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ORIGINAL ARTICLE

Effect of temperature on development, growth, and predation of *Ceratomegilla undecimnotata* (Schneider) (Coleoptera: Coccinellidae) feeding on the black bean aphid, *Aphis fabae* (Scopoli, 1763) (Hemiptera: Aphididae)

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Abstract

Ceratomegilla undecimnotata (Coleoptera: Coccinellidae) exhibits predacious behavior targeting a number of small aphid species, several of which are recognized as pests of cultivated plants. In the present study, the predation rate of *C. undecimnotata*, preying on the black bean aphid under laboratory conditions, was examined. At the highest (35°C) and lowest (17°C) temperatures tested, the mortality was significantly higher than those achieved at the other temperatures studied. Temperatures in the range of 17–35°C had a significant impact on the duration of egg, larval, pupal, and total preimaginal development. The total larval prey consumption ranged between 218.4 and 306.4 aphids. The developmental threshold of the immature stages of *C. undecimnotata* was estimated at 13.6°C and the thermal constant for development of the immature stages was estimated at 207.5 degree-days. This study suggests that *C. undecimnotata* can be an effective biocontrol agent against *Aphis fabae*.

Keywords: biological control, black bean aphid, Coccinellidae, aphids, temperature

Introduction

Aphids pose a significant threat to a wide range of ornamental plants and crops, causing substantial yield losses and making them one of the most important pests in horticulture and agriculture (Łukasik *et al.* 2022). The black bean aphid, *Aphis fabae* (Scopoli, 1763) (Hemiptera: Aphididae) is a polyphagous aphid species (Blackman and Eastop 2007) that can significantly reduce crop yields in more than 80 agricultural and horticultural plant species worldwide (Raymond *et al.* 2001). *Aphis fabae* causes damage directly to the fruits, stems, and leaves of the host plant and indirectly by transmitting more than 30 plant viruses, including cucumber mosaic virus (CMV), plum pox virus (PPV), alfalfa mosaic virus (AMV), pepper veinal mottle virus (PVMV) and lettuce mosaic virus (LMV) (Nebreda *et al.* 2004; Łukasik *et al.* 2022). *A. fabae* is a difficult pest to control due to its rapid reproduction and short generation life span (Abdelmaksoud *et al.* 2023). Chemical insecticides are primarily utilized for black bean aphid management (Skouras *et al.* 2022). Aphid chemical control has led to increased insecticide resistance in many aphid species (Margaritopoulos *et al.* 2021; Bass and Nauen 2023). It also has had adverse effects on the ecosystem (Garratt and Kennedy 2006), and on the populations of natural enemies which subsequently result in resurgences or secondary pest outbreaks (Youn *et al.* 2003).

Predatory insects have an important role among many beneficial natural enemies used in Integrated Pest Management (IPM) and biological control. Most species within the Coccinellidae family, also known as ladybirds, ladybugs, or lady beetles are predators making them effective biological control agents for managing economically important pests in agricultural environments (Mamay and Dusak 2023). Lady beetles prey on many significant pests such as whiteflies (Hodek and Honěk 2009), aphids (Hodek and Honěk 2013), mealybugs (Ferreira *et al.* 2020), scale insects (Eliopoulos *et al.* 2010), spider mites (Obrycki and Kring 1998), psyllids (Hodek and Honěk 2009; Özgen *et al.* 2022), eggs and/or larvae of Lepidoptera, Diptera and Coleoptera (Evans 2009). For instance, *Ceratomegilla undecimnotata* (Schneider) (Coleoptera: Coccinellidae) is one of the most abundant ladybug insects in Greece (Kavallieratos *et al.* 2004) preying only on a few aphid species (Hodek and Honěk 1996), such as *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) (Brun and Iperti 1978; Skouras *et al.* 2015) and *A. fabae* (Brun and Iperti 1978; Kontodimas *et al.* 2008).

