# Development, Fecundity, and Prey Consumption of *Neoseiulus californicus* (McGregor) Fed *Tetranychus cinnabarinus* Boisduval

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**Abstract:** The development, fecundity, and prey consumption of the Aydın *Neoseiulus californicus* population (McGregor) feeding on *Tetranychus cinnabarinus* Boisduval were studied in the laboratory at different temperatures, 65 ± 10% RH, and a 16 h L:8 h D cycle. The total development period (egg to adult) decreased linearly with increasing temperature ($0.012 \times T - 0.093$; $R^2 = 0.950$). The total development threshold obtained from regression analysis was estimated to be 7.8 °C. *Neoseiulus californicus* required, on average, 83.3 DD to complete its development from egg to adult. Mean total and daily fecundity were highest at 25 °C, and were statistically different from those obtained at 20 and 30 °C. The net reproductive rate ($R_0$) was highest at 25 °C (42.92 ♀/♀). The longest mean generation period ($T_0$) occurred at 20 °C (12.96 days) and the shortest occurred at 30 °C (10.12 days). The highest intrinsic rate of increase ($r_m$) for *N. californicus* was observed at 25 °C (0.3373 ♀/♀/day) and the lowest was at 20 °C (0.2467 ♀/♀/day). The numbers of *T. cinnabarinus* eggs, larvae, nymphs, and adult males eaten by *N. californicus* were significantly different between prey densities. Regardless of prey density, *N. californicus* consumed more eggs and larvae than nymphs and adult males. The functional response data of *N. californicus* fit reasonably well to a type-II functional response of the Holling model. The number of eggs laid by female *N. californicus* was the highest when *T. cinnabarinus* eggs were offered as prey.

**Key Words:** *Neoseiulus californicus*, *Tetranychus cinnabarinus*, development, predation, reproduction, longevity

## Avcı Akar *Neoseiulus californicus* (McGregor)'un *Tetranychus cinnabarinus* Boisduval Üzerinde Gelişme, Üreme ve Av Tüketim Kapasitesi

**Özet:** Avcı akar *Neoseiulus californicus* (McGregor)' un Aydın populasyonunun farklı sıcaklıklarda (%65 ± 10 nem ve 16A:8K) *Tetranychus cinnabarinus* Boisduval üzerinde gelişme, üreme ve av tüketim kapasitesi araştırılmıştır. Sıcaklığın artması ile birlikte *N. californicus*'un toplam gelişme süresinin kısaldığı saptanmıştır ($0.012 \times T - 0.093$; $R^2 = 0.950$). *Neoseiulus californicus*'un gelişme eşiği regresyon denkleminden yararlanılarak hesaplanmış ve gelişme eşiğinin 7.8 °C olduğu belirlenmiştir. Bu değerlerden *N. californicus*'un toplam gelişme süresi için gerekli sıcaklıklar toplamı ise 83.3 gün-derece olarak hesaplanmıştır. *Neoseiulus californicus*' un toplam ve günlük yumurta üretimi 25 °C'de en yüksek elde edilmiş ve bu sıcaklıktaki veriler 20 ve 30 °C'de elde edilenlerden istatistiki olarak farklı bulunmuştur. Net üreme gücü ($R_0$), en yüksek 25 °C (42.92 ♀/♀)'de saptanmıştır. Ortalama döl süresi ($T_0$) en uzun 20 °C (12.96 gün)'de, en kısa 30 °C (10.12 gün)' de saptanmıştır. Kalıtsal üreme yeteneği ($r_m$) en yüksek 25 °C (0.3373 ♀/♀/gün)' de, en düşük 20 °C (0.2467 ♀/♀/gün)' de bulunmuştur. *Neoseiulus californicus*' un günlük olarak tükettiği *T. cinnabarinus* yumurta, larva, nimf ve ergin erkek dönemlerinin sayıları ile av yoğunlukları arasında istatistiki olarak önemli fark bulunmuştur. Av yoğunluğu dikkate alınmadığında, *T. cinnabarinus*' un yumurta ve larva dönemleri, nimf ve ergin erkeklere göre daha fazla tüketilmiştir. *Neoseiulus californicus*' un işlevsel tepki tipi Holling modelinin II. işlevsel tepki tipine uymaktadır. *Tetranychus cinnabarinus*' un yumurta dönemi ile beslendiğinde, *N. californicus*' un bıraktığı yumurta sayısı en yüksek bulunmuştur.

