

Post-embryonic development and life table parameters of *Neoseiulus californicus* on *Tetranychus desertorum* and *Panonychus citri* (Acari: Phytoseiidae, Tetranychidae) under laboratory conditions

Desarrollo post-embrional y parámetros de tabla de vida de *Neoseiulus californicus* sobre *Tetranychus desertorum* and *Panonychus citri* (Acari: Phytoseiidae, Tetranychidae) bajo condiciones de laboratorio

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ABSTRACT

The postembryonic development, and life table parameters of the *Neoseiulus californicus* were studied under laboratory conditions in order to evaluate the potentiality of this predator for feeding on two phytophages mites *Tetranychus desertorum* (desert spider mite) and *Panonychus citri* (red spider mite). *Tetranychus desertorum* and *P. citri* may be considered as optimal food for *N. californicus*, which obtained survival rates of 100 %, on them. The time of the postembryonic development was significantly different ($p < 0.05$) between both diets. The periods of ovoposition, postoviposition and longevity of the *N. californicus* were 17.17; 4.37 and 22.53 days, respectively, fed with *T. desertorum*, and 14.84; 5.23 and 21.06 days, respectively, fed with *P. citri*. The demographic parameters of *N. californicus* obtained fed with *T. desertorum* and *P. citri* were: intrinsic rate of increase (r_m) = 0.269 ± 0.004 and 0.307 ± 0.004 , mean generation time (T) = 12.847 ± 0.185 and 10.791 ± 0.142 , net reproductive rate (R_0) = 31.792 ± 1.478 and 27.352 ± 1.187 , finite rate of increase (λ) = 1.309 ± 0.006 and 1.359 ± 0.006 , respectively. The high values of r_m and λ registered for *N. californicus* under experimental conditions are indicators of control potential that this phytoseiid presented as a predator over these phytophages mites.

Keywords: biological control, oviposition, postembryonic development, survival.

RESUMEN

El desarrollo postembrionario y parámetros de tabla de vida de *Neoseiulus californicus* se estudiaron bajo condiciones de laboratorio para evaluar la potencialidad de este depredador para alimentarse sobre los ácaros fitófagos *Tetranychus desertorum* (arañita del desierto) y *Panonychus citri* (arañita roja de los cítricos). *Tetranychus desertorum* y *P. citri* pueden considerarse presas óptimas para *N. californicus* porque la tasa de supervivencia fue de un 100 % con ambos alimentos. La duración del desarrollo postembrionario de *N. californicus* fue significativamente diferente ($P < 0,05$) entre las dos dietas. Los períodos de oviposición, post-oviposición y longevidad de *N. californicus* fueron 17,17; 4,37 y 22,53 días (alimentado con *T. desertorum*) y 14,84; 5,23 y 21,06 días (alimentado con *P. citri*). Los parámetros demográficos de *N. californicus* alimentado con *T. desertorum* y *P. citri*, fueron: tasa intrínseca de crecimiento (r_m) = $0,269 \pm 0,004$ y $0,307 \pm 0,004$, tiempo generacional (T) = $12,847 \pm 0,185$ y $10,791 \pm 0,142$, tasa neta reproductiva (R_0) = $31,792 \pm 1,478$ y $27,352 \pm 1,187$, tasa finita de crecimiento (λ) = $1,309 \pm 0,006$ y $1,359 \pm 0,006$, respectivamente. Los valores altos de r_m y λ registrados para *N. californicus*, bajo las condiciones experimentales, son indicadores del potencial de control que presentaría este fitoseído como depredador de estos ácaros fitófagos.

Palabras clave: control biológico, desarrollo postembrionario, oviposición, supervivencia.

INTRODUCTION

Mites are the most important crop pests after insects (Tello *et al.* 2011). These small arachnids cause severe damage to many crops, especially at high population levels (Mirabal 2003). *Tetranychus desertorum* Banks is associated with more than 173 host plants, distributed in Argentina, Brazil, China, United States, Hawaii, Mexico and Venezuela, among other countries (Bolland *et al.* 1998). The citrus red mite, *Panonychus citri* (McGregor), is a major citrus pest with a worldwide distribution (Shen *et al.* 2016). In Chile, *T. desertorum* and *P. citri* are pests of economic importance (Tello *et al.* 2013; Ragusa *et al.* 2000). *T. desertorum* is distributed from the Arica y Parinacota Region to the La Araucanía Region. In the Tarapacá Region, its hosts include alfalfa (*Medicago sativa* L.), beans (*Phaseolus vulgaris* L.), watermelon (*Citrullus lanatus* Th.) and malabar gourd (*Cucurbita ficifolia* B.) (Klein & Waterhouse 2000). *Panonychus citri* is distributed in Chile from the Arica and Parinacota Region to the General Libertador Bernardo O'Higgins Region. It is associated with citrus lemon (*Citrus limon* (L.) Burm.), tangerine (*C. reticulata* Blanco), orange [*C. sinensis* (L.) Osbeck.], Grapefruit (*C. paradisi* Macfad.) (Klein & Waterhouse 2000).

Predatory mites of the Phytoseiidae family 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 (Çobanoğlu *et al.* 2018; Ghazi *et al.* 2016; De Moraes *et al.* 2004). Although there is abundant information in the world regarding its characteristics, systematics and geographical distribution, in Chile research has mainly focused on descriptions and distribution of species from the central and southern part of the country, being scarce knowledge about the biodiversity of phytoseiid mites, especially in northern Chile. Information on existing species in the Tarapacá Region has been provided by Ragusa (2000), Ragusa *et al.* (2000), Ragusa & Vargas (2002), Ragusa (2003), Tello *et al.* (2011) and Peralta & Tello (2019). *Neoseiulus californicus* (McGregor) [= *Cydnodromus californicus* (McGregor)] is an effective biological controller of red spider mites, other plague mites and small insects (Castagnoli & Simoni 2003).

