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Life table of *Delphastus catalinae* (Horn) (Coleoptera: Coccinellidae) on cotton whitefly, *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae) as prey

Biologische Eigenschaften von *Delphastus catalinae* (Horn) (Coleoptera: Coccinellidae) als Prädator der Weißen Fliege *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae)

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Summary

Developmental time, longevity and fecundity of *Delphastus catalinae* (Horn), a predator of *Bemisia tabaci* (Genn.), were evaluated under laboratory conditions. Developmental time from egg to adult was 22.3, 15.57 and 18.41 days at 25, 30°C and at fluctuating temperatures of 25/35°C (12/12 h), respectively. It was also found that temperatures above 35°C were lethal, since all eggs were killed. The female adult's longevity and reproduction differed with temperatures. Mean adult longevities were 105.25, 40.2 and 42.1 days, and total fecundities were 213.72, 118.94, and 117.93 eggs/♀ at 25, 30°C and at fluctuating temperatures of 25/35°C, respectively. Additionally, life tables were constructed from data obtained to compare the effects of different temperatures. The highest reproductive rate was 88.93 at 25°C. In contrast, at 30°C the highest intrinsic rate of increase and the shortest generation time were 0.127 and 28.14 days, respectively. The results indicate that the optimum temperature for mass rearing of *D. catalinae* ranges from 25°C to 30°C.

Key words: *Delphastus catalinae*, developmental time, fecundity, life table, longevity, predator, temperature

Zusammenfassung

Ziel der vorliegenden Untersuchung war die Ermittlung der Entwicklungsdauer, Lebensdauer und Reproduktionsrate von *Delphastus catalinae* (Horn) (Coleoptera: Coccinellidae), ein Räuber der Weißen Fliege *Bemisia tabaci* (Genn.) (Homoptera: Aleyrodidae), im Labor. Die Entwicklungsdauer vom Ei bis zum Adulten betrug durchschnittlich 22,3, 15,57 und 18,41 Tage bei konstanten Temperaturen von 25°C bzw. 30°C und Wechseltemperaturen von 25/35°C (12/12 h). Temperaturen von über 35°C wirkten tödlich. Die Lebensdauer der Adulten betrug im Durchschnitt 105,25, 40,2 und 42,1 Tage bei konstanten Temperaturen von 25°C und 30°C sowie Wechseltemperaturen von 25/35°C. Die durchschnittliche Gesamtreproduktion betrug 213,72, 118,94 und 117,93 Eier/♀ bei 25°C, 30°C und 25/35°C. Darüber hinaus wurden sogenannte „Lebenstafeln" zum Vergleich der Auswirkungen der verschiedenen Temperaturen aus den Daten erstellt. Lebensdauer und Reproduktionsrate der adulten Weibchen variierten in Abhängigkeit von der Temperatur. Die höchste Reproduktionsrate betrug 88,93 bei 25°C. Bei 30°C betrugen die höchste spezifische Zuwachsrate 0,127 Tage und die kürzeste Generationsdauer 28,14 Tage. Die Ergebnisse deuten darauf hin, dass das Temperaturoptimum für die Massenzucht von *D. catalinae* zwischen 25°C und 30°C liegt.

Stichwörter: *Bemisia tabaci*, *Delphastus catalinae*, Entwicklungsdauer, Lebensdauer, Räuber, Reproduktion, Temperatur

1 Introduction

Cotton whitefly, *Bemisia tabaci* (Genn.) is one of the most important cotton pests in the East Mediterranean region of Turkey. Population levels of *B. tabaci* are changing from year to year especially in irrigated cotton fields, since the major outbreak in 1974, in the East Mediterranean region of Turkey (Sengonca 1975; Sengonca and Yurdakul 1975; Kaygisiz 1976; Tunc 1983; Anonymous 1994; Sekeroglu et al. 1998). The pest causes reduction in plant vigour and production of honeydew on foliage where subsequently sooty molds develop. *B. tabaci* also transmits some plant-pathogenic viruses (Lodos 1982). In the East Mediterranean region of Turkey, estimated crop loss caused by *B. tabaci* in irrigated and rain-fed cotton growing areas is 40% and 15%, respectively (Sengonca and Yurdakul 1975; Sekeroglu et al. 1998).

