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BIOLOGICAL CHARACTERISTICS AND HEAT REQUIREMENTS FOR *Coccinella undecimpunctata* – *Sitobion avenae* AND *Coccinella 9-punctata* – *Aphis craccivora* FEEDING SYSTEMS AT VARYING TEMPERATURE REGIMES

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ABSTRACT

Laboratory experiments were carried out to examine some biological characteristics and heat requirements of the two coccinellid species; viz. *Coccinella undecimpunctata* L. and *Coccinella 9-punctata* L. (Coccinellidae: Coleoptera) when reared on *Sitobionavenae*(F.)and *Aphis craccivora* Koch (Aphididae: Hemiptera)at varying constant temperature regimes of 18, 23, 28, and 33 ˚C, respectively. The obtained results showed that the developmental time of *C. undecimpunctata*and *C. 9-punctata*immature stages declined as temperature degrees increased with the shortest developmental time was recorded at 33 ˚C which lasted 15.29 ± 0.98 and 14.00 ± 1.35 days, respectively. Daily larval consumption increased as both temperature and larval age increased with the highest consumption for the fourth instars at 33 ˚C which recorded by 99.71 ± 14.49 and 105.40 ± 10.54 for *C. undecimpunctata* and *C. 9-punctata*, respectively. Female and male longevities for both predator species increased as temperature decreased, whereas the females' fecundity increased as temperature increased. Furthermore, the total consumption of female and male of both species increased as temperature increased with the highest consumption recorded during the oviposition period. The total consumption of females was higher than that of males for both predator species, and the corresponding daily consumption values were higher for females than those of males at varying temperatures. The developmental rates for all stages of both species declined as temperature decreased. The lower developmental threshold (T_0) recorded the lowest for pupal and larval stages of *C.undecimpunctata* and *C.-9 punctata*, respectively. The corresponding amount of heat units which required to completing the development of *C. undecimpunctata* and *C. 9-punctata* averaged 380.73± 27.71 and 363.83 ± 14.44dd's, respectively.This study showed that *C. undecimpunctata* and *C. 9-punctata*successfully complete their development in a wide range of temperatures from 18 to 33 ˚C, indicating their high potential for use in biological control programs against *S. avenae*and *A. craccivora,* respectively.

Keywords: Developmental rate, degree-days, heat units, lower developmental threshold.

INTRODUCTION

Many coccinellids, are well known as insect predators, playing an important role as biological control agents in regulating the population of several insect pests especially aphids, coccids, and other soft bodies' insects.

Aphidophagous ladybirds are considered to be a great economic in agro-ecosystem through their successful employment in the biocontrol of aphids, and have been received increasing attention from ecologists all over the world due to some of their characteristics, such as: ability to feed on a wide range of prey, to be very voracious, and to have a rapid numeric response (e.g., Agarwala*et al*., 1988; Hodek and Honěk, 1996; Bari and Sardar, 1998; Pervez and Omkar, 2005). Prior to introduce any predator in biological control program, it should be estimated its efficiency under different environmental factors, among them the predation activity of varying developmental stages, female reproductive success, body size, prey species and density, plant architecture, prey type, temperature, and relative humidity are considered the most important factors (Skirvin*et al*., 1997; Kajita and Evans, 2010; Koch *et al*., 2003; Sarmento*et al*., 2007; Bayoumy and Michaud, 2012; Bayoumy *et al*., 2014; Bayoumy *et al*., 2015).

*Coccinella undecimpunctata*L. and *Coccinella 9-punctata*L. (Coleoptera: Coccinellidae) are dominant coccinellid species in Mansoura region (Ghanim and El-Adl, 1987). Both species areeuriphagous predators, which prefers to feed on aphids (Hodek and Honěk, 1996), and *C. undecimpunctata*offers interesting potential as bio-control agents in the context of integrated pest management, IPM (Cabral et al., 2011). Several investigators in different places of the world studied the predation activity of certain coccinellid predators (Sethi and Atwal, 1964; Smith, 1965; Ghanim and El-Adl, 1987; El-Serafi*et al*., 2004; Ghanium*et al*., 2009; and Bayoumy, 2011;Osman and Bayoumy, 2011; Bayoumyand Michaud, 2012; Bayoumy *et al*., 2014). Temperature controls the development rate of many organisms, plants, and invertebrate animals, including insects and nematodes which require certain amounts of heat to develop from one stage in their cycles to another one. This measure of accumulated heat is known as degree-days(dd's). Growth and development of insect are dependent on temperature where the temperature increase, development time decreases until the temperature become high enough to have a negative effect. This limit is defined as temperature threshold. The lower development threshold (T_0) for a species is the minimum temperature at which development can continue and below it the development fails. Numerous entomologists in different parts of the world estimated the heat requirement of certain insect pests including the coccinellid predators either in the lab (Zalom*et al*., 1983; Uygun and Atlhan 2000; Omkar and Pervez, 2004; Ghanim*et al*., 2014; Abd El-Halim, 2015) or in the field (Awadalla*et al*., 2014) to estimate the amount of heat for completing their development, to predicate with their abundance, and/or to protect them from the extensive use of chemical pesticides. Although the biology and consumption of these species have been investigated, no study aimed to theoretically estimated the thermal requirements for these predator species specifically *C. 9-punctata* (e.g., Ghanim and El-Adl, 1987; Abdel-Salam, 2004; Mari *et al*., 2005; Cabral *et al*., 2006; Solangi*et al*., 2007; Mohamed and Ghanim, 2008; El-Heneidy*et al*., 2008). Therefore, the present investigation aimed to study some biological attributes of *C. undecimpunctata*- *S. avenae* and *C. 9-punctata*-*A. craccivora* feeding systems to use it in the estimation ofthe lower thermal development and then the amount of heat required to development of these coccinellid predators.

