



Full Length Article

Predation Preference and Fecundity Potential of *Neoseiulus californicus* (Acari: Phytoseiidae) to *Tetranychus turkestanii* (Acari: Tetranychidae) and *Tetranychus truncatus* (Acari: Tetranychidae)

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Abstract

Xinjiang is the largest cotton producing areas in China as well as in the world, where spider mites are dominant pests greatly damaging cotton production. *N. californicus* is an important predatory mite. To evaluate control potential for *N. californicus* to act as a bio-agent in Xinjiang main cotton regions, the functional response and preference experiments were conducted with *N. californicus* to two main local spider mites: *T. turkestanii* and *T. truncatus*. The results revealed that the predatory capacity of *N. californicus* on *T. turkestanii* was higher than that on *T. truncatus* at various prey densities and ratios treatments. Both functional responses followed a Holling- II type by logistic regression model analysis. Manly's preference index of *N. californicus* indicated that *T. turkestanii* was the preferable prey at all ratios and prey densities tested. The attack rate of *N. californicus* on *T. turkestanii* (0.766) was greater than *T. truncatus* (0.444) and the handling time on *T. turkestanii* (0.122) was shorter than *T. truncatus* (0.197). The fecundity parameters of life tables for experimental populations of *N. californicus* preying on *T. turkestanii* and *T. truncatus* were examined. The values indicated that *N. californicus* population developed faster and had a higher reproductive rate when feeding on *T. turkestanii* than on *T. truncatate*. All experimental data showed that *N. californicus* could be a good bio-control agent for mite control of Xinjiang main cotton regions. © 2019 Friends Science Publishers

Keywords: Fecundity potential; Functional response; *Neoseiulus californicus*; Prey preference; *Tetranychus turkestanii*; *Tetranychus truncatate*

Introduction

Xinjiang is the largest cotton production areas in China as well as in the world. Spider mites in Xinjiang cotton areas have been increasing year by year and have caused serious economic losses. *T. turkestanii* is the dominant population of spider mites damaging cotton production in Xinjiang (Zhang *et al.*, 2008; Wang *et al.*, 2014a, b, 2017), besides *T. truncatus* has caused great damage of cotton production in Xinjiang in recent years (Mohammad *et al.*, 2014; Wang *et al.*, 2014b, c; Li *et al.*, 2015). Predatory mite, *N. californicus*, is a good natural enemy of spider mites (Gerson *et al.*, 2003; Jiang *et al.*, 2015). The natural populations of *N. californicus* are widely distributed almost all over the world (Fraulo *et al.*, 2008; Li *et al.*, 2014; Yuan *et al.*, 2015). They exist on many fruit plants and crops like citrus, corn, grapevine and strawberry etc. (Easterbrook *et al.*, 2001; Barber *et al.*, 2003; Fraulo *et al.*, 2008; Qin *et al.*, 2013; Clare and William, 2016; Chen *et al.*, 2016). *N. californicus* has been as a good biocontrol commodity of spider mites (Castagnoli *et al.*, 1999; Li *et al.*, 2014; Liu, 2017; Carla *et*

al., 2018; Zhang *et al.*, 2018), such as *Tetranychus urticae*, *Panonychus ulmi*, *Raoiella indica*, *Panonychus citri*, *Polyphagotarsonemus latus*, but has no reports about controlling *T. turkestanii*. Despite the predatory potential of *N. californicus*, surprisingly little is known about the predatory selection process to *T. turkestanii* and *T. truncatus* and the functional response of predator-prey interaction are rarely known by people. The test is very necessary to forecast the efficacy of *N. californicus* as bio-control agent of spider mite in Xinjiang cotton regions. So it is urgently needed to know which one mite species is preferable by *N. californicus*, and how *N. californicus* responds to changes at various densities and prey species ratios.

It is a stubborn problem to prevent and manage spider mite under dry and high-temperature conditions, which cannot rely on commercially available predatory mites. Interestingly, because of biological and ecological plasticity, some predatory mite species evolved to adapt considerable intra-specific variability to certain low humidity and high-temperature. Among these commercially available predatory mite species, *N. californicus* qualified as the most suitable one for intra-specific comparisons among strains

(Castagnoli and Simoni, 1991; Castagnoli et al., 1995; Castagnoli, 1996; Castagnoli and Simoni, 1999; Greco et al., 1999; Barber et al., 2003; Gotoh et al., 2004; Walzer et al., 2008; Zhang et al., 2012; Ghazy et al., 2018). A dry and high-temperature tolerant strain of *N. californicus* has been successfully screened out in previous research of our laboratory.

