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Research Article

Keywords: Neoseiulus californicus, Lepidoglyphus destructor, Tetranychus urticae, life table, mass rearing, biological control, factitious prey

Posted Date: November 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11533316/v1

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Additional Declarations: No competing interests reported.

Evaluating *Lepidoglyphus destructor* as Factitious Prey for Mass Rearing *Neoseiulus californicus*: Age-Stage, Two-Sex Life Table Approach

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Short running title: Life Tables of *Neoseiulus californicus* on two different preys

Abstract: *Neoseiulus californicus* is a key biological control agent against spider mites, valued for its tolerance to high temperature and low humidity. Efficient mass rearing of this predator requires identifying cost-effective factitious prey. In this study, we assessed the demographic performance of *N. californicus* when fed its natural prey, *Tetranychus urticae* (TuNc), and a potential factitious prey, *Lepidoglyphus destructor* (LdNc), using the age-stage, two-sex life table approach. Egg development time, pre-adult survival, and male longevity did not differ significantly between diets. However, the total developmental period was significantly shorter and female longevity was significantly longer in the TuNc group ($p < 0.05$). Fecundity was markedly higher on *T. urticae* (42.2 eggs per female) than on *L. destructor* (22.2 eggs per female), representing a 1.9-fold difference. The finite rate of increase (λ) was greater for TuNc (1.32 d^{-1}) than for LdNc (1.17 d^{-1}), with population doubling times of 2.5 d and 4.4 d, respectively. Despite reduced reproductive efficiency relative to its natural prey, *N. californicus* sustained positive population growth on *L. destructor*. These findings demonstrate that *L. destructor* is a viable and cost-effective factitious prey, supporting decentralized commercial mass production of *N. californicus* on grain substrates.

Keywords: *Neoseiulus californicus*; *Lepidoglyphus destructor*; *Tetranychus urticae*; life table; mass rearing; biological control; factitious prey

1. Introduction

The predatory mite *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) is widely employed as a biological control agent against major agricultural pests, including spider mites, thrips, and whiteflies (Kim et al. 2008; Rahmani et al. 2009; Knapp et al. 2018). Classified as a Type II selective predator of tetranychid mites, *N. californicus* offers ecological advantages over obligate specialists such as *Phytoseiulus persimilis* (McMurtry et al. 2013). Notably, it exhibits greater tolerance to elevated temperatures and low humidity, coupled with a flexible generalist diet that enables survival on alternative

food sources—including pollen, phytophagous insects, and astigmatid mites—when primary prey is scarce (Goleva and Zebitz 2013; Massaro et al. 2016; Eini et al. 2022). These traits allow *N. californicus* to establish and persist across diverse agroecosystems, making it a valuable candidate for augmentative biological control programs (Castagnoli et al. 1999; Song et al. 2016; Rezaie et al. 2017).

Despite its proven efficacy, the commercial adoption of *N. californicus* remains limited by the high cost and logistical complexity of traditional mass-rearing systems in Korea (van Lenteren 2012; Hwang et al. 2019). Rearing predatory mites on their natural prey, such as the two-spotted spider mite *Tetranychus urticae* Koch, requires maintaining host plants. This plant-based production chain is labor-intensive, space-demanding, vulnerable to plant diseases, and difficult to scale efficiently (Gazoly et al. 2024). To overcome these constraints, developing cost-effective mass-rearing protocols using factitious prey—such as grain- or stored-product mites—has become a priority in biological control research. Astigmatid mites can be cultured cheaply and at high densities on grain substrates, eliminating the need for host plants (Castagnoli et al. 2006; Barbosa and de Moraes 2015).

Although several alternative prey species and artificial diets have been tested for *N. californicus*, most studies have been restricted to small-scale laboratory trials that do not adequately capture population dynamics or mass-production potential (Castagnoli et al. 2006; KUŞTUTAN and ÇAKMAK 2009; Barbosa and de Moraes 2015; Song et al. 2019; Rhodes and Liburd 2019). Furthermore, a critical gap remains in understanding the demographic trade-offs of rearing *N. californicus* on factitious versus natural prey. The astigmatid mite *Lepidoglyphus destructor* (Schrank) is a promising option due to its rapid reproduction on wheat bran substrates and scalability (Castagnoli et al. 2006; Simoni et al. 2006; Barbosa and de Moraes 2015; Massaro et al. 2016; Khanamani et al. 2017). However, comprehensive evaluation of how *L. destructor* influences the life history, survival, reproduction, and population growth potential of *N. californicus* under standardized life table parameters is still lacking.

To address this gap, the present study compared the demographic performance of *N. californicus* when fed its natural prey (*T. urticae*) versus the factitious prey (*L. destructor*). Using the age-stage, two-

sex life table approach, we analyzed stage-specific development, longevity, fecundity, and population projection parameters. The primary objective of this study was to determine whether *L. destructor* can sustain positive population growth and serve as a viable, cost-effective factitious prey for mass rearing, thereby providing foundational demographic data to optimize commercial production protocols for *N. californicus*.

2. Materials and methods

2.1. Rearing of prey and predatory mites

The predatory mite *N. californicus* was purchased from Koppert (The Netherlands). The factitious prey mite *L. destructor* was collected from a grain storage facility in Gunwi, Korea, and subsequently mass-reared in the laboratory during 5 years.

To enable decentralized and scalable production, a pouch-based rearing system ("breeding pouch") was developed. Each pouch was constructed from a sterilization pouch with a transparent plastic front and a medical-grade dialysis paper backing (60 g m^{-2}; KD Corporation, Yongin, Korea). Pouches were cut to 21 × 29 cm and heat-sealed along one side.

Lepidoglyphus destructor was initially cultivated in 1 L of a wheat bran. If the population density reached a minimum of 2.0×10^6 individuals, 1,000 *N. californicus* individuals were introduced into the medium. The mixture was transferred into a pouch and sealed, with each pouch serving as an experimental replicate. For mass rearing, a modified double-box system was used (Jung et al. 2018; Hwang et al. 2019). Two sealed pouches were placed inside an inner plastic container (6.5 L, 31 × 22 × 11 cm), which was housed within a larger outer plastic box (22 L, 54 × 36 × 18 cm) containing 100 mL of water to maintain humidity. Relative humidity (RH) inside the double-box system was maintained at 90 ± 5%. The entire setup was placed in an MIR-552 environmental chamber (Sanyo, Tokyo, Japan) maintained at 25 ± 1 °C, 60 ± 5% RH, and a 16:8 h (L:D) photoperiod for 2 weeks. Subculturing was performed when the density of *N. californicus* exceeded 1.0×10^4 individuals per pouch (1 L).

Lepidoglyphus destructor was reared following the same protocol, with subculturing initiated when densities exceeded 2.0×10^6 individuals per pouch. During subculturing, the pouch contents were mixed 1:1 (v/v) with fresh wheat bran substrate and transferred into new pouches. The wheat bran was adjusted to 15–20% moisture using a JGL-188 grain moisture meter (Hedao, Fujian, China), stored at −20 °C, and thawed at room temperature (25 °C) for 1 h before use.

Tetranychus urticae was reared inside nylon-mesh cages (50 × 40 × 50 cm; 100 mesh) containing 3-week-old kidney bean seedlings (*Phaseolus vulgaris*). Rearing conditions were maintained at 25 ± 1 °C, 60 ± 10% RH, and a 16:8 h (L:D) photoperiod. To prevent mite escape, each cage was placed on a tray filled with 1% detergent water.

