Arch Biol Sci. 2018;70(4):737-747 https://doi.org/10.2298/ABS180620038M

Suitability of *Aphis gossypii* Glover, *Aphis fabae* Scop. and *Ephestia kuehniella* Zeller eggs for the biology and life-table parameters of *Adalia decempunctata* (L.) (Coleoptera: Coccinellidae)

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Received: June 20, 2018; **Revised**: August 18, 2018; **Accepted**: August 28, 2018; **Published online**: September 20, 2018

Abstract: *Adalia decempunctata* (L.) is a common predator in agroecosystems and the natural environment. Its biology and life table were studied in nymph/adult hosts of *Aphis gossypii* Glover, *Aphis fabae* Scop. and on the eggs of *Ephestia kuehniella* Zeller. Raw data of all individuals of *A. decempunctata* were analyzed using the age-stage, two-sex, life-table theory. The results of this study indicate a shortest immature developmental period (IDP) of *A. decempunctata* feeding on eggs of *E. kuehniella* (18.33 days) and the longest on *A. fabae* (21.82 days). The longest longevity was, however, after feeding on *A. gossypii*. The fecundity rate of females on *E. kuehniella* was the highest (2405.12 eggs/female). The intrinsic rates of increase of *A. decempunctata* were 0.177, 0.171 and 0.155 day^{-1} when feeding on *A. gossypii, E. kuehniella* eggs and *A. fabae*, respectively. The highest finite rates of increase (λ) were 1.193 and 1.187 day^{-1} when reared on *A. gossypii* and *E. kuehniella*, respectively. The mean generation time for *A. fabae* (41.40 days) was significantly higher compared to other hosts. The results of this study showed that the quality of the host influenced to a great extent the rate of energy reserves in emerged females. We conclude that all three host species can be considered as essential preys. These hosts influence the larval developmental period and reproduction in adult *A. decempunctata*; however, the results of the biochemical assays pointed to *A. gossypii* and *E. kuehniella* eggs as preferred hosts.

Key words: *Adalia decempunctata*; biological control; aphid; population growth parameters

INTRODUCTION

The ten-spotted lady beetle *Adalia decempunctata* (L.) originated in the Palaearctic region and it has been reported in Europe, North Africa and West Asia [1, 2]. This eurytopic species inhabits broadleaf forest trees [3] and orchards infested with aphids [1, 4]. The insect is a common predator of aphids in agroecosystems and natural habitats. *A. decempunctata* is mostly concentrated on trees and is rarely observed in shrubs and grasses [5]. The host range of *A. decempunctata* includes aphids [1, 2], mealybugs and psyllids [6,7]. There are reports on the presence of this predator on pest-infected fruit and forest trees in Iran [8-10].

Aphids, including *Aphis gossypii* and *Aphis fabae*, belong to a diverse group of agricultural and horticultural pests. These pests are predominantly found in America, Europe, Asia and other temperate regions. Aphids damage plants directly by sucking their sap or they indirectly cause damage by introducing viruses [11,12]. Aphidophagous lady beetles are commonly employed for biological control of aphids [13]. The undesirable environmental impacts of some non-native biological control agents [14] has changed the attitudes towards the use of the predatory potentials of native species [15]. Therefore, it is of considerable importance to identify the biological traits of every lady beetle on suitable hosts. Such studies help scien-

How to cite this article: Mojib-Haghghadam Z, Jalali Sendi J, Zibaee A, Mohaghegh J. Suitability of *Aphis gossypii* Glover, Aphis fabae Scop. and *Ephestia kuehniella* Zeller eggs for the biology and life-table parameters of *Adalia decempunctata* (L.) (Coleoptera: Coccinellidae). Arch Biol Sci. 2018;70(4):737-47.

tists select the proper food sources for them in order to implement the results for practical applications. Based on quantitative data such as developmental parameters, survival in larvae and reproduction of adults, the prey can be categorized as either essential or alternative [1,16-18]. Essential prey satisfies all of the requirements for growth, development and reproduction of predators, whereas alternative prey acts as an energy source for the survival of the predator in the absence of essential prey [1,19]. Studying the range of essential prey for lady beetles is an important step in understanding their potential as biological control agents against specific pests [20].

Mass rearing of aphidophagous predators is usually done on aphids that require a tritrophic system to produce the predators, prey and the prey's host plants. Problems of discontinuity that can occur at one of these levels hinders production and can lead to high market prices of predators [15]. Hence, the selection of suitable food sources for mass production of natural enemies is very important. Eggs of lepidopterans such as *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae), the Mediterranean flour moth, are commonly used as food sources in mass production of some predators, including lady beetles [21,22]. Demographic studies have been used to determine the potential of natural enemies in biological control programs [23-25]. The intrinsic rate of increase of a population is the best descriptive parameter for population growth of certain species. Using this parameter, one host can be selected as the most suitable prey for a chosen lady beetle species to initiate a biological control program [26].