MATERIALS AND METHODS

Biological characteristics of *C. undecimpunctata* and *C. 9-punctata*

A permanent culture of coccinellid predators and aphid species were maintained in the laboratory of the Economic Entomology Department, Faculty of Agriculture, Mansoura University. Experiments were carried out under four constant temperature regimes, 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1, and 70 ± 5 % R.H. The used predator species, *C. undecimpunctata* and*C.9-punctata*were obtained from the laboratory culture. Twenty newly hatched first instars of each predator species were isolated into Petri-dishes (9.0 cm in diameter). The bottom of each dish was covered with a filter paper to facilitate the predator's larvae movement. A known number of different stages of each aphid species (*S. avenae* and *A. craccivora*) was offered daily at 10 AM and the devoured individuals were recorded. A small plant leaflet was introduced daily in each Petri-dish as a food source for the aphids for keeping them alive as long as possible. The remained aphids and their parts were removed daily from each Petri-dish before a new food. The total number of aphid species consumed by each predator larva was estimated. The developmental times for the larval and pupal stages were also estimated. Each adult predator received the same type of prey as that of its larval instars. Immediately after emergence from the pupal stage, each predator individuals were sexed and the isolated into the Petri-dishes. Known numbers of each aphid species were provided daily on a plant leaflet to each predator. Counting the consumed aphids and removing the non-devoured aphids in each Petri-dish were practiced daily before providing the new aphids. After five days of emergence, copulation took place and the two sexes were immediately separated and isolated into the Petri-dishes. The daily number of the laid eggs per each predator female during her oviposition period was counted. The total number of each aphid species consumed daily by a male or female and the total daily number of deposited eggs for each predator female species were recorded. The daily means of food consumption during longevity of each predator species were calculated.

B. Heat requirements (degree-days) of *C. undecimpunctata* and *C. 9-punctata*

The coccinellid predators, *C. undecimpunctata* and *C. 9-punctata* were reared under four constant temperature degrees (18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C) to estimate the thermal requirements as a predicating tool for the annual generation of these predators. The lower developmental threshold temperature (t_0) was estimated from the x- intercept point of the linear regression analysis (with t_0= -a/b) to determine the relationship between development rate (calculated as the inverse of the number of days required for development at that temperature, 1/d) and incubation temperatures for values within the linear range, resulting in the regression equation y = a + bx; where x is the temperature and y is the development rate (Arnold, 1960;

Campbell et al., 1974). Regression lines were determined by using the SigmaPlot 11.0 (Systat, 2008).

The thermal constant (K) required for development of each stage on each temperature (the amount of thermal energy required for completion of development of 50% of individuals at constant temperatures, expressed as degree-days (dd's) accumulated above the lower developmental threshold)were estimated according to Fletcher (1981) and Obrycki and Tauber(1981) equation as follows:

$$K=D(T-T_0)$$

Where: D is the development duration in days, T is the temperature (˚C) at which development occurs and T_0 the lower developmental temperature threshold.

Statistical analysis

Data for larval, pupal, and total development durations, total larval consumption, female and male longevities, female fecundity, total female and male consumptions, and thermal units (dd's) were analyzed by One-way ANOVA and means separated using Duncan's Multiple Range Test (α = 0.05)

RESULTS AND DISCUSSION

1. Biological characteristics of *C. undecimpunctata* and *C. 9-punctata*

Coccinella undecimpunctata L.

