

## Biological parameters of *Cydnodromus picanus* and *Phytoseiulus persimilis* raised on the carmine spider mite, *Tetranychus cinnabarinus* (Acari: Phytoseiidae, Tetranychidae)

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### Abstract

V. Tello, R. Vargas, J. Araya, and A. Cardemil. 2009. Biological parameters of *Cydnodromus picanus* and *Phytoseiulus persimilis* raised on the carmine spider mite *Tetranychus cinnabarinus* (Acari: Phytoseiidae, Tetranychidae). Cien. Inv. Agr. 36(2):277-290. The postembryonic development, consumption and life table parameters of *Cydnodromus picanus* Ragusa and *Phytoseiulus persimilis* (Athias-Henriot) were studied at  $29.44 \pm 1.47$  °C and  $42.35 \pm 5.01$ % of RH with a photoperiod of 14:10 h (L:D) in order to evaluate the potential of these predators for feeding on the carmine spider mite *Tetranychus cinnabarinus* (Boisduval). Eggs, larvae and protonymphs of *T. cinnabarinus* may be optimal food for *C. picanus*, which obtained survival rates of 100%, 97% and 93%, respectively, on them. The survival of *P. persimilis* was around 6.7% with diets based on eggs, larvae and protonymphs, showing a high mortality level by dehydration when fed with eggs. The time of the postembryonic development was significantly shorter ( $p < 0.05$ ) for *C. picanus* than for *P. persimilis* when they were fed with eggs, larvae and deutonymphs of *T. cinnabarinus*. When fed with eggs and a combination of different stages of *T. cinnabarinus*, the intrinsic rate of growth ( $r_m$ ) was significantly higher ( $p < 0.05$ ) for *C. picanus* (0.289 and 0.307, respectively) than for *P. persimilis* (0.019 and 0.025, respectively). The values of the finite rate of growth ( $\lambda$ ) were also significantly ( $p < 0.05$ ) higher for *C. picanus* (1.34 and 1.36) than for *P. persimilis* (1.02 and 1.03) when they were nourished with eggs and a mixed diet, respectively. The high values of  $r_m$  and  $\lambda$  found for *C. picanus* in the experimental conditions are indicators of the possible control that this phytoseiid mite, as a predator of *T. cinnabarinus*, would potentially offer under the conditions of lower relative humidity encountered in the arid zone of the desert of Chile.

**Key words:** Biological control, life table, postembryonic development, predation.

### Introduction

Acari predators are important bio-control agents. They are essential in the integrated

pest control programs that are becoming of great importance, particularly in the management of phytophagous acari. The family Phytoseiidae is a group of predator acari, with around 2,250 species, that are the subject of intensive studies because of their role as predators of agricultural pests (McMurtry and Croft, 1997).

In Chile, 48 species of acari phytoseiids have been reported associated with cultivated plants or weeds. Some of these acari have been reported as a factor in regulating populations of phytophagous acari of economic importance, such as *Tetranychus urticae* Koch, *T. cinnabarinus* Boisduval, *Panonychus ulmi* Koch and *P. citri* McGregor (Ragusa, 2000; Ragusa *et al.*, 2000; Ragusa *et al.*, 2002; Rioja and Vargas, 2008).

A very promising species is *Cydnodromus picanus* Ragusa [= *Neoseiulus picanus* (Ragusa), Moraes *et al.*, 2004], a phytoseiid of the sub-family Amblyseiinae, recorded as a new species for science by Ragusa (2000). *C. picanus* was found on *Citrus aurantium* in Pica, Iquique (20° 29' 12,4" S; 69° 19' 33,9" W), Region of Tarapacá. According to Ragusa *et al.* (2000), this species could be used in hot and dry agroecosystems, where it is hard to find acari phytoseiids that are adapted to these extreme conditions to control tetranychids. On the basis of the classification of McMurtry and Croft (1997), *C. picanus* is a general predator belonging to the type III life style. This was confirmed by the works by Ragusa *et al.* (2000) and Rioja and Vargas (2008), who proved that this species can grow and develop on pollen of *Hirschfeldia incana*, *Persea americana*, *Oxalis* sp, and *Ricinus* sp.

In relation to its predatory capacity, Ragusa *et al.* (2000) determined that the life parameters of *C. picanus* turn it into a promising candidate to be used in programs of biological control of the two-spotted mite (*T. urticae*) and the citrus red mite [(*Panonychus citri* (McGregor)]. In addition, Rioja and Vargas (2008), reached a similar conclusion after evaluating the predatory capacity of *C. picanus* on avocado red mite [*Oligonychus yothersi* (McGregor)] since it has a high intrinsic rate of growth ( $r_m$ ) as compared with *O. yothersi*, indicating that its predator population has the capacity to control this phytophagous acarus through generations. Therefore, these authors state that *C. picanus* is a promising natural enemy of avocado red mite, and its potential use has to be evaluated in the integrated management of citrus and avocado acari.

