pISSN: 0259-9996 – eISSN: 2783-3968

Journal of Entomological Society of Iran

2026, (4), 429–447

Research Article

Effect of sugarcane cultivars on life table parameters and parasitism capacity of *Telenomus busseolae* Gahan (Hymenoptera: Platygastridae), an egg parasitoid of *Sesamia nonagrioides* (Lefèbvre)

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Abstract. The stem borer, *Sesamia nonagrioides* (Lefèbvre), is one of the most important pests of sugarcane in most sugarcane-growing countries worldwide, particularly in Iran. The selection of sugarcane cultivars compatible with the parasitoid wasp, *Telenomus busseolae* Gahan may contribute to the development of effective management strategies against the sugarcane stem borer in Iran. The efficacy of *T. busseolae* fed on *S. nonagrioides* eggs was evaluated on six sugarcane cultivars, SP70-1143, CP57-614, CP73-21, CP69-1062, CP48-103, and IRC99-02, at 27±1°C, relative humidity of 60±5%, and a photoperiod of 16: 8 (L: D) h. Life table data were analyzed using the age-stage, two-sex life table method, and the CONSUME-MSChart was applied to estimate parasitism rate parameters. The longest developmental period of *T. busseolae* was on SP70-1143, and the shortest was estimated on CP48-103. The lowest percentages of parasitism and adult wasp emergence were observed on SP70-1143, whereas the highest values were observed on CP69-1062 and CP48-103. The highest intrinsic rate of increase (r) was observed in CP48-103 (0.242 day^{-1}) and CP69-1062 (0.237 day^{-1}), whereas the lowest was observed in SP70-1143 (0.175 day-1). The finite parasitism rate (ω) of the parasitoid on CP48-103 (0.357 host eggs/day) and CP69-1062 (0.350 host eggs/day) was significantly higher than that of the cultivars. According to the obtained results, the sugarcane cultivars significantly influenced the life table parameters, parasitism capacity, percentage parasitism, and percentage adult emergence of *T. busseolae*. Furthermore, the findings showed that SP70-1143 was inappropriate, whereas CP69-1062 and CP48-103 were appropriate in terms of the parasitism efficiency of *T. busseolae*. These results can be used for developing an efficient integrated pest management program against the sugarcane stem borer.

Keywords: Sugarcane cultivar, stem borer, performance, parasitism capacity, parasitism efficiency.

Article info

Received:	22 June	2026
Accepted:	12 September	2026
Published:	28 October	2026

Subject Editor: Hossein Madadi

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DOI : https://doi.org/10.22034/jesi.46.4.4

Introduction

Sugarcane, *Saccharum officinarum* L. (Poaceae), a multipurpose tropical crop, is well known for its many nutritional and economic uses worldwide (Khalid *et al.*, 2020; Mehdi *et al.*, 2024). In Iran, sugarcane is usually cultivated commercially from six cultivars: SP70-1143 (Sao Paulo, Brazil), CP48-103, CP69-1062, CP57-614, CP73-21 (Canal Point, USA), and IRC99-02 (a crossbred in Cuba and selected in Iran) (Mortazavi Malekshah *et al.*, 2022). Due to monoculture, sugarcane is susceptible to many biotic factors, including plant diseases and insect

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pests. Among various pests, stem borers of the genus *Sesamia* are considered the most destructive insect pests affecting this plant in southern Iran and other regions worldwide (Goebel *et al*., 2014). *Sesamia nonagrioides* (Lefèbvre) (Lepidoptera: Noctuidae) is a major and economically important pest in sugarcane-growing areas of Iran and worldwide (Askarianzadeh *et al*., 2008). The feeding of stem borer larvae on shoots or stems of sugarcane inflicts heavy economic losses to commercial cultivars and significantly reduces both the quality and quantity of extracted sugar (Sattar *et al*., 2016; Nikpay *et al*., 2017).

The management program for *S. nonagrioides* is multi-pronged and requires multiple control methods. Among different control methods, chemical insecticides are not suitable against *S. nonagrioides* due to the endophagous behavior of larvae that hide inside stems, as well as the adverse effects of these compounds on human health, the environment, and natural enemies (Daniali, 1985; Wright & Verkert, 1995). Thus, with the development of sustainable agriculture in several countries, one of the ecologically adopted techniques is the application of biological control methods. The genus *Telenomus* has several species that are very important in regulating stem borer populations in Iran and worldwide (Polaszek *et al*., 1993). *Telenomus busseolae* Gahan (Hymenoptera: Platygastridae) is the most dominant species of the egg parasitoid wasps of *Sesamia* spp. in southern Iran (Baniabbasi, 1981), Southern Africa, the Middle East, and Southern Europe (Polaszek *et al*., 1993). This species is a native endoparasitoid with a relatively high ability to locate hosts and parasitize hidden egg masses (Conti *et al*., 2003). *T. busseolae* is massively produced in insectariums and subsequently released in sugarcane farms in Khuzestan Province (Nikpay *et al*., 2014).

Plants can influence tritrophic interactions, bottom-up effects (Soufbaf *et al*., 2010; Khanamani *et al*., 2014; Abedi *et al*., 2020). Host plant quality, as the first trophic level, can affect the fitness of herbivorous insects as the second trophic level and foraging signs (herbivore-induced plant volatiles, plant tissue damage, and vibrations or movements of the host) of their natural enemies as the third trophic level (Ghorbanian *et al*., 2019; Abedi *et al*., 2020). Mortazavi Malekshah *et al*. (2022) revealed that the physicochemical characteristics of sugarcane cultivars including primary compounds such as protein and carbohydrates, secondary metabolites such as tannins, phenolic compounds, and flavonoids, as well as defensive traits such as trichomes and silica in leaves and sheath, can affect the survival, development, and fecundity of *S. nonagrioides*. In their study, the cultivars CP69-1062 and CP48-103 were classified as susceptible, whereas the cultivar SP70-1143 was identified as the most resistant. Also, Babamir-Satehi *et al*. (2022) showed that secondary metabolites of sugarcane cultivars can reduce the growth and survival rate of *S. cretica* Lederer. Previous studies have demonstrated that host plant cultivars can influence the performance of *T. busseolae.* Halabian *et al*. (2013) assessed the performance of *T. busseolae* on *S. cretica* eggs reared on commercial sugarcane cultivars (CP69-1062, CP57-614, and CP48-103). They showed that the efficiency of *T. busseolae* on CP57-614 was lower than on CP69-1062 and CP48-103. Jamshidnia & Sadeghi (2014) reported that *S. critica* eggs were more favorable than *S. nonagrioides* eggs for the development of this parasitoid. Cheraghi *et al*. (2018) studied the influence of egg age of *S. cretica* on the preference and life table of *T. busseolae* and found that 12-h-old eggs of the host were suitable for mass rearing of *T. busseolae.* The studies by Ghorbanian *et al*. (2019) on pepper cultivars and *Myzus persicae*, and by Abedi *et al*. (2020) on pomegranate cultivars and *Ectomyelois ceratoniae*, indicated that plant cultivar characteristics significantly affected the biology and demographic variables of insect pests and their parasitoids. Furthermore, Mortazavi *et al*. (2022) demonstrated that sugarcane cultivars significantly influenced the biological performance of *S. nonagrioides.* Therefore, evaluating the performance of biological control agents on different cultivars is essential for developing effective biological control programs (Weathersbee *et al*., 2004). This requires assessing the population growth capacity and parasitism rates of biocontrol agents on various cultivars (Nikooei *et al*., 2017).

Recent studies have emphasized the importance of host plant effects in multitrophic interactions, as host plant characteristics can influence herbivore performance and, consequently, interactions between herbivores and their natural enemies. In sugarcane agroecosystems, complex interactions among plants, herbivorous insects, pathogens, and natural enemies have been documented, highlighting the importance of considering plant-mediated and multitrophic relationships when evaluating biological control systems (Gallan *et al*., 2023). Such interactions may indirectly affect parasitoid performance by altering host quality. Although previous studies have evaluated the effects of sugarcane cultivars on the performance of *T. busseolae*, their effects on the demographic performance and parasitism capacity of this parasitoid remain insufficiently understood. Therefore, this study

aimed to evaluate the effects of six commercial sugarcane cultivars (CP69-1062, CP48-103, CP57-614, CP73-21, IRC99-02, and SP70-1143) on the life-table parameters and parasitism capacity of *T. busseolae* developing on *S. nonagrioides* eggs obtained from larvae reared on these cultivars under controlled laboratory conditions. Accordingly, cultivar-associated differences in host quality may be reflected in the survival, development, reproduction, population growth, and parasitism capacity of *T. busseolae.* These findings may contribute to a better understanding of cultivar-associated variation in parasitoid performance and the potential compatibility of sugarcane cultivars with parasitoid-based biological control programs.