To establish an effective biological control program, it is crucial to thoroughly analyze and understand the stage structure, growth, reproductive ability, and predation capabilities of the predators involved (Farhadi *et al.* 2011). This study primarily aimed to accomplish two key objectives: (a) To evaluate the impact of different temperatures on development, adult body weight, gender distribution, and predation rates of *C. undecimnotata*. (b) To determine the thermal requirements for the development of immature stages of *C. undecimnotata* when reared on *A. fabae* under controlled laboratory conditions, including the lower developmental threshold and thermal constant.

Materials and Methods

Insect culture

An *A. fabae* colony was collected from a local cultivated field with broad beans [*Vicia faba* L. (Fabaceae)] near Kalamata, Messinia, Greece, and transferred to the Laboratory of Agricultural Entomology and Zoology of the Department of Agricultural Science at the University of the Peloponnese (Kalamata, Prefecture of Messinia, Greece). Species identification was made in the laboratory, using taxonomic keys described by Blackman and Eastop (1984). The black bean aphid colony was maintained on broad bean plants in cages (40 × 45 × 50 cm) at 20 ± 1°C, 50 ± 5% RH, and 16L : 8D.

A *Ceratomegilla undecimnotata* colony was initiated with about 100 adults collected from peach trees in Argolida in May of 2018 and transferred to the Laboratory of Agricultural Entomology and Zoology of the Department of Agricultural Science at the University of the Peloponnese (Kalamata, Prefecture of Messinia, Greece). Species identification was conducted in the laboratory using the taxonomic keys provided by Kovář (1973). The predator insects were maintained in cylindrical acrylic glass containers (30 cm diam. × 50 cm ht.) and kept in an environmentally controlled room (25 ± 1°C, 65 ± 2% RH, and 16L : 8D photoperiod). An overabundance of black bean aphids infesting broad bean plants was supplied every 2 days in a glass container housing the *C. undecimnotata*.

Pre-imaginal development, survival and aphid consumption

Ceratomegilla undecimnotata eggs laid within a 12-hour period were randomly collected for this study. The egg incubation period and hatchability were studied by placing newly laid eggs of *C. undecimnotata* in Petri dishes at 10 different temperatures (14.0 ± 0.5, 17.0 ± 0.5, 20.0 ± 0.5, 22.5 ± 0.5, 25.0 ± 0.5 27.5 ± 0.5, 30.0 ± 0.5, 32.5 ± 0.5 35 ± 0.5 and 37.5 ± 0.5°C), 65 ± 5% RH and L16 : D8, in controlled environmental chambers. Daily, egg hatching was recorded, and each newly hatched larva was carefully placed individually in a Blackman's box (7.7 × 4.5 × 2 cm) with a fine camel hair brush, at the base of which, a piece of water-saturated moss was placed (Blackman 1971). A broad bean leaf was introduced into each box and its petiole was inserted into the moss. Three hundred 1-2-day old wingless adults of *A. fabae* were placed daily on the broad bean leaf. Each larva was examined every 24 hours, and molting was recorded. Concurrently, living aphids were counted and subsequently removed. To maintain a consistent population, 300 new wingless aphids were introduced into the Blackman's box as replacements. When required, a fresh broad bean leaf was used to replace the old one. At each temperature, each egg and the larvae that hatched from it were treated as a separate replicate.

The newly emerged adults were weighed on a Precisa 40SM-200A (PAG Oerlikon AG, Switzerland) electronic balance. Before measurements, the insects were immobilized by exposure to –20°C for 2–3 min.

Data analysis

The normality of the data was assessed through the Kolmogorov-Smirnov test. One-way ANOVA was conducted to examine the effect of temperature on total and preimaginal development. Similarly, two-way ANOVA was used to analyze the effects of temperature and sex on adult weight. Total and daily aphid consumption at different temperatures for each predator was analyzed using one-way ANOVA. Post-hoc comparisons of means were carried out using Duncan's test. The Chi-square test was used to assess differences in survival percentages between the different temperature treatments. In cases where two percentages yielded a significant chi-square value, pairwise comparisons were performed with Bonferroni correction SPSS version 23 (SPSS Inc., Chicago, IL, USA, 2020).