The predator acarus *Phytoseiulus persimilis* (Athias-Henriot) is specialized in consuming phytophagous acari (*Tetranychus* spp.). It has been used in the biological control of *T. urticae* in strawberry through massive releases in areas such as North America (Strand, 1994), Northern Europe (Scopes, 1985), the Mediterranean Sea (Benuzzi and Antoniaci, 1995) and Korea (Kim and Park, 2006). According to Naher and Haque (2007), *P. persimilis* is the most commercialized and widely released phytoseiid predator in greenhouses. It has been widely studied for its capacity for the biological control of tetranychid acari in many crops (Sabelis, 1985; Naher and Haque, 2007). Çakmak *et al.* (2005) have suggested that *P. persimilis* has enormous potential for the biological control of *T. cinnabarinus* in protected strawberry in Aydin (Turkey), where temperatures over 30 °C and relative humidities (RHs) below 60% are unfavorable conditions for the development of predatory acari. Its predatory action on phytophagous mites in Chile is practically unknown.

The carmine spider mite is associated with more than 120 host plants of economic importance worldwide, including cotton, strawberry, ornamental plants, deciduous fruit trees, tomato, eggplant, and other vegetables, with a wide distribution in different parts of the world (Çakmak and Demiral, 2007).

In Chile, the prevailing climatic conditions in the desert zone (high temperature and low RH) are very favorable for the development of phytophagous acari. An important species within this group is the carmine spider mite, *T. cinnabarinus*. The primary hosts of this mite are alfalfa, carnation, bean, strawberry and melon in Chile. It is distributed from the I Region to the VII Region. In the I Region (Tarapacá), it is mainly associated with melon and carnation, and it is usually controlled chemically (Klein and Waterhouse, 2001).

The purpose of this study was to evaluate the biological parameters of *C. picanus* and *P. persimilis* on a diet composed of carmine spider mite at different stages of development in similar experimental conditions to those found in the dry zone of the desert of Chile.

## Materials and methods

The bioassays were conducted at the Centro Regional de Investigación La Cruz, (Instituto de Investigaciones Agropecuarias (INIA), La Cruz, Chile) at  $29.44 \pm 1.47^\circ\text{C}$  and  $42.35 \pm 5.01\%$  relative humidity (RH) with a photoperiod of 14:10 h (light:darkness). The phytoseiid acari predators *C. picanus* and *P. persimilis* were used. *C. picanus* was collected from trees of *C. aurantium* in Pica, Chile, and *P. persimilis* was collected from Chilean bell flower (*Nolana* sp., Nolanaceae) in La Cruz, Chile ( $32^\circ 49' \text{ S}$ ;  $71^\circ 17' \text{ W}$ ). These phytoseiid predators were reared to increase their population size, and they were fed with two-spotted spider mites (*T. urticae*). The carmine spider mite (*T. cinnabarinus*) was collected from Quillota (Region of Valparaíso) and bred in carnations (*Dianthus caryophyllus* 'Celta').

The bioassays with phytoseiid predators were performed in 6 x 6 cm black acrylic dishes (Swirski *et al.*, 1970). Glue (Point Sticken Glue, Point Chile S.A.) was placed in the margin of the dishes to prevent acari from escaping from dishes. The observations were made with the aid of a stereoscopic microscope at 40X magnification (Zeiss Stemi, Germany) during all the periods of work.

### Postembryonic development

The potential development of *C. picanus* and *P. persimilis* from the state of egg to adult was determined in the bioassay of postembryonic development. *C. picanus* and *P. persimilis* were fed simple diets consisting of a single prey state that consisted of eggs, larvae, protonymphs, deutonymphs, or adults of *T. cinnabarinus*. One 20-h-old egg (as a maximum) was placed on a 6 x 6 cm diameter dish and observed daily at the same time until the adult state was obtained. These eggs were obtained from different females that were reared for approximately four generations from the beginning of rearing. Food was administered daily and consisted of diets of 10 individuals of each prey state. In addition,

tests in high RH were carried out with *P. persimilis*, in 57 x 42 x 19 cm plastic chambers at  $28.12 \pm 0.05^\circ\text{C}$  and  $76.50 \pm 0.24\%$  RH. The diets evaluated in these conditions were eggs, protonymphs and deutonymphs of *T. cinnabarinus*. The survival, duration and consumption of each state of development of the phytoseiid predators were evaluated. Each bioassay was replicated 30 times, each replicate consisting of one phytoseiid egg per dish.

### Prey consumption

The consumption of prey was evaluated in all the pre-imaginal stages and in virgin and mated females (ovipositors) using eggs of *T. cinnabarinus*. In the tests with juvenile stages, it was carried out as explained above for the postembryonic development tests, administering 30 eggs of *T. cinnabarinus* for each individual per day. In the tests with virgin females, recently emerged females were taken from isolated dishes. Each female was isolated in a dish, and the diet consisted on 30 eggs per day of *T. cinnabarinus*. In the tests with mated females, a young female and a young male were placed in an isolated dish, and after first oviposition was recorded, the female was transferred to a new dish with 40 eggs per day of *T. cinnabarinus*. The numbers of eggs consumed during all the developmental preimaginal stages were counted, or until the female died. Each test was replicated 25 times, and each replicate consisted of one juvenile per female phytoseiid per dish.

