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Development and reproductive performance of *Amblyseius eharai* (Acari: Phytoseiidae) fed on different stages of *Tyrophagus* sp. as a potential factitious prey for mass rearing

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ABSTRACT

Predatory mites belonging to the family Phytoseiidae are key biological control agents of pest mites and thrips in various agricultural systems. This study evaluated the developmental and reproductive performance of *Amblyseius eharai* when fed on different developmental stages (egg, larva, adult, and mixed) of *Tyrophagus* sp., a storage mite with potential as a factitious prey for mass rearing. Results showed that *A. eharai* successfully completed its life cycle on all prey stages, with the shortest developmental duration (7.9 ± 0.19 days) observed when feeding on *Tyrophagus* eggs. Females fed on larval and adult stages exhibited higher fecundity (≈41 eggs/female) and longer longevity (up to 41.1 ± 0.6 days). Life table parameters indicated stable population growth across all treatments, with intrinsic rates of increase (r_m) ranging from 0.222 to 0.227 females/female/day and finite rates of increase (λ) from 1.248 to 1.255. These results demonstrate that *Tyrophagus* sp. can serve as an effective and economical alternative prey for the mass rearing of *A. eharai*, potentially enhancing the large-scale production and field application of this predator in integrated pest management programs.

Key words: *Amblyseius eharai*, Biological control, Factitious prey, Life table parameters, Mass rearing, Phytoseiidae, *Tyrophagus* sp.

INTRODUCTION

Predatory mites belonging to the family Phytoseiidae play a crucial role as biological control agents against a wide range of pest species commonly found in greenhouses and net houses worldwide (Gerson and Weintraub, 2012). Consequently, extensive research has focused on developing rearing techniques for phytoseiid mites using diverse food sources, including various prey and pollen types (Muma, 1971; Saito and Mori, 1975, 1981; Castagnoli, 1989; Marisa and Sauro, 1990; Croft *et al.*, 1998; Zhang *et al.*, 2005; Lee and Gillespie, 2011; Zannou and Hanna, 2011; Ranabhat *et al.*, 2013; McMurtry *et al.*, 2013; Ji *et al.*, 2015).

Among these predators, *Amblyseius eharai* is recognized as a type III-b generalist predator, capable of feeding on multiple prey species and sustaining development on pollen (McMurtry and Croft, 1997, McMurtry *et al.*, 2013). Within the larval stage, members of Phytoseiidae are categorized into three feeding types: obligatory feeding larvae (OFL), non-feeding larvae (NFL), and facultative feeding larvae (FFL), with *A. eharai* belonging to the OFL category (Chittenden and Saito, 2001).

Originally described by Amitai and Swirski, *A. eharai* (Acari: Phytoseiidae) is a native species that typically appears early in the apple-growing season in Korea (Kim *et al.*, 2003). It has also been documented in Japan, China, Taiwan, and Malaysia (Ehara, 2002; Yao, 2012) and is recognized as an effective biocontrol agent for several pest mites and thrips, such as *Aceria litchii* (Keifer) (Acari: Eriophyidae), *Calepitrimerus vitis* (Nalepa) (Acari: Eriophyidae), *Panonychus citri* (McGregor) (Acari: Tetranychidae), *Pseudodendrothrips mori* (Niwa) (Thysanoptera: Thripidae), *Tetranychus kanzawai* (Kishida) (Acari: Tetranychidae), and *Tetranychus urticae* (Koch) (Waite and Gerson, 1994; Lee *et al.*, 1995, 2016; Kim *et al.*, 2003; Kakimoto *et al.*, 2004; Ji *et al.*, 2013).

Particularly, *A. eharai* is known as one of the most effective predators of *Panonychus citri*, a major pest infesting citrus crops (Chittenden and Saito, 2001; Kishimoto, 2005; Momen and Amer, 1999; Zhang and Li, 2012, Ji *et al.*, 2013). In addition, the species contributes significantly to the suppression of plant-feeding mites on apple trees during the early growing season (Kim *et al.*, 2003). Its occurrence has been reported across a variety of plant species with different leaf morphologies, including conifers, shrubs, herbs, and vines (Ryu *et al.*, 1997). It has also been recorded on several agricultural and ornamental crops such as tea, longan, bamboo, Japanese medlar, cotton, and other ornamental plants (Kakimoto *et al.*, 2004).

