Journal of Biological Control, 31(3): 146-158, 2017, DOI: 10.18311/jbc/2017/16431

Research Article

Effect of constant temperature regimes on the biological parameters of an anthocorid predator *Orius tantillus* (Motsch)

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ABSTRACT: Experiments were conducted to investigate the effect of different temperature regimes (16, 20, 24, 28, 32 and 36±1°C) on the biological and fertility table parameters of *Orius tantillus* (Motsch.), an efficient indigenous predator of various thrips species in India Temperature influenced the development and reproduction of *O. tantillus.* Based on the biological parameters, *viz*. longevity, fecundity and fertility parameters, 24°C was recorded to be the optimum temperature for rearing *O. tantillus.* The temperature of 16°C had a detrimental effect on nymphal survival, while 36°C on fecundity. Thus, 16 and 36°C were recorded as unsuitable for rearing *O. tantillus*. The lower threshold temperatures for development of eggs and nymphs of *O. tantillus* were 8.66 and 6.92°C, respectively, indicating that the eggs are more heat-sensitive than the nymphs. Based on the T_0 values, *O. tantillus* appears to be less heat sensitive in comparison to other *Orius* spp. The information generated through this study could be used for further improving the standardized production protocol for *O. tantillus* and also for planning and timing field releases to target thrips species.

KEY WORDS: Biological parameters, effect of temperature, fertility parameters, *Orius tantillus,* rearing, *Sitotroga cerealella,* thermal requirement

(Article chronicle: Received: 14.07.2017; Revised: 15.09.2017; Accepted: 25.09.2017)

INTRODUCTION

Vegetables, grains, fruits and ornamental crops are often attacked by various species of thrips causing serious crop loss. attack *Thrips tabaci* Lindeman is a serious problem on onion, garlic, cotton, etc., *Scirtothrips dorsalis* Hood on rose, chilli, grapes, etc., *Rhipiphorothrips cruentatus* Hood on rose, mango, guava and *Caliothrips indicus* (Bagnall) on sorghum, paddy, groundnut etc. Thrips also act as vectors of microbial pathogens. Their short life cycle and their cryptic life style, have enabled them to become resistant to insecticides. Anthocorid predators have been recorded as potential predators of thrips species and *Orius* spp. are most commonly recorded. The commonly recorded predators occurring on different thrips species in India are *Orius tantillus* (Motsch.) and *Orius maxidentex* Ghauri. These predators are found attacking thrips species like *Haplothrips ganglbaueri* Schmutz, *Thrips palmi* Karny, *Anaphothrips sudanensis* Tryb., *Caliothrips graminicola* (Bagn. & Cam.), *Scirtothrips dorsalis* Hood, *T. tabaci*, *Baliothrips biformis* (Bagn.), *Caliothrips indicus* (Bagn.), *Microcephalothrips abdominalis* (D. L. Crawford), *Megalurothrips usitatus* Bagnall and *Thrips hawaiiensis* (Morgan) (Ananthakrishnan and Thangavelu, 1976; Kumar and Ananthakrishnan, 1984; Muraleedharan and Ananthakrishnan, 1978; Thontadarya and Rao, 1987; Men, 1999). *O. tantillus* has a wide distribution in India, Sri Lanka, Thailand, Malaysia, China, Australia, Micronesia, Solomon Islands, Kenya, Nigeria, and Tanzania (Hernandez, 1999). Ballal and Gupta (2011) have provided elaborate information on the research work carried out in India on the identification, production and evaluation of anthocorid predators. A protocol has been developed at the ICAR-National Bureau of Agricultural Insect Resources, Bangalore, India, for rearing *O. tantillus* on eggs of the Angoumois grain moth *Sitotroga cerealella* (Olivier) (Gupta and Ballal, 2006; 2009).

Temperature is one of the main elements which influence insect development. Temperature has a profound influence on the biological parameters of different species of *Orius* viz., *Orius laevigatus* (Fieber) (Alauzet *et al.,* 1994; Cocuzza *et al.,* 1997); *O. sauteri* (Poppius) (Nagai and Yano, 1999); *O. strigicollis* (Poppius) (Kim *et al.,* 1999; Ohta, 2001); *O. albidipennis* (Reuter) (Cocuzza *et al.,* 1997); *O. insidiosus* (Say) (Mendes *et al.* 2005), *O. thyestes* Herring (Carvalho *et al.,* 2005); *O. similis* Zheng (Zhou *et al.,* 2006; Zhang *et al.,* 2012); *O. thripoborus* (Hesse) and *O. naivashae* (Poppius) (Bonte *et al.,* 2012). The effect of different laboratory hosts on fertility parameters of *O. tantillus* has been studied by Ballal *et al.* (2012) and of temperature on the biological parameters of *O. tantillus* when fed on the target pest *T. palmi* by Nakashima and Hirose (1997). Through laboratory studies on the effect of constant temperature regimes on the developmental rate of an insect, information can be generated on its thermal requirements, which can further be used to predict the seasonal occurrence and population dynamics (Bernal and Gonzalez, 1993). The current study was taken up to understand the effect of temperature on the biological and fertility table parameters and the thermal requirements of *O. tantillus* when it preys on the alternate laboratory host, *S. cerealella*. The outcome of the study is expected to have a bearing on understanding the rearing requirements and feasibility of field establishment of *O. tantillus*.

MATERIALS AND METHODS

Insect cultures

Sitotroga cerealella (National Accession No. NBAII-MP-GEL-01) was cultured in the live insect repository of ICAR - National Bureau of Agricultural Insect Resources, Bangalore, India. UV-irradiated eggs of S. cerealella were utilized as laboratory host material for rearing *O. tantillus* (National Accession No. NBAII-MP-ANT-06) based on studies by Gupta and Ballal (2006, 2009). Nymphs and adults of *O. tantillus* were initially collected from maize fields and acclimatized to laboratory conditions by rearing for five generations on laboratory host eggs before initiating the experiments.

