected to an analysis of variance (ANOVA) based on factorial design using general linear model (three factors); factor (T): temperature with two levels (25 and 30 °C); factor (P): diet type with four levels (*P. citri* immature stages, *P. citri* adult stages, *E. orientalis* immature stages and *E. orientalis* adult stages); factor (D): density of diet with five levels (10, 20, 40, 60 and 80 individual/leaf). Differences in means were compared using Tukey's Honestly Significant Difference test at the 1% probability level (Wickens and Keppel 2004) and t-test. The data were statistically analyzed using the new version of SPSS.

RESULTS

Effect of prey type on the developmental period and fecundity of N. californicus

The developmental stages of *N. californicus* successfully completed when fed on the two citrus mites, *E. orientalis* and *P. citri*. However, the developmental period of the predator, when fed on the mobile stages of *P. citri* significantly decreased compared to when fed on the mobile stages of *E. orientalis* (Table 1).

Table 1. Developmental periods, longevity and life span (Mean ± SE, days) of *Neoseiulus californicus* fed on *Eutetranychus orientalis* and *Panonychus citri* at 28 ± 1 °C.

Stage duration	Mean ± S.E.	
Female	***E. orientalis* (n = 24)**	***P. citri* (n = 27)**
Egg	1.29 ± 0.09 a	1.37 ± 0.09a
Larva	1.37 ± 0.10a	1.07 ± 0.05b
Protonymph	1.54 ± 0.10a	1.22 ± 0.08b
Deutonymph	1.50 ± 0.10a	1.30 ± 0.09a
Preadult	5.71 ± 0.13a	4.96 ± 0.13b
Adult longevity	28.46 ± 0.79a	24.22 ± 0.73b
Life span (Total longevity)	34.17 ± 0.81a	29.19 ± 0.74b
Male	***E. orientalis* (n = 11)**	***P. citri* (n = 9)**
Egg	1.36 ± 0.15a	1.33 ± 0.17a
Larva	1.36 ± 0.15a	1.00 ± 0.00b
Protonymph	1.45 ± 0.16a	1.11 ± 0.11a
Deutonymph	1.36 ± 0.15a	1.22 ± 0.14a
Preadult	5.54 ± 0.24a	4.67 ± 0.23b
Adult longevity	26.36 ± 1.13a	20.67 ± 1.02b
Life span (Total longevity)	31.91 ± 1.12a	25.33 ± 1.11b

Numbers in parentheses represent the number of replicates.
Means in each row with the different letters are significantly different (Paired bootstrap test, $P \leq 0.05$).

There were no significant differences in the egg incubation period, either female or male, when the predator fed on the mobile stages of the two citrus mites. The developmental period of larva and protonymph of *N. californicus* females was significantly lower when fed on mobile stages of *P. citri* than on mobile stages of *E. orientalis*.

Table 2. Mean durations (days) and fecundity (± SE) of *Neoseiulus californicus* females fed on *Eutetranychus orientalis* and *Panonychus citri* at 28 ± 1 °C.

Biological aspects	*E. orientalis*	*P. citri*
APOP (days)	1.58 ± 0.12a	1.37 ± 0.09a
TPOP (days)	7.29 ± 0.15a	6.33 ± 0.16b
Oviposition-period (days)	18.00 ± 1.22a	14.00 ± 1.02b
Total fecundity (eggs/female)	29.42 ± 1.28b	34.00 ± 1.88a

APOP Adult pre-oviposition period and TPOP total pre-oviposition period.
Means in each row with the different letters are significantly different (Paired bootstrap test, $P \leq 0.05$).

The pre-adult durations of *N. californicus* of both sexes were significantly different between the two-type of prey ($P < 0.05$). It was shorter of *N. californicus* female when fed on mobile stages of *P. citri* (4.96 days) than on mobile stages of *E. orientalis* (5.71 days) (Table 1). Likewise, the adult longevity and life span time of both sexes of *N. californicus* were significantly shorter when fed on mobile stages of *P. citri* (24.22, 29.19, and 20.67, 25.33 days, respectively) than fed on mobile stages of *E. orientalis* (28.48, 34.17, and 26.36, 31.91days, respectively).

The effects of feeding on two types of prey on adult pre-oviposition period (APOP), total pre-oviposition period (TPOP) and total fecundity (eggs/female) of *N. californicus* are displayed in Table 2. The variations in adult pre-oviposition period (APOP) were insignificant between the two types of prey ($P > 0.05$). The total pre-oviposition period (TPOP) of *N. californicus* was longer when fed on mobile stages of *E. orientalis* (7.29 days) than when feeding on the mobile stages of *P. citri* (6.33 days). The oviposition period was significantly longer when fed on the mobile stages of *E. orientalis* than on the mobile stages of another mite ($P < 0.05$). Despite this, the total fecundity of *N. californicus* females fed on mobile stages of *P. citri* was higher 34 eggs/female over an oviposition period of 14 days than 29.42 eggs/female over an oviposition period of 18 days for females fed on mobile stages of *E. orientalis*.

Effect of prey type on the population parameters of Neoseiulus californicus

The life table parameters of *N. californicus* were affected by the prey type (Table 3). The maximum values of the intrinsic rate of increase (r) and the finite rate of increase (λ) were 0.257 and 1.293, respectively for *N. californicus* fed on the mobile stages of *P. citri*, whereas the low values were 0.208 and 1.231 for *E. orientalis* mobile stages, respectively.

Table 3. Life table parameters (Mean ± SE) of *Neoseiulus californicus* fed on *Eutetranychus orientalis* and *Panonychus citri* at 28 ± 1 °C.

Life table parameters	*E. orientalis*	*P. citri*
Intrinsic rate of increase (r) (day^{-1})	0.208 ± 0.01b	0.257 ± 0.01a
Finite rate of increase (λ) (day^{-1})	1.231 ± 0.01b	1.293 ± 0.01a
Net reproductive rate (R_0) (offspring/individual)	17.65 ± 2.40a	22.95 ± 2.41a
Gross reproductive rate (*GRR*) (offspring/individual)	20.25 ± 2.48a	25.79 ± 2.84a
Mean generation time (T) (day)	13.79 ± 0.24a	12.18 ± 0.29b
Doubling time (*DT*) (day)	3.33 ± 0.19a	2.69 ± 0.12b

Means in each row with the different letters are significantly different (Paired bootstrap test, $P \leq 0.05$).

The net (R_0) and gross (*GRR*) reproductive rates were not affected by the prey type, they were (17.65 and 20.25 eggs/individual) when fed on *E. orientalis* mobile stages, and (22.95 and 25.79 eggs/individual) when the food was *P. citri* mobile stages, respectively.

The values of mean generation time (*T*) and doubling time (*DT*) obtained for *N. californicus* fed on *P. citri* were lower (12.18 and 2.69) than the values obtained for this phytoseiid fed on *E. orientalis* (13.79 and 3.33), respectively.

Age-specific survival rate (l_x) and fecundity curve

The age-specific survival rate of *N. californicus* individuals when fed on the mobile stages of *P. citri* and *E. orientalis* is illustrated (Fig. 1). The total lifetime of *N. californicus* when fed on the mobile stages of *E. orientalis* was 41 days, while it decreased to 35 days when fed on the mobile stages of *P. citri*.