In Korea, *A. eharai* is considered the most prevalent phytoseiid mite, exhibiting a broad prey spectrum encompassing thrips, aphids, and various pest mites (Kakimoto *et al.*, 2004; Ji *et al.*, 2013). Numerous studies have investigated its rearing performance using different prey species and pollen sources, including the pioneering works of Saito and Mori (1975), Wei *et al.* (1993), Pu *et al.* (1995) and Thao *et al.* (2023).

Tyrophagus sp. is a group of storage mites known as common pests of grains, wheat flour, breakfast cereals, pet food, baking mixes, cereal-based products, dried plant materials, cheese, corn, and dried fruits (Hughes, 1976; Rodriguez and Rodriguez, 1987; Solomon, 1946), as well as decaying plant and animal materials (Krezeczkowski, 1961). According to Baker and Wharton (Baker and Wharton, 1952), *Tyrophagus putrescentiae* is also capable of transmitting certain plant diseases under field conditions.

Tyrophagus sp. has a short life cycle and high reproductive rate, which vary depending on food availability, humidity, and temperature. The developmental period from egg to adult under optimal conditions has been reported as 9.4, 7.2, and 8.5 days at temperatures of 25, 30, and 32.5°C, respectively (Sánchez-Ramos, 2007).

Although members of the Astigmata group are well known as storage pests, they also have important applications in the mass rearing of predatory mites (Phytoseiidae). One of the major advances in the development of predatory mite mass-rearing technology has been the use of astigmatid mites as alternative prey (Vangansbeke *et al.*, 2023). As early as 1960, Burnett

(1960) demonstrated the potential use of *Tyrophagus castellanii* (Hirst) for rearing predatory mites such as *Cheyletus eruditus* (Schrank) (Cheyletidae) and *Melichares dentriticus* (Berlese) (Blattisocidae).

In recent years, modern studies have further confirmed the value of *Tyrophagus* spp. in the commercial rearing of predatory mites. For instance, *Neoseiulus cucumeris* has been successfully reared on *Tyrophagus putrescentiae* and *Tyrophagus curvipenis* Fain and Fauvel (Li *et al*., 2021); likewise, *Blattisocius mali* (Acari: Blattisocidae) has also been effectively reared on *T. putrescentiae* (Pirayeshfar *et al*., 2022).

However, studies on *Amblyseius eharai* using prey from the Astigmata group remain very limited. Preliminary observations from our research indicate that *A. eharai* can develop and reproduce effectively when fed on *Tyrophagus* sp. Therefore, this study aims to investigate the basic biological characteristics of *A. eharai* when reared on *Tyrophagus* sp., in order to evaluate the potential use of this mite species as an alternative food source for the mass rearing of predatory mites.

MATERIALS AND METHODS

Rearing of *Tyrophagus* sp. (prey culture)

Populations of *Tyrophagus* sp. were collected from flour mills, animal feed stores, and grain storage facilities in the Mekong Delta region and maintained in the laboratory as a food source for *A. eharai.* The mites were reared in 1-L plastic containers containing a rearing medium composed of 70% wheat bran and 30% freeze-dried egg yolk powder. Sterilized rice husk (irradiated under UV light) was used as the rearing substrate at a depth of approximately 1 cm. About 1 g of *Tyrophagus* sp. (≈900–1000 individuals) and 1 g of diet were added to each container, and fresh diet was supplied daily.