Effect of different constant temperatures on biological parameters of *Orius tantillus*

The biological parameters of *O. tantillus* were studied at different constant temperature regimes, *viz.* 16, 20, 24, 28, 32 and 36±1°C. Incubators with 12L/12D cycles were maintained at the above-mentioned temperatures with relative humidity maintained at 60±10%. Five pairs of freshly emerged *O. tantillus* adults were placed in pearl pet plastic container (500 ml) with UV- irradiated *S. cerealella* eggs as feed @ 8 eggs per adult per day, bean pieces (4-5 pieces) (for moisture and as oviposition substrate) and cotton strands (to avoid cannibalism). Three such sets were maintained at each temperature. Mortality of adults was recorded in the ovipositional containers and longevity tabulated. The bean pieces with eggs of *O. tantillus* were collected at 24hr intervals and kept in small round ventilated jewel boxes (diameter 7.5

cm and height 2.5 cm) for hatching. Freshly hatched nymphs were placed in a separate container (round ventilated plastic jewel box) and provided with UV-irradiated *S. cerealella* eggs as feed @ 4 eggs per day per nymph from day 1 to day 7 and 6 eggs per nymph per day from day 8 till the day of adult formation. Adults that emerged, were collected and their sex was determined by microscopic observation. The incubation, nymphal and total developmental periods were recorded. Fecundity was recorded in terms of adult progeny per female. To understand the effect of temperature on the above-mentioned biological parameters the data on developmental time, longevity, total progeny per female and percent female progeny recorded at different temperature regimes were subjected to ANOVA.

Effect of different temperature regimes on the fertility table parameters of *Orius tantillus*

From the lab reared *O. tantillus* culture, five pairs of adults were released into each ovipositional container (500 ml pearl pet plastic container). The containers were provided with UV-irradiated *S. cerealella* eggs (@ 8 eggs per adult per day) as feeding, bean pieces (4-5) as oviposition substrates and cotton lint to avoid cannibalism. Twelve such sets were maintained at each test temperature 16, 20, 24, 28, 32 and 36±1°C. After every 24 hr, the bean pieces with *O. tantillus* eggs were collected and observed under the microscope to record the number of eggs laid, after which they were placed in small round ventilated jewel boxes (diameter 7.5 cm and height 2.5 cm) for hatching. This was continued till adult mortality in all ovipositional containers and male and female longevity was recorded. The freshly hatched nymphs were provided with UV- irradiated *S. cerealella* eggs as feed @ 4 eggs per day per nymph from day 1 to day 7 and 6 eggs per nymph per day from day 8 till the day of adult formation. When adults emerged, they were collected and observed under the microscope to differentiate the sex and to record the female progeny.

Since nymphs did not survive at 16°C and fecundity was nil at 36°C, fertility table studies of *O. tantillus* were conducted at four temperature regimes, *viz*., 20, 24, 28 and 32°C. The age specific survival (l_x) and age specific fecundity (m_x) at each pivotal age x were worked out for the entire reproductive period. The number of individuals alive at age x as a fraction of 1 was recorded as l_x and the number of female offspring produced per female at age interval x as m_x. Utilising these, the fertility table parameters were calculated based on the methods suggested by Birch (1948) and Andrewartha and Birch (1954).

Net reproductive rate (R_0) = $\Sigma l_x m_x$; Approximate duration of a generation (T_c) = $\Sigma l_x m_x / R_0$; Approximate intrinsic rate of increase (r_c) = $\log_e R_0 / T_c$; Precise intrinsic rate of increase (r_m) = $e^{-r_m} \times l_x m_x = 1$; Net generation time (T) = $\log_e R_0 / r_m$; Finite rate of increase (λ) = anti $\log_e r_m$; Weekly multiplication of the population (r_w) = $({}_e rm)^7$; Hypothetical F_2 females = $(R_0)^2$; Doubling Time (DT) = $\log_e 2/r_m$; Weekly multiplication rate (WMR)= $(\lambda)^7$.

Studies on thermal requirements

Studies on thermal requirements were restricted to four temperature regimes *viz.* 20, 24, 28 and 32°C (as was mentioned for fertility table studies). The data recorded on the incubation period, nymphal period and total developmental period of *O. tantillus* at the different test temperatures were used to calculate the developmental rate or reciprocal of developmental time (1/developmental time). These values as the dependent variables were used for regression analysis with temperature (the independent variable). Estimate of the respective lower development threshold was calculated by the x intercept method by setting regression equation to zero development per day as suggested by Arnold (1959). The thermal constant (K) is defined as the number of day degrees above the developmental stage, mathematically being the reciprocal of the slope (b) of the regression line and was calculated as suggested by Morris and Fulton (1970).

Table 1. Biological parameters of *O. tantillus* when reared at different constant temperatures

