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Life table and demographic parameters of the coccinellid predatory species, *Hippodamia convergens* Guérin-Méneville (Coleoptera: Coccinellidae) when fed on two aphid species

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Abstract

The study aimed to determine the effect of two aphid species; *Lipaphis erysimi* (Kaltenbach) and *Aphis gossypii* Glover (Hemiptera: Aphididae) on life table and demographic parameters of *Hippodamia convergens* Gu`erin-M´ eneville (Coleoptera: Coccinellidae). The developmental period of all life stages of *H. convergens* was shorter when fed on *L. erysimi*. Net reproductive rate (R_o) was higher (159.85 offspring/individual) on *L. erysimi*, while it was 87.85 offspring/individual on *A. gossypii*. Mean generation time (T) was shorter (30.49 d) on *L. erysimi* than on *A. gossypii* (45.1 days). Values of the intrinsic rate of increase (r) and finite rate of increase (λ) were calculated as 0.166 days^{-1} and 1.181 days^{-1}, respectively, on *L. erysimi* that were higher than on *A. gossypii* (0.099 days^{-1} and 1.104 days^{-1}, respectively). Similarly, the survival rate was also higher when the predator was fed on *L. erysimi*. Overall, the findings suggest using *L. erysimi* as a better source of prey than *A. gossypii* for rearing *H. convergens*.

Keywords: *Hippodamia convergens*, *Aphis gossypii*, *Lipaphis erysimi*, Life table parameters

Background

Coccinellidae is a very heterogeneous group of Coleopteran due to their feeding behavior (Sutherland and Parrella 2009). Coccinellids are very important predators and their food resources depend on prey abundance in the environment where they live (Dixon 2000). They are polyphagous and feed on many economic agricultural insect pests such as mealy bugs, aphids, thrips, scale insects, mites, leafhoppers, and other soft-bodied insects (Khan et al. 2009).

Life parameters of any biological control agent such as development rate and reproductive parameters depend on various biotic and abiotic factors (Jervis et al. 2005). Among the biotic factors, the quality and abundance of food are very important, influencing directly the growth and development of the predator (Dixon 2000). If the food source is unavailable or few or of poor quality, the developmental period usually increases and the reproductive parameters such as fecundity rate and oviposition decrease (Hodek et al. 2012). Previous investigations have reported the importance of foods to the coccinellids reproduction (Omkar and Srivastra, 2003; Lundgren and Wiedenmann 2004; Berkvens et al. 2008 and Lundgren 2009).

Among the coccinellid beetles, prey food varies as they reproduce and develop optimally, when they fed on

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various aphid species (Omkar and Mishra 2005 and Pervez et al. 2018). Aphids are polyphagous insect pests causing economic losses to various agricultural crops (Aslam et al. 2005). Amin et al. (2017) reported 17 different host plants of *Aphis gossypii* in Pakistan. According to Jessie et al. (2015), a specialist aphid is more toxic to coccinellid predators than a generalist aphid.

To successfully mass rearing the coccinellids in a biological control program, assessment of their population characteristics, such as growth rate, fecundity, and predation rate is very important (Yu et al. 2013). Further, the provision of adequate and nutritional diet is a major concern in the predation potential and biology of coccinellids (De Clercq et al. 2005).

The main objective of this study was to evaluate the effect of two aphid species; *Lipaphis erysimi* (Kaltenbach) and *Aphis gossypii* Glover (Hemiptera: Aphididae) on the life table and demographic parameters of the coccinellid predator, *H. convergens* under laboratory conditions.

Materials and methods

The experiment was performed in the Entomology Laboratory at China-Pakistan Joint Research Centre, University of Sargodha, Pakistan.

Aphid species

The parthenium weed, *Parthenium hysterophorus* L. (family: Asteraceae) and wheat plant, *Triticum aestivum*, (Family: Poaceae) were grown in plastic containers (10 cm diameter) at 25 ± 2 °C, 65 ± 5% RH and a photoperiod of 14:10 (L:D). Plants were irrigated with tap water, and pot weights were recorded twice each day to maintain the soil water contents which were kept the same for both plant species. The nymphs and adults of *L. erysimi* from wheat plants and *A. gossypii* from parthenium weed were collected directly from the field, released on the respective host plants and the cultures were maintained up to the 3rd generation.