In Turkey, some studies on biology and management of *B. tabaci* in cotton fields have been performed (Sengonca 1975; Kaygisiz 1976; Stam and Tunc, 1983; Kismir 1983; Sekeroglu et al. 1998). The importance of sustainable integrated whitefly management, combining optimally all available tactics to maintain whitefly populations below levels that will cause economic loss, has increased (Ellsworth et al. 1995). Because of the outbreaks of *B. tabaci* on cotton in the 1970 s, considerable attention has been focused toward biological control of the pest. Although a lot of natural enemies of *B. tabaci*, such as *Eretmocerus mundus* Mercet, *Encarsia* sp., *Prospaltella* sp.nr. *aspiticola* M., *Chrysoperla carnea* (Steph), *Nabis pseudoferus* Remane, *Geocoris* spp., *Orius* spp. and *Deraecoris* spp. were found in the East Mediterranean region of Turkey, their populations are not suffient to suppress the whitefly (Kaygisiz 1976; Kismir 1983, 1992; Sekeroglu et al. 1998).

Among numerous natural enemies, *Delphastus catalinae* (Horn) (reported previously as *D. pusillus*) is one of the most intensively studied ladybeetle predators (Hoelmer et al. 1994a). All members of the genus *Delphastus* spp. (Coleoptera: Coccinellidae) are known as predators of whitefly species. *D. catalinae* is widely distributed across the central and southern United States (Gordon 1994). Studies on biology, life history and behaviour of *D. catalinae* were conducted by Hoelmer et al. (1993), Hoelmer et al. (1994b), Heinz and Parella (1994), Heinz and Nelson (1996), Heinz and Zalom (1996) and Liu (2005). Heinz et al. (1994) reported that releases of *D. catalinae* (Horn) into *B. tabaci* exclusion cages resulted in 55–67% decrease of whitefly densities and concluded that the predator has potential to suppress the pest in open cotton fields. Therefore, *D. catalinae* has been introduced as an alternative predator of cotton whitefly, *B. tabaci* into the East Mediterranean region of Turkey. The knowledge of biological characteristics of a predator species is important in determining its impact on *B. tabaci*. Those characteristics include development rate at various temperatures, the longevity and fecundity of the female and population growth rate.

A life table study of *D. catalinae* was carried out to compare the results with those reported previously, since these results were obtained from different host plant species. In this study, life table parameters of *D. catalinae*, a predatory beetle of whitefly species, was investigated on *B. tabaci* under laboratory conditions.

2 Materials and methods

Approximately 20 individuals of *D. catalinae* were provided by Tong-Xiau Liu (Texas Agricultural Experiment Station, Texas A&M University, USA), following the FAO regulations (Anonymous 1997) to initiate the rearing (Anonymous 1997). *D. catalinae* was reared on heavily *B. tabaci*-infested cotton, *Gossypium hirsutum* L., according to a modified method for culturing *Serangium parcesetosum* Sicard, another predator of *B. tabaci* (Yigit 1992). Cotton whitefly provided with regular prey supply was reared on cotton. Cotton seeds were sown in soil in plastic pots (18 cm diameter). The pots were maintained in a glasshouse until the seedlings reached a height of 30 cm. They were then transferred to a constant temperature room at 27 ± 2°C under 16 h illumination and 70 ± 10% relative humidity (R. H.) and placed next to the plants infested with *B. tabaci*. These plants were kept in this room for 2 or 3 weeks to obtain sufficient prey density (appr. 25 eggs or larvae + pupa per cm^2 of leaf area). Twelve heavily infested plants (four pots, each with three to four plants) were placed in 50 x 110 x 80 cm growth cages, the sides of which were covered with cheese-cloth and the top with a glass pane. The cages were maintained in a constant temperature room at 25 ± 1°C under 16 h illumination and 70 ± 10% R. H. Then mixed sexes of *D. catalinae* adults were introduced into the cages (15–20 adults per cage).