Using dominant native species in biological control programs are greatly appreciated. Being an important predator of aphids on forest and fruit trees, *A. decempunctata* was considered for this study. Examination of current literature indicates there have been no studies that cover the various biological characteristics of this important predator. Therefore, the current study was undertaken in order to throw some light on the life-table traits after rearing on three different hosts. We also attempted to find a possible relationship that may exist with energy reserves in the hosts. These results may contribute to an improvement to rearing methods of *A. decempunctata*, as well as to our better understanding of its predatory potentials as an effective biological control agent.

MATERIALS AND METHODS

Stock culture

Fava beans (*Vicia fabae* L.) and cucumber (*Cucumis sativus* L.) seeds were separately sown in pots 20 cm in diameter and were maintained in a greenhouse at 24±4°C, 70±10% relative humidity (RH) and a 14:10 h light:dark (L:D) photoperiod. The adults of *A. fabae* and *A. gossypii* that were free of parasitoids were collected from the cucumber and fava bean farms of Pir Bazar village (37°21'16.08" N, 49°25'54.72" E) in Guilan province, Iran. The aphids were released separately onto plants growing under the conditions described above. After initial release, the development of the aphids was monitored daily. The aphid nymphs were transferred to new plant cultures with a fine brush before flying forms appeared. After onset of parthenogenesis, the released adults were removed from the colony and aphids of cohort age were obtained.

To initiate *A. decempunctata* colonies, adults were directly collected from the pomegranate trees infested with *Aphis punicae* Passerini during spring. They were then placed in transparent plastic culture containers (12×10×6 cm^3) and maintained in a growth chamber set at 24±1°C, 65±5% RH and 16:8h L:D photoperiod. A hole (3 cm in diameter) was made on the lid of each container and was covered with a piece of mesh for ventilation. Egg clusters obtained from this population were separately reared on *A. gossypii*, *A. fabae* and *E. kuehniella* eggs. The adults emerging from these eggs were used to initiate the colony in the laboratory. Fresh eggs (less than 24 h in age) of the flour moth were stored at -18°C for a maximum of 2 months until use. They were obtained (in 30 g packs) every two months from an insectarium in the city of Gorgan (36°50′19″N 54°26′05″E) in Golestan province, Iran.

Life table of *A. decempunctata*

Three groups of eggs of *A. decempunctata* for each host (n=100), with lifespans of less than 24 h were separated. The eggs were then placed in plastic Petri dishes (8 cm in diameter) in a growth chamber (24±1°C, 65±5% RH and a photoperiod of 16:8h L:D). After hatching, one-day-old larvae were individually transferred to plastic containers (8×6×4 cm^3) with a 3-cm hole on the lid, covered with a piece of mesh. The first fourth-instar larvae of *A. decempunctata* were separately reared on their specific host up to the pupal stage. The emerged adults were weighed and then transferred to Petri dishes (10 cm in diameter) in order to mate. The mated females were placed in new containers ($12\times10\times6$ cm^3). Each container contained the host, *E. kuehniella* eggs under the age of 24 h, or the third-instar nymphs of *A. fabae* or *A. gossypii.* The oviposition rate of the new generation females was recorded until the death of individual *A. decempunctata* adults.

Biochemical assays

The energy reserves of food sources (i.e. *A. gossypii, A. fabae* and *E. kuehniella* eggs) and of *A. decempunctata* females were evaluated by biochemical assays. About 0.1 g of each host and three individuals of *A. decempunctata* adults (with clipped wings) were homogenized in 300 µL of distilled water in a homogenizer. The samples were centrifuged at 10000 *x* g for 30 min at 4°C and the supernatants were maintained at -18°C until use. Each assay was repeated three times.

Protein determination

Protein was determined according to Lowry et al. [27] using a protein kit procured from Zist Chemical (Iran). Fifty µL of reagent was added to 20 µL of the supernatant of each sample and incubated for 15 min prior to reading the absorbance at 545 nm.

Determination of triglyceride concentration

Triglyceride concentrations were determined using a diagnostic kit (Pars Azmoon; Iran), with phosphate buffer (50 mM, pH 7.2), 4 mM 4-chlorophenol, 2 mM adenosine triphosphate, 15 mM Mg^{2+}, 0.4 kU/L glycerokinase, 2 kU/L peroxidase, 2 kU/L lipoprotein lipase, 0.5 mM 4-aminoantipyrine and 0.5 kU/L glycerol-3-phosphate-oxidase as the reagents. Twenty µL of supernatant were incubated with 50 µL of reagent for 15 min at 25°C [28]. The optical density (OD) of the samples and standards was read at 546 nm. The following equation was used to calculate the amount of triglyceride:

$$\text{mg/dL} = \frac{\text{OD of sample}}{\text{OD of standard}} \times 0.01126$$

Glycogen assay

The glycogen assay was carried out according to the method of Chun and Yin [29]. All three hosts (0.1 g) and three individuals of *A. decempunctata* adults that fed on these hosts (with clipped wings) were immersed in tubes containing 1 mL of 30% KOH in Na_2SO. The samples were covered with aluminum foil to avoid evaporation and were then boiled in a water bath for 20-30 min. Then, the tubes were shaken and cooled on ice. Glycogen was precipitated from the solution by adding 2 mL of 95% EtOH to the solutions. The samples were shaken and incubated on ice for 30 min. The tubes containing the samples were then centrifuged at 10000 *x* g for 30 min. The supernatant was discarded and the pellets (glycogen) were redissolved in 1 mL of distilled water before shaking. The glycogen standard (0, 25, 50, 75 and 100 mg/mL) was prepared before adding 5% phenol. The samples were incubated in an ice bath for 30 min. The standards and samples were read at 492 nm with distilled water serving as blank.