Temperature (±1 ºC)	Total developmental period (Days)					% hatching#	% nymphal survival	Longevity (Days)		Progeny/ female*	% female progeny (Sex ratio - F:M)
	Incubation period	Nymphal period		Total developmental time							
		Male	Female	Male	Female			Male	Female		
16	17.0±1.0^{c}	-	-	-	-	5.6±1.5 (14.1)^{c}	0.0 (4.05)^{b}	-	-	-	-
20	11.3± 0.3^{b}	16.1± 1.3^{c}	18.9± 0.7^{c}	27.1± 1.3^{d}	29.9± 0.7^{d}	73.8±1.4 (59.6)^{a}	90.0±0.6 (72.1)^{a}	15.0± 2.8^{b}	22.50± 6.4^{b}	13.2± 4.0^{ab}	66.0±2.0^{a} (2.3: 1)
24	6.0± 0.6^{a}	15.0± 1.5^{bc}	14.3± 0.6^{b}	21.0± 1.5^{c}	20.3± 0.6^{c}	73.6±1.1 (59.4)^{a}	91.0±2.3 (73.4)^{a}	32.3± 3.8^{a}	38.3± 3.3^{a}	22.4± 7.7^{a}	59.2±2.4^{ab} (1.5: 1)
28	5.7± 0.3^{a}	12.3± 0.6^{b}	12.7± 0.9^{b}	18.0±0.1^{b}	17.9± 0.2^{b}	74.6±1.0 (60.1)a	90.6±0.7 (72.6)^{a}	14.0± 2.6^{b}	18.7± 2.7^{b}	26.2± 5.6^{a}	55.2± 2.8^{b} (1.2: 1)
32	4.8± 0.5^{a}	9.2± 0.9^{a}	9.2± 1.3^{a}	14.2± 0.3^{a}	13.6± 0.3^{a}	73.7±1.0 (59.5)^{a}	90.6±1.4 (73.1)^{a}	10.6± 3.6^{b}	16.8± 2.5^{b}	13.8± 2.5^{b}	50.3±4.6^{b} (1.2: 1)
36	4.7±0.3^{a}	8.7±0.3^{a}	9.3±0.9^{a}	12.7±0.3^{a}	13.3±0.3^{a}	44.4±18.2 (42.1)^{b}	91.3±4.1 (75.2)^{a}	1.3±0.3^{c}	2.7±0.3^{c}	0.0^{b}	-
F	72.39	10.81	19.16	39.91	165.22	15.96	121.07	18.45	15.92	4.49	4.80
df	5, 12	4, 10	4, 10	4, 10	4, 10	5,12	5,12	4,10	4, 10	4, 10	3, 8
P	<0.0001	0.001	0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0001	0.0002	0.025	0.03
LSD at $P \leq 0.05$	1.8	3.2	2.9	2.9	1.7	14.3	7.92	8.2	10.1	15.02	10.3

Figures in brackets are angular transformed values

* Progeny/female measured in terms of adult progeny

Values followed by the same letter are not statistically different

RESULTS AND DISCUSSION

Effect of different temperature regimes on the biological parameters of *Orius tantillus* Developmental time

There was an inverse relationship between developmental time and temperature, which has been reported in several *Orius* spp. *viz. O. laevigatus* (Alauzet *et al.,* 1994), *O. strigicollis* (Kim *et al.,* 1999) and *O. insidiosus* (Mendes *et al.,* 2005). In the current study, significant reduction in developmental time occurred at higher temperatures of 28, 32 and 36°C). Though hatching occurred at 16°C, the nymphs could not survive to become adults at this temperature, while ≥90% survival was recorded at all other test temperatures. Nagai *et al.* (1998) reported on a total developmental time of 10.1 days for *O. tantillus* when reared on frozen eggs of *Ephestia kuehniella* Zeller and 9.8 days on nymphs of *T. palmi.* The extended developmental time of *O. tantillus* in our study at all temperatures (12.7 to 29.9 days) could be attributed to the host used for rearing. The developmental period of *O. strigicollis* was observed to be different when reared on cotton aphids (Kim *et al.,* 1999) and *Frankliniella occidentalis* (Pergande) (Ohta, 2001). In general, shorter developmental periods have been reported for other *Orius* spp. (Ohta, 2001; Nagai and Yano, 1999; Cocuzza *et al.*, 1997).

Longevity and Fecundity

Male and female longevity at 24°C (32.3 and 38.3) days respectively, were significantly higher than the longevity recorded at the other test temperatures and progeny production was on par at 20, 24 and 28°C. While longevity was adversely affected at a low temperature of 20°C and temperatures higher than 24°C, progeny production was significantly reduced at 32 and 36°C. Though the adult females survived for 17 days at 32°C, the significantly lower progeny production could be due to unsuccessful mating at this temperature. A balanced or female biased sex ratio was recorded at all test temperatures. Our results on higher progeny production at 24°C and 28°C corroborate with the reports by Alauzet *et al.* (1994) and Sanchez and Lacasa (2002) on *O. laevigatus;* Mendes *et al.* (2005), Carvalho *et al.* (2005) and Soglia *et al.* (2007) on *O. insidiosus* and Carvalho *et al.* (2005) on *Orius thyestes* Herring. Considering both survival and progeny production, it could be concluded that 24°C is the optimum temperature for mass rearing *O. tantillus. Thrips palmi,* one of the target pests of *O. tantillus,* was reported to lay maximum number of eggs at 25°C (Sreekanth *et al.*, 2006). Since *O. tantillus* was also recorded to be most active and fecund at this temperature, this anthocorid can be considered as an ideal candidate for field testing against *T. palmi.*

Effect of different temperature regimes on the age-specific survival and fecundity and fertility table parameters

Figures 1 to 4 present the age specific survival and fecundity (in terms of female progeny production) of *O. tantillus* at different test temperatures. Immature stages of *O. tantillus* occupied 29, 19, 17 and 13 days, respectively at 20, 24, 28 and 32°C. First mortality occurred when the female was 7, 8, 14 and 5 days, respectively and hundred per cent mortality occurred after 41, 45, 31 and 25 days, respectively. Female progeny production continued till mortality at 20°, while at 24°C till the female was 41 days old. At 28 and 32°C, female progeny production ceased when the female was 27 and 21 days old, respectively. Thus, considering the age specific female progeny production too, 24°C appeared to be the most suitable temperature.

The net reproductive rate (R_o) of *O. tantillus* was higher at 24 and 28°C in comparison to 20 and 32°C (Table 2). At 32°C, fertility table parameters, *viz.*, r_c, r_m, λ and WMR were highest, while doubling time was lowest. Doubling time was highest at 20°C (14.1 days). However, hypothetical F_2 females was lowest at this temperature. At 24 and 28°C, reproductive rate and hypothetical F_2 females were higher than that recorded at 20 and 32°C and WMR was higher that recorded at 20°C.

