Consumption rate and predatory preference of the predaceous mite, *Neoseiulus californicus* to *Tetranychus urticae* and *Eotetranychus lewisi* on strawberry in California, USA

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We studied the predatory efficiency and preference of *Neoseiulus californicus* to *Tetranychus urticae* and *Eotetranychus lewisi* on strawberry. The results indicated that *N. californicus* preferred to consume *E. lewisi* and cause more mean per cent reduction (90.00–96.66) compared to *T. urticae* (60.00–80.00). Although *N. californicus* appeared to prefer *E. lewisi*, its efficiency in feeding upon *T. urticae* makes it a useful natural enemy in an IPM programme for the control of *T. urticae* and *E. lewisi* on strawberry.

Keywords: *Eotetranychus lewisi*, *Neoseiulus californicus*, pest management, strawberry, *Tetranychus urticae*.

STRAWBERRY belongs to family Rosaceae and is cultivated worldwide for its fruit. It is found to be infested with tetranychid mite species. The two-spotted spider mite (TSSM), *Tetranychus urticae* Koch (Acari: Tetranychidae), is one of the most harmful tetranychid mite pests of strawberry and can cause significant reduction in crop yield[1]. The leaves have a speckled look in the early stages of infestation. As the plants become heavily infested, leaves turns yellow and are finally shed.[2] At present, *Eotetranychus lewisi* (McGregor) is emerging as another major pest on strawberry in southern California, USA, and has caused significant damage, particularly to organic fields. Pest control advisors (PCAs) along California's central coast had observed infestation of *E. lewisi* on strawberries, but their populations remained low compared to the key mite pest, i.e. TSSM[3–6]. However, at present, the population of *E. lewisi* has increased along with TSSM.

The damage symptoms caused by both mite pests are quite similar on strawberry. The recent *E. lewisi* outbreaks have caused significant damage to the fruit, particularly organic production, thereby becoming a key pest of commercially grown strawberries. Control of mites is through pesticides, but in some cases pesticide sprays worsen the problem, because they negatively affect natural enemies[7]. A friendly way to control mites is biological control. Among several natural enemies, phytoseiid mites are the most important biological control agents[8]. The phytoseiid species, *Phytoseiulus persimilis* Athias-Henriot proved to be effective for the control of TSSM, but was not effective against *E. lewisi*. However, it has been suggested that another phytoseiid, *Neoseiulus californicus* McGregor might provide control against both species. The present study was planned to explore the predatory potential and preference of the predaceous mite, *N. californicus* against *T. urticae* and *E. lewisi*, when both the mite pest species are simultaneously feeding on strawberry.

The populations of *T. urticae* and *E. lewisi* used for experiments were collected from the culture maintained in the laboratory of Department of Entomology, University of California, Davis, USA. The leaves of strawberry used for all experiments were collected from fields where no chemicals were used. These leaves were dipped in water containing detergent and then washed several times with clean water. Castor beans were grown in the laboratory. For conduct of all the experiments, leaves were kept on water-saturated filter paper (Whatman™ – 90 mm) in Petri dishes. The leaves were replaced whenever needed to provide sufficient food to prey mite species. The research experiments were conducted in the laboratory from August to November in a biological oxygen demand (BOD) incubator. The temperatures were maintained in three different BOD incubators at 15°C, 20°C and 25°C.

The preference of *N. californicus* was evaluated on active stages of *T. urticae* and *E. lewisi*. Active stages of *T. urticae* and *E. lewisi* (five nymphs and five adults) were released onto a leaf at three temperatures (15°C, 20°C and 25°C). Five adults of *N. californicus* were released onto the leaf under stereozoom microscope. Before introduction, the predatory mites were starved for 24 h. Petri dishes containing prey and predator were kept in incubators at 15°C, 20°C and 25°C. The number of nymphs and adults of *T. urticae* and *E. lewisi* killed by *N. californicus* was recorded after 24, 48 and 72 h. Three replications were made with a control that was maintained without predators.

To evaluate the consumption of active stages (nymphs and adults) by predatory mite, 20 active stages (10 nymphs and 10 adults) of *T. urticae* and *E. lewisi* were released onto a clean detached strawberry leaf, separately. Twenty gravid females of both the pests were released separately on the strawberry leaf. Females were removed after 48 h on getting maximum number of eggs of *T. urticae* and *E. lewisi*. The predatory mites used were starved for 24 h and five adults were released onto the leaf under stereozoom microscope. Observations on consumption of eggs and active stages of *T. urticae* and *E. lewisi* were recorded after 24, 48 and 72 h of release of predatory mites. The experiment was replicated thrice.