Statistical analysis

The life-table data of all individuals of *A. decempunctata* (males, females and individuals that did not reach the adult stage) were analyzed using age-stage, two-sex, life table theory [30] and the method described by Chi [31]. Data analysis and population parameters were calculated using the TWOSEX-MSChart .

The age-stage-specific survival rate (S_{xj}) (where x=age in days and j=stage; the first stage is the egg-larva stage, the second stage is the pupal stage, the third and fourth stages are the female and male, respectively), the age-specific survival rate (l_x), the age-specific fecundity (m_x) and the population parameters (r is the intrinsic rate of increase; λ is the finite rate of increase, $\lambda = e^r$; R_0 is the net reproductive rate; T is the mean generation time) were calculated according to Chi and Liu [30].

The intrinsic rate of increase was estimated using the iterative bisection method from the Euler-Lotka formula, with the age indexed from 0 to ∞ [32]:

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

The age-specific survival rate (l_x), which is the survival from age 0 to age x, was measured using the following formula:

$$2)\ l_x=\Sigma_{j=1}^{\beta} S_{xj}$$

where β is the number of stages. The age-specific fecundity (m_x), which is the average number of eggs produced by any individual at age x, was measured using the following formula:

$$3)\ m_x = \sum_{j=1}^{\beta} S_{xj} f_{xj} \Big/ \sum_{j=1}^{\beta} S_{xj}$$

The product of l_x and m_x is the age-specific net maternity ($l_x m_x$). The sum of $l_x m_x$ gives the net reproductive rate (R_0), and the number of offspring produced by an individual during its lifespan was measured based on the following formula:

$$4)\ R_0 = \sum_{x=0}^{\infty} l_x m_x$$

The average generation time (T) is the duration that a population needs to multiply R_0-fold when the stable increase rate r and λ are reached, $e^{rT}=R_0$ or $\lambda^T=R_0$, and was calculated using the following formula:

$$5)\ T = \text{In}R_0 / r$$

The life expectancy (e_{xj}), which represents the duration that an individual of age x and stage j is expected to survive, was measured according to Chi and Su [33] as:

$$6)\ e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{\beta} \acute{S}_{iy}$$

where $\acute{S}_{iy}$ is the probability that an individual of age x and stage y will survive to age i and stage y by assuming $\acute{S}_{xj} = 1$.

The reproductive value (V_{xj}) denotes the contribution an individual of age x and stage j provides to the future population, and was calculated by the following formula:

$$7)\ V_{xj} = \frac{e^{r(x+1)}}{S_{xj}} \sum_{i=x}^{\infty} e^{-r(i+1)} \sum_{y=j}^{\beta} \acute{S}_{iy} f_{iy}$$

The means and SEs of the biological traits and life-table parameters were estimated using the bootstrap procedure with 100000 resamplings. To detect the differences, a paired bootstrap test procedure was used based on the confidence interval of the differences . Sigma Plot ver. 12.0 was used to draw the figures [34].

The normality of the biochemical assay and the adult weight data were checked using the Kolmogorov-Smirnov test (SPSS 17.0.1). All comparisons were analyzed by one-way ANOVA, followed by Tukey's *post-hoc* test and accepted as significant at p<0.05 (SAS 9.3 2010). The nonparametric Kruskal-Wallis test was used to analyze the adult weight data (SPSS 17.0.1).

RESULTS

Biochemical parameters of hosts

The results of one-way ANOVA revealed differences in the total protein content of various food sources (p<0.01) (Table 1). *E. kuehniella* eggs and *A. gossypii* had higher total protein contents than *A. fabae.* However, *A. fabae*, with the lowest triglyceride content (0.021±0.0001 mg/dL), showed statistically significant differences compared to the other two hosts (p<0.01). Generally, the *E. kuehniella* eggs had significantly higher glycogen contents than the aphids (p<0.01) (Table 1).

Biochemical parameters of *Adalia decempunctata* reared on three host species

The total protein content of *A. decempunctata* reared on different food sources were significantly different

Table 1. The mean (±SE) values of storage macromolecules in different hosts and in *A. decempunctata* females reared on hosts at 24°C.