Neoseiulus californicus has a high tolerance for high temperatures. Gotoh *et al.* (2004) recorded a hatchability of 97.8 % and a mortality of 14.4 % at 35 °C for this phytoside. At 34 °C, *N. californicus* presented a hatching of 97.1 % and a survival to adulthood of 74.3 % (El Taj & Jung, 2012). Canlas *et al.* (2006) studied the developmental time (in days) of immature stages of *N. californicus* at five constant temperatures. The developmental time was shortest at 35 °C with

an average of 3.41 days for males and 3.78 days for females. Kim *et al.* (2012) indicate daily fecundity of *N. californicus* was greatest at 24 °C (1.9 daily egg/female) and 36 °C (1.8 daily egg/female), without statistical difference between both temperatures.

The average annual maximum and minimum temperatures recorded in Pica are 35.4±0.3 °C and 6.00±1.1 °C, respectively, and the average relative humidity is 37.0±3.1 % (Source: Agromet, INIA Agrometeorological Network, <http://agromet.inia.cl/estaciones.php#estaciones>).

The objective of this study was to evaluate the effect of two phytophagous mites (*T. desertorum* and *P. citri*) on the biological parameters of *N. californicus* in laboratory conditions that mimic the climatic conditions of the Pica Oasis.

MATERIALS AND METHODS

TRIAL LOCATION

The bioassays were performed in the laboratories of the Huayquique Campus dependent on the Arturo Prat University, under experimental conditions of 30.90±0.01 °C temperature, 43.32±0.03 % relative humidity (RH) and 14 hours light (L) and 10 hours dark (D) photoperiod. These micro-environmental conditions tried to emulate those that normally occur in the desert of northern Chile, where high temperatures and low levels of relative humidity are normally recorded.

BIOLOGICAL MATERIAL

Neoseiulus californicus was collected at the Canchones Experimental Station (20°26'40.18"S; 69°32'03.87"W), on alfalfa (*Medicago sativa* L.). For reproduction, 12 cm diameter black plastic plates were used (Swirski *et al.* 1970), using *T. cinnabarinus* as food. *Tetranychus desertorum* was collected in alfalfa plants at the Canchones Experimental Station. Both mites were multiplied in bean plants (*Phaseolus vulgaris* L.), grown sequentially (planted every 7 days) in plastic flower pots. *Panonychus citri* was collected from Pica (20°29'12.43"S; 69°19'33.92"W) on *C. sinensis*. This mite was raised on grapefruit fruits (*Citrus paradisi* Macfad) in 7-day infestation sequences. The three species of mites were kept in breeding conditions at 25.97±0.36 °C, 60.17±1.14 % RH and photoperiod of 14:10 h (L:D).

POST EMBRYONIC DEVELOPMENT

In these trials the potential for development from the egg-to-adult state of *N. californicus* was determined, fed a mixed diet of different stages administered *ad libitum* of *T. desertorum* and *P. citri* separately. A 20-hour-old egg was placed on a 4x4

cm diameter plate, observed daily, at the same time, until the adult was obtained. These eggs came from different females kept in breeding with approximately ten generations elapsed since the establishment of the breeding. The survival and duration of each of the developmental states of phytoseiids was evaluated. The trials had 30 (for *P. citri*) and 31 (for *T. desertorum*) repetitions, corresponding to each repetition one phytoseiid egg per plate. All observations were made with a stereoscopic magnifying glass Carl Zeiss Stemi SV 6 (Germany).

LIFE TABLE PARAMETERS

The methodology described by Birch (1948) and applied by Ragusa *et al.* (2000), Vargas *et al.* (2005) and Tello *et al.* (2009a, 2009b) was used for determining the life table parameters of *N. californicus*. These parameters were: the intrinsic rate of increase (r_m), net reproductive rate (R_0), generation time (T) and the finite rate of increase (λ). In each plate a couple of phytoseiids was arranged, registering the ovipostura every 24 hours until the death of the female. The dead males were replaced so that the female was constantly fertilized. In addition to oviposture, the survival of the females in the cohort, the survival of the juveniles and the proportion or sex ratio were determined. The trials had 31 repetitions for *P. citri* and 30 repetitions for *T. desertorum*, corresponding to each repetition one female phytoseiid per plate.

DESIGN AND STATISTICAL ANALYSIS

A completely randomized design was used for all experiments. Normality was evaluated through the Shapiro-Wilks test. The survival percentage was analyzed through the non-parametric Wilcoxon test (Mann-Whitney U, $p < 0.05$, Zar 2010). To compare the duration of the egg to adult cycle between males and females, the t-Student test was applied ($p < 0.05$). For the life table, the survival rate (l_x) was expressed as the number of individuals alive at a time x, while the fecundity rate at a specific age (m_x) was calculated based on the number

of female offspring produced from a female in a time x. The estimated population parameters were: 1) net reproductive rate (R_0), 2) generation time (T), 3) intrinsic rate of increase (r_m), and 4) finite rate of increase (λ), which were estimated at from the results of fecundity and survival of females. The life table parameters were calculated through the R statistical data analysis environment, version 3.5.1. (R Core Team 2018) using the life table computer program.r (Nunes-Maia *et al.* 2014). To make comparisons between the life table parameters of the phytoseiid fed with two species of tetranychids, the standard deviation at a 95 % confidence interval was estimated using the Jackknife statistical technique (Ansaloni *et al.* 2007). The biological parameters were subsequently compared through a t-Student test ($p < 0.05$).

RESULTS

SURVIVAL AND DURATION OF THE LIFE CYCLE OF *N. CALIFORNICUS* FED WITH DIFFERENT DIETS.