Cotton leaves bearing more than 300 eggs, nymphs and puparia of *B. tabaci* were placed upside down in Petri dishes (9 cm in diameter and 1.7 cm high) onto a damp tissue paper for *D. catalinae* to feed upon. For the experiments, 10 paired adults of *D. catalinae* of mixed sexes were collected from rearing cages and left on the top of the infested leaves and allowed to deposit eggs to the leaves for 24 h.

In order to determine the duration of the development of *D. catalinae*, the adults were removed after 24 h from the Petri dishes mentioned above and the eggs laid were incubated at 25 or 30 ± 1°C constant and 25 – 35 ± 1°C fluctuating temperatures (12/12 h) and examined twice daily. The duration of embryonic development was recorded after hatching of the larvae from eggs. The newly hatched larvae (L_1) were singly transferred using a camel hairbrush into Petri dishes containing cotton leaves infested with *B. tabaci* at the temperatures mentioned above. During the experiment, *B. tabaci*-infested leaves were renewed when needed. The Petri dishes were checked twice daily for moulting of successive larval instars and pupation period was determined starting from the day L_4 become immobile and attached themselves to Petri dishes to the day when the adults started emerging.

During the experiment, the mortality of *D. catalinae* eggs, of different larval instars and pupae was recorded daily.

To establish the sex ratio of *D. catalinae*, a minimum of 72 emerged adults at each temperature from rearing cages were examined under a stereoscopic microscope. The percentages of females and males were calculated.

For recording longevity of *D. catalinae*, at least 10 paired adults newly emerged on the same day were placed into the same Petri dishes and provided with sufficient food. These adults were kept in the same Petri dishes approximately one week for mating. At the end of this period, each mated adult was transferred individually into another Petri dish containing *B. tabaci*-infested cotton leaves. Males and females were always provided with sufficient prey in these Petri dishes. During the experiment, the first and the last egg-laying days were also recorded for the pre-oviposition, oviposition and post-oviposition periods of *D. catalinae* females. The longevity was also recorded.

For establishing fecundity of *D. catalinae* during their oviposition period, the number of laid eggs was recorded daily and removed from the Petri dishes during the experiment. A minimum of 17 replicates was set up in the experiments at each temperature.

All experiments were carried out at 25, 30 and 35 ± 1°C constant and 25 – 35 ± 1°C fluctuating temperatures (12/12 h) in a climatically controlled chamber at 60 ± 10% R. H.

Differences in developmental time, longevity and fecundity were calculated by analysis of variance (ANOVA), and means were separated using Duncan's multiple comparison test ($P \leq 0.05$). All data collected from these experiments were used to draw up life tables of *D. catalinae* at each temperature. The life tables were drawn up according to Birch (1948) using the formula:

$$\sum l_x \, m_x \, e^{-r\,x} = 1$$

where x: age in days, r: intrinsic rate of increase, l_x: age-specific survival, m_x: age-specific number of female offspring. A Basic computer programme written by Abou-Setta et al. (1986) was used to calculate life table parameters.

3 Results

Developmental periods of the immature stages are presented in Table 1. The egg incubation period of *D. catalinae* decreased significantly with increasing constant temperatures ranging from 4.56 days to 3.55 days at 25 ± 1°C and 30 ± 1°C, respectively (Table 1). There was no statistical difference between 25°C and 25–35°C fluctuating temperature. After

Table 1: Mean developmental duration of immature stages of *Delphastus catalinae*, feeding on *Bemisia tabaci* as prey on cotton leaves at three temperatures *, **

		Duration of immature developmental stages (days)							
Temperature (°C)	n	Egg Mean ± SE	L_1 Mean ± SE	L_2 Mean ± SE	L_3 Mean ± SE	L_4 Mean ± SE	Prepupa Mean ± SE	Pupa Mean ± SE	Total (egg to adult emergence) Mean ± SE
25 ± 1	20	4.56 ± 0.58bD	1.89 ± 0.48aAB	1.55 ± 0.63bA	1.89 ± 0.50bB	2.61 ± 0.54aC	2.44 ± 0.50bC	7.49 ± 0.45cE	22.30 ± 0.85c
30 ± 1	21	3.55 ± 0.23aD	1.77 ± 0.57aB	1.21 ± 0.31aA	1.24 ± 0.30aA	2.20 ± 0.48bC	1.71 ± 0.46aB	4.02 ± 0.57aE	15.57 ± 1.35a
25 – 35 ± 1	17	4.47 ± 0.42bD	1.80 ± 0.42aAB	1.58 ± 0.30bA	1.52 ± 0.49cA	2.38 ± 0.62abC	2.00 ± 0.46aB	4.75 ± 0.87bD	18.41 ± 1.48b

