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Host stage preference and demographic parameters of *Leptomastix dactylopii* (Hymenoptera: Encyrtidae) on vine mealybug *Planococcus ficus* (Hemiptera: Pseudococcidae)

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Abstract

Background: This study was conducted to investigate host stage preference and demographic parameters of the parasitoid species, *Leptomastix dactylopii* Howard (Hymenoptera: Encyrtidae), the parasitoid of vine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae), an important pest in vineyards in many countries.

Results: The results revealed that *L. dactylopii* was not able to develop on the 1st and 2nd nymphal instars of *P. ficus* and preferred female mealybugs as the host to the 3rd nymphal instar. Hind tibia length and head capsule width of both female and male parasitoids emerged from the mummies of mealybugs parasitized in the female stage were greater than the values of the parasitoids emerged from the mummies of mealybugs parasitized in the 3rd nymphal instar. Demographic parameters of the parasitoid were calculated with the use of development and reproduction data obtained from life table of *L. dactylopii*. The intrinsic rate of increase was determined as ($r = 0.1527 \text{ d}^{-1}$), finite rate of increase as ($\lambda = 1.1650 \text{ d}^{-1}$), net reproductive rate as ($R_0 = 46.0667$ offspring), and mean generation time as ($T_0 = 25.0830 \text{ d}$).

Conclusions: It was concluded that *L. dactylopii* was able to develop, especially in the female and in the 3rd nymphal instar of *P. ficus* and could be used for biological control of the vine mealybug.

Keywords: Biological control, *Leptomastix dactylopii*, *Planococcus ficus*, Life table, Vine mealybug

Background

Vine mealybug *Planococcus ficus* (Signoret) (Hemiptera: Pseudococcidae) is one of the most important pests of *Vitis* spp. (Vitaceae), primarily in Mediterranean countries, as well as in South Africa, Pakistan, Argentina, California, and Mexico (Daane et al. 2012). It was reported that the vine mealybug feeds on nearly 40 plant species belonging to 24 families and 30 genera in 46 different countries (García Morales et al. 2016). *P. ficus* generates

damage through sucking plant sap from almost all parts of the host, including vine roots (Ben-Dov 1994). Due to the development of saprophytic fungi on the honey-like substances it secretes, plant photosynthesis capacity, fruit quantity, and overall plant quality decrease (Godfrey et al. 2002). It also causes significant yield losses in vineyards, even in small populations, through serving as a vector for viral diseases (Tsai et al. 2010).

Today, broad-spectrum insecticides are generally used to control the vine mealybug. However, repeated insecticide applications throughout the production season have various negative effects on the environment, non-target organisms, and especially natural enemies in the environment (Prabhaker et al. 2012). Because of these

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negative aspects of chemical control, biological control is commonly practiced against *P. ficus*. Although *P. ficus* has several natural enemies from different orders and families (Cocco et al. 2021). The parasitoids; *Anagyrus pseudococchi* (Girault) and *Coccidoxenoides perminutus* Girault (Hymenoptera: Encyrtidae) are among the most important natural enemies used for the control of vine mealybug in various countries (Sime and Daane 2014).

Leptomastix dactylopii is a solitary koinobiont endoparasitoid. It prefers the 3rd nymph and young female stages of the host (Muştu and Kılınçer 2015). Although the homeland of *L. dactylopii* was previously thought to be Brazil (Compere 1939), recent studies reported that it might be originated from Africa (Kol-Maimon et al. 2015). *L. dactylopii* has low tolerance to low temperatures.

Although *L. dactylopii*, a polyphagous species, parasitizes more than 20 mealybug species, its main host is the citrus mealybug (Anga and Noyes 1999). It prefers the 3rd nymph and female stages of the citrus mealybug (de Jong and van Alpen 1989). *L. dactylopii* was obtained during surveys conducted in vineyards of South Africa (Walton and Pringle 2004), Tunisia (Mahfoudhi and Dhoubi 2009), and Iran (Fallahzadeh et al. 2011). It was indicated in recent laboratory studies that *L. dactylopii* was a potential candidate to be used as a biological control agent for the vine mealybug (Marras et al. 2016).

This study was conducted to determine the host period preference of *L. dactylopii* on *P. ficus* nymph and adult stages and to calculate its life table parameters on the vine mealybug.

Methods

Insect cultures

A *Planococcus ficus* colony was collected from *Morus alba* L. (Moraceae) in Adana city, Turkey transferred to the laboratory, and placed on sprouted potatoes. Potatoes to be used as food for the vine mealybug were kept at 4 °C for 2 weeks and then sprouted in dark ovens at 15–18 °C. Mass production of mealybugs was carried out on potatoes sprouted at 25 ± 1 °C and 60 ± 10% RH. Mealybug eggs collected from ovisac females of *P. ficus*, with the aid of a soft-tipped brush, were smeared onto sprouted potatoes. Egg-infested potatoes were placed in 3-lt plastic jars covered with muslin mesh, with ventilation openings. Development of mealybugs was regularly checked. Culture continuity was ensured by smearing new eggs onto newly sprouted potatoes.

