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Effect of Eggplant Varieties and Temperatures on Development and Fertility Life Tables of *Chrysoperla carnea* (steph.) (Neuroptera: Chrysopidae)

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ABSTRACT

An experiment was conducted at the Experimental farm, Faculty of Agriculture, Mansoura University, to evaluate the effect of three eggplant (*Solanum melongena* L.) varieties (Classic, 0111 and Anan) on development and age-specific fertility life table of the green lacewing predator, *Chrysoperla carnea* (Steph.) that fed upon the cotton aphid, *Aphis gossypii* Glover reared at three various temperatures (20, 25 and 30 ± 1˚C) and 60 ± 5% R.H. The results showed that a significant difference among the larval developmental times at the three temperature regimes within each eggplant variety. Similarly, the entire development (egg-adult) of *C. carnea* was significantly differed among host varieties, hosting aphids, within each temperature regime. For the life table parameters, the highest value of gross reproductive rate (GRR) for *C. carnea* was obtained when provisioned with aphids reared on Classic variety at 30˚C. Moreover, the longest mean generation time (T) and doubling time (DT) were achieved when the predator fed upon prey that reared on Anan and 0111 varieties, respectively. Further, the lowest and highest values of the net reproductive rate (R_o) were obtained when the predator provided with prey from Classic and 0111 varieties, respectively. Additionally, the highest value of the intrinsic rate of increase (r_m) was obtained when the *A. gossypii* fed on Classic variety at 30 ˚C. It can be concluded that both eggplant verities and temperature had significant effects on the developmental time and life table parameters of the predator. Hence, to optimize the mass rearing of *A. gossypii* as a preferred prey for *C. carnea*, Classic variety of eggplant has to be considered. As well, the range of temperature between 25-30˚C would maximize the performance of predator under rearing conditions. This information on tritrophic interactions and subsequent life table estimates of *C. carnea* improves IPM programs of aphids.

Keywords: aphids, green lacewing, eggplant, temperature, tri-trophic interactions

INTRODUCTION

The green lacewing, *Chrysoperla carnea* (Steph.) (Neuroptera: Chrysopidae), is considered one of the most efficient predators that found in several corps around the world (Abdel-Salam, 1995). This predator is successfully employed to control population of aphid species in various agroecosystems (Easterbrook *et al.,* 2006; Jokar and Zarabi, 2012). It is also a successful predator in mass rearing programs especially in hot spot areas (e.g. greenhouses), because they have high consumption rate and searching activity than that of any other predator (Shaukat, 2018). To use these predators in biological control systems, it is required to understand their life table parameters before releasing them in the farms. *C. carnea* is a generalized predator that preyed a wide range of insects and appeared in the same time and space to feed upon populations of the prey. One of the main preys of the *C. carnea* is the cotton aphid, *Aphis gossypii* Glover (Hemiptera: Aphididae). *A. gossypii* is a cosmopolitan species highly distributed in tropical, subtropical and warm regions. It attacks several species host plants (Blackman and Eastop, 1984).

Life table parameters are fundamental component in ecological studies and general biology (Alasady *et al.*, 2010; Jokar and Zarabi, 2012). Information regarding the growth, survival, and reproduction of an insect at various environmental conditions is fundamental to its management (Mandour, 2010). In addition, the prey that maximizes these biological parameters of a natural enemy has to be considered in future mass production programs. Population growth rate is a vital ecological parameter of the growth of an organism under given conditions that expressed as the intrinsic rate of increase, r_m (Southwood and Henderson, 2009). In biological control, it is not only helpful for comparing between beneficial species, but also for comparing the efficiency of a natural enemy at different environmental conditions (Orphanides and Gonzales, 1971; Nechols *et al*., 1989).

