Demographic parameters of *Coccinella septempunctata* L. against *Macrosiphum euphorbiae* (Thomas) on tomato

PRIYANKA SHARMA*[1], PREM LAL SHARMA[1], SUBHASH CHANDER VERMA[1]
[1]Department of Entomology, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan- 173230, INDIA
*Corresponding author Email: ps366502@gmail.com

Abstract: The seven-spotted ladybird beetle, *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) is a polyphagous destructive predator with cosmopolitan distribution. The present study aimed to study the demographic parameters of *C. septempunctata* on different instars of potato aphid, *Macrosiphum euphorbiae* (Thomas) (Homoptera: Aphididae) on tomato crop. The pre-adult period was the longest on second instar which is significantly at par with fourth instar while the shortest on third instar of *M. euphorbiae*. The population growth parameters like gross reproductive rate (GRR), net reproductive rate (R_o), intrinsic rate of increase (r) and true generation time (T) were evaluated. The GRR was highest on third instar while lowest on first instar which is statistically different from each other. *C. septempunctata* females reared on third instar of *M. euphorbiae* had the highest fecundity which is statistically different from first and second instar. It was concluded that the *C. septempunctata* possesses good attributed qualities of biocontrol agent against *M. euphorbiae* and can be exploited as one of promising biological control agent for the protection of plant against the potato aphid.

Keywords: *Coccinella septempunctata, Macrosiphum euphorbiae,* Demographic parameters, Life table
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1. Introduction

Aphids (Hemiptera: Aphididae) are among the most important crop pests with complex life cycle (Bass *et al*., 2014). Among aphids, *Macrosiphum euphorbiae* Thomas, native to North America, is a polyphagous pest infesting a large number of hosts in the family Solanaceae including tomato (Zandi-Sohani *et al.*, 2018). The pest damages the crops not only because of the direct effects of high population densities but also as vector of several plant viruses (van Emden and Harrington, 2007). The insecticides are most commonly used to control this aphid, however, serious environmental consequences like pest resurgence, secondary pest outbreaks, killing of non-target organisms, insecticide residues, insecticide resistance, etc. have increased interest to explore eco-friendly and sustainable methods to manage this pest. Biological control could, therefore, be a viable option for its management (Safaei *et al.*, 2016). The use of natural enemies with other control strategies poses a valid substitute to control pest population in the ecosystem (Javed *et al*., 2018). So, the development of IPM seeks to upsurge natural control by conservation and preservation of entomophagous fauna (Rogers *et al*., 2007).

The polyphagous predators like coccinellids, are effective biological control agents of several aphid pests which need to be evaluated against this pest. The seven-spotted ladybird beetle, *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) is a polyphagous destructive predator with cosmopolitan distribution *C. septempunctata* counted as an ecologically and economically important predator which play important role in maintaining equilibrium of sap-sucking insect population (Boopathi *et al.,* 2017). The principal food of *C. septempunctata* is aphids, whereas honeydew, pollen, nectar, mildew, mites and coccids are considered as secondary foods (Deligeorgidis *et al.,* 2005).

Before using *C. septempunctata* as a biological control agent in the field, it is necessary to study the efficacy under laboratory conditions. Effectiveness of a biological control agent can be better understood by studying its demographic parameters against the target pest. There are two types of life table *i.e.* age-specific and stage-specific life table. In insect ecology, the age-specific is the most common type which is based on survival and reproduction of single cohort of individuals (Sahito *et al.,* 2017). The life table provides comprehensive description on growth, development, survival, longevity, and reproduction of insect population. The fertility table demonstrates reproduction potential of female insects at different times (Chi, 1988). It is a better model for investigating the characteristics of life history due to sexual dimorphism, higher capacity to reproduce, easy availability, simple laboratory maintenance, and shorter life cycles (Omkar and Mishra, 2005). The various biotic and abiotic factors influence the life parameters of bio-control agent (Jervis *et al.,* 2005). Among the biotic factors, the growth and development of the predator depends on the quality and abundance of the prey. The development period usually increases and reproductive parameters decreases if prey is unavailable or scarce or of poor quality (Hodek *et al.*, 2012). Therefore, keeping in view the above facts the present study demographic parameters of *C. septempunctata* against potato aphid on tomato will be carried out.

2. Material and methods
Maintenance of insect cultures

2.1 Potato aphid, *M. euphorbiae*

The pure culture of potato aphid, *M. euphorbiae* was maintained on tomato seedlings raised in pots in the Biocontrol Research Laboratory of Department of Entomology, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh). *M. euphorbiae* was collected from the field and released on tomato plants. The exhausted and dried tomato and potato plants were replaced periodically with fresh seedlings/plants to ensure continuous supply of the aphid for the experiments.

2.2 Predator, *C. septempunctata*

C. septempunctata were collected from the field and confined in glass jars along with their prey for feeding and oviposition. Freshly laid eggs were kept in petri dishes for hatching. Newly emerged larvae were separated and transferred to glass vials or petri dishes along with their prey. These larvae were checked daily and food changed daily till they reach the pupal stage. Pupae were collected carefully and kept in jars for the emergence of adults. *C. septempunctata* adults were reared on the prey for one generation before using for the experiments.