The obtained results in Table (1) showed that the incubation period decreased as temperature increased with the lowest period (3.1 ± 0.52) at 33 C. Statistical analysis revealed that there was significant effect for temperature on larval ad pupal durations and total development. The larval duration of the predator averaged 20.74 ± 1.10, 16.74 ± 0.95, 10.61 ± 0.87, and 8.99 ± 0.74 days when fed on *S. avenae* under constant temperature degrees of 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C, respectively, whereas the pupal stage period lasted an average of 7.53 ± 0.8, 7.00 ± 0.56, 5.30 ± 0.40, and 3.70 ± 0.32 days at the same temperatures, respectively. The total development time of *C. undecimpunctata* averaged 36.17 ± 1.85, 29.04 ± 1.5, 15.29 ± 0.89, and 19.01 ± 1.16 at 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C, respectively.

Statistical analysis revealed that there was significant effect for temperature on larval stage consumption.The consumption of larval instars of *C. undecimpunctata* when fed on *S. avenae*increased as temperature and their growth increased with the highest consumption for the fourth instars at 33°C. The daily consumption per an individual larva averaged 25.57 ± 5.15, 41.82 ± 12.41, 76.12 ± 11.08, and 99.74 ± 14.49 at 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C, respectively (Table 2).

Statistical analysis showed that there was significant effect for temperature on male and female longevities.The female and male longevities of *C. undecimpunctata* decreased as temperature increased with the shortest longevity averaged 50.95 ± 2.10 and 40.22 ± 0.89 for female and male at 33 ˚C, respectively, whereas the daily number of deposited eggs per female increased as temperature increased with the highest number (30.11 ± 8.66 eggs/female/day) at 33 ˚C (Table 3).

Statistical analysis showed that there were significant effects for temperature on total consumption for males and females during their longevity.The total consumption of female *C. undecimpunctata* was the highest during oviposition period followed by postoviposition and preoviposition periods. As presented in Table (4), *C. undecimpunctata* males consumed more aphids (*S. avenae*) than females during their longevity only at 33 ˚C. Furthermore, the total consumption for female and male during their longevities and the daily consumption per female and male increased with increasing temperature with the highest total female consumption of 6943.57 ± 39.64 aphids, the highest total male consumption of 7397 ± 32.46 aphids, the highest daily female consumption of 136.28 ± 18.9 aphids, and the highest daily male consumption of 183.83 ± 38.46 aphids at 33 ˚C.

The developmental rates for completion of embryogenesis, larval, pupal, and total development of *C. undecimpunctata* when fed on *S. avenae*increased as the temperature increased. The lower developmental threshold (T_0) derived from the linear relationship between developmental rate (1/d) and the four tested temperatures (Fig. 1) was the lowest for pupal stage (5.42 ˚C), whereas the egg stage was the more tolerant stage for lower temperature (11.38 ˚C). The thermal units, expressed as degree-days (DD's), required for each developmental stage showed that the larval stage needs to more heat unit to develop at each temperature tested compared to other stages. The correspondingthermal unites required for each stage of *C. undecimpunctata* to complete its development on a given temperature was 55.40 ± 3.99, 223.29 ± 16.95, 109.85 ± 11.88, and 380.73 ± 27.71 for egg, larval, and pupal stages, and total life cycle, respectively. Furthermore, statistical analysis revealed that there was significant effect for temperature on thermal units required for complete the development (Table 5).

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***Coccinella 9-punctata* L.**

The obtained results in Table (6) showed that the incubation period decreased as temperature increased with the lowest period (3.0 ± 0.37) at 33 ˚C. Statistical analysis showed that there was significant effect for temperature on larval ad pupal durations and total development. The larval duration of the predator averaged 16.64 ± 1.35, 11.89 ± 1.1, 8.56 ± 0.92, and 7.00 ± 0.63 days when fed on *Aphis craccivora* under constant temperature degrees of 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C, respectively, whereas the pupal stage period lasted an average of 6.10 ±0.44, 4.21 ± 0.30, 4.21 ± 0.30, and 4.00 ± 0.26 days at the same temperatures, respectively. The total development time of *C. undecimpunctata* averaged 27.54 ± 1.89, 20.14 ± 1.63, 29.04 ± 1.5, and 36.17 ± 1.85 at 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C, respectively.

Statistical analysis showed that there was significant effect for temperature on larval stage consumption.The consumption of larval instars of *C. 9-punctata* when fed on *A. craccivora increased* as temperature and their growth increased with the highest consumption for the fourth instars at 33°C. The daily consumption per an individual larva averaged 25.05 ± 3.84, 48.62 ± 4.32, 76.73 ± 5.89, and 105.40 ± 10.54 at 18 ± 1, 23 ± 1, 28 ± 1, and 33 ± 1 ˚C, respectively (Table 7).

