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Developmental and life table of *Neoseiulus californicus* (Acari: Phytoseiidae) fed on three astigmatid mites and *Tetranychus urticae* (Acari: Tetranychidae)

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Abstract

The developmental time and life table of *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) preying on *Tetranychus urticae* Koch (Acari: Tetranychidae) and three astigmatid mites, *Carpoglyphus lactis* (L.) (Acari: Carpoglyphidae), *Rhizoglyphus echinopus* (Fumouze and Robin) (Acari: Acaridae) and *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae) at 25±1°C, 65±5% RH. and 16L: 8D. To evaluate their prospect role for mass rearing of predator in lab. Results indicate that on the four tested species of mites, *N. californicus* can feed and develop. Prey diets had a significant effect on the immature development period for both sexes of *N. californicus*. The longest life cycle for *R. echinopus* was 8.43 and 8.15, and the shortest period for *T. urticae* was 5.97 and 5.85 days for females and males, respectively. The highest total number of eggs (45.33) was laid by per female when fed on *T. urticae* while the lowest value was 31.67 eggs when fed on *R.echinopus*. The highest intrinsic rate of natural increase (r_m) and finite rate of increase (λ) when fed on *T. urticae* motile stages was (0.297 individuals/♀/day and 1.34 offspring/individual/day) indicating a daily increase of 29% and a 1.34-fold increase from generation to generation., whereas the lowest (r_m) was (0.220 individuals/♀/day) was recorded when fed on *R.echinopus*. Gross reproduction rate (GRR) recorded the highest value (34.23 offspring/individual) when fed on *T. urticae* and the lowest value (26.79 offspring/individual) when fed on *R. echinopus*. In conclusion, dried fruit mites and spider mites are better for *N. californicus* than *T. putrescentiae* and *R. echinopus* for mass rearing.

Introduction

Many species of predatory mites in the family Phytoseiidae are important bio-control agents of some phytophagous mites and insects. The predatory mite, *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) is one of the major predators of spider mites and a selective predator of tetranychid mites as type II feeds on many species of the family Tetranychidae (McMurtry *et al.*, 2013). *Amblyseius swirskii* (Athias-Henriot) (Acari: Phytoseiidae) and

N. californicus are mass produced predators and commercially available for the biological control of tetranychid mites, thrips, and whiteflies (Knapp *et al.*, 2018).

The two spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) is one of the most harmful pests in most agricultural systems worldwide. There are about 1161 species of its host plants, including ornamentals, fruits, crop field and vegetables (Migeon and Dorkeld, 2023). *Tyrophagus putrescentiae* (Schrank) (Acari: Acaridae), a cheese mite, can be found in a range of habitat, including dried goods, organic materials, seeds, and mushroom beds (Eraky, 1995). This mite decreased germination from 20 to 70% for cereals and from 4 to 100% for vegetables (Van Hage-Hamsten and Johansson, 1992).

Carpoglyphus lactis (L.) (Acari: Carpoglyphidae)is a dried fruit mite that mainly infests stored commodities rich in sugar and acids, such as dairy products, honey, rotten fruits, flour, cured ham, wine, and dry fruits (Chmielewsky, 1971). The bulb mite, *Rhizoglyphus echinopus* (Fumouze and Robin) (Acari: Acaridae is the main pest of stored onion and allium and roots of ornamental plants (Zhang, 2003).

The interest in *N. californicus* as a control agent is increased by the possibility of mass producing on alternate feeding and cheaper diets, such as astigmatid mite and pollen (Castagnoli and Simoni, 1999). The dried fruit mite *Carpoglyphus lactis* L. has been commercially used to mass-rear several species of predatory mites (Liu and Zhang, 2017). Several studies used astigmatid mites as food for phytoseiid mites (Mesbah *et al.*, 2019 and Zhang and Zhang, 2021).

Many researchers studied the effect of prey type on development and reproduction of *N. californicus:* El-Laithy and El-Sawi, 1998 on spider mite and eriophyid mite; Gotoh *et al.* (2006) on *T. urticae*; Ali and El-Liathy (2005) on spider mite; Kuştutan and Çakmak (2009) on *Tetranychus cinnabarinus* (Boisduval) (Acari: Tetranychidae) and Elhalawany *et al.* (2017) on three phytophagous mites.

