pISSN: 0259-9996 – eISSN: 2783-3968

Journal of Entomological Society of Iran

2026, 46 (4), 401–414

Research Article

Demographic comparison of *Clitostethus arcuatus* (Col., Coccinellidae) feeding on two different whitefly species, *Bemisia tabaci* and *Aleyrodes singularis* (Hem., Aleyrodidae)

Shahram Farrokhi[1], Rezvaneh Moradian[2], Habib Abbasipour[2], Jalal Shirazi[1] & Shahab Manzari[3]

1. *Biological Control Research Department, Iranian Research Institute of Plant Protection, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran*

2. *Department of Plant Protection, Faculty of Agriculture, Shahed University, Tehran, Iran*

3. *Insects Taxonomy Research Department, Iranian Research Institute of Plant Protection, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran*

Abstract. *Clitostethus arcuatus* (Rossi) is a predatory coccinellid that feeds on whiteflies on various plants, such as ash, pomegranate, mulberry and prickly lettuce. In the present study, the biological parameters of *C. arcuatus* against two whitefly species were investigated under laboratory conditions. Two populations of *C. arcuatus* were separately reared on prickly lettuce leaves (*Lactuca serriola* L.) infested with *Bemisia tabaci* (Gennadius) and *Aleyrodes singularis* Danzig (Hemiptera, Aleyrodidae). Egg cohorts of the predatory ladybird reared on two whitefly species were prepared in plastic Petri dishes. The recorded data on the duration of immature stages and daily oviposition were analyzed and compared using the TWOSEX-MSChart software. Results showed that none of the growth parameters of the two ladybird populations were statistically affected. Although the life expectancy of *C. arcuatus* reared on the cotton whitefly, *B. tabaci*, was longer compared with that on *A. singularis*, the fecundity of the ladybirds fed on *A. singularis* (287.83 eggs per female) was significantly higher than that fed on *B. tabaci* (155.51 eggs per female). The highest age-stage reproductive value (v_{xj}) of female *C. arcuatus* from the *A. singularis* colony on 34th day (70.26) was more than twice the calculated for ladybird females from the *B. tabaci* colony on 45th day (31.2). Based on our results and the relative ease of propagation of the host plant, rearing *C. arcuatus* on prickly lettuce infested with *A. singularis* offers more advantages than rearing on *B. tabaci*.

Keywords: predatory ladybug, prey quality, life table, whitefly, biological control

Article info
Received: 10 September 2025
Accepted: 12 September 2026
Published 24 October 2026

Subject Editor: Hossein Madadi

Corresponding author: Shahram Farrokhi

E-mail: shahram.farrokhi@gmail.com

DOI: https://doi.org/10.22034/jesi.46.4.2

Introduction

Clitostethus arcuatus (Rossi) (Col.: Coccinellidae), is a polyphagous predatory beetle that prefers aleyrodid species and has been used to control *Siphoninus phillyreae* (Haliday) in California (Adapted from: Tavadjoh *et al.*, 2010). According to the literature, this coccinellid has been reported as a predator of 13 species of whiteflies (Hem.: Aleyrodidae), including *S. phillyreae*, *Siphoninus immaculatus* (Heeger), *Dialeurodes citri* (Ashmead), *Aleurothrixus floccosus* (Maskell), *Bemisia tabaci (Gennadius)*, *Parabemisia myricae* (Kuwana), *Aleurotuba jelinekii* (Frauenfeld), *Paraleyrodes minei Iaccarino, Aleyrodes proletella L., Trialeurodes vaporariorum (Westwood), Aleyrodes singularis* Danzig, *Stenaleyrodes vinsoni Takahashi and Aleuroclava jasmini* (Takahashi) (Bellows *et al.*, 1992; Evans, 2008; Hodek & Honěk, 2009; Yazdani & Zarabi, 2009; Manzari & Farrokhi, 2019, Farrokhi *et al.*, 2025). In addition, it also feeds on the eggs of *Tetranychus urticae* Koch (Liotta, 1981; Liotta *et*

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al., 2003) as well as aphids (Agekyan, 1977; Gerling *et al.,* 2001). *Clitostethus arcuatus* is widely distributed in the Palaearctic region and has so far been reported from many countries across Europe, Asia, Africa, and the Americas (Adapted from Bellows *et al.*, 1992 and Tavadjoh *et al.*, 2010). It was first reported in Fars province of Iran by Yazdani & Assadi (1989) and currently seems to have a general distribution in the country (personal observations). The *C. arcuatus* is active as a natural control agent on ash whitefly, *S. phillyreae*, and *A. singularis* (Yazdani & Zarabi, 2009). In Egypt, the multiplication and release of 480,000 *C. arcuatus* in apple, olive, pear and pomegranate orchards infested with ash whitefly, while reducing the pest population, led to the establishment of this ladybird (Abd-Rabou, 2006; Abd-Rabou & Simmons, 2010). In recent years, its predatory activity has been reported on *A. jasmini* infesting mulberry trees in the green space of Tehran, Iran. Among the 16 predator species collected, *C. arcuatus* was the most common and dominant predator of the pest (Manzari & Farrokhi, 2019; Farrokhi & Manzari, 2021). In the studies conducted by Bagheri (2013) and Bagheri *et al.* (2015), the biology and population dynamics of *A. jasmini*, and the efficiency and effectiveness of *C. arcuatus* as its natural enemy, were evaluated in citrus orchards in Dezful, Khuzestan province, Iran.

Life table studies are a fundamental approach in population ecology and have predominantly been used by researchers to obtain detailed descriptions of a population's survival, growth, and reproduction. Such studies are used to describe development time and survival rate at each growth stage, and predict the population size of an insect, as well as its age structure at a given time (Southwood & Henderson, 2009). Among the several methods available for constructing a life table, the age-stage, two-sex life table has the advantage of accounting for both males and females and for changes in growth rates among individuals (Chi & Liu, 1985; Chi, 1988). Chi *et al.* (2022) have explained the merits of the age-stage two-sex life table and consider it a key tool for evaluating insect population characteristics for describing growth, development, survival, and reproduction under specific environmental conditions, and providing a theoretical basis for predicting population dynamics and developing biological control strategies. The approach reveals the biological differences between the total pre-oviposition period (TPOP) and the adult pre-oviposition period (APOP) and accurately illustrates the stage overlap among generations, overcoming the limitations of traditional female age-specific life tables (Chi *et al.*, 2023). So far, the age-stage, two-sex life table has been used to describe the biological parameters of many arthropod species (Yu *et al.*, 2005; Atlihan & Chi, 2008; Kavousi *et al.*, 2009; Farhadi *et al.*, 2011; Rounagh & Samih, 2014). Moreover, the age-stage two sex life table method can be used in the optimization of the mass production of natural enemies and their hosts to justify the cost of production. In recent research, Pourarian *et al.* (2024) reported on the mass-rearing characteristics of the carob moth to assess the feasibility of biocontrol in pomegranate orchards using *Trichogramma* spp. Nevertheless, there are few detailed studies of the life table of *C. arcuatus* under laboratory conditions.