Hosts and lady beetles grown on them		Storage macromolecules (mg/dL)		
		Protein	Glycogen	Triglyceride
Hosts	*A. gossypii*	4.704±0.02a*	0.202±0.001b	0.033±0.0001a
	A. fabae	3.887±0.07b	0.113±0.006c	0.021±0.0001b
	E. kuehniella	5.003±0.01a	0.247±0.01a	0.035±0.0001a
Lady beetles	G1**	1.692±0.01a*	0.170±0.01a	0.014±0.0002a
	G2	1.283±0.09b	0.156±0.001b	0.012±0.0002c
	G3	1.664±0.1a	0.166±0. 002a	0.013± 0.0001b

*Means followed by different letter in each column (for three hosts and lady beetles) are significantly different Tukey test, P<0.05). **G1-G3 (Groups 1-3 of females *A. decempunctata* reared on *A. gossypii*, *A. fabae*, *E. kuehniella* eggs, respectively)

Table 2. Means (±SE) of development time of different immature stages, adult longevity (days) and adult weight (mg±SE) of *A. decempunctata* fed on three hosts at 24ºC.

parameter	*A. gossypii*	*A. fabae*	*E. kuehniella* eggs
Egg	2.59±0.06a*	2.6±0.06a	2.44±0.06a
First instar	2.41±0.09b	2.75±0.07a	2.27±0.06b
Second instar	2.31±0.12ab	2.56±0.08a	2.05±0.11b
Third instar	2.09±0.10b	2.46±0.07a	1.98±0.07b
Fourth instar	4.53±0.07b	4.9±0.08a	4±0.08c
Prepupa	1.02±0.01a	1.04±0.02a	1a
Pupa	4.83±0.09b	5.51±0.08a	4.64±0.09b
Pre-adult	19.79±0.28b	21.82±0.20a	18.33±0.19c
Adult longevity (all)	93.92±1.37a	83.63±0.93c	88.81±1.61b
Adult (female)	96.69±1.72a	86.96±1.05b	94.09±1.79a
Adult (male)	89.10±1.85a	79.64±1.21b	82.61±2.32b
Female weight	8.8±0.08 No. 33	8±0.17 No.30	8.5±0. 1 No.33
Male weight	7.3±0.17 No.19	7±0.11 No.25	7.5±0.13 No.28

*Means in each row followed by the same letter are not significantly different (paired bootstrap test, P<0.05)
No.=numbers of replicates, adults weights were analyzed by Kruskal-Wallis nonparametric procedure.

Table 3. Reproductive attributes of *A. decempunctata* females fed on three hosts at 24ºC.

Biological parameters	*A. gossypii*	*A. fabae*	*E. kuehniella* eggs
TPOP (days)	22.12±0.37a*	24.63±0.26b	22.7±0.29a
APOP (days)	2.58±0.10b	2.88±0.11b	4.55±0.11a
Oviposition period (days)	88.72±1.6a	77.66±1.15c	82.70±1.81b
Fecundity (eggs/female)	2382.60±50.3a	1876.8±49.71b	2405.12±76.92a

*Means in each row followed by the same letter are not significantly different (paired bootstrap test, P<0.05)

Table 4. Life table parameters (means±SE) of *A. decempunctata* fed on three hosts at 24ºC.

Parameters	*A. gossypii*	*A. fabae*	*E. kuehniella* eggs
r (day^{-1})	0.177±0.005a*	0.155±0.004b	0.171±0.004a
λ (day^{-1})	1.193±0.006a	1.168±0.005b	1.187±0.005a
R_0 (offspring)	873.622±122.16a	632.625±94.67a	881.87±124.39a
T (day)	38.23±0.59b	41.40±0.43a	39.53±0.44b

*Means in each row followed by the same letter are not significantly different (paired bootstrap test, P<0.05)

(p<0.05). The highest total protein contents were recorded for females reared on *A. gossypii* (1.692±0.01 mg/dL) and *E. kuehniella* eggs (1.664±0.01 mg/dL). The lowest total protein content was recorded for females reared on *A. fabae* (1.283±0.09 mg/dL) (Table 1). Our results also revealed significant differences in triglyceride (p<0.01) and glycogen contents (p<0.01) (Table 1). In contrast to *A. fabae*, the females reared on *A. gossypii* and *E. kuehniella* eggs showed higher glycogen contents (0.170±0.01 and 0.166±0.002, respectively) (Table 1).

Biological indices of *Adalia decempunctata*

Development, survival and oviposition of *A. decempunctata*

The mean durations of the developmental stages of *A. decempunctata* bred on *A. fabae*, *A. gossypii* and *E. kuehniella* eggs are presented in Table 2. The results showed that the incubation and prepupal duration was not significantly affected by the host on which lady beetle larva fed (p>0.05). However, the mean developmental period of the fourth-instar and of pre-adult stages in *A. decempunctata* bred on three host species differed significantly (p<0.05). The duration of the pre-adult stage was the shortest (18.33±0.19 days) in *A. decempunctata* beetles fed on *E. kuehniella* eggs, and the longest (21.82±0.20 days) in lady beetles fed on *A. fabae* (p<0.05) (Table 2). A paired bootstrap test revealed that *A. decempunctata* reared on *A. gossypii* lived longer (96.69±1.72 days for females and 89.1±1.85 days for males), while those fed on *A. fabae* had shorter longevity (86.96±1.05 days for females and 79.64±1.21 days for males) (p<0.05) (Table 2). Adults of *A. decempunctata* fed on different hosts displayed statistically significant differences in their longevities. So, in contrast to the adults that fed on *A. fabae*, feeding on *A. gossypii* resulted in the longest longevity (p<0.05) (Table 2). The results of the nonparametric Kruskal Wallis test showed statistically significant differences in the weights of emerging females reared on hosts (p=0.0001, x^2=17.26). Females that fed on *A. gossypii* and *E. kuehniella* eggs were heavier than those that fed on *A. fabae* (Table 2). On the other hand, males showed no statistically significant differences in weight between the three hosts (p=0.052, x^2=5.899) (Table 2).