**Anahtar Sözcükler:** *Neoseiulus californicus*, *Tetranychus cinnabarinus*, gelişme, avlanma kapasitesi, üreme, ömür uzunluğu

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## Introduction

The carmine spider mite *Tetranychus cinnabarinus* is one of the most important pest species and is distributed worldwide. It attacks more than 100 plant species, including such crops as strawberry, cotton, deciduous fruits, vegetables, and ornamental plants (Jeppson et al., 1975). It is one of the most serious pests of fig, strawberry, cotton, and vegetables (cucumber, tomatoes, eggplant, bean, and pepper) in Aydın, Turkey (Çakmak and Başpınar, 1998; Akşit et al., 2003; Çakmak et al., 2003). *Tetranychus cinnabarinus* causes considerable economic damage due to reductions in both the yield and quality of produce in this area, and is controlled by pesticide sprays (Çakmak and Başpınar, 1998; Akşit et al. 2003; Çakmak et al., 2003). Due to pesticide resistance and environmental pollution, there is an increasing demand for sustainable, environmentally friendly control methods. As such, biological control with phytoseiid mites has been effectively used for controlling spider mites on many cultivated crops (Helle and Sabelis, 1985; van Lenteren et al., 1992). McMurtry (1982) reported phytoseiids being used at the time or with the potential for use in control programs against agricultural and horticultural pests. Among the species being used in such control programs is *Neoseiulus californicus* (McGregor), also known as *Amblyseius californicus*.

*Neoseiulus californicus* prefers tetranychid mites as food, but will also consume other phytophagous mites, such as *Polyphagotarsonemus latus* and *Tarsonemus pallidus*, and even pollen when the primary prey is unavailable (McMurtry and Croft, 1997). As *N. californicus* is used commercially, natural populations are also found in Europe, South Africa, East Asia, and North and South America (Ma and Laing, 1973; Mesa et al. 1990; Castagnoli and Simoni, 1991; Raworth et al., 1994; Rencken and Pringle, 1998; Gotoh et al., 2004a; Canlas et al., 2006). *Neoseiulus californicus* is found naturally in Turkey and was first recorded on strawberry, peach, bean, and pepper associated with *Tetranychus urticae* and *Panonychus ulmi* in 2001 (Çakmak and Çobanoğlu, 2006). Although some studies have been conducted on the general biology and predation ability of *N. californicus* strains on *Tetranychus urticae*, *T. kanzawai, Mononychellus progresivus, Amphitetranychus viennensis, Panonychus ulmi*, and *P. citri* (Ma and Laing, 1973; Mesa et al., 1990; Castagnoli and Simoni, 1991; Rencken and Pringle, 1998; Castagnoli et al., 1999;

Gotoh et al., 2004a, 2006; Canlas et al., 2006), the Aydın *N. californicus* population and its prey, *T. cinnabarinus*, have not been studied. The degree of adaptation of *N. californicus* to this prey species and its efficiency in controlling mite populations vary with the strain of species and environmental conditions, such as host plant type, ambient temperature, and relative humidity (Helle and Sabelis, 1985). The present study, therefore, was designed to evaluate the development rate and fecundity of the Aydın *N. californicus* population at different temperatures, as well as its predation ability at various prey stages and densities under laboratory conditions.

## Materials and Methods

### Mite Rearing

*Tetranychus cinnabarinus* was obtained from strawberry fields in Sultanhisar, Aydın, Turkey, and reared on bean plants (*Phaseolus vulgaris* cv. 'Barbunia') at 25 ± 2 °C and 65 ± 10% RH under a 16-h light regime. Clean plants were grown in a climate room (same regime) until they were 2 weeks old and were subsequently added biweekly to the spider mite culture.

*Neoseiulus californicus* was obtained from a strawberry field in Kuşadası, Aydın, Turkey, and reared at 25 ± 1 °C on detached bean leaves infested with *T. cinnabarinus*. These leaves were placed on an inverted flowerpot in a water-containing tray covered with a Plexiglas container. Some 2-3 leaves from the spider mite culture were added to the cultures biweekly.