Culture of *H. convergens*

The initial culture of *H. convergens* was initiated by collecting adults from the field and maintained in plastic jars (20 cm length and 15 cm diameter) with an abundant supply of aphid species. The culture was maintained separately on each aphid species. The rearing jars were provided by a crumpled paper to support as an oviposition site. The eggs laid were collected daily, transferred to clean Petri dishes and allowed to hatch. The culture was maintained at the laboratory conditions of 25 ± 2 °C and 65 ± 5% RH. Newly emerged larvae of *H. convergens* from the stock were the ones used in the experiments.

Life table parameters

To study the pre-imaginal development and survival, groups of about 40 eggs of *H. convergens* were obtained from the adults reared on the 2 different aphid species that placed separately in clean Petri plates. The egg incubation period was recorded at 12 h intervals. On hatching, larvae were fed on *A. gossypii* and *L. erysimi* separately. The experimental unit consisted of falcon centrifuge polypropylene tube (12 cm in length and 3 cm in diameter) containing 1 predator larva and aphid diet that was provided daily. First and second larval instars of *H. convergens* were provided by 10 1st and 2nd nymphal instars of each aphid species and later larval instars were provided by 20 3rd and 4th instars of each host aphid. Development of larval and pupal durations was recorded at 12 h intervals. The adults of *H. convergens* were selected from the corresponding experiment with the immature stages. Additional culture was also maintained to harvest a sufficient number of adult females when required. The adult pairs of *H. convergens* were isolated, and kept in transparent plastic jars containing 1–2 branches of each host plant; dipped in plastic vials containing water. Similarly, the adult pairs were fed daily on *L. erysimi* and *A. gossypii*. The laid eggs were separated daily for each couple. Data were recorded daily to determine the fecundity rate and adult longevity. The fecundity rate, developmental duration, adult preovipositional period (APOP), and total APOP based on an age-stage two-sex life table (Chi 1988) was determined by using the computer program TWOSEX-MSChart (Chi 2016). Age-specific survival rates and life expectancy were calculated according to Chi and Liu (1985) and Chi and Su (2006), respectively.

Data analysis

The developmental duration and population parameters were calculated using TWOSEX-MSChart program. The bootstrapping technique with 100,000 replications was used to minimize the variation in the

Table 1 Developmental period (mean ± SE) of *Hippodamia convergens* fed on two aphid species

Life stages	n	*A. gossypii*	*n*	*L. erysimi*
Egg incubation	40	3.15 ± 0.12a	40	2.45 ± 0.08b
L1	38	4.03 ± 0.12a	40	2.55 ± 0.08b
L2	32	5.10 ± 0.14a	36	2.61 ± 0.09b
L3	24	5.50 ± 0.23a	34	2.32 ± 0.07b
L4	23	6.82 ± 0.19a	32	3.81 ± 0.13b
Pupa	23	6.82 ± 0.19a	32	4.47 ± 0.10b
Adult longevity	22	30.6 ± 0.56b	32	36.4 ± 0.50a

SE was estimated by Bootstrapping (100,000 replications), *L1–L4* indicate the larval instar, means sharing similar letters in each row are not significantly different at *P* > 0.05, *n* = numbers of individual *H. convergens* that completed a stage results for calculating the mean and standard error of the population (Efron and Tibshirani 1993). Using raw data, the stage mean, age-stage-specific survival rate (S_{xj}), age-stage reproductive value (V_{xj}), age-stage-specific fecundity (f_{xj}), age-stage life expectancy (E_{xj}), age-specific survival rate (l_x), age-specific fecundity (m_x), age-specific net maternity ($l_x m_x$), and life table parameters (R_o, net reproductive rate; r, intrinsic rate of increase; λ, finite rate of increase; and T, mean generation time) were calculated. The significant difference between means was estimated using quick paired bootstrapping (paired 1 by 1) function in TWOSEX-MSChart program (Chi 2018).