This relationship between the developmental rate (Y, inversely related to the duration of the developmental period in days, D) and temperature (T) for all developmental stages and total immature development was examined. Linear regression was used to model this relationship using the equation Y = a + b*T. The lower temperature threshold for development (T_0) was determined as the point where the regression line crosses the x-axis, represented as -a/b. The sum of day-degrees (DD) requirements, which signifies the inverse of the slope (1/b), was also calculated as part of the analysis, following the methodology outlined in Katsarou *et al.* (2005). Statistical analyses were conducted using SPSS version 23 (SPSS Inc., Chicago, IL, USA, 2020).

Results

Pre-imaginal survival

None of the *C. undecimnotata* eggs or larvae successfully completed their development at the lowest (14°C) and highest (37.5°C) temperatures tested. As a result, no data are available for these treatments. Table 1 summarizes the total preimaginal survival, as well as the survival rates at the egg, larval, and pupal stages for *C. undecimnotata*. Temperature had a statistically significant effect on the percentage of individuals that completed total preimaginal development successfully ($\chi^2 = 213.90$; df = 7, $p < 0.01$), egg ($\chi^2 = 201.61$; df = 7, $p < 0.01$), larvae ($\chi^2 = 64.36$; df = 7, $p < 0.01$), and pupae ($\chi^2 = 32.06$; df = 7, $p < 0.01$). At the highest (35°C) and lowest (17°C) temperatures employed, the mortality percentages were 93.6% and 76.9%, respectively. These values were significantly higher than those achieved at the other temperatures studied ($p < 0.05$). In the temperature range from 20 to 30°C, the percentages of individuals that completed their total preimaginal development ranged from 54.3% to 23.3%, with no significant difference between them. The pupae and fourth instar larvae exhibited low or no mortality.

Preimaginal development and adult weight

Temperatures in the range of 17–35°C had a significant impact on the duration of egg ($F_{7,178} = 123.6$, $p <0.001$), larval ($F_{7,178} = 803.0$, $p <0.001$), pupal ($F_{7,178} = 634.1$, $p <0.001$) and total preimaginal development ($F_{7,178} = 1494.8$, $p < 0.001$) as illustrated in Table 2. The developmental duration time for each life stage decreased from 17 to 32.5°C but then increased between 32.5 and 35°C. The shortest developmental period was recorded for all life stages at 32.5°C. The larval stage displayed the highest duration of development time across all temperatures tested. The mean adult weight was significantly influenced by temperature ($F_{7,178} = 3.65$, $p < 0.001$) and sex ($F_{1,178} = 153.0$, $p < 0.001$) (Fig 1). Adults' weight was 20.61, 21.46, 22.40, 20.97, 21.84, 20.33, 20.42, and 18.58 mg at temperatures of 17°C, 20°C, 22.5°C, 25.0°C, 27.5°C, 30.0°C, 32.5°C, and 35.0°C, respectively. Adult weight was significantly lower at 35°C while the males were lighter than the females at all temperatures tested. The weight of *C. undecimnotata* males was recorded as 18.13 mg, 20.09 mg, 20.45 mg, 18.87 mg, 19.20 mg, 18.48 mg, 18.27 mg, and 17.35 mg at temperatures of 17°C, 20°C, 22.5°C, 25.0°C, 27.5°C, 30.0°C, 32.5°C, and 35.0°C, respectively. In comparison, female weights were measured as 23.09 mg, 23.28 mg, 24.35 mg, 23.25 mg, 22.57 mg, 21.91 mg, 22.21 mg, and 22.25 mg across the same temperature range.