In a study, Bellows *et al.* (1992) reported a mean developmental time of 15.6 days from egg to adult, 78% survival, and 202 eggs laid by females during their 82 days of longevity when the predator was reared on the ash whitefly at 28.2 °C. Yazdani *et al.* (2012) employed a traditional life-table method to evaluate host effects on *C. arcuatus*. The predator had a shorter developmental duration (~26 days) and higher reproductive attributes (lifetime fecundity of 228.1 eggs/female) against the ash whitefly at 25 °C compared to those against the greenhouse whitefly (~29 days and 224.1 eggs/female), respectively. Tavadjoh *et al.* (2010) reared the predator on the ash whitefly at 27 °C and reported lower fecundity (181.8 eggs/female). It is highly believed that under regular conditions, hosts are the primary source affecting the population growth rate of predators. Several investigations have demonstrated the host impact on the population dynamics of *C. arcuatus*. For example, Yazdani & Zarabi (2011) reared *C. arcuatus* in the laboratory on different diets, including eggs of *Siphoninus phillyreae*, *Trialeurodes vaporariorum*, and *Sitotroga cerealella*, as well as an artificial diet consisting of honey, yeast, and pollen. Then they demonstrated that prey quality affects the predator's consumption rate, developmental time, and fecundity. According to the predator's fecundity and rate of consumption, its population size can increase faster on *T. vaporariorum* eggs than on other prey. Nehasil *et al.* (2026) presented information on external and internal prey characteristics affecting predators, which may be one of the main assumptions of the present study. For example, females of *Cryptolaemus monrouzieri* delay oviposition and withhold mature eggs in their lateral oviducts in the absence of wax filaments produced by the prey (all stages of *Planococcus citri*). Contact chemical cues perceived by females when probing the wax filaments with their mouthparts are the signals that induce the

search for oviposition sites and the onset of egg laying (Merlin *et al*., 1996). It is well accepted that specific lipids are necessary dietary requirements for all insects, particularly the immature stages (Reinecke, 1985). Unlike *B. tabaci*, patches of *A. singularis* nymphs are characterized by a distinctive phenotype composed of the nymphs' exuviae, which are piled on the nymph, and by a covering layer of wax secreted by the adults (Guershon & Gerling, 2001). Therefore, this study aimed to compare the population growth and biological parameters of *C. arcuatus* fed on two whitefly species that differ in their wax secretions, and to identify suitable prey and improve the rearing method for this predatory coccinellid.

Materials and methods

Host plant selection

Several host plants, including *Gossypium herbaceum* (cotton, Sahel variety), *Phaseolus vulgaris* (common bean), *Salvia splendens* (scarlet sage), *Euphorbia pulcherrima* (poinsettia), *Hibiscus rosa-sinensis* (Chinese hibiscus), *A. theophrasti*, *Helianthus annuus* (common sunflower), *Solanum lycopersicum* (tomato) and *Lactuca serriola* (prickly lettuce) were evaluated to select the most suitable host plant for the whiteflies multiplication. Preliminary results and observations indicated that prickly lettuce (*L. serriola*) is the most suitable plant for establishing colonies of both whitefly species.

Rearing of whiteflies and establishing the colony of *C. arcuatus*

B. tabaci, cotton whitefly and *A. singularis*, lettuce whitefly populations were collected from velvetleaf, *Abutilon theophrasti* (Malvaceae), and prickly lettuce, *Lactuca serriola* (Asteraceae) from Gorgan and north of Tehran, respectively. The underside of the leaves and the immature stages of *A. singularis* were completely covered with a white waxy powder. To prepare the most suitable plant for both desired whitefly species, prickly lettuce plants were transplanted into pots with a diameter of 20 and a height of 18 cm. They were used in two separate greenhouse units for insect rearing. Plastic Petri dishes with diameters of 7 and 9 cm and a height of 14 mm, equipped with ventilation holes and wet cotton wool to maintain humidity, were used to establish and maintain the *C. arcuatus* colony. For this purpose, separate Petri dishes containing *L. serriola* leaves infested with over a hundred different biological stages of *B. tabaci* and *A. singularis* were placed in the germinator (600 liters; Noorsanat Ferdows Co.) at 26 ± 1 °C, 55 ± 5% RH and a photoperiod of 16L / 8D, and they were checked every three days. Before the life-table experiments, *C. arcuatus* populations were reared for at least two generations on these two whitefly species.

Determining the life table of *C. arcuatus* in laboratory conditions

Life table experiments were performed in laboratory conditions at 26 ± 1°C, 60 ± 5% RH and a photoperiod of 16 hours of light and 8 hours of darkness. To establish a cohort of the predatory ladybird, 10 to 15 pairs of adult *C. arcuatus* were placed in plastic Petri dishes with a diameter of 9 cm and a height of 14 mm with whitefly-infested leaves of *L. serriola* to lay eggs. A hole with a diameter of 1.5 cm was made in the lids of the Petri dishes, and the lids were covered with mesh cloth for ventilation. Moisture was provided by wet cotton wool. After 12 hours, adult ladybirds were removed and the leaves were carefully checked for *C. arcuatus* eggs under a stereomicroscope. Therefore, two populations of *C. arcuatus* were reared separately for at least two generations on prickly lettuce leaves infested with either *the B. tabaci* or the *A. singularis* population. When adults emerged, male and female *C. arcuatus* less than 1 day old were transferred to Petri dishes in pairs. Then, egg cohorts of the predatory ladybird reared on *B. tabaci* (69 ladybird eggs) and *A. singularis* (43 ladybird eggs) were prepared in plastic Petri dishes with a diameter of 9 cm and a height of 14 mm. Related prey of each cohort were offered on host plant leaves in Petri dishes and replaced every three days until the first-instar larvae emerged. These first-instar larvae were transferred separately into Petri dishes with the aforementioned characteristics and fed on whitefly eggs and nymphs on the lower surface of prickly lettuce leaves, following the method of Rounagh & Samih (2014). Daily observations were made of the developmental duration of the predator's immature stages (egg, larva, and pupa) in both cohorts. When adults emerged, male and female *C. arcuatus* less than 1 day old were transferred to Petri dishes in pairs. In this way, the daily fecundity and adult longevity were recorded separately for both cohorts until the death of the last adult individual in each cohort.