The R_0 and r_m values recorded for *O. tantillus* in the current study were lower than that reported for the same species by Kawamoto *et al.,* (1999), probably due to the different host used for rearing and the longer generation time. The r_m values were, however comparable with those recorded for other species of *Orius* viz. *O. strigicollis* at 20 and 25°C (Kakimoto *et al.*, 2005; Song *et al.,* 2001) and *O. insidiosus* at 24°C (Tommassini *et al.,* 2004). However, they were lower than that reported for *O. strigicollis, O. sauteri* and *Orius minutus* (Linnaeus) at other temperatures (Kakimoto *et al.,* 2005). At 32°C, higher r_m, lower doubling time

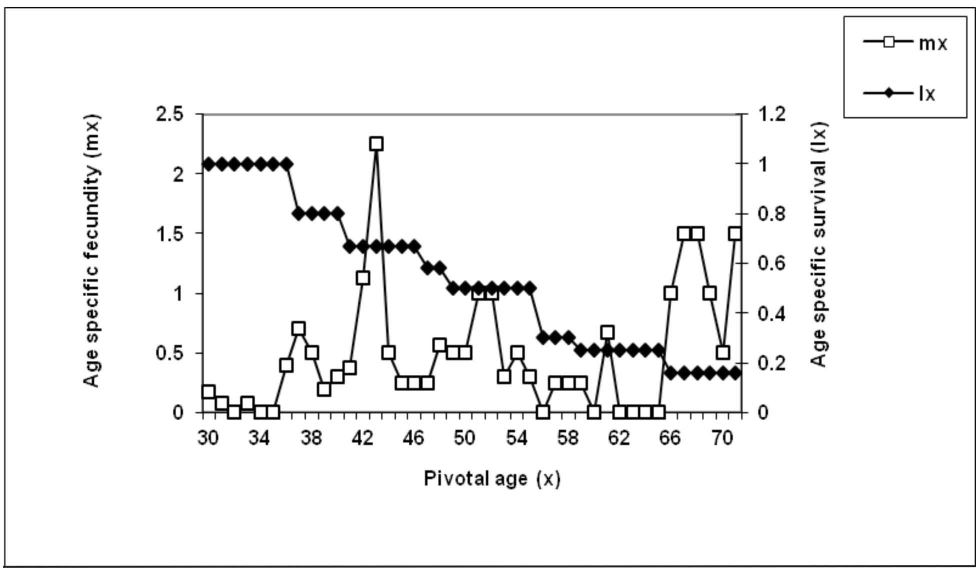

Fig. 1. Age specific survival (l_x) and fecundity (m_x) of *Orius tantillus* at 20°C.

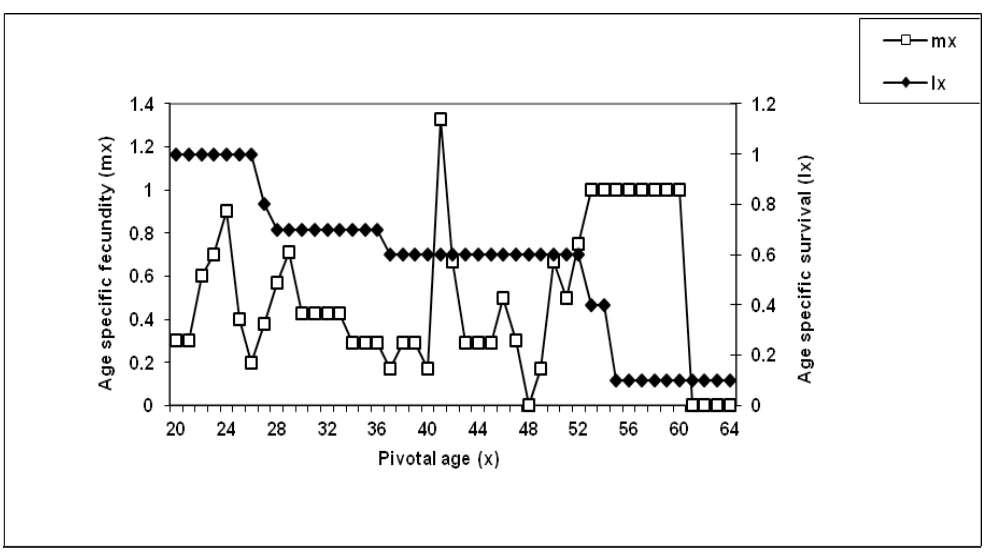

Fig. 2. Age specific survival (l_x) and fecundity (m_x) of *Orius tantillus* at 24°C.