The highest daily fecundity (peak of m_x) was 2 eggs/individual/day which occurred on day 11 of the life span of *N. californicus* when fed on the mobile stages of *P. citri*, while it decreased to 1.57 eggs/individual/day on day 13 of the life span when fed on the mobile stages of *E. orientalis*. The age-specific survival rate (l_x), age-specific fecundity (m_x), and age-stage-specific fecundity (f_{xj}) of *N. californicus* are given in Figure 1. The age-stage-specific fecundity (f_{xj}) is the number of eggs oviposited by individuals of age *x* and stage *j* per day. The highest peaks of f_{xj} for *N. californicus* occurred on the 11th day (2.67 eggs) when fed on the mobile stages of *P. citri*, while it occurred on the 13th day (2.29 eggs) when fed on the mobile stages of *E. orientalis*. The first oviposition occurred at the age of five days when fed on the mobile stages of *P. citri*, while it occurred at age of six days when fed on the mobile stages of the other mite. Likewise, the $l_x m_x$ of the female offspring showed the same trend when fed on the mobile stages of *P. citri* and *E. orientalis*.

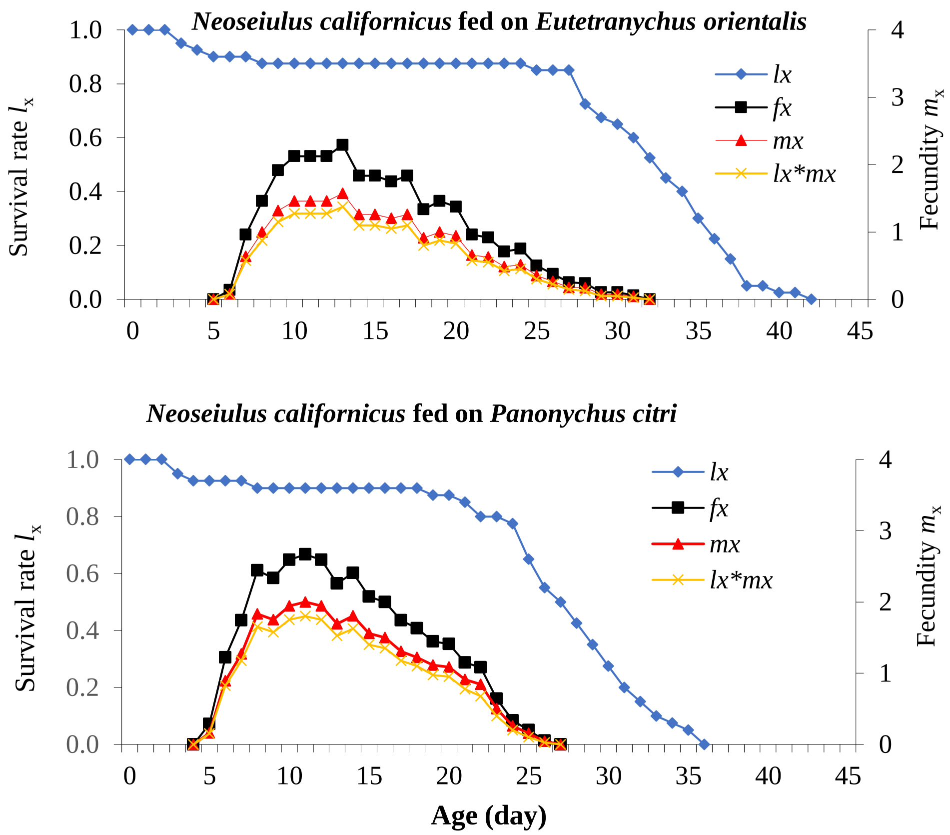

Figure 1. Age specific survival rate (l_x), fecundity (m_x), maternity ($l_x m_x$) and age-stage specific fecundity (f_{xj}) of offspring from *Neoseiulus californicus* females fed on movable stages of *Eutetranychus orientalis* and *Panonychus citri*.

Predation and reproduction rate

The effect of temperature with two levels (T), diet type with four levels (P) and density of diet/ leaf with five levels (D) alone, and the interaction between them on the predation and reproduction rate of *N. californicus* were evaluated (Table 4). The consumption rate of *N. californicus* for its prey was significantly ($p < 0.01$) affected by the temperature, it was (8.33 and 11.74 individuals) for 25 ± 1 °C and 30 ± 1 °C, respectively. Consequently, the daily number of eggs deposited by *N. californicus* gravid females significantly increased from (0.96 eggs/female /day) to (1.31 eggs/female /day) when the temperature increased from 25 ± 1 °C to 30 ± 1 °C (Fig. 2).

Table 4. Analysis the effect of the main factors temperature (T) with two levels, diet type (P) with four levels, density of diet (D) with five levels and the interaction between them on the predation and reproduction rate of *Neoseiulus californicus* females.

Source of variance	df	Daily predation rate of *N. californicus*			Daily reproduction rate of *N. californicus*		
		MS^y	*F*-value	*P*-value	MS^y	*F*-value	*P*-value
Temperature (T)	1	812.64	5079.70	0.000	8.71	202.61	0.000
Diet type (P)	3	1437.14	8983.21	0.000	11.12	258.86	0.000
Density of diet (D)	4	559.96	3500.19	0.000	2.87	66.74	0.000
T × P	3	54.52	340.76	0.000	0.79	18.45	0.004
T × D	4	26.06	162.92	0.000	0.10	2.35	0.06
P × D	12	79.04	494.03	0.000	0.177	4.12	0.000
T × P × D	12	7.40	46.25	0.000	0.059	1.37	0.18
Error	240	0.160			0.043		
Total	279						

Factorial design using general linear model; factor (T): temperature with two levels (25 and 30 °C); factor (P): diet type with four levels (*P. citri* immature stages, *P. citri* adult stages, *E. orientalis* immature stages and *E. orientalis* adult stages); factor (D): density of diet with five levels (10,20,40,60 and 80 individual/leaf).
^{y}MS: Mean square. ns = non-significant ($p > 0.01$).

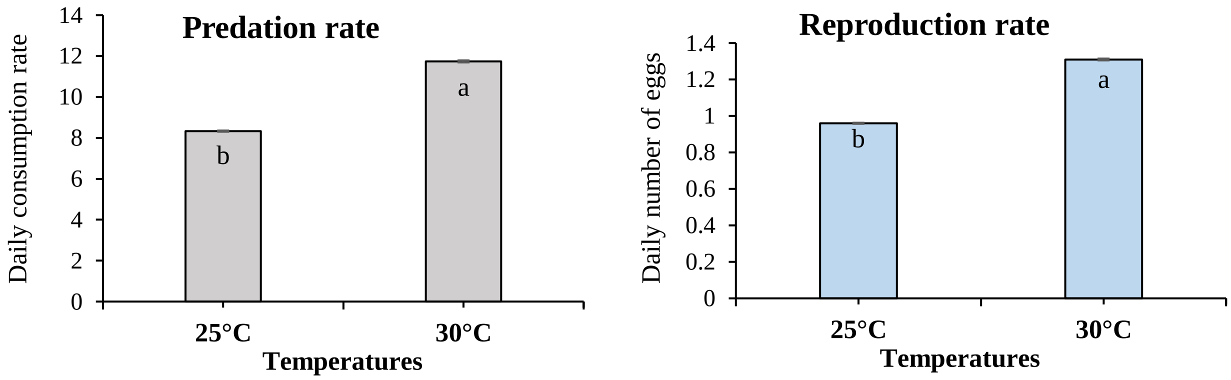

Figure 2. Effect of temperature (T) with two levels on the daily predation and reproduction rate of *Neoseiulus californicus* female.

The highest consumption rate was 15.20 individuals with immature stages (larvae + nymphs) of *P. citri*, followed by 12.43 individuals with *E. orientalis* immature stages. whereas the lowest consumption rate found (5.73 individuals) with *E. orientalis* adult stages (females + males). Thus, the oviposition rate was significantly higher when preyed on immature stages of *P. citri* and *E. orientalis* (1.55 and 1.37 eggs/female/day) than on adult stages (0.92 and 0.69 eggs/female/day), respectively, for both preys (Fig. 3).