Data analysis

The collected data for each cohort were prepared in Notepad and analyzed using the age-stage two-sex life table model (Chi & Liu, 1985; Chi, 1988) with TWOSEX-MSChart software (Ver. 2019) (Chi, 2019). The growth and development parameters of immature stages, total and adult preoviposition periods (TPOP and APOP), the age-specific survival rate (l_x), the age-stage-specific survival rate (s_{xj}), the age-stage-specific fecundity (f_{x7}) and the age-specific fecundity (m_x), the age-stage-specific life expectancy (e_{xj}), and the age-stage-specific reproductive value (v_{xj}), and the population parameters, including the intrinsic rate of increase (r), the finite rate of increase (λ), the net reproductive rate (R_0), and the mean generation time (T) were calculated based on Chi & Liu (1985) and Chi (1988). The main components of the calculation are age (x), survival (l_x), and age-specific fecundity (m_x), which were used to calculate the parameters of population growth under the stable age-stage distribution (SASD).

$$GRR = \sum_{x=\alpha}^{\beta} m_x$$

$$R_0 = \sum_{x=\alpha}^{\beta} l_x m_x$$

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

$$\lambda = e^r$$

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

$$DT = \frac{\ln 2}{r}$$

The bootstrap method with 100,000 replicates was used to estimate the means and standard errors of all parameters. The paired bootstrap test was used to compare the treatments (Wei *et al.*, 2020). Moreover, the lower and upper limits of the confidence intervals of the means were assessed by using 100,000 paired differences between treatments. If the lower confidence limit is positive, it means the confidence interval does not include zero and there is significant difference between treatments (Chi *et al.*, 2023; Smucker *et al.*, 2007; Akca *et al.*, 2015). SigmaPlot 12.0 was used to generate curves for all demographic parameters.

Results

Biological traits and life table parameters of *C. arcuatus*

The duration of different life stages of *C. arcuatus* is shown in Table 1. In general, the coccinellid life history includes egg, four larval instars, pupa and adult stages. The incubation periods were 4.38 and 4.56 days for *B. tabaci* and *A. singularis*, respectively. Similarly, the total developmental time of all four larval instars was recorded as 12.35 and 12.19 days on the respective hosts. Nevertheless, the second instar larva of *C. arcuatus* completed its development significantly >1 day shorter on *A. singularis* compared with that on *B. tabaci*. Eventually, the total immature developmental time of *C. arcuatus* took 17.01 and 16.86 days when reared on *B. tabaci* and *A. singularis*, respectively, without any significant difference. Based on the results, male longevity was calculated to be 138.29 days on *B. tabaci* which did not significantly differ from that on *A. singularis* (121.07 days), however, the development period of the adult female predator on the later host was significantly shorter (62.25 days) compared with that on the former host (98.62 days) (Table 1). The results on the fecundity and duration of different life stages of this coccinellid are provided in Table 2. It was proved that the total life span of *C. arcuatus* was significantly longer when fed on *B. tabaci* (108.05 ± 9.64 days) compared with that of the predator reared on *A. singularis* (66.58 ± 9.90 days).

Table 1. Duration (day) of different growth stages of *Clitostethus arcuatus*, on two whitefly species as prey under laboratory conditions (26 ± 1 °C, 60 ± 5% RH, 16:8 h L:D)

Stage	*Bemisia tabaci*		*Aleyrodes singularis*		CI 95%	*P*- value
	No.	Mean±SE	No.	Mean±SE		
Egg	67	4.38±0.07	32	4.56±0.18	(-0.223, 0.572)^{ns}	0.388
L1	65	1.10±0.03	31	1.19±0.07	(-7.338, 0.244)^{ns}	0.293
L2	61	2.19±0.07	30	1.96±0.03	(7.382, 0.386)*	0.004
L3	58	2.18±0.06	29	2.31±0.13	(-0.163, 0.403)^{ns}	0.408
L4	56	2.51±0.11	28	2.17±0.16	(-0.043, 0.720)^{ns}	0.081
Total larval duration	56	7.94±0.11	28	7.64±0.22	(-0.183, 0.827)^{ns}	0.210
Pupa	54	4.66±0.09	25	4.72±0.19	(-0.372, 0.479)^{ns}	0.807
Total immature stages	54	17.01±0.17	25	16.86±0.31	(-0.524, 0.883)^{ns}	0.619
Male adult	27	138.29±13.90	13	121.07±13.36	(-20.61, 55.01)^{ns}	0.368
Female adult	27	98.62±11.80	12	62.25±12.00	(3.280, 69.419)*	0.031

ns: If the lower confidence limit is negative, it means the confidence interval (CI) includes zero and there is no significant difference between treatments; ***:** If the lower confidence limit is positive, it means the confidence interval (CI) does not include zero and there is significant difference between treatments at the probability level of 5%; L1−L4: Larva 1−Larva 4

In general, irrespective of the rearing host, male beetles had a lifespan almost 40 days longer than that of females (Table 2). Moreover, the adult pre-oviposition period (APOP) and total pre-oviposition period (TPOP) of female *C. arcuatus* reared on *B. tabaci* were 12.50 and 29.83 days while those of the beetle propagated on *A. singularis* were 10.55 and 28.44 days, respectively, showing no significant differences. On the other hand, despite rearing both prey hosts on the same host plant, the predator had a much longer lifespan on *B. tabaci* than *on A. singularis*. Nevertheless, females fed on *A. singularis* laid an average of 287.83 eggs, which was significantly higher than that of beetles fed on *B. tabaci* (155.51 eggs/female) (Table 2). Despite the nonsignificant differences among population growth parameters of the two populations of *C. arcuatus*, particularly the intrinsic rate of increase (Table 4), the total survival rate of immature stages of the predator reared on *B. tabaci* (0.78%) was significantly higher compared with that of the ladybird reared on *A. singularis* (0.58%) (Table 3). By referring to Table 3, it is inferred that the majority of immature mortality in *C. arcuatus* occurs at the egg stage when fed on *A. singularis* (~25%). Generally, the sex ratio of the beetles reared on both hosts was almost equal and close to 1: 1 (F: M). The age-stage survival rates (s_{xj}) of *C. arcuatus* are plotted in Fig. 1. It is strongly established that the predator propagated on *B. tabaci* had a higher survival rate compared with those of the predator fed on *A. singularis* for almost all stages. The age-specific survival rate (l_x) captures the simplest relationship between age and the distribution of deaths in a population (Southwood & Henderson, 2009). Based on the Fig. 2, the probabilities by which the predator individuals reared on *B. tabaci* would survive to the age of 25, 50, 100 and 150 days were 72, 59, 49 and 46%, respectively; nevertheless, the same probabilities for those reared on *A. singularis* were estimated as 55, 44, 37 and 25%, respectively. It is obvious that the mortality rate of *C. arcuatus* on both hosts was high in juveniles and decreased as the predator matured. Again, in adulthood, coinciding with population aging, mortality increased.