The influence of aphid species on biology and life parameters of chrysopid species is discussed by several authors (El-Serafi *et al*., 2000; Sattar *et al*., 2011; Jokar and Zarabi, 2012; Khuhro *et al*., 2012; Hameed *et al*., 2013). The effect of temperature is also discussed in many researches works of temperature and varieties on the life table (Saljoqi *et al*., 2015; Pathan *et al*., 2016). Several studies in Brazil have evaluated the efficiency of lacewings in controlling aphids on grasses, such as *Schizaphis graminum* (Rondani) on sorghum (Fonseca *et al*., 2001; Figueira *et al.,* 2002) and *Rhopalosiphum maidis* (Fitch) on corn (Maia *et al*., 2004). These studies have revealed that this predator can develop at temperatures ranging from 12 to 30°C. However, the current knowledge on the fertility life tables of predators with respect to host plant varieties and climatic conditions has not yet fully explored. Only, Farrokhi *et al*. (2017) investigated the effect of four host plants (peach, almond, pepper, and potato) on *Myzus persicae* (Sulzer) - *C. carnea* interactions. The importance of eggplant and the threat to its production has led to increased interest in alternative control methods. Integrated Pest Management (IPM) is an applicable alternative, depends on the complementary use of host plant, chemicals, and biocontrol agents. Several tactics, including host plant resistance (Reddy and Baskaran, 2006), *C. carnea* (Sharanabasava and Manjunatha, l998a, b) and neem oil (Sharanabasava *et al*., 1999), have been proven to be effective in controlling spider mite populations on other vegetable crops. Therefore, this study aims to study the effect of three eggplant varieties (Classic, 0111 and Anan) and three temperature regimes on development and the life table parameters of *C. carnea* that preyed *A. gossypii*.

MATERIALS AND METHODS

1. Aphid culture

Seedlings of eggplant (*Solanum melongena* L.) varieties namely Classic, 0111 and Anan were sown in the greenhouse. The experimental area of the green house was 360 m^2 located at the Experimental field, Faculty of Agriculture, Mansoura University. The cotton aphid, *Aphis gossypii* Glover, was collected from heavily infested crops (squash and cucumber) growing at the Experimental farm. Once the seedlings inside the greenhouse reached 10 cm in highest, the infestation was started using the nymph of *A. gossypii* that transferred using hair brush to each host plant variety. These plants were watered and fertilized in the due time as required. After one month from plantation. These infestations were used either in rearing predators or in feeding experiments of predators.

2. Predator culture

Adult *C. carnea* were aspirated from ficus trees heavily infested with scale insects and mealybugs in the morning (7 AM). In the laboratory, these adults were divided into two transparent containers (15 cm diam × 30 cm ht) (ca. 20 adults each). The container tops were covered with black mesh screens (to serve as an oviposition substrate) fixed in place with a rubber band. Adult of lacewings in the containers were supplied every 48 hours with a fresh diet of honey and brewer's yeast (1:1) which offered on small pieces of sponge, and water on other sponges. These containers were kept at 25.0 ± 1.0 °C, 60.0 ± 5% RH, and a 14:10 (L:D) day length. Eggs holders that deposited on the mesh screens were removed daily using fine scissors into Petri-dishes and kept at 25.0 ± 1.0 °C, 60.0 ± 5% RH, and a 14:10 (L:D). Upon eclosion, first-instar was isolated in Petri-dishes (5.5 cm in diameter) to prevent cannibalism and fed upon *Sitotroga* eggs that supplied *ad libitum* and water on a small sponge, both refreshed every 24 h, until pupation occurred. Upon emergence, adults of C. *carnea* were placed in jars (ca. 20 per jar) to ensure mating and reared as described above.

3. Development

Development of *C. carnea* was monitored at three different temperatures (20, 25 and 30 ± 1 °C) with a relative humidity of 60.0 ± 5.0% and a photoperiod of 14 L:10 D. The aphids were provided as a diet in each trial for each predator species was collected from the three eggplant verities. Upon eclosion, three groups of larvae, each consisted of 20 neonate larvae isolated in Petri-dishes (each 5.5 cm in diam.). As the predator's instar grew, the aphid amount was gradually increased. Every day, the number of aphid consumed by each individual larva, died individuals were counted and recorded.