Statistical analysis revealed that there was significant effect for temperature on male and female longevities.The female and male longevities of *C. 9-punctata*decreased as temperature increased with the shortest longevity averaged 45.74 ± 1.50 and 30.17 ± 0.68for female and male at 33 ˚C, respectively, whereas the daily number of deposited eggs per female increased as temperature increased with the highest number (29.03 ± 8.71 eggs/female/day) at 33 ˚C. The female fecundity increased with increasing temperature to record the highest fecundity of 890.56 ± 11.32 at 33 ˚C(Table 8).

Statistical analysis revealed that there were significant effects for temperature on total consumption for males and females during their longevity.The total consumption of female *C. 9-punctata*was the highest during oviposition period followed by postoviposition and preoviposition periods. As presented in Table (9), *C. 9- punctata*females consumed more aphids (*A. craccivora*) than males during their longevity. Furthermore, the total consumption for female and male during their longevities and the daily consumption per female and male increased with increasing temperature with the highest total female consumption (5189.36 ± 35.20 aphids), the highest male total consumption (2750.657 ± 26.70 aphids), the highest daily female consumption (113.45 ± 23.47 aphids), and the highest daily male consumption (91.17 ± 9.52 aphids) at 33 ˚C.

The developmental rates for completion of embryogenesis, larval, pupal, and total development of *C. 9-punctata*when fed on *A. craccivora* increased as the temperature increased. The lower developmental threshold (T_0) derived from the linear relationship between developmental rate (1/d) and the four tested temperatures (Fig. 2) was the lowest for larval stage (7.64 ˚C), whereas the tolerant stage was the egg stage (10.72˚C). However,the thermal units, expressed as degree-days (DD's), required for each developmental stage showed that the larval stage needs to more heat unit to develop at each temperature tested compared to other stages. The corresponding thermal unites required for each stage of *C. 9-punctata*to complete its development on a given temperature was 50.03 ± 12.58, 176.71 ± 3.88, 66.53 ± 15.8, and 363.83 ± 14.44 for egg, larval, and pupal stages, and total life cycle, respectively (Table 10).

The obtained results for both predator species regarding their development, larval and adult stage consumptions, fecundity, and female and male longevities are partially confirmed by works of Ghanim and El-Adl (1987), Abdel-Salam (2004), Mari *et al*. (2005), Cabral *et al*. (2006), Solangi*et al*. (2007), Mohamed and Ghanim (2008), El-Heneidy*et al*. (2008). However, results of lower developmental threshold and degree-days are disagreed with that of Jalali*et al*. (2014). The lower developmental thresholds for total development (egg to adult) of *Coccinellaundecimpunctataaegyptica*(Reiche) recorded 14 ˚C and the degree-day (dd's) requirements for total development were 166.67dd's. This may be attributed to the different prey species used as food sources in both studies. Nevertheless, these results were relatively closed to those of Skouras *et al*. (2015) for*Coccinella undecimnotata* Schneider to the tobacco aphid, *M. persicaenicotianae* at five constant temperatures (17, 20, 23, 26, and 29 ˚C).The obtained results for total fecundity, daily oviposition per female, and lower developmental threshold for *C. undecimpunctata* are closed to those obtained by Xia *et al*. (1999) for *Coccinellaseptempunctata* L. reared on *Aphis gossypii* Clover at 15, 20, 25, 30, and 35 ± 0.5 ˚C.

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الخصائص البيولوجية والاحتياجات الحرارية لنظامي التغذية ابو العيد 11 نقطة – من الحبوب و ابو العيد 9 نقاط – من البقوليات علي درجات حرارة متعددة