Leptomastix dactylopii was supplied from the Biyolojik Tarım (Biological Agriculture (Biyotar), Erzincan, Hatay, Turkey) Company. The potatoes infested with mealybugs at the 3rd and unmated female stages were placed into plastic jars covered with muslin mesh and with

ventilation holes. A stock culture was obtained by placing a certain number of female and male parasitoids (30 ♀ and 30 ♂) into the jars. With the resultant new parasitoids, new cultures were created under suitable conditions and the continuity of the culture was ensured. *L. dactylopii* was adapted by rearing it for 3 generations on *P. ficus* before the experiments.

Host stage preference of *Leptomastix dactylopii* on *Planococcus ficus*

In the present experiments, 1st, 2nd, and 3rd nymphal instars, and adult female stage of *P. ficus* were offered to the parasitoid females to parasitize in 2 different ways; with 20 separately from each stage (no-choice) and 5 from each stage together (choice).

To obtain mealybugs to be used in the experiments at the appropriate period, sprouted potatoes in plastic containers with 4 × 10 × 11 cm dimensions, covered with muslin mesh and with ventilation openings, were smeared with mealybug eggs daily, in 2 containers per day, throughout the experiments. The development and molting of mealybugs in the containers were followed through daily observations and the mealybugs that reached the appropriate stage were used in the experiments. Newly molted mealybugs were collected from the potatoes with the aid of a soft-tipped brush one day before the experiment, transferred onto vine leaves in previously prepared Petri dishes, and the mealybugs were allowed to settle on the leaves. About 1/3 of the Petri dishes (5.5 × 1.4 cm), with a ventilation opening and covered with muslin mesh, in which nymphs and adult mealybugs were transferred, were filled with 1% water agar and a disc-shaped vine leaf (Narince cultivar) was placed on the agar with the bottom surface facing up.

Each newly hatched parasitoid female to be used in the experiments was left for feeding and mating in the Petri dishes containing a male individual and 50% honey for 24 h after they became adult. Then, a female parasitoid was released into a Petri dish, previously prepared as stated above. Following a 24-h trial period, parasitoid females were removed from the Petri dishes and the Petri dishes with mealybugs were placed into the climate cabinet at 25 ± 1 °C, 60 ± 10% RH, and 16:8 (light: dark) conditions. Petri dishes were renewed every 3 days and mealybugs were transferred to new dishes with fresh leaves. After 10 days, mummified individuals were placed into Eppendorf tubes and waited for emergence. Emerged individuals were then placed into Eppendorf tubes containing 70% alcohol and the width of head capsule and the length of tibia of the left hind leg were measured. Morphometric measurements were made under a Leica stereo-binocular microscope using the Leica IM50 Image software. At the end of the experiments, the proportion

of mummified host, proportion of non-emerged parasitoids, proportion of female parasitoids, and development time, head capsule width, and tibia lengths in each mealybug stage of the parasitoid were determined. Experiments were conducted in 20 replications.

Development, reproduction, and life table of *Leptomastix dactylopii* on *Planococcus ficus*

To obtain female mealybugs to be used in the experiments, daily mealybug cultures were generated with the method described above. Pre-ovipositional female mealybugs were collected from the potatoes with the aid of a soft-tipped brush one day before the experiments and transferred to the vine leaves in the Petri dishes, previously prepared as described above, to have 20 individuals in each Petri dish and the mealybugs were allowed to settle on leaves. Leaves were supplemented with 50% diluted honey to feed the parasitoids in Petri dishes.

Before the experiments, 30 parasitoid mummies were collected from the parasitoid stock culture and placed together into 1-lt plastic jars with muslin mesh-covered ventilation holes. The mummies were checked daily and emerged parasitoid adults were released into Petri dishes containing mealybugs, which were prepared beforehand, to have 1 ♀ and 1 ♂ parasitoid in each Petri dish. Parasitoids were removed from the test dish after 24 h and transferred to a new Petri dish prepared in the same way. From the day of emergence to death, parasitoids were transferred to new Petri dishes prepared as described above.

The Petri dishes used in the experiments were placed into climate cabinets at 25 ± 1 °C, $60 \pm 10\%$ RH, and 16:8 (light: dark) conditions and mummification was observed through daily checks. Fully mummified individuals were placed into separate Eppendorf tubes in the same climate cabinet and waited for adult parasitoids to emerge. At the end of the experiments, development time of parasitoid on vine mealybug, adult life span, number of oviposition days, number of juveniles, and female-male ratios were determined.