Materials and methods

Sugarcane cultivars

The cutting stems of six commercial sugarcane cultivars (CP69-1062, CP57-614, CP48-103, CP73-21, IRC99-02, and SP70-1143) were provided from the sugarcane cultivars bank of Sugarcane & By-products Development Research & Training Institute of Khuzestan, Iran.

Insect culture

Sesamia nonagrioides eggs were collected from the sugarcane fields of Sugarcane and Byproducts Development Company of Khouzestan, Iran. They were maintained in a growth chamber at 27 ± 1°C, a relative humidity of 60 ± 5%, and a photoperiod of 16:8 (L:D) h at the Iranian Research Institute of Plant Protection, Agricultural Research, Education, and Extension Organization (AREEO), Tehran, Iran. The collected eggs were placed in 9 cm Petri dishes with a moist cotton pad to keep humidity. Neonate larvae up to the third larval instar were reared on the cutting stems of each cultivar in larval-rearing plastic containers (19 ×13 × 4 cm) and maintained in a growth chamber under the environmental conditions mentioned above. The larvae were fed on sugarcane stems and shoots. Every 2–3 days, the old stems were replaced with fresh ones as needed. Larvae that reached the third instar were individually transferred onto cut stems and maintained there until pupation. Each set of ten larval-infested stems was transferred into a Plexiglas jar (25 × 17 cm, Venus Co., Tehran, Iran). Ventilation of rearing containers was provided by a fine mesh placed on top of them (Mortazavi *et al.*, 2022). After pupation, they were sexed (Sreng, 1984) and sterilized using a 5% sodium hypochlorite solution (Ranjbar Aghdam & Kamali, 2002). Afterward, male and female pupae were individually placed in a new container (7 × 3 cm with lids) and kept in a growth chamber under the same environmental conditions as during larval rearing until adult emergence. The species *S. nonagrioides* was confirmed based on the morphological characteristics of the male genitalia (Ranjbar Aghdam, 2002). Mating and oviposition of adults were done by transferring 3–7 pairs of newly emerged moths (< 24 h. age) in clear cylindrical containers (17 × 25 cm). 3–5 sugarcane shoots are supplied in each container to provide oviposition substrate, and a small cotton soaked in a 10% water-honey solution is provided to feed the moths (Ranjbar Aghdam & Kamali, 2002). The moths laid eggs under the leaf sheath of the sugarcane shoots. Then, egg masses were collected daily by a soft brush (No. 0.000) and subsequently used in the experiments. To assess the colony's adaptation to each sugarcane cultivar, the insect was reared for one generation on each cultivar, and the eggs obtained from the second generation were used in the experiments. The *T. busseolae* colony originated at the insectarium of Sugarcane and Byproducts Development Company in Khuzestan, Iran, in September 2021. The parasitized eggs were held in glass tubes (3 cm diameter × 20 cm length) until emergence of the parasitoid wasps in a growth chamber at 27 ± 1°C, a relative humidity of 60 ± 5%, and a photoperiod of 16:8 (L:D) h. Immature stages of the parasitoid wasp, *T. busseolae*, were reared (Ranjbar Aghdam & Kamali, 2005) on the eggs of *S. nonagrioides* (<24 h old) on each examined sugarcane cultivar, separately. For this purpose, strips of polyester radiological film (15 cm long × 2 cm wide) were supplied and sterilized using 95% ethyl alcohol solution (Ranjbar Aghdam & Kamali, 2005). Then, the eggs of *S. nonagrioides*, as the natural host of *T. busseolae*, were glued to radiological film strips using a 14% diluted honey solution. Each film strip was transferred into a glass test tube as mentioned above. Then, a single mated female of *T. busseolae* (<24 h old) was placed in each test tube, and the opening side of the tubes was closed with corks. Test tubes were kept in a growth chamber set to the aforementioned environmental conditions until adult wasps emerged. The adults were fed with a small piece of filter paper soaked in a 20% water-honey solution. To adapt and homogenize the parasitoid wasps, *T. busseolae* was reared for two generations on *S. nonagrioides* reared on each sugarcane cultivar, and the third generation of the parasitoid wasp was utilized in the experiments.

Development, survival, and parasitism rate of *Telenomus busseolae*

To determine the influence of various sugarcane cultivars on the development, survival of immature stages, and parasitism rate of *T. busseolae*, 10 glass test tubes (3 cm diameter × 20 cm length) were selected for each sugarcane cultivar. All replicates for the different cultivars were conducted within the same experimental period and under identical environmental conditions. Then, 100 healthy and apparently viable eggs of *S. nonagrioides* were carefully counted and glued on the surface of radiographic film strips, and each strip was transferred to a test tube (Cheraghi *et al.*, 2018). Then, a pair of *T. busseolae* (male and female) from the third generation of the laboratory colony was randomly selected and released in each tube. These tubes were blocked with cotton wool and held in a growth chamber under the previously mentioned environmental conditions for 24 hours. The wasps were removed from the test tubes. The tubes were monitored daily until the parasitoid wasps emerged from their eggs, and the emergence time was recorded. Emerged wasps were sexed based on antennal character. Clubbed antennae of females are completely distinct from filiform antennae of males (Polaszek *et al.*, 1993). Then, these wasps were transferred to a new tube for mating. Daily checks of the tubes were conducted until the emergence of the last parasitoid wasps. Finally, the developmental time and survival rate of the parasitoid wasp were calculated for each treatment. Also, the percentage of parasitism (%) was calculated in each tube. Parasitized eggs were identified based on the characteristic darkening and change in coloration associated with parasitoid development. Furthermore, the emergence percentage was estimated as the ratio of adult wasps to the total number of parasitized eggs in each test tube.

Life table of *Telenomus busseolae*

To evaluate the life table parameters of *T. busseolae*, 30-40 pairs of male and female wasps (<24 h old) were reared on *S. nonagrioides* eggs on each sugarcane cultivar. Each pair was transferred individually into the glass tubes and placed in the same conditions mentioned above. Inside each test tube, 100 eggs of *S. nonagrioides* were attached to radiological film strips. The tubes were checked daily, and the parasitoid wasps were transferred to a new tube with 100 host eggs. Checking the tubes continued until the wasps died. The parasitized eggs from the previous 24h were maintained separately for each female under the same environmental conditions until the emergence of the parasitoids. Developmental time and survival of immature parasitoids were recorded. Also, adult longevity of the parasitoid wasps was estimated for both males and females. For females, the oviposition period was defined as the interval between the first and last days of the oviposition, and fecundity was calculated as the total number of host eggs parasitized by each female during its oviposition period. Age-stage, two-sex life-table parameters were estimated using data from both male and female parasitoids following the approach of Chi & Liu (1985) and the procedures described by Chi *et al.* (2020).

Data analysis

The parasitism percentage and adult emergence of *T. busseolae* were assessed for normality using the Kolmogorov–Smirnov test, and homogeneity of variances was assessed using Levene's test in SPSS version 22.0. The results showed that the data followed a normal distribution and had homogeneity of variances. Subsequently, a one-way ANOVA was used to analyze the variance, and Tukey's test was used to compare the means at the 5% significance level. Development time and life table parameters of *T. busseolae* were estimated using the age-stage, two-sex life table method (Chi & Liu, 1985; Chi *et al.*, 2020) with the TWOSEX-MS Chart (Chi, 2022a). Additionally, the variances and standard errors for the development period and demographic parameters were estimated via bootstrapping with 100,000 resamples (Yu *et al.*, 2013; Chi *et al.*, 2020), and the means of the bootstrap values were compared using the paired-bootstrap test (Bahari *et al.*, 2018).