Also, the density 40 individuals or more of diet type had a significant ($p < 0.01$) effect on increasing the predation and reproduction rate of *N. californicus* compared to the diet densities of less than 20 individuals (Fig. 4). Also, significant differences were observed between the consumption rate of *P. citri* and *E. orientalis*. It was highest on *P. citri* immatures, while the lowest was recorded when fed on adult stages of *E. orientalis*. This indicates the predator's preference for *P. citri* than *E. orientalis* (Fig. 3).

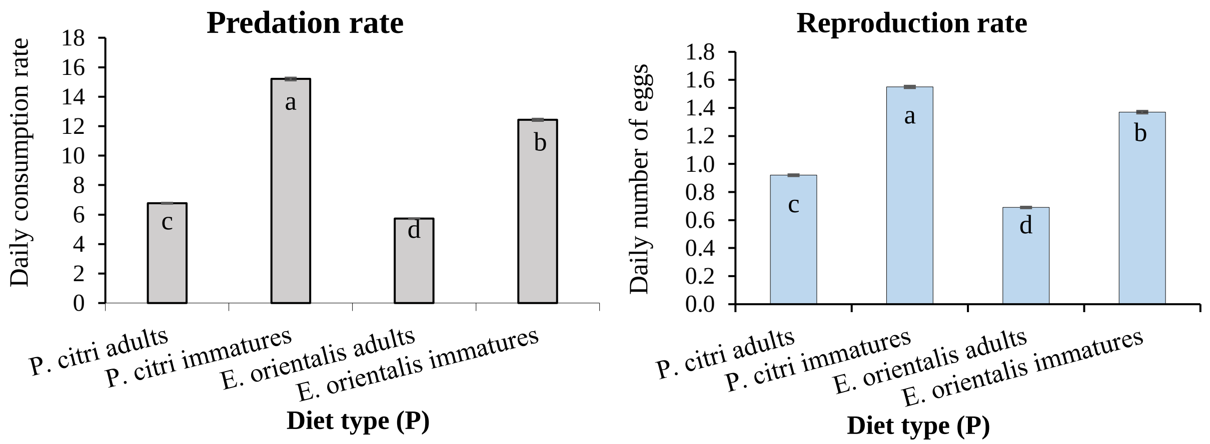

Figure 3. Effect of diet type (P) with four levels on the daily predation and reproduction rate of *Neoseiulus californicus* female.

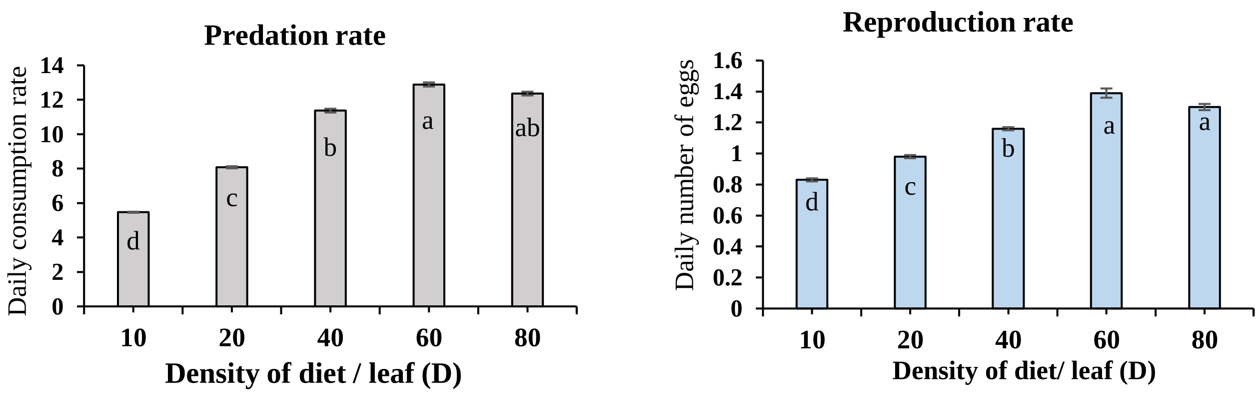

Figure 4. Effect of density of diet/leaf with five levels (D) on the daily predation and reproduction rate of *Neoseiulus californicus* female.

The bilateral interactions between the factors mentioned above, (T × P), (T × D) and (P × D) significantly affected ($p < 0.01$) the predation rate of *N. californicus* (Figs. 5–7). With interactions between (T × P), the highest consumption rate was at 30 ± 1 °C with immature stages of *P. citri* (17.79 individuals) compared to the other temperature and diet type. Likewise (T × D), the consumption rate peaked at 30 ± 1 °C and the density of diet of 60 individuals. With increasing density of diet, most immature stages were consumed in comparison to adult stages. In other words, in the case of (P × D), the highest consumption rate was on immature stages of *P. citri* (21.22 individuals) when a density reached 60 individuals, while the lowest consumption rate was on adult stages of *P. citri* and *E. orientalis* (4.48 and 4.14 individuals) when density was 10 individuals, respectively (Fig. 7).

An increase in density of diet led to a slight increase in the number of eggs laid by females when feeding on immature or adult stages of *P. citri* and *E. orientalis*. Thus, the lowest oviposition rate of *N. californicus* was observed when the density of diet was 10 individuals/leaf, while the highest observed when the density of diet reached 60 individuals/leaf (Fig. 4). The result from the interaction between temperature and diet type (T × P) showed that the highest female reproduction rate was 1.74 and 1.69 eggs/female/day when preying on *P. citri* and *E. orientalis* immature stages at 30 °C, respectively; while this rate decreased when the adult stages of *E. orientalis* were consumed at 25 °C (Fig. 5).

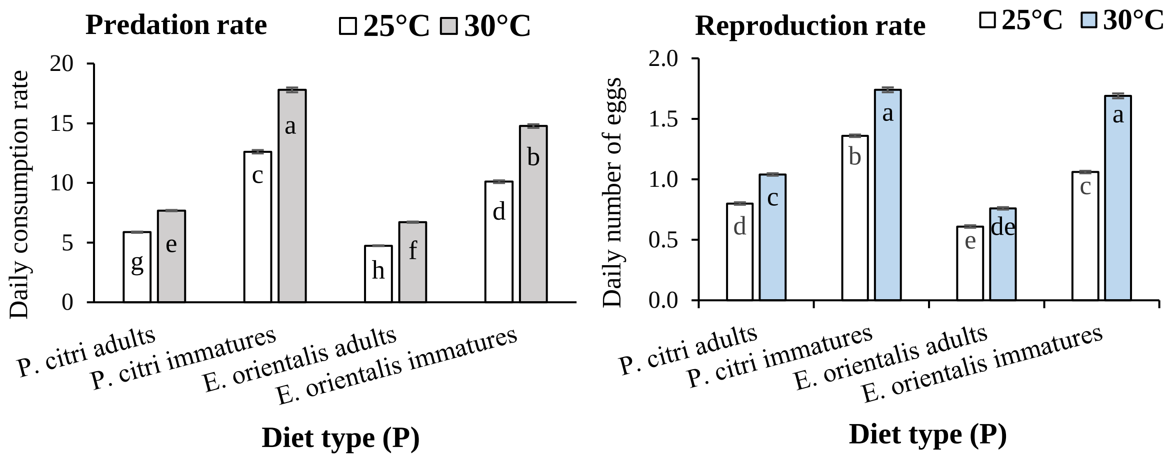

Figure 5. Effect of the interactions between temperature with two levels (T) and diet type with four levels (P) on the daily predation and reproduction rate of *Neoseiulus californicus* female.

