

Article

Life table parameters of *Neoseiulus californicus* (Acari: Phytoseiidae), on the European red mite, *Panonychus ulmi* (Acari: Tetranychidae) in laboratory condition

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Abstract

The life table parameters of *Neoseiulus californicus* (Athias-Henriot), a generalist predator of spider mites and small insects were investigated in laboratory condition at two constant temperatures: 20 and 25°C, 60 ± 5% relative humidity and a photoperiod of 16:8 h (L:D). The European red mite, *Panonychus ulmi* (Koch), an important pest of apple orchards in Iran, was used as prey (all stages). The duration of the immature stages ranged varied from 7.52 to 5.12 days, at 20 and 25°C, respectively. The net reproductive rate (R_0) increased with increasing temperature from 20.84 female offspring to 31.46 female offspring at 20–25°C, respectively. The values of the intrinsic rate of increase (r_m) and finite rate of increase (λ) were obtained to be highest at 25°C (0.237 day⁻¹ and 1.26 day⁻¹, respectively), which was greater than those estimated at 20°C (0.161 day⁻¹ and 1.17 day⁻¹, respectively). The mean generation time (T) decreased with increasing temperature from 18.86 days to 14.45 days at 20–25°C, respectively. In conclusion, results showed that *N. californicus* would be able to develop at temperatures range of 20–25°C feeding on *P. ulmi* and has the suitable potential to control it.

Keywords: Biological control, intrinsic rate of natural increase, predatory mite, reproduction, spider mite

Introduction

Spider mites (Acari: Tetranychidae) are very detrimental and widespread pests throughout apple growing areas around the world (Kasap 2005; Bolland *et al.* 1998). The European Red Mite, *Panonychus ulmi* (Koch) is one of the most important pests of ornamentals and fruit trees, attacking apples, pears, grapes, almonds and strawberries throughout the world. On apple, high populations of mites can lead to foliar bronzing, premature leaf drop, and small, poorly and colored fruit (McMurtry *et al.* 1970). There are many reports about the significant losses in apple orchards by *P. ulmi* causing, especially when in regions that mainly broad-spectrum pesticides were used (Markoyiannaki *et al.* 2000; Balan *et al.* 2001; Auger *et al.* 2003; Khan & Zhu 2006).

Spread of *P. ulmi* to most apple-growing areas has probably been caused by the distribution of nursery stock carrying winter eggs. European red mite is major pest in apple orchards in Iran (Rahmani *et al.* 2010). In commercial orchards, the potential of *P. ulmi* to cause severe economic damage necessitates chemical control several times a year (Croft 1975).

Phytoseiid mites are the most important natural enemies of pest mites (McMurtry 1977; McMurtry & Croft 1997) to be considered in integrated pest management. *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) is a predatory mite widely distributed (McMurtry 1977; McMurtry & Croft 1997) and have been used to the control of spider mites in the field and greenhouse horticultural crops in Europe, North and South America and Asia (Copping 2001). Its versatility as a predator has been noteworthy not only because it can prey on almost all stages of the two-spotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae) but also it has the ability to prey on some tetranychid mite species, as well as on other pest mites and small insects and can also survive on pollen (Croft *et al.* 1998). The use of *N. californicus* for pest control is increasingly gaining importance because of the pressure on growers to find alternatives to chemical pesticides and for this reason commercially mass-produced. *Neoseiulus californicus* have been on sale in various countries of the world (Copping 2001).

Toyoshima & Hinomoto (2004) compared biological characters of a native Japanese *N. californicus* strain to commercial one at 20°C to control spider mites in the field. Gotoh *et al.* (2004) determined the effect of five constant temperatures on its life history parameters using a diet of eggs of the red form of *T. urticae*.

Ample information is available about this predator's interactions with *Tetranychus* species, such as the two spotted spider mite, *T. urticae* Koch (Helle & Sabelis 1985), the Pacific spider mite, *T. pacificus* (McGregor) (Amano & Chant 1977; Takahashi & Chant 1994), the tomato spider mite, *T. evansi* Baker & Pritchard (de Moraes & McMurtry 1985), the gorse spider mite, *T. lintearius* (Dufour) (Pratt *et al.* 2003) and the Carmine spider mites, *T. cinnabarinus* Boisduval (Kustutan and Cakmak 2009), however information on its interaction with *P. ulmi* is relatively poor. In addition little information is available on the effect temperature on development on *N. californicus* when feeding on *P. ulmi* (Khan & Sengonca 2002; Gotoh *et al.* 2006).