Statistical analysis

Since the data obtained from the experiments for host stage preference of *L. dactylopii* on *P. ficus* did not meet the parametric test conditions, a Kruskal–Wallis test was used to compare percent mummification ratios in no-choice tests and a Dunn–Bonferroni test was used to compare different groups. Independent-Samples Mann–Whitney *U* test was used for the analysis of proportion of non-emerged parasitoids. In choice tests, a Friedman test was used in the analysis of proportion of mummified host and a Dunn–Bonferroni test was used to determine different groups. Proportion of non-emerged parasitoids

was analyzed with the use of the Related-Samples Wilcoxon Signed Rank test. SPSS 22.0.0.0 software was used for statistical analysis of host stage preference trials.

With the use of the development and reproduction data of *L. dactylopii* on vine mealybug, life table parameters revealing significant information about the parasitoid were obtained. These parameters were calculated based on age-stage specific two-sex life table analyses (Chi and Liu 1985; Chi 1988). The TWOSEX MSChart software was used to analyze life table raw data (Chi 2021). Age-stage-specific survival rate (s_{xj}) (x age and j stage), age-stage-specific fecundity (f_{xj}), age-specific longevity (l_x), female age-specific fecundity (m_x) and age-specific maternity ($l_x m_x$) values were calculated.

In the age-stage-specific two-sex life table, l_x and m_x parameters were calculated with the use of the following equations:

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

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

Net reproductive rate (R_0) was calculated with the use of the following equation. Net reproductive rate was obtained by multiplying age-specific longevity (l_x) by age-specific fecundity (m_x) rates.

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

Intrinsic rate of increase (r) (day^{-1}) was calculated with the use of the following equation (Goodman 1982):

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

The other life table parameters were calculated as follows:

Finite rate of increase, (λ) (d^{-1}), ($\lambda = e^r$).

Mean generation time, (T) (d), $T = \ln(R_0/r)$, (time span required to increase population size up to net reproductive rate).

Age and stage-specific life expectancy, (e_{xj}), was calculated with the use of the following equation (Chi and Su 2006).

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

Age and stage-specific reproductive value (v_{xj}) was calculated with the use of the following equation (Tuan et al. 2014).

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

For calculated life table parameters, 100,000 artificial bootstraps (Bootstrapping is a statistical procedure that resamples a single dataset to create many simulated samples) (Efron and Tibshirani 1993) were produced with the use of TWOSEX MSChart (Chi 2021) software and means and standard errors of life table parameters were obtained.

Results

Host stage preference of *Leptomastix dactylopii* on *Planococcus ficus*

In no-choice trials, *L. dactylopii* could not develop in the 1st and 2nd nymph stages of the vine mealybug ($H=74.738$, $df=3$, $p < 0.001$). Although it was observed that there were parasitized individuals in the first 2 nymphal instars, the parasitized nymphs generally died and mummification was not encountered in any of them. Therefore, the 1st and 2nd nymphal instars of vine mealybug were considered unsuitable host stages for *L. dactylopii*. When the mealybug stages, in which the parasitoid can develop were examined, although the number of mummies formed in female *P. ficus* stage parasitized by *L. dactylopii* was higher than the number of mummies in the 3rd nymphal instar, difference between the 2 groups was non-significant ($Z = -18.050$, $p=0.052$) (Table 1). When the number of parasitoid adults that could not emerge from the mummies were compared, there was non-significant difference between the parasitoid mummies formed in the female and the 3rd nymphal instar ($U=207.500$, $p=0.841$) (Table 1). When the sex ratios of the parasitoid adults emerging from the mummies in both mealybug periods were examined, the number

emerging from the adult mealybug mummies was higher than the number of female parasitoids emerging from the mealybug mummies parasitized in the 3rd nymphal instar (Table 1). When the development times of *L. dactylopii* in the female and 3rd nymph stages of vine mealybug were compared, the development of both female ($U=526.500$, $p=0.003$) and male ($U=1827.500$, $p < 0.001$) parasitoids on adult mealybugs was longer than their development on the 3rd nymphal instar mealybugs (Table 2).

When the morphometric characteristics of the parasitoids were examined, it was observed that the difference between the hind tibia lengths of both female parasitoids ($U=530.000$, $p=0.003$) and male ($U=2323.000$, $p=0.003$) parasitoids emerged from mealybug mummies parasitized in female and the 3rd nymphal instar was significant. Similarly, when the head capsule widths of the parasitoids that emerged from the mummies in both mealybug periods were compared, there were significant differences in head capsule widths of both female parasitoids ($U=668.500$, $p < 0.001$) and male ($U=2435.000$, $p < 0.001$) parasitoids.

