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Source: Systematic and Applied Acarology, 21(5) : 647-656

Published By: Systematic and Applied Acarology Society

URL: https://doi.org/10.11158/saa.21.5.6

Systematic & Applied Acarology 21(5): 647–656 (2016)
http://doi.org/10.11158/saa.21.5.6

ISSN 1362-1971 (print)
ISSN 2056-6069 (online)

Article

Effects of host plant species on the development and reproduction of *Neoseiulus bicaudus* (Phytoseiidae) feeding on *Tetranychus turkestani* (Tetranychidae)

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Abstract

The leaf structure of the host plant can affect the development and reproduction of the predatory enemies of spider mites. The objective of this study was to compare the effects of five host plant species [cucumber (*Cucumis sativus* L.), cotton (*Gossypium hirsutum* L.), eggplant (*Solanum melongena* L.), tomato (*Lycopersicon esculentum* Mill.) and green bean (*Phaseolus vulgaris* L.)] on the development and reproduction of *Neoseiulus bicaudus* feeding on *Tetranychus turkestani*. There were significant differences in the characteristics of trichomes on the surfaces of the host plant species. Tomato leaves had the greatest trichome density (782 trichomes/cm^2) whereas green bean leaves had the least density (58 trichomes/cm^2). Cucumber had the longest trichomes (1.58 mm) and green bean had the shortest (0.14 mm). *N. bicaudus* developed into adulthood and completed its development on all five plant species. The total immature period of *N. bicaudus* feeding on *T. turkestani* was shortest (5.07 d) on tomato. *N. bicaudus* on cucumber had the longest previposition period (2.78 d) and the shortest oviposition period (11.96 days). Total fecundity was highest on green bean (42.4 eggs/day/female) and lowest on cucumber (20.81 eggs/day/female). The female/male sex ratio was highest on cucumber (0.76) and lowest on tomato (0.65). The net reproductive rate (R_0) was 14.55 on cucmber, 23.54 on cotton, 21.79 on eggplant, 24.05 on tomato, and 34.61 on green bean. In conclusion, among the five host plant species in this study, green bean was best and cucumber was worst for the development and reproduction of *N. bicaudus* preying on *T. turkestani*.

Key words: host plant, predatory mite, spider mite, predation, life parameters

Introduction

The host plant species can affect the population establishment and performance of predator mites (Walter, 1996; Romero & Benson, 2004; Tanga & Mohamed, 2013). The microenvironment of plant surfaces seems uniform to the human eye, but quite complex to arthropods (Buitenhuis *et al*., 2015; Roda & English, 2003). The characteristics of host plant can modify interaction between herbivore insects and their enemies (Grostal & O'Dowd, 1994; Norton *et al*., 2001; Momen & Hussein, 2011). The host plant species affects the oviposition, growth and development of predatory mites in the following ways: (i) by influencing the activity of predatory mites, (ii) by providing shelter for the mites from natural enemies, (iii) by altering the microenvironment, and (iv) by trapping and retaining food sources such as pollen and fungal spores (Romero *et al.*, 2011; Rebecca, 2014; Skirvin & Fenlon, 2001; Buitenhuis *et al*., 2014).

Neoseiulus bicaudus (Wainstein) is a species of predatory mites, while belong to phytoseiidae. It was recently observed in the Xinjiang Uygur Autonomous Region of northwest China (Wang *et* *al.,* 2015a). It was previously recorded from Iran, Russia, Greece, Cyprus, and the United States (De Leon, 1962; Wainstein, 1962; Schuster & Pritchard, 1963; Faraji *et al.,* 2007; Palevsky *et al.,* 2009). Wang *et al.,* (2015a) redescribed this species and discussed the morphological differences between the Chinese population of this species with *Cydnodromus comitatus* (De Leon, 1962), *Amblyseius scyphus* (Schuster & Pritchard, 1963), *Amblyseius micmac* (Chant and Hansell, 1971) and *Amblyseius hirotae* (Ehara, 1985), which were considered as the synonyms of *N. bicaudus*. Wang *et al.* (2015b) described the different stage morphology and predatory behavior of *N. bicaudus.* Li *et al*. (2015) studied the effects of temperature on the development and reproduction of *N. bicaudus*.

