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Comparative biology and demography of the predatory mite *Neoseiulus longispinosus* (Evans) on five prey species of *Tetranychus* (Acari: Phytoseiidae, Tetranychidae)

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Abstract
Biological parameters (development and reproduction) and life table of *Neoseiulus longispinosus* were studied at 25±2 ^{0}C temperature and 65±5% relative humidity continuously on five different species of spider mites *Tetranychus urticae, T. ludeni, T. macfarlanei, T. truncatus* and *T. neocaledonicus* to ascertain its preference across different prey species. The mean developmental duration (egg-adult) of *N. longispinosus* was lowest on *T. truncatus* (4.75±0.03 days) and highest on *T. macfarlanei* (7.36±0.05 days). The highest longevity of *N. longispinosus* female was observed when it fed on T. macfarlanei (19.25± 0.62 days) but maximum fertility and daily ovipositional rate were recorded on *T. neocaledonicus* (29.76±1.57 and 2.17±0.836, respectively). The net reproduction rate (R_0), intrinsic rate of increase (r_m) and finite rate of increase (λ) of *N. longispinosus* were highest on *T. neocaledonicus* (21.18±0.01, 0.22±0.06 and 1.24±0.01, respectively) followed by *T. macfarlanei* (17.04±0.07, 0.16±0.03, 1.18±0.04, respectively). The r_m-value of the predator on different prey species ranged from 0.13±0.04 to 0.22±0.04 per day. The results demonstrated *N. longispinosus* as a potential predator of all the five species of *Tetranychus*, but *T. neocaledonicus* and *T. macfarlanei* were more preferred as prey.

Keywords: Biological control, phytoseiidae, spider mite, life table, pest management

Introduction
The number of mite species recorded from India increased from 35 in 1950’s to almost 2670 by the end of 2010, of which the share of phytophagous mites was around 700 species and the associated predatory mites were more than 320 species [1]. *Tetranychus urticae* Koch, *Tetranychus ludeni* Zacher, *Tetranychus macfarlanei* Baker and Pritchard, *Tetranychus truncatus* Ehara *and Tetranychus neocaledonicus* André (Tetranychidae), commonly known as spider mites are some of the most devastating pests in tropical and neotropical agroecosystems. However, *T. urticae* has been an alarming pest on bean, brinjal, cotton, cucurbits and okra which build up from February and decline during July under north Indian conditions [2]. *T. ludeni* is also recognized as a major pest of summer vegetables and occurs in the field from April to June [1]. *T. macfarlanei* exploits cucurbits as its major host infesting the older crops than the younger ones and also attack several medicinal crops in recent years [3, 4]. *T. truncatus* feeds on several crop plants such as brinjal, cotton, peach, papaya, peanut and cassava [5]. *T. neocaledonicus* has been recorded damaging vegetable crops like brinjal, bitter gourd, tomato, potato and fruit crops mango and fig [6].
Phytoseiids are one of the largest plant inhabiting pro-active predatory mite group that feed on spider mites, false spider mites, gall mites, thrips and whiteflies, which render them a group of efficient biological control agents in agricultural ecosystems in the country [7]. It is the most studied predatory mite group because of its high searching capacity, adaptability to a wide range of environments, density-dependent functional response and high multiplication rate [8]. So far many phytoseiid species have been exploited as biocontrol agents outside India except *Neoseiulus longispinosus* (Evans). It belongs to the ‘Type II Species’ group characterized by specialized predators of profusely webbing spider mites, mostly *Tetranychus* spp. [9]. It is well adapted to warmer temperature regimes and poly house environments [10] and also showed a high level of tolerance to conventional insecticides and acaricides [11] which recognise them as a useful component in the IPM strategy.

Biology and life table of *N. longispinosus* have been studied on *Tetranychus* mites in a scattered manner. Hence it was felt necessary to study its biology and demography on major *Tetranychus* species which are known emerging pests of agricultural and horticultural crops in peninsular India. The predator's preference for a particular prey mite species needs to be identified based on its development and reproduction performance to synergise with a suitable mass production technique. With this background, the developmental biology, reproduction and life table of *N. longispinosus* were studied on five selected species of *Tetranychus*, with which the predator is most often associated naturally.

Materials and methods

Maintenance of *Tetranychus* prey cultures

Pure cultures of spider mite species, *Tetranychus ludeni, T. macfarlanei, T. neocaledonicus, T. truncatus* and *T. urticae* maintained in the laboratory rearing separately on excised mulberry leaves, kept on moist foam placed in polythene trays at 25±2 ^{0}C temperature and 65±5% relative humidity in the laboratory. The identification of prey cultures was done every alternate week during the entire study period to avoid any adultartation. These stock cultures were reared for more than six months completing 25-30 generations before using in the studies.

Maintenance of *Neoseiulus longispinosus* culture

The adult predatory mites of *N. longispinosus* were obtained from the polycarbonate house of All India Network Project on Agricultural Acarology, UAS, GKVK, Bengaluru where the mites were reared on Selection-9 variety of French bean plants infested with *T. urticae*. The predatory mites were cultured in the laboratory (25±2 ^{0}C temperature and 65±5% relative humidity) on mulberry leaves on moist foam placed in polythene trays by providing respective prey mite species as food. Identification of both the predator and prey mites from each colonies were done every alternate week during the entire study period. *N. longispinosus* was reared on respective prey species at least for 10 generations (2½-3 months) before using in the studies.

Development of *N. longispinosus* on *Tetranychus* mites

Developmental biology of *N. longispinosus* was studied in the laboratory (25±2 ^{0}C temperature and 65±5% relative humidity) on excised mulberry leaf bits infested with five different species of *Tetranychus* mites *viz. T. urticae, T. macfarlanei, T. truncatus, T. neocaledonicus and T. ludeni* separately. For studying the biology of *N. longispinosus* on each species of prey mite the mulberry leaves were cut into bits of one square inch and 50 such bits were maintained on wet foam sheet in rectangular polyethene trays. Each leaf bit was infested with 10 gravid females of selected *Tetranychus* species and allowed to lay eggs and colonize to serve as food for the predator. When a sufficient number of eggs were observed on each of the fifty leaf bits (approximately 24 hours), one freshly laid egg (less than two hours old) of *N. longispinosus* was transferred to each leaf bit. The predatory mite eggs were allowed to hatch, pass through different instars and develop into adults by feeding on respective *Tetranychus* mites (as prey). The time required to pass through different stages *viz.*, incubation, larval, protonymphal and deutonymphal period were recorded every 3-6 hours under Zeiss Stemi 200 ^{0}C stereo zoom microscope.