The present study was to assess the biological and life table parameters of *N. californicus* reared on three astigmatid mites and *T. urticae* Koch with the aim of mass rearing.

Materials and methods

1. Stock culture of predatory mite *Neoseiulus californicus*:

The predatory mite *N. californicus* was collected from weeds and vegetable plants at Qaha Station, Qalyubia governorate, Egypt. The colonies were reared for five years in plastic pots, planted with *Phaseolus vulgaris* (L.) infested with *T. urticae*. The mass-rearing method was reported previously (Ibrahim *et al*., 2010). The dried fruit mite *C. lactis* is capable of sustaining the development and reproduction of *Amblyseius herbicolus* (Chant) (Acari: Phytoseiidae). The longevity of adult *A. herbicolus* was less than 20 days when given *C. lactis* and only 13 days when fed with pollen (Zhang and Zhang, 2021).

2. Prey mite culture:

T. urticae was collected from the castor bean, *Ricinus communis* L. On a foam plate (15x20 cm), clean mulberry leaves with the lower surface facing up were placed on wet cotton pads resting on sponges for two months. The mulberry leaves were replaced with fresh ones every five days. The dried fruit mites *C. lactis* collected from pollen stored in honeycombs, *R. echinopus* collected from stored onion and *T. putrescentiae* collected from stored cereals. The mites were mass-reared on wheat bran and dried yeast media with a ratio of (4:1 wt) in plastic containers (11 X 8 × 3 cm) soaked with distilled water in another plastic container. The mass-rearing method was reported previously (Elhalawany *et al.*, 2022).

3. Experimental design:

Newly 60 females of *N. californicus* were collected from mass-rearing and transferred to a new arena of mulberry leaves for each food and adapted for three months. To study the effect of four prey species previously mentioned on *N. californicus* developmental time (Egg to adult), survival and life table parameters. Four groups of 30 newly deposited eggs for each colony were singly transferred with a fine brush to leaf discs of mulberry leaves (2.5 cm.) and were put on the cotton pieces in Petri-dish (30 replicates were made for each food).

Four holes (3 cm diameter) were opened in a Petri dish (15 cm diameter) plastic cover. Leaf discs were placed ventral-side up and replaced when needed. A piece of cotton dampened with water was put between the cover plate and around the edges of the disk and painted with Vaseline to prevent mites escape (Figure 1).

This method was proposed by (Elhalawany, 2019). The observation was carried out twice daily as different biological aspects, the number of eggs laid until the female died. Every day the newly laid eggs were placed in small groups on other infested leaves and followed until adulthood to determine the developmental rate, mortality and sex ratio. All arenas were kept in the controlled laboratory at 25±2°C, 65±5% RH., and photoperiod of 16L:8D.