No significant differences were detected between the survival rates of the two diets ($W = 914.50$; $p = 0.3094$). It is clearly observed that the two foods had a positive influence when they were supplied reaching a survival of 100 %, being able to be characterized as optimal foods for *N. californicus*.

The duration of the cycle from egg to adult of *N. californicus* was 6.39 (SD: ± 0.95 ; $n = 31$) days fed with *T. desertorum* and 5.57 (± 0.57 ; $n = 30$) days, fed with *P. citri*, with highly significant differences between both ($t = -4.02$, $fd = 53$, $p < 0.0001$). In Table 1, it is observed that there were no significant differences between the two diets at the level of duration time of protonymphs ($t = 0.11$, $fd = 59$, $p = 0.9139$) and deutonymphs ($t = -0.17$, $fd = 59$, $p = 0.8626$). The mobile states of larvae and adults (males and females) showed significant differences when fed with *T. desertorum* and *P. citri*. In the case of *N. californicus* larvae, they lasted significantly longer when fed with *P. citri* ($t = 4.71$, $fd = 59$, $p < 0.0001$).

TABLE 1. Effect of food type (*Tetranychus desertorum* and *Panonychus citri*) on the duration of post-embryonic development of *Neoseiulus californicus*. / Efecto del tipo de alimento (*Tetranychus desertorum* y *Panonychus citri*) sobre la duración del desarrollo postembrionario de *Neoseiulus californicus*.

Food	n ¹	Egg ²	Larva ²	Protonymph ²	Deutonymph ²	Adult		Egg-adult ³
						Female ³	Male ³	
<i>T. desertorum</i>	31	2.45±0.57 b	1.16±0.37 a	1.42±0.50 a	1.35±0.49 a	6.37±0.99 A b	6.50±0.84 A b	6.39±0.95 b
<i>P. citri</i>	30	1.13±0.35 a	1.67±0.48 b	1.43±0.50 a	1.33±0.48 a	5.58±0.58 A a	5.50±0.55 A a	5.57±0.57 a

¹Number of individuals tested.

²Mean±SD in a column followed by different uppercase letters are significantly different by t-Student ($P < 0.05$).

³Mean±SD in the same row followed by different lowercase letters are significantly different by t-Student ($P < 0.05$).

In the adult state, the females of *N. californicus* fed with *T. desertorum* (adult egg-female = 6.37 days) took significantly longer to reach adulthood than the females fed with *P. citri* (adult female-egg = 5.58 days), ($t = -3.22$, $fd = 42$, $p < 0.05$), the same thing happening with males of *N. californicus* ($t = -2.55$, $fd = 10$, $p < 0.05$).

EFFECT OF TWO FOODS (*T. DESERTORUM* AND *P. CITRI*) ON OVIPOSITION, LONGEVITY AND SURVIVAL OF ADULT FEMALES OF *N. CALIFORNICUS*

The effect of the diet on the duration of the phases of the adult state of *N. californicus* are given in Table 2. No significant differences were found for all these periods between the two diets: pre-oviposition period ($t = 0.00$, $fd = 59$, $p = 0.9999$), oviposition ($t = -1.84$, $fd = 53$, $p = 0.0715$), postoviposition ($t = 0.87$, $fd = 59$, $p = 0.3904$) and longevity ($t = -1.09$, $fd = 53$, $p = 0.2788$). The number of eggs per female was significantly higher ($t = 2.40$, $fd = 59$, $p < 0.05$) when the females of *N. californicus* were fed *T. desertorum*. When expressing this

oviposture rate as eggs/female/day, no significant differences were found ($t = -0.45$, $fd = 59$, $p = 0.6543$).

LIFE TABLE PARAMETERS OF *NEOSEIULUS CALIFORNICUS* FED WITH *TETRANYCHUS DESERTORUM* AND *PANONYCHUS CITRI*.

The maximum daily oviposition rate of *N. californicus* fed with *T. desertorum* was reached on the seventh day and remained at high levels until day 18, from that day it began to decay until it reached zero on day 33. The rate of survival of *N. californicus* fed with *T. desertorum* was maximum until day 8 and then began to decrease from day 13, where it presented a 70 % survival and subsequently fell to 10 % on day 26 (Fig. 1A).

The maximum daily oviposition rate of *N. californicus* fed with *P. citri* was reached on the seventh day and remained at high levels until day 16, from that day it began to decline until it reaches zero on day 30. The rate of survival of *N. californicus* fed with *P. citri* was maximum until day 7 and after which it

TABLE 2. Durations of phases of the adult state and the oviposition rates of *Neoseiulus californicus* fed with *Tetranychus desertorum* (n = 31) and *Panonychus citri* (n = 30) at 29.4 °C, 42.4 % RH, and 14:10 L:D. / Duración de los períodos adultos y tasas de oviposición de *Neoseiulus californicus* alimentado con *Tetranychus desertorum* (n = 31) y *Panonychus citri* (n = 30) a 29,4 °C; 42,4 % HR y 14:10 L:O.

Periods	<i>Tetranychus desertorum</i>	<i>Panonychus citri</i>
	Duration of the adult stages (days±SD)	
Preoviposition	1.00 ± 0.00 a	1.00 ± 0.00 a
Oviposition	17.17 ± 4.63 a	14.84 ± 4.95 a
Postoviposition	4.37 ± 4.80 a	5.23 ± 5.06 a
Longevity	22.53 ± 6.50 a	21.06 ± 8.65 a
Oviposition (eggs no.±SD)		
Total egg·female ⁻¹	44.00 ± 11.20 a	37.55 ± 9.07 b
Egg·female ⁻¹ ·day ⁻¹	2.61 ± 0.42 a	2.67 ± 0.49 a

Means followed by different letters within each row are significantly different according to t-Student test ($p < 0.05$).