The purposes of this study were to calculate the functional response of and determine the potential impact of *N. californicus* on two local main spider mite species; to make preference experiments and determine predator discrimination ability of *N. californicus* with two preys; to examine the Manly's preference indices and fecundity parameters of life tables for two mite species. These results showed that *N. californicus* had a higher preference and fecundity potential for *T. turkestanii* at all prey ratios and densities.

Materials and Methods

Sources of Predator and Prey

A dry and high-temperature tolerant strain of *N. californicus* has been successfully screened out in our laboratory and reared with *Tetranychus urticae* at $26 \pm 1^\circ\text{C}$, L14: D10 photoperiod, and 60–70% RH. *T. turkestanii* and *T. truncatus* were collected from cotton fields near Shihezi University, reared on bean plants more than 20 successive generations, and maintained at $26 \pm 1^\circ\text{C}$, 65% RH, and L14: D10 photoperiod in lab.

Predatory Preference by Functional Response Equation

The test arena were set on leaves of the common bean placed on a water-saturated sponge mat in Petri dishes at $25 \pm 1^\circ\text{C}$, 60% relative humidity and under 14h light: 10h dark conditions.

Firstly a matured female adult of *N. californicus* were placed individually on the test arena and starved for 24 h before predation. Secondly, female adults of *T. turkestanii* and *T. truncatus* were simultaneously put on every test arena at 2, 4, 6, 12, 24, 36, and 48 in density. The ratios were 1:1, 1:2 and 2:1 separately. Finally 24 h later, *N. californicus* were deleted and the eaten *T. turkestanii* and *T. truncatus* were recorded. All cases were replicated five times. Functional response equations were calculated by logistic regression model and Holling disc equation (Holling, 1961):

$$\frac{Ne}{No} = \frac{\exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3 + P_4N_0^4)}{1 + \exp(P_0 + P_1N_0 + P_2N_0^2 + P_3N_0^3 + P_4N_0^4)}$$

Ne: the eaten prey number; N_0 : the initial prey density; P_0 - P_4 : the estimated parameters

$$\frac{1}{Na} = \frac{1}{aTN_0} + \frac{T_h}{T}$$

Na : the attacked prey number; N_0 : the initial prey density; T : the exposure time that the predator had to forage; a : the successful attack rate by a predator; T_h : the handling time of a predator on prey.

Manly's Preference Index

Manly's index (α) (Manly et al., 1972; Chesson, 1983; Krebs, 1989; Sherratt and Harvey, 1993; Roger et al., 2001) was calculated to verify predatory preference at each prey ratio and density:

$$\alpha_i = \frac{\log p_i}{\sum_{j=1}^m \log p_j}, m=1-2$$

α_i : Manly's α for prey species i ; p_i : proportion of prey i remaining at the end of test ($i = 1, 2, \dots, m$); p_j : proportion of all prey species together remaining at the end of test ($j = 1, 2, \dots, m$); m : number of prey species

Fecundity Parameters of Life Tables

The fecundity parameters of life tables for experimental populations of *N. californicus* preying on *T. turkestanii* and *T. truncatus* were constructed as followed:

$$\begin{aligned} R_0 &= \Sigma(lx \cdot mx); \\ T &= \Sigma(lx \cdot mx \cdot x) / \Sigma(lx \cdot mx); \\ r_m &= (\ln R_0) / T; \\ \lambda &= e r_m; \\ t &= (\ln 2) / r_m \end{aligned}$$

x : time interval per day; lx : survival rate during x period; mx : female offsprings per female mite during x period; e : natural constant; R_0 : population reproduction rate; r_m : intrinsic rate of increase; T : life time; λ : finite rate of increase; t : population double time

Results

Predation and Functional Response

The natural mortality of *T. turkestanii* and *T. truncatus* was lower than 3.6% and 3.4% averagely. At density of 2, 4, 6, 8, 12, 24 and 48 prey items, the mean (\pm SE) survival rates (%) were 100, 96 ± 0.8 , 95 ± 1.2 , 96 ± 3.2 , 95.1 ± 3.3 , 97.3 ± 2.1 , 96.3 ± 1.1 for *T. turkestanii* and 100, 96 ± 0.8 , 95.7 ± 2.5 , 96 ± 1.3 , 96.5 ± 1.1 , 96.3 ± 1.7 , 95.6 ± 2.1 for *T. truncatus*. As the high survival rates for the control group, we didn't make corrections to the predation rate estimation (Table 1).