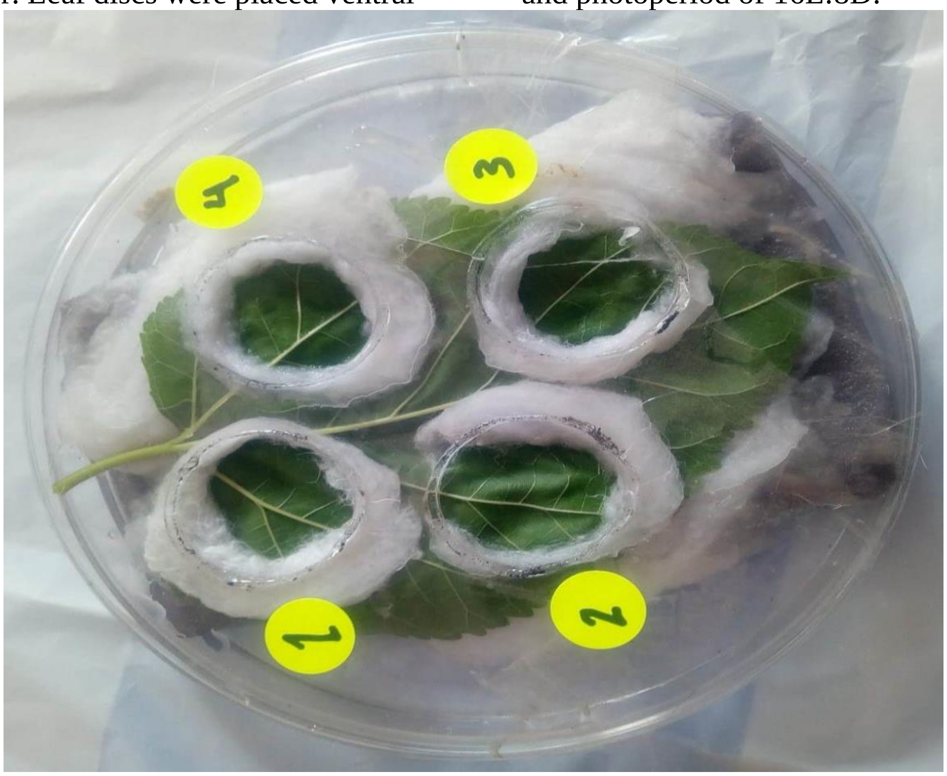

Figure (1): Rearing of *Neoseiulus californicus* on mulberry leaves.

4. Prey consumption:

To assess consumption rates on different life stages, about 15 motile stages of four prey diets were offered as food for females and males. Every day the number of individuals consumed was recorded.

5. Life-table parameters:

Life-table parameters as defined by Birch (1948) were calculated using a BASIC computer program (Abou-Setta *et al.*, 1986). Visual observation was used to identify the sex ratio for each experiment, and life tables were made using the data collected regarding the timing of immature and adult features' development.

6. Statistical analysis:

The obtained data were calculated as the mean ± SD. Significance differences among the biological parameters between the four groups were analyzed using one-way ANOVA and Student's t-test with a 95 % level of significance using SAS statistical software (SAS Institute, 2003).

Results and discussion

1. Developmental time of *Neoseiulus californicus*:

The results as shown in Table (1) indicated that, *N. californicus* completed its developmental time on the studied prey diets successfully (i.e., *C. lactis*, *R. echinopus, T. putrescentiae* and *T. urticae* motile stages). Prey diets had a significant effect on the immature development period for both sexes of this predator.

The incubation period of eggs ranged from 1.50 to 1.67 days for females and 1.40 to 1.65 days for males with no significant difference. Life cycles of both female and male *N. californicus* were longer when they fed on *R. echinopus* motile stages than on motile stages of other prey diets. The mean immature stages of females varied from 4.47 days for *T. urticae* motile stages to 6.77 days for *R. echinopus*. The average life cycle of *N. californicus* varied from 5.96 to 8.43 days for females and from 5.85 to 8.15 days for males.

As regards Table (2), presented the same results as developmental time, pre-oviposition, oviposition and longevity of *N. californicus* were significantly affected by prey diets. The shortest oviposition and longevity periods were respectively 11.87 and 17.16 when fed on *R. echinopus* whereas, the longest period was 20.07 and 23.21 days when fed on *T. urticae.* The highest total number of eggs (45.33) lay by per female when fed on *T. urticae* while the lowest value was 31.67 eggs when fed on *R. echinopus* significantly different from other prey diets. The life span lasted 29.40, 25.59, 26.27, and 29.18 days for females fed on *C. lactis*, *R. echinopus*, *T. putrescentiae* and *T. urticae* motile stages, respectively.

These results are parallel to those achieved by Gotoh *et al.* (2004) who reported the total immature developmental period for females 4.3 days of *N. californicus* fed on *T. urticae* at 25°C. The fecundity of the female was 38.4 eggs when fed on *T. urticae* at 25°C. The life cycle of the predatory mite *Neoseiulus arubdonaxi* was 7.38 days when fed on *T. putrescentiae* (Sanad *et al.,* 2007).

Kuştutan and Çakmak (2009) showed that the mean total and daily fecundity of *N. californicus* were highest at 25°C. The highest net reproductive rate was (42.92 female/female/ generation) at 25°C. Toldi *et al.* (2013) showed that the life cycle of *N. californicus* was higher for females (5.69) than for males (5.35).