### Life table parameters

The effects of two diets on the life table parameters of *C. picanus* and *P. persimilis* were determined. The first diet consisted of 40 eggs per day of the prey, and the second was a mixed diet based on a mixture of different stages (30 eggs + 15 immature mobile + 5 adult females of *T. cinnabarinus*). The methodology described previously was used (Birch, 1948; Ragusa *et al.*, 2000; Vargas *et al.*, 2005). The parameters evaluated were the intrinsic rate of growth ( $r_m$ ), the net

rate of reproduction ( $R_0$ ), generational time ( $T$ ) and the finite rate of natural growth ( $\lambda$ ). A pair of phytoseiids was placed in each dish; the oviposition was recorded every 24 h until the female died. The dead males were replaced to fertilize the female constantly. Each test had 25 replicates of a single phytoseiid female per dish.

The parameters of the phytoseiid predators and the parameters of *T. cinnabarinus* were compared. For this purpose, the parameters of *T. cinnabarinus* were obtained by a method previously proposed with some modifications (Kazak and Kibriti, 2008). Rectangular pieces (3.6 cm<sup>2</sup>) of carnation leaves were obtained only from completely developed leaves of similar ages. The leaf pieces were placed in plastic Petri dishes of 12 cm diameter on a cotton layer water saturated with the abaxial surface upwards. A female and a male were placed in each dish on each piece of leaf. The Petri dishes were placed in plastic trays (41 x 31 x 7 cm) over a saturated sponge. Males were replaced if they died, and oviposition was recorded every 24 h.

#### Design and statistical analysis

A completely randomized design was used for all the experiments. The data for postembryonic development, the duration of adult phases and consumption were transformed to  $\log(x+1)$  before analysis (Zar, 2006). The percent survival was normalized through the angular transformation  $\arcsin\sqrt{x\%^{-1}}$  (Zar, 2006). An analysis of variance (ANOVA) was subsequently performed, and means were separated according to Tukey's multiple comparison test.

The consumption rates of the two phytoseiid species were compared using the Student's t-test. The life table parameters of *C. picanus*, *P. persimilis*, and *T. cinnabarinus* were calculated with the aid of a computer program written in BASIC (Abou-Setta *et al.*, 1986). For comparisons between the life table parameters of the two phytoseiids species, the standard deviation was estimated at a confidence interval of 95% using Jackknife's statistical technique (Maia *et*

*al.*, 2000) available in SAS (SAS Institute, Cary, NC, USA) (La Rossa and Kahn, 2003; Ansaloni *et al.*, 2007). Subsequently, the biological parameters were compared using the Tukey's multiple comparison tests.

#### Results

##### *Survival and duration of the life cycle of C. picanus and P. persimilis*

Diets had a highly significant effect ( $F = 359.46$ ; d.f. = 5, 170;  $p < 0.0001$ ) on the development of *C. picanus* at 42% RH (Table 1). The simple diets based on eggs, larvae and protonymphs of the carmine spider mite positively affected survival, resulting in over 93.33% survival. The deutonymph stage and adults negatively affected survival and were statistically similar to water controls. Imagoes of *C. picanus* were not obtained when the simple diet consisted only of adults of *T. cinnabarinus*.

In the case of *P. persimilis* bred at 42% RH, an extremely low survival (<9.44%) was obtained regardless of the composition of the diet (Table 1). The means among diets were not significantly different from the water control ( $F = 0.50$ ; d.f. = 5, 174;  $p = 0.77$ ). The highest mortality appeared in the egg stage, reaching values over 90%. All of the few survivors reached the adult stage of their development, including the ones on the diet based exclusively on adults of *T. cinnabarinus* that produced phytoseiid imagoes. Due to the very low eclosion obtained in the tests made under 42% of RH, and to discard the effect of any other factor except those that were not the experimental conditions such as manipulation, cannibalism or other, tests in a humid chamber were made at  $28.12 \pm 0.05^\circ\text{C}$  and  $76.50 \pm 0.24\%$  RH. Three states of the prey were evaluated: eggs, protonymphs and deutonymphs. Under these conditions, results of 100% eclosion success and over 95.83% survival to the adult stage were obtained, the differences among the diets were not significant, but statistically different to the water control (Table 1) ( $F = 561.00$ ; d.f. = 3, 92;  $p < 0.0001$ ).

**Table 1.** Effect of diets consisting of different stages of development of the carmine spider mite (*Tetranychus cinnabarinus*) on the postembryonic development of *Cydnodromus picanus* and *Phytoseiulus persimilis*.