### Development Period of Immature Stages

The development period of *N. californicus* from egg to adult emergence was examined at 5 constant temperatures (15, 20, 25, 30, and 35 ± 1 °C), 65 ± 10% RH, and a 16 h L:8 h D cycle. Experiments were conducted with a modified Munger cell (Overmeer, 1985). The Munger cell consisted of a stack of several 60 × 45-mm layers, including 3 acrylic plates, in the following order: bottom acrylic plate (2 mm thick), moistened filter paper, leaf disks, middle plate (5 mm thick, with a 23-mm diameter hole in the center), and top plate (2 mm thick). The stack was held together with 2 large binder clips. Clean leaf disks (3 cm in diameter) were obtained from the bean plant culture and were cut with a cork borer. Leaf disks were put abaxial side up in

the Munger cell. One *N. californicus* gravid female obtained from the stock cultures was introduced onto each leaf disk in a Munger cell and allowed to lay eggs for 12 h. The number of *N. californicus* eggs was reduced to 1 egg by carefully removing excessive eggs with a fine brush; female predatory mites were also removed. The immature stages were observed twice daily until they reached maturity. Prey was provided daily by brushing off bean leaves infested with *T. cinnabarinus* at different development stages. Corpses of the prey were removed from each cell daily.

### Female Longevity and Fecundity

The longevity and fecundity of *N. californicus* were determined at 20, 25, and 30 ± 1 °C, 65 ± 10% RH, and a 16 h L:8 h D cycle. One newly emerged *N. californicus* female and 1 male from the above experiment were subsequently placed in a Munger-cell containing a mixture of *T. cinnabarinus* at different development stages. After mating, the male was removed. Thereafter, the number of eggs laid was recorded daily until all adults died. All *N. californicus* eggs were removed and transferred individually to a new excised bean leaf, and were reared until adulthood to record the sex of the resulting F1 progeny. The oviposition period, and pre- and post-oviposition periods were also calculated. Life tables were constructed from the data obtained for period of development of immature stages, and adult oviposition and development.

### Predation Ability

The predation rate of *N. californicus* was determined in the Munger cell at 25 ± 1 °C, 65 ± 10% RH, and a 16 h L:8 h D cycle. To obtain the different stages of *T. cinnabarinus* that were used in the experiments, 1 fresh bean leaf was put on a layer of water-saturated cotton wool in a plastic petri dish (15 cm in diameter) with its petiole inserted into the cotton wool to keep the leaf fresh. Then, 25 adult *T. cinnabarinus* females were added to the leaves. The next day the adults were removed. Thereafter, prey were transferred to Munger cells with a fine brush. Adult *N. californicus* females obtained from the stock cultures were individually starved in small petri dishes (3.5 cm in diameter) for 16 h prior to the experiments. These petri dishes were closed with parafilm to prevent the predators from escaping, and the parafilm was pierced with a thin insect pin for ventilation. Subsequently, the female predators were confined in the Munger cells and provided *T. cinnabarinus* eggs, larvae, nymphs, or adult males at various densities, i.e. 5, 10, 20, 30, 40, 50, and 80. After 24 h the number of prey consumed and eggs laid by the predator were recorded. The experiment was replicated 20 times.

### Statistical Analysis

Data on development period, longevity, and fecundity, as a function of time, were analyzed separately using one-way ANOVA, followed by Tukey's test at P = 0.05. The thermal threshold for egg development and for egg-to-adult development was computed by employing a linear technique that uses growth rate ($day^{-1}$) as the dependent variable and temperature as the independent variable. The lower development threshold temperature was determined as the x-intercept of the linear equation and DD (degree-day) requirements were determined as the inverse of the slope of the linear equation. Differences in the sex ratio were analyzed using the chi-square test (P = 0.05). Population growth rates at different temperatures were calculated by constructing life tables using the following equation (Birch, 1948): $1 = \sum e^{-r \cdot x} l_x \cdot m_x$.