Life cycle was 7.07 days for *Neoseiulus neoagrestis* Khaustov and Döker (Acari: Phytoseiidae) fed on *T. putrescentiae* (Moradi *et al.,* 2023). The highest mean total egg production of *N.californicus* reach 49.3eggs/ female in *T. urticae* motile stages, and the lowest (12.6 eggs/ female) in motile stages of *Tegolophus guavae* (Boczek) (Acari:Eriophyoidea) (Elhalawany *et al.*, 2017). The fecundity per female at 25 °C (62.29) for *N. neoagrestis* fed on *T. putrescentiae* (Moradi *et al.,* 2023).

Table (1): Mean durations (days ± SD) of *Neoseiulus californicus* fed on immature stages of *Carpoglyphus lactis*, *Rhizoglyphus echinopus*, *Tyrophagus putrescentiae* and *Tetranychus urticae* under laboratory condition.

Developmental stages	Sex	*Carpoglyphus lactis*	*Rhizoglyphus echinopus*	*Tyrophagus putrescentiae*	*Tetranychus urticae*	L.S.D. at 5%
Egg	♀	1.57±0.26 a	1.67±0.24 a	1.63±0.23 a	1.50±0.33 a	0.19
	♂	1.50±0.24 a	1.65±0.24 a	1.60±0.21 a	1.40±0.32 a	0.23
Larva	♀	1.50±0.38 b	2.06±0.35 a	1.73±0.37 b	1.13±0.35 c	0.26
	♂	1.40±0.32 b	1.95±0.37 a	1.55±0.28 b	1.10±0.32 c	0.29
Protonymph	♀	1.80±0.32 b	2.23±0.46 a	1.80±0.32 b	1.53±0.40 b	0.26
	♂	1.75±0.4 ab	2.00±0.33 a	1.75±0.35 ab	1.55±0.37 b	0.30
Deutonymph	♀	1.97±0.3bc	2.53±0.44 a	2.20±0.46 b	1.80±0.37 c	0.28
	♂	2.00±0.3 bc	2.55±0.44 a	2.30±0.48 ab	1.80±0.42 c	0.38
Immature	♀	5.27±0.50 b	6.77±0.88 a	5.70±0.62 b	4.47±0.61 c	0.48
	♂	5.15±0.53 b	6.50±0.91 a	5.60±0.66 b	4.45±0.69 c	0.64
Life cycle	♀	6.83±0.49 b	8.43±0.90 a	7.33±0.75 b	5.97±0.61 c	0.49
	♂	6.65±0.41 b	8.15±0.91 a	7.20±0.79 b	5.85±0.71 c	0.66

Means within a row followed by different letters are significantly different at the 5% level.

Table (2): Longevity (days ± SD) and fecundity (eggs/female) of *Neoseiulus californicus* fed on immature stages of *Carpoglyphus lactis*, *Rhizoglyphus echinopus*, *Tyrophagus putrescentiae* and *Tetranychus urticae* under laboratory condition.

Parameters	*Carpoglyphus lactis*	*Rhizoglyphus echinopus*	*Tyrophagus putrescentiae*	*Tetranychus urticae*	L.S.D. at 5%
Preoviposition	1.93±0.42 b	2.97±0.35 a	2.80±0.32 a	1.43±0.46 c	0.28
Oviposition	18.60±2.13 b	11.87±1.64 d	13.27±1.39 c	20.07±2.19 a	1.36
Postoviposition	2.33±0.49 b	2.27±0.59 b	2.80±0.46 a	1.93±0.42 b	0.38
Longevity	22.56±1.84 a	17.16±1.77 c	18.94±1.29 b	23.21±2.22 a	1.32
Fecundity	41.00±4.21 b	31.67±4.70 c	37.40±3.00 b	45.33±7.67 a	3.79
Daily rate	2.22±0.27 b	2.69±0.39 a	2.84±0.33 a b	2.28±0.47	0.27
Life span	29.40±2.09 a	25.59±2.0 b	26.27±1.53 b	29.18±2.38 a	1.49

Means within a row followed by different letters are significantly different at the 5% level.