The mean per cent mortality of *T. urticae* and *E. lewisi* was calculated. Two-way analysis of variance (ANOVA)

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Table 1. Consumption of *Tetranychus urticae* and *Eotetranychus lewisi* by *Neoseiulus californicus* occurring on the same leaf of strawberry at 15°C, 20°C and 25°C

	Mean % mortality ± SD					
	24 h		48 h		72 h	
Temperature (°C)	*T. urticae*	*E. lewisi*	*T. urticae*	*E. lewisi*	*T. urticae*	*E. lewisi*
15	43.33 ± 11.54	66.66 ± 32.14	60.00 ± 17.32	86.66 ± 5.77	80.00 ± 17.32	96.66 ± 5.77
20	36.66 ± 20.81	33.33 ± 5.77	50.00 ± 10.00	80.00 ± 10.00	60.00 ± 17.32	90.00 ± 0.0
25	36.66 ± 20.81	46.66 ± 25.16	50.00 ± 30.00	83.33 ± 20.81	76.66 ± 5.77	93.33 ± 5.77

Table 2. Comparative efficiency of *N. californicus* in controlling *T. urticae* and *E. lewisi* on strawberry leaves at 15°C, 20°C and 25°C

	Mean % mortality of mites after					
	24 h		48 h		72 h	
Temperature (°C)	*T. urticae*	*E. lewisi*	*T. urticae*	*E. lewisi*	*T. urticae*	*E. lewisi*
15	38.33 ± 7.63	61.66 ± 11.66	43.33 ± 10.40	91.66 ± 5.77	63.33 ± 7.63	96.66 ± 2.88
20	16.66 ± 7.63	60.00 ± 8.66	41.66 ± 5.77	85.00 ± 5.00	55.00 ± 5.00	93.33 ± 2.88
25	20.00 ± 5.00	66.66 ± 7.63	40.00 ± 5.00	88.33 ± 2.88	60.00 ± 5.00	95.00 ± 0.0

on arc-sine transformed data was conducted to evaluate the comparative preference of predatory, *N. californicus* against *T. urticae* and *E. lewisi*.

Data analysis indicated that *N. californicus* was a good predator for the management of both the mite pest species. However, it preferred *E. lewisi* in comparison to *T. urticae* at all the temperatures on the same leaf of strawberry. Maximum mortality of *T. urticae* and *E. lewisi* by *N. californicus* was recorded at the lowest temperature (15°C) compared to 20°C and 25°C (Table 1). It decreased their numbers compared to the control (15°C and 25°C – 0.0% mortality, 20°C – 1% mortality). Mortality of both mites in the control treatments was minimal. The data were subjected to two-way ANOVA soon after transforming data into arc-sine values. It was observed that there was no significant difference between temperatures. The F ratio, degree of freedom and P-value (0.05) were calculated for all the temperatures at 24 h ($F = 1.57$; d.f. = 2; $P > 0.2473$), 48 h ($F = 0.33$; d.f. = 2; $P > 0.723$) and 72 h ($F = 3.21$; d.f. = 2; $P > 0.0763$), and for temperature and species interaction at 24 h ($F = 0.82$; d.f. = 2; $P > 0.4635$), 48 h ($F = 0.15$; d.f. = 2; $P > 0.8554$) and 72 h ($F = 0.05$; d.f. = 2; $P > 0.9469$). Since temperatures was found to be insignificant at all time-periods, so data were compiled for more number of replications. After analysis, it was found that there was significant difference between two species at 48 h ($F = 2.36$; d.f. = 1; $P > 0.0043$) and 72 h ($F = 19.82$; d.f. = 1; $P > 0.0008$), but not at 24 h ($F = 1.27$; d.f. = 1; $P > 0.2813$). This may be due to the less hunger of predator when we introduced it into the leaf with prey. After 48 h and 72 h introduction of predator, the preference for both mite species was statistically different. The predator consumed more *E. lewisi* in comparison to *T. urticae* at all temperatures. The study indicated that *N. californicus* showed a high predation rate on active stages of *E. lewisi* compared to *T. urticae*.