Age-specific survival rates ($l_x$) and the number of female offspring ($m_x$) for each age interval (x) day were used for life table data. From these data, net reproductive rate ($R_0$ = female offspring $female^{-1}$ $generation^{-1}$), intrinsic rate of natural increase ($r_m$ = female offspring $female^{-1}$ $day^{-1}$), and mean generation time ($T_0$ = ln ($R_0/r_m$), in days) were calculated (Laing, 1968). Differences in $r_m$ values were tested for significance by estimating variance using the jack-knife method, which facilitated calculation of the standard errors of $r_m$ estimates. The jack-knife pseudo-value (rj) was calculated for n samples using the following equation (Krebs, 1998): $r_j = n \cdot r_{a11} - (n-1) \cdot r_i$

The mean values of (n − 1) jack-knife pseudo-values for mean growth rate in each treatment were subjected to analysis of variance followed by Tukey's test at P = 0.05. Analysis of development period, longevity, and fecundity of *N. californicus* was conducted using SPSS statistical software (SPSS 2004. SPSS v.13.0 for Windows, SPSS Inc., Chicago, IL, USA.).

The behavioral responses of *N. californicus* to the various prey stages and densities were expressed by fitting Holling's equation to the data (Williams and Juliano, 1985):

$$N_\alpha = TP\alpha N/(1 + \alpha T_h N),$$

where $N_\alpha$ is the number of prey eaten, T is the experimental time (h), P is the number of predators, N is the initial number of prey offered, $\alpha$ is the searching (attack) rate, and $T_h$ is the handling time. Searching rate and handling time, and their asymptotic standard errors were estimated from nonlinear regressions of the disk equation. Confidence limits (95%) were used as indicators of differences between searching rates, as well as handling time of all 4 life stages. SAS statistical software (SAS Institute, 1998. User's Manual, v.7.0., SAS Institute, Cary, NC, USA.) was used to analyze behavioral responses of *N. californicus*.

## Results

### Development Period of Immature Stages

At each of the temperatures between 15 and 30 °C, more than 96% of the eggs (range: 96.5%-98.6%) hatched. At 35 °C, 20% of the eggs hatched, but they did not reach maturity. The survival rate from larva to adult was > 84.5% at temperatures between 15 and 30 °C.

The *N. californicus* egg incubation period decreased significantly as temperature increased, and ranged from 4.18 ± 0.16 days at 15 °C to 1.18 ± 0.03 days at 30 °C (Table 1). Linear regression analysis was applied to the egg development period at the 15-30 °C temperature range. Developmental rates for egg stage ($r_{[Te]}$) increased linearly with increasing temperature ($r_{[Te]} = 0.039 \times T - 0.347$; $R^2 = 0.998$). The theoretical development threshold for the egg stage was 8.9 °C, and 25.6 DD were required for hatching. The shortest post-embryonic development period (larva, protonymph, and deutonymph stage) was at 25 and 30 °C, and was significantly longer at 15 °C (Table 1). The total development period (egg to adult) ($r_{[Tt]}$) also decreased linearly with increasing temperature ($r_{[Tt]} = 0.012 \times T - 0.093$; $R^2 = 0.950$). The total developmental threshold obtained with regression analysis was estimated to be 7.8 °C. *N. californicus* required 83.3 DD to complete its development from egg to adult. Overall, the duration of egg, larva, protonymph, deutonymph, and total development period did not differ significantly between females and males ($P > 0.01$), except for eggs at 15 °C.

Table 1. Duration (in days) of *N. californicus* egg and immature stages fed *T. cinnabarinus* at different temperatures (mean ± SE).

| | | Temperature (°C) | | | | F ratio df = 3 P < 0.001 |
|---|---|---|---|---|---|---|
| | | 15 | 20 | 25 | 30 | |
| $n^z$ | ♀ | 22 | 37 | 26 | 52 | |
| | ♂ | 23 | 24 | 11 | 17 | |
| Egg | ♀ | 4.18 ± 0.16 a[y] | 2.17 ± 0.10 b | 1.57 ± 0.08 c | 1.18 ± 0.03 d | 188.206 |
| | ♂ | 4.86 ± 0.12 a[y] | 2.24 ± 0.16 b | 1.61 ± 0.11 c | 1.18 ± 0.06 d | 155.822 |
| Larva | ♀ | 1.90 ± 0.05 a | 0.70 ± 0.04 b | 0.65 ± 0.05 b | 0.65 ± 0.03 b | 132.869 |
| | ♂ | 1.75 ± 0.06 a | 0.80 ± 0.05 b | 0.56 ± 0.07 c | 0.53 ± 0.05 c | 92.511 |
| Protonymph | ♀ | 3.14 ± 0.09 a | 1.41 ± 0.05 b | 0.97 ± 0.05 c | 0.96 ± 0.04 c | 242.561 |
| | ♂ | 3.04 ± 0.10 a | 1.46 ± 0.07 b | 0.96 ± 0.12 c | 0.97 ± 0.05 c | 121.159 |
| Deutonymph | ♀ | 3.57 ± 0.08 a | 1.45 ± 0.06 b | 1.07 ± 0.04 c | 0.94 ± 0.04 c | 336.367 |
| | ♂ | 3.30 ± 0.09 a | 1.24 ± 0.06 b | 0.96 ± 0.08 c | 0.88 ± 0.08 c | 208.782 |
| Total development period | ♀ | 12.81 ± 0.24 a | 5.73 ± 0.09 b | 4.27 ± 0.08 c | 3.74 ± 0.07 d | 1025.177 |
| | ♂ | 12.96 ± 0.17 a | 5.77 ± 0.13 b | 4.12 ± 0.09 c | 3.58 ± 0.14 d | 829.458 |