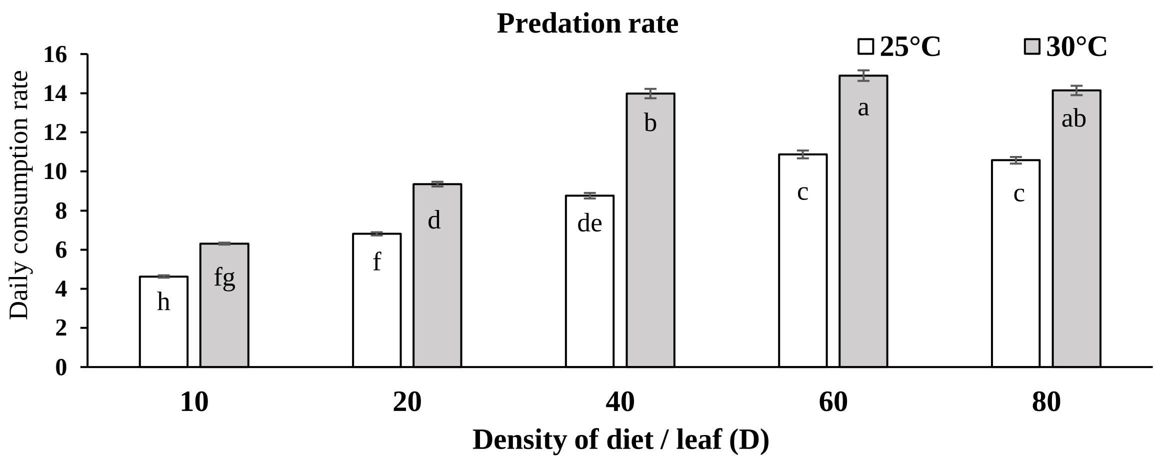

Figure 6. Effect of the interactions between temperature with two levels (T) and density of diet with five levels (D) on the daily consumption rate of *Neoseiulus californicus* female.

However, the triple interaction among the three factors (T × P × D) showed a significant effect on the prey consumption rate (Tables 4, 5). The highest consumption rate by a female predator occurred with immature stages of *P. citri* (24.48 individuals) at a density of 60 individuals per leaf at 30 ± 1°C, while this rate decreased when the adult stages of both prey at a density of 10 individuals per leaf at 25 ± 1 °C were consumed.

As a result of the previously mentioned effect of the three factors alone or through their interaction on increasing the predation rate of the female predator, this also had an impact on the daily rate of eggs deposited by *N. californicus* gravid females. The daily number of deposited eggs was significantly ($p < 0.01$) affected by temperature (T), diet type (P), and density of diet (D) alone as well as the two interactions between (T × P) and (P × D) while this effect was not significant ($p >$

0.01) with the other two and three-way interactions between the three factors (T × D) and (T × P × D) (Table 4).

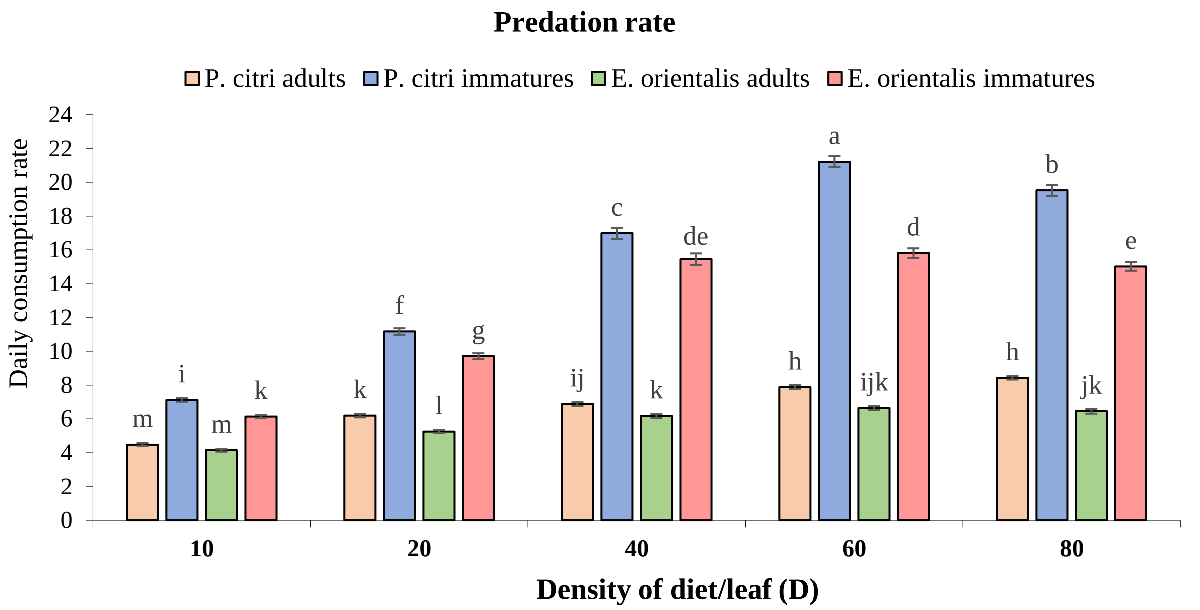

Figure 7. Effect of the interactions between diet type with four levels (P) and density of diet with five levels (D) on the daily consumption rate of *Neoseiulus californicus* female.

Table 5. Effect of the triple interaction between temperature with two levels (T), diet type with four levels (P) and density of diet with five levels (D) on the daily consumption rate of *Neoseiulus californicus* gravid females.

Temp. (T)	Density of diet (D)	Diet type with four levels (P)			
		***P. citri* adults**	***P. citri* immatures**	***E. orientalis* adults**	***E. orientalis* immatures**
25°C	10	3.43 ± 0.09 ^{S}	6.33 ± 0.21 ^{NO}	3.38 ± 0.07 ^{S}	5.38 ± 0.19 ^{PQR}
	20	5.38 ± 0.18 ^{PQR}	9.29 ± 0.19 ^{I}	4.62 ± 0.17 ^{R}	7.95 ± 0.25 ^{K}
	40	5.71 ± 0.10 ^{OPQ}	13.33 ± 0.29 ^{G}	4.95 ± 0.12 ^{QR}	11.05 ± 0.12 ^{H}
	60	6.95 ± 0.20 ^{MN}	17.95 ± 0.33 ^{D}	5.48 ± 0.18 ^{PQ}	13.10 ± 0.46 ^{G}
	80	7.86 ± 0.21 ^{K}	16.14 ± 0.42 ^{F}	5.29 ± 0.16 ^{PQR}	13.00 ± 0.42 ^{G}
30°C	10	5.52 ± 0.08 ^{OPQ}	7.90 ± 0.13 ^{K}	4.90 ± 0.14 ^{QR}	6.90 ± 0.10 ^{MN}
	20	7.00 ± 0.17 ^{LMN}	13.05 ± 0.31^{G}	5.86 ± 0.16 ^{OP}	11.48 ± 0.17 ^{H}
	40	8.05 ± 0.21 ^{JK}	20.62 ± 0.45 ^{C}	7.38 ± 0.23 ^{KLM}	19.86 ± 0.25 ^{C}
	60	8.81 ± 0.18 ^{IJ}	24.48 ± 0.58 ^{A}	7.81 ± 0.17 ^{KL}	18.52 ± 0.35 ^{D}
	80	9.00 ± 0.17 ^{I}	22.90 ± 0.50 ^{B}	7.62 ± 0.26 ^{KLM}	17.05 ± 0.40 ^{E}

The means followed by different letters in the table are significantly different ($p < 0.01$, Tukey's HSD test after factorial design with general linear model. The values are presented as mean ± SE.