Total and daily aphid consumption

Tables 3 and 4 provide information regarding the total and daily average number of aphids consumed over

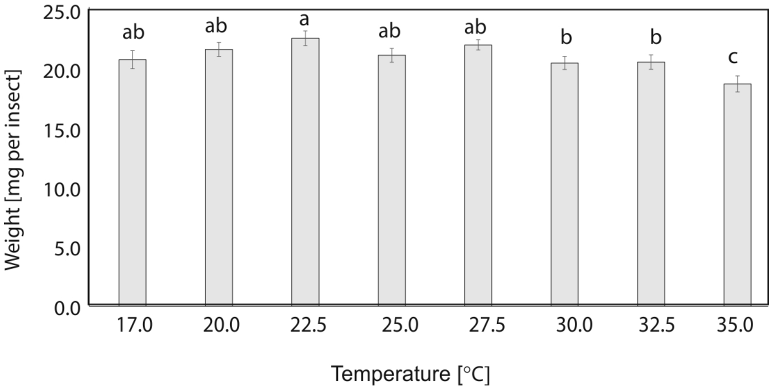

Fig. 1. Adult body weight of *Ceratomegilla undecimnotata* feeding on *Aphis fabae* at eight constant temperatures and long day length. Means followed by a different small letter within a row differ significantly ($p < 0.05$) by Duncan's test

Table 1. Percentage mortality of *Ceratomegilla undecimnotata* feeding on *Aphis fabae* at eight constant temperatures and long day length (L16 : D8)

Life stage	Mortality															
	17°C		20°C		22.5°C		25°C		27.5°C		30°C		32.5°C		35°C	
	N	[%]	N	[%]	N	[%]	N	[%]	N	[%]	N	[%]	N	[%]	N	[%]
Eggs	78	30.8 a	46	21.7 a	32	15.6 a	30	13.3 a	35	17.1 a	40	20.0 a	64	40.6 a	377	77.5 b
L1	54	37.0	36	27.8	27	11.1	26	7.7	27	7.4	32	6.3	38	13.2	85	40.0
L2	34	14.7	26	7.7	24	4.2	24	8.3	25	4.0	30	3.3	33	12.1	51	31.4
L3	29	10.3	24	4.2	23	4.3	23	0.0	24	4.2	29	3.4	29	6.9	35	22.9
L4	26	0.0	23	0.0	22	0.0	23	0.0	23	0.0	28	3.6	27	7.4	27	11.1
L1-L4	51	49.0 ab	36	36.1 bc	27	18.5 bc	26	11.5 c	29	20.7 bc	32	15.6 bc	38	34.2 bc	85	71.8 a
Pupae	26	30.8 a	22	4.5 a	22	0.0 b	23	0.0 b	23	0.0 b	27	3.7 a	25	12.0 a	24	0.0 b
Total	78	76.9 a	46	54.3 abc	32	37.5 bc	30	23.3 c	35	34.3 c	40	35.0 c	64	67.2 ab	377	93.6 d

N – number of individuals examined. Means followed by a different letter within a row differ significantly ($p < 0.05$)

Table 2. Development (in days) of *Ceratomegilla undecimnotata* feeding on apterous adults of *Aphis fabae*, at eight constant temperatures and L16:D8 photoperiod. Numbers in brackets denote standard error of means

Life stage	Temperature [°C]																
	17		20		22.5		25		27.5		30		32.5		35		F
	N	days	N	days	N	days	N	days	N	days	N	days	N	days	N	days	
Eggs	18	7.67 (0.31) a	21	4.81 (0.21) b	22	3.77 (0.09) c	23	2.96 (0.08) d	23	2.65 (0.10) de	26	2.12 (0.06) gf	22	1.77 (0.09) g	24	2.42 (0.25) ef	123.563*
Larvae	18	31.78 (0.55) a	21	20.95 (0.44) b	22	13.82 (0.25) c	23	11.26 (0.32) d	23	8.61 (0.14) e	26	7.23 (0.20) f	22	6.50 (0.18) f	24	7.08 (0.20) f	803.7*
Pupae	18	11.39 (0.20) a	21	8.52 (0.18) b	22	5.86 (0.12) c	23	5.17 (0.08) d	23	3.48 (0.11) e	26	3.19 (0.08) e	22	2.73 (0.10) f	24	2.83 (0.08) f	634.1*
Adults	18	50.83 (0.66) a	21	34.29 (0.49) b	22	23.45 (0.34) c	23	19.39 (0.31) d	23	14.74 (0.16) e	26	12.54 (0.25) f	22	11.00 (0.17) g	24	12.33 (0.25) f	2316.1*