[z]Number of replicates.

Within rows, means followed by the same lower-case letter do not differ significantly (Tukey's test).

[y]Within columns, for both sexes, means differ significantly (t test; $P \leq 0.01$).

## Female Longevity and Fecundity

The longest pre-oviposition and oviposition periods were $2.05 \pm 0.09$ days at 20 °C and $14.55 \pm 0.56$ days at 25 °C, respectively. The duration of the pre-oviposition and oviposition periods at 25 °C was significantly different from that at 20 and 30 °C (Table 2). The post-oviposition period of *N. californicus* was significantly longer and its longevity significantly greater at 20 °C than at higher temperatures (Table 2, Figure 1). Mean total and daily fecundity were highest at 25 °C, which were significantly different from those obtained at 20 and 30 °C.

The sex ratio of *N. californicus* was not significantly different between temperatures ($P > 0.05$). The net reproductive rate ($R_0$) was highest at 25 °C. The longest mean generation time ($T_0$) occurred at 20 °C and the shortest at 30 °C. The highest intrinsic rate of increase ($r_m$) for *N. californicus* was observed at 25 °C and the lowest was at 20 °C (Table 3).

## Predation Ability

The number of *T. cinnabarinus* eggs, larvae, nymphs, and adult males eaten by *N. californicus* was significantly different between prey densities (Table 4, $P < 0.001$). Regardless of prey density, *N. californicus* consumed more eggs and larvae than nymphs and adult males. The highest number of eggs, larvae, nymphs, and adult males consumed by 1 gravid female per day was 20.65, 22.45, 12.10, and 9.85, respectively (Table 4). *N. californicus* responded to increasing densities of *T. cinnabarinus* at different stages of development with increasing



Figure 1. Survivorship curve ($l_x$) and age-specific fecundity rate ($m_x$) of *N. californicus* at different temperatures.

Table 2. Longevity and fecundity of *N. californicus* fed *T. cinnabarinus* at different temperatures (mean ± SE).

| | | Temperature (°C) | | | F ratio df = 2 P < 0.001 |
|---|---|---|---|---|---|
| | $n^z$ | 20 30 | 25 18 | 30 27 | |
| Duration (days) | Pre-oviposition | $2.05 \pm 0.09$ a[y] | $1.47 \pm 0.12$ b | $1.85 \pm 0.12$ a | 6.067 |
| | Oviposition | $12.30 \pm 0.53$ b | $14.55 \pm 0.56$ a | $11.11 \pm 0.52$ b | 8.563 |
| | Post-oviposition | $48.30 \pm 3.61$ a | $19.72 \pm 2.53$ b | $8.59 \pm 1.03$ c | 60.606 |
| | Longevity ♀ | $62.71 \pm 3.61$ a | $35.75 \pm 2.89$ b | $21.55 \pm 1.11$ c | 60.427 |
| Number of eggs per female | Total | $33.10 \pm 1.42$ b | $54.33 \pm 2.11$ a | $37.18 \pm 1.96$ b | 32.931 |
| | Per day | $2.70 \pm 0.04$ c | $3.74 \pm 0.06$ a | $3.33 \pm 0.06$ b | 76.507 |

[z]Number of replicates.
[y]Within rows, means followed by the same lower-case letter do not differ significantly (Tukey's test).