Parameters of the parasitism rate were calculated from the daily parasitism data. The age-stage-specific parasitism rate (c_{xj}) (the count of host insect parasitized per parasitoid of the age x and stage j), the age-specific parasitism rate (k_x) (the average count of host parasitized per each parasitoid at the age x and stage j), age stage-specific survival rate (s_{xj}), age-specific net parasitism rate (q_x), net parasitism rate (C_0) (the average count of parasitized hosts by a parasitoid through its lifespan), transformation rate from host population to parasitoid offspring (Q_p) (the average count of parasitized hosts by a parasitoid to generate an adult wasp), stable parasitism rate (ψ), finite parasitism rate ($\lambda\psi = \omega$) (parasitism potential of a parasitoid population) were determined

accordingly (Chi & Yang, 2003; Wang *et al.*, 2016; Ghorbanian *et al.,* 2019). The CONSUME-MSChart was used to estimate parasitism rate parameters (Chi, 2022b). Variances and standard errors for these parameters were calculated using the bootstrap resampling method, and the paired-bootstrap test was used to compare the means.

Hierarchical cluster analysis was performed to identify underlying patterns and groupings in the data that are not immediately apparent, allowing for a more systematic interpretation of the results. A cluster diagram of sugarcane cultivars was drawn based on the demographic parameters and parasitism capacity of *T. busseolae* parasitizing *S. nonagrioides* eggs on tested sugarcane cultivars, using Ward's method with squared Euclidean distance in SPSS version 22.0.

Results

Parasitism percentage and adult emergence

Fig. 1 shows the percentage of parasitism of *T. busseolae* on *S. nonagrioides* eggs reared on examined sugarcane cultivars. The mean percentage of egg parasitism in *T. busseolae* significantly differed from 58.10% on SP70-1143 to 81.30% on CP48-103 ($F = 30.399$; df = 5, 54; $p < 0.001$). Fig. 2 displays the percentage adult emergence of *T. busseolae* fed on *S. nonagrioides* eggs reared on sugarcane cultivars. The emergence of adult wasps on CP69-1062 and CP48-103 was significantly higher compared to other cultivars ($F = 124.692$; df = 5, 54; $p < 0.001$).

Development and survival rate of *Telenomus busseolae*

Table 1 demonstrates the developmental time and survival rate of *T. busseolae* on *S. nonagrioides* eggs reared on sugarcane cultivars. The average developmental time of *T. busseolae* differed significantly among the examined cultivars. The longest developmental time was 16.19 days on SP70-1143, and the shortest was 15.09 days on CP48-103. Different sugarcane cultivars significantly influenced the survival rate of immature stages. The lowest survival rates were 76.43 ± 4.53% and 77.51 ± 4.65% on SP70-1143 and CP57-614, respectively, and the highest rates were 90.13 ± 3.51% and 88.51 ± 3.61% on CP69-1062 and CP48-103, respectively. There are significant differences among the tested sugarcane cultivars in adult longevity and reproductive variables of *T. busseolae* (Table 1). The longevity of female *T. busseolae* was the longest on CP48-103 and the shortest on SP70-1143. The male adult longevity of *T. busseolae* was significantly longer on CP48-103 than on other cultivars. The results showed that female adult parasitoids reared on each sugarcane cultivar immediately started laying eggs after mating, so the length of the adult pre-oviposition period (APOP), which refers to the duration between adult appearance and the first oviposition, was equal to zero (APOP = 0).

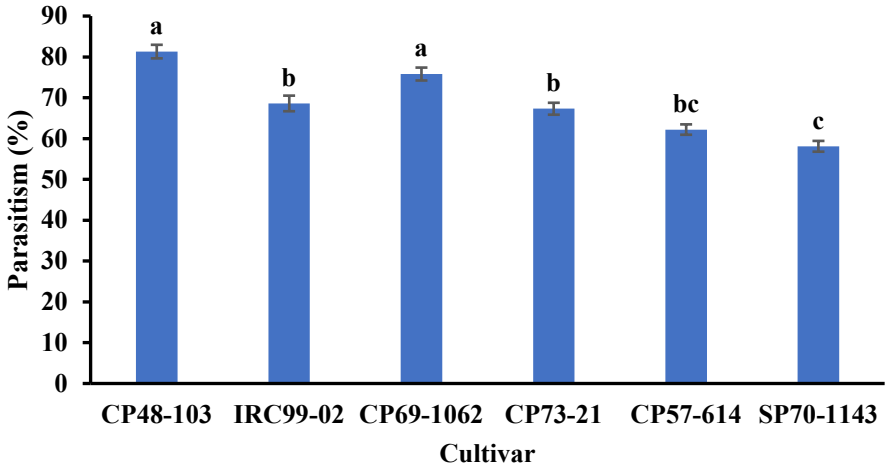


Fig. 1. Mean (±SE) parasitism (%) of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars. Mean values followed by different letters differ significantly according to Tukey's test ($P < 0.05$).

The total pre-ovipositional period (TPOP), the time between egg and the first oviposition, was the shortest on CP69-1062 and CP48-103. *T. busseolae* fed on CP48-103 had the longest oviposition period, whereas those fed on CP57-614 and SP70-1143 had the shortest oviposition period. The lowest and highest fecundity values for *T. busseolae* were SP70-1143 and CP48-103, respectively.

Survival rate and fecundity curves of *Telenomus busseolae*

Fig. 3 displays the age-stage-specific survival rate (s_{xj}) of *T. busseolae* on *S. nonagrioides* eggs reared on the tested cultivars. The highest survival percentages of *T. busseolae* immature stages were on CP69-1062 and CP48-103. Although male adults' survival curves did not differ significantly among the tested cultivars, female adults showed more spread survival curves in CP69-1062 and CP48-103. In Fig. 4, the age-specific survival rate (l_x), age-specific fecundity (m_x), and the age-stage-specific fecundity (f_{xj}) of *T. busseolae* on *S. nonagrioides* eggs reared on different sugarcane treatments are demonstrated.

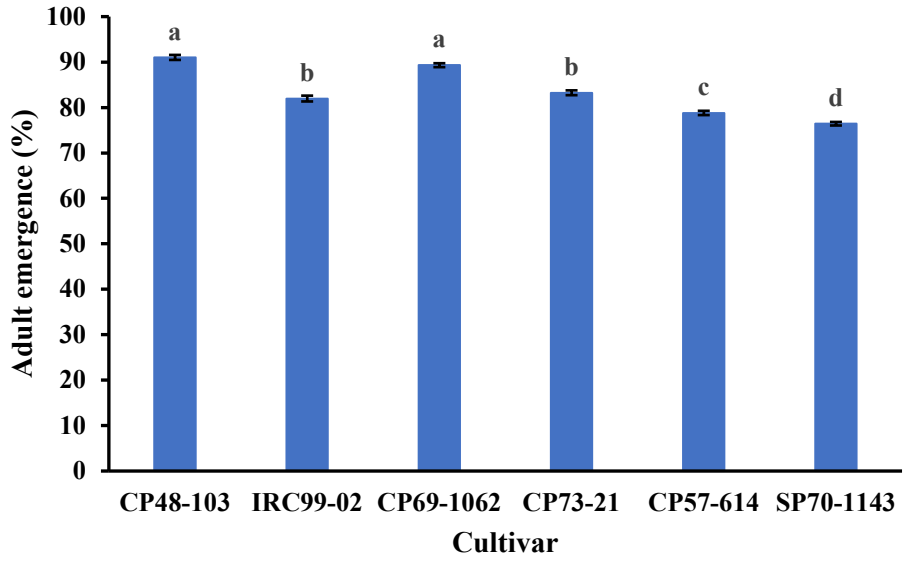


Fig. 2. Mean (±SE) adult emergence (%) of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars. Mean values followed by different letters differ significantly according to Tukey's test ($P < 0.05$).

Table 1. Mean (± SE) developmental time, survival rate, reproductive periods, fecundity and longevity of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

Cultivars	Developmental time (day)	Immature survival (day)	TPOP (day)	Oviposition Period (day)	Fecundity (eggs/female)	Female adult longevity (day)	Male adult longevity (day)
CP48-103	15.09±0.08e	88.51±3.61a	15.10±0.11c	5.21±0.09a	112.83±0.85a	6.38±0.16a	5.60±0.22a
IRC99-02	15.94±0.08bc	80.11±4.42ab	16.14±0.14a	3.76±0.11cd	76.06±1.66c	4.76±0.18bc	4.53±0.23b
CP69-1062	15.49±0.07d	90.13±3.51a	15.59±0.10b	4.12±0.13b	100.12±2.40b	4.85±0.11b	4.55±0.19b
CP73-21	15.80±0.06c	82.53±4.44ab	15.91±0.9a	3.9±0.10bc	80.39±1.48c	4.81±0.16bc	4.12±0.21b
CP57-614	16.13±0.09ab	77.51±4.65b	16.13±0.14a	3.56±0.10d	69.66±1.40d	4.53±0.15bc	4.34±0.23b
SP70-1143	16.19±0.09a	76.43±4.53b	16.17±0.14a	3.5±0.10d	62.96±1.50e	4.46±0.14c	4.29±0.21b

APOP was zero for all treatments.
TPOP, total pre-ovipositional period (from egg to first oviposition).
Means in each column followed by different letters are significantly different ($p< 0.05$, paired bootstrap test).