The spider mite *Tetranychus turkestani* is mainly distributed in Russia, Kazakhstan, America, the Middle East, and Xinjiang, China (Li *et al*., 2014; Lu & Zhang 2000). It is the most important pest mite in Xinjiang, causing damage to many crops including cotton (*Gossypium hirsutum* L.), eggplant (*Solanum melongena* L.), corn (*Zea mays L.*), sorghum (*Sorghum bicolor* L.), medlar *(Achras Sapota* L.), tomato (*Lycopersicon esculentum* Mill.) and beans (*Phaseolus vulgaris* L.). *T. turkestani* directly damages plant leaves. Under severe infestation, plant leaves become yellow and then dry or drop off the plant (Sohrabi & Shishehbor, 2008; Guo *et al*., 2013).

The objective of this study was to develop life tables for *N. bicaudus* preying on *T. turkestani* on five host plant species. Information from this study can be used (i) to understand the effects of different host plant species on *N. bicaudus* populations and to determine which host plant species is the best habitat for *N. bicaudus*, (ii) to increase understanding the interactions among host-pest-predator and (iii) to provide a scientific basis for the efficient release of predatory mites to control field pests.

Materials and methods

Mite colony

Tetranychus turkestani was from a laboratory colony. The colony was initiated in 2010 with individuals collected from a cotton field near Huayuan, Shihezi City, Xinjiang. The colony was maintained on green bean. The laboratory colony of *Neoseiulus bicaudus* was originally collected from Ili, Xinjiang and established in 2013. The colony had been acclimated and propagated on *T. turkestani* for two years. Both colonies were kept in a growth chamber (FLI-2000H, Eyela, Japan) at 26±1 ºC, 60% relative humidity, and a 16:8 h (light : dark) photoperiod.

Plant material

Cucumber (SG), cotton (HG-49), eggplant (ZCQ), tomato (HMN-140) and green bean (SJD) were cultivated in a field near Shihezi University, Xinjiang. When the plants reached their maturity, three plants were selected in each plot. Three leaves were collected from each of the upper, middle, and lower parts of the plants (i.e., nine leaves per plant). This allowed us to compare both trichome density (number of trichomes per cm^2) and trichome length among plant species. The number and length of trichomes on the surface of each leaf were determined under a stereo microscope (Zeiss Discovery V20). The values were then averaged.

Experiment set-up

In a preliminary experiment, two generations of *N. bicaudus* and *T. turkestani* were raised on the five host plant species. Small chambers were constructed by drilling a hole (1 cm diameter) through solid pieces of plexiglass (3 cm long × 2 cm wide × 0.3 cm high) (Xu *et al.,* 2013). A section of a plant leaf was placed on a strip of filter paper and then positioned over the hole at one end of the chamber. One gravid adult female of *N. bicaudus* female and ten adult *T. turkestani* females were transferred into the chambers. Both ends of the chamber were then covered with thin pieces of glass to keep the mites from escaping. The chambers were then placed in growth chambers at 26 ºC, 60% R.H. and 16:8 h (L:D). This humidity is typical of the arid/semi-arid climate of Xinjiang Province. There were 120 replications for each plant species.