TABLE 3. Life table parameters of *Neoseiulus californicus* fed with *Tetranychus desertorum* (n = 31) and *Panonychus citri* (n = 30). / Parámetros de tabla de vida de *Neoseiulus californicus* alimentado con *Tetranychus desertorum* (n = 31) y *Panonychus citri* (n = 30).

Demographic parameters	Food (preys)	
	<i>Tetranychus desertorum</i>	<i>Panonychus citri</i>
R_o	31.792 ± 8.093 a	27.940 ± 8.390 b
r_m	0.276 ± 0.018 b	0.308 ± 0.017 a
T	12.531 ± 0.806 b	10.737 ± 0.554 a
λ	1.318 ± 0.024 b	1.361 ± 0.023 a

Means followed by different letters within each row are significantly different according to t-Student test ($p < 0.05$). Data are reported as the mean ± standard deviation

began to decrease on day 16, where it presented a 68 % survival rate and decreased to 4 % on day 27 (Fig. 1B).

The values of R_0 of the three species were not significantly different ($t = 1.82$; $d.f. = 59$; $p = 0.0732$) (Table 3). The r_m values obtained for *N. californicus* fed with *T. desertorum* were lower than the r_m values obtained for this phytoseiid fed with

P. citri ($t = 7.12$; $d.f. = 59$; $p < 0.0001$). The generational time was different between the two preys ($t = 10.09$; $d.f. = 52$; $p < 0.0001$). *N. californicus* fed with *T. desertorum* had the longest generational time. The finite rate of growth also differed significantly between species ($t = -7.25$; $d.f. = 59$; $p < 0.0001$).

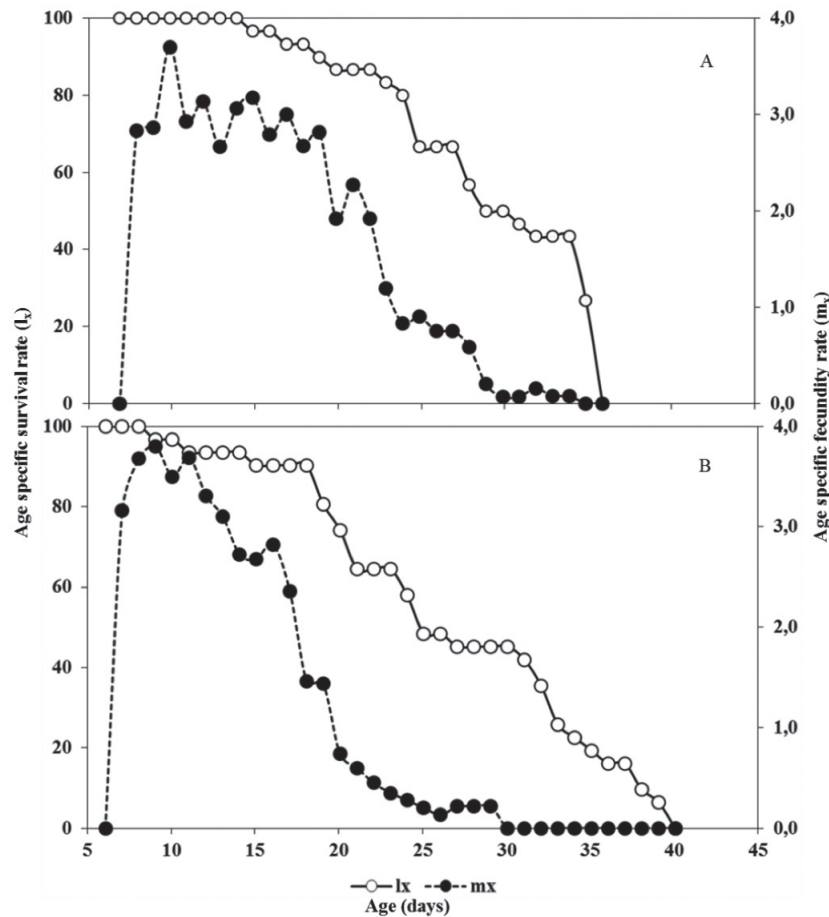


FIGURE 1. Age-specific survivorship (l_x) and age-specific fecundity (m_x) of *Neoseiulus californicus* female fed with *Tetranychus desertorum* (A) and *Panonychus citri* (B). l_x = proportion of females alive at age x . m_x = proportion of females \times age-specific oviposition. / Supervivencia a una edad específica (l_x) y fertilidad a una edad específica (m_x) de hembras de *Neoseiulus californicus* alimentadas con *Tetranychus desertorum* (A) y *Panonychus citri* (B). l_x = proporción de hembras vivas a una edad x . m_x = proporción de hembras \times oviposición a una edad específica.

DISCUSSION

The results obtained in the survival, and development time of *N. californicus* fed with different stages of development of *T. desertorum* and *P. citri* are congruent with those reported by Ragusa *et al.* (2000), who obtained 100 % survival of *C. picanus* (= *Neoseiulus idaeus* Denmark & Muma) fed with *T. urticae* eggs and 96 % with *P. citri*, and also development times for females of *N. picanus* of 4.3 and 3.9 days, respectively, without significant differences ($p < 0.05$) between both

preys. Escudero & Ferragut (2005) obtained for *T. urticae*, *T. turkenstani* Ugarov, *T. ludeni* Zacher and *T. evansi* Baker & Pritchard: 93.2; 91.4; 97.1 and 75.7 % survival, respectively. Gotoh *et al.* (2006) obtained a high survival of *Cydnodromus* (= *Neoseiulus*) *californicus* feeding it with eggs of *T. urticae* and *T. kanzawai* Kishida, therefore, they were considered of high nutritional value. Pratt *et al.* (1999) obtained a high percentage of survival by feeding *Neoseiulus fallacis* (Garman) with different stages of *T. urticae* (100 %) and *T. lintearius* Dufour (94 %).