Rearing of *Amblyseius eharai* (predator culture)

Adult females of *A. eharai* were collected from citrus orchards in Tien Giang Province (Vietnam). The species was identified morphologically and maintained in the laboratory on leaves of kidney bean (*Phaseolus vulgaris*) infested with *Tetranychus urticae*. The leaves were placed on moistened cotton pads in Petri dishes (60 × 15 mm), which were surrounded by a layer of petroleum jelly to prevent mite escape. All colonies were maintained under controlled laboratory conditions at 25 ± 2°C, 70 ± 5% RH, and a 16:8 h (L:D) photoperiod.

Developmental time of *A. eharai* fed on different stages of *Tyrophagus* sp.

Experimental design

Developmental performance of *A. eharai* was evaluated using Petri dish rearing arenas (60 × 15 mm). A newly laid egg (< 24 h old) of *A. eharai* was transferred to each dish and provided with an abundant supply of a single prey stage of *Tyrophagus* sp. (egg, larva, adult or mixed three stages). Thirty individuals were observed for each prey stage. Petri dishes were checked daily to record the duration of each developmental stage (egg, larva, protonymph, deutonymph, and adult). Food was renewed every two days, and the arena was cleaned as needed. The rearing unit was maintained at 25 ± 1°C and 75 ± 5% RH with a 16L: 8D hour photoperiod in a growth chamber.

Data recorded

Duration (days) of each life stage and total development time (egg–adult).

Comparison of developmental time among predator groups fed on different prey stages of *Tyrophagus* sp.

Reproductive performance of *A. eharai* on *Tyrophagus* sp.

Experimental design

The reproductive capacity of *A. eharai* was determined using newly mated adult females (< 24 h old). Each female was placed in an individual Petri dish (60 × 15 mm) and provided with abundant *Tyrophagus* sp. eggs, larvae, or adults as prey (depending on treatment). The experiment was conducted under the same environmental conditions as described above.

Dishes were inspected daily to record pre-oviposition, oviposition, and post-oviposition periods, as well as daily fecundity. Food was replaced and the arena cleaned every two days.

Observations continued until females ceased oviposition for 10 consecutive days.

Parameters measured

Pre-oviposition, oviposition, and post-oviposition periods (days); total number of eggs laid per female, egg hatchability (%), and adult longevity (days).

Life table parameters

The intrinsic rate of increase (r_m) was calculated according to the formula proposed by Birch (1948).

$$\sum l_x m_x e^{-r_m \cdot x} = 1$$

where x equals the female age (days), lx is the age-specific survival of females at age x, and mx is the number of daughters produced per female at age x. The latter parameter is obtained by multiplying the mean number of eggs laid per female by the proportion of female offspring produced at age x.

The net reproductive rate (R_0), i.e. the mean number of female offspring produced per female (females/female) is expressed as:

$$R_0 = \sum \cdot l_x m_x$$

The mean generation time (T) was defined as the length of time that a population needed to increase to R_0-fold of its size (i. e., $e^{r_m T} = R_0$ or $\lambda^T = R_0$) at the stable age–stage distribution. The mean generation time was calculated as follows.

$T = (\ln R_0)/r_m$.

The finite rate of increase (λ) is expressed as:

$\lambda = e^{r_m}$

These parameters were used to compare population growth potential of *A. eharai* when fed on different developmental stages of *Tyrophagus* sp.

Statistical analysis

Data were analyzed using SigmaPlot version 11.0 (Systat Software Inc., San Jose, CA, USA).

A one-way analysis of variance (ANOVA) was used to evaluate the effects of different prey stages of *Tyrophagus* sp. on the developmental time of each immature stage and the reproductive performance (pre-oviposition, oviposition, post-oviposition period, total fecundity, and adult longevity) of *Amblyseius eharai*. When significant differences were detected ($p \leq 0.05$), mean values were compared using Tukey's multiple range test. In cases where Levene's test indicated heteroscedasticity, a nonparametric rank test was applied instead of Tukey's test to ensure the validity of the comparison. All results are expressed as mean ± standard error (SE).