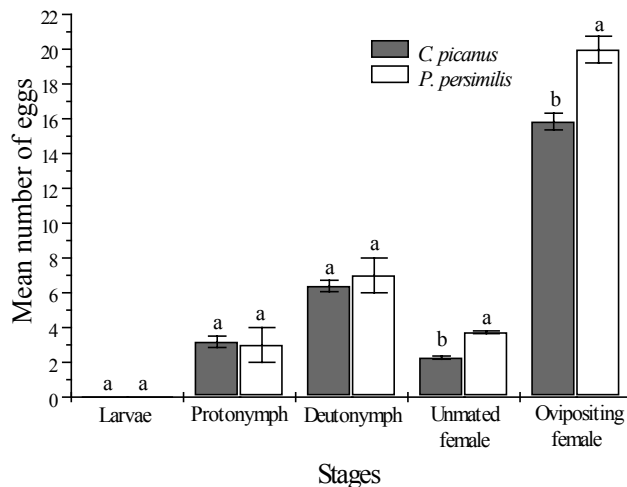
Diet	Individuals reaching adulthood, no.						Survival <sup>1</sup> , %	Duration Egg-adult <sup>1</sup> days ± SE
	n	Eggs	Protonymph	Deutonymph	Adult			
					Female	Male		
<i>C. picanus</i> (42% relative humidity)								
Egg	28	28	28	28	22	6	100.00 ± 0.00 a	4.05 ± 0.05 a
Larvae	28	28	28	28	21	7	96.55 ± 3.46 a	4.33 ± 0.13 a
Protonymph	30	28	28	28	20	8	93.33 ± 4.63 a	5.45 ± 0.14 b
Deutonymph	21	14	14	5	1	0	3.45 ± 3.45 b	4.00 ± 0.00 a
Adult	22	22	22	9	0	0	0.00 ± 0.00 b	—
Water	30	30	30	0	0	0	0.00 ± 0.00 b	—
<i>P. persimilis</i> (42% relative humidity)								
Egg	30	2	2	2	1	1	6.67 ± 4.63 a	5.00 ± 0.00 a
Larvae	30	2	2	2	2	0	6.67 ± 4.63 a	5.00 ± 0.00 a
Protonymph	30	2	2	2	1	1	6.67 ± 4.63 a	5.00 ± 0.00 a
Deutonymph	30	3	3	3	2	1	9.44 ± 5.28 a	6.00 ± 0.00 b
Adult	30	2	2	2	1	1	6.67 ± 4.63 a	6.00 ± 0.00 b
Water	30	2	2	0	0	0	0.00 ± 0.00 a	—
<i>P. persimilis</i> (77% relative humidity)								
Egg	24	24	24	24	14	10	100.00 ± 0.00 a	4.57 ± 0.14 a
Protonymph	24	24	24	24	15	8	95.83 ± 4.17 a	5.20 ± 0.14 b
Deutonymph	24	24	24	24	12	12	100.00 ± 0.00 a	5.67 ± 0.14 b
Water	24	24	24	0	0	0	0.00 ± 0.00 b	—

<sup>1</sup>Means followed by different letters within each column are significantly different according to the Tukey's test ( $p < 0.05$ ). Data are reported as the mean ± standard error.

### Consumption

Highly significant differences were obtained for the rates of consumption among the different stages of *C. picanus* ( $F = 516.54$ ; d.f. = 4, 131;  $p < 0.0001$ ) and *P. persimilis* ( $F = 335.74$ ; d.f. = 4, 51;  $p < 0.0001$ ) (Figure 1). Independent of the phytoseiid species, larvae did not feed on eggs, while the protonymphs of *C. picanus* and *P. persimilis* ( $t = 0.02$ , d.f. = 28,  $p = 0.988$ ) had approximately the same rate of egg consumption, on average,  $3.2 \pm 0.33$  and  $3.0 \pm 1.00$  egg·day<sup>-1</sup>, respectively. Deutonymphs of both

phytoseiids were not significant differences in their consumption of *T. cinnabarinus* eggs ( $t = 0.53$ , d.f. = 28,  $p = 0.604$ ) with averages of  $6.4 \pm 0.33$  and  $7.0 \pm 1.00$  egg·day<sup>-1</sup> for *C. picanus* and *P. persimilis*, respectively. In the case of the adult females, there were highly significant differences in the rate of consumption between *C. picanus* and *P. persimilis* when considering virgin females ( $t = 24.99$ ; d.f. = 24;  $p < 0.001$ ) as well as mated females ( $t = 4.05$ , d.f. = 48,  $p < 0.001$ ). In both cases, the females of *P. persimilis* consumed, on average, a higher number of eggs than the females of *C. picanus* (Figure 1).



**Figure 1.** Daily consumption of eggs of *Tetranychus cinnabarinus* by different stages of *Cydnodromus picanus* and *Phytoseiulus persimilis*. Bars followed by different letters within each stage denote significant differences according to the Student's t test ( $p < 0.05$ ). Bars = standard errors.

### Parameters of their life table

**Rates of oviposition and the duration of adult stages.** The period of preoviposition was very short in *C. picanus* fed with eggs of *T. cinnabarinus*, but it was considerably longer in *P. persimilis* ( $F = 68.02$ ; d.f. = 3, 96;  $p < 0.0001$ ) (Table 3). Independent of the diet, the oviposition, postoviposition and longevity were significantly longer in *C. picanus* than *P. persimilis* fed with eggs of *T. cinnabarinus* ( $F = 26.40$ ; d.f. = 3, 96;  $p < 0.0001$ ,  $F = 44.13$ ; d.f. = 3, 96;  $p < 0.0001$  and  $F = 33.59$ ; d.f. = 3, 96;  $p < 0.0001$ , respectively). The number of eggs per female was significantly higher in *C. picanus* than *P. persimilis* ( $F = 12.75$ ; d.f. = 3, 96;  $p < 0.0001$ ). Differences between the two diets were not significant.

**Rate of net reproduction ( $R_0$ ).** The values of  $R_0$  of the three species were significantly different ( $F = 2,625.81$ ; d.f. = 4, 74;  $p < 0.0001$ ) (Table 4). The highest  $R_0$  value was obtained for *T. cinnabarinus*. Independent of the diet, *C. picanus* exhibited higher  $R_0$  values than *P. persimilis*, which had extremely low  $R_0$  values while feeding on eggs and the mixed diet of *T. cinnabarinus*, reflecting the limited viability of the eggs

of *P. persimilis* at this low reproductive capacity under experimental conditions, especially under the low RH.