Our results also indicated that the host significantly influenced the reproductive attributes of *A. decempunc-*

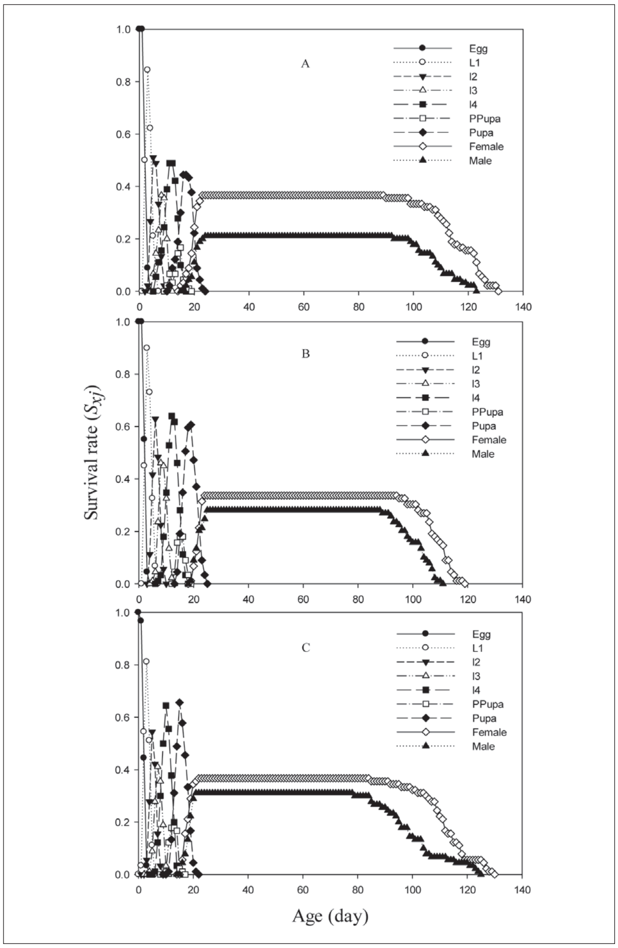

Fig. 1. Age-stage-specific survival rate (S_{xj}) of *A. decempunctata* fed on *A. gossypii* (**A**), *A. fabae* (**B**) and *E. kuehniella* eggs (**C**) at 24ºC.

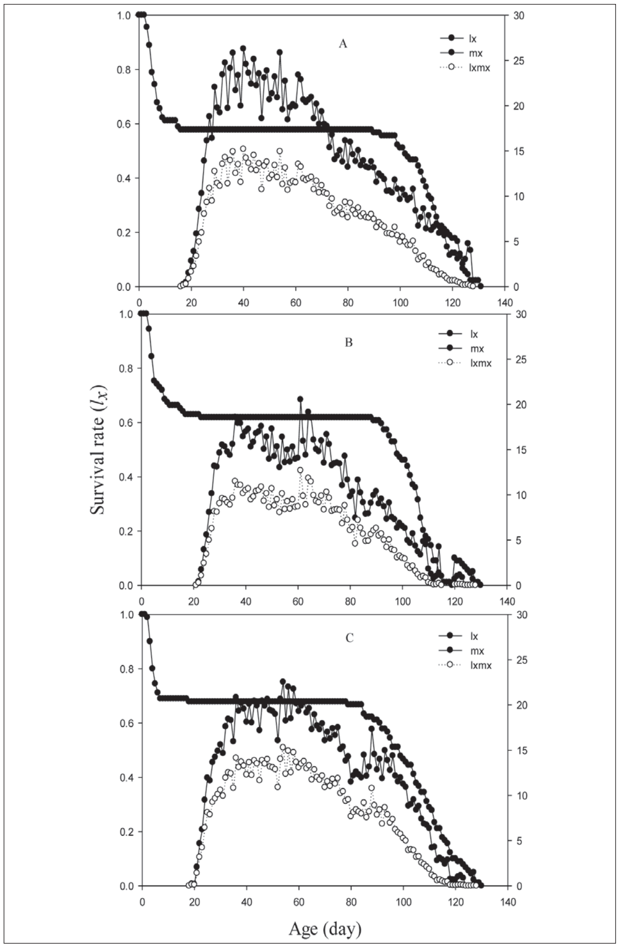

Fig. 2. Age-specific survival rate (l_x), age-specific fecundity (m_x) and age-specific net maternity (l_xm_x) of *A. decempunctata* fed on *A. gossypii* (**A**), *A. fabae* (**B**) and *E. kuehniella* eggs (**C**) at 24ºC.

tata beetles. Similarly, the adult preoviposition period (APOP), the total preovipositional period (TPOP), the oviposition period and fecundity were also influenced (Table 3). The average APOP duration was significantly longer in the lady beetles that fed on *E. kuehniella* eggs. The females of *A. decempunctata* bred on *A. gossypii* and *E. kuehniella* eggs had a shorter TPOP duration period than those reared on *A. fabae* (Table 3). The longest oviposition period (88.72±1.6 days) was recorded for *A. decempunctata* beetles fed on *A. gossypii*, and the shortest oviposition period (77.66±1.15 days) was observed for those fed on *A. fabae*. A lower fecundity was observed in females that fed on *A. fabae* (1876.8±49.71 eggs/female), while the fecundity rate was higher in females that were reared on *A. gossypii* (2382.60±50.3 eggs/female) and on *E. kuehniella* eggs (2405.12±76.92 eggs/female) ($p<0.05$) (Table 3).