DISCUSSION

In this study, we assessed various aspects of the biological parameters and life history features of *N. californicus* under nutritional conditions. Both sexes of *N. californicus* completed their developmental stages successfully on the studied citrus mites. This species has been included under the Type-II category among the phytoseiid predators based on its exclusive preference for spider mites (McMurtry *et al*. 2013). Type II predators have a selective feeding pattern with a special preference of tetranychid mites, and their reproduction on other food items is relatively weak (McMurtry and

Croft 1997; Croft *et al*. 1998).

Our findings shed light on the effects of the prey type on the adult longevity and population growth of this predatory mite. Feeding the predator on the mobile stages of *P. citri* caused a significant reduction in the pre-adult and adult longevity period (4.96 and 24.22 days), respectively; this was accompanied by a significant increase in total fertility. While they were (5.71 and 28.46 days, respectively) when fed on *E. orientalis* mobile stages, despite this, a decrease in total fertility occurred. This may be due to the predator's preference to feed on the mobile stages of *P. citri* (Fig. 3). Mercado *et al.* (2020) confirmed similar findings, stating that the timing of postembryonic development was significantly different between *Tetranychus desertorum* Banks and *P. citri*, the *N. californicus* pre-adult and adult longevity durations were 6.35 and 22.53 days, respectively, when fed on *T. desertorum*, while they were decreased to 5.56 and 21.06 days, respectively when fed with *P. citri*.

Fecundity is a major factor influencing the size of arthropod populations (Loughner *et al*. 2008). In this study, the fecundity of the predator *N. californicus* females was significantly different between the two tested prey (*E. orientalis* and *P. citri*); it was higher (34 eggs/female) over an oviposition period of 14 days when fed on *P. citri* than fed on *E. orientalis* was (29.42 eggs/female) over an oviposition period of 18 days. Similarly, Mercado *et al*. (2020) reported that the fecundity (total eggs/female) of *N. californicus* fed with *T. desertorum* was 44 over an oviposition period of 17.17 days, while on *P. citri* was 37.55 over an oviposition period of 14.84 days. On the contrary, Ragusa *et al*. (2000) discovered no significant variations in total eggs per female when *Cydnodromus picanus* Ragusa fed on *T. urticae* and *P. citri*. These differences may be due to different species of phytoseiids or to the environmental conditions.

Life table parameters with data on the *r* are good indices of population growth under a given set of conditions (Satpute *et al*. 2005; Win *et al*. 2011). In this work, the values of the intrinsic rate of increase(*r*) and the finite rate of increase (λ) parameters were high, but the generation time (*T*) and doubling time (*DT*) were short when the predator fed on *P. citri* mobile stages in comparison with mobile stages of *E. orientalis*.

The high values of *r* and *λ* registered for *N. californicus* fed on *P. citri* mobile stages under experimental conditions are indicators of control potential that this phytoseiid presented as a predator over the citrus red mite, *P. citri*. The good performance of *N. californicus* may be due to *P. citri* being a more nutritious prey for this phytoseiid than *E. orientalis*. Confirming similar findings, Mercado *et al.* (2020) stated that the parameters intrinsic rate of increase (*r*) and finite rate of increase (*λ*) of *N. californicus* when fed on *T. desertorum* and *P. citri* were affected by the prey type; they were (0.269 and 0.307) and (1.309 and1.359), respectively. In this regard, the intrinsic rate of increase indicates the multiplication capacity from one unit of time to the next (Rabinovich 1980), and indicates the potential control of a natural enemy, in time, for a given pest (Persad and Khan 2002; Kontodimas *et al*. 2007).

In this research, the values of R_0, *r*, *λ*, and *T* registered for *N. californicus* fed on *P. citri* mobile stages were 22.95, 0.257, 1.293, and 12.18, respectively, but these values were lower than those reported by Mercado *et al.* (2020) with the same predator and prey, who found that these values were 27.94, 0.308, 1.361, and 10.74, respectively. These variations may be due to difference in the experimental conditions of the tests.

The results obtained from *λ* and *r* can be considered positive, and it can be proposed that *N. californicus* could be an efficient biocontrol agent of red spiders of the family Tetranychidae. It has been shown useful in the past to use life table statistics, such as those presented here, to assess the potential of a biological control agent with local seasonal temperatures (Bernal and González 1997).

In this study, the m_x and f_x values of *N. californicus* were higher when fed on the mobile stages of *P. citri* than when fed on the mobile stages of *E. orientalis*. Similar results were obtained by Fahim and El-Saiedy (2021) when this predator fed on *T. urticae* had reared on 029 and Wanter star strawberry cultivars.

Because of the gap in the availability of information about the interaction of environmental factors on both predators and their prey, especially considering current climate changes, this study was conducted. Before choosing a species to use in a pest management system, it is crucial to have enough knowledge about biological control agents. Invertebrate development, reproduction, and survival all depend on temperature (Bale and Walters 2001). The food type, availability, and climatic conditions like temperature might affect an insect's growth, longevity, and reproduction (Ellers-Kirk and Fleischer 2006).

In this study, we studied the effects of three factors (temperature with two levels (T), diet type with four levels (P) and density of diet with five levels (D)) on predation and reproduction rate of *N. californicus* alone, as well as the interactions between them, using factorial design with general linear model. Wickens and Keppel (2004) stated that whenever the interaction among factors was statistically significant, focusing on the interaction effects is more important than the main effects.

From the results, it became clear to us that the rate of predation increased with raising the temperature and the predator preference to feed on the immature stages of *P. citri* when the prey was available at a high density. This led to an increase in the daily eggs deposited by *N. californicus* female, which explains the affected ability of predation and the total fertility by the type and density of the diet. The consumption rate and daily number of eggs deposited by *N. californicus* gravid females significantly increased when temperature increased (Fig. 2). According to Taj and Jung (2012), the mean daily egg production of *N. californicus* when fed on *Panonychus ulmi* was strongly influenced by temperature and was highest (3.31 eggs/female/day) at 30 °C and lowest (1.01 eggs/female/day) at 15 °C; this result supports our results.

The immatures and adult stages of both prey species, *P. citri* and *E. orientalis* were consumed by *N. californicus* female. As the density of diet increased, predation likewise increased. The same trend was observed with the same species fed on *T. urticae* (mentioned as *T. cinnabarinus*) (Friese and Gilstrap 1982), *P. ulmi* (Jolly 2000), *T. urticae* (Canlas *et al*. 2006; Marafeli *et al*. 2011; Farazmand *et al*. 2012; Song *et al*. 2016; Jahanbazi *et al*. 2023), *T. desertorum* and *P. citri* (Mercado *et al*. 2020), *Tenuipalpus heveae* Baker (Silva *et al.* 2020).

Furthermore, the present results showed that *N. californicus* would prey more on immature stages than adult stages of *P. citri* or *E. orientalis* in all situations when there was ample prey. Similar findings were made by Forero *et al*. (2008) who noted that *N. californicus* consumed more larvae and nymphs, demonstrating the predator's predilection for the mites' juvenile forms. Also, similar results were shown with the same predator fed on *T. urticae* (Canlas *et al*. 2006; Jahanbazi *et al*. 2023). As with their functional responses to *T. urticae* and *T. kanzawai* Kishida, *N. californicus* preferred to feed on larvae, followed by nymphs, and then eggs (Song *et al*. 2016). Additionally, Silva *et al*. (2020) noted that *N. californicus* adults consumed *T. heveae*, eating more nymphs and larvae than other life stages. Additionally, Xiao and Fadamiro (2010) demonstrated that when fed simultaneously, the predators *P. persimilis*, *Galendromus* (*Galendromus*) *occidentalis* (Nesbitt) and *N. californicus* favored the nymphal stage of *P. citri* rather than the eggs. On the contrary, Farazmand *et al*. (2012) found that *N. californicus* preferred the eggs of *T. urticae* than the nymphal stage. This may be due to the difference in the prey type. In terms of both nutritional value and handling time, spider mite larvae may be more advantageous than eggs for generalist phytoseiid mites, according to Blackwood *et al*. (2001). Blommers *et al*. (1977) suggested that when introduced to predators, spider mite adult stages (male or female) would form a less desirable type of food.