**Intrinsic rate of growth  $r_m$ .** The  $r_m$  values obtained for *P. persimilis* were lower than the  $r_m$  values obtained for *C. picanus* and were lower than the  $r_m$  values of *T. cinnabarinus* ( $F = 9,196.20$ ; d.f. = 4, 75;  $p < 0.0001$ ; Table 4). The highest  $r_m$  values were obtained for *C. picanus* fed with a mixed diet or with eggs of *T. cinnabarinus*. Both values were, in addition, significantly higher than the  $r_m$  values of *T. cinnabarinus*. The  $r_m$  values obtained for *C. picanus* on the two diets were the highest, exceeding those of *P. persimilis*, and even more interestingly, they were greater than the  $r_m$  of *T. cinnabarinus*, indicating that the populations of *C. picanus* have the capacity to control *T. cinnabarinus* for generations.

**Generational time.** The generational time was different among the three acarus species used in this study ( $F = 1,645.59$ ; d.f. = 4, 75;  $p < 0.0001$ ) (Table 4). *T. cinnabarinus* had the longest and *P. persimilis* the shortest generational times with diets of all the growth stages and eggs of

**Table 2.** Effect of relative humidity (RH) on the proportion of eggs that survive for different phytoseiid species, results obtained in this study are compared with references.

Phytoseiidae	Food	Survival (%) at %RH:			References
		40	50	60	
<i>Cydnodromus picanus</i>	<i>Tetranychus cinnabarinus</i>	100.0	—	—	Present study
<i>Phytoseiulus persimilis</i>	<i>Tetranychus cinnabarinus</i>	6.7	—	—	Present study
<i>Euseius citrifolius</i>	Pollen of <i>Typha angustifolia</i>	57.0	90.0	97.0	Vis <i>et al.</i> , 2006
<i>Metaseiulus camelliae</i>	<i>Tenuipalpus heveae</i>	13.0	37.0	87.0	Vis <i>et al.</i> , 2006
<i>Iphiseiodes zuluagai</i>	Pollen of <i>Typha angustifolia</i>	3.0	17.0	33.0	Vis <i>et al.</i> , 2006
<i>Zetzellia malviniae</i>	<i>Tenuipalpus heveae</i>	0.0	10.0	50.0	Vis <i>et al.</i> , 2006
<i>Amblyseius acalyphus</i>	Pollen of <i>Thypha angustifolia</i> + <i>Tenuipalpus heveae</i>	0.0	10.0	40.0	Vis <i>et al.</i> , 2006
<i>Agistemus floridanus</i>	<i>Tenuipalpus heveae</i>	0.0	7.0	33.0	Vis <i>et al.</i> , 2006
<i>Iphiseius degenerans</i>	Pollen of <i>Ricinus communis</i>	—	21.8	68.1	Courcy <i>et al.</i> , 2004
<i>Phytoseiulus persimilis</i>	<i>Tetranychus urticae</i>	—	2.6	24.9	Courcy <i>et al.</i> , 2004
<i>Neoseiulus cucumeris</i>	<i>Tyrophagus sp</i>	—	0.0	21.6	Courcy <i>et al.</i> , 2004
<i>Neoseiulus californicus</i>	<i>Tetranychus urticae</i>	—	0.0	4.9	Courcy <i>et al.</i> , 2004

**Table 3.** Durations of the period of the adult stage and the oviposition rates of *Cydnodromus picanus* and *Phytoseiulus persimilis* fed on two types of diets based on stages of development of *Tetranychus cinnabarinus*.

Periods	Simple diet <sup>1</sup>		Mixed diet <sup>2</sup>	
	<i>C. picanus</i> (n=25)	<i>P. persimilis</i> (n=25)	<i>C. picanus</i> (n=25)	<i>P. persimilis</i> (n=25)
<i>Duration of the adult stages, days</i>				
Preoviposition	0.68 ± 0.10 c <sup>3</sup>	2.72 ± 0.21 a <sup>3</sup>	1.00 ± 0.08 b <sup>3</sup>	2.60 ± 0.12 a <sup>3</sup>
Oviposition	18.00 ± 0.33 a	9.08 ± 0.71 b	14.40 ± 0.93 a	8.52 ± 0.95 b
Postoviposition	11.60 ± 0.71 a	6.68 ± 0.32 b	5.60 ± 0.82 b	1.84 ± 0.56 c
Longevity	30.36 ± 0.83 a	18.48 ± 0.81 b	21.00 ± 1.57 b	12.96 ± 1.46 c
<i>Oviposition, eggs, no.</i>				
Total egg · female <sup>-1</sup>	48.96 ± 1.98 a	26.56 ± 2.40 b	36.68 ± 2.59 a	28.20 ± 3.01 b
Egg · female <sup>-1</sup> · day <sup>-1</sup>	2.72 ± 0.11 b	2.90 ± 0.12 b	2.58 ± 0.11 b	3.35 ± 0.08 a

<sup>1</sup>Daily diet consisted of 40 eggs of *T. cinnabarinus*.