2.3 Developmental biology of *C. septempunctata*

Developmental biology of *C. septempunctata* was studied on the different developmental stages of *M. euphorbiae* on tomato at 25°C and 70 ± 5 per cent relative humidity and 14L: 10D photoperiod. Tomato seedlings infested with the aphid were exposed to the adults of each predator separately in cages for oviposition. Eggs laid on a single day were transferred separately in single Petri plates (10cm diameter × 1.5 cm height) for hatching. The eggs were picked up with the help of a camel hair brush. After hatching, the first, second, third, fourth instar grubs and adults were provided with potato aphids daily, respectively until reaching the pupal stage. The fecundity of coccinellid females was recorded on different instars of *M. euphorbiae*. The fecundity of chrysopid females was determined by providing them mixture of 10 per cent honey solution and protenex.

Observations on the development time of egg, larvae, pupae, adult longevity and fecundity were recorded. The longevity of the male and female was recorded by enclosing them in glass chimneys (10× 14.5 cm) and providing them with 10 % honey solution.

2.3 Population growth parameters of *C. septempunctata*

For studying the population growth parameters, fertility tables were constructed. One pair of *C. septempunctata* was released in a glass chimney (10 × 14.5 cm) along with aphid infested leaf placed on small plastic Petri plate and a cotton swab soaked with 10 per cent honey solution as feeding material. After the egg laying, the eggs were picked up with the help of a camel hair brush and placed individually on fresh host plant leaves and transferred to the Petri plates. The old batch of aphids was replaced with a new batch and the process continued until all adults died. The life history data of individuals was examined by using TWO-SEX-MS Chart program based on the age stage, two sex life table theories (Chi, 2018). Following population growth parameters were studied by using the following variables:

s_{xj} = probability that a newly laid egg can survive to age *x* and stage *j*.

f_{xj} = number of hatched eggs produced by female adult at age *x*.

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

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

1. Cumulative reproductive rate (R_x)

$$R_x = \sum_{i=0}^{x} l_i m_i$$

2. Net reproductive rate (R_0)

$$R_0 = \sum_{x=0}^{\infty} \sum_{j=1}^{m} s_{xj}\, f_{xj}$$

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

3. True intrinsic rate of increase (*r*)

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

4. Mean generation time (*T*)

$$T = \frac{lnR_0}{r}$$

5. Finite rate of increase (λ)

$$\lambda = e^{r}$$

6. Doubling time (*DT*)

$$DT = {log_e 2}/{r}$$

7. Age-stage specific life expectancy (*e_{xj}*)

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

8. Age-stage Reproductive value (*v_{xj}*)

$$v_{xj} = \frac{e^{r(x+1)}}{s_{xj}}\sum_{i=x}^{\infty} e^{-r(i+1)}\sum_{y=j}^{m} s'_{iy}f_{iy}$$

3. Results and Discussion

3.1 Developmental biology of *C. septempunctata* against different instars of *M. euphorbiae* on tomato

The developmental biology of *C. septempunctata* was studied on the first, second, third and fourth instars of *M. euphorbiae* on potato. Biological parameters of different developmental stages, except the egg stage of the predator varied significantly. The average incubation period of the predator was 2 days on each prey stage tested. The seven *C. septempunctata* developed through four grub stages on all the prey stages. The average development time from egg to adult was 18.50, 19.82, 17.65 and 19.59 days on the first, second, third and fourth instars of *M. euphorbiae*, respectively which differed significantly. The first, second, third and fourth instar grubs developed in 3.00, 2.00, 2.28 and 4.62 days on first instars of prey; 2.96, 2.68, 2.72 and 4.47 days on second instar of prey; 2.92, 2.59, 2.56 and 3.76 days on third instar of prey; and 3.28, 2.55, 2.88 and 4.06 days fourth instar of prey, respectively which differed significantly. The mean duration of pupal period was 4.62, 4.76, 3.82 and 4.41 days, respectively on first, second, third and fourth instars of *M. euphorbiae*. The female adults lived for 41.75, 51.12, 51.13 and 61.38 days, respectively while male adults lived for 37.12, 38.56, 49.89 and 48.78 days, respectively. *C. septempunctata* had a pre-oviposition period of 5.50, 7.00, 7.75 and 7.88 days, respectively while oviposition period of 13.00, 16.36, 25.62 and 22.88 days, respectively against all the four instars of *M. euphorbiae* (Table 1).