2.2. Experimental setup for life table analysis

To evaluate and compare the life history parameters of *N. californicus* on different prey species, two experimental cohorts were established: one fed on *T. urticae* (TuNc) and the other on *L. destructor* (LdNc). Life table monitoring commenced from the egg stage. To minimize dietary switching stress and maternal effects, colonies of both prey species were maintained separately in Petri dishes for three generations (F1–F3) prior to the experimentation. From the fully acclimated fourth generation (F4), 33 eggs were randomly selected from each colony and individually transferred into 35 × 10 mm Petri dishes (SPL Life Sciences, Korea).

Predators were provided daily with 20 adult individuals of either *T. urticae* or *L. destructor*, and the developmental stage, oviposition period, fecundity, and survival of each predator were recorded daily.

Upon reaching adulthood, the sex of each individual was determined via morphological examination of the ventral shield. To facilitate mating, supplementary colonies were maintained to provide non-experimental mates. Each newly emerged experimental female was paired with a supplementary male, and reciprocally, each experimental male was paired with a supplementary female for 24 h. Following this copulation period, the supplementary mates were subsequently removed. For mated females, the

oviposition period and daily fecundity were concurrently documented. Eggs laid were recorded and removed daily to prevent counting overlaps. All trials were conducted under controlled environmental conditions (25 ± 1°C, 90 ± 5% RH, and a 14:10 h (L:D) photoperiod).

2.3. Life table data analysis

Population parameters were calculated according to the age-stage, two-sex life table theory using the TWOSEX-MSChart program (Huang and Chi 2013; Chi et al. 2020). Within this framework, the age-specific survival rate (l_x) and age-specific fecundity (m_x) were defined as follows:

$$l_x = \sum_{j=1}^{k} s_{xj}$$

$$m_x = \frac{\sum_{j=1}^{k} s_{xj} f_{xj}}{\sum_{j=1}^{k} s_{xj}}$$

where k is the number of stages, s_{xj} is the probability that a newborn survives to age x and stage j, and f_{xj} (specifically $f_{x,5}$ for the adult female stage) is the female age-specific fecundity, defined as the total number of eggs laid at age x divided by the number of surviving females at that age.

The age-specific fecundity (m_x) represents the total number of eggs laid at age x divided by the number of surviving females and males, while the age-specific maternity ($l_x m_x$) was calculated as the total number of eggs laid at age x divided by the initial cohort size. The net reproductive rate (R_0), which represents the total number of offspring produced per individual during its lifetime, was calculated as:

$$R_0 = \sum_{x=1}^{\infty} l_x m_x$$

The intrinsic rate of increase (r) was estimated using the iterative bisection method applied to the Euler–Lotka equation, with age indexed from 0:

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$

The finite rate of increase (λ) and mean generation time (T) were calculated as:

$$\lambda = e^r$$

$$T = \frac{\ln R_0}{r}$$

Additionally, the age-stage life expectancy (e_{xj}), defined as the expected survival duration of an individual at age x and stage j, was computed using the equation described by Chi and Su (2006):

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{k} s'_{iy}$$

where s'_{iy} is the probability that an individual of age x and stage j survives to age i and stage y. The reproductive value (v_{xj}) was determined following the method of Huang and Chi (2012). The parameters analyzed included the intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), mean generation time (T), age-stage-specific survival rate (s_{xj}), age-specific survival rate (l_x), age-specific fecundity (m_x), adult preoviposition period (interval from adult emergence to first egg deposition (APOP), total preoviposition period (interval from egg hatching to first egg deposition)(TPOP), age-specific maternity ($l_x m_x$), age–stage life expectancy (e_{xj}), and reproductive value (v_x) (Chi and Liu 1985; Hsin Chi 1988; Chi and Su 2006; Huang and Chi 2013; Chi et al. 2020; Chi 2025).

Differences in population parameters between treatments were assessed using a paired bootstrap test with 100,000 replicates to estimate confidence intervals (Chi and Liu 1985; Efron and Tibshirani 1994). All graphs were generated using SigmaPlot 12.5.

To further evaluate potential population growth, life table data were analyzed using the TIMING-MSChart program (Chi et al. 2020), following the method of Chi (1990). Variability in population growth was expressed as the 2.5th and 97.5th percentiles (2,500th and 97,500th values) of 100,000 bootstrap replicates of the net reproductive rate (R_0) and finite rate of increase (λ). These bootstrap samples were

subsequently used to project population growth and estimate confidence intervals (Huang et al. 2018; Wang et al. 2023). Differences were considered significant when confidence intervals did not overlap at the 95% level.

3. Results

3.1. Development, longevity, and reproduction

The developmental duration, adult longevity, oviposition period, and female fecundity of *N. californicus* fed on either TuNc or LdNc are summarized in Table 1. Egg development duration did not differ significantly between the two prey treatments (TuNc: 1.42 d; LdNc: 1.52 d; $p = 0.461$). In contrast, the larval, protonymphal, and deutonymphal stages were significantly shorter in the TuNc group ($p < 0.01$), resulting in a 1.09-day shorter total pre-adult duration (TuNc: 4.43 d; LdNc: 5.52 d; $p < 0.001$).

Pre-adult survival rate (S_a) did not differ significantly between prey types ($p = 0.280$). Adult longevity was significantly longer when fed TuNc (30.06 d) than LdNc (21.15 d). Female longevity differed significantly between treatments (TuNc: 35.80 d; LdNc: 24.53 d; $p = 0.025$), whereas male longevity showed no significant difference ($p = 0.395$). Both APOP and TPOP were significantly influenced by prey type. Notably, mean female fecundity was 1.9-fold higher on TuNc (42.20 eggs/female) than on LdNc (22.21 eggs/female; $p < 0.001$). In contrast, oviposition duration exhibited no significant difference between treatment ($p = 0.270$).

3.2 Age-stage population parameters

The age-stage-specific survival rate (s_{xj}) revealed overlapping immature stages in both TuNc and LdNc groups, reflecting individual developmental variation and non-synchronous development (Fig. 1). Adult emergence commenced around day 4 in both groups.

The age-specific survival rate (l_x) declined gradually in early adulthood and sharply in late life, with the TuNc group maintaining higher survival over a more extended period than LdNc (Fig. 2). Female