RESULTS AND DISCUSSION

The developmental duration of *Amblyseius eharai* differed significantly among the prey stages of *Tyrophagus* sp. (Kruskal–Wallis, H = 15.857, df = 3, p= 0.001). Individuals fed on *Tyrophagus* eggs showed the shortest developmental period (7.90 ± 0.19 days) (Table 1), while those fed on immature and adult stages developed more slowly (8.83 ± 0.26 and 9.13 ± 0.21 days, respectively). The mixed-stage diet resulted in an intermediate duration (8.60 ± 0.22 days). Statistical grouping indicated that the egg diet differed significantly from the immature and adult diets (p< 0.05), whereas no difference was detected between the mixed diet and the others (grouping: Egg = a; Immature = b; Adult = b; Mixed = ab).

In the study by Ji *et al.* (2013), the life cycle of *Amblyseius eharai* at 25°C was reported to be 9.7 days when feeding on *Panonychus citri* larvae, which was longer than when feeding on *P. citri* eggs (7.7 days). Similarly, in our study, we also found that when feeding on the eggs of *Tyrophagus* sp., the life cycle of *A. eharai* was shorter compared to when it fed on other developmental stages of *Tyrophagus* sp.

These findings demonstrate that *A. eharai* develops most rapidly when fed on *Tyrophagus* eggs. This may be attributed to the eggs' high digestibility, rich nutrient composition, and immobility, which facilitate feeding efficiency and reduce energy expenditure during prey capture. In contrast, the motile immature and adult stages likely require greater handling effort and offer lower net energy assimilation due to harder cuticles or higher chitin content.

Table 1. Development time (days) of *Amblyseius eharai* fed on different stages of *Tyrophagus* sp.

Diet type (*Tyrophagus* sp. stage)	Developmental duration (mean ± SE; days)			
	n	Min	Max	Mean ± SE
Egg	30	6	10	7.9 ± 0.19a
Immature	30	7	11	8.83 ± 0.26b
Adult	30	7	11	9.13 ± 0.21b
Mixed stages	30	6	11	8.6 ± 0.22ab
H				15.857
df				3
P				0.001

Values followed by different letters differ significantly according to Tukey's multiple comparison test (p< 0.05).

Table 2. Mean ± SE reproduction and longevity of *Amblyseius eharai* on different stages of *Tyrophagus* sp.

Diet type (*Tyrophagus* sp. stage)	Pre-oviposition period (days)*	Oviposition period (days)*	Post-oviposition period (days)*	Female longevity (days)*	Oviposition rate (eggs/female/ day)*	Total number of eggs (eggs/female)*	Hatching egg proportion of the progeny (%)*	Female proportion of the progeny (%)*
Egg	1.63± 0.10 a	22.03 ± 0.40a	4.70 ± 0.34ab	36.27 ± 0.39a	1.77 ± 0.04a	38.73 ± 0.69a	89.63 ± 084c	65.67 ± 1.36a
Immature	3.77 ± 0.23b	23.50 ± 0.45ab	3.77 ± 0.23a	38.43 ± 0.59b	1.75 ± 0.02a	41.13 ± 0.69b	84.08 ± 1.26b	65.52 ± 1.20a
Adult	5.47 ± 0.35c	24.03 ± 0.41b	5.47 ± 0.35b	41.1 ± 0.60c	1.71 ± 0.03a	40.97 ± 0.67b	88.69 ± 1.25c	63.54 ± 1.08a
Mixed stages	4.23 ± 0.42bc	22.43 ± 0.40a	4.23 ± 0.42ab	37.33 ± 0.59ab	1.71 ± 0.04a	38.20 ± 0.66a	82.56 ± 1.33a	64.25 ± 0.89a
H/F	H=56.572	F=4.952	F=4.498	F=14.110	H=5.927	H=13.726	H=24.447	F=0.798
df	3	3	3	3	3	3	3	3
p	<0.001	0.003	0.005	<0.001	0.115	0,003	<0.001	0.498

*: Means within a column followed by the same letter are not significantly different (p<0.05). according to a Tukey test (oviposition period, post-oviposition period, female longevity, hatching egg proportion of the progeny, female proportion of the progeny), according to a Rank test (preoviposition period, oviposition rate, total number of eggs, female proportion of the progeny), H/F-, df- and p values refer to one – way ANOVAs.