The present study revealed that the total larval duration and pupal period of *C. septempunctata* instars on first, second, third and fourth instars of potato aphid was in accordance with the findings of Khan *et al*. (2009) who reported that all instars of *C. septempunctata* completed its larval duration in 12.60days on *Rhopalosiphum maidis* and 11.80days on *Lipaphis trifolii* but took more time on *Aphis nerii* (14.60 days) followed by *Lipaphis erysimi* (14.04 days), *Schizaphis graminum* (14.00 days). Wang *et al.* (2022) observed that the first, second, third and fourth larval instar complete the duration in 2.21, 2.23, 2.19 and 2.19 days, respectively on *Sitobion miscanthi* which corroborate with the our findings. The male and female longevity recorded in present study was similar to the findings of Khan *et al*. (2009) but higher as reported by Wang *et al.* (2022). Also, the same results for larval development were reported by the Rashed *et al.* (2014) but oviposition period was higher on the aphid, *Aphis craccivora.*

Table 1: Developmental biology of *C. septempunctata* against different instars of *M. euphorbiae* on tomato

Parameters (Days)	Prey stage			
	1st instar	2nd instar	3rd instar	4th instar
	Estimate±SE	Estimate±SE	Estimate±SE	Estimate±SE
Egg period	2.00±0.00[a]	2.00±0.00[a]	2.00±0.00[a]	2.00±0.00[a]
1st instar	3.00±0.00[b]	2.96±0.04[c]	2.92±0.08[bcd]	3.28±0.15[a]
2nd instar	2.00±0.00[b]	2.68±0.19[a]	2.59±0.12[a]	2.55±0.17[a]
3rd instar	2.28±0.16[ab]	2.72±0.21[a]	2.56±0.15[a]	2.88±0.18[a]
4th instar	4.62±0.13[a]	4.47±0.13[a]	3.76±0.12[bc]	4.06±0.14[b]
Pupal period	4.62±0.13[a]	4.76±0.12[a]	3.82±0.09[c]	4.41±0.12[ab]
Pre-adult period	18.50±3.36[b]	19.82±0.30[a]	17.65±0.15[c]	19.59±0.29[a]
Male longevity	37.12±3.53[bc]	38.56±1.62[b]	49.89±2.52[a]	48.78±3.02[a]
Female longevity	41.75±2.43[c]	51.12±2.39[b]	51.13±2.46[a]	61.38±1.55[a]
Adult preoviposition period	5.50±0.19[c]	7.00±0.27[b]	7.75±0.16[a]	7.88±0.23[a]
Oviposition days	13.00±1.22[bc]	16.36±1.41[b]	25.62±1.53[a]	22.88±0.77[a]
Total preoviposition period	23.75±0.41[c]	27.38±0.42[a]	25.50±0.19[b]	28.12±0.40[a]

Mean values in a row superscripted with same letter do not differ significantly at p=0.05.

3.2 Life-fertility tables of *C. septempunctata* against first instar of *M. euphorbiae* on tomato

Life-fertility tables of *C. septempunctata* were constructed when reared on the first, second, third and fourth instar of *M. euphorbiae* on tomato and the results thus obtained are presented below:

When *C. septempunctata* fed on first instar of *M. euphorbiae*, the females oviposited at the pivotal age of 23 days with an average of 2.56 eggs per female and age-specific survival rate of 0.64 per cent while the age-specific maternity on 23rd day was 1.64 eggs per female. The age specific fecundity escalated steadily and was maximum (6.27 eggs/female) at the pivotal age of 25 days. The oviposition fluctuated between 0.50 and 6.27 eggs per female. Similarly, the age specific maternity fluctuated between 0.12 and 3.76 eggs per day (Fig 1). Due to variable development rates of different individuals, significant overlaps between age-stage specific survival curves were noted. The age-specific reproductive value (v_x) for the newly laid egg was 1.13 and increased till the pivotal age of 24 days (v_x=30.88). At this age, the age stage reproductive value of adult female (v_{xj}=57.90) (Fig 2) was also maximum and then started to decline and reached 0 at the age of 44 days.