192 age-specific fecundity ($f_{x,5}$) peaked earlier and higher in TuNc ($f_{9,5}$ = 3.73 eggs/d) than in LdNc ($f_{12,5}$ = 2.23
193 eggs/d). Age-specific maternity ($l_x m_x$) also showed higher and earlier reproductive output in TuNc ($l_{10}m_{10}$
194 = 1.7 eggs) compared to LdNc ($l_{13}m_{13}$ = 0.9 eggs) (Fig. 2). Overall, TuNc supported faster development,
195 extended survival, and greater reproduction, whereas LdNc resulted in delayed and reduced output.
196
197 **3.3. Life expectancy and reproductive value**
198 Age-stage-specific life expectancy (e_{xj}) was consistently longer in the TuNc group across all life
199 stages, indicating greater survival potential. In contrast, LdNc-fed individuals exhibited shorter life
200 expectancies, particularly in the adult stages, suggesting weaker population persistence (Fig. 3).
201 Reproductive value (v_{xj}) increased gradually with age and developmental stage, peaking shortly
202 after female oviposition began (Fig. 4). TuNc-fed females exhibited higher and earlier peaks in reproductive
203 value ($v_{7,5}$ = 12.65 d^{-1}) compared to LdNc-fed females ($v_{10,5}$ = 9.81 d^{-1}), with values declining more
204 gradually over time. This highlights the superior contribution of natural prey to overall population growth
205 potential.
206
207 **3.4. Population parameters**
208 Population parameters differed substantially between prey types (Table 2). The intrinsic rate of
209 increase (r) was significantly higher in the TuNc group (0.28 d^{-1}) than in the LdNc group (0.16 d^{-1}; $p <$
210 0.05). The finite rate of increase (λ) followed the same pattern. Net reproductive rate (R_0) was approximately
211 double in the TuNc group (19.18 offspring/individual) compared to the LdNc group (9.42
212 offspring/individual) ($p < 0.05$).
213 Mean generation time (T) was significantly longer in the TuNc group (14.26 d) than in the LdNc
214 group (10.61 d; $p < 0.05$), reflecting an extended female reproductive period. Gross reproductive rate (GRR)
215 was slightly higher in the LdNc group (14.96 offspring/individual) than in the TuNc group (23.84

offspring/individual; $p < 0.05$); Consistent with this observation, all key parameters of population growth (r, λ, R_0, T, GRR) were significantly higher in the TuNc group.

3.5. Population projection

Population projections revealed striking differences in growth dynamics and stage composition between the two prey treatments (Fig. 5). Starting from an initial cohort of 10 eggs, the TuNc population expanded much more rapidly than the LdNc population. By day 30, TuNc-fed populations were projected to reach 6,300 eggs, 5,098 larvae and protonymphs, 2,484 deutonymphs, 2,669 adult females, and 2,417 adult males. In contrast, LdNc-fed populations remained small, with corresponding numbers of only 121 eggs, 123 larvae and protonymphs, 80 deutonymphs, 99 adult females, and 86 adult males.

Stage-specific analysis showed that TuNc-fed populations progressed more rapidly through immature stages and accumulated larger adult cohorts, whereas LdNc-fed populations developed more slowly and exhibited lower survival, resulting in markedly reduced population sizes. Bootstrap simulations of the finite rate of increase (λ) and net reproductive rate (R_0) further confirmed the higher growth potential and lower variability of TuNc-fed populations compared to LdNc-fed populations (Fig. 6).

These projections demonstrate that although *L. destructor* can sustain *N. californicus* populations, *T. urticae* enabled faster development, larger adult cohorts, and more prolific population expansion—outcomes that are critical for efficient mass-rearing and effective biological control applications.

4. Discussion

Efficient, low-cost mass-rearing protocols are essential to improve the commercial viability of *N. californicus* in biological control programs. Although *T. urticae* serves as its primary natural prey, reliance on live host plants imposes substantial space, labor, and economic constraints. Our age-stage, two-sex life table analysis demonstrated that while *T. urticae* supports superior biological and demographic performance,

240 the factitious astigmatid mite *L. destructor* provides a practical alternative capable of sustaining continuous
241 population growth under decentralized rearing conditions.

242 Diet quality plays a pivotal role in shaping the developmental trajectory and reproductive capacity
243 of predatory mites (McMurtry and Croft 1997; El Taj and Jung 2012). Egg hatchability and juvenile survival
244 rates remained consistently high across diets, indicating that *L. destructor* is non-toxic and palatable.
245 However, juvenile development was slower in the LdNc group, suggesting higher metabolic or foraging
246 costs when processing *L. destructor* compared to the natural prey. Furthermore, adult longevity differences
247 were sex-specific: male longevity remained stable across diets, whereas female longevity declined
248 significantly in the LdNc group. This female-specific reduction underscores the heightened nutritional
249 requirements associated with somatic maintenance and egg production (Maklakov et al. 2008; Xu et al.
250 2025).

251 The reduced reproductive performance observed in the LdNc group can be explained by
252 physiological and morphological constraints. As a Type II selective predator, *N. californicus* exhibits broad
253 feeding plasticity (McMurtry et al. 2013). However, astigmatid mites, such as *L. destructor*, possess
254 structural defenses and distinct lipid and protein profiles compared to spider mites (Castagnoli et al. 2006;
255 Massaro et al. 2016). These features likely reduce dietary assimilation efficiency, increasing the energetic
256 demands of digestion and nutrient processing. This added cost may contribute to slower development and
257 diminished reproductive output when *N. californicus* are reared on *L. destructor* (McMurtry and Croft 1997;
258 El Taj and Jung 2012).

259 Reproduction was the trait most strongly impacted by dietary switch. Females reared on *L.*
260 *destructor* exhibited prolonged preoviposition periods, reduced daily peak fecundity, and lower lifetime
261 egg production. Age-specific fecundity and maternity profiles confirmed that *T. urticae* triggers an earlier,
262 higher, and more sustained reproductive output. In contrast, the delayed onset and lowered peak of
263 oviposition in the LdNc group reflect a nutritional trade-off, where females prioritize basic physiological
264 survival over high reproductive investment (Toft and Wise 1999; Lemos et al. 2023)

These individual life-history trade-offs translated into population-level differences. Intrinsic and finite rates of increase, as well as net reproductive rate, were all substantially higher in the TuNc group. Although *T. urticae* supported a longer mean generation time due to an extended female reproductive period, its rapid juvenile development and high fecundity enabled exponential population expansion. Long-term population projections highlighted this divergence, with the TuNc-fed populations generating substantially larger predator cohorts and advancing more rapidly through developmental stages.

Alternative astigmatid prey species (e.g., *Austroglycyphagus lukoschusi*, *Blomia tropicalis*, *Dermatophagoides farinae*, *L. destructor*) consistently support steady population doubling (Castagnoli et al. 1999; KUŞTUTAN and ÇAKMAK 2009; Barbosa and de Moraes 2015; Gazoly et al. 2024). While natural tetranychid prey enables faster reproduction (KUŞTUTAN and ÇAKMAK 2009; Gazoly et al. 2024), astigmatid mites are far superior for practical mass production due to their compatibility with grain-based substrates. Despite lower reproductive efficiency, *L. destructor* maintained a positive finite rate of increase ($\lambda > 1$) and continuous population doubling, confirming its capacity to sustain stable, multi-generational colonies.

From a mass-rearing perspective, the economic advantages of *L. destructor* outweigh its lower per-female fecundity. Rearing *T. urticae* requires substantial greenhouse facilities, host plant cultivation, and continuous disease management (Bustos et al. 2016). In contrast, *L. destructor* can be cultured at extremely high densities on inexpensive wheat bran in compact spaces. This volumetric yield compensates for reduced fecundity, enabling large predator outputs in simple pouch systems at a fraction of the cost.

In conclusion, while *T. urticae* maximizes the biological and reproductive potential of *N. californicus*, *L. destructor* represents a highly practical and cost-effective factitious prey for commercial mass production. By bypassing host plant requirements, *L. destructor* reduces facility costs and labor demands. Future work should explore mixed dietary regimes, optimize prey-to-predator stocking ratios within breeding pouches, assess multi-generational dietary acclimation, and validate the field efficacy of *L. destructor*-reared predators against crop pests.