<sup>2</sup>Daily diet consisted of a mix of 30 eggs plus 15 immature mobiles plus 5 adult females of *T. cinnabarinus*.

<sup>3</sup>Means followed by different letters within each row are significantly different according to Tukey's test (p = 0.05). Data are reported as the mean ± standard error.

*T. cinnabarinus*. For the two predators, in the different diets, the generational time was rather similar, where *C. picanus* fed with a mixed diet had the shortest generational time. Considering  $R_0$  and  $r_m$ , it is possible to estimate that *C. picanus* fed with a mixed diet of life stages of *T. cinnabarinus* will multiply 21.8 times in approximately 10 days.

*Finite rate of growth*. The finite rate of growth also differed significantly between species ( $F = 10,318.64$ ; d.f. = 4, 75;  $p < 0.0001$ ). *C. picanus* fed with either of the two diets had the highest values, but these differed from each other in that the mixed diet was the best. *T. cinnabarinus* obtained a higher  $\lambda$  than *P. persimilis*, with values statistically equal between the two diets (Table 4).

**Table 4.** Life table parameters of *Cydnodromus picanus*, *Phytoseiulus persimilis*, and the carmine spider mite (*Tetranychus cinnabarinus*) (n=25).

Biological parameters <sup>1</sup>	Simple diet <sup>2</sup>		Mixed diet <sup>3</sup>		
	<i>C. picanus</i>	<i>P. persimilis</i>	<i>C. picanus</i>	<i>P. persimilis</i>	<i>T. cinnabarinus</i>
$R_0$	29.129 ± 1.177 b <sup>4</sup>	1.226 ± 0.111 d <sup>4</sup>	21.823 ± 1.541 c <sup>4</sup>	1.302 ± 0.139 d <sup>4</sup>	40.962 ± 4.317 a <sup>4</sup>
$r_m$	0.289 ± 0.003 b	0.019 ± 0.008 e	0.307 ± 0.004 a	0.025 ± 0.009 d	0.200 ± 0.005 c
$T$	11.677 ± 0.148 b	11.112 ± 0.315 c	10.067 ± 0.310 d	10.924 ± 0.476 c	18.552 ± 0.471 a
$\lambda$	1.335 ± 0.004 b	1.019 ± 0.008 d	1.359 ± 0.006 a	1.025 ± 0.009 d	1.222 ± 0.006 c

<sup>1</sup>Biological parameters  $R_0$  = net reproductive rate,  $r_m$  = intrinsic rate of growth,  $T$  = mean generation time, and  $\lambda$  = finite rate of growth.

<sup>2</sup>Daily simple diet consisted of 40 eggs of *T. cinnabarinus*.

<sup>3</sup>Daily mixed diet consisted of 30 eggs plus 15 immature mobiles plus 5 adult females of *T. cinnabarinus*.

<sup>4</sup>Means followed by different letters within each row are significantly different according to Tukey's test ( $p = 0.05$ ).

## Discussion

The percentage of the viability of *C. picanus* eggs obtained in this study greatly exceeds what was previously reported in the literature regarding the survival of eggs at low RH. In this study, 100% eclosion success was obtained at 42%RH.

De Vis *et al.* (2006) stated that *Euseius citrifolius* (Acari: Phytoseiidae) is a highly promising species for use as a biocontrol agent in arid environments. Our results with *C. picanus* allow us to point out that its performance in conditions of low RH could potentially surpass the performance of *E. citrifolius*, as *C. picanus* is a native species of desert environments that evolved in conditions of extreme aridity.

In regards to the lack of specific predatory species from arid environments (Walzer *et al.*, 2007), it has to be added that the phytoseiid species available commercially do not work in these types of conditions (Zundell *et al.*, 2007). According to Bakker *et al.* (1993), air humidity is one of the main factors influencing the efficiency of the acarid predators. Sabelis (1985) and Walzer *et al.* (2007) confirm this point, showing that the egg is the most susceptible state to the most adverse climatic conditions. The other life stages are mobile and may search for more favorable microhabitats to protect themselves from adverse conditions. The prevalence of *C. picanus* in the desert zone of Chile may be partially explained by its capacity to tolerate conditions of low RH. In these regions, RH may reach very low levels annually (10-30%).

Both phytoseiid species showed a high consumption of eggs. Oku *et al.* (2004), when trying to explain the higher preference for this food, hypothesized that they would be more accessible than adults, which take refuge in the web in the presence of predators. Furuichi *et al.* (2005) did not find any differences when offering a mix of *T. kanzawai* females in the state of teliochrysalids (the quiescent state immediately previous to adult emergence) and adult females to *Neosiulus womersleyi*. Both diets were not favorable compared to the results obtained with eggs of the red mite. Adult stages seem to provide less nutritional benefits, or their predation represents a higher energy cost, as they have certain characteristics such as wax layers in their integumentary system or a harder cuticle.

The larvae of both phytoseiids did not feed on any of the states of *T. cinnabarinus* offered as prey. This is the case of many phytoseiids with a type I life style, especially species of *Phytoseiulus* (McMurtry and Croft, 1997; Ferrero *et al.*, 2007). In the case of *C. picanus*, the results obtained coincide completely with previous reports (Ragusa *et al.*, 2000). In the case of *P. persimilis*, similar results were reported previously when larvae of *P. persimilis* were fed with eggs of *T. cinnabarinus* or immature states of *T. urticae* (Ashihara *et al.*, 1978; Chittenden and Saito, 2001).