* Means in columns followed by different small letters indicate significant differences among temperatures at $P \leq 5\%$ (ANOVA).
** Means in the same lines followed by different capital letters indicate significant differences among biological stages at $P \leq 5\%$ (ANOVA).

hatching of the eggs, the development of *D. catalinae* involves four larval, a prepupal, and a pupal stage. For all the temperatures tested, 4th instar larvae required more time to develop than 1st, 2nd and 3rd instars, but the developmental time of pupa was longer than that of the 4th instars. The duration of larval stages in total was 7.94, 6.42, and 7.28 days at 25, 30, and 25–35°C, respectively. *D. catalinae* completed development from egg to adult emergence in 22.30, 15.57, and 18.41 days, at 25, 30, and 25–35°C, respectively (Table 1). The eggs could not hatch and other immature stages could not develop at 35°C constant temperature.

No mortality occurred during pre-pupal and pupal stages of *D. catalinae* at the temperatures tested (Table 2). The mortality rates of the immature stages were affected by temperature, the highest at 25–35°C (51%) and the lowest at 25°C (17%). Total mortality was 17%, 40% and 51% at 25°C, 30°C and 25–35°C, respectively.

The percentage of females to males was 55%, 49% and 52% at 25, 30, and 25–35°C, respectively (Fig. 1). There were no significant differences among the sex ratios at the temperatures tested.

The periods of pre-oviposition, oviposition, post-oviposition of *D. catalinae* on cotton leaves infested with *B. tabaci* are summarized in Table 3. It seems that higher temperature (30°C) decreased the longevity of adults. Mean female longevity was 105.25 days at 25°C and 40.20 days at 30°C. The longevity for females at 25°C was significantly different from the other temperatures tested (Table 3).

Temperature had influenced significantly the total number of eggs laid by *D. catalinae* females (Fig. 2). Mean total number of eggs laid by females at 25°C was significantly higher with 213.72 eggs/♀ than at 30°C and 25–35°C with 118.94 eggs/♀ and 117.93 eggs/♀, respectively.

Age-specific fecundity, m_x, and survival curve, l_x, are shown in Fig. 3. The survival of females at 25°C was longer than that obtained at 30°C and 25–35°C, and became shorter with increase in temperature. Age-specific fecundity of *D. catalinae* reached a peak and declined rapidly at 30°C. The shape of the m_x curve at 25–35°C was similar to that at 30°C. There occurred a weak peak of m_x at 25°C, and offspring was produced over a longer time period (Fig. 3).

Life table parameters of *D. catalinae* adult females feeding on *B. tabaci* at 25°C, 30°C and 25–35°C temperatures are reported in Table 4. The intrinsic rate of increase (r) was calculated as 0.09, 0.127, and 0.107, respectively. Net reproductive rate (R_o) was 88.93, 35.81, and, 28.93 and mean length of a generation (T) was 48.65, 28.14 and, 31.34 days, at temperatures tested, respectively.

Table 2: Mean mortality rate of egg and immature stages of *Delphastus catalinae*, feeding on *Bemisia tabaci* as prey on cotton leaves at three temperatures

Temperature (°C)	n	Mortality during immature stages (%)							Mortality (%) Total
		Egg	L_1	L_2	L_3	L_4	Prepupa	Pupa	
25 ± 1	24	0.00	8.33	0.00	4.50	4.76	0.00	0.00	17
30 ± 1	35	2.85	17.64	0.00	14.21	12.50	0.00	0.00	40
35 ± 1		Eggs and immature stages could not develop							
25 – 35 ± 1	35	48.57	0.00	0.00	5.55	0.00	0.00	0.00	51