AUTHOR CONTRIBUTIONS

Hwal-Su Hwang: Conceptualization, Methodology, Investigation, Software, Formal analysis, Writing – Original draft preparation, Writing – Reviewing and editing. **Duck-Oung Jung:** Conceptualization, Methodology, Investigation, Writing – Reviewing and editing. **Lisheng Zhang:** Data curation, Writing – Reviewing and editing. **Yuyan Li:** Data curation, Writing – Reviewing and editing. **Kyeong-Yeoll Lee:** Conceptualization, Validation, Resources, Visualization, Supervision, Project administration, Funding acquisition, Writing – Reviewing and editing.

ACKNOWLEDGEMENTS

This work was supported by the China-Korea Young Researchers Exchange Program, funded by the Ministry of Science and Technology of the People's Republic of China and the National Research Foundation of Korea.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.33441085.

CONFLICT OF INTEREST

All authors reviewed and approved the manuscript. The authors declare that they have no relevant financial or non-financial interests to disclose.

5. References

Barbosa MFC, de Moraes GJ (2015) Evaluation of astigmatid mites as factitious food for rearing four predaceous phytoseiid mites (Acari: Astigmatina; Phytoseiidae). Biol Control 91:22–26. https://doi.org/10.1016/J.BIOCONTROL.2015.06.010

Bustos A, Rodríguez D, Cure JR, Cantor F (2016) A Simulation Model of the Mass Rearing of *Tetranychus urticae* Koch (Acari: Tetranychidae) on Beans. Neotrop Entomol 45:291–299. https://doi.org/10.1007/S13744-016-0366-1

Castagnoli M, Nannelli R, Tarchi F, Simoni S (2006) Screening of astigmatid mites for mass-rearing *Neoseiulus californicus* (McGregor) (Acari Phytoseiidae). Redia 89:55–58

Castagnoli M, Simoni S, Biliotti N (1999) Mass-rearing of *Amblyseius californicus* (Acari: Phytoseiidae) on two alternative food sources. Ecol Evol Acari 425–431. https://doi.org/10.1007/978-94-017-1343-6_34

Chi H (2025) TWOSEX-MSChart: A computer program for the age-stage, two-sex life table analysis. Zenodo

Chi H, Liu H (1985) Two new methods for the study of insect population ecology. Bull Inst Zool Acad Sin 24:225–240

Chi H, Su HY (2006) Age-Stage, Two-Sex Life Tables of *Aphidius gifuensis* (Ashmead) (Hymenoptera: Braconidae) and Its Host *Myzus persicae* (Sulzer) (Homoptera: Aphididae) with Mathematical Proof of the Relationship Between Female Fecundity and the Net Reproductive Rate. Environ Entomol 35:10–21. https://doi.org/10.1603/0046-225X-35.1.10

Chi H, You M, Atlıhan R, et al (2020) Age-Stage, two-sex life table: an introduction to theory, data analysis, and application. Entomol Gen 40:103–124. https://doi.org/10.1127/ENTOMOLOGIA/2020/0936

Efron B, Tibshirani RJ (1994) An Introduction to the Bootstrap. Chapman and Hall/CRC, New York

Eini N, Jafari S, Fathipour Y, Zalucki MP (2022) How pollen grains of 23 plant species affect performance of the predatory mite *Neoseiulus californicus*. BioControl 67:173–187. https://doi.org/10.1007/S10526-022-10129-7

El Taj HF, Jung C (2012) Effect of temperature on the life-history traits of *Neoseiulus californicus* (Acari: Phytoseiidae) fed on *Panonychus ulmi*. Exp Appl Acarol 56:247–260. https://doi.org/10.1007/S10493-012-9516-2

Gazoly AH, Afifi AAM, Ali FS, Ahmed MM (2024) Life table parameters and predation rate of *Neoseiulus californicus* (Acari: Phytoseiidae) feeding on *Panonychus citri* and *Eutetranychus orientalis* (Acari: Tetranychidae). Persian J Acarol 13:265–282. https://doi.org/10.22073/pja.v13i2.83614

Goleva I, Zebitz CPW (2013) Suitability of different pollen as alternative food for the predatory mite *Amblyseius swirskii* (Acari, Phytoseiidae). Exp Appl Acarol 61:259–283. https://doi.org/10.1007/S10493-013-9700-Z/TABLES/5

Hsin Chi (1988) Life-Table Analysis Incorporating Both Sexes and Variable Development Rates Among Individuals. Environ Entomol 17:26–34. https://doi.org/10.1093/EE/17.1.26

Huang HW, Chi H, Smith CL (2018) Linking Demography and Consumption of *Henosepilachna vigintioctopunctata* (Coleoptera: Coccinellidae) Fed on *Solanum photeinocarpum* (Solanales: Solanaceae): With a New Method to Project the Uncertainty of Population Growth and Consumption. J Econ Entomol 111:1–9. https://doi.org/10.1093/JEE/TOX330

Huang YB, Chi H (2013) Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): With an invalidation of the jackknife technique. J Appl Entomol 137:327–339. https://doi.org/10.1111/JEN.12002;SUBPAGE:STRING:ABSTRACT;WEBSITE:WEBSITE:PERICLES;JOURNAL:JOURNAL:14390418A;REQUESTEDJOURNAL:JOURNAL:14390418;ISSUE:ISSUE:DOI

Huang YB, Chi H (2012) Age-stage, two-sex life tables of *Bactrocera cucurbitae*(Coquillett) (Diptera: Tephritidae) with a discussion on the problem of applying female age-specific life tables to insect

populations. Insect Sci 19:263–273. https://doi.org/10.1111/J.1744-7917.2011.01424.X;ISSUE:ISSUE:DOI

Hwang HS, Jung DO, Park J, Lee KY (2019) Simple mass-rearing technique of a predatory mite *Gaeolaelaps aculeifer* (Canestrini) (Acari: Laelapidae). Entomol Res 49:529–533. https://doi.org/10.1111/1748-5967.12399;REQUESTEDJOURNAL:JOURNAL:17485967

Jung D, Hwang H, Kim J, Lee K (2018) Development of the Mass-rearing Technique for a Predatory Mite *Stratiolaelaps scimitus* (Acari : Laelapidae) Using the Double Box System. Korean J Appl Entomol 57:253–260

Khanamani M, Fathipour Y, Talebi AA, Mehrabadi M (2017) Evaluation of different artificial diets for rearing the predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae): diet-dependent life table studies. Acarologia 57:407–419. https://doi.org/10.1051/ACAROLOGIA/20174165

Kim H-Y, Lee Y-H, Kim J-H, Kim Y-H (2008) Comparison on the Capability of Four Predatory Mites to Prey on the Eggs of *Bemisia tabaci* (Hemiptera: Aleyrodidae). Korean J Appl Entomol 47:429–433. https://doi.org/10.5656/ksae.2008.47.4.429

Knapp M, Houten Y van, Baal E van, Groot T (2018) Use of predatory mites in commercial biocontrol: current status and future prospects. Acarologia 58:72–82. https://doi.org/10.24349/ACAROLOGIA/20184275

KUŞTUTAN O, ÇAKMAK İ (2009) Development, Fecundity, and Prey Consumption of *Neoseiulus californicus* (McGregor) Fed *Tetranychus cinnabarinus* Boisduval. Turkish J Agric For 33:19–28. https://doi.org/10.3906/tar-0806-39