In the current work, comparing the mean daily consumption of *N. californicus* females at different densities of *P. citri* and *E. orientalis* showed that more *P. citri* immatures were consumed. Song *et al*. (2016) showed *N. californicus* consumed more *Tetranychus* immatures at the high density of each prey stage.

An increase in the density of immature stages and adult stages of prey eventually resulted in a higher predation rate, especially at high temperatures.

The oviposition rate of *N. californicus* female increased when density of diet increased. This is true with the same predator studied by Canlas *et al*. (2006) and Marafeli *et al*. (2011). However, if provided exclusively with adult male or female prey, oviposition of *N. californicus* remained low, even though a comparable number of this prey stage was consumed. This might be a result of the size and nutritional value of juvenile spider mites (Blommers 1976; Blommers *et al*. 1977). Several variables, including strains with varied feeding histories and environmental temperature (Castagnoli *et al*. 1999; Gotoh *et al*. 2004), can affect how *N. californicus* functions.

Finally, the current analysis discovered that this predator possessed several of the characteristics listed by McMurtry (1982) for a predatory mite to be a successful biological control agent. Therefore, the *N. californicus* is a crucial component of biological control schemes due to its quick generation time, intermediate fecundity, equivalent r and R_0, in addition to adapt to environmental conditions.

CONCLUSION

The predation activity of *N. californicus* should have been better studied to use it as a biological control agent. The high fecundity, short generation time, and moderate r of population of *N. californicus* indicate significant potential as an effective biological control agent for *P. citri* in citrus orchards. In addition, the present study showed that the performance of *N. californicus* was greatly affected by temperature (T), diet type (P), and density of diet (D) and as well as the interactions between them. The predation rate of *N. californicus* and the daily number of eggs deposited by females significantly increased when fed on immature stages of prey with a density of 40 individuals or more at 30 °C, preferring *P. citri* to *E. orientalis*. *Neoseiulus californicus* seems better adapted to high temperatures and may be a good candidate for biological control of the two citrus mites, *P. citri* and *E. orientalis* attacking citrus orchards.

ACKNOWLEDGEMENTS

Sincere thanks to Dr. Hashim Mohamad Abdel Lattif and Dr. Hatem A. Sharaf El-Din, Faculty of Agriculture, Cairo University, for their help in the statistical analysis of the results.

REFERENCES

Afifi, A.M., Ali, F.S., El-Saiedy, E.M.A. & Ahmed, M.M. (2015) Compatibility and integration of some control methods for controlling *Tetranychus urticae* Koch infesting tomato plants in Egypt. *Egyptian Journal of Biological Pest Control*, 25(1): 75–82.

Bale, J.S. & Walters, K.F.A. (2001) Overwintering biology as a guide to the establishment potential of non-native arthropods in the UK. *In*: Atkinson, D., Thorndyke, M. (Eds.), *Animal developmental ecology*. BIOS Scientific Publishers, Oxford, pp. 343–354.

Bernal, J. & González, D. (1997) Reproduction of *Diaeretiella rapae* on Russian wheat aphid hosts at different temperatures. *Entomologia Experimentalis et Applicata*, 82: 159–166.

Blackwood, J.S., Schausberger, P. & Croft, B.A. (2001) Prey stage preference in generalist and specialist phytoseiid mites (Acari: Phytoseiidae) when offered *Tetranychus urticae* (Acari: Tetranychidae) eggs and larvae. *Environmental Entomology*, 30(6): 1104–1111.

Blommers, L. (1976) Capacities for increase and predation in *Amblyseius bibens* (Acarina: Phytoseiidae). *Zeitschrift fuer Angewand te Entomologie*, 81: 225–244.

Blommers, L., Lobbes, P., Vink, P. & Wegdam, F. (1977) Studies on the response of *Amblyseius bibens* (Acarina: Phytoseiidae) to conditions of prey scarcity. *Entomophaga*, 22(3): 247–258.

Canlas, L.J., Amano, H., Ochiai, N. & Takeda, M. (2006) Biology and predation of the Japanese strain of *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae). *Systematic and Applied Acarology*, 11(2):141–157. DOI: 10.11158/saa.11.2.2

Castagnoli, M. & Liguori, M. (1991) Laboratory observations on duration of copulation and egg production of three phytoseiid species fed on pollen. *In*: Schuster, R. & Murphy, P.W. (Eds.), *The Acari: Reproduction, Development & Life history*. Chapman & Hall, pp. 231–239.

Castagnoli, M., Liguori, M. & Simoni, S. (1999) Effect of two different host plants on biological features of *Neoseiulus californicus* (McGregor). *International Journal of Acarology*, 25(2): 145–150.

Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rates among individuals. *Environmental Entomology*, 17(1): 26–34. DOI: 10.1093/ee/17.1.26

Chi, H. (2023) Computer program for the age-stage, two-sex life table analysis. National Chung Hsing University, Taichung. Available from: http://140.120.197.173/Ecology/prod02.htm

Chi, H. & Liu, H. (1985) Two new methods for the study of insect population ecology. *Bulletin of the Institute of Zoology, Academia Sinica*, 24(2): 225–240.

Chong, J.H. (2022) *Phytophagous mites and their management on ornamental plants*. Clemson (SC): Clemson Cooperative Extension, Land-Grant Press by Clemson Extension, LGP 1154, 9 pp.

Çobanoğlu, S., Faraji, F. & Cilbircioğlu, C. (2018) Re-descriptions of *Amblyseius decolor* (Westerboer) and *Proprioseiopsis sororculus* (Wainstein) (Acari: Phytoseiidae) based on the specimens collected in Turkey and France. *Acarologia*, 58(4): 825–836.

Cock, M.J.W., van Lenteren, J.C., Brodeur, J., Barratt, B.I.P., Bigler, F., Bolckmans, K., Consoli, F.I., Haas, F., Mason, P.G. & Parra, J.R.P. (2010) Do new access and benefit sharing procedures under the convention on biological diversity threaten the future of biological control? *BioControl*, 55: 199–218. DOI: 10.1007/s10526-009-9234-9

Croft, B.A., Monetti, L.N. & Pratt, P.D. (1998) Comparative life histories and predation types: are *N. californicus* & *N. fallacis* (Acari: Phytoseiidae) similar type II selective predators of spider mites? *Environmental Entomology*, 27(3): 531–538.

Ellers-Kirk, C. & Fleischer, S.J. (2006) Development and life table of *Acalymma vittatum* (Coloptera: Chrysomelidae), a vector of *Erwinia tracheiphila* in cucurbits. *Environmental Entomology*, 35 (4): 875–880. DOI: 10.1603/0046-225X-35.4.875

Fahim, S.F. & El-Saiedy, E.M. (2021) Life table parameters of *Amblyseius swirskii* and *Neoseiulus californicus* (Acari: Phytoseiidae) reared on two strawberry cultivars. *International Journal of Acarology*, 47(7): 568–574. DOI: 10.1080/01647954.2021.1976835

Farazmand, A., Fathipour, Y. & Kamali, K. (2012) Functional response and mutual interference of *Neoseiulus californicus* and *Typhlodromus bagdasarjani* (Acari: Phytoseiidae) on *Tetranychus urticae* (Acari: Tetranychidae). *International Journal of Acarology*, 38(5): 369–376. DOI: 10.1080/01647954.2012.655310

Fathipour, Y. & Maleknia, B. (2016) Mite predators. *In*: Omkar (Ed.), *Ecofriendly Pest Management for Food Security*. Elsevier, San Diego, USA, pp. 329–366.