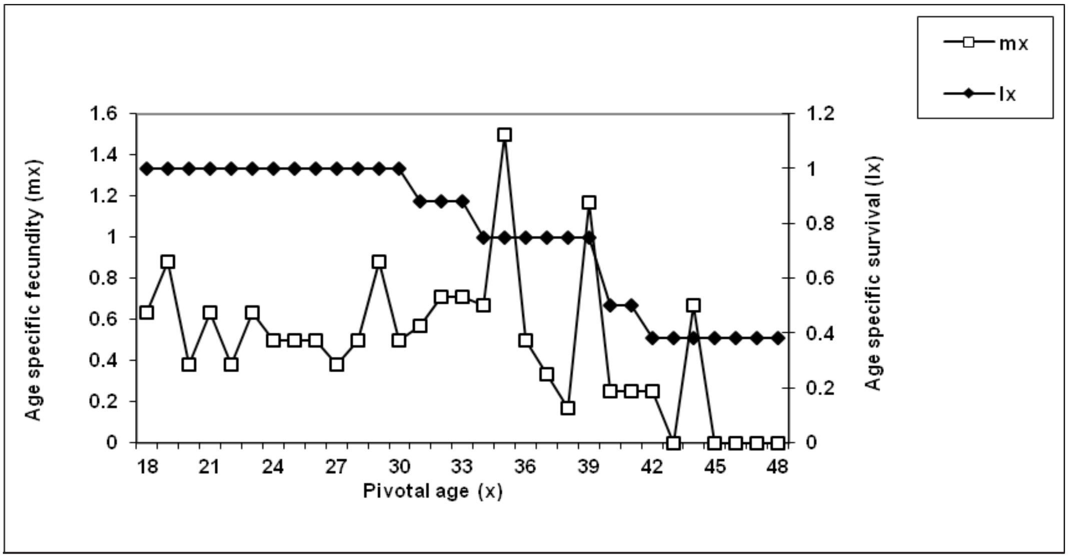

Fig. 3. **Age specific survival (l_x) and fecundity (m_x) of *Orius tantillus* at 28°C.**

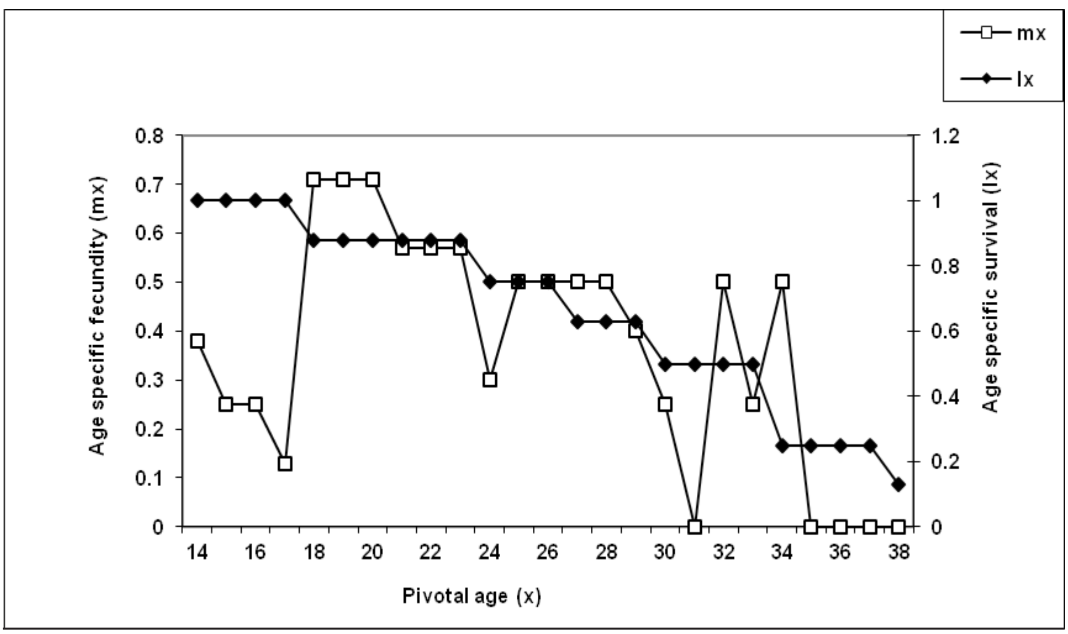

Fig. 4. **Age specific survival (l_x) and fecundity (m_x) of *Orius tantillus* at32°C.**

and higher weekly multiplication rate were recorded, probably due to the shorter generation time. A similar observation was made in *O. sauteri,* where highest r_m value was recorded at 30°C by Nagai and Yano (1999). Though the reproductive rate was higher at 24 and 28°C in comparison to 20 and 32°C, the finite rate of increase recorded at the above temperatures were comparable. This could be because at 24 and 28°C, the increase in offspring production occurred later in the reproductive period, which could have had a negligible effect on the intrinsic rate of increase. At 32°C, several factors which could be advantageous for mass rearing

Table 2. Fertility table of *Orius tantillus* when reared at different temperature regimes

Rearing Temperature (±1°C)	R_0	T_c	r_c	r_m	T	λ	Doubling Time (days)	Hypo. F_2 ♀s	WMR
20	8.24	60.72	0.034	0.049	43.01	1.08	14.14	67.90	1.73
24	10.94	35.93	0.066	0.056	43.01	1.16	12.38	119.68	2.85
28	11.42	32.74	0.074	0.070	35.01	1.19	9.90	130.42	3.41
32	7.01	22.43	0.087	0.097	20.01	1.22	7.14	49.14	4.04

were observed, however hypothetical F_2 females were lesser than that recorded at the other temperatures. Further studies need to be conducted to understand the effect of continuous rearing for several generations at this temperature on the biological parameters of *O. tantillus*. Considering fertility table parameters, 24 and 28°C emerged as the ideal constant temperatures for rearing *O. tantillus*.

The net reproductive rate of the target pest, *T. tabaci* ranges between 20.46 to 81.58 (Madadi *et al.*, 2006), while we observed that R_o value of *O. tantillus* ranged between 7.0 to 11.42. In general, the generation time of thrips is shorter in comparison to that of *Orius* spp., leading to a higher r_m and λ values in the former. The longer generation time and lower reproductive rate of the predator probably indicates that more number of releases of *Orius* would be required for successful biological control of thrips. The significant effect of host plant on survival and reproduction of thrips is evident through the higher generation time (19.09 days), lower r_m and λ values on sweet pepper (0.158 and 1.171, respectively) (Madadi *et al.*, 2006). The comparable r_m and λ values that we recorded for *O. tantillus* gave an indication that it would be worth evaluating *O. tantillus* against *T. tabaci* on sweet pepper, wherein the rate of increase of the predator could match up with that of the pest, with higher chances of establishment.