The age-specific survival rate (lx, mx, and R_o) was calculated as

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

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

Table 2 Comparison of reproductive and life table parameters (mean ± SE) of *Hippodamia convergens* fed on two aphid species

Parameters	*A. gossypii*	*L. erysimi*
APOP	4.286 ± 0.569a	02.60 ± 0.150b
TPOP	35.78 ± 1.094a	20.80 ± 0.415b
Oviposition period	15.90 ± 0.912b	20.10 ± 0.766a
Fecundity	251.0 ± 13.27b	319.7 ± 13.32a
*R*o (offspring individual^{-1})	87.85 ± 19.45b	159.85 ± 25.86a
T (days)	45.10 ± 0.858a	30.49 ± 0.442b
r (days^{-1})	0.099 ± 0.005b	0.166 ± 0.006a
λ (days^{-1})	1.104 ± 0.002b	1.181 ± 0.007a

SE was estimated by bootstrapping (100,000). Whereas APOP, TPOP, *T*, *r*, *λ*, and *R*o represents adult pre-oviposition period, total pre-oviposition period, mean generation time, intrinsic rate of increase, and finite rate of increase, net reproductive rate respectively. Means sharing similar letters in each row are not significantly different at $P > 0.05$

$$R_o = \sum_{x=0}^{\infty} l_x m_x$$

Where k denotes the number of stages, x = age in days, j = stage, R_o (net reproductive rate) is the average number of offspring per female during its whole life cycle. It was calculated by the following equation:

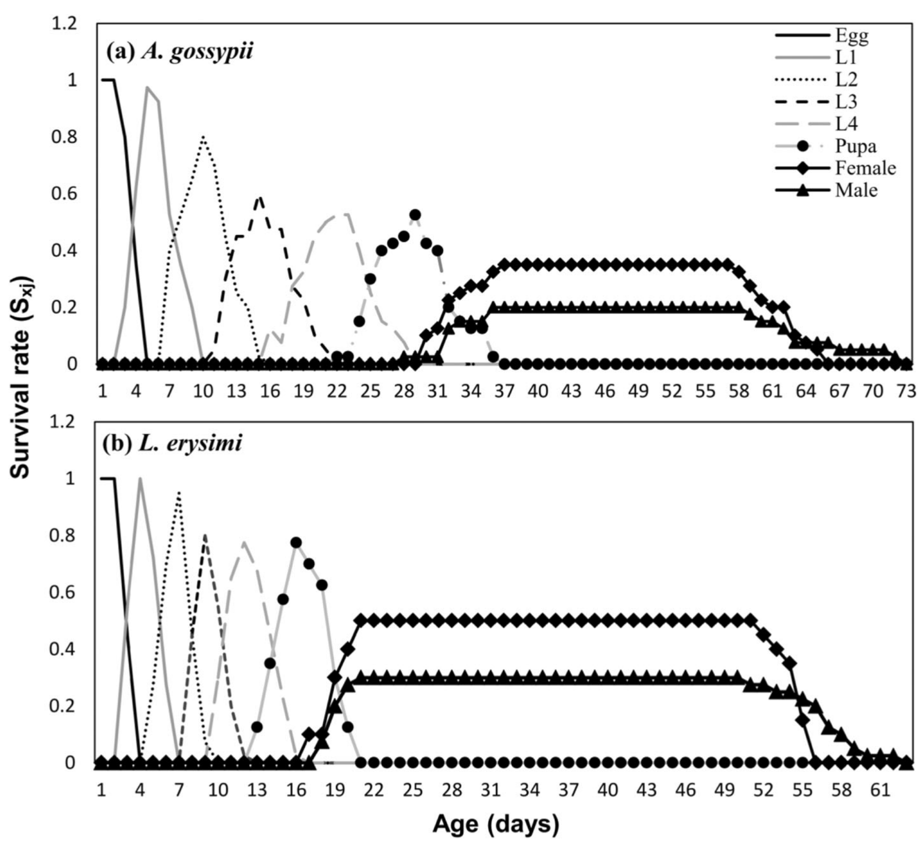

Fig. 1 Age-stage-specific survival rate (S_{xj}) of *Hippodamia convergens* fed on two aphid species

The intrinsic rate of increase (r) (Goodman 1982), finite rate of increase (λ), and mean generation time (T) was calculated as

$$\sum_{x=0}^{\infty} e^{-r(x+1)} l_x m_x = 1$$
$$\lambda = e^r$$
$$T = \ln Ro/r$$

The life expectancy (E_{xj}) was referred as the expected life of an individual of age x and stage j was calculated by the equation suggested by Chi and Su (2006):

$$\mathrm{E}_{xj} = \sum_{i=x}^{\infty} \cdot \sum_{y=j}^{\beta} \mathrm{s}'_{iy}$$

Where $ś_{iy}$ was the probability that individuals of age x and stage j will survive to age i and stage y, and was calculated by assuming ś = 1.