Demography of *N. longispinosus* on *Tetranychus* mites

Demography of *N. longispinosus* in terms of reproduction and life table were studied on mulberry leaves infested with five species of Tetranychus mites separately at 25±2 ^{0}C temperature and 65±5% relative humidity in the laboratory conditions. Predatory mites obtained from the previous study were released on fresh mulberry leaf bits of 2 square cm. arranged on a wet foam sheet placed in polyethene trays at the rate of one female and two males per leaf bit. Each leaf bit was pre-infested with minimum 10 female individuals of respective Tetranychus species, 48 hours before releasing the predator. Egg-laying by each female predatory mite was recorded every day and these eggs were transferred to fresh mulberry leaf bits containing respective prey mites till the female ceased to lay eggs and died naturally. The adults that developed were sexed and the observations like pre oviposition period, oviposition period, post oviposition period, adult female longevity, daily oviposition rate, the average total number of eggs laid by each female (fecundity or fertility rate) were calculated on daily basis.

Statistical analysis

Differences in the duration of developmental stages of *N. longispinosus* on all the prey diets were analysed by one-way analysis of variance (ANOVA) and means were classified by Tukey's HSD test and different reproduction parameters were also analysed similarly. Each of the life table parameters was bootstrapped and analysed by one-way ANOVA followed by the least significant difference test. The computations were furnished in Microsoft Excel and SPSS (SPSS 22.0) and the data were visualized using RStudio. Different life table parameters were computed using the formula suggested by Birch [12] and Atwal and Bains [13]. The net reproduction rate (R0) per female i.e., the average number of newborn females produced by a female during its entire lifetime is the summation of $l_x m_x$ ($R_0 = \sum_{x=0}^{\infty} l_x m_x$) where l_x is the age-specific survival rate, m_x is the age-specific fecundity rate and x is the age of individual in days. Mean generation time (T) is calculated by the formula $T = (\sum x l_x m_x)/R_0$. The intrinsic rate of increase (r_m) is calculated by the formula $r_m = (\ln R_0)/T$. The finite rate of increase (λ) is derived from the formula $\lambda = e^{r_m}$.

Results

Development of *Neoseiulus longispinosus* on five *Tetranychus* species

After incubation, the predatory mite *Neoseiulus longispinosus* completes its development through four distinct postembryonic stages *viz.*, larva, protonymph, deutonymph and adult [14] (Figure 1). The larva is hyaline, smallest in size, inactive with only three pairs of legs which gradually grow in size after each moulting. The protonymph stage onwards, they become equipped with four pairs of legs, actively search for prey and the gut often seems to be pigmented (visible through the transparent cuticle) depending on the food consumed. The adult male is smaller than the female. The duration of development (from egg to adult) of female and male *N. longispinosus* on *T. ludeni, T. macfarlanei, T. neocaledonicus, T. truncatus* and *T. urticae* was 5.77±0.09 & 5.17±0.35, 7.33±0.09 & 6.87±0.36, 5.98±0.08 & 5.82±0.10, 4.74±0.05 & 4.75±0.04 and 5.53±0.06 & 5.67±0.06 days, respectively (Table 1). The total developmental time of *N. longispinosus* (male+female) on *T. ludeni*, *T. macfarlanei*, *T. neocaledonicus* *T. truncatus* and *T. urticae* was 5.78±0.06, 7.36±0.06, 5.89±0.07, 4.75±0.03 and 5.63±0.04 days, respectively. Longer developmental duration for female *N. longispinosus* was observed on *T. macfarlanei*, *T. neocaledonicus* and *T. ludeni* but the male took longer time on *T. urticae* for unknown reasons.

The range of total developmental period of *N. longispinosus* when offered different *Tetranychus* species as prey are compared in Fig. 2. Interestingly, 75 per cent of the predatory mite population took more than 7 days to develop from egg to adult when offered *T. macfarlanei* as prey whereas, the corresponding developmental period was less than 6.5 days when offered *T. urticae*, *T. ludeni* and *T. neocaledonicus*. The entire predator population took less than 5.5 days to complete development when reared on *T. truncatus*.