Thermal requirements in *Orius tantillus*

Linear models are used for calculating lower developmental thresholds and thermal constants in insects, within a range of 15 to 30°C (Bonte *et al.*, 2012). At extremely low or high temperatures, which are deleterious to growth, the relationship between insect developmental rates and rearing temperatures cannot be explained by a straight line. However, though non-linear models can give more accurate descriptions between development and temperature, they cannot be used for the calculation of thermal constants. In the present study, the rates of development of *O. tantillus* were linearly related to temperature between 20 to

32°C.

A significant negative relationship was observed between developmental period (incubation, nymphal and total) and temperature. The regression equations obtained with coefficient of determination (R^2), calculated lower threshold and the thermal constant for each stage are presented in Table 3.

The thermal requirements of *O. tantillus* and threshold temperature for the adult are comparable with the observations made by Alauzet *et al.* (1994) and Tomassini *et al.* (2004) for *O. laevigatus*. However, the development threshold values for *O. tantillus* stages recorded in our study were lower than that recorded for the same species when reared on *T. palmi* (Nakashima and Hirose, 1997). This could be because of the differences in host insect used and the rearing method adopted as these can influence the developmental rates and thereby the calculated threshold values. The calculated lower threshold temperature values indicated that the egg stage of *O. tantillus* is more heat sensitive in comparison to the nymphal stage, while the T_0 values of egg and female nymphal stage were comparable. Egg stage of *O. laevigatus* was observed to be least sensitive in comparison to the nymphal stage (Tommassini *et al.,* 2004 and Sanchez and Lacasa, 2002). In *O. tantillus*, female was observed to be more heat sensitive in comparison to the male, which is comparable to the results reported by Mendes *et al.* (2005) for *O. insidiosus.*

In general, the lower developmental threshold value of *O. tantillus* in comparison to other *Orius* spp. indicates that *O. tantillus* could be less heat sensitive in comparison to species like *O. strigicollis* (Kim *et al.,* 1999; Ohta, 2001), *O. insidiosus* (Mc Caffrey and Horsburgh, 1986; Mendes *et al.,* 2005), *O. niger*

Table 3. Linear regression equations for developmental rate against temperature, lower developmental thresholds and total effective temperatures of *Orius tantillus*

Stage	Regression equation	R^2	T_0 (°C)	K (degree days)
Egg-nymph	y=0.0092x-0.0797	0.873	8.66	108.70
Nymph-adult (male)	y=0.0039x-0.021	0.900	5.38	256.41
Nymph-adult (female)	y=0.0044x-0.0373	0.949	8.48	227.27
Overall nymphal period	y=0.0042x-0.0291	0.921	6.92	238.09
Egg to adult (Male)	y=0.0027x-0.0168	0.989	6.22	370.37
Egg to Adult (female)	y=0.0033x-0.0315	0.976	9.55	303.03
Overall development	y=0.003x-0.0242	0.972	8.06	333.33

(Baniameri *et al.,* 2005a,b), *O. sauteri* (Nagai and Yano, 1999), *O. albidipennis* (Sanchez and Lacasa, 2002), and *O. laevigatus* (Sanchez and Lacasa, 2002). Hence, *O. tantillus* could be considered as a potential bio-agent to target thrips infesting polyhouse crops in temperate regions as it may be able to survive at low temperatures. However, an aspect to be considered is that the estimated T_0 is an extrapolation of the relationship between temperature and development into a region where the relationship is unlikely to be linear. This could lead to ecologically inaccurate estimates. For eg., in the present study, the estimated T_0 value for nymphal development of *O. tantillus* was 6.92, however the actual observation was that nymphs could not survive at constant 16°C. The developmental rates of predatory insects could also vary in the field under varying temperature conditions and when feeding on the actual prey (Tommasini *et al.,* 2004). We have to bear in mind that in field situations, we cannot expect long term constant 16°C or 36°C, periodic respites would occur from cool or hot temperatures (humidity conditions / rainfall contributing towards that), which would alter or enhance the chances of survival of the nymphal and / or adult stages of the anthocorid and improve its performance as a predator. Sanchez and Lacasa (2002) have reported 35.5°C as the upper threshold value for *O. laevigatus* and 40.9°C for *O. albidipennis.* In the current study, though *O. tantillus* adults could not produce any progey at 36°C, the development could be completed, indicating that the study should be conducted at higher temperatures to identify the actual upper threshold for *O. tantillus.*

The thermal constant (K) expressed as the number of degree-days provides an alternative measure of the physiological time required for the completion of a process or a particular developmental event and it is known to be species or stage specific (Damos and Savopoulou-Soultani, 2008). The thermal constant recorded in our study for *O. tantillus* is higher than that recorded for the same species (Nakashima and Hirose, 1997) and other species like *O. sauteri* (Nagai and Yano, 1999), *O. insidiosus* (Mendes *et al.,* 2005) and *O. niger* (Baniameri *et al.,* 2005a). Yeargan (1983) mentions that the concept of a "thermal constant" for a species is a crude approximation. Earlier records have indicated that thermal requirement for development varies with temperature, particularly at low and high. The differences in thermal constants recorded in our study could have been due to the differences in developmental rates, which are dependent on the rearing conditions adopted and the prey insects used.

The life history characteristics of a natural enemy in comparison to that of the pest are to be considered while evaluating its biocontrol potential. Based on the threshold temperatures recorded for the pest and the natural enemy, we can predict the number of generations of the pest and the natural enemy at a particular field temperature and thus the possible role the natural enemy could play in suppressing the pest. The lower threshold temperature (T_0) of *T. tabaci* was observed to be 11.5°C by van Rijn *et al.* (1995) and 10.8°C by Murai (2000) and for *S. dorsalis* 8.5°C (Shibao, 1996). Thus *O. tantillus* appeared to be less heat sensitive in comparison to *T. tabaci,* while it seemed to have a similar response to temperature as *S. dorsalis*.