The survival rate (S_{xj}) of all individuals of *A. decempunctata* fed on three hosts are presented in Fig. 1. Due to variable developmental rates among individuals, the survival rate (S_{xj}) curves showed overlap. Females exhibited higher survival rates than males on all studied hosts. However, when only females were compared, females that fed on *A. gossypii* and *E. kuehniella* eggs had higher survival rates than those fed on *A. fabae* (Fig. 1). The l_x, m_x and l_xm_x of *A. decempunctata* beetles according to the host are presented in Fig. 2. The l_x curve indicates that the longest survival rate was 130 days and was recorded for lady beetles that fed on *A. gossypii* and *E. kuehniella* eggs versus individuals that fed on *A. fabae* (Fig. 2). Also, the m_x and l_xm_x curves confirmed that the population of the predator that was reared on *A. gossypii* and *E. kuehniella* eggs had a higher fecundity. Our results showed

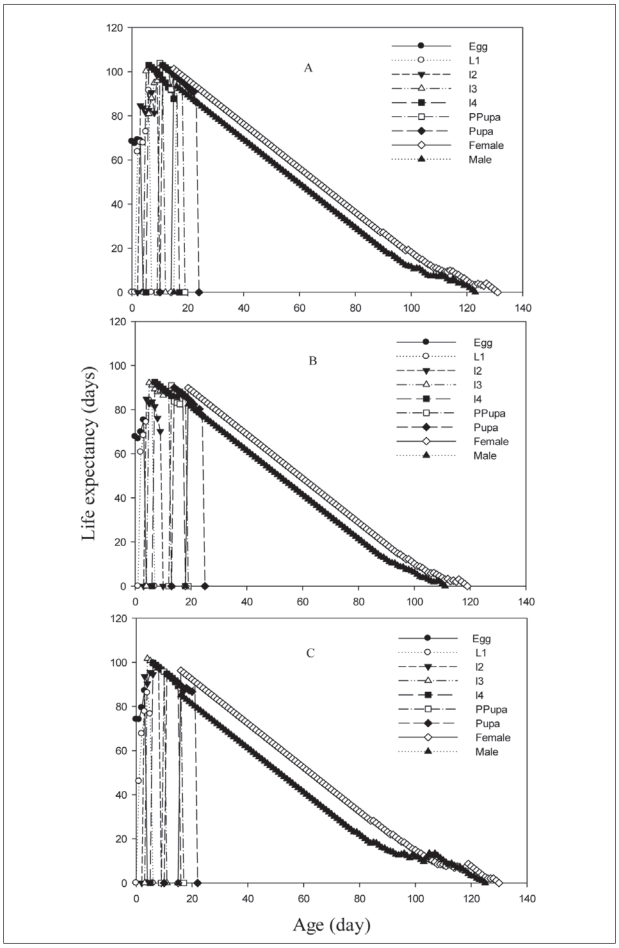

Fig. 3. Age-stage-specific life expectancy (e_{xj}) of *A. decempunctata* fed on *A. gossypii* (**A**), *A. fabae* (**B**) and *E. kuehniella* eggs (**C**) at 24ºC.

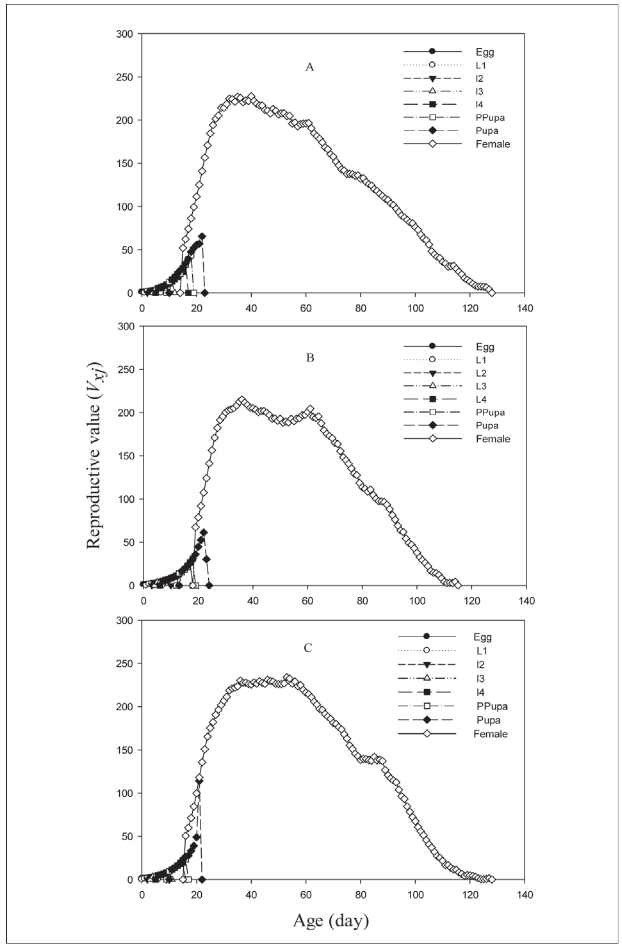

Fig. 4. Age-stage-specific reproductive value (V_{xj}) of *A. decempunctata* fed on *A. gossypii* (**A**), *A. fabae* (**B**) and *E. kuehniella* eggs (**C**) at 24ºC.