محمد حسن محمد بيومي ، احمد محمود ابو النجا ، عبد البديع عبد الحميد غانم و غسان عيسى مشحوت
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اجريت هذه الدراسة تحت الظروف المعملية لدراسة الخصائص البيولوجية والاحتياجات الحرارية لكل من مفترس ابو العيد 11 نقطة وابو العيد 9 نقاط عند التغذية علي من الحبوب ومن البقوليات علي التوالي علي درجات الحرارة 18، 23، 28، 33 م°. اوضحت النتائج المتحصل عليها ان الوقت اللازم لنمو الاطوار غير الكاملة لابو العيد 11 نقطة وابو العيد 9 نقاط انخفضت كلما زادت درجة الحرارة حيث سجلت اسرع نمو لها علي درجة حرارة 33 م° والذي كان 15.29 ± 0.98 و 14.00 ± 1.35 يوم علي التوالي. كما ازداد معدل استهلاك اليرقة اليومي مع زيادة كل من درجة الحرارة وعمر اليرقة مع اعلي استهلاك للعمر اليرقي الرابع تم تسجيله علي درجة حرارة 33 م°والتي سجلت 99.71 ± 14.49 و 105.40 ± 10.54 لكل من ابو العيد 11 نقطة وابو العيد 9 نقاط علي التوالي. عمر الانثي والذكر لكلا المفترسيين ازداد كلما انخفضت درجة درجة الحرارة، في حين ازدادت خصوبة الانثي كلما زادت درجة الحرارة. علاوة علي ذلك فان معدل الاستهلاك الكلي لكل من الانثي والذكر لكلا المفترسيين ازداد مع زيادة درجة الحرارة مع اعلي استهلاك تم تسجيله خلال فترة وضع البيض. سجلت اناث المفترسيين معدلات اعلي من الذكور في الاستهلاك الكلي والاستهلاك اليومي للفريسة علي جميع درجات الحرارة المختبرة. انخفضت معدلات النمو لجميع اطوار المفترسيين مع انخفاض درجات الحرارة.سجل طور العذراء واليرقة اقل حد حرج للنمو مقارنة بالاطوار الاخري لكل من ابو العيد 11 نقطة وابو العيد 9 نقاط علي التوالي. سجلت كمية الوحدات الحرارية اللازمة لاكمال نمو كل من المفترس ابو العيد 11 نقطة وابو العيد 9 نقاط من طور البيضة الي خروج الحشرة الكاملة في المتوسط 380.73 ± 27.71 و 363.83 ± 14.44 وحدة حرارية. اوضحت الدراسة التالية ان كل من مفترس ابو العيد 11 نقطة وابو العيد 9 نقاط اكملوا نموهم بنجاح في مدي واسع من درجات الحرارة يتراوح من 18- 33 م° مما يشير الي كفائتهم العالية وامكانية استخدامهم في برامج المكافحة الحيوية لكل من من الحبوب ومن البقوليات علي التوالي.

Table (1): Developmental time in days (± SE) of *C. undecimpunctata* immature stages when reared on *S.avenae* at four constant temperature regimes.

Immatures / T (°C)	Egg	Larval instars					Pupa	Egg- Adulthood
		1st	2nd	3rd	4th	Total		
18	7.9 ± 0.81	4.71 ± 0.73	3.85 ± 0.61	5.84 ± 0.81	6.34 ± 0.40	20.74 ± 1.10 a	7.53 ± 0.80 a	36.17 ± 1.85 a
23	5.3 ± 0.75	3.17 ± 0.65	3.10 ± 0.57	4.72 ± 0.72	5.75 ± 0.68	16.74 ± 0.96 b	7.00 ± 0.56 a	29.04 ± 1.50 b
28	3.1 ± 0.52	1.90 ± 0.40	1.68 ± 0.31	2.93 ± 0.57	4.10 ± 0.51	10.61 ± 0.87 c	5.30 ± 0.40 b	19.01 ± 1.16 c
33	2.6 ± 0.26	1.53 ± 0.35	1.40 ± 0.26	2.56 ± 0.37	3.50 ± 0.29	8.99 ± 0.74 d	3.70 ± 0.32 c	15.29 ± 0.98 d

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (2): Consumption (± SE) of C. undecimpunctata larval stages and daily consumption per individual larva when reared on S.avenaeenae at four constant temperature regimes.

Consumption / T (°C)	Larval instars					Daily consumption^{-1}
	1st	2nd	3rd	4th	Total larval stage	
18	45.70 ± 1.46	62.36 ± 1.61	186.45 ± 2.46	235.72 ± 2.86	530.23 ± 05.67 c	25.57 ± 05.15
23	56.11 ± 1.75	73.57 ± 1.90	219.72 ± 2.75	350.68 ± 2.96	700.08 ± 06.95 b	41.82 ± 12.41
28	66.76 ±1.80	78.96 ± 2.10	265.42 ± 2.80	396.43 ± 3.50	807.59 ± 09.64ab	76.12 ± 11.08
33	70.64 ± 1.96	82.45 ± 2.50	296.54 ± 3.11	446.75 ± 4.20	896.38 ± 10.72 a	99.71 ± 14.49

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (3): Longevity in days in days (± SE) of C. undecimpunctata adults when reared on S.avenaeat four constant temperature regimes.