Table 2. Duration of different life periods (day) and fecundity of *Clitostethus arcuatus* adults on two whitefly species as prey under laboratory conditions (26 ± 1 °C, 60 ± 5% RH, 16:8 h L:D)

Parameter	*Bemisia tabaci*		*Aleyrodes singularis*		CI 95%	*P*- value
	No.	Mean±SE	No.	Mean±SE		
Total longevity (♂+♀)	69	108.05±9.64	43	66.58±9.90	(14.308, 680.510)*	0.002
Total longevity (♂)	27	154.96±13.94	13	136.92±13.49	(-20.020, 56.067)^{ns}	0.349
Total longevity (♀)	27	116±11.77	12	80.16±12.00	(2.781, 68.826)*	0.033
Oviposition period	27	64.37±7.40	12	59.77±11.89	(-22.905, 31.963)^{ns}	0.743
Fecundity (egg / female)	27	155.51±21.07	12	287.83±70.46	(15.982, 226.855)*	0.025
APOP[a]	24	12.50±1.33	9	10.55±2.42	(-3.484, 7.373)^{ns}	0.477
TPOP[b]	24	29.83±1.39	9	28.44±2.55	(-4.312, 7.091)^{ns}	0.630

ns: If the lower confidence limit is negative, it means the confidence interval (CI) includes zero and there is no significant difference between treatments; ***:** If the lower confidence limit is positive, it means the confidence interval (CI) does not include zero and there is significant difference between treatments at the probability level of 5%; **a:** Adult pre-ovipositional period; **b:** Total pre-ovipositional period

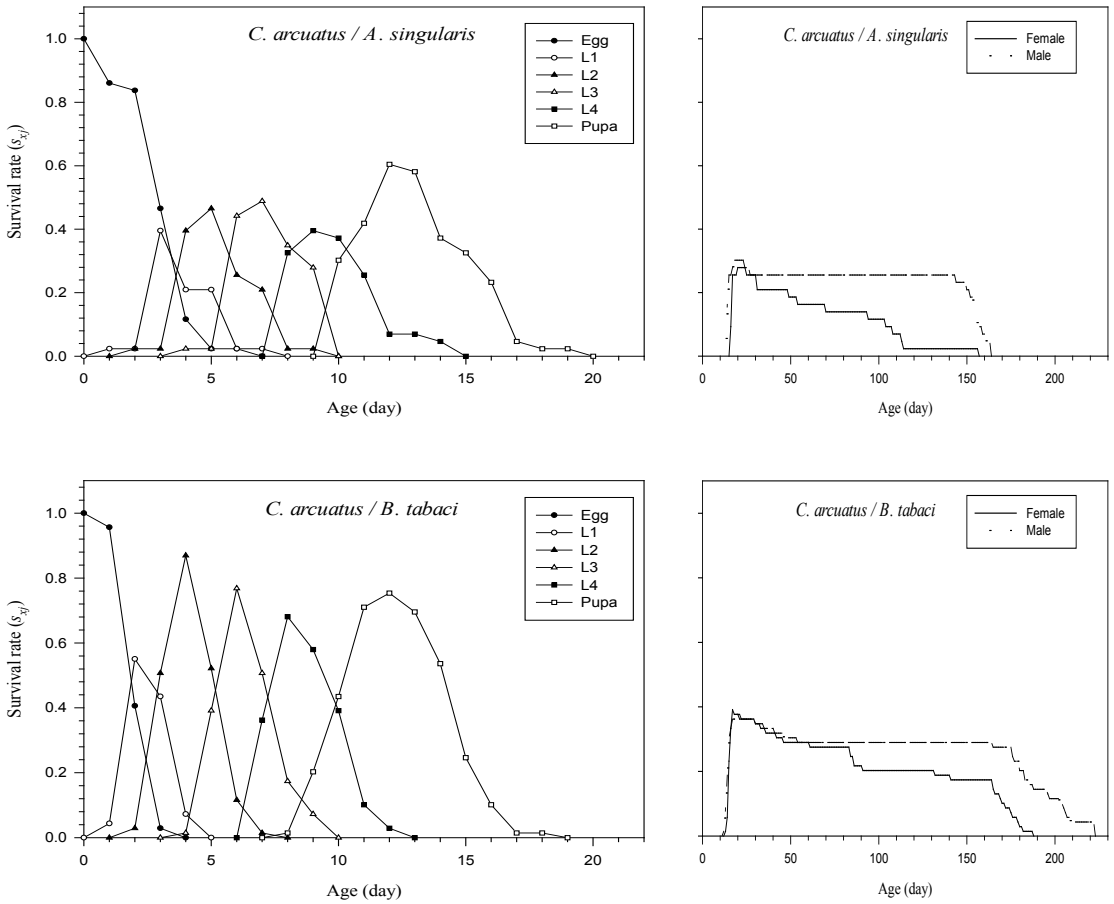


Fig. 1. The age-stage specific survival rates (s_{xj}) of *Clitostethus arcuatus,* on two whitefly species, *Aleyrodes singularis* and *Bemisia tabaci*, under laboratory conditions