The reproductive value (V_{xj}) was calculated by the equation suggested by Tuan et al. (2014):

$$V_{xj} = \frac{e^{r(x+1)}}{S_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{\beta} \mathrm{s}'_{iy} f_{iy}$$

Results and discussion

The developmental period of each stage of *H. convergens* feeding on two aphid species was presented in Table 1. The egg incubation period was shorter (2.45 days) in the females fed on *L. erysimi* than those fed on *A. gossypii* (3.15 days). The findings are also in similar to Abbas et al. (2020) who reported that incubation period of the coccinellid, *Menochilus sexmaculatus* fluctuated feeding on different aphid species. Similarly, the developmental period of all four larval instars was shorter when they fed on *L. erysimi* than on *A. gossypii*. The pupal period was 4.47 days when the larvae were fed on *L. erysimi*, which was shorter than those fed on *A. gossypii* (6.82 days). Adults lived 5.8 days more when fed on *L. erysimi* than on *A. gossypii* host. Adult pre-ovipositional (APOP) and total pre-ovipositional (TPOP) periods were shorter (2.60 and 20.80 days, respectively), when adults fed on *L. erysimi*, while they were 4.86 days of APOP and 35.78 days of TPOP in case of fed on *A. gossypii* (Table 2).

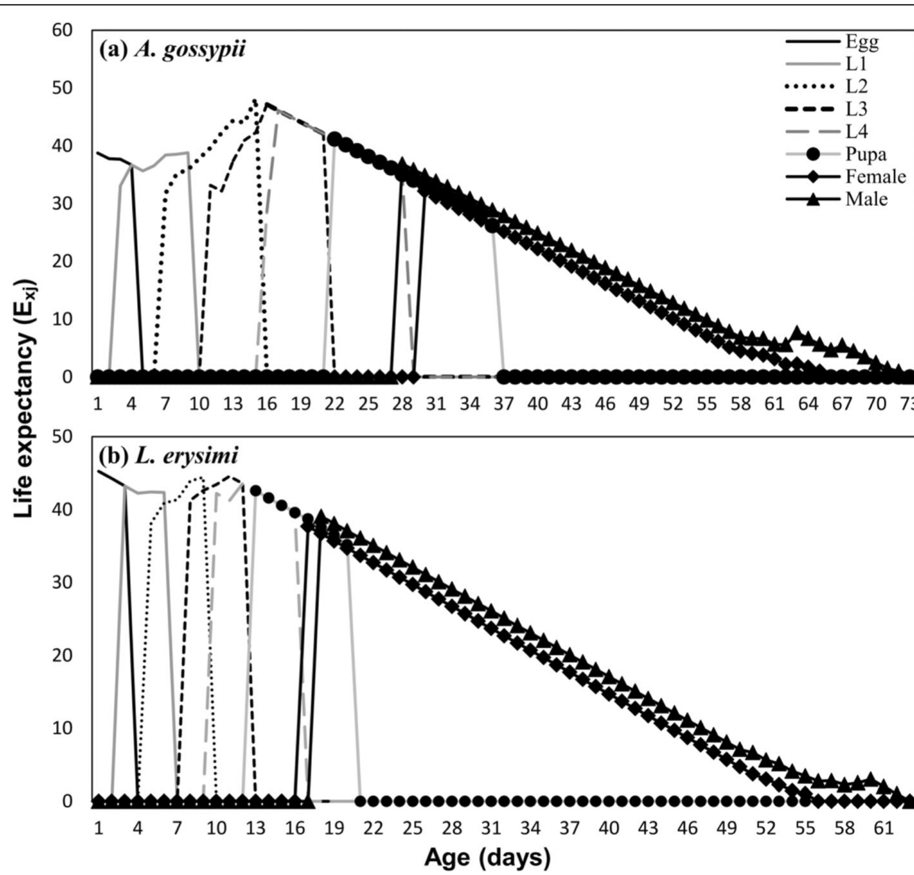

Fig. 2 Age-stage-specific life expectancy (E_{xj}) of *Hippodamia convergens* fed on two aphid species