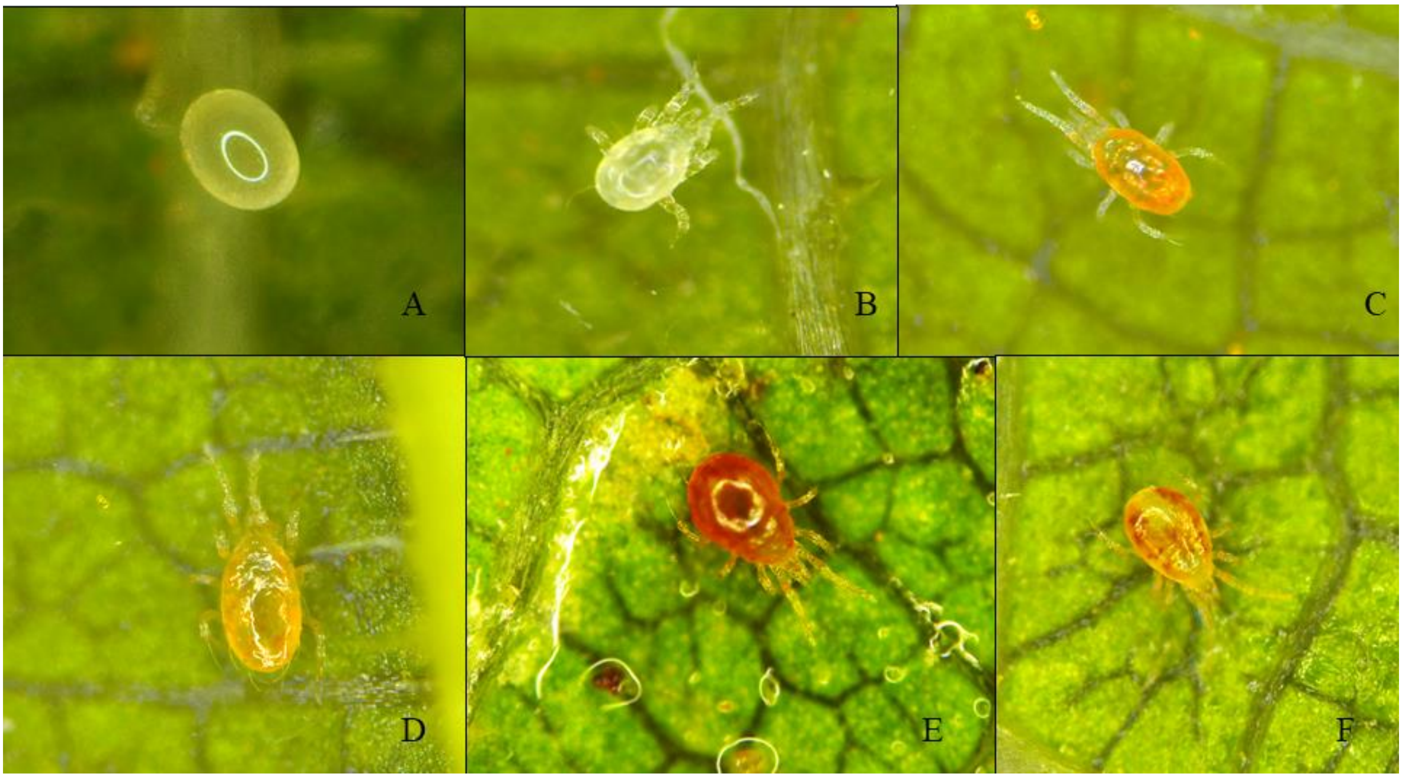


Fig 1: Stereo micrograph of different developmental stages of *Neoseiulus longispinosus*. A) Egg B) Larva C) Protonymph D) Deutonymph E) gravid female F) male (images are not to scale)

Table 1: Development of predator *Neoseiulus longispinosus* on prey species of *Tetranychus*

Developmental stages	**Duration of development (days) on different prey species (Mean±S.E.)***				
	T. ludeni	***T. macfarlanei***	***T. neocaledonicus***	***T. truncatus***	***T. urticae***
Female	**(n=26)**	**(n=29)**	**(n=22)**	**(n=36)**	**(n=31)**
Egg	2.39 ± 0.06a	3.34 ± 0.08c	2.51 ± 0.08ab	2.34 ± 0.03a	2.65 ± 0.07b
Larva	0.71 ± 0.02b	0.83 ± 0.03c	0.87 ± 0.04c	0.60 ± 0.01a	0.66 ± 0.09a
Protonymph	1.35 ± 0.05b	1.69 ± 0.06c	1.4 ± 0.05b	1.00 ± 0.03a	0.84 ± 0.02a
Deutonymph	1.33 ± 0.05c	1.47 ± 0.07cd	1.20 ± 0.04c	0.79 ± 0.03a	1.03 ± 0.04b
Egg-Adult	5.77 ± 0.09b	7.33 ± 0.09d	5.98 ± 0.08bc	4.74 ± 0.05a	5.53 ± 0.06b
Male	**(n=22)**	**(n=21)**	**(n=19)**	**(n=13)**	**(n=17)**
Egg	2.38 ± 0.05a	3.20 ± 0.06c	2.48 ± 0.06a	2.33 ± 0.03a	2.76 ± 0.05b
Larva	0.73 ± 0.02b	0.83 ± 0.04c	0.85 ± 0.03c	0.62 ± 0.01a	0.68 ± 0.03a
Protonymph	1.18 ± 0.09b	1.73 ± 0.08d	1.33 ± 0.05c	1.02 ± 0.02ab	0.81 ± 0.02a
Deutonymph	1.22 ± 0.09bc	1.46 ± 0.09c	1.17 ± 0.04b	0.77 ± 0.03a	1.08 ± 0.04b
Egg-Adult	2.38 ± 0.05a	3.20 ± 0.06c	2.48 ± 0.06a	2.33 ± 0.03a	2.76 ± 0.05b
Egg-Adult (male+female)	5.78 ± 0.06c	7.36 ± 0.06d	5.89 ± 0.07c	4.75 ± 0.03a	5.63 ± 0.04bc

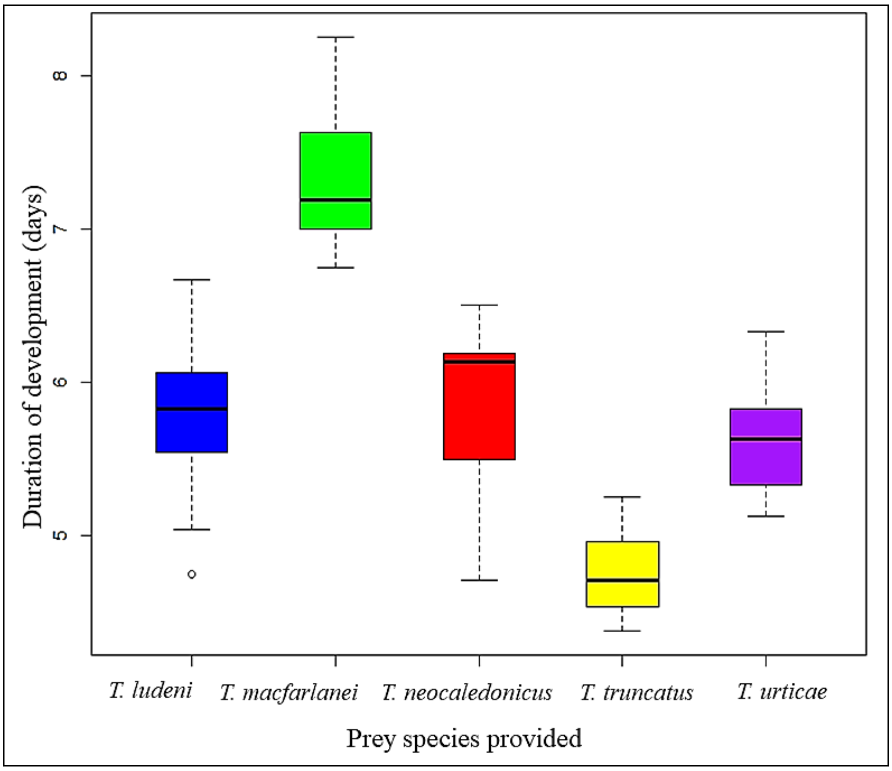


Fig 2: Range of development (egg to adult) of *Neoseiulus longispinosus* (female+ male) on different *Tetranychus* spp. (Each segment between two whisker limits represents 25% of the original population; Hollow circles represent extreme values of the respective population as outliers.