After the *N. bicaudus* eggs were laid, the adult female and all the eggs but one was removed from each chamber. The development of the immature *N. bicaudus* was observed at 12 h intervals. The duration of each developmental stage was noted until all of the *N. bicaudus* reached adulthood. The leaf was not changed until the nymph stage. Afterwards, the leaf was changed daily. After reaching adulthood, the mites were sexed and males and females from the same host plant species were paired inside the chambers. Ten adult *T. turkestani* females were provided as food (Wang *et al.,* 2015b).The number of eggs laid by each female was recorded at 24 h intervals until it died. The eggs were counted and then transferred to clean chambers. The hatchlings were reared to adulthood and their sex-ratio was determined (Xia *et al.* 2012; Gotoh *et al.* 2004; McMurtry & Scriven 1964).

Life history parameters and statistical analysis

Life tables were constructed from the survival and fecundity rates of the *N. bicaudus*. The parameters for each host plant species were calculated using the methods of Birch (1948). Population parameters were calculated according to the following equations. The net reproductive rate, R_o, is given by $R_0 = \Sigma l_x m_x$; the intrinsic rate of increase, r_m, is given by $r_m = (L_n R_o)/T$); the finite rate of increase, λ, is given by $\lambda = e^{rm}$; the mean generation time, T, is given by $T = \Sigma x l_x m_x / \Sigma l_x m_x$); and the doubling time, Dt, is given by $Dt = (L_n 2)/r_m$.

Analysis of variance was conduced using SPSS version 17.0 to determine the effect of host plant species on *N. bicaudus* at different life stages. The means were compared using Duncan's multiple range tests. Differences were considered significant at P<0.05.

Results

Surface traits of the five host plant species

The type and number of trichomes differed among the five host plant species (Table 1). The trichomes of cotton and eggplant were in clusters, whereas those of cucumber, tomato and green bean were single. Cucumber and eggplant trichomes were acicular and hard, whereas trichomes in the other host plants were villiform and soft (Fig. 1). Tomato and eggplant had significantly more trichomes than others ($P < 0.05$). There was no significant difference in the number of trichomes among cotton, cucumber and green bean. Cucumber had the longest trichomes, averaging 1.58 mm in length. Cotton and eggplant had the second longest trichomes (1.30 and 1.10 mm long, respectively) and the bean had the shortest trichomes (0.14mm).

TABLE 1. Description of the trichomes of five host plants.

	Description	Number per cm^2	Length (mm)
Cucumber	Single, erect, acicular, hard	113±25.4 c	1.58±0.13 a
Cotton	Clustered, horizontal, villiform, soft	42±3.5 c	1.30±0.10 b
Eggplant	Clustered, erect, acicular, hard	250±7.1 b	1.10±0.06 b
Tomato	Single, erect, villiform, soft	782±86.1 a	0.62±0.03 c
Green bean	Single, erect, villiform, soft	58±7.3 c	0.14±0.02d

Note: Values are means ± SE. Values within a column followed by different letters are significantly different at P<0.05.