There was a clear difference in *N. californicus*'s selectivity to the two prey species. Under the same density conditions, the predacious number of *N. californicus* feeding on *T. turkestanii* was significantly higher than on *T. truncatus* (Table 1); with the increasing of prey density, the predatory rates also increased for both two preys, however, predation on *T. turkestanii* was apparently higher than on *T.*

Table 1: The mean consumption number of *N. californicus* feeding on two preys at different densities

Density	<i>T. turkestanii</i>	<i>T. truncatus</i>
2	1.40 ± 0.24Ac	0.83 ± 0.31Bd
4	1.80 ± 0.37Ac	1.0 ± 0.27Bd
6	2.60 ± 0.50Ac	1.67 ± 0.21Bd
12	4.80 ± 0.58Ab	2.67 ± 0.42Bc
24	6.40 ± 0.50Aa	3.66 ± 0.33Bb
36	7.40 ± 0.68Aa	5.00 ± 0.26Ba
48	8.00 ± 0.88Aa	5.33 ± 0.42Ba

Note: Mean ± SE in the same row followed by different uppercase letters are significantly different; Mean ± SE in the same row followed by different lowercase letters are significantly different ($P < 0.05$) by Duncan's tests

Table 2: The logistic regression analysis of *N. californicus* fed on two prey mites

Prey	Parameter	Estimate	SE	95% CI
<i>T. turkestanii</i>	b ₀ (Intercept)	1.8455	0.1924	1.3111 2.3798
	b ₁ (Linear)	-1.0132	0.1792	-1.4932 -0.5331
<i>T. truncatus</i>	b ₀ (Intercept)	2.128	0.1591	1.6862 2.5698
	b ₁ (Linear)	-0.8912	0.1777	-1.3845 -0.3978

Table 3: Mean (± SE) estimates of attack rate a and handling time Th of *N. californicus* fed on two prey species

Prey	a	Th	a/Th	1/Th	Na = aTN/(1+aThN)	R ²
<i>T. turkestanii</i>	0.766	0.122	6.265	8.177	Na = 0.771N/(1+0.109N)	0.9412
<i>T. truncatus</i>	0.444	0.197	2.249	5.068	Na = 0.428N/(1+0.0873N)	0.9202

Table 4: Mean (± SE) estimates of prey consumption of *N. californicus* fed on two prey species at different ratios

Prey species ratio	Mean ± SE
1 <i>T. turkestanii</i> :1 <i>T. truncatus</i>	3.78 ± 0.81e
1 <i>T. turkestanii</i> :2 <i>T. truncatus</i>	2.71 ± 0.82ad
2 <i>T. turkestanii</i> :1 <i>T. truncatus</i>	4.47 ± 1.01bc
<i>T. turkestanii</i>	4.60 ± 1.10b
<i>T. truncatus</i>	2.60 ± 0.58a

Note: Means followed by different letters are significantly different ($P < 0.05$) by Duncan's tests

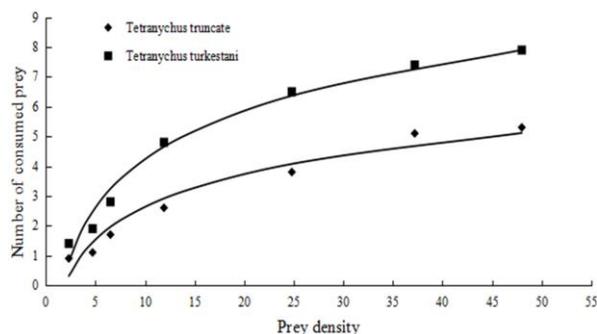


Fig. 1: The functional response curves that *N. californicus* fed on *T. turkestanii* and *T. truncatus* at different prey densities

truncatus. Within each prey species, when higher prey densities, 36 and 48 items, were offered, the difference between the number of maximum consumption for the two prey species seemed not apparent as before.

Predatory Preference

Maximum likelihood was estimated from logistic regression analysis (Table 2). The predatory capacity of *N. californicus* fed on *T. turkestanii* was a significantly negative linear term (Table 2). The functional response curves of two mites eaten by *N. californicus* exhibited both Holling II type curves (Fig. 1). The negative acceleration curve ($F=200.69, P < 0.0001$) displayed that the predacious number declined when the prey density increased (Fig. 1). *N. californicus* fed on *T. truncatus* also fitted the same negative term ($F=191.92, P < 0.0001$).