Temperature was found to be insignificant at all time-periods (at 24 h ($F = 2.27$; d.f. = 2; $P > 0.1458$), 48 h ($F = 1.38$; d.f. = 2; $P > 0.2875$) and 72 h ($F = 2.62$; d.f. = 2; $P > 0.1137$)), and for temperature and species interaction (24 h ($F = 2.61$; d.f. = 2; $P > 0.1141$), 48 h ($F = 0.77$; d.f. = 2; $P > 0.4824$) and 72 h ($F = 0.16$; d.f. = 2; $P > 0.8517$)). Again, data were complied to obtain more replications because there was no significant difference in temperature, and temperature and species interaction. However, the species were found to be significantly different at all time-periods; at 24 h ($F = 79.72$; d.f. = 1; $P > 0.0001$), 48 h ($F = 226.33$; d.f. = 1; $P > 0.0001$) and 72 h ($F = 192.15$; d.f. = 1; $P > 0.0001$). The predation rates of *N. californicus* were found to be significantly higher when *E. lewisi* was offered without *T. urticae* (Table 2), or together with *T. urticae* (Table 1).

The data were converted to mean per cent mortality for comparison of preference of *N. californicus* for nymphs and adults of both species on the same and different leaves of strawberry. The calculated per cent mortality indicated that the predator consumed both nymphs and adults, but its preference was more for nymphs compared to adults (Figures 1 and 2). Favourable temperature for consumption was found to be the lowest temperature (15°C), because of less mobility of both the prey mite species at that temperature compared to 20°C and 25°C.

N. californicus lowered the number of *T. urticae* and *E. lewisi* eggs at all temperatures. After 72 h of introduction of predatory mite, the per cent mortality of eggs of both the mites was found to be maximum at 25°C followed by 20°C and 15°C. It was found that there was statistical difference in mortality of eggs of both the mite species at 48 h ($F = 9.24$; d.f. = 1; $P > 0.0103$) and 72 h ($F = 23.17$; d.f. = 1; $P > 0.0004$). The effect of temperatures was found insignificant at 24 h ($F = 0.69$; d.f. = 2; $P > 0.5166$) and 48 h ($F = 2.33$; d.f. = 2; $P > 0.1395$), except at 72 h ($F = 9.55$; d.f. = 2; $P > 0.0033$) and for temperature and species interaction at 24 h ($F = 2.61$; d.f. = 2; $P > 0.0775$), 48 h ($F = 0.77$; d.f. = 2; $P > 0.316$) and 72 h ($F = 0.16$; d.f. = 2; $P > 0.8632$). The preference of *N. californicus* was more for eggs of *E. lewisi* compared to *T. urticae* after 48 and 72 h of introduction at all the temperatures (Table 3).

The objective of the present study was to estimate the consumption rate and preference of *N. californicus* when both the prey mites were simultaneously present. The results indicate that the predation rate of *N. californicus* was significantly greater on *E. lewisi* than *T. urticae*. The predatory preference of *N. californicus* was again more for *E. lewisi*, even in the presence of *T. urticae* on the same strawberry leaf. This variation in preference with respect to prey mite species may be due to the bigger size and greater mobility of *T. urticae* compared to *E. lewisi*. The predation rate was found to decrease as the prey size increased. This observation is also supported by Holling[9]. The present study also proved that the predator needs more time for handling larger prey compared to smaller ones. The results of El-Badry *et al.*[10] are also consistent with the present study. They found that preference of *Amblyseius gossipi* El-brady was more to *Eutetranychus orientalis* compared to *Tetranychus cinnabarinus* Boisduval due to slow movement of the former prey mite species[10].

The prey preference of any predator is directly related to the presence of preferred prey, when more than one prey is present. The predation rate is directly proportional