For these reasons, experiments were conducted to evaluate the effect of temperature on the development and reproductive of the *N. californicus* using *P. ulmi* as prey as well assess its predation ability under laboratory in order to understand their prey-predator interactions.

Material and Methods

European red mite rearing

Three-year-old apple trees, Golden Delicious were used in experiments. The trees were planted in pots, containing approximately 30 kg of mixture of soil, sand and peat (1:1:1). Adults of *P. ulmi* were collected from the apple orchards without pesticide application region of Nazlo located in West Azerbaijan province in northwestern Iran. Rearing was conducted at the Acarology Laboratory of the Faculty of Agriculture at the University of Urmia, Iran at 25 ± 2°C, and 70 ± 10 % RH and 14 hours photoperiod.

Predatory mite rearing

The colony of *N. californicus* was purchased from Koppert Biological Systems (Spical®; Berkel en Rodenrijs, The Netherlands) in 2012 and maintained on leaves of apple were infested with *P. ulmi*. The stock culture of *N. californicus* was maintained in a controlled growth chamber, 25°C, 60–70% relative humidity (RH) and 16 hours light (L): 8 hours dark (D) conditions. In the present study, each leaf was placed on Huffaker cell which consisted of two glasses (7×10×6 cm). In the middle of each glass there was a small hole (2 cm) (Huffaker 1948). The cell placed on a wet sponge in a plastic tray containing water (Nomiko *et al.* 2005). The prey (*P. ulmi*) was introduced onto the leaves and left to settle for 20 h. Adult female *N. californicus* were then introduced and allowed to feed.

Development of immature stages

Developmental time of *N. californicus* from egg to adult emergence was determined at 20 and 25°C. Ovipositing females were kept on excised apple leaf with sufficient mixture of different developmental stages of *P. ulmi* as prey. Newly laid eggs were reared individually on excised kidney bean leaf as mentioned before. Observations were made at intervals of 12 hours and every molt was recorded until the sample immatures mites emerged into adults. The sex of the emerging adult was likewise recorded too. All stages of *P. ulmi* were provided abundantly and additional preys were supplied whenever necessary. Sample mites that developed into males were discontinued wherein those that developed into females were used for the fecundity studies.

Female survival and reproduction

The fecundity of *N. californicus* was determined at 20 and 25°C. From the above study, before the final molt of the female deutonymph, one adult male was provided and was ensured to mate once. The male was then removed and observations were made at intervals of 6 hours until the first egg was laid. Thereafter, the number of eggs laid was recorded every 24 hours until the ovipositing female died. All the eggs that were laid were removed and transferred individually to new excised apple leaf and were reared until adult to record the sex of the resulting F₁ progeny. Oviposition period, pre- and post-oviposition period was also calculated. The life history parameters at 20 and 25°C, the intrinsic rate of natural increase (r_m), net reproductive rate (R_0), mean generation time (T), and finite rate of increase (λ) was estimated according to the equation given by Birch (1948):

- $R_0 = \sum_{x=\alpha}^{\beta} l_x m_x$
- $T = \text{Ln } R_0 / r_m$
- $r_m = \text{Ln } (R_0) / T$
- $Dt = \text{Ln } (2) / r_m$
- $\lambda = e^{r_m}$

Longevity and fecundity data were analyzed with Mann-Whitney U-test or Kruskal-Wallis test. Multiple comparisons of means were done by Holm-Sidak method (Canlas *et al.* 2006).

Results

Immature development

In both the tested temperatures (20 and 25°C), more than 97% of the eggs hatched and more than 95% matured.