Table 3: Mean longevity of *Delphastus catalinae* females, feeding on *Bemisia tabaci* as prey on cotton at three different temperatures*

Temp. (°C)	n	Longevity (days)			
		Pre-oviposition Mean ± SE	Oviposition Mean ± SE	Post-oviposition Mean ± SE	Longevity Mean ± SE
25 ± 1	16	5.87 ± 0.25 a	93.87 ± 7.66 a	5.50 ± 0.55 a	105.25 ± 7,92 a
30 ± 1	21	3.90 ± 0.30 b	31.71 ± 3.67 b	4.57 ± 0.67 a	40.20 ± 3,89 b
25 – 35 ± 1	20	4.40 ± 0.27 b	33.40 ± 3.03 b	4.30 ± 0.92 a	42.10 ± 3,32 b

* Means in columns followed by different letters indicate significant differences among temperatures tested at $P \leq 5\%$ (ANOVA).

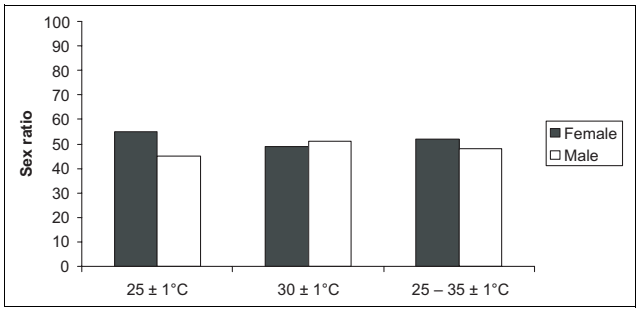

Fig. 1: Sex ratio of *Delphastus catalinae*, feeding on *Bemisia tabaci* as prey on cotton leaves at three temperatures.

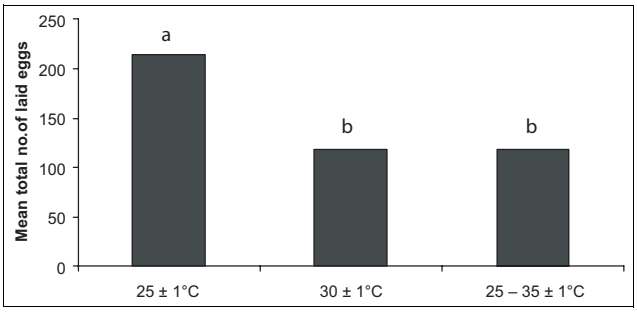

Fig. 2: Mean total number of eggs laid by *Delphastus catalinae*, feeding on *Bemisia tabaci* as prey on cotton leaves at three temperatures [Different letters above bars indicate significant differences among temperatures at $P \leq 5\%$ (ANOVA)].