N – number of individuals examined. Means followed by a different letter within a row differ significantly ($p < 0.05$) by Duncan's test,
*Denotes significance level $p < 0.05$ in one-way Analysis of variance

Table 3. Total aphid consumption of *Ceratomegilla undecimnotata* larvae feeding on adult *Aphis fabae* at eight constant temperatures and long day length. Numbers in brackets denote standard error of means

Life stages	Temperature [°C]																F
	17		20		22.5		25		27.5		30		32.5		35		
	N	TAC	N	TAC	N	TAC	N	TAC	N	TAC	N	TAC	N	TAC	N	TAC	
L1	18	11.33 (1.02) b	21	12.48 (1.06) ab	22	13.82 (1.15) ab	23	14.74 (1.59) a	23	15.43 (1.45) a	26	12.23 (0.58) ab	22	11.23 (0.98) b	24	10.38 (0.48) b	2.76
L2	18	23.33 (1.45) ab	21	24.52 (0.73) a	22	25.91 (1.27) a	23	26.43 (2.38) a	23	27.04 (1.81) a	26	23.12 (1.74) ab	22	22.68 (0.80) ab	24	19.04 (0.65) b	3.09
L3	18	43.94 (1.85) ab	21	42.81 (1.22) ab	22	45.55 (2.31) ab	23	50.13 (3.92) a	23	47.96 (2.26) a	26	43.81 (4.31) ab	22	38.36 (3.70) b	24	37.13 (0.85) b	2.29
L4	18	161.39 (5.37) cd	21	167.81 (4.91) c	22	174.77 (4.02) bc	23	209.30 (3.33) a	23	205.65 (8.37) a	26	186.08 (3.61) b	22	165.95 (3.09) c	24	151.88 (3.20) d	19.54
L1-L4	18	240 (6.20) c	21	247.62 (5.41) bc	22	260.05 (4.74) b	23	300.61 (6.95) a	23	296.09 (8.80) a	26	265.23 (5.67) b	22	238.23 (5.31) c	24	218.42 (3.34) d	23.13

N – individuals examined; TAC – Total Aphid Consumption. Means followed by a different small letter within a row differ significantly ($p < 0.05$) by Duncan's test

Table 4. Mean daily prey consumption of *Ceratomegilla undecimnotata* larvae feeding on adult *Aphis fabae* at four constant temperatures and long day length. Numbers in brackets denote standard error of means

Life stage	Temperature [°C]																F
	17		20		22.5		25		27.5		30		32.5		35		
	N	MDAC	N	MDAC	N	MDAC	N	MDAC	N	MDAC	N	MDAC	N	MDAC	N	MDAC	
L1	18	1.38 (0.12) e	21	2.34 (0.21) e	22	4.15 (0.40) d	23	6.20 (0.80) c	23	9.48 (0.47) ab	26	10.13 (0.66) a	22	10.11 (0.81) a	24	7.92 (0.73) b	31.59*
L2	18	3.37 (0.26) e	21	6.84 (0.41) d	22	11.04 (0.66) c	23	13.24 (0.84) c	23	16.20 (0.67) b	26	20.35 (1.43) a	22	22.25 (0.99) a	24	17.71 (0.83) b	50.50*
L3	18	6.78 (0.32) e	21	10.70 (0.52) e	22	17.94 (0.75) d	23	24.92 (2.60) c	23	38.39 (3.26) a	26	32.40 (1.58) ab	22	33.80 (2.62) ab	24	32.08 (2.05) b	29.62*
L4	18	16.23 (0.50) e	21	22.40 (0.70) d	22	33.09 (0.97) c	23	48.06 (1.64) b	23	53.49 (2.24) ab	26	56.34 (2.62) a	22	54.16 (2.26) a	24	51.56 (2.64) ab	57.87*
L1-L4	18	7.57 (0.20) g	21	11.88 (0.28) f	22	18.90 (0.40) e	23	27.05 (0.82) d	23	34.63 (1.22) b	26	37.27 (1.20) a	22	37.05 (1.01) ab	24	31.28 (0.83) c	160.47*