The female age-stage fecundity (f_{xj}), age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) of *C. arcuatus* are presented in Fig. 2. The maximum egg and offspring productions of the predator occurred during its first half of lifetime on both hosts. Similarly, its maximum age-stage fecundity (f_{xj}) for *B. tabaci* (3.10 eggs/female) and *A. singularis* (8.30 eggs/female) was observed on days 45 and 33 after emergence, respectively. Accordingly, there was a marked reduction in egg laying of *C. arcuatus* on day 107 when reared on *B. tabaci,* while on *A. singularis*, its fecundity was stunted from day 115 to 127. The age-stage life expectancy (e_{xj}) decreased over time. A newly born egg of the predator reared on *B. tabaci* and *A. singularis* had 108.05 and 66.58 days life expectancy, respectively. The same parameter for the male and female *C. arcuatus* adults on the similar hosts was 139.45, 121.92 days and 101, 63.16 days, respectively. Totally, the maximum life expectancy of *C. arcuatus* was recorded in pupal stage (141.23 days) when fed on *B tabaci* (Fig. 3). Results revealed that the reproductive value (v_{xj}), which quantifies the contribution of an individual at age *x* and stage *j* to future population (Fisher, 1930, Pianka, 1994), of *C. arcuatus* increased as females emerged. Therefore, the reproductive value of a newborn individual would be equal to the intrinsic rate of population increase (Yang & Chi, 2006). As Fig. 4 depicts the v_{xj} of *C. arcuatus* fed on *A. singularis* at day 34 was 70.26, being almost two folds higher compared with the v_{xj} of the predator reared on *B. tabaci* at day 45 (31.20). It means that female ladybirds on *A. singularis* and *B. tabaci* showed their highest contribution to the next generation at ages 34 and 45 days, respectively (Fig. 4).

Population growth parameters

Although the mean comparisons did not reveal any significant differences among the population parameters of the predator fed on *B. tabaci* and *A. singularis*, almost all parameters obtained from the latter host were significantly higher (Table 4).

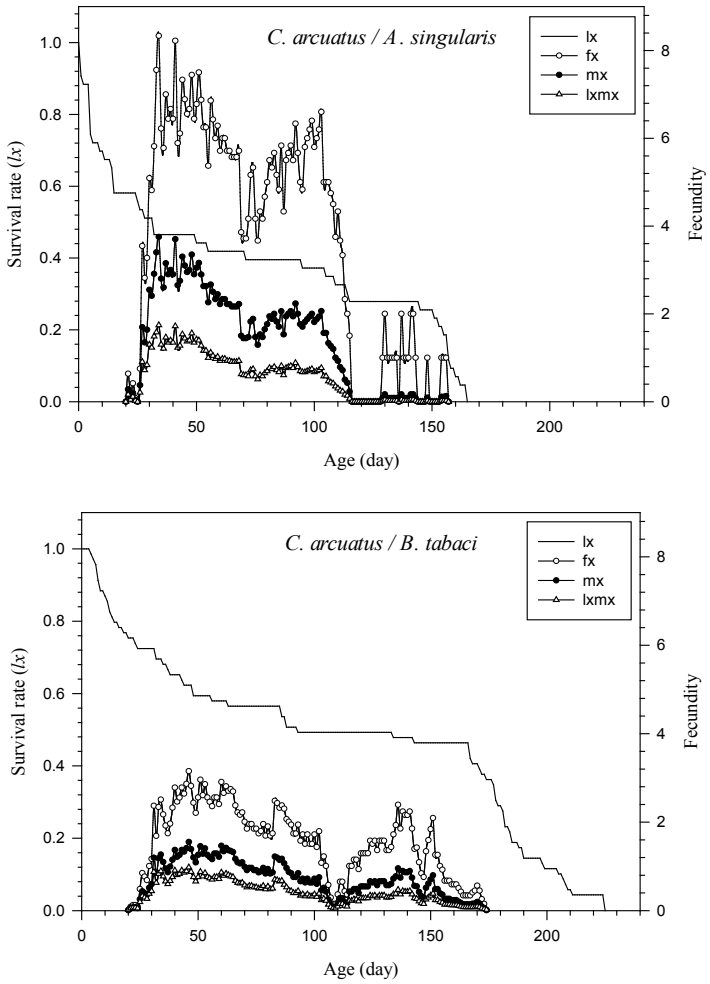


Fig. 2. The age specific survival rate (l_x), the age-stage specific fecundity (f_{x7}), the age-specific fecundity (m_x) and the age-specific maternity ($l_x m_x$) of *Clitostethus arcuatus,* on two whitefly species, *Aleyrodes singularis* and *Bemisia tabaci*, under laboratory conditions

The intrinsic rate of population increase (r) of *C. arcuatus* on *B. tabaci* and *A. singularis* was 0.080 and 0.097 day^{-1}, respectively, being 1.21-fold greater on the latter host. In addition, the finite rate of increase (λ) on the same hosts was estimated at 1.084 and 1.102 per day, respectively. Since the gross reproductive rate (*GRR*) is not regarded a robust test for different mean comparisons, the net reproduction rate (R_0) is obtained by multiplying the survival rate (lx) by the *GRR* value. Similarly, the net reproductive rate was determined as 60.85 and 80.32 offspring/individual for *C. arcuatus* reared on *B. tabaci* and *A. singularis*, respectively. Eventually, the predator generation duration on these hosts was 50.79 and 44.92 days, respectively, which was almost one week shorter in *A. singularis* (Table 4).

Discussion

In the study conducted by Yazdani & Samih (2012) on the life parameters of *C. arcuatus* reared on *T. vaporariorum* and *S. phillyreae* at 25 ± 2 °C and 65 ± 5% RH, the egg incubation and the total larval and pupal development on the mentioned hosts were 2.82 and 3.2 days, 22.31 and 18.6 days and 3.84 and 4.1 days, respectively, which are in contrast with our findings. The total immature development of *C. arcuatus* on cabbage whitefly was 17.2 days (Mota *et al*., 2008), which is similar to that found in the present study (17.01 and 16.86 days on *B. tabaci* and *A. sigularis*, respectively). In Bellows *et al*. (1992) report, the total immature period of the ladybird on ash whitefly was 15.6 days at 28.2 °C, while Yazdani & Samih (2012) recorded the same attributes up to 28.98 and 25.9 days on *T. vaporariorum* and *S. phillyreae* at 25 ± 2 °C, respectively. Differences observed

in findings could be due to host quality, rearing temperature and/or predator population. The immature survival rate of *C. arcuatus* was 0.42 and 0.62 on *T. vaporariorum* and *S. phillyreae* (Yazdani & Samih, 2012) while Bellows *et al.* (1992) and Tavadjoh *et al.* (2010) obtained the same parameter as 0.78 and 0.77 on ash whitefly, respectively. The immature survival rate of the predator for *B. tabaci* (0.78) in our study was similar to the results of Bellows *et al.* (1992) and Tavadjoh *et al.* (2010).