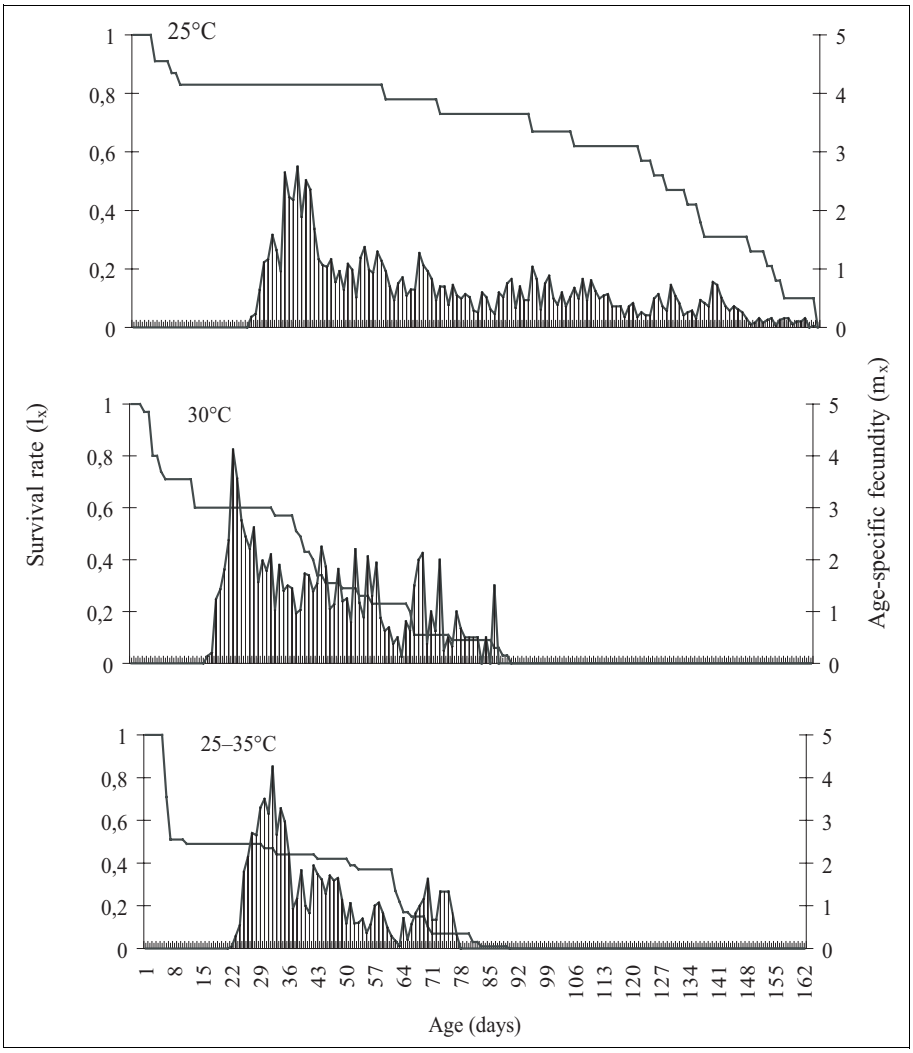

Fig. 3: Age-specific fecundity (m_x) and survival curve (l_x) of *Delphastus catalinae* at different temperatures in the laboratory.

Table 4: Net reproductive rate (R_0), intrinsic rate of increase (r), and mean generation time (T) of *Delphastus catalinae* reared on *Bemisia tabaci* at different temperatures

Temperature (°C)	R_0	r	T (days)
25 ± 1	88.93	0.09	48.65
30 ± 1	35.81	0.127	28.14
25 – 35 ± 1	28.93	0.107	31.34

4 Discussion

The current results indicate that temperature has influenced significantly the mean development duration of all stages of *D. catalinae*. The predatory insect was able to develop with *B. tabaci* as prey on cotton leaves and reached the adult stage at temperatures of 25, 30 and 25–35°C. Muma (1956), Hoelmer et al. (1993) and Liu (2005) found that larval development duration of *D. catalinae* (= *D. pusillus*) was 11.7, 6.7 and 9.6 days at 26.7°C, 28 ± 3°C and 26°C, respectively, which is comparable to 7.94, 6.42, and 7.28 days at 25, 30, and 25–35°C, respectively found in the present study. They also found that development of the 4th larval stage needs more time than development of the other larval stages. Yigit and Uygun (1986) and Canhilal et al. (1995) found similar trends on the other predatory coccinellids, *Stethorus punctillum* Weise and *Nephus includens* Kirsch, respectively.

The present study showed that mean total developmental duration was significantly longer at 25°C than at the other temperatures tested. These results show that development from egg to adult emergence decreased with increasing temperature. Muma (1956), Hoelmer et al. (1993) and Liu (2005) determined 19.7, 21.0 and 18.9 days as adult emergence of *D. catalinae (pusillus)* on citrus leaves infested with *Dialeurodes citrifolii* (Morg) at 26.7°C, on *Euphorbia pulcherrima* Willd., *Phaseolus limensis* Macfady, *Hibiscus rosa-sinensis* L. leaves infested with *B. tabaci* at 28 ± 3°C and on collard (*Brassica oleracea* L. var. *acephala* 'Georgia LS') infested with *B. tabaci* biotype B at 26°C, respectively. Concerning the duration of development, the present results are comparable with earlier studies taking into consideration the difference in temperatures, prey species and prey's host plant species.