The incubation periods of *N. longispinosus* (male+female) observed on *T. truncatus*, *T. ludeni* and *T. neocaledonicus* (2.34±0.02, 2.38±0.04 and 2.49±0.05 days) were significantly shorter than *T. urticae* (2.72±0.04 days) and it was longest on *T. macfarlanei* (3.26±0.05 days). The larval period was shortest on *T. truncatus* (0.63±0.10 days) but almost equally longer on *T. neocaledonicus* (0.86±0.25 days) and *T. macfarlanei* (0.84±0.02 days). The shortest protonymphal period was recorded on *T. urticae* (0.82± 0.02 days) and the longest on *T. macfarlanei* (1.74±0.042 days). The shortest and longest deutonymphal period was observed on *T. truncatus* (0.78±0.02 days) and *T. macfarlanei* (1.52±0.05 days) respectively.

The data of different reproduction parameters of female *N. longispinosus* reared on different *Tetranychus* species are presented in Table 2.

Table 2: Reproduction attributes of predator *Neoseiulus longispinosus* on prey species of *Tetranychus* mites

Reproduction attributes	**Mean±S.E.***				
	***T. ludeni* (n=26)**	***T. macfarlanei* (n=29)**	***T. neocaledonicus* (n=22)**	***T. truncatus* (n=36)**	***T. urticae* (n=31)**
Pre Oviposition Period (days)	1.56±0.008ab	2.36±0.132c	1.30±0.043a	1.78±0.071b	2.27±0.124c
Oviposition Period (days)	13.38±0.900bc	14.21±0.699c	12.73±0.547b	10.82±0.102ab	9.87±0.667a
Post Oviposition Period (days)	2.58±0.138ab	2.69±0.186c	1.86±0.190a	2.15±0.231ab	2.77±0.235c
Adult Female Longevity (days)	17.52±0.852ab	19.25±0.620b	15.89±0.541a	14.75±0.716a	14.92±0.735a
Fertility Rate (total no. of eggs/female)	14.85±0.941b	15.52±0.961b	29.76±1.570c	15.45±1.206b	10.61±0.833a
Daily Oviposition Rate (average no. of eggs/ female/day)	1.42±0.091a	1.87±0.058bc	2.17±0.836c	1.68±0.064b	1.48±0.075a
Sex ratio in the succeeding progeny (♂:♀)	1:2.11	1:2.73	1:2.48	1:1.73	1:1.76

The shortest pre oviposition period for female *N. longispinosus* was recorded on *T. neocaledonicus* and *T. ludeni* (1.30±0.04 and 1.56±0.01 days) followed by *T. truncatus* (1.78±0.07 days), but significantly longer pre oviposition period was recorded on *T. urticae* (2.27±0.12 days) and *T. macfarlanei* (2.36±0.13 days). The female *N. longispinosus* had the longest period for oviposition on *T. macfarlanei* (14.21±0.70 days) but it was shortest on *T. truncatus* (10.82±0.10 days). The shortest post oviposition period was recorded on *T. neocaledonicus* (1.86±0.19 days) but the same was longest on *T. urticae* (2.77±0.24 days). *N. longispinosus* females survived the longest on *T. macfarlanei* preys (19.25±0.62 days) but comparatively lower longevity was observed on *T. urticae* and *T. truncatus* (14.92±0.74 and 14.75±0.72 days). The higher fertility rate of female *N. longispinosus* was recorded on *T. neocaledonicus* (29.76±1.57 eggs/female) but it was lowest on *T. urticae* (10.61±0.83 eggs/female). The daily oviposition rate was significantly higher *on T. neocaledonicus* (2.17±0.84 eggs/female/day) than the other preys offered. The sex ratio of *N. longispinosus* recorded was found female-biased irrespective of the prey in the current study but it was highest when reared on *T. macfarlanei* (1:2.73) followed by *T. neocaledonicus* (1:2.48), *T. ludeni* (1:2.11), *T. urticae* (1:1.76) and *T. truncatus* (1:1.73).

The range of fecundity of *N. longispinosus* when offered different *Tetranychus* species as food are compared in Fig. 3.

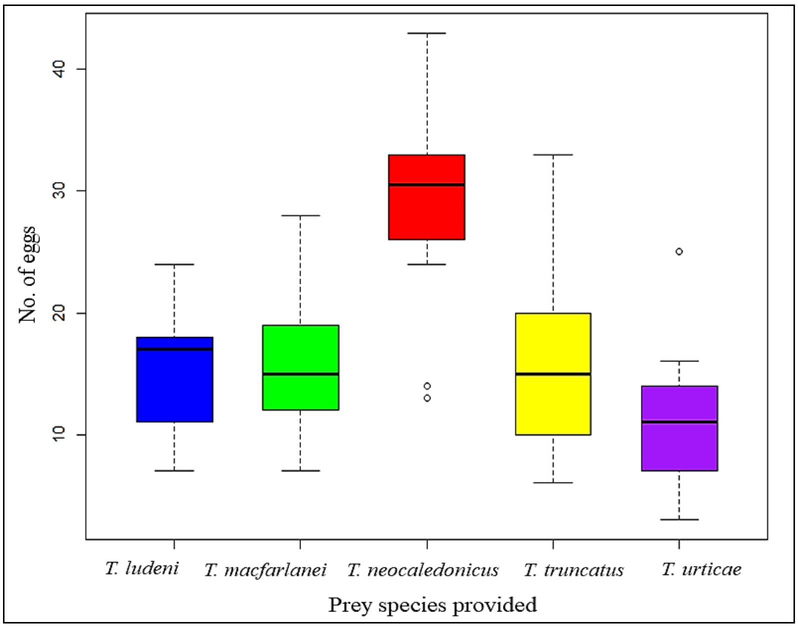
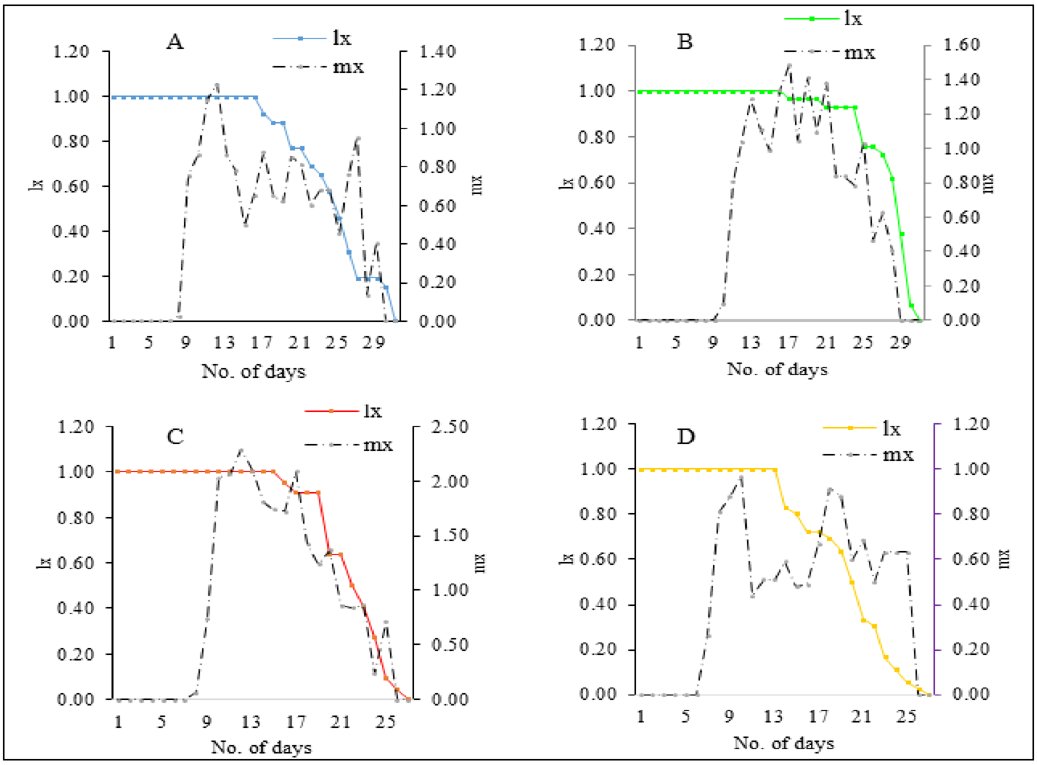