For *C. picanus*, the duration of the adult phase is similar to the duration obtained when feeding the predator with eggs of *T. urticae*, coinciding especially in the longevity of approximately 30 days (Ragusa *et al.*, 2000). In this regard, Ragusa *et al.* (2000) indicated that the most indica-



tive value to compare the reproductive capacity of different phytoseiid acari is the total number of eggs laid by a female, as the number of eggs·female<sup>-1</sup>·day<sup>-1</sup> is regulated by the duration of the oviposition period.

The net reproductive rates obtained for *C. picanus* when fed with eggs and a mixed diet based on *T. cinnabarinus* stages were similar to the results reported by Ragusa *et al.* (2000). Values of  $R_0$  for different phytoseiid species are shown in Table 4. The extremely low values for *P. persimilis* compared to those reported in the literature confirm its diminished reproductive potential (Table 5).

Ragusa *et al.* (2000) obtained a high value of  $r_m$  for *C. picanus* fed with eggs of *T. urticae* (0.377), but a low value for *P. citri* (0.209) fed the same. These values and the values obtained in this study (including the two diets) are rather similar to the values for other type I specialized predators (McMurtry and Croft, 1997), such as *Phytoseiulus* (Table 5). On the other hand, Rioja and Vargas (2008) indicated that the  $r_m$  values of *C. picanus* fed with two different diets (immature states and a mixture of all the states) of *Oligonychus yothersi* (McGregor) were 0.25 and 0.24, respectively, rather close to the  $r_m$  values presented by type III generalist predators, such as *Amblyseius andersoni* (Table 5) (Ragusa *et al.*, 2000).

**Table 5.** Demographic parameters for species of phytoseiids fed on eggs of different species of mites of the genus *Tetranychus*, at the different temperature (°C) and relative humidity (%RH) conditions indicated for each species.

Phytoseiidae	Prey	Biological parameters <sup>1</sup>				Experimental conditions °C; %RH	Reference
		$r_m$	$\lambda$	T	$R_0$		
<i>C. picanus</i>	<i>T. cinnabarinus</i>	0.289	1.335	11.68	29.13	29; 42±5	This study
<i>P. persimilis</i>	<i>T. cinnabarinus</i>	0.019	1.019	11.11	1.23	29; 42±5	This study
<i>P. persimilis</i>	<i>T. ludeni</i>	0.424	—	11.57	40.78	25; 70-80	Escudero and Ferragut, 2005
<i>P. longipes</i>	<i>T. evansi</i>	0.416	1.380	8.17	13.84	30; 80±1	Ferrero <i>et al.</i> , 2007
<i>C. picanus</i>	<i>T. urticae</i>	0.377	1.458	9	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 and Ferragut, 2005
<i>P. persimilis</i>	<i>T. turkestanii</i>	0.367	—	12.79	43.02	25; 70-80	Escudero and Ferragut, 2005
<i>C. californicus</i>	<i>T. ludeni</i>	0.337	—	16.04	47.37	25; 70-80	Escudero and 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>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	1.23	12.92	13.88	25; 80±1	Ferrero <i>et al.</i> , 2007
<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 and Ferragut, 2005
<i>P. fragariae</i>	<i>T. urticae</i>	0.273	1.242	15.6	29.7	25; 88±7	Nascimento <i>et al.</i> , 2008
<i>C. californicus</i>	<i>T. turkestanii</i>	0.267	—	17.89	42.93	25; 70-80	Escudero and Ferragut, 2005
<i>C. californicus</i>	<i>T. urticae</i>	0.209	1.23	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±1	Da Silva <i>et al.</i> , 2005
<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	8.5	25; 88±7	Nascimento <i>et al.</i> , 2008
<i>I. degenerans</i>	<i>T. urticae</i>	0.115	—	20.2	10.3	25; 75±5	Vantomhout, 2006
<i>P. persimilis</i>	<i>T. evansi</i>	0.106	—	14.21	4.37	25; 70-80	Escudero and Ferragut, 2005
<i>K. aberrans</i>	<i>T. urticae</i>	0.095	—	24.76	10.39	25; 65±1	Kasap, 2005
<i>C. californicus</i>	<i>T. evansi</i>	0.084	—	14.5	3.33	25; 70-80	Escudero and Ferragut, 2005

<sup>1</sup>Biological parameters,  $R_0$  = net reproductive rate,  $r_m$  = intrinsic rate of growth, T = mean generation time, and  $\lambda$  = finite rate of growth.

*P. ersimilis* had very low values of  $r_m$  when fed eggs or the mixed diet due to, we assume, the experimental conditions, as the same predator fed with *T. urticae* at  $25 \pm 1^\circ\text{C}$  and 70–80% RH with a photoperiod of 12:12 h L:D had an  $r_m$  of 0.373 (Escudero and Ferragut, 2005).