These findings are contradicted with the studies conducted on seven spotted ladybird, *Coccinella septempunctata* L. that the TPOP beetles was maximum on *L. erysimi* (Ali and Rizvi 2010; Farooq et al. 2018). However, these variations in the results could be due to difference in biotic and abiotic factors (Kontodimas and Stathas 2005). The ovipositional period was also longer (20.1 days), when the female fed on *L. erysimi*, and 15.9 days in female fed on *A. gossypii*. However, Farooq et al. (2018) reported maximum ovipositional period of *C. septempunctata* on *L. erysimi*. Net reproductive rate (R_o) of *H. convergens* varied from 87.85 offspring on *A. gossypii* to 159.8 offspring on *L. erysimi*. Mean generation time (T) varied from 45.1 days on *A. gossypii* to 30.49 days on *L. erysimi*. Similarly, both of the intrinsic rate of increase (r) and finite rate of increase (λ) were higher (0.166 and 1.181 days^{-1}, respectively), when they fed on *L. erysimi* compared to those fed on *A. gosyypii* (0.099 days^{-1} and 1.104 days^{-1}, respectively) (Table 2).

The performance of *H. convergens* was assessed by the interactive effects of two aphid species. *A. gossypii* was less palatable to *H. convergens* than *L. erysimi*. Prey quality may influence the longevity, fecundity, and survival of coccinellid (Ghafouri Moghaddam et al. 2016). Majerus and Kearns (1989) reported that quality of prey has a greater impact on the egg incubation and duration of larval instars of the seven spotted ladybird beetle, *Coccinella septempunctata* L. The development of coccinellids may be affected by the type of prey; food with low-quality delays the development, whereas high-quality or nutritional food promotes the development (Snyder et al. 2000). Obtained results showed that adult longevity of *H. convergens* was higher when those fed on *L. erysimi* as compared to *A. gossypii*. The female longevity was higher than male feeding on both aphid species and the results are comparable with the findings of Sarwar and Saqib (2010). The findings are also in line with Ali and Rizvi (2007), who reported that the duration of coccinellid adult was longer on *L. erysimi* than on *Macrosiphum rosae* (Linnaeus).

Similarly, the female fecundity is also dependent on the quality of host aphid species. In the present study, 319.7 eggs were laid when *H. convergens* was fed on *L. erysimi* and 251.0 eggs for those fed on *A. gossypii*. The prey density may also influence the fecundity rate of coccinellid females. Twenty aphids were provided to each *H. convergens* adult pair; however, Dehkordi et al. (2013) reported that the fecundity rate increased by increasing the prey density.