that the highest peak of egg laying by females feeding on *A. gossypii* (26.28) was at 40 days, for *E. kuehniella* eggs (22.52) it was at 54 days, and for *A. fabae* (20.52) it was at 61 days (Fig. 2). Males and females of *A. decempunctata* feeding on *A. gossypii* had a life expectancy of 93.32 and 101.24 days, respectively. However, males and females feeding on *E. kuehniella* eggs had a life expectancy of 85.14 and 96.24, respectively, and those that fed on *A. fabae* had a life expectancy of 82.44 and 89.8 days, respectively (Fig. 3). The results of reproductive value (V_{xj}) showed that females of *A. decempunctata* contributed immensely to the growth of the population at 40, 53 and 36 days. The reproductive rate increased significantly after commencement of reproduction (Fig. 4).

Population growth parameters

Table 4 summarizes the population growth parameters of *A. decempunctata* according to the host. The results of the paired bootstrap test showed that the r and λ values were higher for *A. decempunctata* beetles fed on *A. gossypii* and *E. kuehniella* eggs than for those fed on *A. fabae*. The r value for *A. decempunctata* beetles varied from 0.177 day^{-1} for individuals bred on *A. gossypii*, to 0.155 day^{-1} for individuals bred on *A. fabae*. The λ value varied from 1.193 day^{-1} for *A. decempunctata* beetles that fed on *A. gossypii* to 1.168 day^{-1} for those that fed on *A. fabae* ($p<0.05$) (Table 4).

It is evident from Table 4 that the T values of *A. decempunctata* beetles feeding on *A. gossypii* and *E. kuehniella* eggs were similar, but they differed significantly from those feeding on *A. fabae*. This parameter was higher for *A. decempunctata* beetles reared on *A. fabae* than those reared on the other two hosts. However, the net reproductive rate (R_0) of the females of *A. decempunctata* did not differ significantly according to the host (Table 4).

DISCUSSION

Our findings indicate that *A. decempunctata* was able to complete its life cycle, reach the adult stage and reproduce successfully in all the three studied hosts. However, the different qualities of food sources significantly influenced population growth parameters and biology. The shortest total developmental period was recorded in *A. decempunctata* individuals that were bred on *E. kuehniella* eggs. The longest period was found in those insects that were bred on *A. fabae.* Blackman [35] studied various species of aphid in order to choose the most appropriate food source for *Adalia bipunctata* (L.). The results of that study revealed that different aphids affected the survival rate and growth period of their predator. The shortest and the highest durations of immature developmental were recorded on *Aulacorthum circumflexum* (Buckton) (9.5 days) and *Aphis sambuci* L. (13.4 days), respectively. Golizadeh and Jafari-Behi [26] also found impacts of three different aphid species (*Macrosiphum rosae* (L.), *A. fabae* and *A. gossypii*) on the biological traits of *Hippodamia variegata* (Goeze). These results indicated that the total developmental period was the shortest for *H. variegata* fed on *A. gossypii* (15.2 days), and the longest in individuals fed on *A. fabae* (18.9 days). De Clercq et al. [15] and Bonte et al. [36] demonstrated that *E. kuehniella* eggs were a more appropriate host for *A. bipunctata* than *Acyrthosiphon pisum* (Harris). The authors arrived at this conclusion based on the better development and lower mortality rates in the lady beetles they studied. Likewise, Wu et al. [37] reported that the type of prey had a significant influence on the developmental period of *H. variegata*. The same authors even reported a significant effect of host plants on which the aphid *A. gossypii* was reared. Thus, the developmental period varied from 15.2 to 18.9 days in different host plants.

Host quality is of great importance to female adults. The weight of *A. decempunctata* females that fed on *A. gossypii* was higher than in those that fed on *A. fabae*. Contrary to our study [21], it was demonstrated that male and female adults of *H. axyridis* reared on *E. kuehniella* eggs were heavier than those that were reared on *A. pisum.* The effect of diet on the weight of the females was also reported in *A. bipunctata* fed on different food regimes [36].

Adult longevity was another issue we examined. We found that the diet affected *A. decempunctata* longevity. Adults that fed on *A. fabae* showed shorter longevity than those fed on *E. kuehniella* eggs and on *A. gossypii*. The influence of the diet on the predators' longevity was also previously described in *H. variegata* [26].