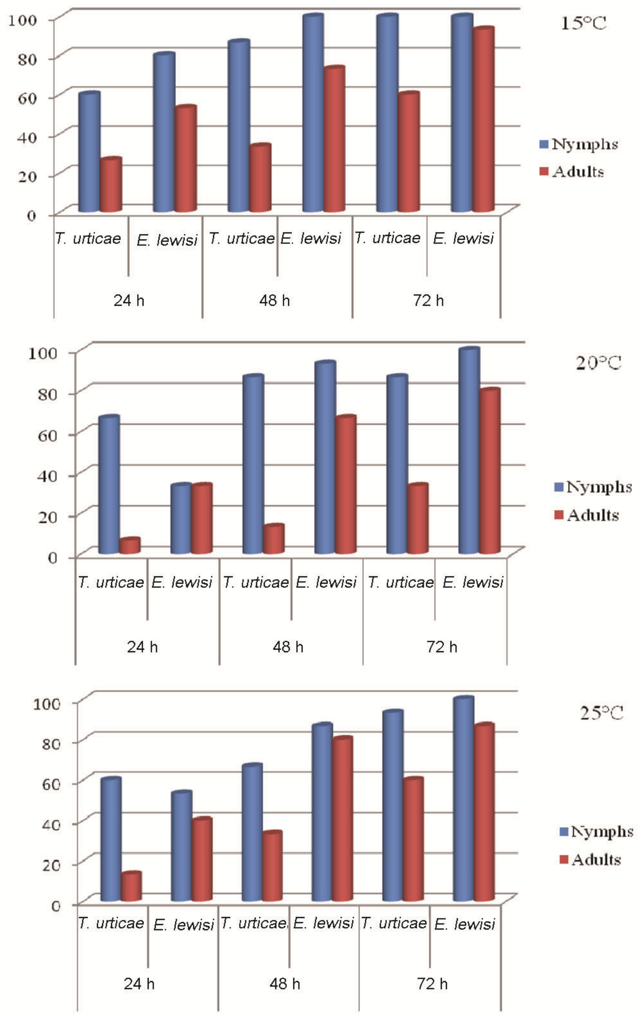

Figure 1. Comparative consumption of nymphs and adults of *Tetranychus urticae* and *Eotetranychus lewisi* by *Neoseiulus californicus* on the same leaves of strawberry at 15°C, 20°C and 25°C.

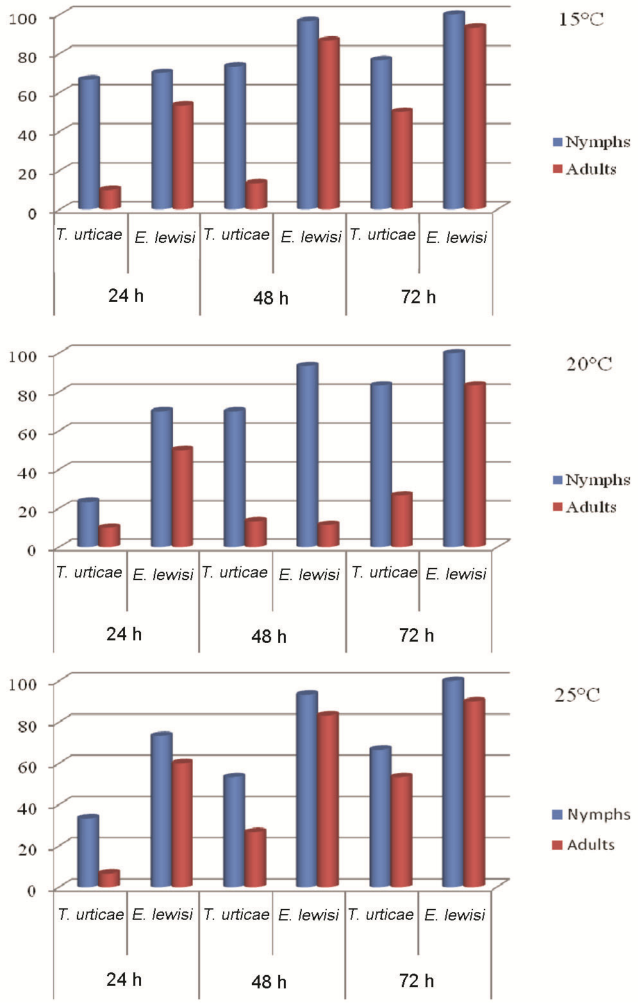

Figure 2. Comparative consumption of nymphs and adults of *T. urticae* and *E. lewisi* by *N. californicus* on strawberry leaves at 15°C, 20°C and 25°C.