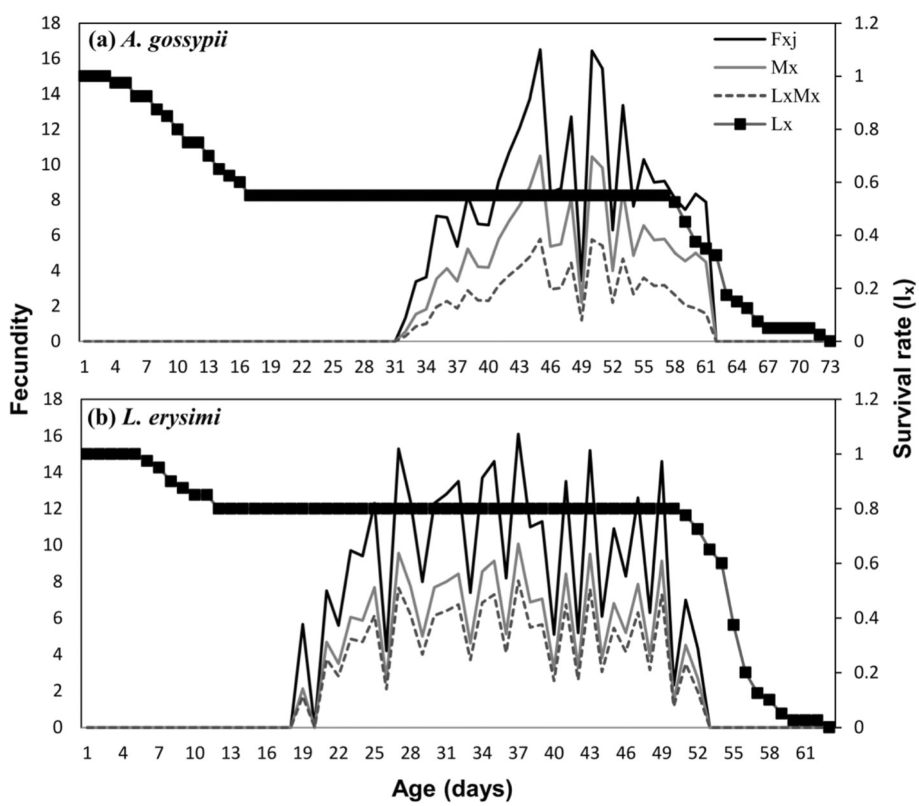

Fig. 3 Age-specific survival rate (*lx*), age-stage-specific fecundity (f_{xj}), age-specific fecundity (mx), and age-specific maternity ($l_x m_x$) of *Hippodamia convergens* fed on two aphid species

The net reproductive rate (R_o), intrinsic rate of increase (r), finite rate of increase (λ), and the survival rate of *H. convergens* were higher in case of *L. erysimi* than those fed on *A. gossypii*. The intrinsic rate of increase (r) is the most valuable parameter in the life table to compare the potential of population growth (Southwood 1966). Predators with short pre-ovipositional periods are expected to have a high r value (Lewontin 1965). In the present study, the r value for *H. convergens* was 0.099 on *A. gossypii* and 0.166 on *L. erysimi*. The r value for coccinellid beetle feeding on *A. gossypii* was reported as 0.178 by Kontodimas and Stathas (2005) and 0.187 by Dehkordi et al. (2013).

The age-stage-specific survival rate (S_{xj}) curves show that the survival rate of *H. convergens* was higher when fed on *L. erysimi* (Fig. 1). The findings are similar to the study of (Ali and Rizvi 2007) *C. septempunctata* in which maximum developmental rate was recorded on *L. erysimi* than other aphid species. Thus, the quality of prey affects the developmental rate of both immature and adult stages. The age-stage-specific life expectancy curves (E_{xj}) was illustrated in Fig. 2. Newly hatched eggs of *H. convergens* were predicted to live for 45.2 d on *L. erysimi*, and 38.78 days on *A. gossypii*. The life expectancy (E_{xj}) of an adult male was found longer than for adult females in the case of both host aphid species. The life expectancies of 37.7 for females and 39.08 for males were recorded when fed on *L. erysimi* after 16 and 17 days, respectively and were higher than values recorded for *A. gossypii* (32.14 for female at 29 days and 36.8 for the male at 27 days) (Fig. 2). The E_{xj} is that an adult is supposed to live at age x and stage j. The E_{xj} gradually reduced with the age if there was no stress (Atlihan and Chi 2008; Bailey et al. 2011). The E_{xj} of same age individuals can be changed, due to difference in the life stages of individuals (Chi and Su 2006). The f_{xj} curve showed that *H. convergens* had a higher fecundity rate on *A. gossypii* than *L. erysimi* species; however, the difference was little. The highest age-stage-specific female fecundity curve (f_{xj}) showed that 16.5 eggs on the 45th and 16.4 on the 51st days were produced, when fed on *A. gossypii*. While 15.3 eggs on the 27th, 16.1 eggs on 37th and 15.2 eggs on 45th days were produced, when female fed on *L. erysimi*. Age-specific survival rate (l_x) of *H. convergens* was higher on *L. erysimi* than *A. gossypii* host aphid species (Fig. 3).