4. Fertility life tables

Life table parameters of *C. carnea* were estimated using a MATLAB computer program. This program is constructed based on Birch's method (1948). To estimate these parameters, the age-specific survival (L_x), age-specific fecundity (M_x), and female age (x) were used for the green lacewing which reared in each temperature on each plant variety. The parameters were as follows; Net reproductive rate ($Ro= \Sigma l_x m_x$), The generation time [$T = (\Sigma l_x m_x x)/(\Sigma l_x mx)$], the intrinsic rate of increase (r_m= In R_o/T), the finite rate of increase ($\lambda= e^{-rm}$), and the growth reproductive rate [GRR= (Σm_x)] were calculated according to Carey (1993). The population doubling time (In $2/r_m$) is estimated according to Mackauer (1983).

5. Statistical analysis

One-way ANOVA was performed to analyze the data of developmental time of *C. carnea* using temperature and eggplant varieties as independent variable. In case of significant, the means were separated using Student-Newman-Keuls Test (Costat Software, 2004).

RESULTS AND DISCUSSION

Developmental time

At 30°C**,** *A. gossypii*-eggplant varieties did affect the incubation period of *C. carnea* ($F_{2,57}$= 3.87, P = 0.03), but did not at 20 and 25 **°**C ($F_{2,57}$ = 1.49, P = 0.23; and $F_{2,57}$ = 1.22, P = 0.303, respectively). The larval development of *C. carnea* significantly differed among the three eggplant varieties, hosting aphid, at 20, 25, and 30 °C with the shortest duration for larvae fed aphids from Classic variety ($F_{2,57}$ = 18.11, P < 0.001; $F_{2,57}$ = 12.72, P < 0.001; and $F_{2,57}$ = 12.54, P < 0.001, respectively). Aphid-eggplant varieties did not affect the duration of pupal stage of *C. carnea* at 20 °C ($F_{2,57}$ = 0.93, P = 0.404), 25 °C ($F_{2,57}$ = 1.18, P = 0.318), and 30 °C ($F_{2,57}$ = 3.35, P = 0.043). In addition, the entire development (egg-adult) was significantly differed at 20 °C ($F_{2,57}$ = 3.75, P = 0.03), 25 °C ($F_{2,57}$ = 5.46, P < 0.001), and 30 °C ($F_{2,57}$ = 14.24, P < 0.001). On the other hand, developmental periods of egg, larval, pupal, and the entire development decreased significantly as temperature increased within each host plant variety.

Saljoqi *et al*. (2015) estimated the developmental parameters of *C. carnea* under four different temperatures (20±1, 24±1, 28±1 and 32±1°C). They noted that a significant difference in the developmental times of different life stages among the tested temperatures. The results also showed that the developmental times for larval instars of *C. carnea* were significantly decreased, when the temperature is increased. Similar results are also reported by Mannan *et al*. (1997). *Chrysoperla carnea* exhibited a shorter development when fed upon aphids which reared on the classic variety of eggplant than other the two eggplant verities. This might be because the nutritional value of classic is high or chemical defense levels are low, or/and the physical structure of the host plant variety is not impeded the aphid feeding, resulting in aphids with bigger sizes (Walde 1995; Kos *et al*. 2012). When aphids are exposed to increasing levels of toxicity, these preys are known to have negative impacts on their feeders (Birch *et al*. 1999). There are various levels of toxicity sequestered by the herbivorous aphids, which create differing factors that could affect the overall tritrophic interaction between the host plants, aphids, and *C. carnea*, since *C. carnea* developing a preference for one host plant aphid species over others (Chaplin-Kramer *et al*., 2011; Kos *et al*., 2012). This is why plants can impact the biological characteristics and predation efficiency of a predator (Price *et al*. 1980).

2. Fertility life table parameters

The optimum life table parameters of *C. carnea* were obtained using herbivorous aphids from eggplant variety of Classic variety at each of the three temperature tested. Further, the parameters obtained for *C.carnea* at 30 °C were better than the other two temperatures for the three varities of eggplant (Table 2). As temperature increased, the values of T and DT were decreased on each of the three eggplant varieties, whereas the values of GRR, r_m, and λ were increased. In respect to R_o, as the temperature increased the value of R_o was increased on Classic and 0111 varieties but decreased on Anan variety.