Table 3. Comparative efficiency of *N. californicus* in controlling eggs of *T. urticae* and *E. lewisi* on strawberry leaves at 15°C, 20°C and 25°C

	Mean % mortality of eggs after					
	24 h		48 h		72 h	
Temperature (°C)	*T. urticae*	*E. lewisi*	*T. urticae*	*E. lewisi*	*T. urticae*	*E. lewisi*
15	53.38 ± 27.53	45.93 ± 12.59	60.95 ± 21.93	68.68 ± 4.52	73.67 ± 11.39	91.41 ± 4.22
20	46.23 ± 15.20	51.05 ± 11.61	50.31 ± 11.62	79.26 ± 8.87	80.95 ± 8.64	93.24 ± 1.53
25	18.97 ± 12.95	58.30 ± 14.14	69.88 ± 10.73	84.72 ± 8.59	91.08 ± 5.28	98.71 ± 2.22

to prey size, and the predators choose larger preys, because they provide more nutrition[11]. In contrast, studies on prey–predator dynamics have proved that the predation rate declines with increase in prey size due to better ability of the prey to defend against its predator[12,13].

Fraulo and Liburd[14] showed that the population of *T. urticae* was suppressed on release of *N. californicus* at a ratio of 1 (prey) : 10 (predator). The predatory mite, *N. californicus* reduced the population of *T. urticae* in the treated plants compared to untreated plants. It effectively maintained TSSM populations below damaging levels (<70 *T. urticae* per trifoliate) and more cost-efficiently in early release treatments of lower TSSM densities[14]. McMurty and Croft also observed that *N. californicus* was able to maintain TSSM populations at a low number[8]. *N. californicus* showed slower metabolism and searching efficiency in comparison to other phytoseiids, but it could survive without food[15]. Shorter development time and more per cent consumption of prey by *N. californicus*, makes it a potential natural enemy to control TSSM populations[16]. In Europe, *T. urticae* and *Phytonemus pallidus* (Banks) have been reported to be the major pests of strawberry. Various experiments were conducted to determine the predatory potential of phytoseiid mites, viz. *Neoseiulus cucumeris* (Oudemans), *N. californicus*, *Anthoseius rhenanus* (Oudemans) and *Euseius finlandicus* Oudemans. The results showed that *N. californicus* and *N. cucumeris* effectively controlled both the mite pests[17]. Researchers have also carried out experiments to find the best biological control agent. They suggested that the predatory potential of *N. californicus* was found to be more compared to *Phytoseiulus persimilis* Athias-Henriot against *T. urticae* on rose[18].

The studies conducted in India also suggested that adult females of *N. longispinosus* consumed more prey mite compared to immature stages[19]. Hassan[20] reported that release of *P. persimilis* resulted in highest reduction of mobile stages of *T. urticae* and lowest reduction of eggs, but *N. californicus* seemed to prefer eggs of *T. urticae* than mobile stages compared to *P. persimilis*. Jayasinghe and Mallik[21] also showed that *N. longispinosus* preferred eggs of *T. urticae* compared to other stages on tomato[21]. In Egypt, studies were conducted to test the efficacy of two predatory mite species, i.e. *Amblyseius swirskii* Athias-Henriot and *N. californicus* against the tetranychid mite, *Tetranychus cucurbitacearum* (Sayed) on eggplant under field condition[22]. The high mortality of tetranychid population was observed with *N. californicus* compared to *A. swirskii*. Therefore, release of *N. californicus* can be a successful management strategy for *T. cucurbitacearum* on eggplant.

In conclusion, the predatory mite, *N. californicus* showed feeding preference to *E. lewisi* compared to *T. urticae.* Thus, it can be part of the integrated mite management programme as a biocontrol agent for the management of mites on strawberry.

1. Sato, M. E., Silva, M., Goncalves, L. R., Souza Filho, M. F. and Raga, A., Differential toxicity of pesticides to *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) and *Tetranychus urticae* Koch (Acari: Tetranychidae) on strawberry. *Neotrop. Entomol*,, 2002, **31**, 449–456.
2. Lourenção, A. L., de Moraes, G. J. and Passos, F. A., Resistance of strawberries to *Tetranychus urticae* Koch (Acari: Tetranychidae). *Ann. Soc. Entomol. Bras*., 2000, **29**, 339–346.
3. Oatman, E. R., Mite species on strawberry in southern California. *J. Econ. Entomol*., 1971, **64**, 1313–1314.
4. Oatman, E. R., Wyman, J. A., Browning, H. W. and Voth, V., Effects of releases and varying infestation levels of the two spotted spider mite on strawberry yield in southern California. *J. Econ. Entomol.*, 1981, **74**, 112–115.
5. Oatman, E. R., Sances, F. V., LaPré, L. F., Toscano, N. C. and Voth, V., Effects of different infestation levels of the two spotted spider mite on strawberry yield in winter plantings in southern California. *J. Econ. Entomol.*, 1982, **75**, 94–96.
6. Strand, L., *Integrated Pest Management for Strawberries*, University of California, Statewide Integrated Pest Management Program, Agriculture and Natural Resources Publication, 2008, 2nd edn.
7. LiBurd, O. E., White, J. C., Rhodes, E. M. and Browdy, A. A., The residual and direct effects of reduced-risk and conventional miticides on two-spotted spider mites, *Tetranychus urticae* (Acari: Tetranychidae) and predatory mites (Acari: Phytoseiidae). *Fla. Entomol.*, 2007, **90**, 249–257.
8. McMurty, J. A. and Croft, B. A., Life-styles of phytoseiid mites and their roles in biological control. *Annu. Rev. Entomol.*, 1997, **42**, 291–321.
9. Holling, C. S., Principles of insect predator. *Annu. Rev. Entomol.*, 1961, **6**, 163–182.
10. El-Badry, E. A., Afifi, A. M., Issa, G. I. and El-Banhawy, E. M., Effectiveness of the predaceous mite, *Amblyseius gossypii* as a predator of the three tetranychid mites (Acarina: Phytoseiidae). *Z. Angew. Entomol.*, 1968, **62**, 189–194.