The results highlight the potential of *Tyrophagus* eggs as an effective factitious prey source for mass rearing of *A. eharai*. Using eggs can shorten the developmental cycle and increase generation turnover in colony production. However, future studies should include life-table analyses to evaluate whether an egg-only diet supports high reproductive output and long-term population sustainability.

The pre-oviposition period of *Amblyseius eharai* varied significantly among prey stages of *Tyrophagus* sp. (Kruskal–Wallis, H = 56.572, df = 3, p< 0.001). Females fed on *Tyrophagus* eggs showed the shortest pre-oviposition duration (1.63 ± 0.10 days) (Table 2), which was significantly shorter than those fed on immature (3.77 ± 0.23 days), adult (5.47 ± 0.35 days), and mixed-stage prey (4.23 ± 0.42 days). Multiple comparison analysis indicated that the egg-fed group differed significantly from all other prey treatments (p< 0.05), whereas no significant difference was detected among the immature, adult, and mixed diets (grouping: Egg = a; Immature = b; Mixed = bc; Adult = c).

This result indicates that *A. eharai* females reached the reproductive stage fastest when provided with *Tyrophagus* eggs as prey. The shorter pre-oviposition period under the egg diet suggests that the eggs of *Tyrophagus* provide superior nutritional quality, particularly higher protein and lipid availability, supporting faster gonadal maturation. Moreover, the immobility and softness of the egg surface likely facilitate feeding efficiency and reduce the energy cost of prey handling.

In contrast, when feeding on immature or adult *Tyrophagus*, females required a longer time before oviposition. This delay could be due to higher chitin content, tougher cuticle structure, and increased prey mobility, which may hinder nutrient assimilation and delay oogenesis.

These findings reinforce the conclusion that *Tyrophagus* eggs are an optimal food source for stimulating early reproduction and maintaining colony productivity of *A. eharai* under laboratory conditions.

The oviposition duration of *Amblyseius eharai* differed significantly among diets (One-way ANOVA, $F_{3,116} = 4.952$, $p = 0.003$; power = 0.829). Female mites fed on adult *Tyrophagus* had the longest oviposition period (24.03 ± 0.41 days), which was significantly longer than those provided with egg (22.03 ± 0.40 days; $p = 0.005$) and mixed-stage prey (22.43 ± 0.40 days; $p = 0.038$). However, no significant difference was found between mites fed on adult and immature stages ($p = 0.802$). Similarly, the oviposition periods of mites fed on egg, immature, and mixed stages of *Tyrophagus* did not differ significantly from each other ($p > 0.05$). These results indicate that adult *Tyrophagus* provided a slightly more suitable diet for prolonging the oviposition period of *A. eharai*, though the overall differences among diets were moderate.

The post-oviposition duration of *Amblyseius eharai* varied significantly among the diets (One-way ANOVA, $F_{3,116} = 4.498$, $p = 0.005$; power = 0.772). The longest post-oviposition period was observed when females were fed on adult *Tyrophagus* (5.47 ± 0.35 days), which was significantly longer than those fed on immature prey (3.77 ± 0.23 days; $p = 0.004$).

However, there were no significant differences among mites fed on adult, egg, or mixed-stage diets ($p > 0.05$). Overall, fed on adult *Tyrophagus*, female *A. eharai* exhibited a significantly prolonged post-oviposition period compared with those fed on immature prey (5.47 ± 0.35 vs 3.77 ± 0.23 days; One-way ANOVA, $F_{3,116} = 4.498$, $p = 0.005$), suggesting that the nutritional composition of the adult prey might support a longer survival period after oviposition.

The female longevity of *Amblyseius eharai* varied significantly depending on the developmental stage of *Tyrophagus sp.* provided as prey (ANOVA, $F = 14.11$, $p < 0.001$).