Adults / T (°C)	Oviposition periods			Female longevity	Male longevity	Fecundity/ Female	Eggs/Female/day
	Pre-oviposition	Oviposition	Inter + Post – oviposition				
18	6.75 ± 0.92	48.95 ± 2.40	32.95 ± 1.42	88.65 ± 3.70 a	61.78 ± 1.18 a	629 ± 10.72 d	12.85 ± 4.47
23	4.97 ± 0.73	40.45 ± 1.96	28.50 ± 1.50	73.92 ± 3.10ab	55.14 ± 1.10ab	770 ± 10.96 c	19.03 ± 5.59
28	4.57 ± 0.58	35.70 ± 1.50	25.70 ± 1.37	65.97 ± 2.96 c	50.91 ± 0.90 b	950 ± 12.18 a	26.61 ± 8.12
33	4.10 ± 0.52	28.10 ± 1.36	18.75 ± 1.10	50.95 ± 2.10 d	40.22 ± 0.84 b	846 ± 11.78 b	30.11 ± 8.66

Table (4): Daily and total consumption (± SE) of C. undecimpunctata adults when reared on S.avenae at four constant temperature regimes.

Adults / T (°C)	Oviposition periods			Female consumption		Male consumption	
	Pre-oviposition	Oviposition	Inter + Post - oviposition	Total	Daily	Total	Daily
18	641.25 ± 5.86	4876.19 ± 26.42	946.80 ± 6.42	6464.24± 30.70b	72.92 ± 8.3	3970.22 ± 26.40ab	64.26 ± 22.37
23	586.17 ± 4.76	5290.88 ± 31.17	723.11 ± 5.31	6600.16 ± 36.51b	89.29±11.8	3996.44 ± 28.51ab	72.48 ± 25.92
28	610.18 ± 5.80	5563.44 ± 35.24	615.14 ± 4.75	6788.76 ± 38.17ab	102.91±12.9	4370.65 ± 31.71a	85.85 ± 35.23
33	636.15 ± 6.22	5780.16 ± 37.56	527.26 ± 3.96	6943.57 ± 39.64a	136.28±18.9	3397.69 ± 32.46b	84.47 ± 38.64

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (5): Developmental rates (1/d), thermal requirements (DD's), and lower developmental threshold (T0) for various developmental stages of C.undecimpunctata reared on S. avenaeat four constant temperature regimes.

Temp. (°C)	Developmental rate				Temperature (°C)	DD's			
	Egg	Larva	Pupa	Egg- Adulthood		Egg	Larva	Pupa	Egg-Adulthood
18	0.127	0.048	0.133	0.0277	18	52.29	206.57	94.60	348.32 c
23	0.189	0.059	0.143	0.0344	23	61.59	250.43	123.06	424.86 a
28	0.323	0.094	0.189	0.0526	28	51.52	211.78	119.67	373.16 b
33	0.385	0.111	0.270	0.0654	33	56.21	224.39	102.05	376.59 b
T_0	11.38	8.04	5.42	8.37	Mean (± SE)	55.40 ± 3.99	223.29 ± 16.95	109.85 ± 11.88	380.73± 27.71

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (9): Daily and total consumption (± SE) of *Coccinella 9-punctata* adults when reared on *Aphis craccivora* at four constant temperature regimes.

Adults / T(°C)	Oviposition periods			Female consumption		Male consumption	
	Pre-oviposition	Oviposition	Inter + Post – oviposition	Total	Daily	Total	Daily
18	420.26 ± 3.70	2653.10 ± 26.17	817.10 ± 4.50	3890.46 ± 30.19 c	61.04 ± 9.38	2412.15 ± 19.16b	43.72 ± 6.42
23	486.19 ± 4.60	2994.17 ± 30.15	915.42 ± 6.42	4395.78 ± 33.16 b	78.48 ± 12.70	2105.19 ± 22.60c	52.03 ± 7.50
28	557.83 ± 4.96	3453.18 ± 31.80	930.18 ± 6.54	4941.29 ± 34.19ab	96.99 ± 17.62	2240.62 ± 25.78b	63.69 ± 8.15
33	580.26 ± 5.50	3670.90 ± 33.15	938.20 ± 6.80	5189.36 ± 35.20 a	113.45 ± 23.47	2750.65 ± 26.70a	91.17 ± 9.52

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (10): Developmental rates (1/d), thermal requirements (DD's), and lower developmental threshold (T_0) for various developmental stages of *Coccinella 9-punctata* reared on *Aphis craccivora* at four constant temperature regimes.

Temp. (°C)	Developmental rate				Temp. (°C)	DD's			
	Egg	Larva	Pupa	Egg-Adulthood		Egg	Larva	Pupa	Egg-Adulthood
18	0.21	0.06	0.16	0.03	18	34.94	172.39	46.79	349.48 b
23	0.28	0.08	0.21	0.05	23	43.35	182.63	57.77	356.28 b
28	0.31	0.12	0.24	0.06	28	54.95	174.28	72.58	361.91ab
33	0.33	0.14	0.25	0.07	33	66.86	177.55	88.96	387.66 a
T_0	10.72	7.64	10.33	5.31	Mean (±SE)	50.03 ± 12.58	176.71 ± 3.88	66.53 ± 15.8	363.83 ± 14.44

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (6): Developmental time in days (± SE) of *C. 9-punctata* immature stages when reared on *A. craccivora* at four constant temperature regimes.