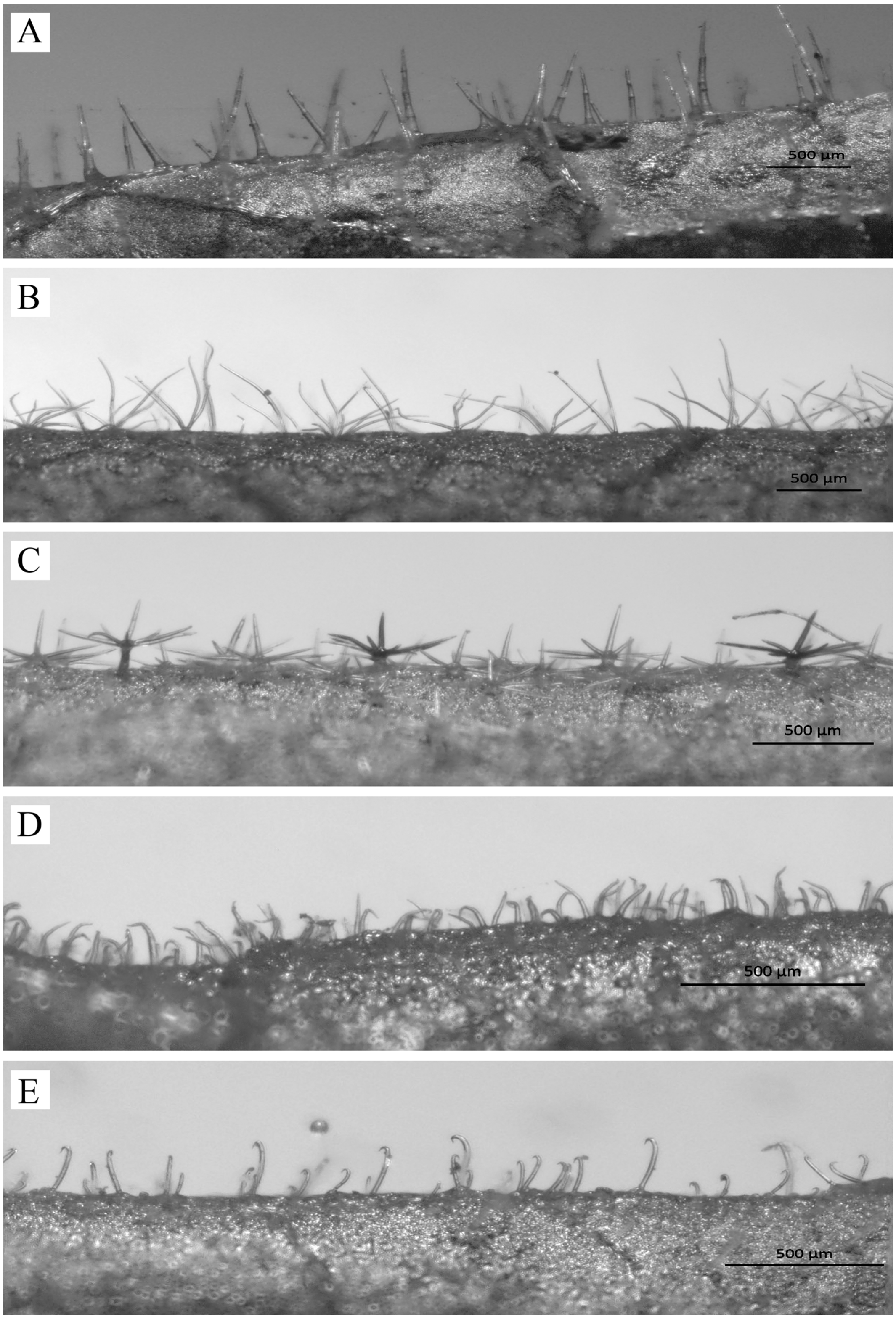

FIGURE 1. Trichomes on leaves of (a) cucumber, (b) cotton, (c) eggplant, (d) tomato, and (e) green bean.

Effects of host plant species on immature stages of N. bicaudus *feeding on* T. turkestani

The egg stage of *N. bicaudus* feeding on *T. turkestani* was significantly longer on cucumber (2.02 d) than on the other host plant species (Table 2). Differences among the other host plant species were not significant. The larval stage was significantly longer on green bean than on cucumber (P<0.05). The protonymph stage was significantly longest on green bean followed by cucumber. The deutonymph stage was longest on cucumber and green bean. The deutonymph stage was shortest on tomato. For *N. bicaudus* females feeding on *T. turkestani*, the immature stage was significantly longer on cucumber and green bean than on eggplant, cotton and tomato. The differences among the latter three plant species were not significant. Overall, the total immature period of *N. bicaudus* feeding on *T. turkestani* was shortest on tomato.