The fecundity (total eggs / female) of *N. californicus* was affected by the diet. Ragusa *et al.* (2000) using *T. urticae* and *P. citri* to feed *N. picanus*, found no significant differences in the total eggs/female. These differences may be due to different species of phytoseiid or to the environmental conditions of the tests, since Ragusa *et al.* (2000) worked with a temperature of 26 ± 1 °C and 70 ± 5 % of RH. Kustutan and Çakmak (2009) recorded a fecundity of 37.18 eggs/female for *N. californicus* fed with *T. cinnabarinus* at 30 °C, similar to our results for *P. citri*. Kazak *et al.* (2002) obtained a total fertility for *Neoseiulus umbricatus* Chant of 43.6 eggs/females at 30 °C, using a diet of all stages of *T. cinnabarinus*.

The larval emergence percentages for *N. californicus* obtained in this study, far exceed the reports published in the literature on the survival of eggs in low RH conditions. *N. californicus* obtained 73 % of hatching at a RH close to 40 %. The high survival of *N. californicus* eggs can be compared with *Euseius citrifolius* (De Vis *et al.* 2006) and *C. picanus* (= *N. idaeus*) at similar RH, found that *E. citrifolius* (Denmark & Muma) and *Metaseiulus camelliae* (Chant & Yoshida-Shaul) have a high viability in their eggs in the low humidity season, indicating that these species persist in the dry season. In the African sub-Sahara, the netropical phytoseiid *Typhlodromus aripo* (De Leon), is an excellent biological control of the cassava spider mite *Mononychellus tanajoa* (Bondar) and is able to survive the dry and hot season, at very low densities in the microenvironment of the cassava apex (Zundell *et al.* 2007). *Neoseiulus idaeus* (Denmark & Muma) is able to survive in arid areas; the eggs of this phytoseiid are very tolerant of low humidity, supporting less than 30 % RH; larval stages survive both the absence of food and water, and the adult stages are good controllers of *Tetranychus* spp. (Van Dinh *et al.* 1988).

According to Bakker *et al.* (1993), air humidity is one of the main factors that influence the efficiency of predatory mites, likewise, Sabelis (1985) and Walzer *et al.* (2007) indicate that the egg is the state most susceptible to adverse weather conditions. The other stages are mobile and can be moved towards favorable microenvironments to protect itself against adverse conditions. Walzer *et al.* (2007) breeding eight *N. californicus* strains from France, Italy, Spain, Chile and the United States at 25 °C and four levels of relative humidity that fluctuated between 64.0 and 75.5 %. The most promising strains lines to act in low humidity environments, with high probability of survival of eggs and juvenile states were found in the California-United States strains and the Sicily-Italy strains. The prevalence of *N. californicus* in the desert zone

of Chile may be partially explained by its capacity to tolerate conditions of high temperature and low RH.

Tello *et al.* (2011), obtained for *P. iorgius* a Ro of 28.913 females/generation when it fed with eggs of *T. desertorum*. These results were similar to those of Abou-Setta *et al.* (1997) who reported rates of 23.69 for *P. rotendus* fed with *T. urticae* eggs. In our study a Ro of 31.792 females/generation was obtained. The small difference in these results may be due to experimental conditions such as temperature, relative humidity and photoperiod. Ragusa *et al.* (2000) obtained rates similar to those obtained in our investigation (29.94 and 28.35 females/generation for *C. picanus* fed with eggs of *T. urticae* and *P. citri*, respectively), however, the photoperiod and temperature were similar, instead the RH was particularly low in our assay, but affecting poorly the eggs viability. This seems to indicate that *N. californicus* has a high reproductive capacity when feeding with these species of tetranychids under these extreme experimental conditions. The Ro rates obtained in this trial for *N. californicus* fed with *T. desertorum* and *P. citri* describe a promising biocontroller for these phytophagous mites.

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 plague (Persad & Khan, 2002; Kontodimas *et al.* 2007). Table 4 shows 28 studies analyzed, ordered by r_m from highest to lowest. To establish comparisons between the studies, the data were grouped into three ranges: high, medium and low, ubicating our study of *N. californicus* fed with *P. citri* in the high range, can be considered as a phytoseiid species highlighted for biological control. *N. californicus* fed with *T. desertorum* it ubicates in the middle range of the table.

It's possible that the good performance of *N. californicus* may be due to *P. citri* being a more nutritious prey for this phytoseiid than *T. desertorum*. It could also be argued that by feeding *N. californicus* with a mixture of all stages of development of each tetranychid, in the case of *T. desertorum*, for producing its females very dense webs (Piedrahita, 1974), this may have affected its performance when it fed with this tetranychid.

Tello *et al.* (2009b) obtained values of $r_m = 0.289$ for *N. picanus* fed with eggs and mixed diet of *T. cinnabarinus*, under experimental conditions of 29 °C and 42 % RH, these values are similar to those obtained in this study with respect to *N. californicus* fed with *T. desertorum* where the $r_m = 0.269$. It is necessary to indicate that there are few studies with relative humidity as low as that of our trials.

TABLE 4. Demographic parameters for species of phytoseiids fed on eggs of different species of mites of the family Tetranychidae, at the different temperature (°C) and relative humidity (% RH) conditions indicated for each species. / Parámetros de tablas de vida para distintos fitoseídos criados sobre huevos de diferentes arañas de la familia Tetranychidae, a diferentes condiciones de temperatura (°C) y humedad relativa (% HR) indicadas para cada especie.