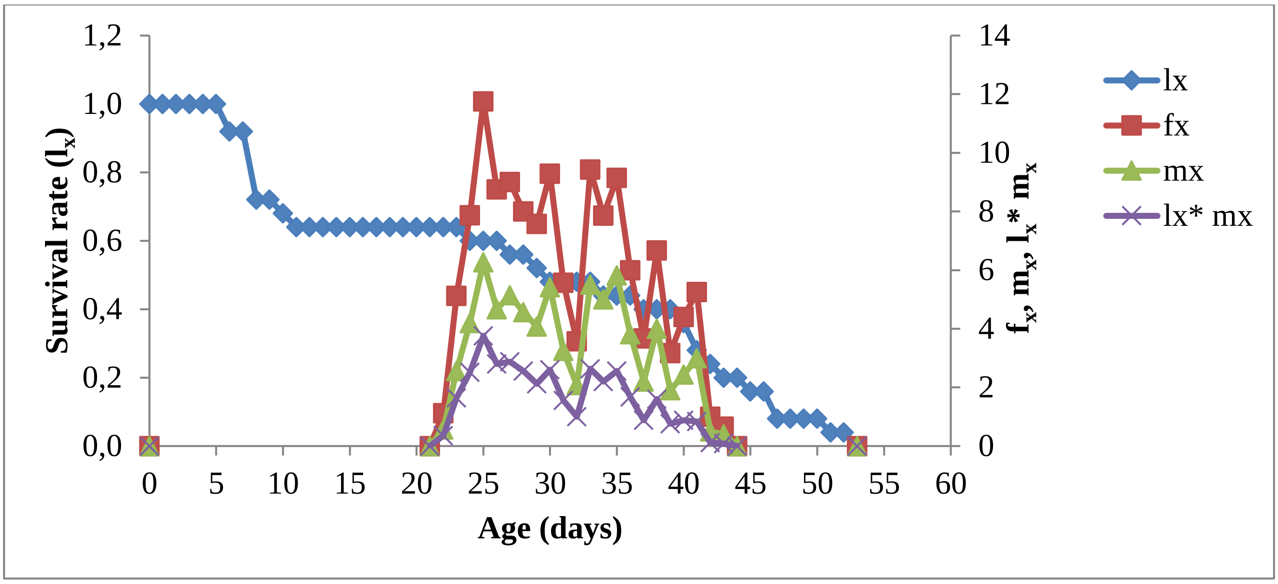

Fig 1. Age-specific survival rate (l_x), age-stage specific fecundity (f_x), age specific fecundity (m_x), and age specific maternity (l_x*m_x) of *C. septempunctata* on 1st instar against *M. euphorbiae* on tomato

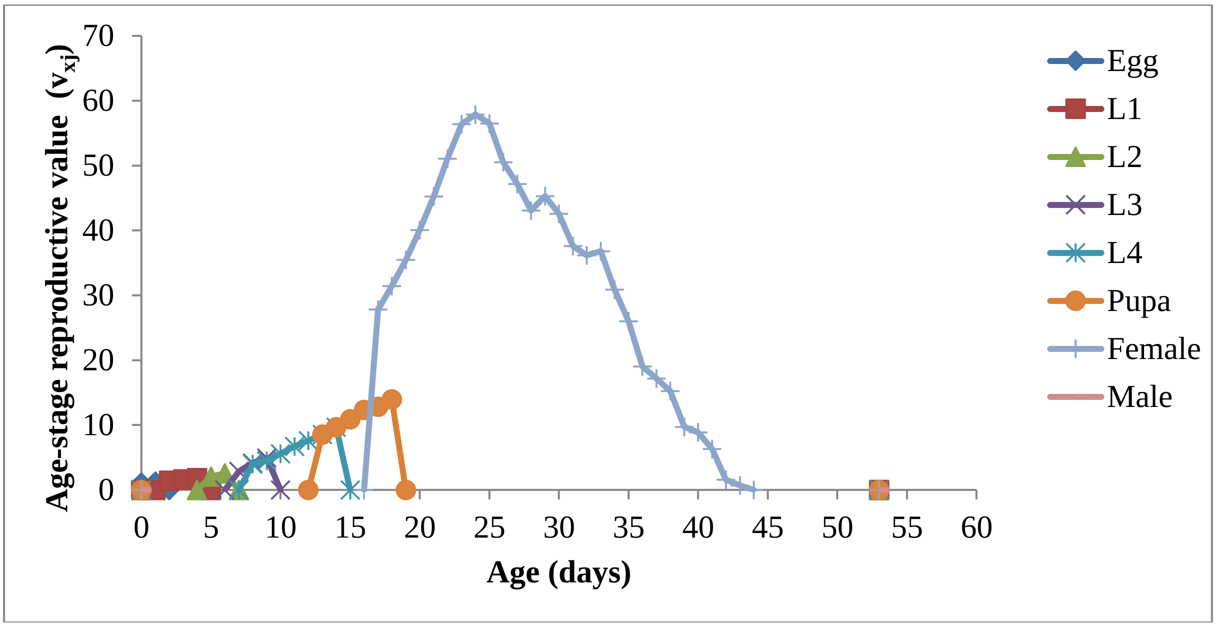

Fig 2. Age-stage reproductive value (v_{xj}) of *C. septempunctata* on 1st instar of *M. euphorbiae* on tomato

3.3 Life-fertility tables of *C. septempunctata* against second instar of *M. euphorbiae* on tomato

The females of *C. septempunctata* oviposited at the pivotal age of 26 days with an average of 2.00 eggs per female and age-specific survival rate of 0.68 per cent while the age-specific maternity on 26th day was 1.36 eggs per female when reared on second instar of *M. euphorbiae*. The oviposition continued till 56th day and the average age specific fecundity oscillated between 2.00 and 13.33 eggs per female. Similarly, the age specific maternity fluctuated between 0.40 and

4.76 eggs per day (Fig 3). The curves of age-stage specific survival rate overlapped significantly demonstrating different development rates of individuals. On the day of egg hatching the value of age-specific reproductive value (v_x) was 1.12 and increased till the pivotal age of 32 days (v_x=44.79). At this age, the age-stage reproductive value (v_{xj}) of adult female was 89.59 (Fig 4) was also maximum and at the pivotal age of 56 days reached to 0.