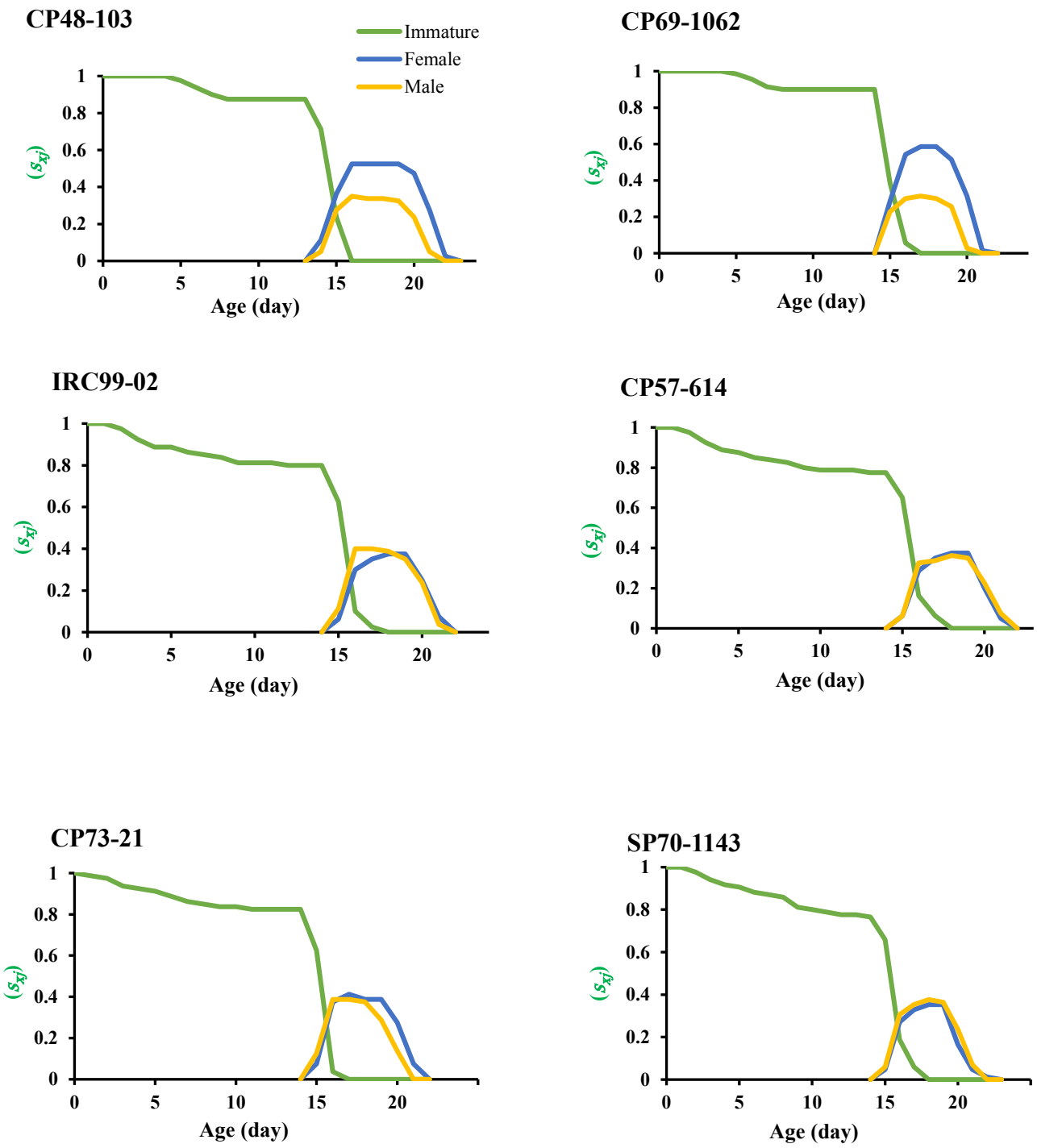


Fig. 3. Age-stage survival rate (s_{xj}) of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

The l_x curve of *T. busseolae* showed the highest convexities on CP69-1062 and CP48-103, and the lowest convexities on SP70-1143 and CP57-614. The mx curve showed that parasitoids began laying eggs earlier on CP48-103, on day 14, compared with the other treatments. Also, maximum daily fecundity occurred on CP69-1062 on day 16, with 23 eggs/individual. In addition, parasitoids had longer longevity and oviposition period on this cultivar. The highest values of f_{xj} of *T. busseolae* on SP70-1143, CP57-614, IRC99-02, CP73-21, CP48-103,

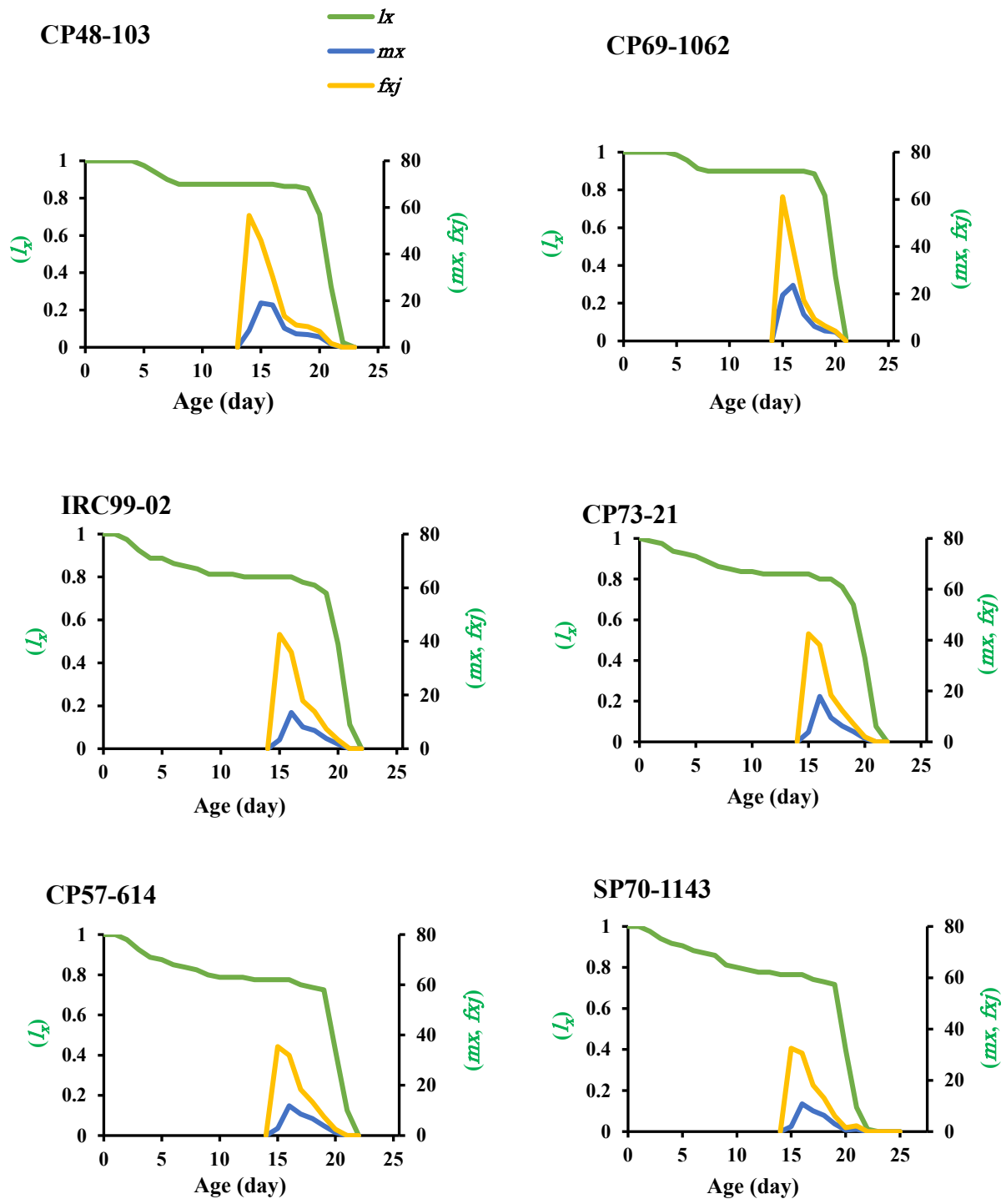


Fig. 4. Age-specific survival rate (*lx*), age-specific fecundity (*mx*), and age-stage-specific fecundity (*fxj*) of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

and CP69-1062 were 33, 35, 42, 43, 56, and 61 eggs/female/day, respectively. According to these graphs, the highest reproduction of *T. busseolae* was on CP69-1062 and CP48-103.