Forero, G., Rodrigues, M., Cantor, F., Rodrigues, D. & Cure, J.R. (2008) Critérios para el manejo de *Tetranychus urticae* Koch (Acari: Tetranychidae) con el ácaro depredador *Amblyseius* (*Neoseiulus*) sp. (Acari: Phytoseiidae) en cultivos de rosas. *Agronomía Colombiana*, 26(1): 78–86.

Friese, D.D. & Gilstrap, F.E. (1982) Influence of prey availability on reproduction and prey consumption of *Phytoseiulus persimilis*, *Amblyseius californicus* and *Metaseiulus occidentalis* (Acari: Phytoseiidae). *International Journal of Acarology*, 8(2): 85–89. DOI: 10.1080/01647958208683283

Gazoly, A.H., Abo-Shnaf, R. & Ali, F.S. (2023) Distribution of mites inhabiting agricultural importance, with emphasis on predators role in pest control. *Egyptian Academic Journal of Biological Sciences*, 16(4): 99–116. DOI: 10.21608/EAJBSA.2023.329416

Ghazi, N.A., Osakabe, M., Negm, M.W., Schausberger, P., Gotoh, T. & Amano, H. (2016) Phytoseiid mites under environmental stress. *Biological Control*, 96: 120–134. DOI: 10.1016/j.biocontrol.2016.02.017

Gotoh, T., Mitsuyoshi, N. & Yamaguchi, K. (2004) Prey consumption and functional response of three acarophagous species to eggs of the two-spotted spider mite in the laboratory. *Applied Entomology and Zoology*, 39(1): 97–105.

Gulati, R. (2014) Eco-friendly management of phytophagous mites. *In*: Abrol, D.P. (Ed.), *Integrated pest management*. Academic Press, pp. 461–491. DOI: 10.1016/B978-0-12-398529-3.00023-3

Jahanbazi, M., Sedaratian-Jahromi, A. & Ghane-Jahromi, M. (2023) Comparative study of predation, preference and switching behaviors of two predatory mite *Neoseiulus californicus* and *Amblyseius swirskii* (Acari: Phytoseiidae). *International Journal of Pest Management*, 69(4): 366–376. DOI: 10.1080/09670874.2021.1944699

Jeppson, L.R., Keifer, H.H. & Baker, E.W. (1975) *Mites injurious to economic plants*. University of California Press, Berkely, 614 pp.

Jolly, R.L. (2000) The predatory potential of *Neoseiulus californicus*: its potential as a biological control agent for the fruit tree spider mite, *Panonychus ulmi*. *The BCPC Conference, Brighton, Pest and Diseases*, Vol. 1, pp. 487–490.

Kontodimas, D.C., Milonas, P.G., Stathas, G.J., Economou, L.P. & Kavallieratos, N.G. (2007) Life table parameters of the pseudococcid predators *Nephus includens* and *Nephus bisignatus* (Coleoptera: Coccinellidae). *European Journal of Entomology*, 104: 407–415. DOI: 10.14411/eje.2007.060

Liu, S., Lv, J., Wang, E. & Xu, X. (2017) Life-style classification of some Phytoseiidae (Acari: Mesostigmata) species based on gnathosoma morphometrics. *Systematic and Applied Acarology*, 22(5): 629–639. DOI: 10.11158/saa.22.5.3

Loughner, R., Goldman, K., Loeb, G. & Nyrop, J. (2008) Influence of leaf trichomes on predatory mite (*Typhlodromus pyri*) abundance in grape varieties. *Experimental and Applied Acarology*, 45: 111–122. DOI: 10.1007/s10493-008-9183-5

Marafeli, Pd.P., Reis, P.R., da Silveira, E.C., Toledo, M.Ad. & Souza-Pimentel, G.C. (2011) *Neoseiulus californicus* (McGregor, 1954) preying in different life stages of *Tetranychus urticae* Koch, 1836 (Acari: Phytoseiidae, Tetranychidae). *Acarologia*, 51(4): 499–506.

McMurtry, J.A. (1982) The use of phytoseiids for biological control: progress and future prospects. In: Hoy, M.A. (Ed.), *Recent advances in knowledge of the Phytoseiidae.* Agricultural Sciences Publications, Berkeley, pp. 23–48.

McMurtry, J.A. & Croft, B.A. (1997) Life-styles of phytoseiid mites and their roles in biological control. *Annual Review of Entomology*, 42(1): 291–321. DOI: 10.1146/annurev.ento.42.1.291

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. DOI: 10.11158/saa.18.4.1

McMurtry, J.A., Sourassou, N.F. & Demite, P.R. (2015) The Phytoseiidae (Acari: Mesostigmata) as biological control agents. *In*: Carrillo, D., Moraes, G.J. & Peña, J.E. (Eds.), *Prospects for biological control of plant feeding mites and other harmful organisms*. Springer, Cham., Vol. 19, pp. 133–149.

Mercado, V.T., Loyola, E.R. & Soto, T.R. (2020) Post-embryonic development and life table parameters of *Neoseiulus californicus* on *Tetranychus desertorum* and *Panonychus citri* (Acari: Phytoseiidae, Tetranychidae) under laboratory conditions. *Gayana*, 84(1): 54–63. DOI: 10.4067/S0717-65382020000100054

Monetti, L.N. & Fernandez, N.A. (1995) Seasonal population dynamics of the European red mite (*Panonychus ulmi*) and its predator *N. californicus* in a sprayed apple orchard in Argentina (Acari: Tetranychidae, Phytoseiidae). *Acarologia*, 36(4): 325–331.

Moraes, G.J. de, McMurtry, J.A., Denmark, H.A. & Campos, C.B. (2004) A revised catalog of the mite family Phytoseiidae. *Zootaxa*, 434: 1–494.

Navia, D., Ochoa, R., Welbourn, C. & Ferragut, F. (2010) Adventive eriophyoid mites: a global review of their impact, pathways, prevention and challenges. *Experimental and Applied Acarology*, 51(1–3): 225–255. DOI: 10.1007/s10493-009-9327-2

Persad, A. & Khan, A. (2002) Comparison of life table parameters for *Maconellicoccus hirsutus*, *Anagyrus kamali*, *Cryptolaemus montrouzieri* and *Scymnus coccivora*. *Biocontrol*, 47: 137–149.

Prakash, A., Rao, J., Mukherjee, A.K., Berliner, J., Pokhare, S.S., Adak, T., Munda, S. & Shashank, P.R. (2014) *Climate change: Impact on crop pests*. Applied Zoologists Research Association (AZRA), Central Rice Research Institute, Odisha, India, 205 pp.

Rabinovich, J.E. (1980) *Introducción a la ecología de poblaciónes animals*. 2nd edition. Compañía Editorial Continental, Mexico, 313 pp.

Ragusa, S., Vargas, R., Tsolakis, H. & Ashbach, R. (2000) Laboratory studies on the influence of various food subtances on some biological and life-table parameters of *Cydnodromus picanus* Ragusa (Parasitiformes, Phytoseiidae) associated with citrus trees in the Chilean desert. *Phytophaga*, 10: 11–23.