The effective accumulated temperature for the target pest *T. tabaci* is 232.6 DD (Murai, 2000) and for *S. dorsalis* 294.1DD (Shibao, 1996), which indicates that two of the target pests also have almost similar DD requirements as the predator under study. Thus, the data generated can be utilized for roughly estimating the development and number of generations per year of the anthocorid in different agro-ecological regions, to compare the DD requirements of the predator with that of different target pests and more importantly to precisely plan and fine-tune the production strategies of *O. tantillus* for field releases in different agro-climatic conditions. However, further studies are required on identifying the thermal requirement of *O. tantillus* when fed on specific target pests and also the actual lower and upper thresholds of the predator in field situations.

REFERENCES

Alauzet C, Dargagnon D, Malausa JC. 1994. Bionomics of a polyphagous predator: *Orius laevigatus* (Het.: Anthocoridae). *Entomophaga* **39**(1): 33–40. Crossref.

Ananthakrishnan TN, Thangavelu K. 1976. The cereal thrips, *Haplothrips ganglbaueri* Schmutz with particular reference to the trends of infestation on *Oryza sativa* and the weed *Echinochloa crusgalli. Proc Indian Acad Sci B*. **83**(5): 196–201.

Andrewartha HG, Birch LC. 1954. *The Distribution and Abundance of Animals*. University of Chicago Press, Chicago. 782 pp.

Arnold CY. 1959. The determination and significance of the base temperature in a linear heat unit system. *Proc Am Soc Hort Sci*. **74**: 430–445.

Ballal CR, Gupta T. 2011. Anthocorids as potential predators. pp. 92 – 111. In: Bhardwaj SC, Singh S, Bhatnagar A (Eds.) *Plant Protection through Eco-friendly Techniques*. Pointer Publishers, Jaipur 272 pp.

Ballal CR, Gupta T, Joshi S. 2012. Effect of different laboratory hosts on the fertility table parameters and continuous rearing of an anthocorid predator *Orius tantillus* (Motsch.). *Pest Manage Hort Ecosys*. **18**(1): 24–28.

Baniameri V, Soleimannejadian E, Mohaghegh J. 2005a. Effect of temperature on development of immature stages of predatory bug *Orius niger* Wolff. *Appl Entomol Phytopathol*. **72**(2): 47–57.

Baniameri V, Soleimannejadian E, Mohaghegh J. 2005b. Life table and age-dependent reproduction of the predatory bug *Orius niger* Wolff (Heteroptera: Anthocoridae) at three constant temperatures: a demographic analysis. *Appl Entomol Zool*. **40**(4): 545–550. Crossref.

Bernal J, Gonzalez D. 1993. Experimental assessment of a degree day model for predicting the development of parasites in the field. *J Appl Entomol*. **116**: 459–466. Crossref.

Birch LC. 1948. The intrinsic rate of natural increase of an insect population. *J Anim Ecol*. **17**: 15–26. Crossref.

Bonte J, Madelena de Ro, Conlong D, De Clercq P. 2012. Thermal biology of the predatory bugs *O. thripoborus* and *O. naivashae* (Hemiptera: Anthocoridae). *Physiol Ecol*. **41**(4): 989–996.

Carvalho LM, Bueno VHP, Mendes SM. 2005. Response of two *Orius* species to temperature. *Bull. OILB/SROP*. **28**(1): 43–46.

Cocuzza GE, De Clercq P, Lizzo S, Van de Veire M, Tirry L, Degheele D, Vacante V. 1997. Life table and predation activity of *Orius laevigatus* and *Orius albidipennis* at three constant temperatures. *Entomol Exp Appl*. **85**: 189–198. Crossref.

Damos PT, Savopoulou-Soultani M. 2008. Temperature-dependent bionomics and modeling of *Anarsia lineatella* (Lepidoptera: Gelechiidae) in the laboratory. *J Econ Entomol*. **101**: 1557–1567 Crossref. PMid:18950037

Gupta T, Ballal CR. 2006. Biology and feeding potential of an anthocorid predator, *Orius tantillus* (Heteroptera: Anthocoridae) on *Sitotroga cerealella Indian J Plant Prot*. **34**(2): 168–172.

Gupta T, Ballal CR. 2009. Protocols for commercial production of *Orius tantillus* (Motschulsky) (Heteroptera: Anthocoridae). *J Biol Control* **23**(4): 385–391.

Hernandez LM. 1999. A review of the economically important species of the genus *Orius* (Heteroptera: Anthocoridae) in East Africa. *J Nat Hist*. **33**: 543–568. Crossref.

Kakimoto K, Urano S, Noda T, Matuo K, Sakamaki Y, Tsuda K, Kusigemati K. 2005. Comparison of the reproductive potential of three *Orius* species, *O. strigicollis*, *O. sauteri*, and *O. minutus* (Heteroptera: Anthocoridae), using eggs of the Mediterranean flour moth as a food source. *Appl Entomol Zool*. **40**(2): 247–255. Crossref.

Kawamoto K, Sasaki M, Nakaima H, Onuma M, Uchida N. 1999. Development and reproductive ability of *Orius tantillus* (Motschulsky) (Hemiptera: Anthocoridae) reared on egg of *Plodia interpunctella* (Hubner). *Res Bull Plant Prot Serv, Japan* **35**: 87–91.

Kim JH, Kim YH, Han MW, Lee GS, Lee JO. 1999. Effect of temperature on the development and oviposition of minute pirate bug, *Orius strigicollis* (Hemiptera: Anthocoridae). *Korean J Appl Entomol*. **38**(1): 29–33.