Fig 3: Range of fecundity of *Neoseiulus longispinosus* on different *Tetranychus* spp. (Each segment between two whisker limits represents 25% of the original population; Hollow circles represent extreme values of the respective population as outliers)

Interestingly, 75 per cent of the predatory mite population exhibited fecundity of fewer than 20 eggs per female when offered with *T. ludeni*, *T. macfarlanei* and *T. truncatus*. More than 80 per cent of the predatory mite population laid less than 15 eggs per female with the prey *T. urticae*. Also, more than 75 per cent of the predatory mites laid more than 20 eggs per female when reared on *T. neocaledonicus*.

Life table of *Neoseiulus longispinosus* on five *Tetranychus* mites

The present study on the life table parameters of *N. longispinosus* with five different *Tetranychus* mites as prey revealed that the predator completed life cycle and reproduced by predating on all the stages of the prey. The age-specific survival (l_x), fecundity (m_x) and maternity ($l_x m_x$) of *N. longispinosus* on each prey species are depicted in Fig. 4. Natural death of adult female *N. longispinosus* started 16th day onwards and highest mortality was observed between 20th and 26th day when reared on *T. ludeni*. The peak fecundity was found in 12th age cohort on the same prey diet. On *T. macfarlanei* the natural death of female *N. longispinosus* started from 15th day onwards but highest rate was observed from 23rd to 29th day whereas peak fecundity was observed in 16th age cohort followed by 18th and 20th age cohort. The natural death started after 15th day when fed with *T. neocaledonicus* and peak fecundity is recorded in 12th age cohort followed by 17th age cohort. Natural mortality on both the prey species of *T. truncatus* and *T. urticae* started from 12th day onwards but peak fecundity was observed in 10th and 22nd age cohort, respectively.



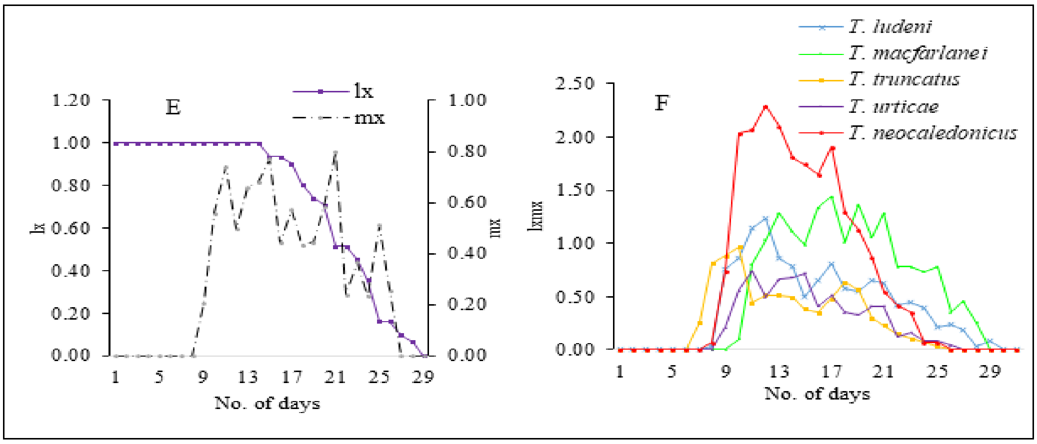


Fig 4: Age specific survival (lx), fecundity (mx) and maternity (lxmx) curves of predator *Neoseiulus longispinosus* on different prey species of *Tetranychus.* A) *Tetranychus ludeni*, B) *T. macfarlanei*, C) *T. neocaledonicus* D) *T. truncatus* E) *T. urticae* F) Age specific maternity curve of *N. longispinosus* on all the prey species

The life table parameters of *N. longispinosus* influenced by different prey species are presented in Table 3. The lowest mean generation time (T) of *N. longispinosus* was recorded on *T. truncatus* (14.07±0.10 days) but was observed highest when reared on *T. macfarlanei* (18.38±0.11 days). The doubling time (DT) of *N. longispinosus* was found shortest on *T. neocaledonicus* (3.51±0.04 days) but was much longer on *T. urticae* (5.82±0.07 days). The predator achieved highest net reproduction rate (R_0) of 21.18±0.12 females/female/generation on *T. neocaledonicus* followed by *T. macfarlanei* (17.04±0.07 females/female/generation) but was lowest on *T. urticae* (7.02± 0.04 females/female/generation). *N. longispinosus* achieved significantly higher intrinsic rate of increase (r_m) and finite rate of increase (λ) when reared on *T. neocaledonicus* (0.22±0.06 and 1.24 per day) than on *T. macfarlanei*, *T. ludeni and T. truncatus* and the lowest r_m and λ were observed on *T. urticae* (0.13±0.04 and 1.14±0.05 per day).