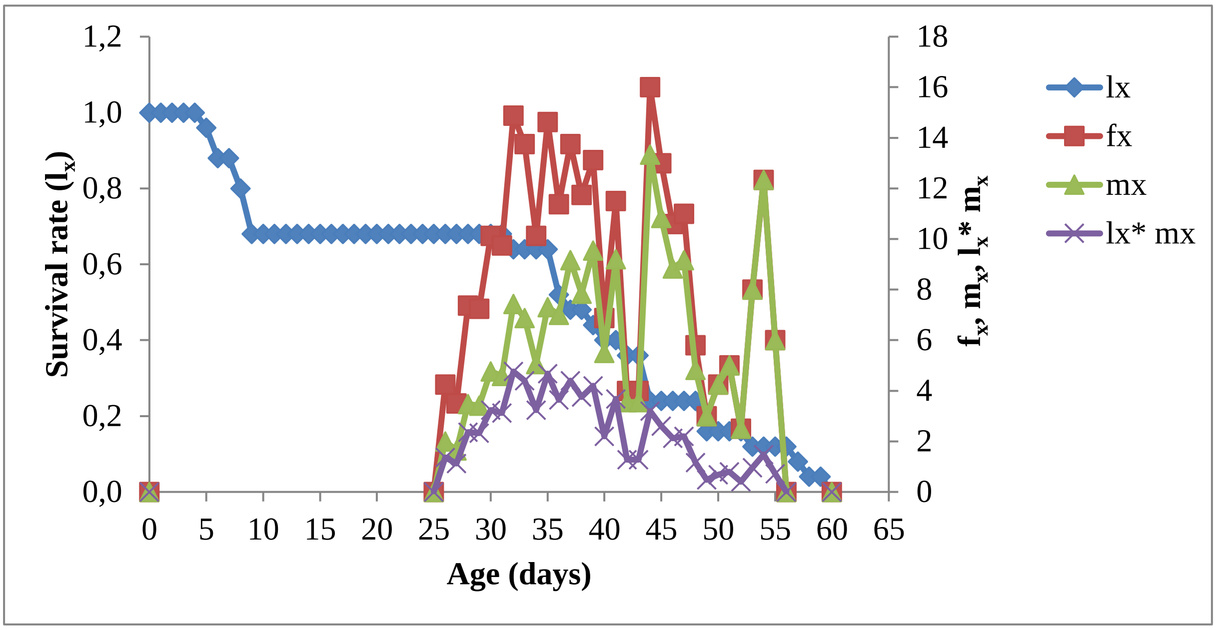

Fig 3. Age-specific survival rate (l_x), age-stage specific fecundity (f_x), age specific fecundity (m_x), and age specific maternity (l_x*m_x) of *C. septempunctata* on 2nd instar of *M. euphorbiae* on tomato

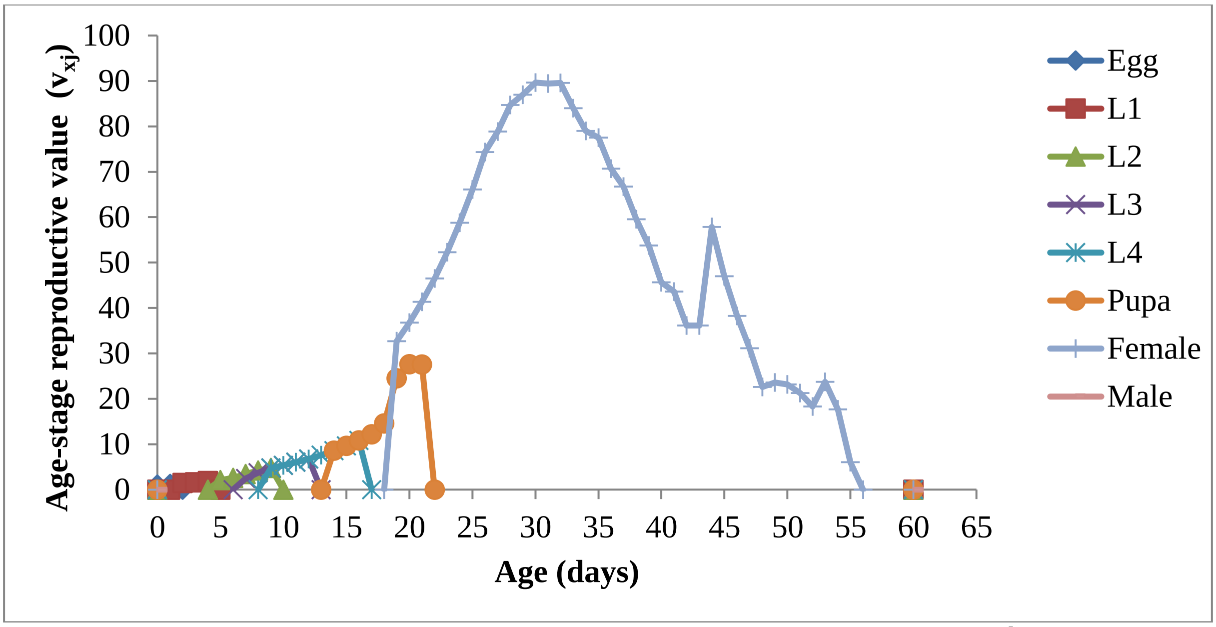

Fig 4. Age-stage reproductive value (v_{xj}) of *C. septempunctata* on 2nd instar of *M. euphorbiae* on tomato