The functional response equation that two preys were eaten by *N. californicus* was presented by Holling's Disc equation: $Na = aTN/(1+aThN)$ (Table 3). The attack rate a was 0.766 for *T. turkestanii* and 0.444 for *T. truncatus*; The handling time T_h was 0.122 for *T. turkestanii* and 0.197 for *T. truncatus*; The predation efficiency a/T_h was 6.265 for *T. turkestanii* and 2.249 for *T. truncatus*. Mean (± SE) estimates of handling time, attack rate and predation efficiency demonstrated that *N. californicus* had distinct responses to different prey species.

When the two kinds of preys were offered at different ratios respectively (1:0, 1:1, 1:2, 2:1, 0:1) and set the densities at 6, 12 and 24 items, the number of prey consumption was significantly affected by prey species ratios (Table 4). When *T. turkestanii* was supplied only (1:0) or together with *T. truncatus* (2:1) simultaneously, the mean (± SE) estimates of prey consumption of *N. californicus* were significantly higher. However, when the two kinds of preys were set at the ratio of 1:1, the prey consumption was descended. Furthermore, the number of prey consumption apparently decreased when the ratio of *T. truncatus* was higher (1:2) or was offered alone (0:1).

As the prey density increased, the mean consumption rates were also increased at every prey ratio (Table 5). However, these mean predatory rates were also markedly affected for each of the prey ratios presented (1 *T. turkestanii*: 1 *T. truncatus*; 1 *T. turkestanii*:2 *T. truncatus*; 2 *T. turkestanii*:1 *T. truncatus*). When increased prey densities were at 6, 12 and 24 prey items, the mean number of prey consumption at the 2 (*T. turkestanii*): 1 (*T. truncatus*) ratio was greatly higher than at 1:1 and 2:1 ratios.

The values of Manly's preference indices (mean ± SE) were calculated and compared by *N. californicus* at different prey ratios and densities (Table 6). *T. turkestanii* got very high preference index values, greater than 0.7 at the ratio of 2:1 and 1:1. Only at the ratio of 1:2, the preference index values of *N. californicus* to *T. turkestanii* were lower (< 0.6), but still higher than 0.5. These calculated values demonstrated that *N. californicus* had a stronger preference to *T. turkestanii* as prey.

Fecundity Potential in Life Tables

To evaluate the potential for *N. californicus* to act as a biological control for two preys, the fecundity parameters of

Table 5: The mean prey consumption by *N. californicus* at each different prey density and ratio

Density	1 <i>T. turkestanii</i> : 1 <i>T. truncatus</i>	1 <i>T. turkestanii</i> : 2 <i>T. truncatus</i>	2 <i>T. turkestanii</i> : 1 <i>T. truncatus</i>
2	0.8 ± 0.37Ad	-	-
3	-	0.60 ± 0.25Bc	1.33 ± 0.33Cc
4	1.8 ± 0.37AcD	-	-
6	2.4 ± 0.67Abc	1.60 ± 0.68Bbc	3.0 ± 0.42Cbc
12	3.75 ± 0.47Ab	2.20 ± 0.20Bb	4.0 ± 1.08Cb
24	5.2 ± 0.37Aa	4.33 ± 0.33Ba	6.40 ± 0.40Ca

Note: Means in the same row followed by different lowercase letters are significantly different; means in a column followed by different uppercase letters are significantly different ($P < 0.05$) by Duncan's tests

Table 6: The Manly's preference index by *N. californicus* at different prey ratios and densities

Ratio	Density	<i>T. turkestanii</i>	<i>T. truncatus</i>	SE
1 : 1	2	0.75	0.25	0.250
	4	0.70	0.30	0.200
	6	0.88	0.13	0.375
	12	0.81	0.19	0.310
	24	0.77	0.23	0.270
1 : 2	3	0.62	0.38	0.190
	6	0.63	0.38	0.125
	12	0.55	0.45	0.050
	24	0.60	0.40	0.170
2 : 1	3	0.75	0.25	0.250
	6	0.92	0.08	0.420
	12	0.83	0.17	0.330
	24	0.77	0.23	0.270

Table 7: The fecundity parameters of *N. californicus* fed on two prey species in life table

Parameter	<i>T. turkestanii</i>	<i>T. truncatus</i>
Net Reproduction rate (R_0)	52.062	34.559
Intrinsic rate of increase (r_m)	0.265	0.234
Generation time (T)	14.935	15.141
Population double time (t)	2.616	2.962
Finite rate of increase (λ)	1.303	1.264

Life tables for experimental populations of *N. californicus* preying on *T. turkestanii* and *T. truncatus* were constructed. At temperature 25°C, the net reproductive rate (R_0), intrinsic rate of increase (r_m) and finite rate of increase (λ) of *N. californicus* fed by *T. turkestanii* were 52.062, 0.265 and 1.303 respectively, greater than on *T. truncatus* ($R_0=34.559$; $r_m=0.234$; $\lambda =1.264$). Meanwhile, when feeding on *T. turkestanii*, the mean generation duration ($T=14.935$) and the population double time ($t=2.616$) were less than of *T. truncatus* ($T=15.141$; $t=2.962$) (Table 7). The results indicated that *N. californicus* population develops faster and had a higher reproductive rate when feeding on *T. turkestanii* than on *T. truncatus*.