Discussion

Biological performance of *Neoseiulus. longispinosus* studied so far in India and worldwide are presented in Table 4. In most of the studies comparative data on different prey diets are lacking. We studied the development, reproduction and life table of *N. longispinosus* simultaneously on five different *Tetranychus* mites *viz.*, *T. ludeni*, *T. macfarlanei*, *T. neocaledonicus*, *T. urticae and T. truncatus* to ascertain the predator's preference for any prey species selected for the experiment.

The total developmental time recorded for *N. longispinosus* on *T. ludeni* in the present study (5.78±0.06 days) was higher than the developmental time of 3.95-4.12 days recorded by Mallik and Channabasavanna (1983) at 27±0.5 ^{0}C, probably due to the lower laboratory rearing temperature in the present study. Chandrasekharappa *et al*. (1995) studied developmental biology of *N. longispinosus* on *T. ludeni* and recorded the mean developmental duration of 3.97-4.12 days at 25 ^{0}C which was lower compared to the duration recorded in our study. The present study appears to be first instance where the development of *N. longispinosus* was investigated exclusively on *T. macfarlanei* as prey and there are no earlier studies to compare the results of the present study. Ullah and Gotoh (2014) showed that *N. womersleyi*, when fed with *T. macfarlanei* took 5.15- 5.17 days to complete its development which is less than the developmental time recorded in the present study. It may be inferred that compared to other predatory phytoseiid species like *N. womersleyi*, rate of development of *N. longispinosus* might be lower on *T. macfarlanei* prey. Despite being a serious pest on beans, cotton and many other agricultural and horticultural crops very few studies have been carried out on biological control of *T. neocaledonicus* using predatory mites and as a result documented literature is lacking on the biology of phytoseiid predators on *T. neocaledonicus*. The total developmental duration of *N. longispinosus* preying on *T. neocaledonicus* recorded in the present study is almost comparable with that of offering other *Tetranychus* mites as prey. This reveals this predator's potential to utilize *T. neocaledonicus* as one of the preferred prey.

Table 4: Biological performance of predator *Neoseiulus longispinosus* on different prey species of *Tetranychus*

Food source	Developmental duration (Egg-Adult) (days)	r_m (per day)	Rearing condition	Authors
T. ludeni	3.95-4.12	0.41	27±0.5 ^{0}C	Mallik and Channabasavanna [25]
	3.97-4.12		25 ^{0}C	Chandrasekharappa *et al.* [29]
	6.95±0.46		27±0.5 ^{0}C	Abhilash and Sudharma [24]
T. truncatus	3.2±0.23		30±0.2 ^{0}C	Nusartlet *et al.* [30]
T. urticae	4.9-5.9		25-30 ^{0}C	Lo and Ho [15]
	5.1-5.7		24 ^{0}C & 70% RH	Shih and Sheih [16]
	4.50-4.60	0.27-0.34	26 ^{0}C	Koldochka [17]
	4.3-8.8		18 ^{0}C-30 ^{0}C	Lee *et al.* [18]
	3.8			Kongchuensin *et al.* [19]
	4.27	0.4	25-28 ^{0}C & 65-85% RH	Ibrahim and Palacio [14]
	6.83	0.26	14-32 ^{0}C & 40-100% RH	Kadu [26]
	7-14			Sharma and Chauhan [21]

	6.24±0.89		28-32 ^{0}C & 78-83% RH	Sanchit and Shukla [22]
	4.18	0.23	26 ^{0}C	Bapugouda *et al.* [23]
T. cinnabarinus	4.4.-5.0		23-33 ^{0}C	Lababidi [31]
T. kanzawai (eggs)	5.06-5.66	0.194	24 ^{0}C	Shih and Sheih [16]
T. kanzawai	6.20		25±1 ^{0}C	Nakagawa [32]
T. kanzawai (eggs)	5-5.02		28 ^{0}C	Ho *et al.* [33]

The total developmental time of *N. longispinosus* recorded in the present study was higher than the developmental duration of *N. longispinosus* recorded by Nusartlet *et al.* (2010) on *T. truncatus* (3.2±0.23 days) and this lower record of developmental time might be due to the higher rearing temperature of 30±2 ^{0}C. The study by Ullah and Gotoh (2014) revealed that *N. womersleyi* when reared on *T. truncatus* prey, took 4.64-4.65 days to complete its overall development close to the present record. The results indicated that phytoseiid mites generally would develop faster on *T. truncatus*. *T. urticae* is the most studied prey species for many of the commercially exploited acarine biocontrol agents including *N. longispinosus*. The total developmental time of *N. longispinosus* on *T. urticae* recorded in the present study is comparable with the developmental time of 4.9- 5.9 days recorded by Lo and Ho [15] and 5.1-5.7 days observed by Shih and Sheh [16]. Koldochka [17] recorded the mean total developmental time of 4.60 days and 4.50 days for female and male *N. longispinosus,* respectively on *T. urticae,* which is lower compared to the present results. Lee *et al.* [18] could record a wide range in egg-adult developmental period (4.3-8.8 days) of *N. longispinosus* on *T. urticae* in 18-30 ^{0}C temperature scale but Kongchuensin *et al.* [19] observed a shorter developmental period (3.8 days) of *N. longispinosus* when offered *T. urticae* as prey. Thamilselvi [20] reported around 10 days of overall developmental period of *N. longispinosus* fed with *T. urticae* which is much higher than the duration recorded in the results of present study. Studies by Ibrahim and Palacio [14] revealed the developmental period of immature stages of *N. longispinosus* reared on *T. urticae* was approximately 0.65 days for larva, 0.87 days for protonymph and 0.95 days for deutonymph close to the findings of the present study. This might be due to more similar temperatures and relative humidity condition of the studies. Sharma and Chauhan [21] studied the development of *N. longispinosus* on *T. urticae* reared on beans and recorded the total developmental time of 7-14 days in the winter months whereas Sanchit and Shukla [22] recorded 6.24±0.89 days for total development on the same prey. A study conducted by Bapugouda *et al.* [23] showed that *N. longispinosus* took from 4.18 days (at 28 ^{0}C) to 4.76 days (at 36 ^{0}C) when fed with *T. urticae* which is shorter in the present study, because of difference in rearing temperature conditions. These large variations in developmental period of *N. longispinosus* suggests that *T. urticae* may not be a very preferred prey in all the situations as the performance of the predator drastically varies with change in atmospheric conditions.