2. Effect of prey diet on life table parameters of *Neoseiulus californicus*:

The evaluation of *N. californicus* life table parameters fed on different prey diets is shown in Table (3). The shortest mean generation time (T_c) was detected when predator mite fed on *T. urticae* motile stages was (11.38 days) however the longest (13.15 days) was recorded when fed on *R. echinopus*. Whereas, the shortest time for population density doubling was 2.60 days was when fed on *C. lactis*, while the longest period (3.15 days) was when fed on *R. echinopus*. The maximum net reproductive rate (R_0) (29.50 female/female/generation) was recorded on *T. urticae*, while the lowest value (18.24 female/female/generation) when fed on *R. echinopus*.

The highest intrinsic rate of natural increase (r_m) and finite rate of increase (λ) when fed on *T. urticae* motile stages was (0.297 individuals/♀/day and 1.34 offspring/individual/day) indicating a daily increase of 29% and a 1.34-fold increase from generation to generation., whereas the lowest (r_m) was (0.220 individuals/♀/day) was recorded when fed on *R. echinopus*. Gross reproduction rate (GRR) recorded the highest value (34.23 offspring/individual) when fed on *T. urticae*,and the lowest value (26.79 offspring/individual) when fed on *R. echinopus* (Table 3).

The current study recorded r_m value ranged from 0.220 to 0.297 ♀/♀/day which is similar to what was recorded for *N. arubdonaxi* when fed on *T. putrescentiae* at 25°C (Sanad *et al.*, 2007). *N. californicus* had an intrinsic rate of natural increase (r_m) of 0.24 when it fed on immature stages of *T.*

urticae, while mites fed on eggs of *T. urticae* or adults of *Tetranychus cucurbitacearum* (Sayed) had an intrinsic rate of natural growth (r_m) of 0.13 (Ali and El-Liathy, 2005).

In addition, the (r_m) reached 0.272 individuals/♀/day with motile stages of *T. urticae* and 0.14 individuals/♀/day with motile stages of the eriophyid *T. guavae* as prey. The shortest time for population doubling (DT) fed on *T. urticae* motile stages is 3.54 days (Elhalawany *et al*., 2017). At 25°C (r_m) value was 0.172 for *N. neoagrestis* fed on *T. putrescentiae* (Moradi *et al.*, 2023). On the contrary, according to Mesbah *et al*. (2019) the predatory mite *A. swirskii* favored immature stages of the bulb mite, *Rhizoglyphus robini* Claparédè (Acari: Acaridae), for female fecundity, and it gives the highest reproduction rate (66.20 eggs) and the highest intrinsic rate of natural increase.

3. Age specific survival rate of *Neoseiulus californicus* fed on different prey diets:

Age-specific survival rate (l*x*) and fecundity (m*x*) curves for *N.californicus* are illustrated in Figure (2). The daily age-specific survival rate was highest for *T. urticae* and *C. lactis*, and decreased for *R. echinopus* and *T. putrescentiae*. The maximum number of eggs produced (Day 13: 2.38 egg/♀/day) when fed on *T. putrescentiae*, the lowest (Day 12: 2.25 egg/♀/day) when fed on *C. lactis*. The 50% mortality of females was 25, 19, 21 and 26 days fed on *C. lactis*, *R. echinopus*, *T. putrescentiae* and *T. urticae* motile stages, respectively (Table 3).

Table (3): Life-table parameters of *Neoseiulus californicus* fed on immature stages of *Carpoglyphus lactis*, *Rhizoglyphus echinopus*, *Tyrophagus putrescentiae* and *Tetranychus urticae* under laboratory condition.