Similar with the findings of the no-choice trials, in choice trials, *L. dactylopii* parasitized the mealybugs

Table 2 Mean developmental time (d), hind tibia length (μm), and head width (μm) of *Leptomastix dactylopii*, when developed in different stages of *Planococcus ficus*

Parameter	n	Mealybug stages		
		3rd nymph	n	Female
		$\bar{x} \pm \text{s.e}$		$\bar{x} \pm \text{s.e}$
Developmental time of female	13	15.69 \pm 0.26 ^b	53	16.89 \pm 0.24 ^{a*}
Developmental time of male	29	14.76 \pm 0.18 ^b	88	15.85 \pm 0.19 ^a
Hind tibia length of female	13	545 \pm 20 ^b	53	671 \pm 24 ^a
Hind tibia length of male	29	422 \pm 14 ^b	88	616 \pm 14 ^a
Head width of female	13	472 \pm 8 ^b	53	646 \pm 17 ^a
Head width of male	29	396 \pm 12 ^b	88	581 \pm 12 ^a

*Means within a row followed by different lowercase letters are significantly different (Mann–Whitney U test, $P \leq 0.05$)

Table 1 Parasitism preference of *Leptomastix dactylopii* on *Planococcus ficus* (%) (non-choice)

Parameter	n	Mealybug stages			
		1st nymph	2nd nymph	3rd nymph	Female
		$\bar{x} \pm \text{s.e}$	$\bar{x} \pm \text{s.e}$	$\bar{x} \pm \text{s.e}$	$\bar{x} \pm \text{s.e}$
Mummified host	20	0 ^b	0 ^b	14.50 \pm 2.14 ^a (58)	42.75 \pm 3.41 ^{a*} (171)
Non-emerged parasitoids	20	–	–	25.82 \pm 7.96 ^A (58)	16.68 \pm 3.40 ^{A**} (171)
Proportion of female parasitoids	20	–	–	0.31 (42)	0.38 (141)

Figures under n indicate number of experimental wasps. Numbers in parentheses indicate total numbers

*Means within a row followed by different lowercase letters are significantly different (Dunn–Bonferroni, $P \leq 0.05$)

**Means within a row followed by different uppercase letters are significantly different (Mann–Whitney U test, $P \leq 0.05$)

Table 3 Parasitism preference of *Leptomastix dactylopii* on *Planococcus ficus* (%) (choice)

Parameter	n	Mealybug stages			
		1st nymph	2nd nymph	3rd nymph	Female
		$\bar{x} \pm \text{s.e}$	$\bar{x} \pm \text{s.e}$	$\bar{x} \pm \text{s.e}$	$\bar{x} \pm \text{s.e}$
Mummified host	20	0 ^b	0 ^b	9.00 ± 2.28 ^b (9)	40.00 ± 2.90 ^{a*} (40)
Non-emerged parasitoids	20	–	–	55.56 ± 17.57 ^A (9)	19.17 ± 6.65 ^{A**} (40)
Proportion of female parasitoids	20	–	–	0.50 (4)	0.68 (31)

Figures under n indicate number of experimental wasps. Numbers in parentheses indicate total numbers

* Means within a row followed by different lowercase letters are significantly different (Dunn–Bonferroni, $P \leq 0.05$)

** Means within a row followed by different uppercase letters are significantly different (Wilcoxon signed rank test, $P \leq 0.05$)

Table 4 The developmental period of female (d), the developmental period of male (d), and preadult mortality rate of *Leptomastix dactylopii*

Parameter	n	$\bar{x} \pm \text{s.e}$
The development period of female	15	18.80 ± 0.11
The development period of male	10	18.00 ± 0.00
Mortality rate in preadult (%)	30	17 ± 7

Standard errors (s.e.) were estimated by using the bootstrap technique with 100,000 re-samplings

in the female stage more than the 3rd nymphal instar ($F_r = 53.055$, $df = 3$, $p < 0.001$). In terms of adult parasitoid emergence, there were non-significant differences between the female and the 3rd nymphal instar ($W = 8.500$, $p = 0.366$), the rate of female parasitoids emerged from female mealybug mummies was higher than that of the mealybugs parasitized in the 3rd nymphal instar (Table 3).

Development, reproduction, and life table of *Leptomastix dactylopii* on *Planococcus ficus*

The data on the developmental stages of *L. dactylopii* are provided in Table 4. The pre-adult developmental period of *L. dactylopii* females was 18.80 days, while pre-adult developmental period of *L. dactylopii* males was 18.00 days. The pre-adult mortality rate of the parasitoid was 17%.