Immature stages T(°C)	Egg	Larval instars					Pupa	Egg-Adulthood
		1st	2nd	3rd	4th	Total		
18	4.8 ± 0.65	4.37 ±0.71	2.90 ± 0.40	3.45 ± 0.62	5.92 ± 0.82	16.64 ± 1.35a	6.10 ±0.44a	27.54 ± 1.89a
23	3.53 ± 0.47	3.18 ± 0.52	1.96 ± 0.32	2.18 ± 0.50	4.57 ± 0.73	11.89 ± 1.10b	4.72 ± 0.37b	20.14 ± 1.63b
28	3.18 ± 0.41	2.46 ± 0.37	1.27 ± 0.30	1.64 ± 0.31	3.19 ± 0.60	8.56 ± 0.92c	4.21 ± 0.30b	15.95 ± 1.50c
33	3.00 ± 0.37	2.11 ± 0.33	1.01 ± 0.27	1.25 ± 0.24	2.63 ± 0.35	7.00 ± 0.63d	4.00 ± 0.26b	14.00 ± 1.35c

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (7): Consumption rates (± SE) of *C. 9-punctata* larval stages and daily consumption per individual larva when reared on *A. craccivora* at four constant temperature regimes.

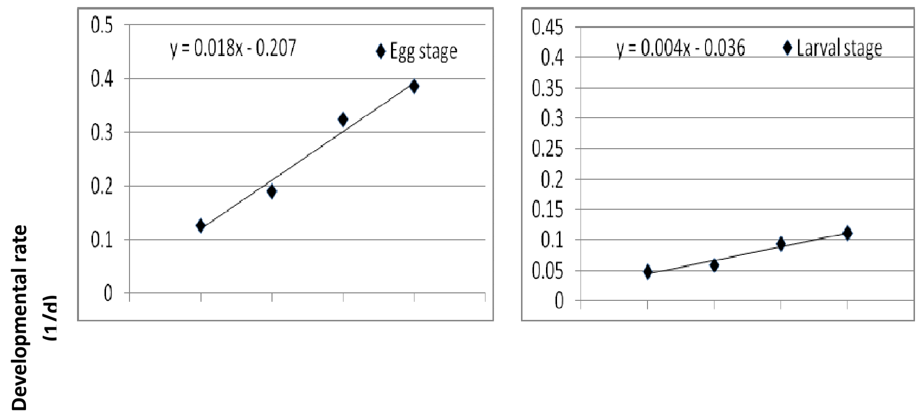
Consumption T (°C)	Larval instars					Daily consumption^{-1}
	1st	2nd	3rd	4th	Total consumption	
18	31.92 ± 0.97	45.57 ± 1.42	153.16 ± 2.10	186.15 ± 2.40	416.80 ± 4.10 d	25.05 ± 3.04
23	40.32 ± 1.10	59.16 ± 1.53	188.46 ± 2.34	290.17 ± 2.73	578.11 ± 4.75 c	48.62 ± 4.32
28	52.71 ± 1.33	62.14 ± 1.74	240.13 ± 2.64	301.80 ± 2.96	656.78 ± 5.42 b	76.73 ± 5.89
33	60.18 ± 1.62	69.10 ± 1.94	248.12 ± 3.15	357.42 ± 3.26	737.82 ± 6.64 a	105.40 ± 10.54

Values labeled by the same letters are not significantly differed at the 5% probability level

Table (8): Longevity in days and total and daily fecundity (± SE) of *Coccinella 9-punctata* adults when reared on *Aphis craccivora* at four constant temperature regimes.

Parameters / T(°C)	Oviposition periods			Female longevity	Male longevity	Fecundity/ Female	Eggs/Female/ day
	Pre-oviposition	Oviposition	Inter + Post – oviposition				
18	6.32 ± 0.48	40.58 ± 2.15	16.84 ± 0.96	63.74 ± 3.22 a	55.17 ± 1.6a	650.43 ± 9.40 c	16.03 ±4.37
23	5.15 ± 0.45	37.46 ± 1.94	13.40 ± 0.80	56.01 ± 2.61ab	40.44 ±1.11 b	801.50 ± 10.36 b	21.39 ± 5.34
28	4.75 ± 0.41	34.81 ± 1.52	11.39 ± 0.74	50.95 ± 1.94 b	35.18 ± 0.9c	920.40 ± 12.15 a	26.44 ± 7.99
33	4.56 ± 0.35	30.68 ± 1.30	10.50 ± 0.62	45.74 ± 1.50 c	30.17 ± 0.86 d	890.56 ± 11.32 a	29.03 ± 8.71