Discussion

As two major mite pests in Xinjiang cotton fields, *T. turkestanii* and *T. truncatus* are often mixed together with other spider mites to form a mixture of pests, which has become an important restrictive factor damaging high yield

and good quality of cotton in Xinjiang. The predator's predation on prey is a complex behavioral process that is influenced by many factors, such as the predator's density, behavioral characteristics, predation habits, prey's density and habits as well as environments. Exploring the inter-relationships among them will play an important role in the implement improvement of biological control (Gerson et al., 2003; Zhang, 2003).

Holling II type functional response is the most common form of predatory response to predation in mites. The former studies have shown that the functional response of *N. californicus* on males of *T. urticae* is Holling II type; Zheng et al. (2013) found that *Euseius finlandicus* preferred to eggs and nymphs of *T. truncatus* when *E. finlandicus* preyed each period of *T. truncatus*; Cui et al. (2011) found that *Amblyseius barkeri* feeding on *T. truncatus* displayed the same functional response curve of Holling II type. The results of present study showed that the functional responses of *N. californicus* to each development period of *T. turkestanii* and *T. truncatus* are also Holling II type curves. Initially, with the density of prey increased, the predation of *N. californicus* increased. As prey density further increased, the predator's prey rate slowed down and the number of predation tended to saturate, while the functional response manifested itself as a negative acceleration. However, when the two prey species were offered simultaneously, the predation of *T. turkestanii* was significantly higher than of *T. truncatus*, and *N. californicus* had very higher preference index for *T. turkestanii*. It was found that the growth and reproductive speeds of *N. californicus* feeding on *T. turkestanii* are faster than of *T. truncatus*. Therefore, it is clearly indicated that *N. californicus* has a higher predation preference and reproductive potential for *T. turkestanii* than of *T. truncatus*.

In addition, our data come from laboratory trials which showed that there is no or very little web produced in tested arenas, while spider mites webs surrounds at all prey stages in natural fields. Whether *N. californicus* is uncomfortable with webs or used to webs is still an unresolved question. Therefore we should take seriously in understanding our laboratory results in combination with natural field conditions. Our results still needs further experimental testing in cotton fields. Although, laboratory trials provide basic data for the population growth of both predacious and phytophagous mites, environmental conditions in the field fluctuate diurnally and seasonally among climatic and

geographic regions, and could have substantial effects on mites that laboratory studies cannot reveal (Montserrat *et al.*, 2013; Vangansbeke *et al.*, 2015). The mites' biology as affected by the natural environment is still not fully understood and it is essential to know their behavior under natural conditions. Recently, Ghazy *et al.* (2018) simulated natural climate patterns and investigated the development and reproduction of the predatory mite *N. californicus* and the pest mite *T. urticae* at three Japanese cities in different latitudes. The data showed that *N. californicus* and *T. urticae* have similar trends, which are both highly adaptable to temperatures and other environmental factors, such as relative humidity may have contributed to the observed inter-specific variations. This information, together with our results of laboratory observations, could be useful for planning biological control programs for phytophagous mites and for successful establishment of predacious mites in new habitats.

The present study results showed that *N. californicus* has great potential in preventing and controlling the dominant mite, *T. turkestanii*, in Xinjiang cotton fields. Therefore, the introduction and reproduction of *N. californicus* into Xinjiang cotton fields in large scale will effectively reduce the persistence and richness of mite pest populations, and thereby reduce use and pollution of chemical pesticides.

Conclusion

In this study, it was clearly demonstrated that *N. californicus* had higher predation preference and fecundity potential on *T. turkestanii*. As far as we know, it is the first study searching the predation capacity of *N. californicus* on this prey species. The results indicated that *N. californicus* can greatly prevent and manage *T. turkestanii* which is dominant population of spider mites in Xinjiang cotton areas. Therefore, the introduction and propagation of *N. californicus* in Xinjiang, the largest region of cotton production worldwide, will effectively decrease the persistence and abundance of damaging spider mites population. Furthermore, field experiments in larger environmental conditions about predator and prey population reduction are needed to validate this.

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