L. dactylopii did not need an adult pre-ovipositional period (APOP) and could parasitize its host at the first day of emergence. The total pre-ovipositional period (TPOP) (sum of pre-adult developmental time and adult pre-ovipositional period) of *L. dactylopii* was 18.80 days (Table 5). Number of oviposition days of the parasitoid was 17.07 days and fecundity was 92.13 offspring. Longevity of female and male adults was 22.07 and 19.80 days, respectively. The total life span of parasitoid females and males were 40.87 and 37.80 days, respectively.

Table 5 Adult preoviposition period (APOP), total preoviposition period (TPOP) (sum of developmental time and adult preoviposition period), and reproductive parameters of *Leptomastix dactylopii*

Parameter	n	$\bar{x} \pm \text{s.e}$
APOP (d)	15	0
TPOP (d)	15	18.80 ± 0.11
Oviposition days (d)	15	17.07 ± 1.71
Fecundity (offspring)	15	92.13 ± 9.87
Longevity of female (d)	15	22.07 ± 2.43
Longevity of male (d)	10	19.80 ± 1.87
Total lifespan of female (d)	15	40.87 ± 2.45
Total lifespan of male (d)	10	37.80 ± 1.87

Standard errors (s.e.) were estimated by using the bootstrap technique with 100,000 re-samplings

Age and stage-specific survival rate (s_{xj}) indicated survival probability of a newly oviposited eggs until age x and stage j (Fig. 1). The survival probability of a newly oviposited *L. dactylopii* egg to an adult stage was 50% for females and 33% for males. Age-specific longevity (l_x), female age-specific fecundity (f_{x8}), whole population fecundity (m_x), and age-specific maternity ($l_x m_x$) values are presented in Fig. 2. The l_x curve is a simplified version of the curve in Fig. 1 and was calculated as the sum of all surviving individuals in different periods.

The data on development and reproduction of *L. dactylopii* were used to calculate life table parameters (Table 6). The intrinsic rate of increase (r) of the parasitoid on *P. ficus* was calculated as 0.1527 d^{-1} and net reproductive rate (R_0) was calculated as 46.0667 offspring.

Life expectancy (e_{xj}) indicates expected life span of an individual at age x and stage j , reproductive value (v_{xj}) indicates the contribution of an individual at age x and period j to the future population. While the maximum life expectancy of a newly oviposited *L. dactylopii* egg was determined as 36.03 days (Fig. 3), the female

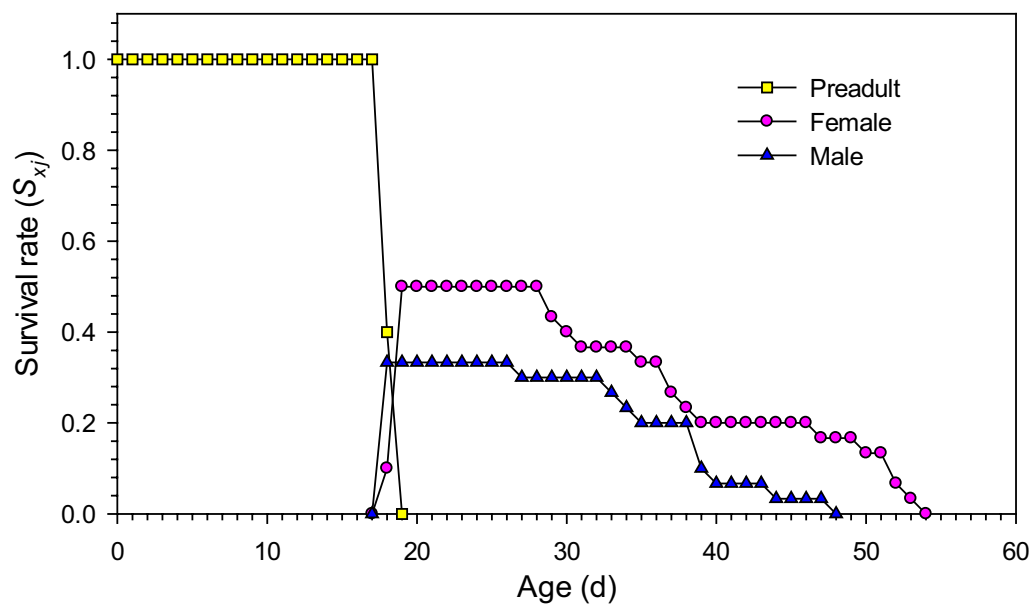


Fig. 1 Age-stage-specific survival rate (s_{xj}) of *Leptomastix dactylopii* on *Planococcus ficus*