Immature survival rate was more than 90% at both of the temperatures 20 and 25°C. The total developmental time from egg to adult was 7.52 days for females at 20°C, and 5.12 days, at 25°C. Developmental times at two tested temperatures were not significantly different from each other ($P > 0.05$). The egg stage was the longest stage for each temperature tested, decreasing from 3 days at 20°C to 1.8 days at 25°C. The durations of the larval, protonymphal and deutonymphal stages were about the same, for the two temperatures tested. Duration of the whole immature phase (egg to adult emergence) decreased from 7.52 days to 5.12 days at 20°C and to 25°C, respectively (Table 1). The longevity of adults was highest at 20°C and decreased as the temperature increased (Table 1).

Table 1. Mean (\pm SE) developmental time and adult longevity (days) of *Neoseiulus californicus* of female (N= 25) at two constant temperatures under a 16L: 8D photoperiod.

Temp. (°C)	Egg	Larvae	Protonymph	Deutonymph	Adult longevity	Total developmental period	life span
20	3.00 \pm 0.02	1.08 \pm 0.06	1.64 \pm 0.10	1.80 \pm 0.082	50.40 \pm 0.10	7.52 \pm 0.167	57.52 \pm 0.217
25	1.80 \pm 0.09	1.04 \pm 0.04	1.20 \pm 0.12	1.09 \pm 0.09	36.80 \pm 0.082	5.12 \pm 0.17	43.12 \pm 0.203

Reproduction

At both temperatures, all emerged females oviposited within 2.64–4.12 days after emergence (Table 2). However, the fecundity and daily fecundity rates increased as increasing temperature ranging from 20 and 25°C (Table 2). The pre-oviposition period ranged from 4.12–2.64 days, oviposition from 17.88–16.48 days, and post-oviposition from 28.4–17.68 days at 20 and 25°C, respectively. The oviposition periods was 17.88 and 16.48 days, at 20 and 25°C, respectively.

Table 2. Mean durations (\pm SE) of adult phases (days) and fecundity of the *Neoseiulus californicus* at two constant temperatures, under a 16L: 8D photoperiod fed on *Panonychus ulmi*.

Stage	Temperature	
	20°C	25°C
Pre-oviposition	4.12 \pm 0.09	2.64 \pm 0.11
Oviposition	17.88 \pm 0.02	16.48 \pm 0.03
Post-oviposition	28.4 \pm 0.18	17.68 \pm 0.64
Eggs/female/day	1.16 \pm 0.09	1.91 \pm 0.02
Fecundity	20.84 \pm 0.09	31.64 \pm 0.13
N	25	25

Life table parameters

Calculated life table parameters are given in Table 3. The net reproductive rate (R_0) was highest at 25°C followed by 20°C. The intrinsic rate of natural increase (r_m) and finite rate of increase (λ) increased with temperature to 0.237 day⁻¹ and 1.2682 day⁻¹ at 25°C. The mean generation time (T , in days) and doubling time (D) decreased with increasing temperature.

Table 3. Population growth parameters of *Neoseiulus californicus* feeding on *Panonychus ulmi* at two temperatures: net reproductive rate (R_0), mean generation time (T), intrinsic rate of increase (r_m), and finite rate of increase (λ).

Temp. (°C)	Population growth parameter			
	R_0	T	r_m	λ
20	20.84	18.86	0.16101	1.1747
25	31.64	14.54	0.237569	1.2682

Discussion

The predatory mite *N. californicus* developed successfully at temperatures of 20 and 25°C with a low mortality rate of 6% and at least, 97% of eggs hatched into protonymph and only about 3% of the larvae did not reach maturity. The developmental period in *N. californicus* was the shortest among predatory mite species that have been studied, especially at the higher temperatures such as 25 and 30°C (Table 4). Compared with other predatory mites, *N. californicus* has the lowest thermal constant, but an intermediate lower threshold (Table 4). Generally, short developmental period and high fecundity are desirable traits for biological control agents of spider mites (Taj & Jung 2012).

In comparing of *P. ulmi* and *T. urticae* as food sources, the predator developed faster when feeding *P. ulmi* (Gotoh *et al.* 2006). For *N. californicus*, Taj & Jung (2012) reported a development period of 6.4 days at 20 °C and we found 7.52 days fed on *P. ulmi* while Kim *et al.* (2009) reported a development period of 8.7 days at 20°C fed on *T. urticae*. This increase in developmental rate might be attributable to differences in the nutritional quality of the prey provided.