Temperature has influenced the total mortality rate of *D. catalinae* during development from egg to adult emergence; larval stages were more sensitive than prepupa and pupa and total mortality at 25°C was lower than at 30°C and 25–35°C. It is concluded that temperatures higher than 30°C are not suitable for development of *D. catalinae*. Liu (2005) reported the total survival rate of *D. catalinae* from egg to pupa at 26°C as 88.4%, and he also recorded no mortality for egg, 1st instar larvae and pupa stages. Yigit and Uygun (1986) stated that the mortality rate of eggs and 1st instar larvae of the coccinellid, *S. punctillum* Weise decreased as temperature increased to 30°C. The present results are supported by the previous studies.

The percentage of female emerged adults varied from 49% to 55% at the temperatures tested. Liu (2005) also found a similar sex ratio for *D. catalinae*.

The statistical analysis of data indicates that longevity of *D. catalinae* varied significantly depending on temperature. The longevity was higher at 25°C than at 30 and 25–35°C (Table 3). MUMA (1956), HOELMER et al. (1993) and LIU (2005) determined 26.7, 60.5 and 146.6 days as the longevity of *D. catalinae (D. pusillus)* on citrus leaves infested with *Dialeurodes citrifolii* at 26.7°C, on *Euphorbia pulcherrima*, *Phaseolus limensis*, *Hibiscus rosa-sinensis* leaves infested with *B. tabaci* at 28 ± 3°C and on collard infested with *B. tabaci* biotype B at 26°C, respectively. In addition to that, ONCUER (1983) and UYGUN and ELEKCIOGLU (1998) suggested that longevity of *Chilocorus bipustulatus* (L.), another predatory coccinellid, depends on prey and host plants species.

Mean fecundity of *D. catalinae* females was significantly affected by temperature. It was higher at 25°C than at 30 and 25–35°C (Fig. 2). HOELMER et al. (1993) and LIU (2005) found that the fecundity of *D. catalinae (D. pusillus)* was 183.2 and 544.0 eggs/♀ on *Euphorbia pulcherrima*, *Phaseolus limensis*, *Hibiscus rosa-sinensis* leaves infested with *B. tabaci* at 28 ± 3°C and on collard infested with *B. tabaci* biotype B at 26°C, respectively. Variations of both longevity and fecundity between the present and the former studies might be explained by different plant species/cultivars, temperatures and prey species used. The variation in fecundity, especially when the prey species was the same, might be due to different *B. tabaci* strains used in different studies.

The r_m value at 30°C was higher than the values obtained at other temperatures tested. However, the maximum R_o value per *D. catalinae* female was obtained at 25°C, compared with the other temperatures. R_o value did not reflect the highest r_m because of the longer generation time (T) at 25°C, compared with 30°C and 25–35°C. It suggests that a suitable mass-rearing temperature for *D. catalinae* between 25°C and 30°C. LIU (2005) found that the r_m value of *D. catalinae* at 26°C on collard was 0.158. It is obvious that the r_m value obtained from this study (Table 4) is different from that of *D. catalinae* on collard (LIU 2005). On the other hand, LIU et al. (1997) and REN et al. (2002) found that the intrinsic rate of increase (r_m) for *Nephasis oculatus* (Baltchley), another predatory coccinellid preying on whiteflies (*B. tabaci* biotype B) on different host plants at 26°C was 0.078 and 0.055, respectively. They concluded that the life table parameters in coccinellids could be specific or related to prey types, or are affected by various biotic factors, such as host plants, or abiotic factors, such as temperature. The shape of m_x curves at 25 and 30°C in this study were similar to those of *S. punctillum*, another predatory coccinellid species (SEKEROGLU and YIGIT 1992). Mass rearing of the predatory insect is impossible at temperatures as high as 35°C.

The results of this study show that *D. catalinae* feeds on *B. tabaci* successfully on cotton leaves and can complete its development exclusively with this prey under laboratory conditions. The current results also provide knowledge about biological parameters of this predator on cotton, which might be considered basic information for further investigations to suppress *B. tabaci* populations under field conditions.

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