Life table parameters of *Telenomus busseolae*

Table 2 shows the values of demographic parameters of *T. busseolae* on evaluated cultivars. All calculated parameters of *T. busseolae* were significantly influenced by sugarcane cultivars. The parameters *GRR* and R_0

showed the highest values in parasitoids reared on CP69-1062 and CP48-103, and no significant differences were found for parasitoids reared on other sugarcane cultivars. The values of r and λ were lowest on SP70-1143 and highest on CP69-1062 and CP48-103. The lowest T values were observed on CP69-1062 and CP48-103.

Parasitism capacity of *Telenomus busseolae*

Fig. 5 reveals the age-stage-specific parasitism rate of *T. busseolae*. The c_{xj} value on the 1st day of adult emergence for CP69-1062 and CP48-103 was higher than for the other cultivars. Furthermore, the maximum values of c_{xj} were observed on CP69-1062 (61.10 eggs on the 15th day) and CP48-103 (56.57 eggs on the 14th day), while the minimum value was observed on SP70-1143 (32.5 eggs on the 15th day). The maximum and minimum values of k_x were 23.58 eggs and 10.81 eggs at the 16th day on the CP69-1062 and SP70-1143 cultivars, respectively (Fig. 6). Moreover, the lowest q_x values of *T. busseolae* were on SP70-1143, and the highest on CP48-103 (Fig. 6).

The values of the parasitism rate of *T. busseolae* are displayed in Table 3. The C_0 values of the parasitoid and stable parasitism rate (ψ) on cultivars CP69-1062 and CP48-103 were higher compared to the other sugarcane cultivars. The transformation rate (Q_p) did not differ significantly among the tested cultivars. The value of Q_p was 1, which indicates that *T. busseolae* lays one egg in each *S. nonagrioides* egg. The finite parasitism rates (ω) on the susceptible (CP48-103 and CP69-1062) and resistant (SP 70-1143) sugarcane cultivars were 0.357, 0.350, and 0.255 host eggs per parasitoid, respectively.

Cluster analysis

In Fig. 7, the dendrogram of sugarcane cultivars based on the demographic parameters and parasitism capacity of *T. busseolae* parasitizing *S. nonagrioides* eggs is shown. The tested sugarcane cultivars were classified into two main clusters: A (cultivars CP57-614, IRC99-02, SP70-1143, and CP73-21); B (cultivars CP69-1062 and CP48-103).

Table 2. Mean (± SE) life table parameters of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

Cultivars	Sample size (n)	*GRR* (offspring)	R_0 (offspring)	r (day^{-1})	λ (day^{-1})	T (day)
CP48-103	40	69.75±6.64a	59.25±6.32a	0.242±0.0067a	1.271±0.008a	16.97±0.110b
IRC99-02	30	37.25±4.95b	28.53±4.17b	0.188±0.0086bc	1.206±0.014bc	17.76±0.129a
CP69-1062	40	72.29±7.33a	58.67±6.04a	0.237±0.0063a	1.267±0.008a	17.14±0.095b
CP73-21	33	42.87±5.16b	33.15±4.45b	0.198±0.0079b	1.219±0.009b	17.60±0.088a
CP57-614	30	35.09±4.60b	26.11±3.80b	0.183±0.0085bc	1.211±0.010bc	17.81±0.129a
SP70-1143	30	31.76±4.42b	22.91±3.41b	0.175±0.0086c	1.194±0.011c	17.83±0.124a

Means in each column followed by different letters are significantly different ($p < 0.05$, paired bootstrap test). *GRR*, gross reproductive rate; $R0$, net reproductive rate; r, intrinsic rate of increase; λ, finite rate of increase; T, mean generation time.

Table 3. Mean (± SE) parasitism rates of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

Cultivars	Sample size (n)	Net parasitism rate (C_0) (host eggs)	Transformation rate (Qp) (host eggs per viable parasitoid egg)	Stable parasitism rate (ψ) (host eggs/day)	Finite parasitism rate (ω) (host eggs/day)
CP48-103	40	59.25±6.32a	1.00±0.00a	0.280±0.011a	0.357±0.016a
IRC99-02	30	28.54±4.17b	1.00±0.00a	0.230±0.013b	0.278±0.016b
CP69-1062	40	58.98±6.11a	1.00±0.00a	0.276±0.015a	0.350±0.015a
CP73-21	33	33.15±4.44b	1.00±0.00a	0.240±0.012b	0.293±0.016b
CP57-614	30	26.11±3.81b	1.00±0.00a	0.225±0.012b	0.271±0.017b
SP70-1143	30	22.91±3.42b	1.00±0.00a	0.214±0.012b	0.255±0.0171b

Means in each column followed by different letters are significantly different ($p < 0.05$, paired bootstrap test).