TABLE 2. Effect of host plant species on the development time (days) of immature *N. bicaudus* feeding on *T. turkestani*

Plant species	Egg (d)	Larval (d)	Protonymph(d)	Deutonymph(d)	Total immature(d)
Cucumber	2.02±0.09 a	0.54±0.02 b	1.51±0.06 b	1.74±0.07 a	5.82±0.13 a
Cotton	1.59±0.05 b	0.56±0.03 ab	1.46±0.05 bc	1.53±0.05 bc	5.13±0.07 c
Eggplant	1.63±0.03 b	0.59±0.02 ab	1.37±0.04 c	1.60±0.04 ab	5.19±0.06 c
Tomato	1.69±0.03 b	0.59±0.02 ab	1.35±0.04 c	1.44±0.06c	5.07±0.08 c
Green bean	1.65±0.03 b	0.62±0.02 a	1.66±0.03 a	1.71±0.03 a	5.65±0.06 b

Note: Values are means ± SE. Values within a column followed by different letters are significantly different at P<0.05.

Effects of host plants on adult development of N. bicaudus *feeding on* T. turkestani

The pre-oviposition period of *N. bicaudus* feeding on *T. turkestani* was significantly longer on cucumber (2.78 d) than on the other host plant species. Conversely, the oviposition period of *N. bicaudus* was significantly shorter on cucumber (11.96 d) than on the other host plant species. The post-oviposition period and total life span were both longest on green bean (11.93 and 31.05 d, respectively) and shortest on cucumber (4.37 amd 19.11 d. respectively). There was no significant difference in either the post-oviposition period or the life span of *N. bicaudus* among cotton, eggplant and tomato. The female/male sex ratio was highest on cucumber (0.76) and lowest on tomato (0.65) (Table 3).

TABLE 3. Effect of host plant species on the development time (days) of *N. bicaudus* adults feeding on *T. turkestani*

Plant species	Pre-oviposition (d)	Oviposition (d)	Post- oviposition (d)	Life span (d)	Female : male
Cucumber	2.78±0.11 a	11.96±0.77 b	4.37±0.66 c	19.11±1.12 c	0.76
Cotton	2.30±0.09 b	15.48±0.65 a	9.44±0.83 ab	27.22±1.08 b	0.73
Eggplant	2.31±0.083 b	16.03±0.74 a	8.63±1.06 b	26.97±1.45 b	0.70
Tomato	1.70±0.13 c	16.27±0.64 a	7.03±1.18 b	25.00±1.41 b	0.65
Green bean	2.52±0.44 b	16.60±0.77 a	11.93±1.47 a	31.05±1.66 a	0.66

Note: Values are means ± SE. Values within a column followed by different letters are significantly different at P<0.05.

Effects of different host species on the fecundity of N. bicaudus *feeding on* T. turkestani

Daily fecundity and daily female fecundity were both highest on green bean (2.55 eggs/day/female and 1.69 female eggs/day/female, respectively) and lowest on cucumber (1.71 eggs/day/female and 1.29 female eggs/day/female, respectively). The daily fecundity of *N. bicaudus* was significantly greater on green bean than on the other host plants. Total fecundity was greatest on green bean (42.2 eggs /female) and least on cucumber (20.81 eggs/female). There was no significant difference in total fecundity on cotton and on eggplant (Table 4).

TABLE 4. Effect of host plant species on the fecundity of *N. bicaudus* feeding on *T. turkestani*

Plant species	Daily fecundity (Eggs/day/female)	Daily female fecundity (Female eggs/day/female)	Total fecundity (Eggs/female)
Cucumber	1.71±0.08 d	1.29±0.069 d	20.81±1.86 d
Cotton	2.10±0.07 bc	1.54±0.05 b	32.37±1.78 c
Eggplant	1.98±0.07 c	1.39±0.05 cd	32.03±2.06 c
Tomato	2.25±0.08 b	1.47±0.05 bc	37.66±1.77 b
Green bean	2.55±0.10 a	1.69±0.06 a	42.40±2.36 a

Note: Values are means ± SE. Values within a column followed by different letters are significantly different at $P<0.05$.