Lemos F, Bajda S, Duarte MVA, et al (2023) Imperfect diet choice reduces the performance of a predatory mite. Oecologia 201:929–939. https://doi.org/10.1007/S00442-023-05359-0

Maklakov AA, Simpson SJ, Zajitschek F, et al (2008) Sex-Specific Fitness Effects of Nutrient Intake on Reproduction and Lifespan. Curr Biol 18:1062–1066. https://doi.org/10.1016/j.cub.2008.06.059

385 Massaro M, Martin JPI, de Moraes GJ (2016) Factitious food for mass production of predaceous phytoseiid
386 mites (Acari: Phytoseiidae) commonly found in Brazil. Exp Appl Acarol 70:411–420.
387 https://doi.org/10.1007/S10493-016-0087-5
388 McMurtry JA, Croft BA (1997) Life-styles of Phytoseiid mites and their roles in biological control. Annu
389 Rev Entomol 42:291–321. https://doi.org/10.1146/ANNUREV.ENTO.42.1.291/CITE/REFWORKS
390 McMurtry JA, De Moraes GJ, Sourassou NF (2013) Revision of the lifestyles of phytoseiid mites (Acari:
391 Phytoseiidae) and implications for biological control strategies. Syst Appl Acarol 18:297–320.
392 https://doi.org/10.11158/SAA.18.4.1
393 Rahmani H, Fathipour Y, Kamali K (2009) Life history and population growth parameters of *Neoseiulus*
394 *californicus* (Acari: Phytoseiidae) fed on *Thrips tabaci* (Thysanoptera: Thripidae) in laboratory
395 conditions. Syst Appl Acarol 12:91. https://doi.org/10.11158/saa.14.2.2
396 Rezaie M, Saboori A, Baniamerie V, Hosseini-Gharalari A (2017) The effect of strawberry cultivars on
397 functional response and prey-stage preference of *Neoseiulus californicus* (Acari: Phytoseiidae) on
398 *Tetranychus urticae* (Acari: Tetranychidae). J Entomol Zool Stud 5:27–35
399 Rhodes EM, Liburd OE (2019) Predatory Mite, *Neoseiulus californicus* (McGregor) (Arachnida: Acari:
400 Phytoseiidae). Edis 2005:. https://doi.org/10.32473/EDIS-IN639-2005
401 Simoni S, Nannelli R, Goggioli D, et al (2006) Biological and demographic parameters of *Neoseiulus*
402 *californicus* (McGregor) (Acari Phytoseiidae) reared on two astigmatid mites. Redia 89:59–63
403 Song ZW, Nguyen DT, Li DS, De Clercq P (2019) Continuous rearing of the predatory mite *Neoseiulus*
404 *californicus* on an artificial diet. BioControl 64:125–137. https://doi.org/10.1007/S10526-019-
405 09923-7
406 Song ZW, Zheng Y, Zhang BX, Li DS (2016) Prey consumption and functional response of *Neoseiulus*
407 *californicus* and *Neoseiulus longispinosus* (Acari: Phytoseiidae) on *Tetranychus urticae* and
408 *Tetranychus kanzawai* (Acari: Tetranychidae). Syst Appl Acarol 21:936–946.
409 https://doi.org/10.11158/SAA.21.7.7

Toft S, Wise DH (1999) Growth, development, and survival of a generalist predator fed single- and mixed-species diets of different quality. Oecologia 119:191–197. https://doi.org/10.1007/S004420050776/METRICS

van Lenteren JC (2012) The state of commercial augmentative biological control: plenty of natural enemies, but a frustrating lack of uptake. BioControl 57:1–20. https://doi.org/10.1007/S10526-011-9395-1

Wang XQ, Ou HD, Li HX, et al (2023) Adverse impacts of development on the deltamethrin-exposed host *Ephestia elutella* (Lepidoptera: Pyralidae) on population parameters of *Habrobracon hebetor* (Hymenoptera: Braconidae). Crop Prot 167:106211. https://doi.org/10.1016/J.CROPRO.2023.106211

Xu Y, Zhang K, Han X, Zhang ZQ (2025) Early life food intake modulates effects of diet restriction on lifespan and fecundity in later life in a predatory mite (Acari: Phytoseiidae). Curr Zool 71:295–303. https://doi.org/10.1093/CZ/ZOAE047

Tables and Figures

Table 1. Developmental duration (mean ± SE) and survival of *Neoseiulus californicus* life stages reared on the natural prey *Tetranychus urticae* (TuNc) and the factitious prey *Lepidoglyphus destructor* (LdNc) at 25 °C under a photoperiod of 16:8 (L:D).

Developmental time of *Neoseiulus californicus* (days)						
Biological parameters	TuNc treatment		LdNc treatment		Relative ratio (TuNc/LdNc)	*p* - value
	N	Mean ± SE	*N*	Mean ± SE		
Egg (d)	33	1.42 ± 0.09	33	1.52 ± 0.09	0.93	0.46143
Larva–Protonymph (d)	32	1.72 ± 0.08**	30	2.07 ± 0.09	0.83	0.00463*
Deutonymph (d)	30	1.30 ± 0.08**	27	1.96 ± 0.22	0.66	0.00574*
Pre-adult (d)	30	4.43 ± 0.09***	27	5.52 ± 0.21	0.80	0.00001*
Pre-adult survival rate (s_a)	33	0.91 ± 0.05	33	0.82 ± 0.07	1.11	0.28015
Total longevity (d)	33	30.06 ± 2.87*	33	21.15 ± 2.17	1.42	0.01258*
Female adult	15	35.80 ± 4.01*	15	24.53 ± 3.01	1.46	0.02533*
Male adult	15	29.33 ± 3.81	12	25.33 ± 2.81	1.16	0.39549

Total longevity (d)	30	32.57 ± 2.78	27	24.89 ± 2.05	1.31	0.02552*
APOP (d)	15	1.27 ± 0.28**	14	2.50 ± 0.14	0.51	0.00038*
TPOP (d)	15	5.60 ± 0.34***	14	8.21 ± 0.40	0.68	< 0.00001*
Oviposition day (d)	15	13.73 ± 1.11	14	11.93 ± 1.20	1.15	0.27015
Fecundity (Offspring/individual)	15	42.20 ± 3.50***	14	22.21 ± 2.67	1.90	< 0.00001*

Note: Using TWOSEX-MSChart program (Huang and Chi 2013, Chi 2020), the standard errors (SEs) were estimated using 100,000 bootstrap replicates.

* $p < 0.05$. ** $p < 0.01$, *** $p < 0.001$.

Table 2. Population parameters (mean ± SE) of *Neoseiulus californicus* calculated using the age-stage, two-sex life table when fed on *Tetranychus urticae* (TuNc) or *Lepidoglyphus destructor* (LdNc).

Population parameter	Bootstrap (Mean ± SE)		Relative ratio (TuNc/LdNc)	***P***
	TuNc	LdNc		
r (d^{-1})	$0.28 \pm 0.02^{***}$	0.16 ± 0.02	1.75	0.00031^{*}
λ (d^{-1})	$1.32 \pm 0.03^{***}$	1.17 ± 0.02	1.13	0.00028^{*}
R_0 (offspring/female)	$19.18 \pm 3.98^{***}$	9.42 ± 2.15	2.04	0.00031^{*}
T (d)	$10.61 \pm 0.35^{*}$	14.26 ± 0.59	1.34	0.03064^{*}
GRR (offspring/female)	$23.84 \pm 4.61^{***}$	14.96 ± 3.08	1.59	$< 0.0001^{*}$

r, intrinsic rate of increase; λ, finite rate of increase; R_0, net reproductive rate; T, mean generation time (offspring/individual); GRR, gross reproduction rate.