At 20 °C, the survivorships (L_x) for female age intervals of *C. carnea* were 0.75, 0.6, and 0.7 on classic, 0111, and Anan varieties. At 25 °C were 0.75, 0.65 and 0.6 on classic, 0111, and Anan varieties. At 30°C (L_x) were 0.8, 0.85,0.8 respectively. This implies that most of eggs had developed to maturity using aphids from Classic variety especially at 20 and 25 °C, and mortality happened gradually during the ovipositional period. At 20 °C, the maximum oviposition rate per female per day (M_x) was 3.53 on 22th day, 3.3 on 9th day and 3.7 on 7th day on classic, 0111, and Anan varieties, respectively. At 25 °C, these values were 3.811 on 30th day, 3.23 on 34th day and 3.5 on (7 and 14th) day at the three tested varieties, respectively, and at 30 °C, these values were 4.94 on 18th day, 3.29 on 14th day and 3.43 on 16th day at the three host plant varieties respectively (Figures 1, 2, and 3).

Table 1. Developmental times (±SEM) (in days) of immature stages of *Chrysoperla carnea* when fed upon *Aphis gossypii* that reared on three eggplant varieties under three different temperatures.

Host Varieties	Temperature	Incubation Period	Larval instars				Pupal Stage	Egg-Adult
			1st	2nd	3rd	Total		
Classic	20	$5.1\pm0.16\ a^{A}$	$4.4\pm0.16\ a^{C}$	$3.7\pm0.16\ a^{B}$	$4.57\pm0.16\ a^{A}$	$12.73\pm0.27\ a^{C}$	$14.4\pm0.71\ a^{A}$	$32.17\pm0.98\ a^{B}$
	25	$3.6\pm0.16\ b^{A}$	$3.7\pm0.16\ b^{B}$	$3.25\pm0.16\ b^{B}$	$3.88\pm0.21\ b^{B}$	$10.83\pm0.28\ b^{B}$	$9.5\pm0.32\ b^{A}$	$23.93\pm0.47\ b^{B}$
	30	$2.8\pm0.16\ c^{B}$	$3.2\pm0.16\ c^{B}$	$2.9\pm0.16\ b^{B}$	$3.33\pm0.15\ b^{B}$	$9.3\pm0.25\ c^{C}$	$6.83\pm0.19\ c^{A}$	$19.07\pm0.49\ c^{B}$
0111	20	$5.2\pm0.32\ a^{A}$	$5.2\pm0.16\ a^{B}$	$4.2\pm0.16\ a^{A}$	$5.11\pm0.29\ a^{A}$	$14.53\pm0.45\ a^{B}$	$15.84\pm0.64\ a^{A}$	$34.5\pm1.49\ a^{AB}$
	25	$3.8\pm0.15\ b^{A}$	$4.10\pm0.07\ b^{A}$	$3.95\pm0.18\ b^{A}$	$4.17\pm0.16\ a^{AB}$	$12.22\pm0.24\ b^{A}$	$9.\ 81\pm0.36\ b^{A}$	$25.83\pm0.37\ b^{A}$
	30	$3.2\pm0.06\ c^{A}$	$3.4\pm0.17\ c^{B}$	$3.2\pm0.10\ b^{AB}$	$3.7\pm0.16\ b^{AB}$	$10.3\pm0.26\ c^{B}$	$6.94\pm0.37\ c^{A}$	$20.24\pm0.45c^{B}$
Anan	20	$5.4\pm0.17\ a^{A}$	$5.8\pm0.09\ a^{A}$	$4.45\pm0.11a^{A}$	$5.35\pm0.24\ a^{A}$	$15.6\pm0.28\ a^{A}$	$16.05\ \pm1.0\ a^{A}$	$37.0\ \pm1.16\ a^{A}$
	25	$3.9\pm0.13\ b^{A}$	$4.2\pm0.12\ b^{A}$	$4.3\pm0.13a^{A}$	$4.47\pm0.12\ b^{A}$	$13\pm0.23\ b^{A}$	$10.42\pm0.43\ b^{A}$	$27.29\pm0.47b^{A}$
	30	$3.3\pm0.11\ c^{A}$	$3.8\pm0.09\ c^{A}$	$3.6\pm0.11b^{A}$	$3.95\pm0.17\ b^{A}$	$11.35\pm0.26\ c^{A}$	$7.71\pm0.14\ c^{A}$	$22.35\pm0.26c^{A}$