Effects of host plant species on life table parameters of N. bicaudus *feeding on* T. turkestani

The net reproductive rate (R_0) of *N. bicaudus* feeding on *T. turkestani* ranged from 14.55 on cucumber to 34.61 on green bean (Table 5). The longest mean generation time was 14.47 d on green bean followed by 9.45 d on eggplant, 9.29 d on cotton, 8.84 d on tomato, and 8.20 d on cucumber. The maximum intrinsic rate of natural increase (r_m) was 0.36 on tomato; the minimum was 0.25 on green bean. However, the maximum doubling time was on green bean (2.83) whereas the minimum was on tomato (1.93). The finite rate of increase (λ) ranged from 1.28 on green bean to 1.44 on tomato (Table 5).

TABLE 5. Life table parameters on *N. bicaudus* feeding on *T. turkestani* on five host plants

Plant species	Net reproductive rate (R_0)	Mean generation time (T, in days)	Intrinsic rate of natural increase (r_m)	Population doubling time (Dt)	Finite rate of increase (λ)
Cucumber	14.55	8.20	0.33	2.12	1.39
Cotton	23.55	9.29	0.34	2.04	1.41
Eggplant	21.79	9.45	0.33	2.13	1.39
Tomato	24.05	8.84	0.36	1.93	1.44
Green bean	34.61	14.47	0.25	2.83	1.28

Note: Values are means ± SE. Values within a column followed by different letters are significantly different at $P<0.05$.

Survival rate and daily female fecundity of N. bicaudus *feeding on* T. turkestani

The survival curves of *N. bicaudus* on different host species were all type I (Fig. 2). Furthermore, there were differences among the survival rates. The survival rate (l_x) decreased significantly in the later developmental stages, especially on cucumber. On cucumber, *N. bicaudus* females began dying on d 11. All of the females died by d 35. On cotton, the female mites began dying on d 16. All of the females died by d 40. The survival was longest on eggplant (49 d).

Most *N. bicaudus* individuals completed their life span on these five plant species. The curves of age-specific fecundity (m_x) peaked soon after the onset of reproduction and varied considerably among the different host plant species. The age-specific fecundity of *N. bicaudus* peaked on d 3 on cucumber and cotton, d 8 on eggplant, d 6 on tomato, and d 11 on green bean. The life span of *N. bicaudus* was longest on green bean and cotton and shortest on cucumber.