In present study fed on *P. ulmi*, *N. californicus* had a lifetime fecundity of 31.64 eggs at 25 °C, less than that have been reported previously in other studied (Table 4), including the Spical strain (43.8–47.7 eggs (Gotoh *et al.* 2006)) fed on *P. ulmi*. The fecundity of present population studied fed on *P. ulmi*—also was less than the other strains, at 25°C, when those strains were fed on *T. urticae* (e.g. the Spical strain, 46.2–46.7 eggs (Gotoh *et al.* 2006)), the Riverside strain (43.3 eggs (Ma & Laing 1973)) or (54.5 eggs (Croft *et al.* 1998)), and an indigenous Japanese strain (41.6 eggs (Gotoh *et al.* 2004)).

Also, Taj & Jung (2012) reported a lifetime fecundity (63.9 eggs at 25°C) fed on *P. ulmi* that noticeably was greater than the similar studies.

The reported daily oviposition rate of *N. californicus* fed on *P. ulmi* by Gotoh *et al.* (2006) was 3.0–3.2 eggs/female/day at 25°C, while we found a lower number 1.91 eggs/female/day. On the other hand, at 25°C and a diet of *T. urticae*, the egg production rate of different *N. californicus* strain including Riverside strain (3.1 eggs/female/day, Ma & Laing 1973)), the Japanese strain (3.3–3.4 eggs/female/day (Gotoh *et al.* 2006)) and the Korean strain (3.2 eggs/female/day (Taj & Jung 2012)) was almost similar

together. In terms of biological control, the use of various developmental stages seems beneficial. Jung *et al.* (2003) reported that the inability of a native phytoseiid mite, *Neoseiulus womersleyi*, to consume *P. ulmi* eggs hindered the biological control program for the spider mite complex of *T. urticae* and *P. ulmi*.

Table 4. Synopsis of net reproductive rate (R_0), intrinsic rate of natural increase (r_m) and mean generation time (t_G) for some phytoseiid species.

species ^a	Temp. tested (°C)	R_0	r_m	t_G	Prey ^b	References
<i>N. californicus</i>	25	29.10	0.29	11.70	<i>T. urticae</i> (G) (egg stage)	Ma & Laing (1973)
	25	25.30	0.19	16.70	<i>M. progresivus</i> (all stages)	Mesa <i>et al.</i> (1990)
	25	29.90	0.19	17.40	<i>T. urticae</i> (G) (all stages)	Mesa <i>et al.</i> (1990)
	25	36.60	0.26	13.90	<i>T. urticae</i> (G) (all stages)	Castagnoli & Simoni (1991)
	25	11.20	0.23	11.60	<i>T. urticae</i> (G) (all stages)	Rencken & Pringle (1998)
	25	-	0.12	-	<i>T. urticae</i> (G) (all stages) on tomato	Castagnoli <i>et al.</i> (1999)
	25	-	0.27	-	<i>T. urticae</i> (G) (all stages) on strawberry	Castagnoli <i>et al.</i> (1999)
	25	28.60	0.27	15.30	<i>T. urticae</i> (G) (all stages) on lima bean	Gotoh <i>et al.</i> (2004)
	25	22.90	0.21	17.50	<i>T. urticae</i> (G) (all stages) on kidney bean	Canlas <i>et al.</i> (2006)
	25±1	32.95	0.31	11.23	<i>T. urticae</i> (R) (egg stage) on common bean	Gotoh <i>et al.</i> (2006)
	25	49.24	0.25	15.31	<i>P. ulmi</i> (all stages) on apple	Taj & Jung (2012)
	25±1	33.94	0.30	11.50	<i>T. kanzawai</i> (egg stage) on tea	Gotoh <i>et al.</i> (2006)
	25±1	34.04	0.31	11.94	<i>A. viennensis</i> (egg stage) on cherry	Gotoh <i>et al.</i> (2006)
	25±1	42.9	0.33	11.14	<i>T. cinnabarinus</i> (all stages) on kidney bean	Kustutan & Cakmak (2009)
	25±1	28.81	0.31	11.02	<i>P. ulmi</i> (all stages) on apple	Gotoh <i>et al.</i> (2006)
25±1	31.02	0.29	11.68	<i>P. citri</i> (egg stage) on sour orange	Gotoh <i>et al.</i> (2006)	
25	31.64	0.23	14.54	<i>P. ulmi</i> (all stages) on apple	Present study	