Table 3. Net reproductive rate ($R_0$), intrinsic rate of increase ($r_m$), generation time ($T_0$), and sex ratio of *N. californicus* fed *T. cinnabarinus* at different temperatures.

| Temperature (°C) | Net reproductive rate ($R_0$) (♀ / ♀) | Intrinsic rate of increase ($r_m$)[z] (♀ / ♀ / day) | Generation time ($T_0$) (days) | Sex ratio (♀ / (♀ + ♂))[y] |
|---|---|---|---|---|
| 20 | 24.49 | 0.2467 c | 12.96 | 0.74 |
| 25 | 42.92 | 0.3373 a | 11.14 | 0.79 |
| 30 | 24.61 | 0.3164 b | 10.12 | 0.66 |
| F ratio | | 109.039 P < 0.001 | | |

[z]Within the column, means followed by the same letter do not differ significantly (Tukey's test).
[y]Within the column, means do not differ statistically (chi-square test).

Table 4. Average daily number of various stages and densities of *T. cinnabarinus* consumed by an *N. californicus* gravid female (mean ± SE).

| Prey density | n | Prey stage | | | | |
|---|---|---|---|---|---|---|
| | | Egg | Larva | Nymph | Adult male | F ratio |
| 5 | 20 | 4.85 ± 0.08 e[f] | 4.40 ± 0.13 d[f] | 3.55 ± 0.18 e[g] | 3.40 ± 0.19 d[g] | 19.597 |
| 10 | 20 | 9.55 ± 0.15 d[f] | 6.65 ± 0.36 d[g] | 5.80 ± 0.29 d[h] | 5.25 ± 0.27 c[h] | 46.216 |
| 20 | 20 | 16.45 ± 0.34 c[f] | 11.80 ± 0.66 c[g] | 9.30 ± 0.47 c[h] | 7.00 ± 0.31 b[i] | 74.491 |
| 30 | 20 | 16.65 ± 0.62 bc[f] | 17.20 ± 0.80 b[f] | 8.95 ± 0.49 c[g] | 8.80 ± 0.47 a[g] | 57.354 |
| 40 | 20 | 16.50 ± 0.74 c[g] | 22.45 ± 0.81 a[f] | 9.75 ± 0.48 bc[h] | 9.30 ± 0.52 a[h] | 89.142 |
| 50 | 20 | 18.75 ± 0.71 ab[g] | 22.05 ± 1.06 a[f] | 11.30 ± 0.54 ab[h] | 9.85 ± 0.53 a[h] | 61.743 |
| 80 | 20 | 20.65 ± 0.50 a[f] | 21.70 ± 0.64 a[f] | 12.10 ± 0.56 a[g] | 9.85 ± 0.37 a[h] | 125.900 |
| F ratio | | 116.384 | 116. 922 | 44.389 | 38.514 | P ≤ 0.001 |

Within columns, means followed by the same letter (a-e) do not differ significantly (Tukey's test).
Within rows, means followed by the same letter (f-i) do not differ significantly (Tukey's test).

consumption; however, the predation rate started to level off at densities of 40-50 prey (Figure 2).

The functional response data of *N. californicus* fit reasonably well to a type-II functional response of the Holling model. The handling time ($T_h$) and searching rate ($\alpha$) changed according to the different stages of *T. cinnabarinus* offered to the predator. The handling time of larvae was lower than that of eggs, nymphs, and adult males. On the other hand, the searching rate was highest for eggs, and the lowest was for adult males (Table 5).

*N. californicus* oviposition rates were significantly different at various prey stages and densities (Table 6, P < 0.001). The number of eggs laid by a female fed different stages of *T. cinnabarinus* increased up to a supply of 20 prey per day. As a result, the maximum number of eggs laid by a female predator fed egg, larva, nymph, and adult male stages was 3.10, 1.90, 1.85, and 1.45, respectively. The daily oviposition rate of *N. californicus* was the highest when *T. cinnabarinus* eggs were offered as prey (Table 6, P < 0.001).

Figure 2. Functional responses of *N. californicus* adult females fed different stages and densities of *T. cinnabarinus*.