Reproduction parameters of *N. longispinosus* on prey species of *T. macfarlanei*, *T. neocaledonicus* and *T. truncatus* have not been well studied so far however, the reproductive performance of *N. longispinosus* on prey species *T. ludeni* and *T. urticae* are available in few instances. Abhilash and Sudharma [24] reported a slightly lower female longevity (13.2±3.7 days) but higher fertility rate (25.2±3.83 eggs/ female) and daily oviposition rate (2.02±0.59 eggs/female/day) of *A. longispinosus* on *T. ludeni* compared to the corresponding values in the present study. Ibrahim and Palacio [14] recorded sex ratio of 1:2.56 (♂:♀) of *A. longispinosus* reared on *T. urticae* which is higher than the sex ratio recorded in the present study. Investigations carried out by Sanchit and Shukla [22] revealed higher oviposition (18.60±2.61 days), post oviposition period (3.50±1.01 days) and fertility rate (38.04±4.63 eggs/female) but lower pre oviposition period (1.61±0.03 days) of *A. longispinosus* reared on *T. urticae*. The deviations in the values from present study may be due to the higher rearing temperature (28-32 ^{0}C) and relative humidity (78-83%). Bapugouda et al. [23] worked out the sex ratio (♂:♀) of *N. longispinosus* on *T. urticae* and reported highly female-biased ratio of 1:3.11 compared to the present study (1:1.76).

The life table parameters of *N. longispinosus* have been extensively studied on *T. urticae* and *T. ludeni* but data for the same is lacking on other prey species such as *T. macfarlanei*, *T. neocaledonicus* and *T. truncatus* The intrinsic and finite rate of increase and the net reproduction rate recorded in the present study were lower than the values obtained by Mallik and Channabasavanna [25] (0.41/day, 1.51/day and 53.27 females/female/generation) who investigated life table parameters of *A. longispinosus* on *T. ludeni* but the mean generation time reported by them (9.69 days) was lower than the result obtained in the present study. Koldochka [17] investigated life table parameters of *N. longispinosus* feeding on different life stages of *T. urticae* and found a higher net reproduction rate (10.30-29.40 females/female/generation), intrinsic rate of increase (r_m) (0.27-0.35/ day) and mean generation time (8.50-8.60 days) than the values obtained in the present study. Ibrahim and Palacio (14) reported a higher net reproduction rate (36.7 females/female/generation), mean generation time (9.0 days), intrinsic rate of increase (0.4/day) but lower doubling time (1.7 days) of *A. longispinosus* feeding on *T. urticae* compared to the present study. A study conducted by Kadu [26] also revealed higher R_0 (37.88females/ female/day), T (19.50days) and rm (0.26/day) of *A. longispinosus* feeding on *T. urticae* compared to the present study which may be due to broad range of temperature (14-32 ^{0}C) in his study. Life table studies carried out by Bapugouda *et al.* [23] also showed higher R_0 (28.77 females/ female/ generation), r_m (0.23/day) and T (14.31 days) but lower λ (0.10/day) of *N. longispinosus* reared on *T. urticae*.

Nguyen and Shih [27] studied the life table parameters of *N. womersleyi* and *Euseius ovalis* on *T. urticae* and recorded higher intrinsic rate of increase (0.248 and 0.237/day) and net reproductive rate (24.86±2.19 and 17.86±1.74 females/female/day). Ullah and Gotoh [28] studied the lifetable parameters of *N. womersleyi* on *T. macfarlanei* and *T. truncatus* and their results revealed higher intrinsic rate of increase (0.30/day and 0.297/day) and finite rate of increase (1.35/day and 1.346/day), mean generation time (14.27 and 14.46 days), doubling time (2.29 and 2.33 days) and net reproduction rate (13.20 and 36.03 females/female/generation) when fed with the mentioned preys, respectively. These indicate that *N. longispinosus* can utilize *T. macfarlanei* and *T. truncatus* as preferred prey like other phytoseiid predators.

Conclusions

The present study ascertains that the predatory mite *Neoseiulus longispinosus* would complete its development and reproduce by feeding on all stages of the five species of *Tetranychus* mites used in the experiment. Overall performance of *N. longispinosus* was better on *T. neocaledonicus* followed by *T. macfarlanei* in terms of the rate of increase and reproduction output, but the female survival is better on *T. macfarlanei*. It can be concluded that for the mass production of *N. longispinosus*, most suitable prey species are *T. neocaledonicus* and *T. macfarlanei* as these can trigger the increase in population due to shorter doubling time and higher intrinsic rate of increase and sustain the same with sufficient adult longevity and higher fertility rate. These satisfy the prime requirements for a biological control programme to be successful. The present results can be a way forward for the agricultural researchers and stakeholders of our country to biologically control the acarine menace in the cultivated crops.