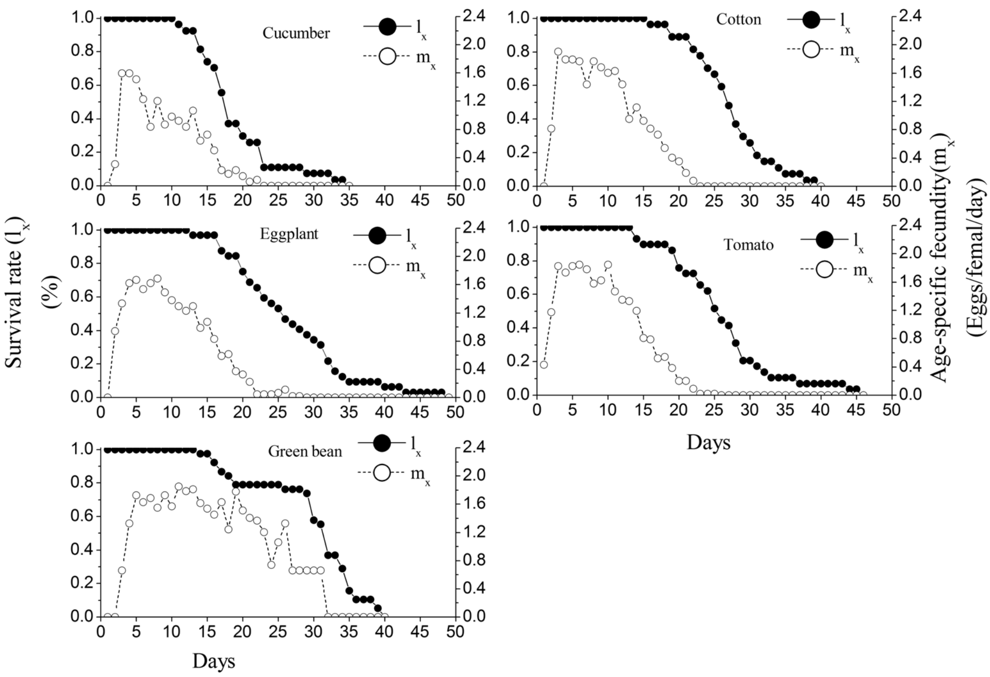

FIGURE 2. Effects of five host plant species on the survival and daily fecundity of *N. bicaudus* females feeding on *T. turkestani*. Abbreviations: l_x, age-specific survival rate; m_x, age-specific fecundity.

Discussion

The host plant is an interactive component of biological control practices and the characteristics of the host plant need to be considered when determining the predator release rate (Krips *et al.*1999; Loughner *et al.*2008; Madadi *et al.* 2007; Romero & Vasconcellos 2005). Life tables of both predatory mites and spider mites on different plant species provide important information that is needed for the efficient release of predatory mites to control pests in crop fields (Villanueva & Childers 2006; McMurtry *et al.* 2004; Gotoh & Kitashima 2006).

The length and number of trichomes differed among the five host plant species. Tomato and eggplant had significantly more trichomes than the other host plants. Cucumber had the longest trichomes. Cotton and eggplant had the second longest trichomes and the bean had the shortest trichomes.

In the current study, host plant species significantly affected the total immature time of *N. bicaudus* feeding on *T. turkestani*. Specifically, the generation period of *N. bicaudus* was shortest on tomato (5.0 d) and longest on cucumber (5.8 d). In contrast, Collier (2007) reported that host plant species (papaya versus snap bean) had no effect on the duration of the preimaginal stages of immature *N. idaeus* reared on *T. urticae*. The differences between our results and those of Collier may be due to differences in the characteristics of the host plant species and predatory mites in the two studies (Collier *et al.* 2007).

The fact that adult *N. bicaudus* females showed difference total fecundity in the five host plants. Total fecundity was greatest on green bean (42.2 eggs /female) and least on cucumber (20.81 eggs/ female). There was no significant difference in total fecundity on cotton and on eggplant. Overall, the results indicate that the total fecundity decreases as trichome length increases. The number of trichomes have no obvious impacts on the total fecundity. However, Loughner (2008) reported that a lack of trichomes was associated with much lower predator numbers. The fecundity is an important factor that effects on the number of arthropod (Loughner *et al.* 2008).

The maximum net reproductive rate (R_0) was on green bean (34.61). The minimum was on cucumber (14.55). The total duration of the immature stages, oviposition time, total fecundity, and net reproductive rate (R_0) all indicate that *N. bicaudus* did best on green bean and tomato and worst on cucumber. This result shows the trichome length negatively affected the population growth of *N. bicaudus*. These results emphasize the importance of the host plant characteristics on the performance of natural enemies.

This study was conducted in a laboratory with constant environmental conditions, whereas, in addition to the host plants, the other environment conditions also have effect on the development and reproduction of *N. bicaudus.* So additional work must be completed before exact recommendations can be made related to the efficient release of predatory mites to control field pests.

Acknowledgements

We thank Professor Jeff Geer from College of Agriculture, Shihezi University, Xinjiang for his generous help with revising the manuscript. This research was supported by Xinjiang Corps Outstanding Youth Fund (No.2014CD004), National High Technology Research and Development Program of China (863 Program) (No. 2011AA100508).

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Submitted: 20 Jan. 2016; accepted by Q.-H. Fan: 18 Apr. 2016; published: 5 May 2016