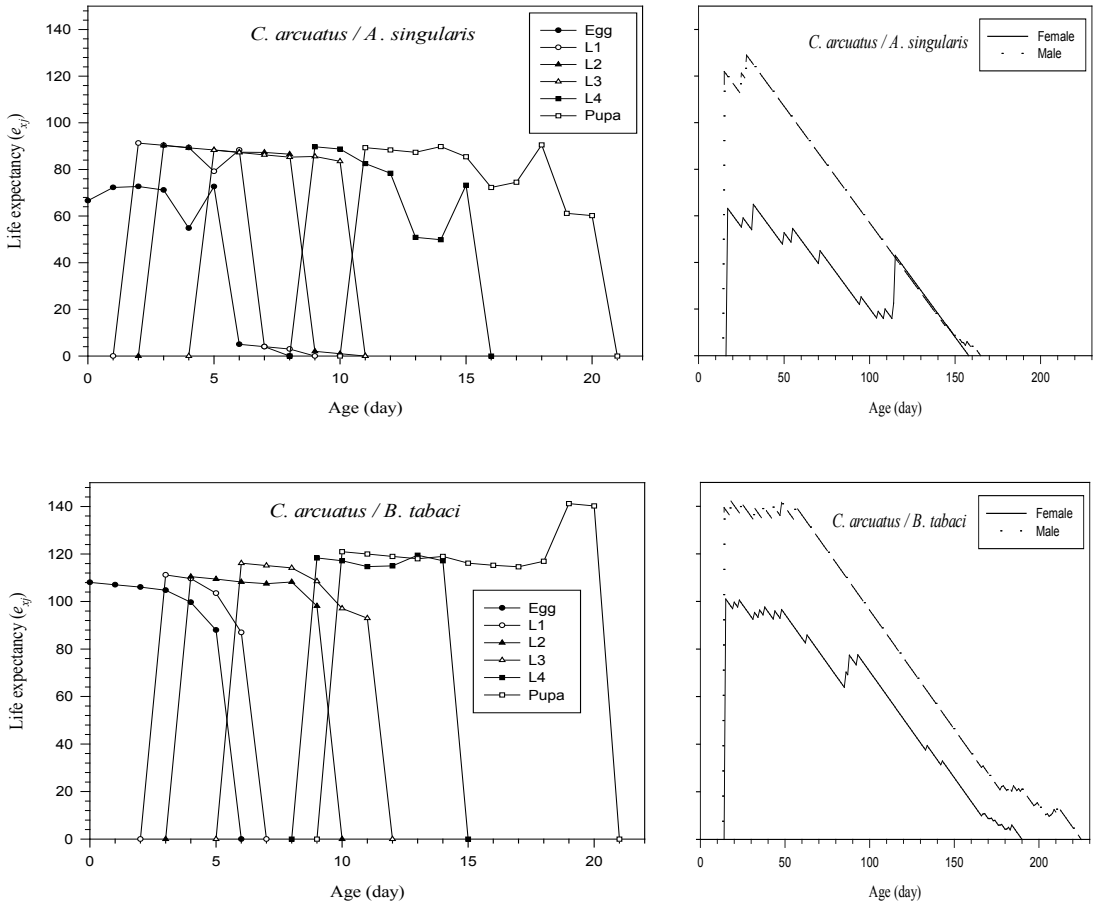


Fig. 3. The age-stage specific life expectancy (e_{xj}) of *Clitostethus arcuatus,* on two whitefly species, *Aleyrodes singularis* and *Bemisia tabaci*, under laboratory conditions

Table 3 Survival rate (Mean ± SE) of *Clitostethus arcuatus* immature stages on two whitefly species as prey under laboratory conditions (26 ± 1 °C, 60 ± 5% RH, 16:8 h L:D

Stage	*Bemisia tabaci*	*Aleyrodes singularis*	CI 95%	*P*- value
Egg	0.97±0.02	0.74±0.06	(8.980, 0.363)*	0.001
L1	0.97±0.02	0.96±0.03	(-7.157, 7.422)ns	0.964
L2	0.93±0.02	0.96±0.03	(-5.630, 0.114)ns	0.528
L3	0.95±0.02	0.96±0.03	(-6.823, 0.100)ns	0.723
L4	0.96±0.02	0.96±0.03	(-8.169, 8.176)ns	1
Pupa	0.96±0.02	0.89±0.05	(-5.380, 0.195)ns	0.269
Immature stages	0.78±0.04	0.58±0.07	(2.361, 0.377)*	0.025

ns: If the lower confidence limit is negative, it means the confidence interval (CI) includes zero and there is no significant difference between treatments; ***:** If the lower confidence limit is positive, it means the confidence interval (CI) does not include zero and there is significant difference between treatments at the probability level of 5%; L1−L4: Larva 1−Larva 4