Table 5. Searching rate ($\alpha$), handling time ($T_h$), and confidence limits of the Holling disk equation for *N. californicus* fed different stages of *T. cinnabarinus*.

| Prey stages | $\alpha$ (prey/h) (asymptotic SE) | 95% CL | | $T_h$ (h/prey) (asymptotic SE) | 95% CL | |
|---|---|---|---|---|---|---|
| | | Lower | Upper | | Lower | Upper |
| Egg | 1.676 (0.3044) | 0.8932 | 2.4581 | 0.0411 (0.0032) | 0.0327 | 0.0495 |
| Larva | 1.114 (0.2622) | 0.4403 | 1.7882 | 0.0300 (0.0050) | 0.0170 | 0.0430 |
| Nymph | 1.022 (0.1498) | 0.6366 | 1.4066 | 0.0717 (0.0044) | 0.0603 | 0.0830 |
| Adult male | 0.9626 (0.0908) | 0.7293 | 1.1960 | 0.0840 (0.0031) | 0.0760 | 0.0920 |

## Discussion

The development period for eggs, larvae, and nymphs, as well as total development period of the Aydın *N. californicus* population decreased significantly as temperature increased (Table 1, $P < 0.001$). At 25 °C the total development period for the Aydın *N. californicus* population fed *T. cinnabarinus* was shorter than that of Chilean (Ma and Laing, 1973), Italian (Castagnoli and

Simoni, 1991), and African strains (Rencken and Pringle, 1998), but similar to Japanese (Gotoh et al., 2004a; Canlas et al., 2006) and Spical® strains (Gotoh et al., 2006). This might be due to different responses of *N. californicus* to different food supplies, as well as to local strains used. The lower threshold temperature in the Aydın *N. californicus* population was lower than that of Italian (Castagnoli and Simoni, 1991), African (Rencken

Table 6. Average daily number of eggs deposited by *N. californicus* gravid females fed various stages and densities of *T. cinnabarinus* (mean ± SE).

| Prey density | n | Prey stage | | | | |
|---|---|---|---|---|---|---|
| | | Egg | Larva | Nymph | Adult male | F ratio |
| 5 | 20 | 1.30 ± 0.11 c[d] | 0.55 ± 0.14 c[e] | 0.85 ± 0.13 c[de] | 0.50 ± 0.11 c[e] | 9.040 |
| 10 | 20 | 2.40 ± 0.11 b[d] | 0.95 ± 0.14 bc[ef] | 1.20 ± 0.19 bc[e] | 0.70 ± 0.15 bc[f] | 26.012 |
| 20 | 20 | 3.00 ± 0.15 a[d] | 1.45 ± 0.14 ab[e] | 1.45 ± 0.11 ab[e] | 1.10 ± 0.17 ab[e] | 34.604 |
| 30 | 20 | 2.90 ± 0.18 ab[d] | 1.65 ± 0.16 a[e] | 1.60 ± 0.13 ab[e] | 1.45 ± 0.14 a[e] | 20.133 |
| 40 | 20 | 2.85 ± 0.13 ab[d] | 1.65 ± 0.17 a[e] | 1.80 ± 0.14 a[e] | 1.10 ± 0.14 ab[f] | 25.333 |
| 50 | 20 | 3.10 ± 0.12 a[d] | 1.55 ± 0.14 ab[e] | 1.85 ± 0.15 a[e] | 1.30 ± 0.18 a[e] | 28.963 |
| 80 | 20 | 3.00 ± 0.14 a[d] | 1.90 ± 0.14 a[ef] | 2.00 ± 0.12 a[e] | 1.45 ± 0.13 a[f] | 22.591 |
| F ratio | | 21.964 | 10.727 | 8.147 | 6.048 | P ≤ 0.001 |

Within columns, means followed by the same letter (a-c) do not differ significantly (Tukey's test).
Within rows, means followed by the same letter (d-f) do not differ significantly (Tukey's test).

and Pringle, 1998), American (Hart et al., 2002), and Japanese strains (Gotoh et al., 2004a; Canlas et al., 2006). The thermal constant of the Aydın *N. californicus* population was higher than that of the Japanese strain (Gotoh et al., 2004a; Canlas et al., 2006), but lower than that of the Italian (Castagnoli and Simoni, 1991), American (Hart et al., 2002), and African strains (Rencken and Pringle, 1998).

Mean total and daily fecundity of the Aydın *N. californicus* population were highest at 25 °C and were significantly different from those obtained at 20 and 30 °C. These findings are in agreement with results obtained for total fecundity of the Japanese *N. californicus* strain (Gotoh et al., 2004a; Canlas et al., 2006). On the other hand, the highest daily fecundity of the Japanese *N. californicus* strain was at 30 °C (Gotoh et al., 2004a; Canlas et al., 2006).