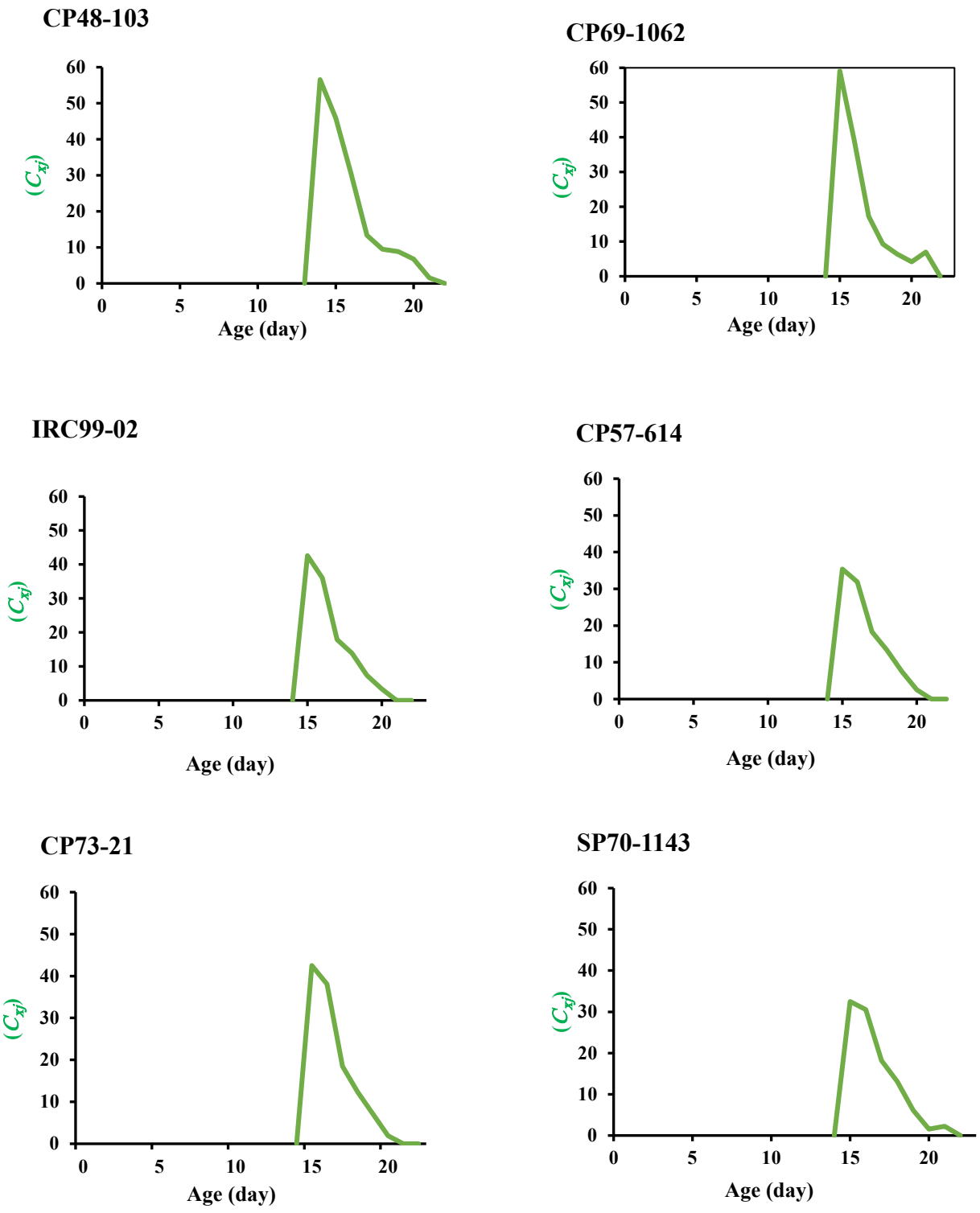


Fig. 5. The age-stage specific parasitism rate (C_{xj}) of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

Discussion

The documented variability in the biological performance of *T. busseolae* among sugarcane cultivars may be associated with differences in the physicochemical characteristics of the host plants. Such characteristics can

directly or indirectly influence the ability of natural enemies to locate, accept, and develop on their hosts (Madahi *et al.*, 2019; Abedi *et al.*, 2020). Parasitoid wasps reared on CP69-1062 and CP48-103 had the highest parasitism rate, adult emergence percentage, and survival rate, indicating that these cultivars have strong potential to increase the fitness (survival, oviposition, growth, and adult emergence) of parasitoids. Moreover, the lowest percentages of parasitism and adult emergence were observed on cultivar SP70-1143.

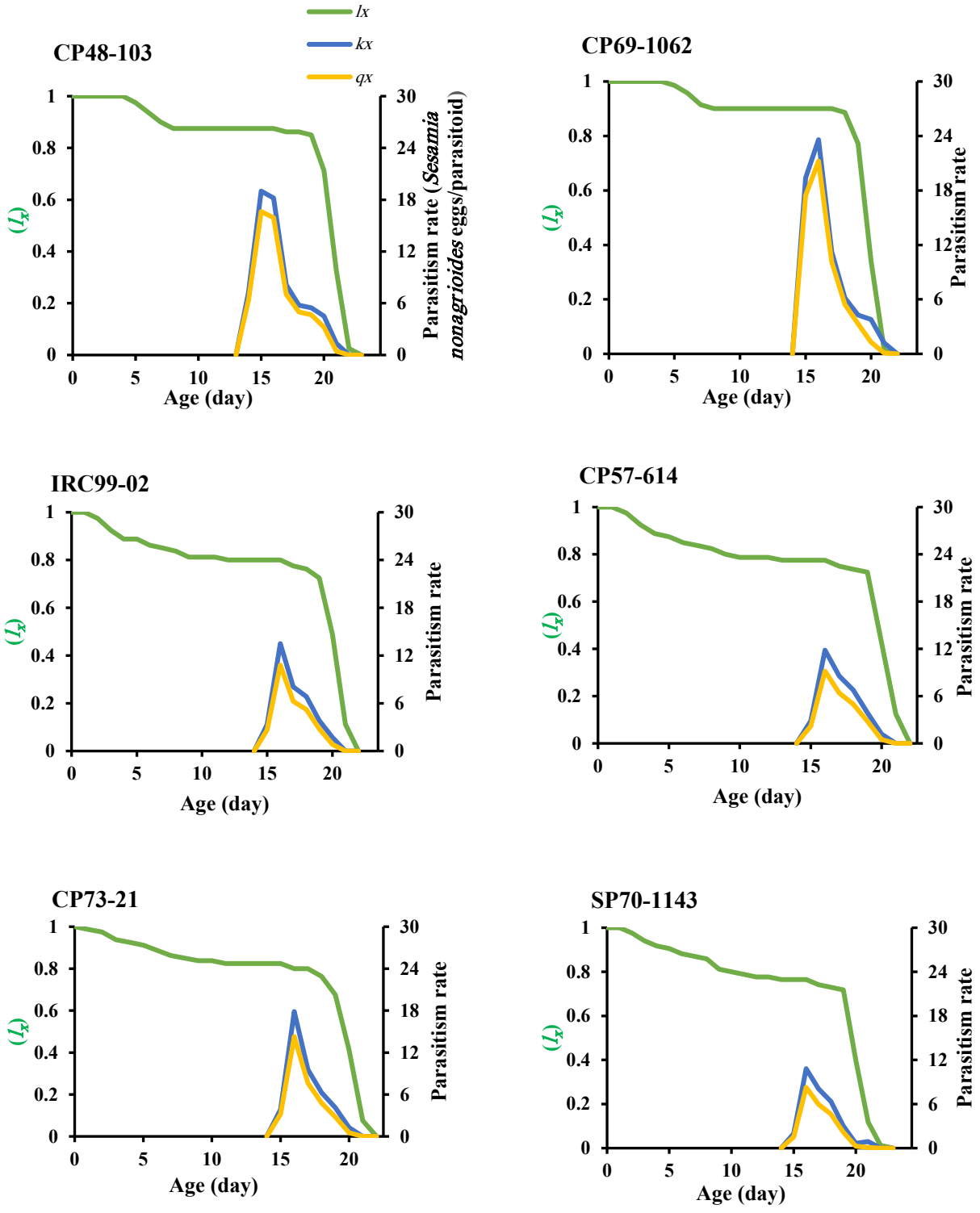


Fig. 6. Age-specific survival rate (*lx*), age-specific parasitism rate (*kx*), and age-specific net parasitism rate (*qx*) of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on examined sugarcane cultivars.

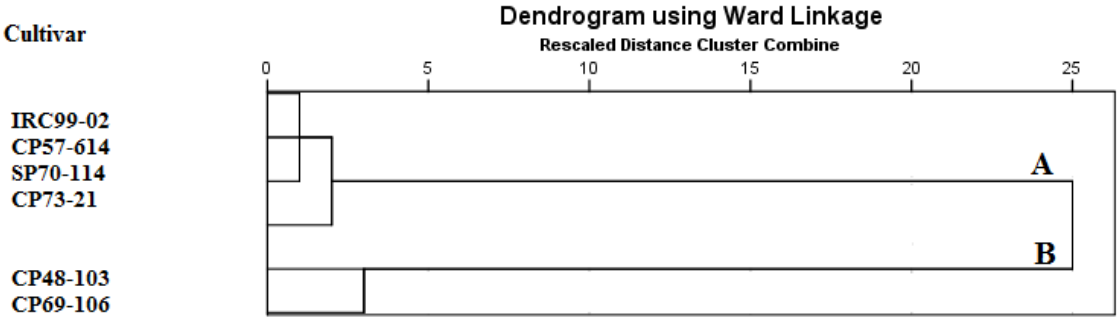


Fig. 7. Dendrogram of sugarcane cultivars classified based on the demographic parameters and parasitism capacity of *Telenomus busseolae* parasitizing *Sesamia nonagrioides* eggs on these cultivars (Ward's method).