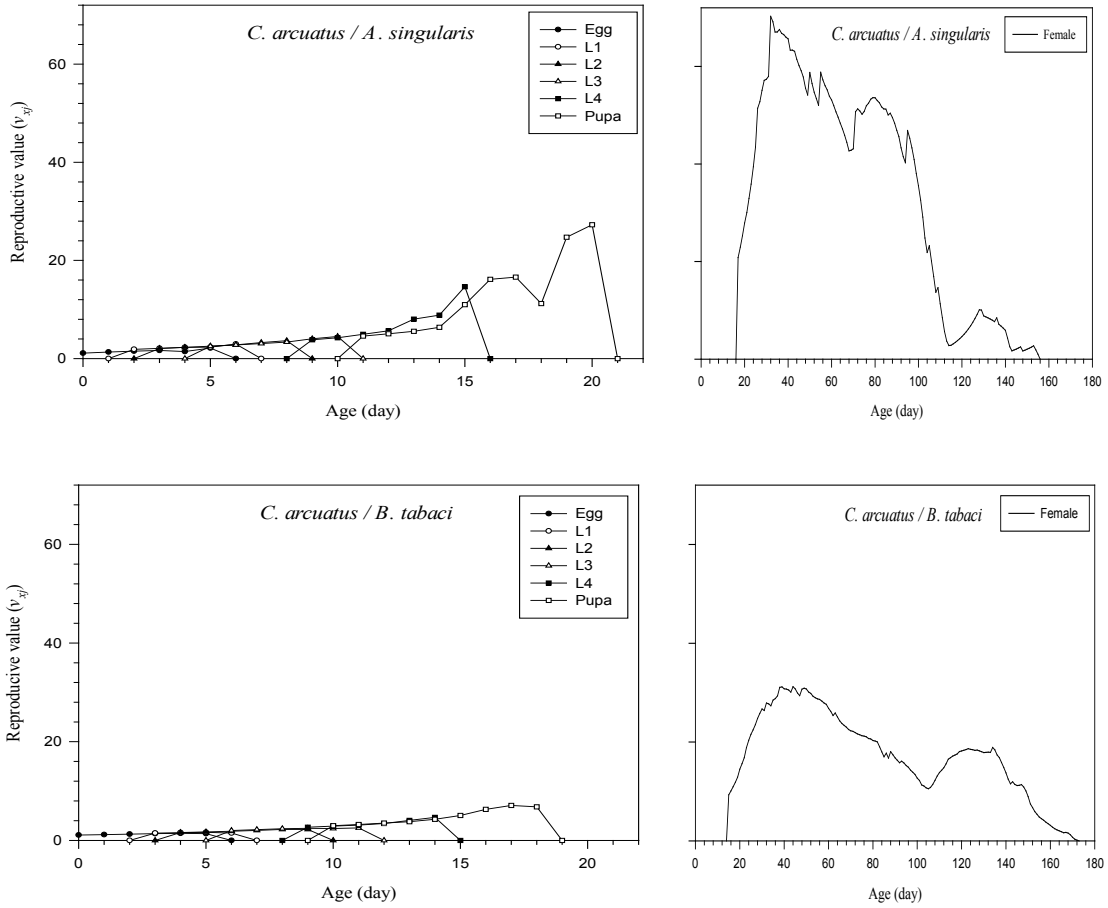


Fig. 4. The age-stage specific reproductive value (v_{xj}) of *Clitostethus arcuatus,* on two whitefly species, *Aleyrodes singularis* and *Bemisia tabaci*, under laboratory conditions

The adult/total pre-ovipostional period (APOP/TPOP), the egg laying duration, the fecundity and longevity of male and female adults of *C. arcuatus* reared on the cabbage whitefly were reported by Mota *et al.* (2008) as 9.2 days, 28.9 days, 31.2 eggs / female and 56.3 and 48.8 days, respectively, which are different with our results on the similar parameters for the predator reared on *A. singularis* (10.55 days, 59.77 days, 287.83 eggs/female and 136.92 and 80.16 days, respectively). Nevertheless, Bellows *et al.* (1992) and Tavadjoh *et al.* (2010) reported lifetime fecundities of 202 and 181.8 eggs per female, respectively, for predators fed on ash whitefly, which are lower than those observed in the present study. Besides, our findings showed longer longevity for male predators on both hosts, which is corroborated by Mota *et al.* (2008); however, Yazdani & Zarabi (2010) reported a longer lifespan for female coccinellids.

Table 4. Stable population parameters (Mean ± SE) of *Clitostethus arcuatus*, fed on two different whitefly species under laboratory conditions (26 ± 1 °C, 60 ± 5% RH, 16:8 h L:D

Parameter*	*Bemisia tabaci* (n=69)	*Aleyrodes singularis* (n=43)	CI 95%	*P*- value
r (day^{-1})	0.0808±0.005	0.0976±0.011	(-8.890, 3.962)^{ns}	0.196
λ (day^{-1})	1.0842±0.005	1.1025±0.012	(-9.683, 4.336)^{ns}	0.197
GRR (offspring)	108.33±20.40	188.44±60.25	(-44.60, 204.70)^{ns}	0.206
R_0 (offspring)	60.85±12.24	80.32±27.42	(-39.36, 78.41)^{ns}	0.518
T (day)	50.79±2.17	44.92±3.08	(-1.81, 12.97)^{ns}	0.133
DT (day)	8.56±0.58	7.09±1.06	(-1.27, 3.21)^{ns}	0.195

* see "Materials and Methods" for abbreviations; **n:** number of cohort; **ns:** If the lower confidence limit is negative, it means the confidence interval (CI) includes zero and there is no significant difference between treatments; ***:** If the lower confidence limit is positive, it means the confidence interval (CI) does not include zero and there is significant difference between treatments at the probability level of 5%.

The sex ratio of *C. arcuatus* in the present research on both hosts was nearly equal (1M:1F), as reported by Yazdani & Zarabi (2011). However, in some predator colonies, the sex ratio could be biased toward males (1.38M:1F) (Tavadjoh *et al.*, 2010). Reports are indicating that the *C. arcuatus* intrinsic rate of increase (*r*) and generation time (*T*) were 0.14 day^{-1} and 23.61 days on the cabbage whitefly (Mota *et al.*, 2008), 0.063 day^{-1} and 43.4 days on the greenhouse whitefly and 0.075 day^{-1} and 40.69 days on the ash whitefly (Yazdani & Samih, 2012), respectively. Here, the same parameters were estimated at 0.0808 day^{-1} and 50.79 days for *B. tabaci,* and at 0.0976 day^{-1} and 44.92 days for *A. singularis*, respectively, which are mostly higher than the mentioned values. As mentioned in the introduction, there are more than 10 species of whiteflies introduced as the preferred hosts for *C. arcuatus*. Most of these prey, especially frequently occurring species on which the predator is highly dependent nutritionally, in their immature stages, are significantly covered with mealy and waxy secretions (field observations and reviews of photographs and scientific sources). Such a host range could indicate a predator's preference for hosts that produce relatively high levels of waxy material. Also, the results of the present study regarding the adult's development period and fecundity of *C. arcuatus* (Table 2), and its host preference in nature to *S. phillyreae* and *A. singularis*, suggest that this predator may require a certain amount of wax and fat in its diet to complete its life cycle in the shortest time. Of course, further studies are warranted to test this hypothesis.

According to Figures 1-4 and Table 4, and by comparing the attributes of *C. arcuatus*, it could be concluded that the predator fed on *B. tabaci* had longer longevity and higher life expectancy. Still, when reared on *A. singularis*, it exhibited higher fecundity, intrinsic rate of increase, and reproductive value. Therefore, regarding the feasibility of host plant (*L. serriola*) production, mass rearing of *C. arcuatus* on *A. singularis* would be more economical compared with *B. tabaci*. Additionally, as the reproductive value plot (Fig. 4) shows, it is recommended to maintain the predator colony for no more than 3 months. In addition, considering the higher survival rate of *C. arcuatus* immature stages on *B. tabaci*, they can be reared on *B. tabaci* (fed on *L. serriola*) and adults are transferred to and multiplied on *A. singularis* on the same host plant, provided no substantial reduction in the predator fecundity and intrinsic rate of increase (*r*) is observed by its long-term rearing on *B. tabaci*. Certainly, proving some of the presented assumptions and optimizing the rearing conditions for this predatory coccinellid require further investigation.