The $r_m$ value we obtained for the Aydın *N. californicus* population fed *T. cinnabarinus* was 0.3373 at 25 °C, which is higher than that reported for other *N. californicus* strains that have been studied. There is wide variation in $r_m$ values among *N. californicus* strains. This variation could be due to different prey used in different experiments. For example, the $r_m$ of the Spical® *N. californicus* strain was higher when fed *T. urticae* than when fed *T. kanzawai, Amphitetranychus viennensis, Panonychus citri*, and *P. ulmi* (Gotoh et al., 2006). In

contrast, Mesa et al. (1990) reported that the $r_m$ of the Colombian *N. californicus* strain fed both *Mononychellus progresivus* and *T. urticae* were the same. When the Japanese *N. californicus* strain was fed *T. urticae* eggs (Gotoh et al., 2004a), its $r_m$ value (0.274) was higher when fed active stages ($r_m = 0.209$) (Canlas et al., 2006). Additionally, the host plant of the prey may affect $r_m$ values. Castagnoli et al. (1999) reported that the $r_m$ value of the Italian *N. californicus* strain was higher when the mites were fed *T. urticae* reared on strawberry leaves than when they were fed *T. urticae* reared on tomato leaves. Similarly, Gotoh et al. (2006) observed a higher $r_m$ value (0.328) with the Spical® *N. californicus* strain fed *T. urticae* reared on cherry leaves than when fed *T. urticae* reared on bean leaves ($r_m = 0.311$). At 25 °C the mean generation time ($T_0$) of the Aydın *N. californicus* population was close to that of the African, Chilean, and Spical® strains (Rencken and Pringle, 1998; Ma and Laing, 1973; Gotoh et al., 2006), and lower than that of the Colombian, Italian, and Japanese strains (Mesa et al., 1990; Castagnoli and Simoni, 1991; Gotoh et al., 2004a; Canlas et al., 2006). The net reproduction rate ($R_0$) of the Aydın *N. californicus* population was higher than that of other *N. californicus* strains. Interspecific and intraspecific variation in the population growth parameters can be expected when different prey stages are offered to predatory mites (Sabelis, 1985).

*N. californicus* responded to increasing densities of *T. cinnabarinus* at different developmental stages with increasing consumption; however, the predation rate started to level off at a density of 40-50 prey. Similar results were obtained by Canlas et al. (2006), and Friese and Gilstrap (1982). Regardless of prey density, *N. californicus* consumed more eggs and larvae than nymphs and adult males. These results, thus, are in agreement with the findings of Canlas et al. (2006), who reported that the Japanese *N. californicus* strain prey more on *T. urticae* juvenile stages than adult males or females. The number of eggs laid by *N. californicus* increased as prey density increased, up to a density of 20, and then reached a plateau. The highest daily oviposition rate was observed when eggs were offered as prey. Canlas et al. (2006) observed that oviposition of the Japanese *N. californicus* strain increased when egg, larva, and nymph densities increased, and remained low if provided exclusively with adult male or female prey.

The functional response data of *N. californicus* fit reasonably well to a type-II functional response of the Holling model, in which predators display a decrease in the predation rate as prey density increases. Similar functional responses have been reported for Italian, Argentinean, and Japanese *N. californicus* strains (Castagnoli and Simoni, 1999; Cedola et al., 2001; Gotoh et al., 2004b).

Neither *N. californicus* nor other predatory mites, such as *P. persimilis*, are available commercially in Turkey. Although commercially available *P. persimilis* and *N. californicus* are now widely used to control spider mites in greenhouse crops in Central Europe, they perform poorly in the Western Mediterranean (Escudero and Ferragut, 2005), probably because they are not well adapted to local climatic conditions. For that reason, efforts are being directed at the development of a biological control program using native phytoseiid mites. Our results indicate that the Aydın *N. californicus* population exhibited a high capacity for population increase when fed *T. cinnabarinus*, and thus may be able to provide effective control of spider mites in the field. For support of this hypothesis field experiments are needed to investigate the effect of the Aydın *N. californicus* population on spider mite populations, either alone or in combination with other predatory mites.

## Acknowledgments

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