Females fed on adult *Tyrophagus sp.* lived the longest (41.1 ± 0.60 days), showing a statistically significant difference compared to those fed on eggs (36.27 ± 0.39 days), immature stages (38.43 ± 0.59 days), and mixed stages (37.33 ± 0.59 days). The differences among the egg, immature, and mixed diets were not statistically significant ($p > 0.05$). These results indicate that adult stages of *Tyrophagus sp.* serve as the most suitable food source for extending the longevity of *A. eharai* females, while other diets support moderate but comparable lifespans.

The mean oviposition rate of *Amblyseius eharai* females did not differ significantly among the four diet treatments (Kruskal–Wallis, $H = 5.927$, $df = 3$, $p = 0.115$).

Although females fed on *Tyrophagus* eggs exhibited the highest average egg-laying rate (1.77 ± 0.04 eggs/female/day), the differences compared to other diet types were not statistically significant. This suggests that *A. eharai* can maintain a relatively stable reproductive rate regardless of prey developmental stage, indicating its broad prey adaptability and reproductive resilience across varying prey conditions.

The total number of eggs laid per female of *Amblyseius eharai* varied significantly among treatments (Kruskal–Wallis, $H = 13.726$, $df = 3$, $p = 0.003$). Females reared on adult *Tyrophagus* produced the highest total number of eggs (40.97 ± 0.67 b), which was not significantly different from those fed on immature *Tyrophagus* (41.13 ± 0.69 b). However, both of these treatments showed significantly higher fecundity compared with females reared on mixed stages (38.20 ± 0.66 a) and egg stages (38.73 ± 0.69 a) of *Tyrophagus* sp.

These results indicate that *A. eharai* females achieved better reproductive performance when feeding on the adult or immature stages of *Tyrophagus*, suggesting that these stages provide a more balanced or nutritionally suitable diet for egg production.

The egg hatching rate of *Amblyseius eharai* differed significantly among treatments (Kruskal–Wallis, $H = 24.447$, $df = 3$, $p < 0.001$). Females fed on adult and

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egg stages of *Tyrophagus* sp. showed the highest hatching rates (88.69 ± 1.25 c and 89.63 ± 0.84 c, respectively), with no significant difference between these two groups. These rates were significantly higher than those observed in females fed on immature (84.08 ± 1.26 b) and mixed stages (82.56 ± 1.33 a) of *Tyrophagus* sp.. This result indicates that eggs of *A. eharai* tend to develop more successfully when the females feed on adult or egg stages of *Tyrophagus* sp., suggesting these prey stages provide more suitable nutrients, thereby supporting better embryonic development.

The proportion of female offspring (F1) of *Amblyseius eharai* did not differ significantly among the four diets provided, including egg, immature, adult, and mixed stages of *Tyrophagus* sp. (p= 0.498). Mean female ratios ranged from 63.54 ± 1.08% to 65.67 ± 1.36%, with overlapping standard errors, indicating no meaningful variation.

These results suggest that the developmental stage of *Tyrophagus* sp. used as prey had no significant influence on the sex ratio of the subsequent generation of *A. eharai*. According to Tukey's test, all treatments belong to the same statistical group (a).

The survival curve (lx) of *Amblyseius eharai* showed a typical type I pattern across all diet treatments, with high survival during the early and middle stages of life and a gradual decline toward the end of the reproductive period. The survival rate tended to remain close to 1.0 until approximately day 22 (Fig. 1), then decreased progressively thereafter. Among the diets, females fed on the adult stage of *Tyrophagus sp.* exhibited slightly longer survival duration compared to those fed on immature or mixed stages.