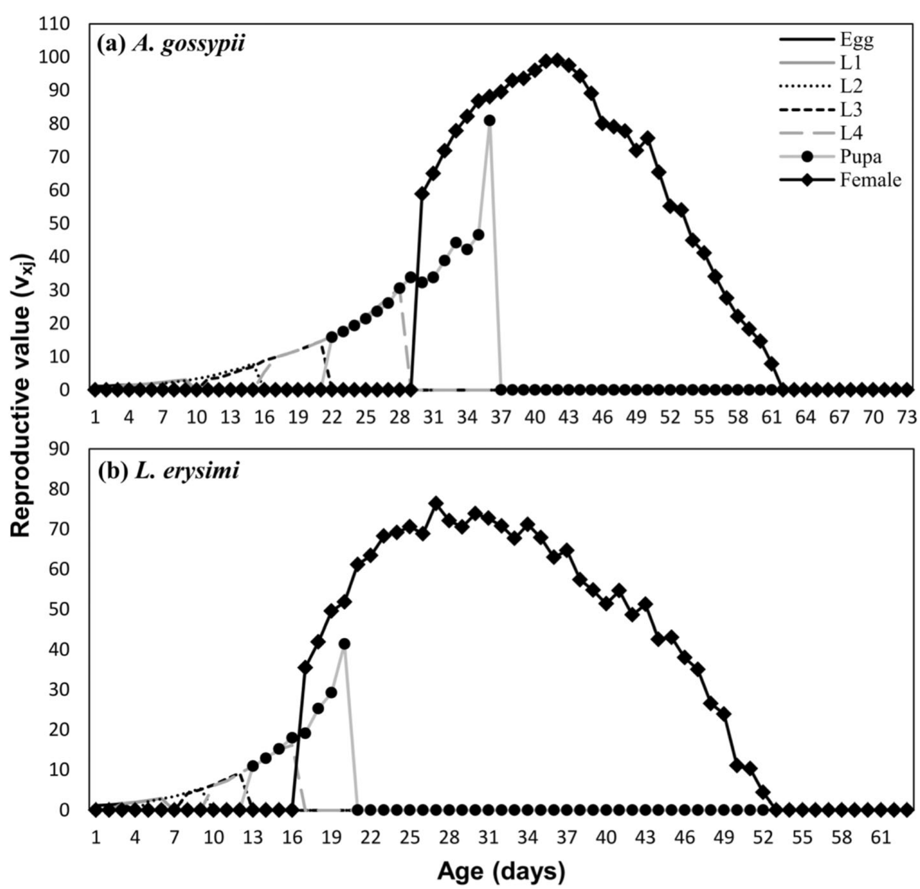

Fig. 4 Age-stage-specific reproductive rate (V_{xj}) of *Hippodamia convergens* fed on two aphid species

Age-stage-specific reproductive rates (V_{xj}) representing the contribution of an individual of age x and stage j to the future population is given in Fig. 4. The contribution of an adult female of *H. convergens* to the future population was higher relative to other life stages. V_{xj} value of adult females was recorded 76.3 after 27 days fed on *L. erysimi* and 98.2 after 42 days on *A. gossypii* species (Fig. 4). However, all the biological parameters may be influenced by various biotic and abiotic factors, including the host plant, nature of the prey species, and the environmental conditions. The high-quality food decreases the length of pre-ovipositional period (Omkar and Srivastava, 2003) and consumption of highly nutritive food support early ovariole maturation and sustained a longer oviposition period (Honek 1980).

Conclusion

Conclusively, aphid species influenced the demographic parameters of *H. convergens. L. erysimi* was a suitable prey than *A. gossypii* where *H. convergens* had good development and demographic parameters. The present findings could be useful for mass rearing of *H. convergens* predator.

Abbreviations

S_{xj}: Age-stage-specific survival rate; V_{xj}: age-stage reproductive value; f_{xj}: age-stage-specific fecundity; E_{xj}: Age-stage life expectancy; l_x: Age-specific survival rate; m_x: Age-specific fecundity; $l_x m_x$: Age-specific net maternity; R_o: Net reproductive rate; r: Intrinsic rate of increase; λ: Finite rate of increase; T: Mean generation time

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Authors' contributions

M Arshad MI Ullah planned and designed the project and experimental layout. MI Khan, U Shahid, M Abrar, and MM Niaz performed the experiment. M Tahir and M RIzwan performed the statistical analysis. The manuscript was prepared by M Arshad and reviewed by MI Ullah and M Rizwan. All authors read and approved the final manuscript.

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Availability of data and materials

Data will not be shared

Ethics approval and consent to participate

Not applicable

Consent for publication

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Competing interests

The authors declare that they have no competing interests

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