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References

1. Singh J, Raghuraman M. Emerging scenario of mite pests in India. Zoosymposia. 2011; 6:172-179.
2. Singh RN, Singh J. Incidence of *Tetranychus cinnabarinus* (Boisd.) (Acari: Tetranychidae) in relation to weather factors in Varanasi. Pestology. 1993; 17(1):18-23.
3. Jeppson LR, Keifer HH, Baker EW. Mites injurious to economic plants. 1st ed. California: University of California Press, 1975.
4. Biswas H, Gupta SK, Saha GK. Life cycle of *Tetranychus macfarlanei* Baker and Pritchard (Acari: Tetranychidae): a new pest of medicinal plants in West Bengal. Proceedings of the Zoological Society. 2013; 66(2):149-153.
5. Sakunwarin S, Chandrapatya A, Baker GT. Biology and life table of the cassava mite, *Tetranychus truncatus* Ehara (Acari: Tetranychidae). Systematic and Applied Acarology. 2003; 8(1):13-24.
6. Prasad R, Singh J. Status of mite pest fauna prevailing in brinjal agro-ecosystem. Uttar Pradesh Journal of Zoology. 2011; 31(1):15-23.
7. Gupta SK, Kumar PS. The underestimated worth of predatory and parasitic mites in India: does it really have to import exotic species for biological control?. CAB Reviews. 2018; 13:1-17.
8. Gerson U, Smiley R, Ochoa R. Mites (Acari) for Pest Control. Backwell Science, New Jersey, 2003.
9. McMurtry JA, Croft BA. Life-styles of phytoseiid mites and their roles in biological control. Annual Review of Entomology. 1997; 42(1):291-321.
10. Mallik B, Onkarappa S, Kumar HM. Management of spider mites, *Tetranychus urticae* Koch on rose using phytoseiid predators, *Amblyseius longispinosus* (Evans) in polyhouse. Pest Managemnt in Horicultural Ecosystem. 1998; 4(1):46-48.
11. Sugeetha G. Studies on development of insecticide resistant strains of *Amblyseius longispinosus* (Evans) (Acari: Phytoseiidae) (M.Sc. Dissertation). University of Agricultural Sciences, Bengaluru, 2007, 221.
12. Birch L. The intrinsic rate of natural increase of an insect population. The Journal of Animal Ecology. 1948; 1:15-26.
13. Atwal AS, Bains SS. Applied Animal Ecology. Kalyani Publishers, Ludhiana, 1974.
14. Ibrahim YB, Palacio VB. Life history and demography of the predatory mite, *Amblyseius longispinosus* Evans. Experimental & Applied Aarology. 1994; 18(6):361-369.
15. Lo KC, Ho CC. Influence of temperature on life history, predation and population parameters of *Amblyseius longispinosus* (Acarina: Phytoseiidae). Chung-hua nung yeh yen chiu.= Journal of Agricultural Research of China, 1979.
16. Shih CI, Shieh JN. Biology, life table, predation potential and intrinsic rate of increase of *Amblyseius longispinosus* (Evans). Chih wu pao hu hsueh hui hui kan. Plant Protection Bulletin, 1979.
17. Kolodochka LA. Pre-adult development of some species of predacious phytoseiid mites at a constant temperature. Vestnik Zoologii. 1985; 3:56-9.
18. Lee SW, Lee MH, Choi KM, Hyun JS. Development, fecundity, and prey consumption of the predacious phytoseiid mite, *Amblyseius longispinosus* (Evans), under different temperatures. Research Reports of the Rural Development Administration-Plant Environment, Mycology and Farm Products Utilization (Korea R.). 1987; 29:277-281.
19. Kongchuensin M. Biology of the two-spotted spider mite. *Tetranychus urticae* Koch and its predatory mite, *Amblyseius longispinosus* (Evans) on strawberry. Entomology and Zoology Gazette. 1989; 11:195-204.
20. Thamilselvi M. Studies on predatory mites of Tamil Nadu (Dissertation). Tamil Nadu Agricultural University, Coimbatore, 1990, 116.
21. Sharma A, Chauhan U. Standardization of Rearing Technique for *Neoseiulus* (= *Amblyseius*) *longispinosus*, a Predator of two Spotted Spider Mite. Indian Journal of Plant Protection. 2013; 41(4):320-5.
22. Sanchit SM, Shukla A. Biological attributes of predatory mite, *Amblyseius longispinosus* (evans) (acari: phytoseiidae). Journal of Experimental Zoology, India. 2016; 19(2):981-4.
23. Bapugouda K, Gowda CC, Srinivasa N. Mass production of predatory mite, *Neoseiulus longispinosus* (Evans) on two spotted spider mite, *Tetranychus urticae* Koch, using pole bean (*Phaseolus vulgaris* L.). Journal of Entomology and Zoology Studies. 2019; 7(1):1174-1179.
24. Abhilash B, Sudharma K. Biology and predating potential of *Amblyseius longispinosus* (Evans). Insect Environment. 2002; 8:155-6.
25. Mallik B, Channa Basavanna GP. Life history and life tables of *Tetranychus ludeni* and its predator *Amblyseius longispinosus* (Acari: Tetranychidae; Phytoseiidae). Indian Journal of Acarology. 1983; 8:1-2.
26. Kadu SN. Biology and feeding potential of predatory mite, *Ambiyseius longispnosus* (Evans) on some mites infesting apple (Dissertation). Dr. Y. S. Parmar University of Agriculture and Forestry, Solan, 2007, 214.
27. Nguyen TV, Shih CI. Life-table parameters of *Neoseiulus womersleyi* (Schicha) and Euseius ovalis (Evans) (Acari: Phytoseiidae) feeding on six food sources. International Journal of Acarology. 2012; 38(3):197-205.

28. Ullah MS, Gotoh T. Life-table attributes of *Neoseiulus womersleyi* (Schicha) feeding on five tetranychid mites (Acari: Phytoseiidae, Tetranychidae). International Journal of Acarology. 2014; 40(4):337-48.
29. Chandrashekarappa B, Mallik B, Harish KM. Effect of temperature and humidity on the biology of predatory mite *Amblyseius longispinosus* and *Amblyseius tetranychivorus* (Acari: Phytoseiidae). Fifth National Symposium in Acarology. University of Agricultural Sciences, Bengaluru. 1995.
30. Nusartlert N, Vichitbandha P, Baker GT, Chandrapatya A. Life history of *Amblyseius longispinosus* reared on eggs and larvae of six spider mites species (Tetranychidae) and effect of some pesticides on its mortality. 12th International Congress of Acarology. Amsterdam. 2006.
31. Lababidi MS. Development, longevity, fecundity and sex ratio of the predatory mite *Amblyseius longispinosus* (Evans) with *Tetranychus cinnabarnus* (Boisd.) as prey. Anzeiger fuer Schaedlingskunde Pflanzenschutz Umweltschutz (Germany, FR). 1989; 62(1):14-18.
32. Nakagawa T. Growth and prey quantity of *Amblyseius longispinosus* (Evans) as a predator of *Tetranychus kanzawai* Kishida [on tea plant]. Proceedings of the Association for Plant Protection of Kyushu (Japan). 1984.
33. Ho CC, Lo KC, Chen WH. Comparative biology, reproductive compatibility, and geographical distribution of *Amblyseius longispinosus* and *A. womersleyi* (Acari: Phytoseiidae). Environmental Entomology. 1995; 24(3):601-7.