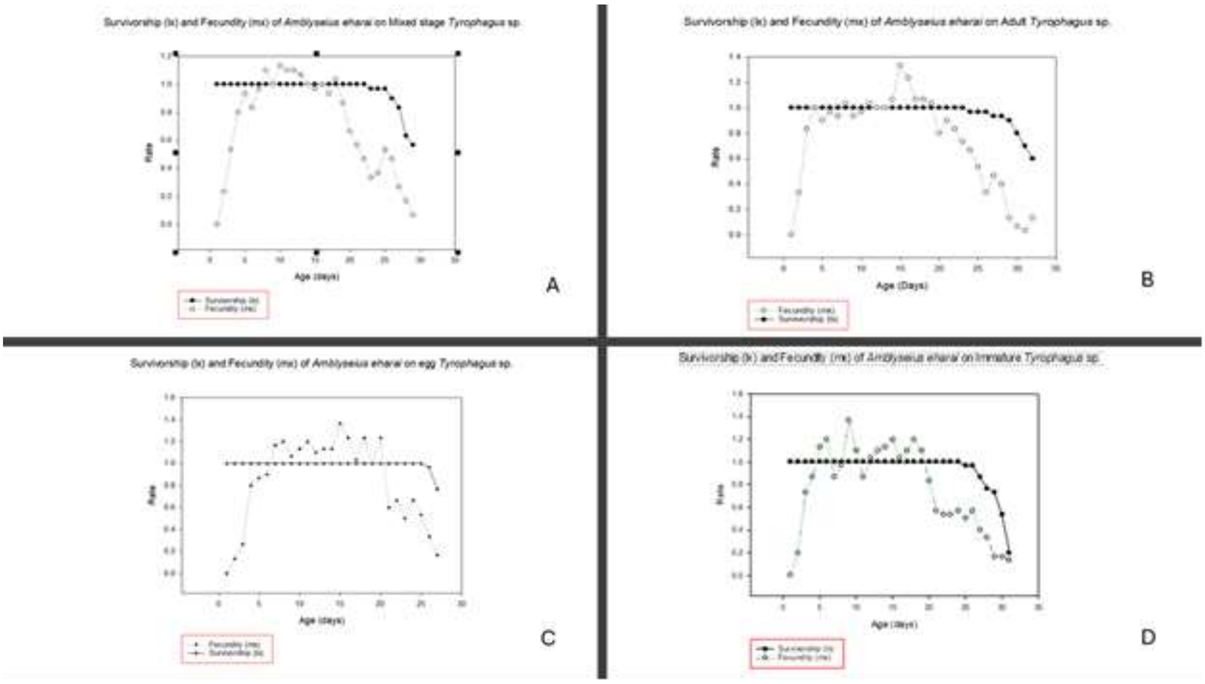

Fig. 1. Survival and reproduction curves of *A. eharai* on different stages of *Tyrophagus* sp.

The fecundity curve (mx) displayed a unimodal distribution, with egg production beginning around day 2–3, reaching a peak between days 10–18, and then gradually declining. The age-specific fecundity curve (m_x) of *A. eharai* showed a unimodal pattern with minor fluctuations, indicating that egg production peaked once and gradually declined thereafter. The highest fecundity peak was observed when *A. eharai* was fed on immature and egg stages of *Tyrophagus* sp., suggesting that these diets provided better nutritional quality for egg production. In contrast, females fed on the mixed-stage diet showed a lower and narrower reproductive peak, indicating a possible nutritional imbalance or variable prey size.

Overall, the overlapping patterns of lx and mx indicate that reproductive activity of *A. eharai* coincided with the period of highest survival, reflecting a stable reproductive strategy and efficient utilization of prey resources under all feeding conditions tested.

The reproductive and population growth parameters of *A. eharai* showed slight variations depending on the developmental stage of *Tyrophagus* sp. used as prey. The net reproductive rate (R_0) ranged from 20.28 to 23.57 (Table 3) females per female, being highest when *A. eharai* fed on adult *Tyrophagus* sp. and lowest on mixed stages. The generation time (T) was relatively similar among treatments (13.35–14.25 days), indicating stable population turnover regardless of prey stage. The intrinsic rate of increase (r_m) fluctuated narrowly between 0.222 and 0.227 females/female/day, with corresponding finite rates of increase (λ) from 1.248 to 1.255, showing that *A. eharai* populations can grow efficiently on all developmental stages of *Tyrophagus* sp.. Overall, feeding on adult or immature *Tyrophagus* sp. slightly enhanced reproductive potential, while mixed-stage diets produced marginally lower growth rates.