Kumar NS, Ananthakrishnan TN. 1984. Predator thrips interactions with reference to *Orius maxidentex Ghauri* and *Carayonocoris indicus* Muraleedharan (Anthocoridae: Heteroptera). *Proc Indian Natl Sci Acad B*. **50(**2): 139–145.

Madadi H, Kharazi PA, Ashouri A, Neishabouri JM. 2006. Life history parameters of *Thrips tabaci* (Thys: Thripidae) on cucumber, sweet pepper and egg plant under laboratory conditions. *J Entomol Soc Iran* **25**(2): 45–62.

McCaffrey JP, Horsburgh RL. 1986. Biology of *Orius insidiosus* (Heteroptera: Anthocoridse): a predator in Virginia apple orchards. *Environ Entomol*. **15**(4): 984–988. Crossref.

Men UB. 1999. *Orius maxidentex* Ghauri as predator on sunflower thrips. *Insect Environ*. **5**(1): 22–23.

Mendes SM, Bueno VHP, Carvalho LM. 2005. Development and thermal requirements of *Orius insidiosus* (Say) (Hemiptera: Anthocoridae). *Rev Bras Entomol*. **49**(4): 575–579. Crossref.

Morris RF, Fulton WC. 1970. Models for the development and survival of *Hyphantria cunea* in relation to temperature and humidity. *Mem Entomol Soc Canada* **70**: 1–60.Crossref.

Murai T. 2000. Effect of temperature on development and reproduction of the onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) on pollen and honey solution. *Appl Entomol Zool*. **35**(4): 499–504.Crossref.

Muraleedharan N, Ananthakrishnan TN. 1978. Bioecology of four species of Anthocoridae (Hemiptera: Insecta) predaceous on thrips, with key to genera of anthocorid from India. Ocassional paper, *Rec Zool Surv India* **11**: 1–32.

Nagai K, Hirose Y, Takagi M, Nakashima Y, Hiramatsu T. 1998. Selection of alternate prey for rearing *Orius tantillus* (Motschulsky). *Jpn J Appl Entomol Zool*. **42**(2): 85–87. Crossref.

Nagai K, Yano E. 1999. Effect of temperature on the development and reproduction of **Orius sauteri** (Poppius) (Heteroptera: Anthocoridae), a predator of Thrips palmi Karny (Thysanoptera: Thripidae). *Appl Entomol Zool*. **34**(2): 223–229. Crossref.

Nakashima Y, Hirose Y. 1997. Temperature effects on development of *Orius tantillus* (Het.: Anthocoridae), a predator of *Thrips palmi* (Thys.: Thripidae). *Entomophaga* **42**(3): 337–342. Crossref.

Ohta I. 2001. Effect of temperature on development of *Orius strigicollis* (Heteroptera: Anthocoridae) fed on *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Appl Entomol Zool*. **36**(4): 483–488. Crossref.

Sanchez JA, Lacasa A. 2002. Modelling population dynamics of *Orius laevigatus* and *Orius albidipennis* (Hemiptera: Anthocoridae) to optimize their use as biological control agents of *Frankliniella occidentalis* (Thysanoptera: Thripidae). *Bull Entomol Res* **92**(1): 77–88. PMid:12020365

Shibao M. 1996. Effects of temperature on development of the chilli thrips, *Scirtothrips dorsalis* Hood (Thysanoptera: Thripidae) on grape. *Appl Entomol Zool* **31**(1): 81–86.Crossref.

Soglia MCM, Bueno VHP, Carvalho LM. 2007. Effect of alternative prey on development and consumption of *Orius insidiosus* (Say) (Hemiptera, Anthocoridae) and oviposition behavior on chrysanthemum cultivars. *Rev Bras Entomol*. **51(**4): 512–517.Crossref.

Song JH, Kang SH, Kang AS, Lee KS, Han WT. 2001. Determination of optimum conditions for mass rearing of minute pirate bug *Orius strigicollis*. *Korean J Appl Entomol*. **40**(2): 111–115.

Sreekanth M, Sriramulu M, Rao RDVJP, Babu BS, Babu TR. 2006. Effect of different temperatures on the developmental biology of *Thrips palmi*, the vector of peanut bud necrosis on greengram. *Indian J Plant Prot*. **34**(1): 136–137.

Thontadarya TS, Rao KJ. 1987. Biology of *Orius maxidentex* Ghauri (Hemiptera: Anthocoridae), a predator of the sorghum earhead midge, *Contarinia sorghicola* (Coquillet). *Mysore J Agric Sci*. **21**(1): 27–31.

Tommasini MG, van Lenteren JC, Burgio G. 2004. Biological traits and predation capacity of four *Orius* species on two prey species. *Bull Insectology* **57**(2): 79–93.

van Rijn PCJ, Mollema C, Steenhius BGM. 1995. Comparative life history studies of *Frankliniella occidentalis* and *Thrips tabaci* (Thysanoptera: Thripidae) on cucumber. *Bull Entomol Res*. **85**(2): 285–297. Crossref.

Yeargan KV. 1983. Effects of temperature on developmental rate of *Trissolcus euschiti* (Hymenoptera: Scelionidae), a parasite of stink bug eggs. *Ann Entomol Soc Am*. **76**: 757–760. Crossref.

Zhang SC, Zhu F, Zheng XL, Lei CL, Zhou XM. 2012. Survival and developmental characteristics of the predatory bug *Orius similis* (Hemiptera: Anthocoridae) fed on *Tetranychus cinnabarinus* (Acari: tetranychidae) at three constant temperatures. *Eur J Entomol*. **109**: 503–508. Crossref.

Zhou XM, Zhu F, Li H, Lei CL. 2006. Effect of temperature on development of *Orius similis* Zheng (Hemiptera: Anthocoridae) and on its predation activity against *Aphis gossypii* Glover (Hemiptera: Aphididae). *Pan-Pac Entomol*. **82**(1): 97–102