N – individuals examined; MDAC – Mean Daily Aphid Consumption. Means followed by a different letter within a row differ significantly ($p < 0.05$) by Duncan's test,
*Denotes significance level $p < 0.05$ in one-way Analysis of variance

the complete larval development and each individual larval instar of *C. undecimnotata*. The highest aphid consumption was observed at 25 and 27.5°C. The fourth instar larvae consumed more aphids than the other larval instars. The results of one-way ANOVA showed a significant difference in total aphid consumption between the different temperature conditions ($F_{7,178} = 23.1$, $p < 0.001$). During the fourth larval instar of *C. undecimnotata*, the highest daily aphid consumption occurred consistently across all temperature conditions. Significant differences were observed between temperatures and mean daily aphid consumption ($F_{7,178} = 160.5$, $p < 0.001$). The lowest mean daily aphid consumption for all life stages was recorded at 17.0°C.

Temperature thresholds and degree-day (DD) calculations

The estimated temperature thresholds for the different developmental stages of *C. undecimnotata* were as follows: 13.05°C for the egg, 13.87°C for the larva, and 13.58°C for the pupa (Table 5). The values of DD per instar were calculated as 34.10 DD for the egg, 117.83 DD for the larvae, and 51.02 DD for the pupae. The cumulative temperature required for the transition from egg to adult for this aphid predator was 207.15 DD, with a temperature threshold of 13.57°C (Table 5).

Discussion

This study determined the effects of eight constant temperatures on the developmental time, survival, and predation of *C. undecimnotata*. The developmental time of a coccinellid predator can be affected by factors such as the nutritional quality of the prey and temperature (Islam *et al.* 2022). An increase in temperature significantly reduced the duration of development of the egg, larval, and pupal stages, as well as the total developmental time from the egg to the adult stage. The results show that high temperature (35.0°C) increased the duration time for the egg, larval, pupal, and egg to adult stages. High temperatures are commonly linked to oxidative damage due to the increased generation of reactive oxygen species (ROS) (Zhang *et al.* 2014). Oxidative stress has been observed to impede growth and extend the lifespan of *H. armigera* and various other insect species (Zhang *et al.* 2017). The findings from this research, when considered alongside existing results, suggest that developmental delays contributing to increased lifespan under different stress conditions may be a prevalent occurrence in insects (Ullah *et al.* 2022).

In the present study, the significant differences in the duration of development of the different life stages of *C. undecimnotata* suggest a sensitivity to temperature fluctuations. The preimaginal development (from egg to adult) in *C. undecimnotata* ranged from 50.8 to 11.00 days, corresponding to temperatures of 17 and 32.5°C, respectively. The overall developmental period (from egg to adult emergence) of *C. undecimnotata* was found to be similar to the study of Skouras *et al*. (2015) [48.5 to 14.4 days, corresponding to temperatures ranging from 17 to 29.0°C, respectively]. Papachristos *et al.* (2015) reported a developmental time of the predator (first instar larvae to adult) between 15.8 to 18.7 days when feeding on *A. fabae* (depending on the aphid host plant), 16.4 days when feeding on *Macrosiphoniella sanborni* (Gillette) (Hemiptera: Aphididae) and 22.9 days when feeding on *Brevicoryne brassicae* L. (Hemiptera: Aphididae) at 24°C. While differences between studies can be partly attributed to diverse experimental protocols, disparities may also arise from plant-herbivore – predator interactions that extend beyond the plant species to the cultivar level (Papachristos *et al.* 2015).