Table 3. Life table parameters of *Amblyseius eharai* on different stages of *Tyrophagus* sp.

Diet type (*Tyrophagus* sp. stage)	n	Net reproductive rate (R_0. females per female)	Generation time (T. days)	Intrinsic rate of increase (r_m. females/female/day)	Finite rate of population increase (λ)
Egg	30	22.617	13.852	0.225	1.253
Immature	30	23.104	13.846	0.227	1.255
Adult	30	23.568	14.246	0.222	1.248
Mixed stages	30	20.278	13.350	0.225	1.253

The oviposition period of *Amblyseius eharai* when feeding on *Tetranychus urticae* decreases as environmental temperature increases, with oviposition periods of 22.85 days and 19.65 days at 21.6°C and 24.1°C, respectively (Park and Lee, 2020), and 21.27 days as reported by Thao *et al.* (2023). In this study, the oviposition period of *A. eharai* when feeding on *Tyrophagus* spp. averaged from 22 to 24 days, depending on the prey stage.

The intrinsic rate of increase (r_m) of *A. eharai* when feeding on *Tyrophagus* sp. at 25°C, as reported in this study, is comparable to that observed when feeding on *P. citri* (r_m = 0.221) and *T. urticae* (r_m = 0.226) (Thao *et al.*, 2023), and is higher than that reported by Ji *et al.* (2013) (r_m = 0.1711).

In the study by Jie *et al.* (2014), when *Carpoglyphus lactis* was provided as prey, the total number of eggs laid by *Amblyseius eharai* females was 51.1 eggs per female, with a daily oviposition rate of 2.5 eggs per female per day. Its net reproductive rate (Ro) was 33.849, the female ratio was 66.24%, and the intrinsic rate of increase (rm) was relatively high (0.253). These findings, together with the results of the present study, indicate that storage mites can serve as an effective alternative food source for mass rearing *A. eharai*.

The survival curve (lx) of *A. eharai* followed a typical Type I pattern, with high survival during immature stages and a gradual decline in adult females, as also reported for *N. cucumeris* (Asgari *et al.*, 2022). The age-specific fecundity (mx) curve was unimodal, peaking in the early reproductive phase and declining thereafter, reflecting the normal reproductive strategy of phytoseiid mites that allocate maximum energy to early oviposition (Asgari *et al.*, 2022). The population parameters (r_m, λ, Ro) obtained in this study confirm that *A. eharai* can maintain positive population growth when feeding on *Tyrophagus* sp., highlighting its potential use in biological control programs targeting acarid mites in stored products or in the early stages of mass-rearing systems.

Overall, our findings indicate that *Tyrophagus* sp. eggs and larvae provide sufficient nutrition for *A. eharai* to complete its life cycle and reproduce effectively. This demonstrates the feasibility of using *Tyrophagus* sp. species as a cost-effective alternative prey for laboratory culture of *A. eharai*, similar to how

T. putrescentiae and *C. lactis* have been utilized for other predatory mites. Further optimization of diet composition and rearing conditions could enhance its practical use in mass production systems.

CONCLUSION

The results of this study demonstrated that *Amblyseius eharai* can successfully complete its life cycle when fed on *Tyrophagus* sp., with its developmental and reproductive parameters being comparable to those obtained when feeding on key pest species such as *T. urticae* and *P. citri*. Among the tested prey stages, the larval stage of *Tyrophagus* sp. provided the highest fecundity and longest female longevity. In addition, using the egg stage of *Tyrophagus* sp. as a food source during the developmental period of *A. eharai* could be considered if a shorter life cycle is desired.

These findings indicate that *Tyrophagus* sp. has great potential as an alternative prey for mass rearing *A. eharai*, thereby supporting the development of biological control programs using this predatory mite.

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