Phytoseiidae	Prey (Tetranychidae species)	r_m	λ	T	Ro	Experimental conditions °C, % RH	References
<i>P. persimilis</i>	<i>T. ludeni</i>	0.424	—	11.57	40.78	25, 70-80	Escudero & Ferragut (2005)
<i>P. longipes</i>	<i>T. evansi</i>	0.416	1.380	8.17	13.84	30, 80±10	Ferrero <i>et al.</i> (2007)
<i>C. picanus</i>	<i>T. urticae</i>	0.377	1.458	9,00	29.9	26, 70±5	Ragusa <i>et al.</i> (2000)
<i>P. persimilis</i>	<i>T. urticae</i>	0.373	—	12.85	45.61	25, 70-80	Escudero & Ferragut (2005)
<i>P. persimilis</i>	<i>T. turkestanii</i>	0.367	—	12.79	43.02	25, 70-80	Escudero & Ferragut (2005)
<i>C. californicus</i>	<i>T. urticae</i>	0.34	1.405	10.45	19.73	30, 70-80	Gotoh <i>et al.</i> (2004)
<i>C. californicus</i>	<i>T. ludeni</i>	0.337	—	16.04	47.37	25, 70-80	Escudero & Ferragut (2005)
<i>C. californicus</i>	<i>T. urticae</i>	0.311	1.365	11.23	32.95	25, 70-80	Gotoh <i>et al.</i> (2006)
<i>N. californicus</i>	<i>P. citri</i>	0.307	1.360	10.79	27.40	29, 42	This study
<i>C. californicus</i>	<i>T. kanzawai</i>	0.306	1.359	11.5	33.94	25, 70-80	Gotoh <i>et al.</i> (2006)
<i>P. longipes</i>	<i>T. evansi</i>	0.293	1.230	12.92	13.88	25, 80±10	Ferrero <i>et al.</i> (2007)
<i>N. californicus</i>	<i>P. ulmi</i>	0.290	1.340	11.81	31.88	30, 65±75	El Taj & Jung (2012)
<i>C. picanus</i>	<i>T. cinnabarinus</i>	0.289	1.335	11.68	29.13	29, 42±5	Tello <i>et al.</i> (2009b)
<i>C. californicus</i>	<i>T. urticae</i>	0.285	1.250	16.79	16.74	30, 70-80	Canlas <i>et al.</i> (2006)
<i>C. californicus</i>	<i>T. urticae</i>	0.283	—	17.46	49.25	25, 70-80	Escudero & Ferragut (2005)
<i>C. californicus</i>	<i>T. urticae</i>	0.274	1.316	15.303	28.56	25, 70-80	Gotoh <i>et al.</i> (2004)
<i>P. fragariae</i>	<i>T. urticae</i>	0.273	1.242	15.60	29.70	25, 88±7	Nascimento <i>et al.</i> (2008)
<i>N. californicus</i>	<i>T. desertorum</i>	0.269	1.310	12.85	31.80	29, 42	This study
<i>C. californicus</i>	<i>T. turkestanii</i>	0.267	—	17.89	42.93	25, 70-80	Escudero & Ferragut (2005)
<i>P. iorgius</i>	<i>T. desertorum</i>	0.225	1.252	14.961	28.91	23, 70±5	Tello <i>et al.</i> (2011)
<i>C. picanus</i>	<i>P. citri</i>	0.209	1.233	15.93	28.35	26, 70-75	Ragusa <i>et al.</i> (2000)
<i>C. californicus</i>	<i>T. urticae</i>	0.209	1.230	17.55	22.92	25, 70-80	Canlas <i>et al.</i> (2006)
<i>P. macropilis</i>	<i>T. urticae</i>	0.193	1.213	18.45	35.34	26, 60±10	Da Silva <i>et al.</i> (2005)
<i>N. umbricatus</i>	<i>T. cinnabarinus</i>	0.180	—	17.50	23.50	30, 65±10	Kazak <i>et al.</i> (2002)
<i>N. idaeus</i>	<i>T. urticae</i>	0.168	—	10.15	5.53	25, 77±2	Collier <i>et al.</i> (2007)
<i>P. fragariae</i>	<i>T. evansi</i>	0.123	1.131	17.4	8.50	25, 88±7	Nascimento <i>et al.</i> (2008)
<i>I. degenerans</i>	<i>T. urticae</i>	0.115	—	20.2	10.30	25, 75±5	Vantorhout (2006)
<i>P. persimilis</i>	<i>T. evansi</i>	0.106	—	14.21	4.37	25, 70-80	Escudero & Ferragut (2005)

Biological parameters, R_0 = net reproductive rate, r_m = intrinsic rate of growth, T = mean generation time, and λ = finite rate of growth.

According to Sabelis (1985), phytoseiid species with $\lambda > 1.2$ are considered good candidates for the biological control of prolific mites. However, some species of phytoseiids, such as *Typhlodromus pyri* Scheuten, with low r_m and λ , are considered as very important biological control agents of *Panonychus ulmi* (Koch) in the field (Hansen & Johnsen 1986). Our results are very similar to those obtained by Escudero & Ferragut (2005) with *N. californicus* on *T. urticae* (1.33 females/day). The results obtained from λ and r_m can be considered positive, and it can be proposed that *N. californicus* could be an efficient biocontroller agent of red spiders of the Tetranychidae family. *N. californicus* generates high expectations as a biological controller in arid areas of northern Chile. *N. californicus* could be used in hot and dry agroecosystems where it is difficult to find phytoseiids adapted to extreme conditions for the control of tetranychids, since the strain of *N. californicus* found in the Atacama Desert, would be more adapted to conditions of food shortage and aridity.