Means followed by the same small lowercase letters in a column among temperatures in each variety and the same uppercase capital letters among Varieties in each temperature are not significantly different at the 5% level of probability (Student- Newan- Keuls Test).

Table 2. Life table parameters of *Chrysoperla carnea* females at three constant temperatures when provided with herbivorous aphids reared from three eggplant varieties.

Varieties	Temp. (°C)	Life table parameters					
		Mean generation time (T) (in days)	Doubling time (DT) (in days)	Gross reproductive rate (GRR)	Net Reproductive rate (R_o)	Intrinsic rate of increase (r_m)	Finite rate of increase (λ)
Classic	20	53.7518	9.9305	59.25	42.6	0.06980	1.0723
	25	41.4528	7.2719	77.84	52.0	0.09532	1.1
	30	34.6526	5.9079	85.91	58.3	0.11732	1.1245
0111	20	55.1185	11.4169	49.60	28.4	0.06071	1.0626
	25	42.6539	8.4159	64.88	33.6	0.08236	1.0858
	30	34.4906	6.2354	68.33	46.3	0.11116	1.1176
Anan	20	58.6207	10.967	61.98	40.7	0.06320	1.0652
	25	44.3577	8.4222	70.68	38.5	0.08230	1.0858
	30	35.9243	6.7571	82.44	39.9	0.10258	1.108

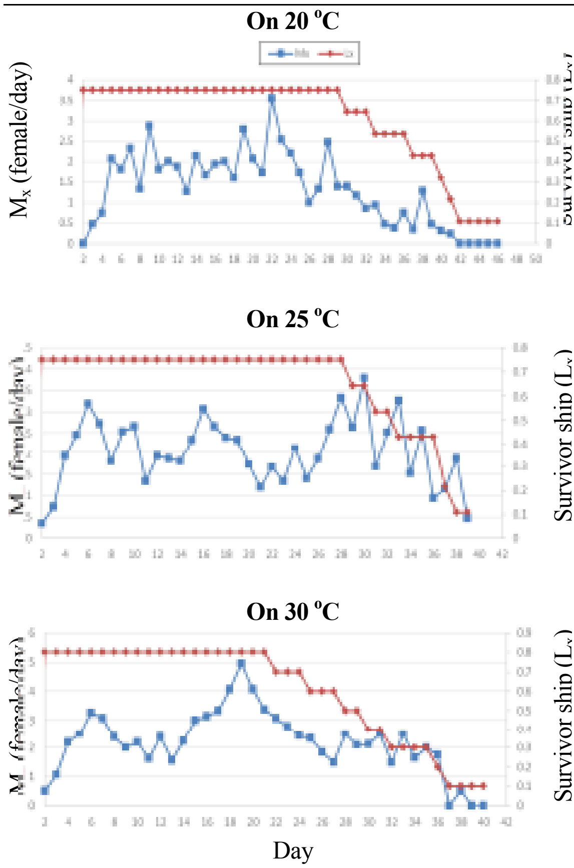

Figure 1. Age-specific fecundity (Mx) and survivorship (Lx) of *Chrysoperla carnea* when fed upon *A. gossypii* that collected from Classic variety of eggplant at three constant temperatures.