Parameters	*Carpoglyphus lactis*	*Rhizoglyphus echinopus*	*Tyrophagus putrescentiae*	*Tetranychus urticae*
Mean generation time (T_c)[a]	12.44	13.15	12.19	11.38
Survival rate %	90.0	80.0	85.0	90.0
Sex ratio (females/total)	0.75	0.72	0.70	0.76
50% mortality [a]	26.0	19.9	20.8	26.0
Net reproductive rate (R_0)[b]	27.67	18.24	22.21	29.50
Intrinsic rate of increase (r_m)[c]	0.266	0.220	0.254	0.297
Finite rate of increase (λ) [c]	1.30	1.24	1.28	1.34
Doubling time (DT)	2.60	3.15	2.39	2.33
Gross reproductive rate (GRR)[d]	33.65	26.79	29.61	34.23

[a]Days, [b]♀/♀,[c]♀/♀/day, [d] offspring/individual, $R_0 = \Sigma(lx \times m_x)$; $T_c = \Sigma(x \times l_x \times m_x) / \Sigma(l_x \times m_x)$; $r_m = Ln(R_0)/T$; $DT = Ln(2)/r_m$, $\lambda = \exp(r_m)$ and $GRR = \Sigma mx$.

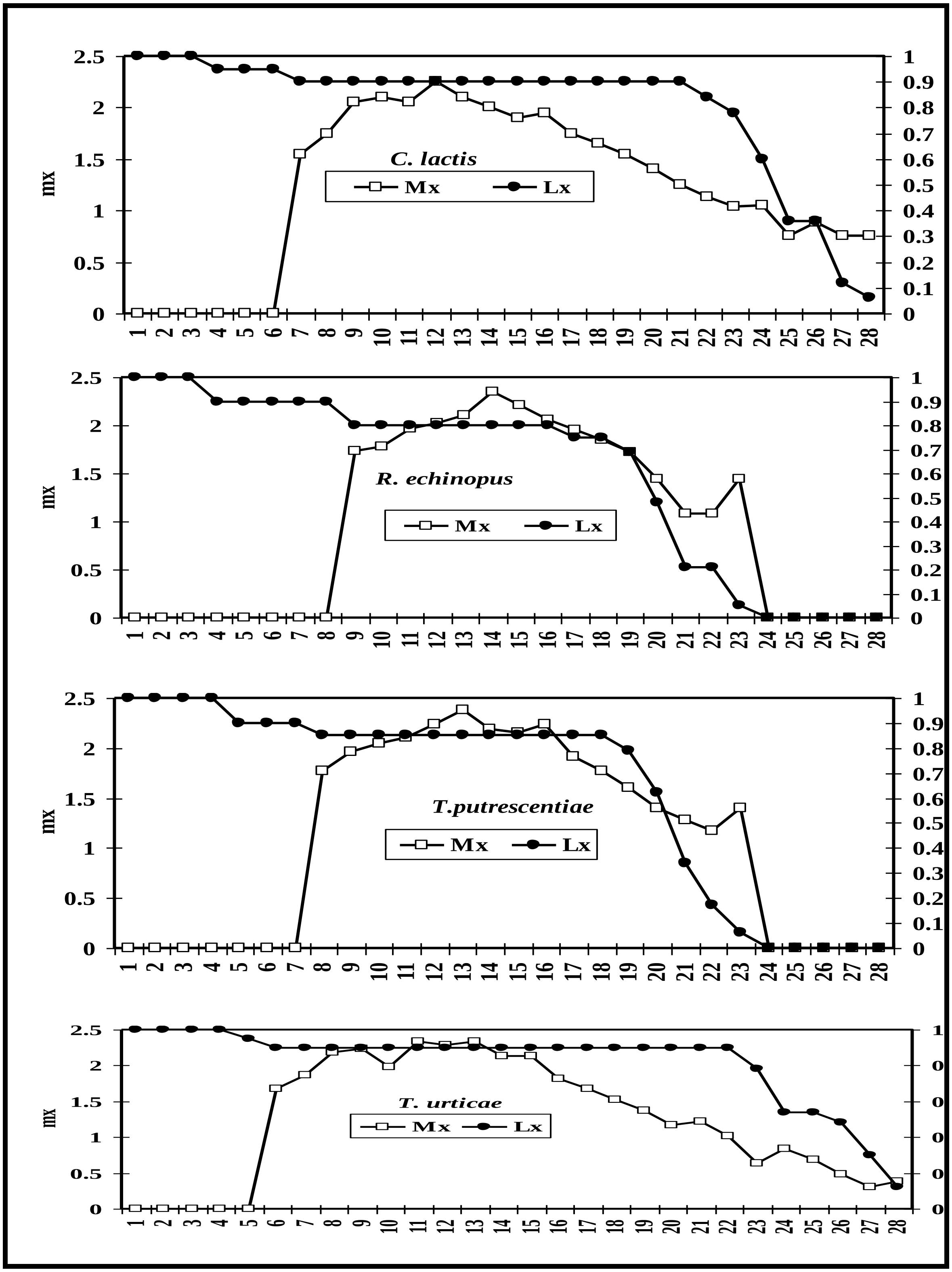

Figure (2): The age specific survivorship (l_x) and age-specific fecundity (m_x) curves for *Neoseiulus californicus* fed on *Carpoglyphus lactis, Rhizoglyphus echinopus, Tyrophagus putrescentiae* and *Tetranychus urticae* immature stages.

4. Consumption rate of *Neoseiulus californicus*:

The larvae and protonymphal stages of predatory mite were more slowly active than other stages. The consumption rate increased by increasing stage of the predator, thus the adult stages consumed more prey compared with the nymph stages. The rate of prey consumed increased with the predator's stage, thus adult stages consumed more prey than nymph stages, also the predation rate of females was higher than males. Statistical analysis indicated a significant effect of prey diets on predation rates of *N. californicus*. The total number of preys devoured by the female during the longevity was 148.93, 140.67, 143.87 and 138.07 when fed on *C. lactis*, *R. echinopus*, *T. putrescentiae* and *T. urticae* motile stages, respectively (Table 4).