REFERENCES

- Abou-Setta, M.M., Fouly, A.H., Childers, C.C. 1997. Biology of *Proprioseiopsis rotendus* (Acari: Phytoseiidae) reared on *Tetranychus urticae* (Acari: Tetranychidae) or Pollen. The Florida Entomologist 80(1): 27-34.
- Ansaloni, T., Aucejo, S., Jacas, J.A. 2007. Estimating the intrinsic rate of increase of *Tetranychus urticae*: which is the minimum number of immature individuals to consider? Experimental and Applied Acarology 41: 55-59.
- Bakker, F.M., Klein, M.E., Mesa, M.C., Braun, A.R. 1993. Saturation deficit tolerance spectra of phytophagous mites and their phytoseiid predators on cassava. Experimental and Applied Acarology 17(1-2): 97-113.
- Birch, L.C. 1948. The intrinsic rate of natural increase of an insect population. Journal of Animal Ecology 17: 15-26.
- Bolland, H.R., Gutiérrez, J., Fletchmann, C.H.W. 1998. World catalogue of the spider mite family (Acari: Tetranychidae): Leiden, Koninklijke Brill NV. 408 p.
- 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: 141-157.
- Castagnoli, M., Simoni, S. 2003. *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae): survey of biological and behavioural traits of a versatile predator. Redia 86: 153-164.
- 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.
- Collier, K., Albuquerque, G., De Lima, J., Pallini, A., Molina-Rugama, A. 2007. *Neoseiulus idaeus* (Acari: Phytoseiidae) as a potential biocontrol agent of the two-spotted spider mite, *Tetranychus urticae* (Acari: Tetranychidae) in papaya: performance on different prey stage – host plant combinations. Experimental and Applied Acarology 41: 27-36.
- Da Silva, F., Vasconcelos, G., Gondim, M., Oliveira, J. 2005. Exigências térmicas e tabela de vida de fertilidade de *Phytoseiulus macropilis* (Banks) (Acari: Phytoseiidae). Neotropical Entomology 34:291-296.
- De Moraes, G.J., Mcmurtry, J.A., Denmark, H.A., Campos, C.B. 2004. A revised catalog of the mite family Phytoseiidae. Zootaxa 434: 1-494.
- De Vis, R.M.J., De Moraes, G.J., Bellini, M.R. 2006. Effect of air humidity on the viability of predatory mites (Acari: Phytoseiidae, Stigmaeidae) common on rubber trees in Brazil. Experimental and Applied Acarology 38 (1): 25-32.
- El Taj, H.F., Jung, C. 2012. Effect of temperature on the life-history traits of *Neoseiulus californicus* (Acari: Phytoseiidae) fed on *Panonychus ulmi*. Experimental and Applied Acarology 56(3): 247-260.
- Escudero, L.A., Ferragut, F. 2005. Life-history of predatory mites *Neoseiulus californicus* and *Phytoseiulus persimilis* (Acari: Phytoseiidae) on four spider mite species as prey, with special reference to *Tetranychus evansi* (Acari: Tetranychidae). Biological Control 32: 378-384.
- Ferrero, M., Moraes G.J., Kreiter, S., Tixier, M.-S., Knapp, M. 2007. Life tables of the predatory *Phytoseiulus longipes* feeding on *Tetranychus evansi* at four temperatures (Acari: Phytoseiidae, Tetranychidae). Exp. Appl. Acarol. 41: 45-53.
- 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.
- Gotoh, T., Yamaguchi, K., Mori, K. 2004. Effect of temperature on life history of the predatory mite *Amblyseius (Neoseiulus) californicus* (Acari: Phytoseiidae). Experimental and Applied Acarology 32: 15-30.
- Gotoh, T., Tsuchiya, A., Kitashima, Y. 2006. Influence of prey on developmental performance, reproduction and prey consumption of *Neoseiulus californicus* (Acari: Phytoseiidae). Experimental and Applied Acarology 40:189-204.
- Hansen, E.W., Johnsen, S. 1986. Predatory mites of the family Phytoseiidae in Denmark (Acarina, Gamasina). Entomologiske Meddelelser 53(3): 137-142.
- Kazak, C., Yildiz, S., Sekeroglu, E. 2002. Biological characteristic