These contrasts in the percentage parasitism and emergence of *T. busseolae* on sugarcane cultivars may be associated with cultivar-related differences in host quality. Mortazavi Malekshah *et al.* (2022) reported that CP69-1062 and CP48-103 were susceptible cultivars against *S. nonagrioides*, because they had the lowest secondary metabolites (tannins, phenolics, and flavonoids), shoot hardness, and trichome density. These plant factors significantly affected the oviposition preference of *S. nonagrioides*. Therefore, cultivar-associated differences in plant characteristics may have indirectly influenced *T. busseolae* performance through potential changes in host quality during the larval development of *S. nonagrioides* on different sugarcane cultivars. Hence, the most susceptible sugarcane cultivars showed the highest value of parasitism and adult wasp emergence. These outcomes agree with those of Jamshidnia *et al.* (2009), who revealed that the percent parasitism of *T. busseolae* reared on *Sesamia* spp. eggs was considerably higher on cultivar CP48-103 than on cultivars CP69-1062, CP57-614, and SP70-1143. Similarly, Sobhani *et al.* (2015) studied the efficiency of *Habrobracon hebetor* Say parasitizing *Ectomyelois ceratoniae* (Zeller) larvae fed on various pomegranate cultivars. They showed that pomegranate cultivars considerably influenced the parasitism percentage of *H. hebetor*, so that the susceptible cultivar G-Shahpar Varamin had the highest parasitism percentage. Also, this cultivar was introduced as a compatible cultivar for parasitoids (parasitoid-friendly) in integrated pest management programs for *E. ceratoniae*. Therefore, the parasitism rate among parasitoids can differ considerably depending on the host plant species (Golizadeh *et al.*, 2008) and even among different cultivars of the same plant species (Ghorbanian *et al.*, 2019). The low percentage of parasitism of *T. busseolae* on SP70-1143 may be associated with differences in the physicochemical and biochemical characteristics of the tested sugarcane cultivars, which may subsequently affect *S. nonagrioides* egg quality and parasitoid performance. Previous studies have characterized SP70-1143 as a relatively resistant sugarcane cultivar, with higher silica content and elevated levels of secondary metabolites associated with resistance to *S. nonagrioides* (Mortazavi Malekshah *et al.*, 2022; Babamir-Satehi *et al.*, 2022). Such differences in host plant quality may, in turn, affect the suitability of *S. nonagrioides* eggs for development and parasitism of *T. busseolae*. This interpretation is consistent with the documented importance of plant–pest–parasitoid interactions, whereby plant characteristics may indirectly influence parasitoid performance through changes in host quality (Harvey, 2005). In particular, previous research has shown that plant-derived nutrients and defensive compounds consumed by herbivores may alter the composition and quality of their eggs, thereby affecting the performance of egg parasitoids (Becker *et al.*, 2023).

The findings of the present study showed that *T. busseolae* parasitizing *S. nonagrioides* eggs from various sugarcane cultivars was able to complete its life cycle. Still, the growth rates and survival rates of the parasitoid on the tested sugarcane cultivars were significantly different. In the present study, the relatively fast growth of *T. busseolae* on the cultivar CP48-103 indicates the positive effect of this cultivar on the immature survival and development period of this natural enemy. Moreover, low survival and delayed development time of this parasitoid were recorded on SP70-1143. Differences in the mortality and immature duration of parasitoids across tested sugarcane cultivars are likely attributable to differences in food quality, which influence parasitoid growth (Ghorbanian *et al.*, 2019; Abedi *et al.*, 2020). Previously, it has been reported that the highest and lowest concentrations of secondary metabolites (tannins, phenols, and flavonoids) were respectively related to SP70-1143

and CP48-103 (Mortazavi Malekshah *et al*., 2022). Therefore, the shortest immature period of *T. busseolae* on CP48-103 may be associated with reduced levels of secondary metabolites in it. In some herbivorous insects, plant-derived secondary compounds acquired through maternal feeding can be transferred to the eggs (Newcombe *et al*., 2014), suggesting a possible pathway through which cultivar-related differences in plant chemistry could indirectly affect parasitoid development. However, this mechanism has not been demonstrated for *S. nonagrioides* or the secondary metabolites of CP48-103 and therefore requires further investigation.

Also, the shortest developmental period of *T. busseolae* on SP70-1143 may be due to the high concentration of secondary compounds in this cultivar (Mortazavi Malekshah *et al.,* 2022). These factors can reveal antibiosis resistance in the resistant cultivar SP70-1143, which refers to the host plant's ability to adversely affect the insect pest's biological processes (Smith, 2005).Hence, according to the findings of Mortazavi Malekshah *et al*. (2022), and considering plant-pest-parasitoid interactions, among the biochemical characteristics of the tested cultivars, tannins, phenols, and flavonoids play the most important inhibitory role in the survival and growth rate of *T. busseolae*. Orr *et al*. (1985) indicated that the immature period of *Copidosoma floridanum* (Ashmead) reared on *Pseudoplusia includens* Walker on a susceptible soybean cultivar was shorter than that on a resistant cultivar. Also, Abedi *et al*. (2020) recorded that the development period of two species of *Venturia canescens* Gravenhorst on *E. ceratoniae* larvae reared on resistant cultivars of pomegranate (Esfahani-Daneghermez and Meles-Danesyah) is longer than that of a susceptible cultivar (Shahvare-Danesefid cultivar). The differences in the developmental periods of parasitoids across cultivars could be linked to the nutritional quantity and quality or the physical characteristics of the cultivars. Therefore, the efficiency of parasitoids in an environment can be influenced by herbivores (the second level of nutrition) and plants fed by herbivores (the first level of nutrition). Hence, the quality of the host plant, the first level of nutrition, affects the biological characteristics of parasitoids, the third level of nutrition (Golizadeh *et al*., 2008; Wang *et al*., 2016; Abedi *et al*., 2020; Rezaei *et al*., 2022).

Outcomes of this research indicated that adult females of *T. busseolae* had higher longevity and fertility on CP48-103 and CP69-1062. Therefore, these cultivars were more appropriate than others for the growth and parasitism efficacy of *T. busseolae*. These outcomes can be due to lower levels of phenols, flavonoids, and tannins in them (Mortazavi Malekshah *et al*., 2022). These compounds, which are often involved in plant defense mechanisms, appear to reduce the reproductive capacity of the parasitoid wasps. Hence, cultivars with low concentrations of these metabolites likely provide a more favorable environment for *T. busseolae*, leading to the production of female wasps with greater reproductive capacity. In addition, the lowest adult longevity and reproduction of *T. busseolae* females reared on SP70-1143 are likely due to the high concentration of phenols, flavonoids, and tannins in it (Mortazavi Malekshah *et al*., 2022), which results in a decrease in female longevity and reproductive capacity. This is confirmed by Mortazavi Malekshah *et al*. (2022), who reported that the longevity and reproduction of *S. nonagrioides* females are negatively correlated with the secondary metabolite content in the examined sugarcane cultivars. Therefore, the nutritional quality and secondary metabolite levels of plant cultivars play a main role in determining the growth rate, survival rate, and reproductive capacity of phytophagous pests, as well as the size and weight of their progeny (Khanamani *et al*., 2014; Abedi *et al*., 2019; Mortazavi Malekshah *et al*., 2022). Furthermore, these factors, in turn, affect the development, survival, and reproductive capacity of their natural enemies (Soufbaf *et al*., 2012; Ghorbanian *et al*., 2019; Abedi *et al*., 2020).

The intrinsic rate of increase (r) is a key parameter for assessing pest-natural enemy interactions. It is strongly influenced by the nutritional quality of the host plant at the first trophic level. The value of this parameter is affected by immature development period, reproductive time, and fecundity (Southwood & Henderson, 2000). The parasitoids that were reared on *S. nonagrioides* eggs developed on CP69-1062 and CP48-103 had the highest value of r. This was associated with a shorter development time, a higher survival rate, and higher fecundity of *T. busseolae* on these cultivars. On the contrary, *T. busseolae* developed more slowly and produced fewer eggs when reared on SP70-1143, resulting in a lower r value. The main reason for the increase in the values of r and other growth population parameters (R_0, *GRR*, and λ) of *T. busseolae* on CP69-1062 and CP48-103 is likely due to the low amounts of secondary metabolites (tannins, phenols, and flavonoids) in these two cultivars (Mortazavi Malekshah *et al*., 2022). Also, the lowest values of population growth parameters for *T. busseolae* on SP70-1143 are likely due to the poor nutritional quality of this cultivar, which contains a lower concentration of primary compounds than the other tested cultivars. These findings are consistent with previous evidence that host plant

characteristics can influence parasitoid performance indirectly through effects on herbivore host quality. For example, Gharekhani *et al.* (2024) showed that tomato cultivar and nitrogen status influenced the demographic parameters of *Trichogramma principium* developing on *Helicoverpa armigera* eggs. Such cultivar-associated differences may be related to plant defensive compounds, which can act as natural defenses by reducing insects' ability to extract sufficient nutrients, thereby affecting host quality and subsequent parasitoid performance (Mortazavi Malekshah *et al.*, 2022).