3.4 Life-fertility tables of *C. septempunctata* against third instar of *M. euphorbiae* on tomato

C. septempunctata completed the pre-adult period in 25 days with 0.68 per cent survival when fed on third instar of *M. euphorbiae.* The age-specific fecundity and age-specific maternity were 2.94 eggs per female and 2.00 eggs per female, respectively on the first day of emergence. The oviposition continued till 71st day and the average age specific fecundity oscillated between 2.06 and 15.00 eggs per female. The age specific fecundity increased gradually and was maximum (15.00 eggs/female) at the pivotal age of 68 days (Fig 5). At birth, the age-specific reproductive value (v_x) for predator when reared on third instar of *M. euphorbiae* was 1.13 which increased to 54.74 on 38th day of pivotal age. At this age, the maximum age stage reproductive value of adult female (v_{xj}=109.47) (Fig 6) was recorded and then decline in the value observed which reached to 0 at the age of 71 days.

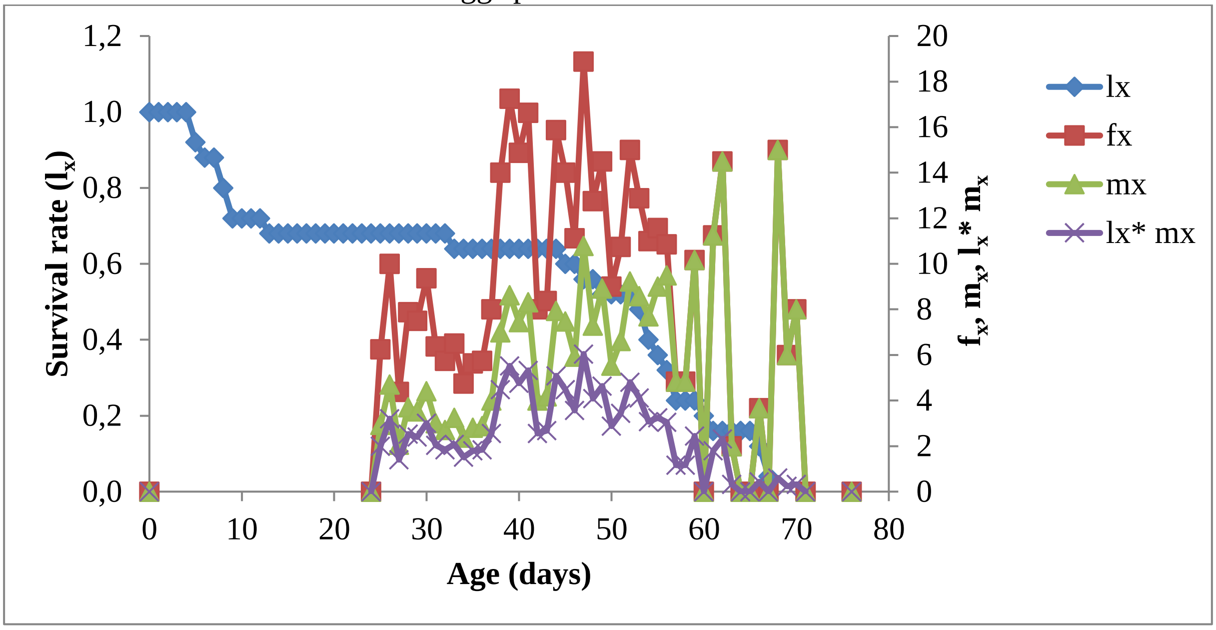

Fig 5. Age-specific survival rate (l_x), age-stage specific fecundity (f_x), age specific fecundity (m_x), and age specific maternity (l_x*m_x) of *C. septempunctata* on 3rd instar of *M. euphorbiae* on tomato