Results show that the mortality of *C. undecimnotata* at the egg, larval (L1 to L4) stages, and overall from egg to adult significantly increased when exposed to high or low temperatures. The results of this research at low temperatures are in line with Skouras *et al.* (2015) who reported that the mortality of *C. undecimnotata* significantly increased when exposed to low temperatures (17.0°C). Between 17.0 and 35.0°C, the highest mortality among the developmental stages of *C. undecimnotata* occurred in the eggs and the first instar larvae. Previous studies on other coccinellid

Table 5. Developmental threshold (T_0) and degree day (DD) requirements in *Ceratomegilla undecimnotata* feeding on *Aphis fabae* at four constant temperatures and long day length

Life stage	T_0	DD	Equation	R^2 (df)	*P*
Egg	13.05	34.10	$Y = -0.38264X + 0.029323$	0.70 (1, 153)	< 0.05
Larvae	13.87	117.83	$Y = -0.11775X + 0.008486$	0.91 (1, 153)	< 0.05
Pupae	13.58	51.02	$Y = -0.26622X + 0.019599$	0.86 (1, 153)	< 0.05
Egg – adult	13.57	207.51	$Y = -0.06541X + 0.004819$	0.96 (1, 153)	< 0.05

predators, such as those by Pervez (2004), have also reported elevated mortality in first instars, likely attributed to their diminutive size and the delicate nature of their thin cuticle, rendering them more susceptible to physical stressors.

There is a lack of comprehensive information on the biology and ecology of *C. undecimnotata* (Kontodimas *et al.* 2008; Skouras *et al.* 2015). Specifically, there is a lack of data on *A. fabae* consumption by its predators and how temperature influences aphid consumption. The mean daily aphid consumption of *C. undecimnotata* showed an increase with rising temperatures between 17.0 and 30.0°C. Similarly, Skouras *et al.* (2015) reported the same pattern for larvae of *C. undecimnotata* fed *M. persicae* at temperatures between 17.0 and 29.0°C. In the current study, aphid consumption increased from the first to the fourth instar. Fourth instar larvae demonstrated higher aphid consumption than the cumulative intake of other larval instars. This increased voracity in fourth instar larvae is a phenomenon commonly observed in other coccinellid species, such as *Hippodamia variegata* (Coleoptera: Coccinellidae) when feeding on *Myzus persicae nicotianae*, *A. fabae*, *Aphis gossypii* Glover, *Brevicoryne brassicae* L., *Macrosiphum euphorbiae* (Thomas) (Hemiptera: Aphididae) (Mandour 2013; Skouras *et al.* 2015;), *Hippodamia convergens* Guérin-Méneville and *Coccinella septempunctata* L. when feeding on *M. persicae* (Katsarou *et al.* 2005), and *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) when preying on *A. gossypii* (Lee and Kang 2004).

In this study, the lowest developmental threshold and day-degree was identified as 13.6°C and 207.5 DD, respectively. Comparatively, a study on a northern Greek population of *C. undecimnotata* indicated a requirement for 256.5 DD above a lower developmental threshold of 12.7°C (Skouras *et al.* 2015). Discrepancies in the thermal requirements for *C. undecimnotata* development may be attributed to differences in prey species (*A. fabae* vs *M. persicae*) and food quality. Additionally, differences in experimental conditions, such as the temperatures tested, could contribute to variations between studies.

The diversity in adult body weight had a clear impact on several reproductive factors, particularly fecundity and oviposition duration time of females, as highlighted in the study by Shah and Khan (2014). Moreover, in the case of *C. septempunctata,* Omkar and Srivastava (2003) observed that increased or decreased consumption of essential prey resulted in increased or decreased body weight, respectively. In our study, *C. undecimnotata* exhibited the lowest prey consumption at 35.0°C, and concurrently, at this temperature, they matured into the smallest adults.

Conclusions

The results of this study suggest that *C. undecimnotata* has potential as a biocontrol agent against *A. fabae*. Nevertheless, further research is needed to comprehensively assess the impact of this lady beetle in various cropping systems and different natural conditions.

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