The results of this study revealed the relationship between the fecundity of *A. decempunctata* females and a particular host. We report a higher rate of fecundity for two hosts, *A. gossypii* and *E. kuehniella* eggs, and slightly lower for *A. fabae*. The higher rate of fecundity could be related to the indirect effect of the plant source that the prey feeds on. Bonte et al. [36] also reported >1800 eggs per *A. bipunctata* females fed on *E. kuehniella* eggs. Our results are in agreement with the results of Cabral et al. [38] who determined that *Myzus persicae* (Sulzer) was a better host than *Aleyrodes proletella* (L.) for *Coccinella undecimpunctata* (L.) because of the higher fertility, fecundity and longevity. Similarly, De Clercq et al. [15] demonstrated a higher fecundity in *A. bipunctata* females that fed on *E. kuehniella* eggs compared to those that fed on *A. pisum.*

Again the influence of host on shorter TPOP and longer APOP are characteristics of females that fed on *E. kuehniella* eggs. These results are in agreement with the results of Jalali et al. [39] on *A. bipunctata*.

Life-table parameters are considered appropriate tools for evaluating the suitability of prey for lady beetles as predators. Studies have revealed that the life-table parameters of predaceous coccinellids on different hosts enable the selection of the best host [26,39,40]. Of the life-table parameters, the *r* value is one of the most important as this factor compares the population growth potential under specific climatic and food conditions. Also, this parameter reflects the overall effect of prey on the growth, development, fecundity and survival of a predator population [41].

The highest *r* value was recorded for *A. decempunctata* fed on *A. gossypii* and *E. kuehniella* eggs, which indicates that these hosts enhanced the growth of this predator's population. The R_0 value of *A. decempunctata* did not significantly vary in different hosts. Also, the significantly high λ value and the lowest *T* value represent specific parameters for *A. decempunctata* beetles that fed on *A. gossypii* and *E. kuehniella* eggs. Similar results have been reported for other predators [26,38,42]. Phoofolo and Obrycki [43] found that prey quality is of major importance for the reproductive capacity of lady beetles. Females fed on *Ostrinia nubilalis* (Hubner) eggs had the highest *r* and R_0 rates. Thus, *O. nubilalis* was recognized as an appropriate host for growth and oviposition of female *Coleomegilla maculata* (De Geer) lady beetles. Our findings are in agreement with several other studies [40,44].

The results of the biochemical assay showed that *A. gossypii* and *E. kuehniella* eggs had higher protein, triglyceride and glycogen contents than *A. fabae*. The quality of the host type affected the energy reserves of emerging females. Females fed on *A. gossypii* and *E. kuehniella* eggs during the larval stage contained more total protein, triglycerides and glycogen than those fed on *A. fabae*. Proteins are essential for reproduction, metamorphosis and general maintenance of insects [45]; likewise, glycogen and lipids are also necessary for reproduction, survival, distribution and diapause of insects [46]. Thompson [47] has argued that the quality of food directly affects the pre-adult period and the reproductive capacity in predatory insects. Therefore, food sources that are rich in energy reserves have a higher quality and are beneficial for insect growth, development and reproduction. According to these data, we conclude that the shorter developmental period, higher *r* and λ values, fecundity and adult longevity of *A. decempunctata* fed on *A. gossypii* and *E. kuehniella* eggs were related to the higher quality of the food sources. It was shown [21] that a low mortality rate in the pre-adult stage of *H. axyridis* fed on *E. kuehniella* eggs was influenced by the quality of the prey. Chemical assays also confirmed our finding that variations in the protein and lipid contents of *E. kuehniella* eggs were higher than for *A. pisum*. The same group of authors also established that females fed on *E. kuehniella* eggs had higher protein contents than to those fed on *A. pisum*, which affected the reproductive capacity (fecundity and fertility) of females. Lundgren and Seagraves [48] showed the benefits of food (nectar) on the physiology of *C. maculata*. They reported a 50% increase in survival and a 30% increase in the fecundity, size and glycogen content of oocytes.

CONCLUSION

In the present study, all hosts were characterized as essential prey species for *A. decempunctata* beetles by comparing the biological and life-table parameters. This conclusion is based on the observation that feeding on *A. gossypii, A. fabae* and *E. kuehniella* eggs had positive effects on developmental stages and adult longevity and fecundity. However, because of the higher protein, lipid and glycogen contents, *A. gossypii* and *E. kuehniella* eggs were better hosts. Further investigations are necessary in order to evaluate the predatory potential of *A. decempunctata* beetles for the control of aphids in agroecosystem and natural environment.

Funding: This research did not receive any specific grant from funding agencies in the public, commercial or not for profit sectors.

Acknowledgments: This study is a part of PhD dissertations in the University of Guilan. We would like to thank the authorities of the Department of Plant Protection, the Faculty of Agricultural Sciences, University of Guilan and the Iranian Research Institute of Plant Protection, Tehran, Iran for providing us with research facilities and for their financial support.

Author contributions: ZM-H and JJS designed the study, ZM-H performed the experiments and analyzed the data. All authors wrote the manuscript and approved the final version.

Conflict of interest disclosure: All authors of the present paper confirm no actual or potential conflicts of interest, including any financial, personal, or other relationships with people or organizations.

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