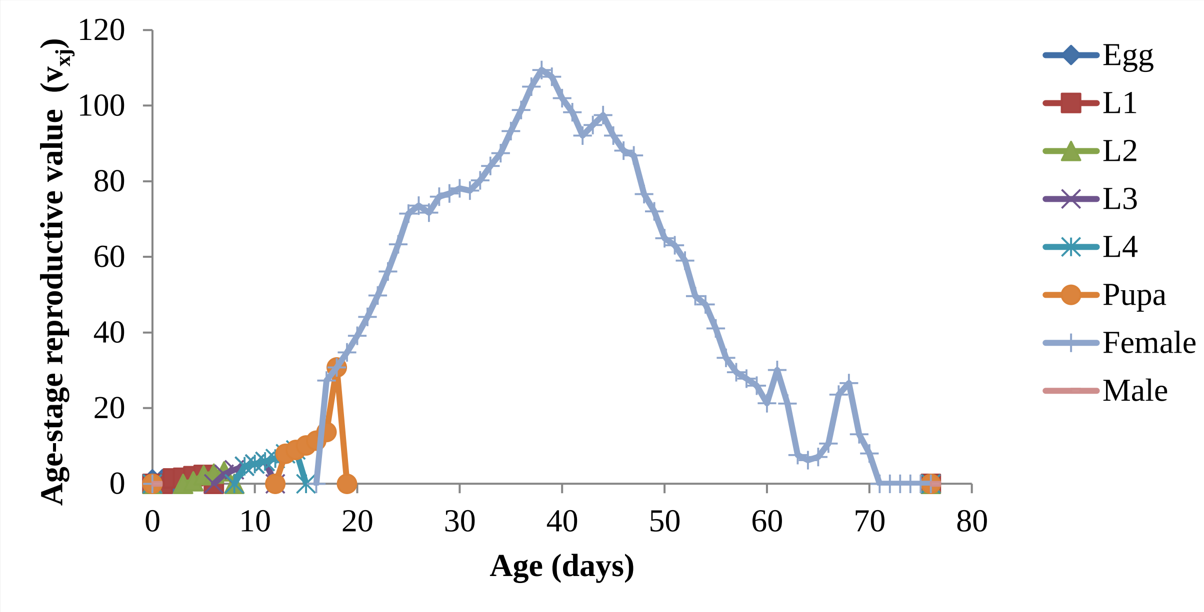

Fig 6. Age-stage reproductive value (v_{xj}) of *C. septempunctata* on 3rd instar of *M. euphorbiae* on tomato

3.5 Life-fertility tables of *C. septempunctata* against fourth instar of *M. euphorbiae* on tomato

The egg laying of *C. septempunctata* reared on fourth instar of *M. euphorbiae* started at the pivotal age of 26 days with an average of 0.59 eggs per female and age-specific survival rate of 0.68 per cent while the age-specific maternity on 26th day was 0.40 eggs per female. The maximum age specific fecundity was 10.43eggs/female at the pivotal age of 46days. The average age specific fecundity oscillated between 0.59 and 10.43 eggs per female and oviposition continued till 62 days. Likewise, the age specific maternity fluctuated between 0.40 and 5.84 eggs per day (Fig 7). The age-specific reproductive value (v_x) was 1.12 at birth and increased to 64.28 on the pivotal age of 42 days. The age-stage reproductive value of adult female was also maximum (v_{xj}=120.53) on 62 day of pivotal age (Fig 8) and then started to decline.

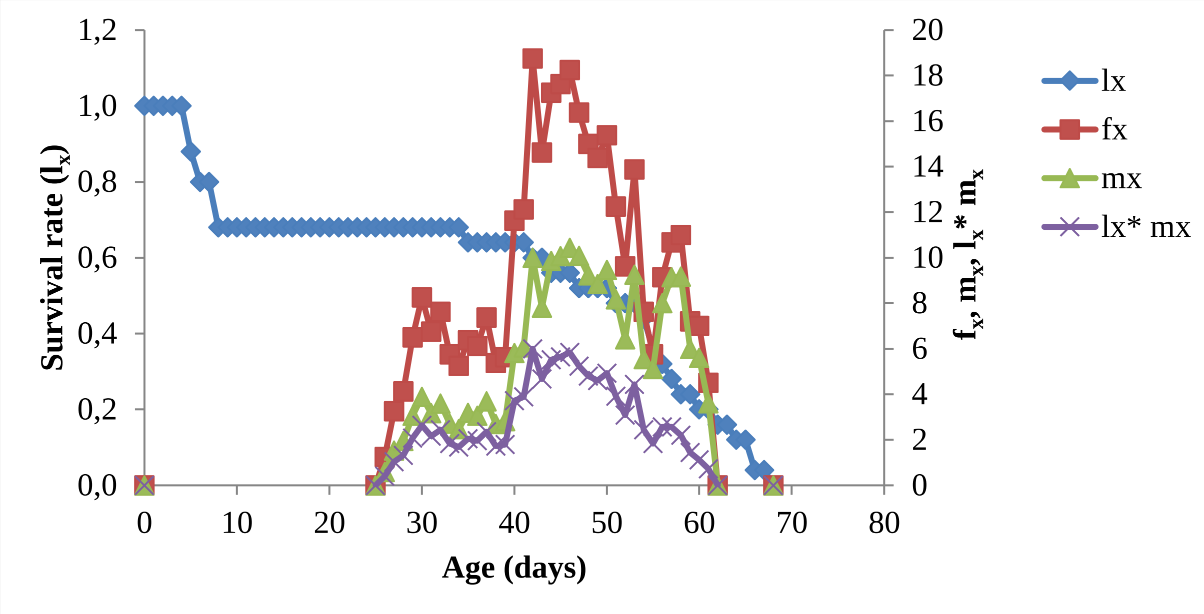

Fig 7. Age-specific survival rate (l_x), age-stage specific fecundity (f_x), age specific fecundity (m_x), and age specific maternity (l_x*m_x) of *C. septempunctata* on 4th instar of *M. euphorbiae* on tomato