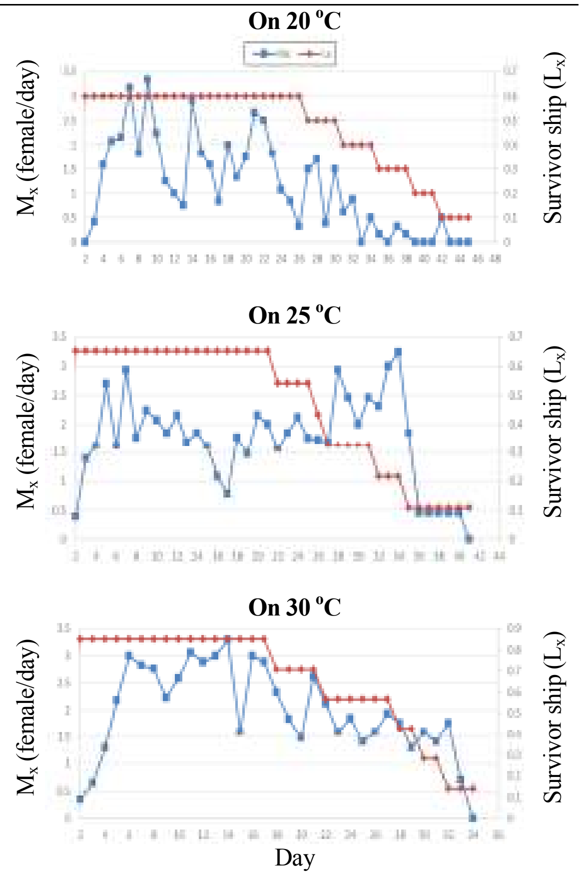

Figure 2. Age-specific fecundity (Mx) and survivorship (Lx) of *Chrysoperla carnea* when fed upon *Aphis gossypii* that obtined from 0111 variety of eggplant at three constant temperatures.

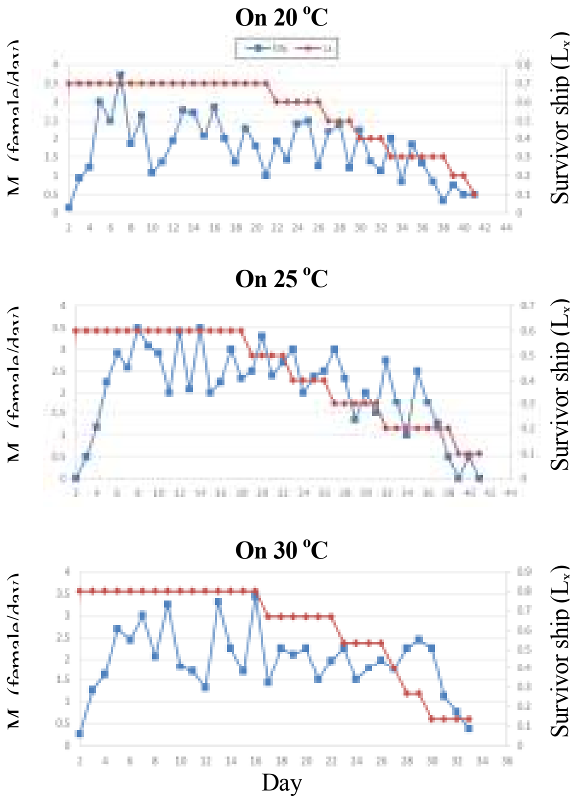

Figure 3. Age-specific fecundity (Mx) and survivorship (Lx) of *C. carnea* when fed upon *A. gossypii* that obtined from Anan variety of eggplant at three constant temperatures.