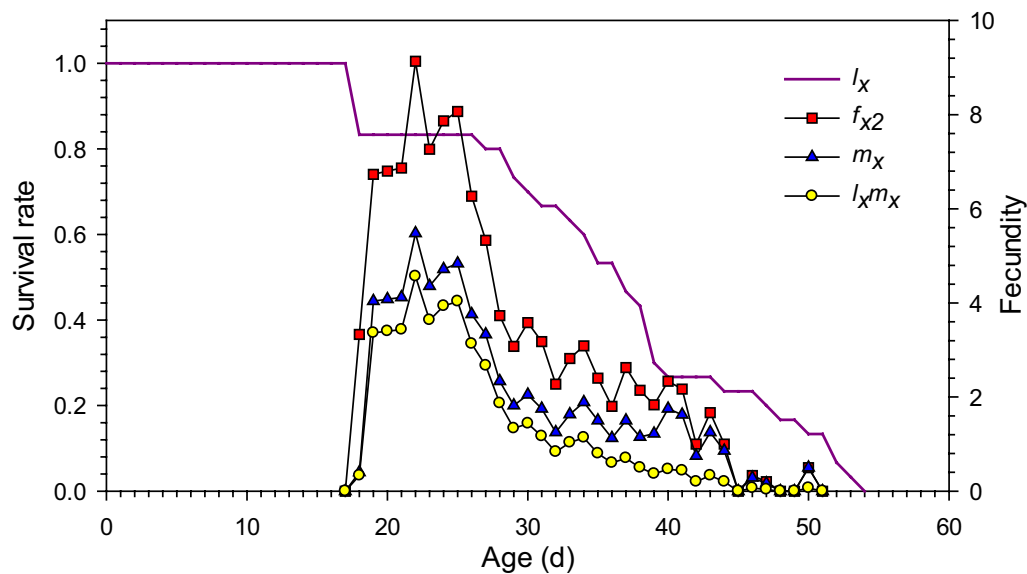


Fig. 2 Age-specific survival rate (l_x), female age-specific fecundity (f_{x2}), age-specific fecundity (m_x), and age-specific maternity ($l_x m_x$) of *Leptomastix dactylopii* on *Planococcus ficus*

parasitoid reached the highest reproductive value at day 19 ($v_{19} = 41.62$ offspring) (Fig. 4).

Discussion

Zinna (1959) reported that the parasitoid *L. dactylopii* preferred to parasitize the host *P. citri* generally at the 3rd instar nymphs and females and rarely parasitized the 2nd

instar nymphs. de Jong and van Alphen (1989) divided *P. citri* into 4 size classes and reported that *L. dactylopii* parasitized size class 3 (consists mainly of 3rd nymph instar with some 2nd and 4th) and size class 4 (consists of pre-ovipositing females and ovipositing females) mealybugs of *P. citri*. They also indicated that female parasitoids were developed from oviposited female hosts and

Table 6 Population parameters intrinsic rate of increase (r), finite rate of increase (λ), net reproductive rate (R_0), and mean generation time (T) of *Leptomastix dactylopii*

Parameter	$\bar{x} \pm s.e$
r (d^{-1})	0.1527 ± 0.0088
λ (d^{-1})	1.1650 ± 0.0102
R_0 (offspring)	46.07 ± 9.69
T (d)	25.08 ± 0.44

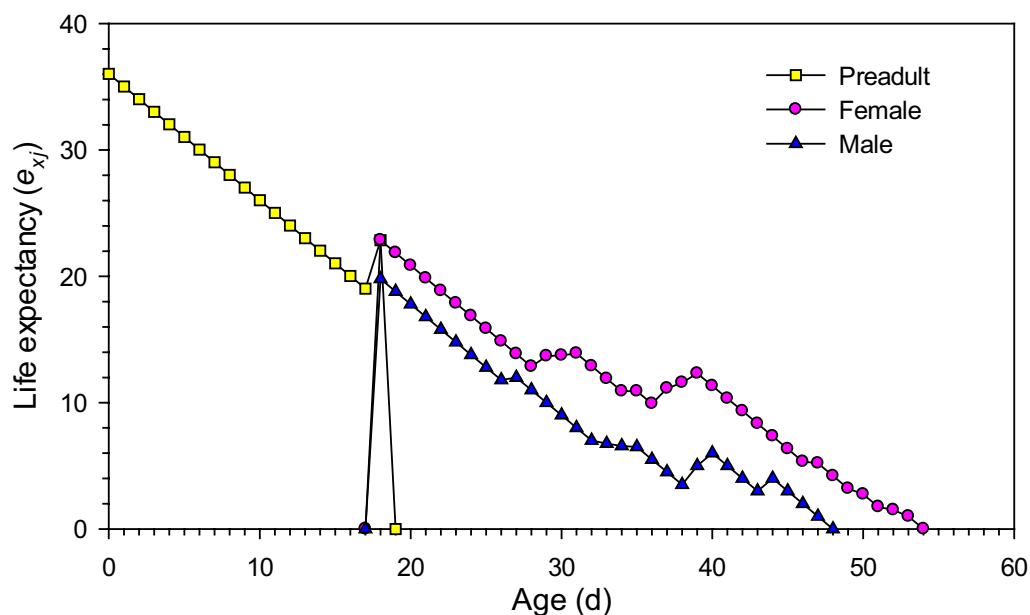
Standard errors (s.e.) were estimated by using the bootstrap technique with 100,000 re-samplings