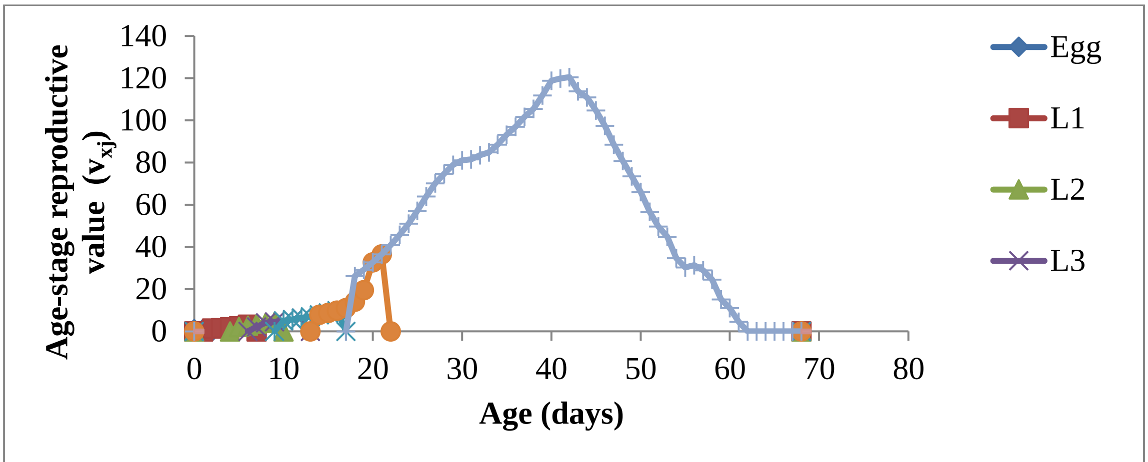

Fig 8. Age-stage reproductive value (v_{xj}) of *C. septempunctata* on 4th instar of *M. euphorbiae* on tomato

3.6 Population growth parameters of *C. septempunctata* against different instars of *M. euphorbiae* on tomato

Population growth parameters of *C. septempunctata* on varied stages of *M. euphorbiae* were calculated using fertility tables. The gross reproductive rate of *C. septempunctata* was 77.38, 190.01, 266.68 and 212.03 offspring per individual on first, second, third and fourth instar of *M. euphorbiae*, respectively. The net reproductive rate of *C. septempunctata* was 38.04, 71.84, 116.80 and 106.64 offspring per individual on respective instars of *M. euphorbiae*, respectively. During the reproductive period each female laid an average of 118.88, 224.50, 365.00 and 333.25 eggs on four instars of potato aphid, respectively which differed significantly. The population of *C. septempunctata* completed a generation in 29.95, 36.42, 39.55 and 41.76 days with an intrinsic rate of increase of 0.121, 0.117, 0.121 and 0.112 offspring per individual per day and finite rate of increase of 1.129, 1.125, 1.128 and 1.118times per day on different instars of *M. euphorbiae*, respectively. The growth parameters revealed that the population of *C. septempunctata* would double its population in 5.71, 5.91, 5.76 and 6.19 days on various instars of *M. euphorbiae*, respectively.

The population growth parameters of *C. septempunctata* evaluated against *M. euphorbiae* are in accordance with the results of Khan *et al*. (2009) who reported the fecundity of 367 eggs on *L. erysimi*, 347 eggs on *S. graminum*, 304 eggs on *R. maidis* and 273 eggs on *T. trifolii* and Wang *et al.* (2022) recorded less fecundity i.e. 39.46 eggs on *S. miscanthi*. The findings of Wang *et al.* (2022) are in contradiction with our findings who reported net reproductive rate (R_o), intrinsic rate of increase (r) and finite rate of increase (λ) of 0.2335 day^{-1}, 1.2630 day^{-1} and 34.21 offspring, respectively.

Table 43: Population growth parameters of *C. septempunctata* against different instars of *M. euphorbiae* on tomato

Parameters	Prey stage			
	1st instar	2nd instar	3rd instar	4th instar
	Estimate±SE	Estimate±SE	Estimate±SE	Estimate±SE
Fecundity (eggs/predator)	118.88±12.98^{c}	224.5±21.71^{b}	365.00±11.67^{a}	333.25±11.57^{a}
Gross reproductive rate (GRR) (offspring/individual)	77.38±19.67^{b}	190.01±44.83^{a}	266.68±49.55^{a}	212.03±42.73^{a}
Net reproductive rate (R_o) ((offspring/individual))	38.04±11.72^{ab}	71.84±21.96^{a}	116.8±34.24^{a}	106.64±31.20^{a}
Intrinsic rate of increase (r) (offspring/individual/day)	0.121±0.011^{a}	0.117±0.009^{a}	0.121±0.009^{a}	0.112±0.008^{a}
True generation time (T) (days)	29.95±0.68^{d}	36.42±0.93^{c}	39.55±0.54^{b}	41.76±0.60^{a}
Finite rate of increase (λ) (offspring/day)	1.129±0.013^{a}	1.125±0.01^{a}	1.128±0.01^{a}	1.118±0.009^{a}
Doubling time (DT) (days)	5.71±0.68^{a}	5.91±0.55^{a}	5.76±0.51^{a}	6.19±0.54^{a}

Mean values in a row superscripted with same letter do not differ significantly at p=0.05.

4. Conclusion

The demographic parameter studies are of fundamental significance to develop a biological control programme to control potato aphid, *M. euphorbiae*. It was concluded that the *C. septempunctata* possesses good attributed qualities of biocontrol agent against *M. euphorbiae* and can be exploited as one of promising biological control agent for the protection of plant against the potato aphid.

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