Author's Contributions

Shahram Farrokhi: Methodology, setup, and data analysis, writing original draft. **Rezvaneh Moradian:** Investigation, draft preparation. **Habib Abbasipour:** Review and editing. **Jalal Shirazi:** Data analysis, review, and final editing of the manuscript. **Shahab Manzari**: Review and editing.

Author's Information

Shahram Farrokhi	✉ shahram.farrokhi@gmail.com	https://orcid.org/0000-0002-3056-0610
Rezvaneh Moradian	✉ r.moradian@shahed.ac.ir	https://orcid.org/0009-0004-0922-1392
Habib Abbasipour	✉ abasipour@shahed.ac.ir	https://orcid.org/0000-0001-6589-7363
Jalal Shirazi	✉ jalal.shirazi@gmail.com	https://orcid.org/0000-0001-9303-8056
Shahab Manzari	✉ manzaris@gmail.com	https://orcid.org/0000-0003-3874-6564

Funding

Financial support for this study was provided by a grant from the Iran National Science Foundation (INSF) and Agricultural Research, Education and Extension Organization (AREEO) (Project No.: 96010619) to S. Manzari.

Data Availability Statement

The dataset created and analyzed in the current study will be available upon request.

Acknowledgments

The authors are extremely grateful to Professor Dr. Hsin Chi for scientific guidance and for providing the TWOSEX-MSChart software. The Iranian Research Institute of Plant Protection (IRIPP) is also commended for providing research facilities as an IRIPP research project (No.: 57-16-16-053-970391).

Ethics Approval and Consent to Participate

This article does not contain any studies with human participants or animals.

Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose.

Generative AI statement

During the preparation of this work, the authors used ChatGPT and DeepL to improve the manuscript's readability. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the publication's content.

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Citation: Farrokhi, S., Moradian, R., Abbasipour, H., Shirazi, J. & Manzari, S. (2026) Demographic comparison of *Clitostethus arcuatus* (Col.: Coccinellidae) feeding on two different whitefly species, *Bemisia tabaci* and *Aleyrodes singularis* (Hem.: Aleyrodidae). *Entomol. Soc. Iran*, 46(4), 401–414.

DOI: https://doi.org/10.22034/jesi.46.4.2

URL: https://jesi.areeo.ac.ir/article_136452.html

pISSN: 0259-9996 – eISSN: 2783-3968

Journal of Entomological Society of Iran

2026, 46 (4), 401–414

Research Article

مقایسه پراسنجه‌های دموگرافی کفشدوزک لکه‌هلالی تغذیه شده با دو گونه سفیدبالک (Hem., Aleyrodidae)، *Aleyrodes singularis* و *Bemisia tabaci*

شهرام فرخی[1]، رضوانه مرادیان[2]، حبیب عباسی پور[2]، جلال شیرازی[1] و شهاب منظری[3]

۱. بخش تحقیقات کنترل بیولوژیک، مؤسسه تحقیقات گیاه‌پزشکی کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی (تات)، تهران، ایران

۲. گروه گیاه‌پزشکی، دانشکده کشاورزی، دانشگاه شاهد، تهران، ایران

۳. بخش تحقیقات رده‌بندی حشرات، مؤسسه تحقیقات گیاه‌پزشکی کشور، سازمان تحقیقات، آموزش و ترویج کشاورزی (تات)، تهران، ایران

چکیده: کفشدوزک لکه‌هلالی، *Clitostethus arcuatus* (Rossi) شکارگر سفیدبالک‌ها روی میزبان‌های گیاهی مختلف از جمله زبان‌گنجشک، انار، توت و کاهو وحشی است. در این بررسی، جدول زندگی و پراسنجه‌های زیستی این کفشدوزک روی دو گونه سفیدبالک در شرایط آزمایشگاه مورد ارزیابی قرار گرفت. به منظور تدارک تخم‌های هم‌زاد از دو جمعیت کفشدوزک شکارگر، کفشدوزک‌های لکه‌هلالی به‌صورت جداگانه روی برگ‌های کاهو وحشی (*Lactuca serriola* L.) آلوده به سفیدبالک پنبه *Bemisia tabaci* (Genn.) و سفیدبالک کاهو وحشی *Aleyrodes singularis* Danzig داخل ظروف پتری پلاستیکی پرورش داده شدند. داده‌های ثبت شده مربوط به طول دوره‌های رشدی نابالغ و تخم‌ریزی روزانه حشرات ماده با استفاده از نرم‌افزار TWOSEX-MSChart تجزیه آماری و مقایسه شدند. نتایج نشان داد که پراسنجه‌های رشدی دو جمعیت کفشدوزک لکه‌هلالی اختلاف معنی‌داری با یکدیگر نداشتند. با وجود طولانی‌تر بودن امید به زندگی کفشدوزک‌های پرورش یافته روی *B. tabaci* در قیاس با جمعیت وابسته به *A. singularis*، میزان باروری کفشدوزک‌های تغذیه شده با *A. singularis* (۲۸۷/۸۳ عدد تخم به ازاء هر ماده) به‌صورت معنی‌داری بیشتر از جمعیت پرورش یافته روی سفیدبالک پنبه (۱۵۵/۵۱ عدد تخم به ازاء هر ماده) بود. بیشترین مقدار ارزش تولیدمثلی سن ـ مرحله (v_{xj}) کفشدوزک‌های لکه‌هلالی جمعیت مربوط به سفیدبالک کاهو وحشی در روز سی و چهارم (۷۰/۲۶) بیش از دو برابر بیشترین میزان محاسبه شده برای کفشدوزک‌های ماده پرورش یافته روی سفیدبالک پنبه در روز چهل و پنجم (۳۱/۲) بدست آمد. بر اساس نتایج آزمایش‌های انجام شده و همچنین با توجه به سهولت تکثیر گیاه میزبان، پرورش کفشدوزک لکه‌هلالی روی کاهو وحشی آلوده به سفیدبالک *A. singularis*، دارای مزیت‌های نسبی بیشتری در مقایسه با سفیدبالک پنبه می‌باشد.

کلمات کلیدی: کفشدوزک شکارگر، کیفیت طعمه، جدول زندگی، سفیدبالک، کنترل بیولوژیک

اطلاعات مقاله

دریافت: ۱۴۰۴/۰۶/۱۹

پذیرش: ۱۴۰۵/۰۶/۲۱

انتشار: ۱۴۰۵/۰۸/۰۲

دبیر تخصصی: حسین مددی

نویسنده مسئول: شهرام فرخی

ایمیل: shahram.farrokhi@gmail.com

DOI: https://doi.org/10.22034/jesi.46.4.2

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