mostly male parasitoids were developed from the 3rd nymphal instar and pre-ovipositing female mealybugs (de Jong and van Alphen 1989). Similarly, in parasitizing preference trials conducted with and without options, it was determined that *L. dactylopii* parasitized the female and 3rd nymphal instar of *P. ficus* and mealybug females were more preferred than the 3rd nymphal instar by the parasitoid. In addition, similar to the studies with *P. citri*, the number of female parasitoids emerging from *P. ficus* females was higher than those parasitized in the 3rd nymphal instar for both trials. However, although it was observed that *L. dactylopii* tried to parasitize vine mealybug individuals in the 1st and 2nd nymphal instar, mummification was not encountered in these stages. It was observed that the 1st and 2nd instar nymphs attempted to be parasitized by *L. dactylopii* immediately tried to move away from the place where they feed as a defensive response and these nymphs ultimately died out.

In the present study, the rate of female parasitoids emerging from adult mealybugs in choice trials was higher than in no-choice trials. Since there are a limited number of female mealybugs in choice trials than in no-choice trials, the parasitoid might oviposit a greater number and laid more fertilized diploid eggs on female mealybugs in choice trials.

Marras et al. (2016) reared *L. dactylopii* separately on *P. ficus* and *P. citri* and exposed the parasitoids to hosts from which they were reared and the other host mealybug species as a cross. The researchers reported that hind tibia lengths of the female parasitoids obtained for all groups were between 640 and 660 μm . In the present study, hind tibia lengths of male and female individuals parasitized during the adult mealybug stage were determined as 671 μm and 616 μm , respectively.

Life table parameters revealed that development of female parasitoids lasted shorter time than the males. In previous studies conducted at 25 °C with near relative humidity and lighting conditions, quite different durations were reported for the development of *L. dactylopii* on *P. citri*. Battaglia et al. (1996) reported a developmental duration of female and male individuals of *L. dactylopii* as 18.39 and 16.11 days, respectively. Telli and Yiğit (2004) reported pre-adult development period of *L. dactylopii* female as 22.85 days. Yang and Sadof (1997) reported development durations of *L. dactylopii* on three different plant cultivars of *Coleus blumei* (Benth) (Lamiaceae) as 21.9, 20.2, and 20.7 days, and mortality rates as 6.48, 12.59 and 4.44%, respectively. In the present

**Fig. 3** Age-stage-specific life expectancy (e_{xi}) of *Leptomastix dactylopii* on *Planococcus ficus*

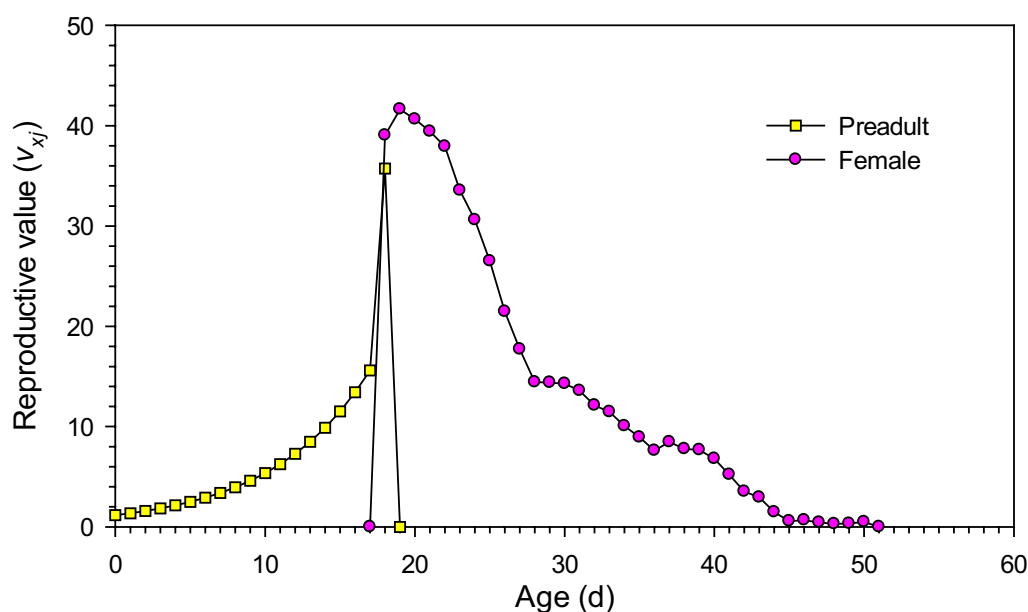


Fig. 4 Age-stage-specific reproductive value (v_{xj}) of *Leptomastix dactylopii* on *Planococcus ficus*