- and life tables of *Neoseiulus umbricatus* Chant (Acari: Phytoseiidae) at three constant temperatures. *J. Pest Science*, 75: 118-121.
- Kim, T., Ahn, J.J., Lee, J.-H. 2012. Age- and temperature-dependent oviposition model of *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) with *Tetranychus urticae* as prey. *Journal of Applied Entomology* 137(4): 282-288.
- Klein, C., Waterhouse, D.F. 2000. Distribution and importance of arthropods associated with agriculture and forestry in Chile. ACIAR Monograph N° 68. 231 pp.
- 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.
- Kuştutan, O., Çakmak, I. 2009. Development, fecundity, and prey consumption of *Neoseiulus californicus* (McGregor) fed *Tetranychus cinnabarinus* Boisduval. *Turkish Journal of Agriculture and Forestry* 33: 19-28.
- Mirabal, L. 2003. Los ácaros depredadores como agentes de control biológico. *Revista de Protección Vegetal* 18(3): 145-152.
- Muma, M.H. 1971. Food habits of phytoseiidae (Acarina: Mesostigmata) including common species on Florida citrus. *The Florida Entomologist* 54(1): 21-34.
- Nascimento, G., Moraes, G.J., Delalibera, I., Knapp, M. 2008. Life history of the predatory mite *Phytoseiulus fragariae* on *Tetranychus evansi* and *Tetranychus urticae* (Acari: Phytoseiidae, Tetranychidae) at five temperatures. *Experimental and Applied Acarology* 44: 27-36.
- Nunes-Maia, A., Almeida-Pazianotto, R., Barreto-Luiz, A., Marinho-Prado, J., Pervez, A. 2014. Inference on arthropod demographic parameters: Computational advances using R. *Journal of Economic Entomology* 107(1): 432-439.
- Peralta, O., Tello, V. 2019. Phytoseiid mites (Acari: Phytoseiidae) from the Region of Tarapacá, northern Chile, with a description of a new species and a key to species. *International Journal of Acarology* 45(3): 148-158.
- Persad, A., Khan, A. 2002. Comparison of life table parameters for *Maconellicoccus hirsutus*, *Anagyrus kamali*, *Cryptolaemus montrouzieri* and *Scymnus coccivora*. *Biocontrol* 47: 137-149.
- Piedrahita, J. 1974. Biología de *Tetranychus desertorum* Banks (Acarina, Tetranychidae) y pruebas de resistencia de siete variedades de frijol (*Phaseolus vulgaris*) a su ataque. *Acta Agronómica* 24(1-4): 94-114.
- Pratt, P.D., Schausberger, P., Croft, B.A. 1999. Prey-food types of *Neoseiulus fallacies* (Acari: Phytoseiidae) and literatura versus experimentally derived prey-food estimates for five phytoseiid species. *Experimental and Applied Acarology* 23: 551-565.
- R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: <https://www.R-project.org/>.
- Rabinovich, J.E. 1980. Introducción a la ecología de poblaciones animales. CECSA. 313 pp.
- Ragusa, S. 2000. A new *Cydnodromus* (Parasitiform, Phytoseiidae), from the desert of the northern Chile. *Phytophaga* 10: 3-103.
- Ragusa, S. 2003. Description of a new genus and two new species of phytoseiid mites (Parasitiformes Phytoseiidae) collected in Chile. *Acarologia* 43:337-344.
- Ragusa, S., Vargas, R. 2002. On some phytoseiid mites (Parasitiformes, Phytoseiidae) from Chile. *Phytophaga* 12: 129-139.
- Ragusa, S., Vargas, R., Tsolakakis, H., Ashbach, R. 2000. Laboratory studies on the influence of various food substances 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.
- Sabelis, M.W., 1985. Predation on spider mites. En: Helle, W., Sabelis, M.W. (Eds) *Spider Mites, Their Biology, Natural Enemies and Control*: 103-127. *World Crop Pests*, Vol. 1B. Elsevier, Amsterdam.
- Shen, X.M., Liao, C.Y., Lu, X.P., Wang, Z., Wang, J.J., Dou, W. 2016. Involvement of three esterase genes from *Panonychus citri* (McGregor) in fenpropathrin resistance. *International Journal of Molecular Science* 17(8): 1361. doi: 10.3390/ijms17081361.
- Swirski, E., Amitai, S., Dorzia, N. 1970. Laboratory studies of the feeding habits, post-embryonic survival, and oviposition of the predaceous mites *Amblyseius chilensis* Dosse and *Amblyseius hibisci* Chant (Acariña: Phytoseiidae) on various kinds of food substances. *Entomophaga* 15: 93-106.
- Tello, V., Briceño, V., Castillo, P. 2011. Parámetros biológicos de *Proprioseiopsis iorgius* sobre *Tetranychus desertorum* (Acari: Phytoseiidae, Tetranychidae). *Revista Colombiana de Entomología* 37(1): 62-66.
- Tello, V., Castillo, P., Briceño, R., Sánchez, M. 2013. Parámetros biológicos de *Tetranychus desertorum* (Acari: Tetranychidae) sobre hojas de poroto. *IDESIA* 31(4): 27-33.
- Tello, V., Vargas, R., Araya, J. 2009a. Parámetros de vida de *Tetranychus cinnabarinus* (Acari: Tetranychidae) sobre hojas de clavel, *Dianthus caryophyllus*. *Revista Colombiana de Entomología* 35(1): 47-51.
- Tello, V., Vargas, R., Araya, J., Cardemil, A. 2009b. Biological parameters of *Cydnodromus picanus* and *Phytoseiulus persimilis* raised on the carmine spider mite, *Tetranychus*

- cinnabarinus* (Acari: Phytoseiidae, Tetranychidae). *Ciencia e Investigación Agraria* 36(2): 277-290.
- Vantornhout, I. 2006. Biology and ecology of the predatory mite *Iphiseius degenerans* (Berlese) (Acari: Phytoseiidae). PhD thesis, Ghent University, Ghent, Belgium.
- Van Dinh N., Sabelis M.W., Janssen, J. 1988. Influence of Humidity and Water Availability on the Survival of *Amblyseius idaeus* and *A. anonymus* (Acarina: Phytoseiidae). *Experimental and Applied Acarology* 4: 27-40.
- Vargas, R., Olivares, N., Cardemil, A. 2005. Desarrollo postembrionario y parámetros de tabla de vida de *Typhlodromus pyri* Scheuten, *Cydnodromus californicus* (McGregor) (Acarina: Phytoseiidae) y *Brevipalpus*. *Agricultura Técnica (Chile)* 65(2): 147-156.
- Walzer, A., Castagnoli, M., Simoni, S., Liguori, M., Palevsky, E., Schausberger, P. 2007. Intraspecific variation in humidity susceptibility of the predatory mite *Neoseiulus californicus*: Survival, development and reproduction. *Biological Control* 41: 42-52.
- Zar, J.H. 2010. *Biostatistical Analysis*. 5th Edition, Prentice-Hall/Pearson, Upper Saddle River. 944 p.
- Zundell, C.H., Hanna, R., Scheidegger, U., Nagel, P. 2007. Living at the threshold: Where does the neotropical phytoseiid mite *Typhlodromus aripo* survive the dry season? *Experimental and Applied Acarology* 41(1-2): 11-26.

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