Satpute, N.S., Deshmukh, S.D., Rao, N.G.V. & Nimbalkar, S.A. (2005) Life tables and the intrinsic rate of increase of *Earias vittela* (Lepidoptera: Noctuidae) reared on different hosts. *International Journal of Topical Insect Science*, 25(2): 73–79. DOI: 10.1079/IJT200561

Shapiro, S.S. & Wilk, M.B. (1965) An analysis of variance test for normality (complete samples). *Biometrika*, 52(3–4): 591–611. DOI: 10.1007/s10493-007-9081-2

Silva, da E.M., Toscano, L.C., Alves-Eigenheer, M., Maruyama, W.I. & Silva, da A.G. (2020) *Neoseiulus californicus* preying on *Tenuipalpus heveae. Pesquisa Agropecuária Tropical*, 50: e64329. DOI: 10.1590/1983-40632020v5064329

Skendžić, S., Zovko, M., Živković, I.P., Lešić, V. & Lemić, D. (2021) The impact of climate change on agricultural insect pests. *Insects*, 12(5): 440. DOI: 10.3390/insects12050440

Song, Z.W., Zheng, Y., Zhang, B.X. & Li, D.S. (2016) Prey consumption and functional response of *Neoseiulus californicus* and *Neoseiulus longispinosus* (Acari: Phytoseiidae) on *Tetranychus urticae* and *Tetranychus kanzawai* (Acari: Tetranychidae). *Systematic and Applied Acarology*, 21(7): 936–946. DOI: 10.11158/saa.21.7.7

Taj, H.F. & Jung, C. (2012) Effect of temperature on the life-history traits of *Neoseiulus californicus* (Acari: Phytoseiidae) fed on *Panonychus ulmi*. *Experimental & Applied Acarology*, 56: 247–260. DOI: 10.1007/s10493-012-9516-2

Tixier, M.-S. (2018) Predatory mites (Acari: Phytoseiidae) in agro-ecosystems and conservation biological control: A review and explorative approach for forecasting plant-predatory mite interactions and mite dispersal. *Frontiers in Ecology and Evolution*, 6: 192. DOI: 10.3389/fevo.2018.00192

Vacante V. (2010) *Citrus mites: Identification, bionomy and control*. CABI Publishing, Wallinford, 378 pp.

Van Lenteren, J.C. (2012) The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. *BioControl*, 57: 1–20. DOI: 10.1007/s10526-011-9395-1

Wei, M.F., Chi, H., Guo, Y.F., Li, X.W., Zhao, L.L.& Ma, R.Y. (2020) Demography of *Cacopsylla chinensis* (Hemiptera: Psyllidae) reared on four cultivars of *Pyrus bretschneideri* and *P. communis* (Rosales: Rosaceae) pears with estimations of confidence intervals of specific life table statistics. *Journal of Economic Entomology*, 113(5): 2343–2353. DOI: 10.1093/jee/toaa149

Wickens, T.D. & Keppel, G. (2004) *Design and analysis: A researcher's handbook*. 4th edition. Pearson College Div, 624 pp.

Win, S.S., Muhamad, R., Ahmad, Z.A. & Adam, N.A. (2011) Life table and population parameters of *Nilaparvata lugens* Stal. (Homoptera: Delphacidae) on Rice. *Tropical Life Sciences Research*, 22(1): 25–35.

Xiao, Y. & Fadamiro, H.Y. (2010) Functional responses and prey-stage preferences of three species of predacious mites (Acari: Phytoseiidae) on citrus red mite, *Panonychus citri* (Acari: Tetranychidae). *Biological Control*, 53: 345–352. DOI: 10.1016/j.biocontrol.2010.03.001

Zein, H.S., Afifi, A.M., Ali, F.S., Shaurub, E.-S. & Ahmed, M.M. (2022) Target-site insensitivity to some acaricides in a field population of *Tetranychus urticae* Koch (Acari: Tetranychidae) from Egypt. *Persian Journal of Acarology*, 11(2): 323–337. DOI: 10.22073/pja.v11i2.71694

پراسنجه‌های جدول زندگی و میزان شکارگری *Neoseiulus californicus* (Acari: Phytoseiidae) با تغذیه از *Panonychus citri* و *Eutetranychus orientalis* (Acari: Tetranychidae)

ايه حضوري جزولي، عبد الله محمد عفيفي، فاطمة سمير علي، محمود منير أحمد*

گروه جانورشناسی و نماتدشناسی کشاورزی، دانشکدهٔ کشاورزی، دانشگاه قاهره، جیزه، مصر؛ رایانامه‌ها: *Gazolyaya@yahoo.com*، *amafifi@agr.cu.edu.eg*، *famasamir@hotmail.com*، *mahmoudmonir@agr.cu.edu.eg*

* نویسندهٔ مسئول

چکیده

این مطالعه با هدف ۱) بررسی تأثیر دو کنهٔ مرکبات *Panonychus citri* (McGregor) و *Eutetranychus orientalis* (Klein) به عنوان غذا بر پراسنجه‌های زیستی *Neoseiulus californicus* (McGregor) و ۲) ارزیابی تأثیر جداگانه سه عامل (دما با دو سطح (T)، نوع جیره با چهار سطح (P) و تراکم جیره با پنج سطح (D)) بر شکارگری و سرعت تولیدمثل *N. californicus* و همچنین برهم‌کنش بین آنها با استفاده از طرح فاکتوریل با مدل خطی عمومی انجام شد. بر اساس نتایج، تغذیه کنهٔ شکارگر *N. californicus* روی مراحل متحرک *P. citri* باعث کاهش معنی‌دار دوره‌های پیش از بلوغ و بالغ ماده‌ها (۴/۹۶ و ۲۴/۲۲ روز) شد. افزایش معنی‌داری در باروری کل (۳٤ تخم/ماده) طی یک دوره تخمگذاری ۱٤ روزه در مقایسه با تغذیه با *E. orientalis* مشاهده شد. همچنین مقادیر پراسنجه‌های نرخ ذاتی افزایش (*rm*) و نرخ متناهی افزایش (λ) بیشتر و در عین حال طول نسل (T) و زمان دو برابر شدن (DT) در هنگام تغذیه شکارگر از مراحل متحرک *P. citri* در مقایسه با *E. orientalis* کوتاه‌تر بود. با استفاده از طرح فاکتوریل با مدل خطی عمومی، میزان شکارگری *N. californicus* و تعداد تخم‌های گذاشته شده روزانه توسط ماده به‌طور معنی‌داری (p < ۰/۰۱) تحت تأثیر جداگانه سه عامل دما (T) ، نوع جیره (P) و تراکم رژیم غذایی (D) و برهم‌کنش بین آنها قرار گرفت. باروری زیاد، زمان تولیدمثل کوتاه و سرعت متوسط افزایش ذاتی جمعیت *N. californicus* افزون بر سازگاری بهتر با دماهای زیاد نشان دهنده پتانسیل فراوان به عنوان عامل مهار زیستی موثری برای دو کنهٔ مرکبات *P. citri* و *E. orientalis* مهاجم باغ‌های مرکبات است. این نتایج تنها در تصمیمات مدیریت آفات قابل استفاده است.

واژگان کلیدی: مهار زیستی، کنه‌های مرکبات، پراسنجه‌های جدول زندگی، *Neoseiulus californicus*، کارایی شکارگری.

اطلاعات مقاله: تاریخ دریافت: ۱٤۰۲/۷/۹، تاریخ پذیرش توسط *آ. فرازمند*: ۱٤۰۲/۱۱/۲، تاریخ چاپ: ۱٤۰۳/۱/۲۷