study, pre-adult development duration of female and male individuals of *L. dactylopii* on *P. ficus* was identified as 18.80 and 18.00 days, respectively, and mortality rate of the parasitoid was determined as 17%.

Zinna (1959) reported that *L. dactylopii* adults could survive for up to 35 days on their host *P. citri*, while female parasitoids lived an average of 31 days and male parasitoids lived an average of 16 days. Telli and Yiğit (2004) reported the total lifespan of male and female *L. dactylopii* on *P. citri* as 9.42 and 21.57 days, respectively. Yang and Sadof (1997) reported the lifespan of female adults of *L. dactylopii* on *P. citri* grown on three different *C. blumei* cultivars as 22.8, 20.4, and 20.6 days, respectively. In the present study, which was conducted under almost identical climate conditions as previous ones, longevity of *L. dactylopii* on *P. ficus* was 22.07 days for female parasitoids and 19.8 days for male parasitoids. Yang and Sadof (1997) reported fecundity of the parasitoid on *P. citri* grown on 3 different *C. blumei* as 65.8, 51.2, and 63.6 offspring, respectively. In the present study, fecundity of *L. dactylopii* was found to be 92.13 offspring. The present fecundity value was quite higher than the values by Yang and Sadof (1997) and it was determined that *L. dactylopii* could reproduce quite well on *P. ficus*. The intrinsic rate of increase is an important parameter designating development of a population. Battaglia et al. (1996) reported the intrinsic rate of increase in *L. dactylopii* on *P. citri* at 25 °C as 0.128 d⁻¹. In the present study, the intrinsic rate of

increase in the parasitoid was calculated as 0.1527 d⁻¹. Such a value indicated that *L. dactylopii* could reproduce quite successfully on *P. ficus*. Walton and Pringle (2005) reported the intrinsic rate of increase (r), the net reproduction rate (R_0), and the mean generation time (T) of *P. ficus* at 25 °C as 0.169, 248.01, and 38.0 days, respectively. Although the net reproductive value of *L. dactylopii* was much lower than that of *P. ficus*, difference in the r values between the two insect was small. Also, the mean generation time of *L. dactylopii* was much shorter than that of *P. ficus*. These values obtained are promising for the use of *L. dactylopii* in biological control of *P. ficus*.

Total life expectancy of a newly oviposited *L. dactylopii* egg until it becomes an adult was identified as 0.83 (Fig. 1). Marras et al. (2016) reported that survival rate of *L. dactylopii* on *P. ficus* was higher than 86% and such a high survival rate indicated that *P. ficus* was a suitable host for *L. dactylopii*. Quite similar findings were obtained in the present study and Marras et al. (2016). While the longevity curve of *L. dactylopii* female ended on the 54th day, the fecundity curve ended on the 51st day (Fig. 2). Parallel to this result, it was observed that the reproductive curve of the female ended on the 51st day (Fig. 4). Chi and Su (2006) indicated that reproductive value of a newborn individual was the same as the finite rate of increase (λ). Accordingly, it was determined that reproductive value and infinite rate of increase in a newborn individual of *L. dactylopii* on *P. ficus* were the same and this value was 1.16.

Conclusions

In this study, host stage preference of *L. dactylopii* on *P. ficus* and life table parameters was determined under laboratory conditions and potential use of the vine mealybug as host of the parasitoid was assessed. It was concluded that *L. dactylopii* was able to develop, especially in the female and in the 3rd nymphal instar of *P. ficus* and could be used for biological control of the vine mealybug. However, some previous studies indicated that the parasitoid might have difficulties in adaption to the vineyard ecosystem and could not overwinter in the Mediterranean basin and countries with similar climate characteristics. Thus, it was thought that annual inoculative releases of *L. dactylopii* might increase the chance of success in biological control of the vine mealybug. Further research is recommended to test the efficiency of this parasitoid on vine mealybug under field conditions.

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Author contributions

MM designed the study, analyzed the data, and wrote the manuscript. FND, BT conducted the laboratory experiments. All authors read and approved the final manuscript.

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Availability of data and materials

The data that support the findings of this study are available from the corresponding author.

Declarations

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Not applicable.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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