Table (4): Number of preys consumed (Mean ± SD) of *Neoseiulus californicus* fed on immature stages of *Carpoglyphus lactis*, *Rhizoglyphus echinopus*, *Tyrophagus putrescentiae* and *Tetranychus urticae* under laboratory condition.

Parameters	*Carpoglyphus lactis*	*Rhizoglyphus echinopus*	*Tyrophagus putrescentiae*	*Tetranychus urticae*	L.S.D. at 5%
Female					
Larva	3.00±0.76 a	2.53±0.64 ab	2.27±0.80 b	1.67±0.62 c	0.51
Protonymph	3.27±0.88 a	2.80±0.68 a	2.93±0.70 a	2.80±0.68 a	0.54
Deutonymph	4.67±1.23 a	4.07±0.96 a	4.13±1.36 a	3.80±1.47 a	0.92
Preoviposition	17.80±2.98 a	15.27±2.02 b	17.40±2.32 a	16.13±2.10 ab	1.74
Oviposition	110.73±7.83 a	106.87±5.13ab	105.60±6.39ab	103.13±9.32 b	5.36
Postoviposition	20.40±3.72 a	18.53±2.17 a	20.87±2.00 a	18.80±3.59 a	2.17
Adult longevity	148.93±8.8 a	140.67±5.25 b	143.87±7.87 ab	138.07±11.1b	6.23
Male					
Larva	2.60±0.52 a	2.7±0.67 a	2.4±0.84 a	1.3±0.48 b	0.58
Protonymph	2.80±0.63 a	2.9±0.74 a	3.0±0.67 a	2.4±0.52 a	0.58
Deutonymph	3.70±1.16 a	3.7±0.82 a	3.6±0.70 ab	2.8±0.79 b	0.80
Adult longevity	103.4±18.90ab	103.8±6.56ab	106.6±6.65 a	93.4±12.45 b	11.11

Means within a row followed by different letters are significantly different at the 5% level.

Similar results were obtained by El-Laithy and El-Sawi (1998) who evaluated the predation rate of *N. californicus* on *T. urticae* and *Eriophyes dioscoridis*. Regardless of diet source, the maximum rate of prey consumed was seen during the oviposition stage. Gotoh *et al.* (2004) observed that immature females were more frequently preyed upon than immature males. According to Mesbah *et al.* (2019), A. swirskii has a high capability for predation when fed on immature stages of the bulb mite, *R. robini*.

In conclusion, when we compare the suitability of the four prey diets for *N.californicus,* we must conclude that the dried fruit mite and spider mite is better food than *T. putrescentiae* and *R. echinopus* for mass rearing the predator.

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