In evaluating the effectiveness of a parasitoid, both the finite parasitism rate and the intrinsic rate of population increase must be considered, and an efficient parasitoid has the highest values of these factors (Yu *et al.*, 2013). According to our findings, ω and r values of *T. busseolae* reared on cultivars CP69-1062 and CP48-103 were higher than those of the other cultivars. Consequently, CP69-1062 and CP48-103, as more favorable cultivars (with the lowest amounts of secondary metabolites), were relatively suitable compared with other sugarcane cultivars for rearing and increasing the efficiency of *T. busseolae*. Thus, higher secondary compound content in the resistant cultivar SP70-1143 adversely affected the development, reproduction, and performance of the parasitoids. Similarly, other authors have shown the adverse impact of resistant cultivars on parasitoid efficiency (Kauffman & Flanders, 1985; Reed *et al.*, 1991; Nikooei *et al.*, 2017). Our result is in accordance with reports of Ghorbanian *et al.* (2019), who found that *Diaeretiella rapae* (McIntosh) fed on *Myzus persicae* (Sulzer) reared on the sensitive pepper cultivar had the highest r value compared to aphids raised on the resistant cultivars. Similarly, Abedi *et al.* (2020) reported that the population parameters of *V. canescens* feeding on *E. ceratoniae* in resistant pomegranate cultivars showed a significant negative correlation with the secondary metabolites of the host plants, and that this parasitoid responded negatively to higher secondary metabolite concentrations.

Since each parasitoid requires only one host to complete its life cycle, the quality of the host insect, which is influenced by the host plant quality, affects the efficiency of the parasitoids (Harvey *et al.*, 2003). In this study, variation in parasitoid efficiency among sugarcane cultivars is attributed to differences in primary and secondary metabolite levels (Mortazavi Malekshah *et al.*, 2022). Abedi *et al.* (2020) studied the interactions between *E. ceratoniae* and its parasitoid, *V. canescens*, across different pomegranate cultivars. They showed that the parasitoid's efficiency was higher on the susceptible cultivar Shahvare Danesefid. Thus, the cultivars compatible with biological control agents could enhance the performance of pest management techniques (Sobhani *et al.*, 2015).

Conclusion

Our findings showed that the sugarcane cultivar significantly affected the biological performance and parasitism capacity of *T. busseolae*. These results provide further insight into the tri-trophic interactions among sugarcane, *S. nonagrioides*, and *T. busseolae*. Cluster analysis based on life-table and parasitism parameters identified CP69-1062 and CP48-103 as the most suitable cultivars for *T. busseolae*, whereas SP70-1143 showed lower suitability for parasitism. These results suggest a potential trade-off between host plant resistance and parasitoid performance, highlighting the importance of cultivar selection when developing parasitoid-based biological control programs against *S. nonagrioides.* Considering the high yield and climatic adaptability of these six cultivars in Iranian sugarcane fields, future field studies are needed to validate cultivar–parasitoid compatibility and determine the optimal timing, frequency, and density of parasitoid releases under different cultivar and environmental conditions. Such studies may provide valuable information to integrate cultivar selection and parasitoid-based biological control into sustainable integrated pest management programs for *S. nonagrioides.*

Author's Contributions

Seyedeh Atefeh Mortazavi Malekshah: investigation, methodology, formal analysis, draft preparation, visualization and Conceptualization; **Hossein Ranjbar Aghdam**: methodology, visualization; formal analysis, final review and editing, supervision, project administration and funding acquisition; **Bahram Naseri:** methodology, visualization; formal analysis, final review and editing, supervision; **Jabraeil Razmjou**: final review and editing; **Seyed Ali Asghar Fathi**: final review and editing.

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Funding

This work was supported by the University of Mohaghegh Ardabili and the Iranian Research Institute of Plant Protection without an approved Grant.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Acknowledgments

This research received financial and technical support from the University of Mohaghegh Ardabili and the Iranian Research Institute of Plant Protection, which is greatly appreciated.

Ethics Approval and Consent to Participate

Insects were used in this study. All aplicable international, national, and institution alguidelines for the care and use of animals were followed. This article does not contain any studies with human participants performed by the authors.

Conflict of Interest

The authors declare no conflict of interest.

Generative AI statement

The authors declare that no Gen AI was used in the creation of this manuscript.

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Citation: Mortazavi Malekshah, S. A., Ranjbar Aghdam, H., Naseri, B., Razmjou, J., Fathi, S. A. A. (2026). Effect of sugarcane cultivars on life table parameters and parasitism capacity of *Telenomus busseolae* Gahan, an egg parasitoid of *Sesamia nonagrioides* (Lefèbvre). *Entomol. Soc. Iran*, 46(4), 429–447.

DOI :https://doi.org/10.22034/jesi.46.4.4

URL: https://jesi.areeo.ac.ir/article_136479.html

pISSN: 0259-9996 – eISSN: 2783-3968

Journal of Entomological Society of Iran

2026, (4), 429–447

Research Article

تاثیر ارقام مختلف نیشکر بر پارامترهای جدول زندگی و ظرفیت پارازیتیسمی (Hym., Platygastridae) *Telenomus busseolae*، پارازیتوئید تخم *Sesamia nonagrioides* (Lefèbvre)

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چکیده: کرم ساقه‌خوار *Sesamia nonagrioides* (Lefèbvre)، یکی از مهم‌ترین آفات نیشکر در اکثر کشورهای نیشکرخیز جهان، به ویژه ایران می‌باشد. انتخاب ارقام نیشکر سازگار با زنبور پارازیتوئید، *Telenomus busseolae* Gahan، می‌تواند به توسعه راهبردهای مؤثر برای مدیریت ساقه‌خوار نیشکر در ایران کمک کند. عملکرد *T. busseolae* تغذیه‌شده با تخم‌های *S. nonagrioides* روی شش رقم نیشکر، SP70-1143، CP57-614، CP73-21، CP69-1062، CP48-103 و IRC99-02، در اتاقک رشددر دمای ۱±۲۷ درجه‌ی سلسیوس، رطوبت نسبی ۵±۶۰ درصد و دوره‌ی نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی بررسی شد. داده‌های جدول زندگی با استفاده از روش جدول زندگی دو جنسی تجزیه و تحلیل شدند. به منظور برآورد پارامترهای نرخ پارازیتیسم از نرم‌افزار CONSUME-MSChart استفاده شد. طولانی‌ترین دوره رشدی *T. busseolae* روی رقم SP70-1143 و کوتاه‌ترین آن روی رقم CP48-103 بود. کمترین درصد پارازیتیسم و درصد ظهور زنبور بالغ روی رقم SP70-1143 ثبت شد، در حالی که بیشترین مقادیر آنها روی ارقام CP69-1062 و CP48-103 ثبت شد. بیشترین نرخ ذاتی افزایش جمعیت (r) روی ارقام CP48-103 (۰/۲۴۲ بر روز) و CP69-1062 (۰/۲۳۷ بر روز) مشاهده شد، در حالی که کمترین مقدار در رقم SP70-1143 (۰/۱۷۵ بر روز) به دست آمد. نرخ متناهی پارازیتیسم (ω) زنبور پارازیتوئید روی ارقام CP48-103 (۰/۳۵۷ تخم میزبان در روز) و CP69-1062 (۰/۳۵۰ تخم میزبان در روز)، به طور قابل توجهی بالاتر از سایر ارقام مورد بررسی بود. طبق نتایج به دست آمده، ارقام نیشکر به طور قابل توجهی روی پارامترهای جدول زندگی، ظرفیت پارازیتیسم، درصد پارازیتیسم و درصد ظهور حشرات بالغ *T. busseolae* تأثیر گذاشتند. علاوه بر این، یافته‌ها نشان داد که رقم SP70-1143 برای کارایی پارازیتیسم *T. busseolae* نامناسب بود، در حالی که ارقام CP69-1062 و CP48-103 مناسب بودند. این نتایج می‌تواند برای توسعه یک برنامه مدیریت تلفیقی کارآمد علیه کرم ساقه‌خوار نیشکر مورد استفاده قرار گیرد.

کلمات کلیدی: ارقام نیشکر، کرم ساقه خوار، عملکرد ظرفیت پارازیتیسم، کارایی پارازیتیسم.

اطلاعات مقاله

دریافت: ۱۴۰۵/۰۴/۰۱

پذیرش: ۱۴۰۵/۰۶/۲۱

انتشار: ۱۴۰۵/۰۸/۰۶

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DOI : https://doi.org/10.22034/jesi.46.4.4

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