Note: Standard errors (SE) were estimated using the bootstrap technique with 100,000 re-samplings.

$^{*}p < 0.05$. $^{**}p < 0.01$, $^{***}p < 0.001$

Figure legends

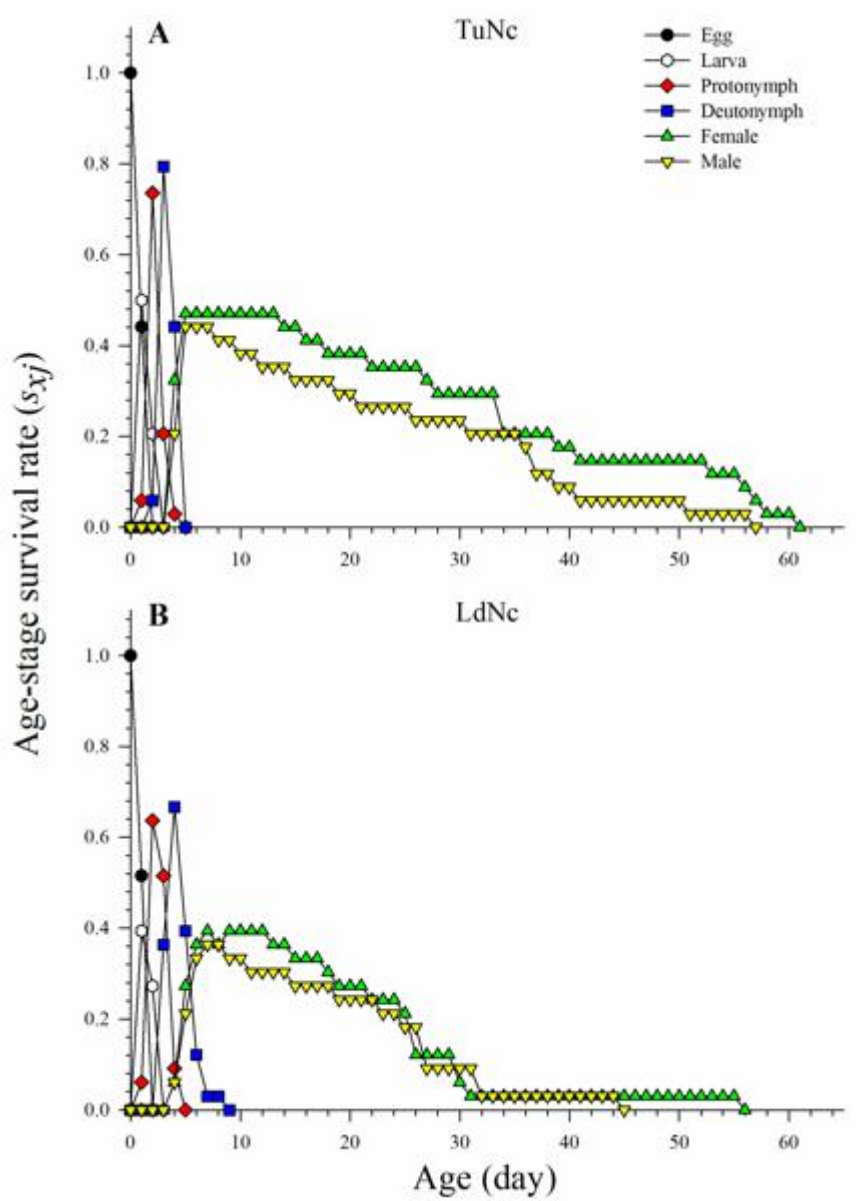


Figure 1. Age-stage-specific survival rate (s_{xj}) of *Neoseiulus californicus* fed on the natural prey *Tetranychus urticae* (TuNc) and the factitious prey *Lepidoglyphus destructor* (LdNc). Curves represent the probability that a newly laid egg will survive to age *x* and stage *j*.

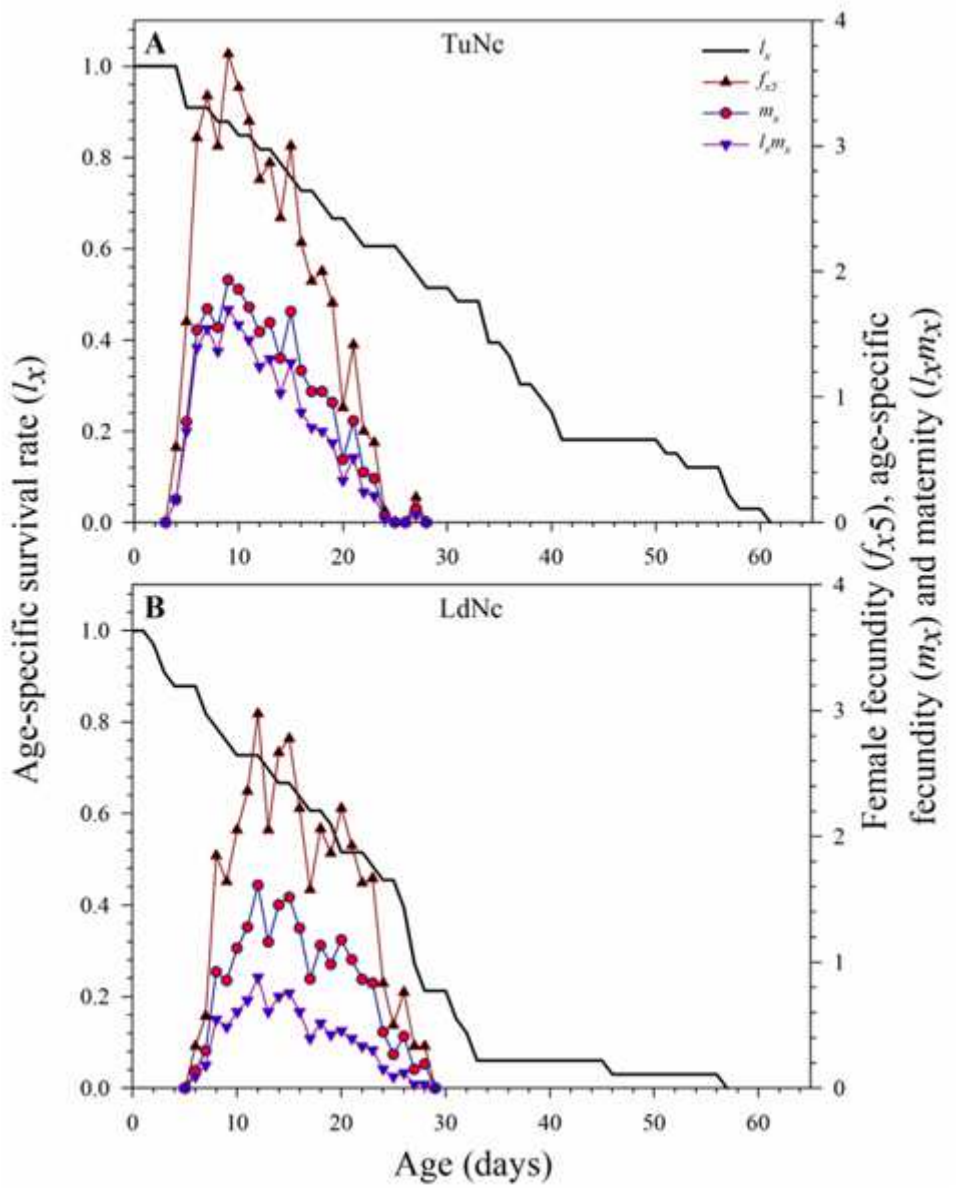


Figure 2. Age-specific survival rate (l_x), female age-specific fecundity ($f_{x,5}$), age-specific fecundity (m_x), and age-specific maternity (l_xm_x) of *Neoseiulus californicus* reared on (A) *Tetranychus urticae* (TuNc) and (B) *Lepidoglyphus destructor* (LdNc).