^a N *Neoseiulus*, A *Amblyseius*, P *Phytoseiulus*, T *Typhlodromus*

^b T *Tetranychus*, M *Mononychellus*, A *Amphitetranynchus*, P *Panonychus*.

Mite stages provided: G green form, R red form

Summary table was idea lifted and modified from Gotoh *et al.* 2004.

Our results indicated that postoviposition period of *N. californicus* (17.68 day) accounts for about 55% of the total adult longevity (Table 2) which was close to the Korean native population (21.94 days), the Japanese native population (12.9 days; Gotoh *et al.* 2004) and higher than the Italian strain (9.00 days; Castagnoli & Simoni 1991) the African strain (8.30 days; Rencken & Pringle 1998) and the American strain (9.90 days; Hart *et al.* 2002).

The long post-oviposition period of this predatory mite is presumably to be due to the shortage of sperms that were inseminated after the adult eclosion, because female phytoseiid mites usually require multiple matings to attain their full reproductive capacity (Gotoh *et al.* 2004). If this also the case with *N. californicus*, then multiple mating would increase egg production (shorting the postoviposition period) and increasing food uptake (Gotoh *et al.* 2004). Unmated females had significantly greater longevity and a significantly lower predation rate (number of prey consumed) than mated females in *Phytoseiulus macropilis* (Banks), *P. persimilis* and *A. andersoni* (Prasad 1967; Amano & Chant 1977). This is because phytoseiid mites allocate a remarkably large fraction (about 70% in *P. persimilis*) of food ingested to egg production and therefore oviposition is strongly correlated with predation (Sabelis & Janssen 1994).

There are many reports on the life-history traits of predatory mites in relation to their importance as biological control agents (Gotoh *et al.* 2004). The r_m -value of *N. californicus* in present study was 0.237 day⁻¹ at 25°C which is close to the obtained values for Korean strain (Taj & Jung 2012), the Japanese strain (Gotoh *et al.* 2004), Chile strain (Ma & Laing 1973) and Italian strain (Castagnoli & Simoni 1991; Castagnoli *et al.* 1999), but higher than the value of the Colombian strain (Mesa *et al.* 1990; Table 4). The R_0 - and T-values were 31.64 offspring and 14.54 days at 25°C respectively. A similar tendency was observed in the Korean strain, the Japanese strain and the Chilean strain of *N. californicus* (Ma & Laing 1973). There is large variation in the r_m -values among predatory mite species (Gotoh *et al.* 2004). It is speculated that this is because there are interspecific differences in the population growth parameters (Gotoh *et al.* 2004). A wide difference in r_m -values is sometimes found between populations of the same species (Table 4).

A part of this variation can be explained by different life stages of the prey that are supplied to the predatory mites. When *T. occidentalis* (Nesbitt) was fed on active stages of the Pacific spider mite *Tetranychus pacificus* McGregor, its r_m -values (0.207 day⁻¹) was lower than when it was fed on eggs of *T. pacificus* (r_m = 0.244 day⁻¹) (Bruce-Oliver and Hoy 1990). Similarly, the r_m -values of *T. occidentalis* (Croft 1972) and *Amblyseius longispinosus* (Evans) (Kolodochka 1983) were larger when they fed on eggs of *T. urticae* than when they fed on nymphs or adult females of the same species. Furthermore, the estimated r_m -values of the Italian strain of *A. californicus* were larger when the mites were fed *T. urticae* (stages not specified) that had been reared on strawberry leaves (r_m = 0.274 day⁻¹) than when they were fed *T. urticae* that had been reared on tomato leaves (r_m = 0.118 day⁻¹) (Castagnoli *et al.* 1999). This shows that it is important to know the diet and host plant histories of the predatory mites in order to design a successful biological control program.