The mean generation time (T) and doubling time (DT) of *C. carnea* were decreased as the temperature increased, which is proved by Yu *et al.* (2013) and Saljoqi *et al.* (2015). The longest and shortest times of generation time (T) of *C. carnea* were estimated when the *A. gossypii* is reared on Classic (34.65 d) and 0111 (58.62 d) varieties. However, the shortest and the longest values of DT are calculated when the aphid is reared on Classic and 0111 varieties, respectively. Farrokhi *et al.* (2017) found the longest and shortest mean generation times (T) of *C. carnea* were 41.84 and 35.59 d using *M. persicae* from the potato and peach, respectively. Moreover, it can be realized that the maximum and minimum values of gross reproductive rate (GRR) were occurred when the prey is rearing on Classic and 0111varieties, respectively. The highest value of r_m was obtained at 30 °C using aphids collected from Classic variety, which partially consistent with results of Saljoqi *et al.* (2015) and Farrokhi *et al.* (2017). The intrinsic rate of increase (r_m) values in this study ranged from 0.0607 to 0.11732 at different eggplant varieties and temperature. Farrokhi *et al.* (2017) found that the highest intrinsic rate of increase (r_m) and finite rate of increase (λ) for *C. carnea* were obtained using aphids from peach (0.1460 and 1.15 d^{-1}, respectively). Additionally, the results revealed that the shortest doubling time (DT) of the *C. carena* was obtained at the highest temperature (30 °C) which is consistent with those of El-Serafi *et al.* (2000). Additionally, it can be noted that the value of R_o of the predator is increased as temperature increased. The same was observed by Nagai *et al.* (1999) and its minimum and maximum values were obtained when the prey is rearing on 0111 and Classic varieties, respectively, indicating that the type of the variety can affect the life table parameters.

It can be concluded that both eggplant verities and temperature had significant effects on the developmental time and life table parameters of the predator. Hence, to optimize the mass rearing of *A. gossypii* as a preferred prey for *C. carnea*, Classic variety of eggplant has to be considered. As well, the range of temperature between 25-30 °C would maximize the performance of predator under rearing conditions. This information on tritrophic interactions and subsequent life table estimates of *C. carnea* can optimize IPM programs.

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تأثير أصناف البأذنجان ودرجات الحرارة على جداول الحياة لمفترس أسد المن الأخضر

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اجريت تجربة فى مزرعة كلية الزراعة جامعة المنصورة لتقييم تأثير ثلاثة أصناف من نبات الباذنجان (الكلاسيك و ١١١٠ وعنان) على النمو ومقاييس جداول الحياة لمفترس أسد المن الأخضر وذلك بتغذيته على حشرة منّ القطن وذلك على وثلاثة درجات الحرارة المختلفة (٢٠ و ٢٥ و ٣٠±١ درجة مئوية ورطوبة نسبية ٦٠±٥%). أشارت النتائج أن هناك إختلاف معنوى خلال الطور اليرقى للمفترس على درجات الحرارة المختلفة لكل صنف من أصناف الباذنجان . وكان هناك إختلاف معنوى للأصناف الثلاثة العائلة للمن فى فترة التطور من البيضة للحشرة الكاملة للمفترس داخل كل درجة حرارة . وبالنسبة لمعاملات جدول الحياة فإنه تم ملاحظة أن أعلى قيمة لمعدل التكاثر (GRR) كان عند تربية حشرة منّ القطن على صنف الكلاسيك على درجة حرارة ٣٠ مº. وأن متوسط فترة الجيل (T) والزمن اللازم لتضاعف الجيل (DT) كانت على صنفى عنان و ١١١٠ بالترتيب. وأشارة النتائج أيضاً أن أقل وأعلى قيمة لمعامل صافى الخصوبة (R_o) للمفترس كانت عندما تم تربية الفريسة (حشرة منّ القطن) على صنفى ١١١٠ و كلاسيك بالترتيب. بالإضافة إلى ذلك كانت أعلى قيمة لمعدل الزيادة الطبيعى (r_m) كانت عند تربية حشرة منّ القطن على صنف الكلاسيك فى درجة حرارة٣٠ مº.ومن النتائج يمكن إستناج أن كل من أصناف الباذنجان ودرجات الحرارة لها تأثير معنوى عل فترة النمو وجداول الحياة للمفترس . ومن خلال النتائج يتضح أنه لتعظيم الإنتاج الكمى لحشرة من القطن كفريسة مفضلة لمفترس أسد المن الأخضر فإنه يوصي بإستخدام صنف الباذنجان كلاسيك فى عملية التربية الكمية للمنّ .كما يوصي بتربية المفترس فى المدى الحرارى ٢٥-٣٠ مº لتعظيم النمو والإنتاج للمفترس وفى النهاية فان هذه المعلومات على التفاعلات ثلاثية التغذية ومقاييس جداول الحياة تفيد فى برامج المكافحه المتكاملة لحشرة المنّ .