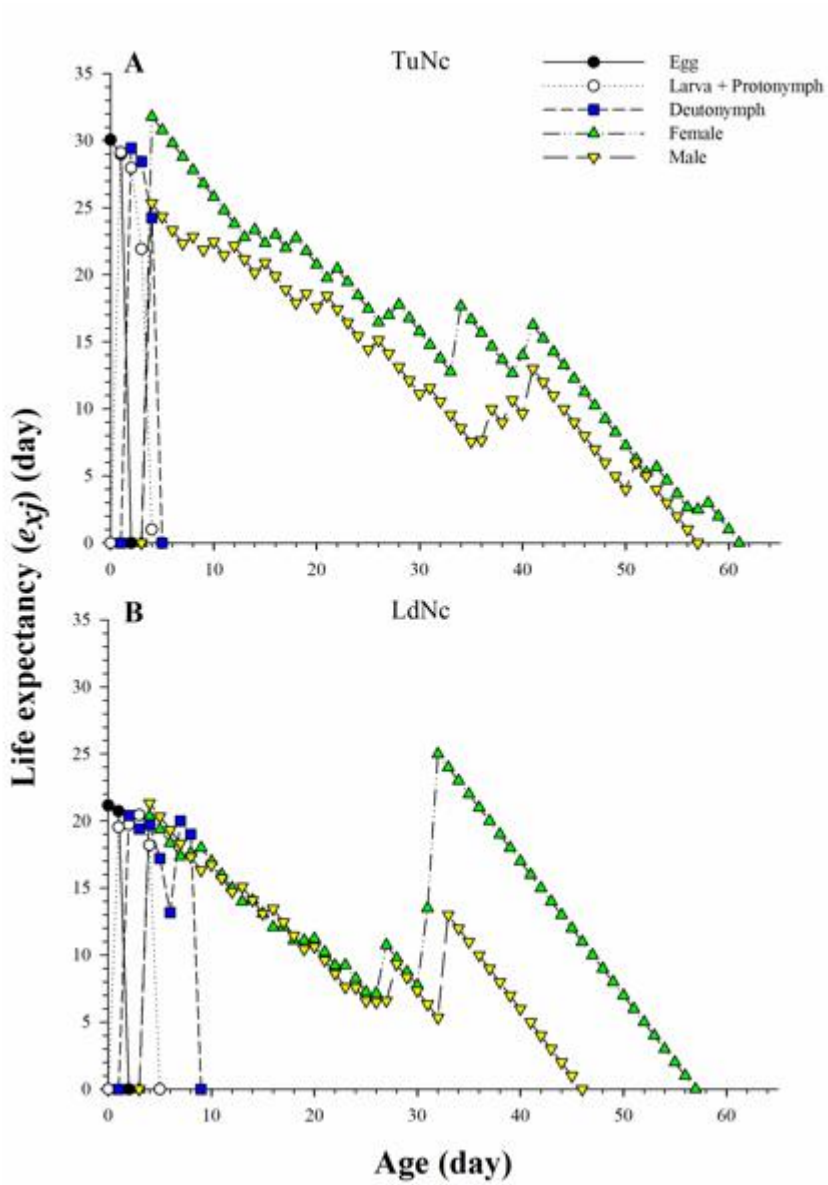


Figure 3. Age-stage-specific life expectancy (e_{xj}) of *Neoseiulus californicus* fed *Tetranychus urticae* (TuNc) and *Lepidoglyphus destructor* (LdNc).

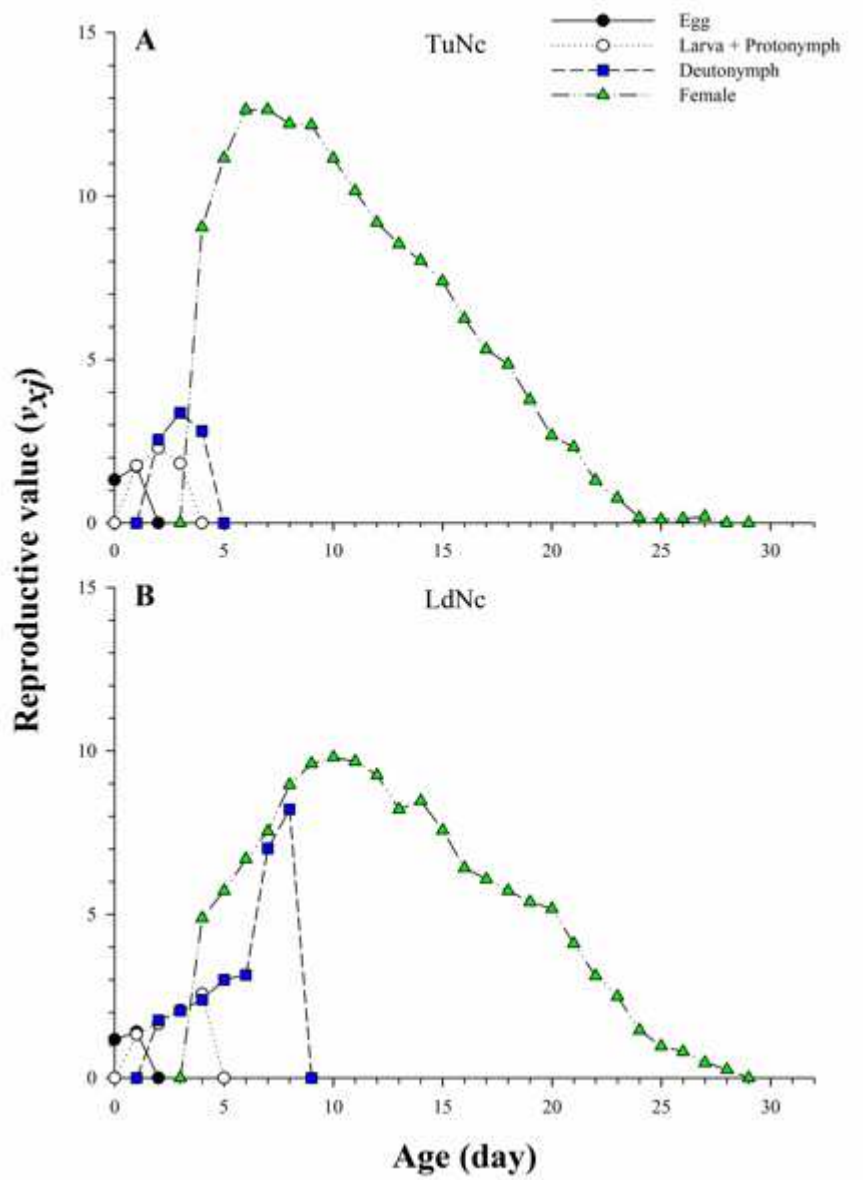


Figure 4. Age-stage-specific reproductive value (v_{xj}) of *Neoseiulus californicus* fed on *Tetranychus urticae* (TuNc) and *Lepidoglyphus destructor* (LdNc), indicating the expected contribution of individuals of age *x* and stage *j* to future population growth. The larva and protonymph stages were combined for plotting because the average duration of the larval stage was less than one day.