11. Charnov, E. L., Optimal foraging, the marginal value theorem. *Theor. Popul. Biol.*, 1976, **9**, 129–136.
12. Pastorok, R. A., Prey vulnerability and size selection by *Chaoborus* larvae. *Ecology*, 1981, **62**, 1311–1324.
13. Sabelis, M. W., How to analyse prey preference when prey density varies? A new method to discriminate between effects of gut fullness and prey type composition. *Oecologia*, 1992, **82**, 289–298.
14. Fraulo, A. B. and Liburd, O. E., Biological control of two-spotted spider mite, *Tetranychus urticae*, with predatory mite, *Neoseiulus californicus*, in strawberries. *Exp. Appl. Acarol.*, 2007, **43**, 109–119.
15. Greco, N. M., Tetzlaff, G. T. and Liljesthrom, G. G., Presence–absence sampling for *Tetranychus urticae* and its predator *Neoseiulus californicus* (Acari: Tetranychidae) on strawberries. *Int. J. Pest. Manage.*, 2004, **50**, 23–27.
16. Sabelis, M. W. and Janssen, A., Evolution and life history patterns in the Phytoseiidae. In *Mites: Ecological and Evolutionary Analysis of life History Patterns* (ed. Houck, M. A.), Chapman and Hall, New York, USA, 1994.
17. Fitzgerald, J., Bylemans, D., Peusens, G., Trandem, N. and Tuovinen, T., Control of phytophagous mites on strawberry in Europe by predatory phytoseiid mites or heat treatment. *Bull. OILB-SROP*, 2005, **28**, 221–224.
18. Sacco, M., Arato, E., Gaggero, L., D'Aquila, F. and Pasini, C., Introduction of *Neoseiulus californicus* (Mc Gregor) and comparison between chemical and biological control against *Tetranychus urticae* Koch and other phytophagous insects of rose. *Prot. Colt.*, 2010, **3**, 49–55.
19. Rahman, V. J., Babu, A., Roobakkumar, A. and Perumalsamy, K., Life table and predation of *Neoseiulus longispinosus* (Acari: Phytoseiidae) on *Oligonychus coffeae* (Acari: Tetranychidae) infesting tea. *Exp. Appl. Acarol.*, 2013, **60**, 229–240.
20. Hassan, A. S., Biological and chemical control of two-spotted spider mite and important insects infesting sweet pepper in greenhouses in Egypt. Ph D thesis, Faculty of Agriculture, Cairo University, Egypt, 2013, p. 134.
21. Jayasinghe, G. G. and Mallik, B., Management of two spotted spider mite, *Tetranychus urticae* Koch on tomato using phytoseiid predator, *Neoseiulus longispinosus* (Evans), under green house conditions. In International Symposium on Agriculture and Environment, University of Ruhuna Sri Lanka, 2014.
22. El-Saiedy, E. M. A., Hassan, M. F., El-Bahrawy, A. F., El-Kady, G. A. and Kamel, M. S., Efficacy of two phytoseiid predators and a biopesticide against *Tetranychus cucurbitacearum* (Sayed) (Acari: Tetranychidae) on eggplant at Ismailia Governorate, Egypt. *Egypt J. Biol. Pest Control*, 2014, **25**, 71–74.

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