The r_m -values (0.16–0.237 day⁻¹) of the *N. californicus* strains are similar to or slightly higher than those of *Tetranychus* mites such as *T. urticae* (0.218–0.282 day⁻¹) (Sabelis 1985) and *T. kanzawai* Kishida (0.187–0.284 day⁻¹) (Gotoh & Gomi 2003). Although the r_m -values of spider mites are affected by characteristics of the host plant,

the results given here suggest that *N. californicus* has the potential become an effective biological control agent. However, intraspecific variation in the r_m -values of *N. californicus* and their close resemblance to the r_m -values of spider mites may reduce its potential as a biocontrol agent during the peak season of spider mites (Gotoh *et al.* 2004).

Details of strain, diet and study conditions including the plant media can be influenced on life table parameters. See Tables 7 and 8 for more comparisons among studies. It is obvious that the reproductive capacity of *N. californicus* is higher than that of many other generalist phytoseiids such as *Amblyseius orientalis* (Xia *et al.* 1998), *A. degenerans* (Takafuji & Chant 1976) and *A. bibens* (Blommers 1976).

Life table statistics, such as those presented here, provide a valuable tool to help evaluate the potential of a biological control agent in the context of local seasonal temperatures and use of this approach has proved successful previously (Bernal & González 1997). As compared to other strains or species of *Neoseiulus* in the world, the higher fecundity and R_0 value, short generation time, and moderate r_m of the population of *N. californicus* indicate significant potential as an effective biological control agent of *P. ulmi*.

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پارامترهای جدول زیستی کنه *Neoseiulus californicus* (Acari: Phytoseiidae) با تغذیه از کنه قرمز اروپایی *Panonychus ulmi* (Acari: Tetranychidae) در شرایط آزمایشگاهی

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چکیده

پارامترهای جدول زیستی کنه *Neoseiulus californicus* (Athias-Henriot)، یکی از شکارگرهای عمومی کنه‌های تارتن و حشرات کوچک در شرایط آزمایشگاهی در دو دمای ۲۰ و ۲۵ درجه سلیسیوس و رطوبت نسبی 5 ± 60 درصد و در شرایط نوری ۸:۱۶ (تاریکی: روشنایی) مورد بررسی قرار گرفت. کنه قرمز اروپایی *Panonychus ulmi* (Koch)، از آفات مهم باغ‌های سیب در ایران، به عنوان طعمه (تمام مراحل زیستی) مورد استفاده قرار گرفت. طول مدت مراحل نابالغ به ترتیب از ۵/۱۲ تا ۷/۵۲ روز در محدوده زمانی ۲۰ و ۲۵ درجه سلیسیوس متفاوت بود. با افزایش دما

از ۲۰ به ۲۵ درجه سلیسیوس، نرخ خالص تولیدمثل (R_0) از ۲۰/۸۴ نتاج ماده به ۳۱/۴۶ نتاج ماده افزایش یافت. بیشترین مقدار نرخ ذاتی رشد (r_m) و نرخ متناهی افزایش (λ) در دمای ۲۵ درجه سلیسیوس (به ترتیب ۰/۲۳۷، ۱/۲۶ روز) به دست آمد که بیشتر از مقادیر محاسبه شده در دمای ۲۰ درجه سلیسیوس بود (به ترتیب ۰/۱۶۱، ۱/۱۷ روز). میانگین مدت زمان یک نسل (T) کنه‌های ماده با افزایش دما از ۲۰ به ۲۵ درجه سلیسیوس، از ۱۸/۸۶ به ۱۴/۵۴ روز کاهش پیدا کرد. به طور کلی، نتایج نشان داد که در محدوده دمایی ۲۰-۲۵ درجه سلیسیوس، کنه *N. californicus* با تغذیه از کنه *P. ulmi* قادر به رشد و نمو بوده و توانایی مناسب برای کنترل آن دارد.

واژگان کلیدی: تولیدمثل، کنترل بیولوژیک، کنه تارتن، کنه شکاگر، نرخ ذاتی افزایش جمعیت

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