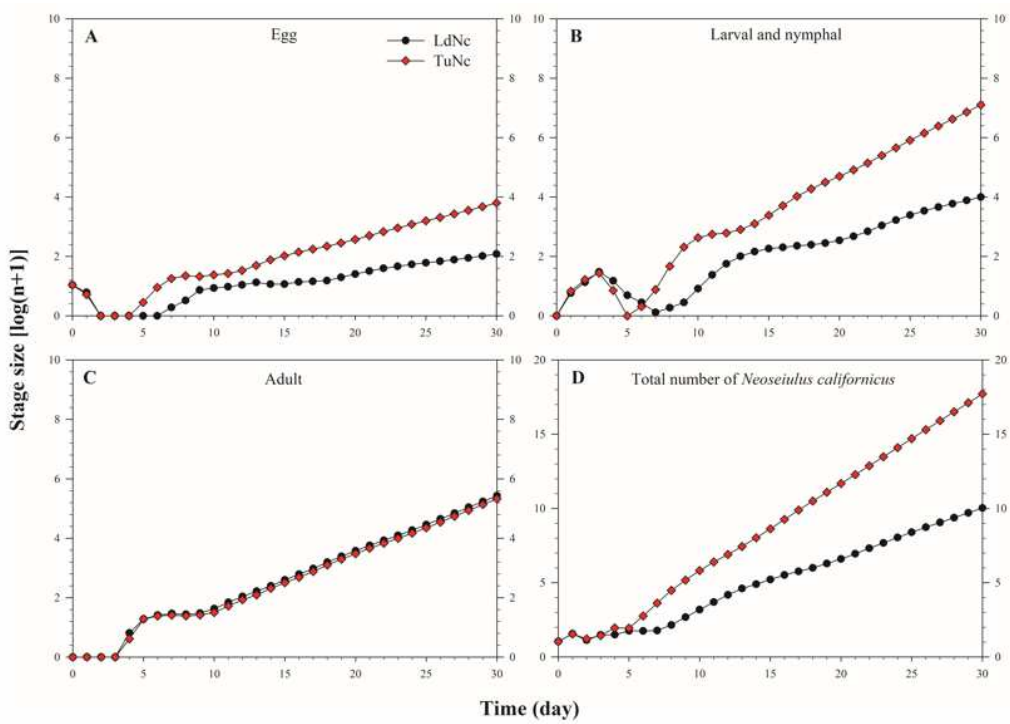


Figure 5. Simulated population growth and stage-specific distribution of *Neoseiulus californicus* fed on *Tetranychus urticae* (TuNc) and *Lepidoglyphus destructor* (LdNc) over time. Panels show (A) eggs, (B) larval and nymphal stages, (C) female and male adults, and (D) all developmental stages combined.

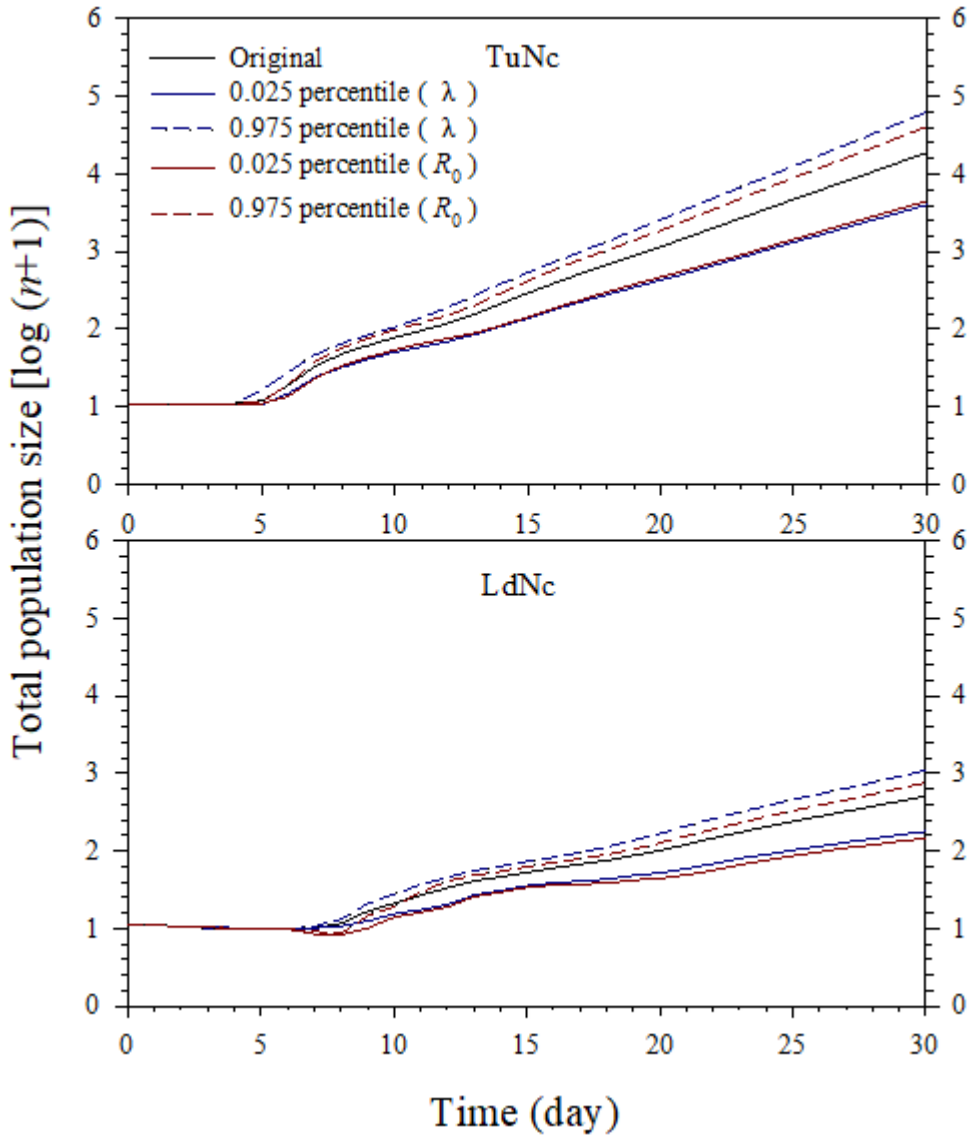


Figure 6. Population projection of *Neoseiulus californicus* starting from an initial cohort of 10 eggs, fed on *Tetranychus urticae* (TuNc) or *Lepidoglyphus destructor* (LdNc). Projections show the original cohort data (black solid lines) and the 2.5% (solid lines) and 97.5% (dashed lines) confidence intervals from 100,000 bootstrap replicates of the finite rate of increase (λ, blue lines) and net reproductive rate (R_0, red lines).