Values labeled by the same letters are not significantly differed at the 5% probability level


Developmental rate
(1/d)
y = 0.018x - 0.207
Egg stage
0.5
0.4
0.3
0.2
0.1
0
y = 0.004x - 0.036
Larval stage
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0

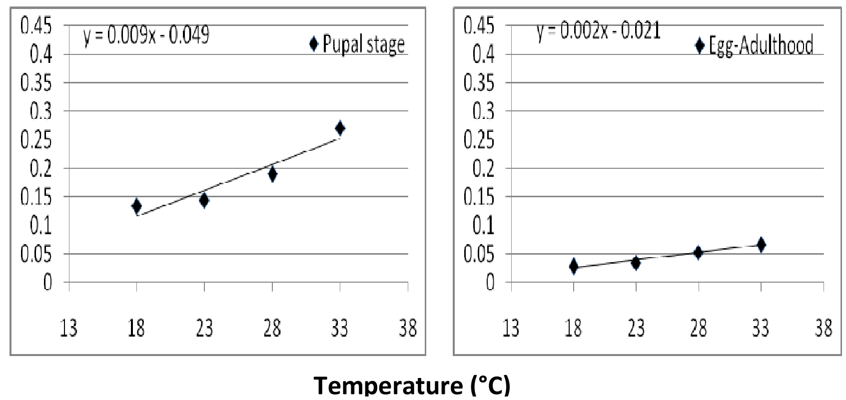
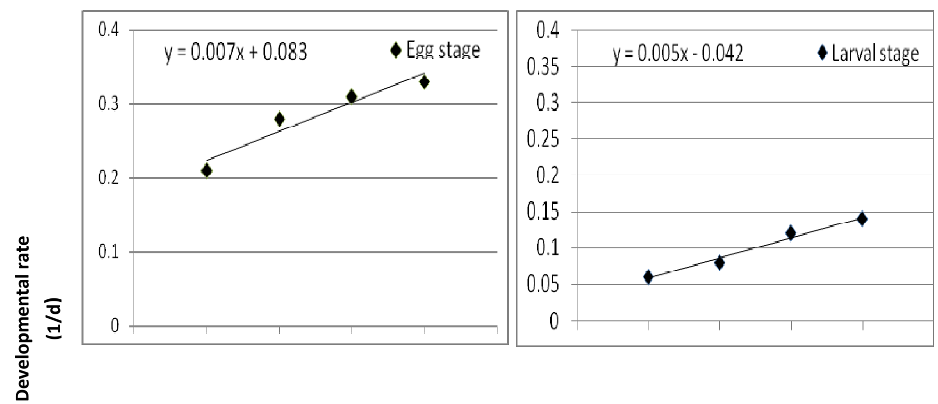


Fig. 1: Relationship between developmental rate (1/d) and various temperatures for various developmental stages of *C.undecimpunctata* reared on *S.avenae* to mathematically extract the lower developmental thresholds (T_0 = -a/b).


Developmental rate
(1/d)
0.4
0.3
0.2
0.1
0
y = 0.007x + 0.083
Egg stage
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
y = 0.005x - 0.042
Larval stage

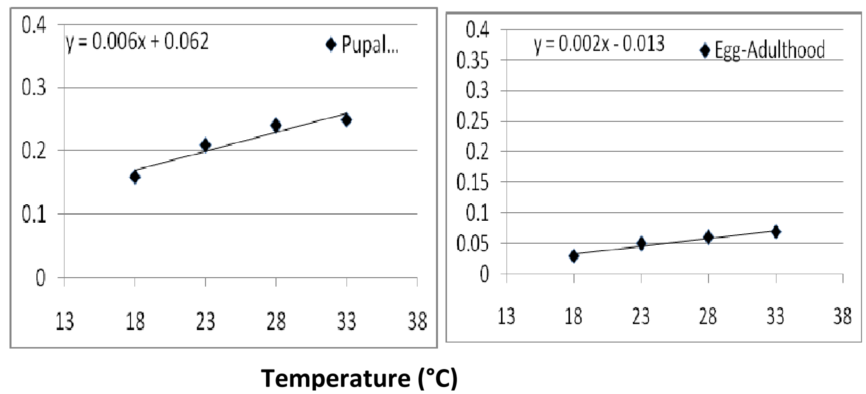


Fig. 2: Relationship between developmental rate (1/d) and various temperature for various developmental stages of *C. 9-punctata* reared on *A.s craccivora* to mathematically extract the lower developmental thresholds (T_0 = - a/b).