Ragusa *et al.* (2000) also found a small generational time (T) for *C. picanus* fed with eggs of *T. urticae* (9 days). In turn, when this predator was fed with eggs of *P. citri*, its generational time increased to 15.9 days. Rioja and Vargas (2008) obtained T values of 12.46 and 13.91 days for *C. picanus* fed with a diet of mobile states and with a mixed diet of *O. yothersi*, respectively. From Table 4, it is clear that a diet of *T. cinnabarinus* produces T values coinciding with the values obtained for other phytoseiids in conditions of more favorable humidity, indicating that the experimental conditions did not extend the generational time as previously seen in other studies. From analyzing Table 5, it is clear that the T values for *P. persimilis* are within the values obtained by other authors in experimental conditions of 70–80% RH. This parameter seems to be unaffected by low humidity.

According to Sabelis (1985), phytoseiid species whose  $\lambda$  exceeds the numeric value of 1.2 are considered as promising candidates for biological control of prolific red spider mites. The values of this parameter obtained in this study are very close to the values obtained by Ragusa *et al.* (2000) for *C. picanus* fed with *T. urticae* eggs ( $\lambda=1.458$ ). On the other hand, Rioja and Vargas (2008) indicated that *C. picanus* fed with mobile stages and a mixed diet of *O. yothersi* had  $\lambda$  values higher than 1.2 (1.29 and 1.27, respectively). If the results obtained for the intrinsic rate of growth in this study are added to these results, it may be proposed that *C. picanus* may be an efficient controller of red spider mites of the family Tetranychidae, thus behaving as a type II selective predator, such as *N. californicus* (Table 5).

The values of  $\lambda$  obtained for *P. persimilis* with the two diets were lower than the values for the

carmine spider mite. If the low values presented for the parameters  $r_m$  and  $R_0$  are added, it may be stated that the reproductive capacity of *P. persimilis* in conditions of low RH is very depressed, making this predator unable to control populations of the carmine spider mite in arid conditions, such as the conditions in northern Chile. The  $\lambda$  value presented by *P. persimilis* in more favorable conditions surpasses the value of 1.2 (Escudero and Ferrugut, 2005). Those are the  $\lambda$  values expected for specialist predators of this nature (Table 5).

*C. picanus* and *P. persimilis* complete their embryonic development and achieve reproduction when feeding preferably on eggs and juvenile states of *T. cinnabarinus* in laboratory conditions. The life table parameters shown by *C. picanus* are higher than the parameters exhibited by *P. persimilis* under the experimental conditions used ( $29.44 \pm 1.47^\circ\text{C}$ ,  $42.35 \pm 5.01\%$  RH and a photoperiod of 14:10 h (L:D)). *P. persimilis* had a high mortality due to the dehydration of its eggs at 42.35% RH. *C. picanus* could potentially control populations of *T. cinnabarinus* at the field level; this requires an evaluation of its predatory action in order to include it within an integrated management program for the carmine spider mite, in carnation or melon, in arid zones of Chile.

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### Resumen

V. Tello, R. Vargas, J. Araya y A. Cardemil. 2009. **Parámetros biológicos de *Cydnodromus picanus* Ragusa y *Phytoseiulus persimilis* (Athias-Henriot) (Acari: Phytoseiidae), sobre la araña cinabarina, *Tetranychus cinnabarinus* (Boisduval) (Acari: Tetranychidae).** *Cien. Inv. Agr.* **36(2):277-290**. El desarrollo postembrionario, consumo y parámetros de tabla de vida de *Cydnodromus* (= *Neoseiulus*) *picanus* Ragusa y *Phytoseiulus persimilis* (Athias-Henriot), fueron estudiados a  $29,44 \pm 1,47^\circ \text{C}$ ,  $42,35 \pm 5,01\%$  de H.R. y un fotoperíodo de 14:10 h (L:O), para evaluar la potencialidad de estos depredadores sobre la araña cinabarina *Tetranychus cinnabarinus* Boisduval. Los huevos, larvas y protoninfas de *T. cinnabarinus* pueden ser considerados alimentos óptimos para *C. picanus* obteniéndose una supervivencia de 100, 97 y 93%, respectivamente. La supervivencia de *P. persimilis* fue de alrededor del 6,7% con los mismos alimentos, presentando una alta mortalidad a nivel de huevos por deshidratación. La duración del desarrollo postembrionario de *C. picanus* fue significativamente menor ( $P < 0,05$ ) que el de *P. persimilis* al ser alimentados con huevos, larvas y deutoninfas de *T. cinnabarinus*. La tasa intrínseca de crecimiento ( $r_m$ ) fue significativamente mayor ( $P < 0,05$ ) para *C. picanus* (0,289 y 0,307) que para *P. persimilis* (0,019 y 0,025) alimentados con huevos y una mezcla de diferentes estados de *T. cinnabarinus*, respectivamente. Los valores de la tasa finita de crecimiento ( $\lambda$ ) también fueron significativamente ( $P < 0,05$ ) mayores para *C. picanus* (1,34 y 1,36) que para *P. persimilis* (1,02 y 1,03) al alimentarlos con huevos y dieta mixta, respectivamente. Los valores altos de  $r_m$  y  $\lambda$  registrados para *C. picanus* en las condiciones experimentales son indicadores del posible control potencial que presentaría este fitoseido como depredador de *T. cinnabarinus* en condiciones de baja humedad relativa que son encontradas en las zonas áridas del desierto de Chile.

**Palabras clave:** Control biológico, depredación, desarrollo postembrionario, tabla de vida.

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