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Influence of elevated temperature on the fitness of Diamondback moth, *Plutella xylostella* (L.) in cauliflower

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Abstract

Aim: To understand the effect of elevated temperature on the bionomics and fitness parameters of *Plutella xylostella* which would help in predicting the population growth rates and formulating appropriate management tactics.

Methodology: In the present investigation, the fitness parameters of diamondback moth were studied at six different temperatures (31, 32, 33, 34, 35 and 36°C) in cauliflower in Open Top Chambers. Observations were recorded on the survival, longevity and fecundity at daily interval. The raw data on bionomics and life table parameters were analyzed using TWO-SEX-MS chart.

Results: The total life cycle of *P. xylostella* was longer at 31°C and it declined with increasing temperatures. However, *P. xylostella* did not complete its development at 35 and 36 °C. The intrinsic rate of increase (r_m) increased from 0.22 at 31°C to 0.28 at elevated temperature of 34°C. Temperature also had a significant effect on the net reproductive rate (R_0), Gross Reproductive Rate (GRR) and finite rate of increase (λ).

Interpretation: The fitness parameters will help to predict the change that occur in *P. xylostella* population due to climate change and global warming.

Key words: Diamondback moth, Life table, Population dynamics, Temperature

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Introduction

Diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) is a devastating pest of cruciferous vegetable crops across the world (Garrad et al., 2016, Jaleel et al., 2019, Steinbach et al., 2017). The yield loss due to this destructive insect pest is estimated to be around 50- 80% (Dhaliwal et al., 2010). Globally, 4-5 billion US dollars have been spent on the management of *P. xylostella* (Zalucki et al., 2012). The ability to complete number of generations per year, higher reproductive rate and insecticide resistance has made *P. xylostella* management difficult (Furlong et al., 2013, Gu et al., 2010, Shelton and Wyman, 1992).

Insects are poikilothermic organisms, its growth, reproduction, survival and abundance are influenced by factors like temperature and photoperiod (Awmack and Leather, 2002, Malaquias et al., 2010, Hallman and Denlinger, 1998). Thermal conditions required for the successful development of the pest vary in different ecological regions (Chen et al., 2017, Gomi et al., 2003). Study of such variations are the need of the moment since global warming is likely to increase by 1.5°C between 2030 and 2052 (IPCC, 2018).

Precise knowledge of insect adaptations to changing climatic condition plays a vital role in effective management practices (Vargas et al., 2000). Life table parameters like intrinsic rate of increase (r_m) are important population measurement which helps to identify suitable Integrated Pest Management (Huang and Chi, 2013; Southwood and Henderson, 2000).

The effect of temperature on the biology of *P. xylostella* has been studied across the globe (Golizadeh et al., 2009; Liu et al., 2002; Shirai, 2000). However, most studies have been carried out under more extensive temperature variations, i.e., 10°C to 30°C. As we are impending towards the era of climate change, it is essential to know the demography of insect pests even with infinite small temperature variations. Hence, in the present study, the fitness parameters of diamondback moth were studied on six sequential temperature treatments by using two-sex life table. Exploring the relationship between temperature and *P. xylostella* population will be useful for formulating accurate management practices in the future.

Materials and Methods

The seed of cauliflower (*Brassica oleracea* var. *botrytis*) variety Arka Kanti was grown in pots in a greenhouse and used for the experiments. The mother culture of *P. xylostella* larvae and pupae were collected from the cauliflower fields of Thondamuthur and Narasipuram, Coimbatore during February 2019. The collected larvae were reared on the leaves of cauliflower at $28 \pm 2^\circ\text{C}$, $70 \pm 5\%$ RH in plastic containers ($13 \times 15 \times 11$ cm) covered with a fine muslin cloth. The pupae formed were placed in adult emergence cage ($60 \times 60 \times 60$ cm) which consisted clear, plexiglass on one side and remaining sides made of fine nylon

mesh gauze. An opening was made on one side for providing fresh leaves and food. Honey solution (10%) was soaked in a cotton wick (10 cm) and given to adult as feed along with fresh cauliflower leaves (Golizadeh et al., 2009). The cage was covered with black muslin cloth for egg laying. Every 24h, the leaves with freshly laid eggs were collected from the cage and used for experiments.

A cubical open top chamber was built with high-quality multilayer polycarbonate sheets (4-6 mm thickness) partially opened top side $4\text{ m} \times 4\text{ m} \times 4\text{ m}$ made with galvanized iron (GI). The structure was outfitted with humidity and temperature supervising control and wireless signal transmission amenities along with SCADA (Supervisory Control and Data Acquisition) integration technology. Ceramic IR heaters could elevate the temperature around 10°C than control (ambient condition) autonomously in each OTC. Using SCADA system, a control signal from the controller was received by heaters which were a final control element (FCE). Different temperature regimes were attained correspondent to set temperature. Cauliflower plants were grown in pots for each temperature treatments in open top chambers.

Developmental parameters of *P. xylostella* were studied at six constant temperatures (31, 32, 33, 34, 35 and 36°C) in separate open top chambers. For studying the fitness parameters, ten *P. xylostella* eggs were collected from the surface of the leaf using small camel hair brush and placed on a leaf disc on water - soaked cotton in each 10 Petri dishes. A total of 100 eggs were examined at each temperature. A circular hole of 3 cm diameter fitted with fine nylon mesh was made on the lid for ventilation. The eggs were carefully examined until hatching. Each egg was noted as a replication. The newly emerged I instar larvae from each temperature treatment were placed individually on cauliflower leaf disc placed on water - soaked cotton in Petri dishes (4.5 cm dia, 4 cm ht). Fresh cauliflower leaves were given every day during the experimental period. The mortality, developmental time of each instar and life cycle of *P. xylostella* were recorded at each temperature treatment.

Fecundity and longevity of *P. xylostella* adults were examined at four constant temperatures (31, 32, 33 and 34°C). Temperature 35 and 36°C were excluded due to 100% mortality. Fifteen mating pairs were used for each treatment. Each pair was released in glass tubes covered with fine cloth. Crushed aluminium foil sheets swabbed with cauliflower leaf extract was provided as a substrate for oviposition. Egg laden foil sheets were replaced with new aluminium foil sheets every 24 hr and the number of eggs laid were counted until adults died.

The biological parameters of *P. xylostella* were analyzed according to age- stage, two sex life table program TWO-SEX-MS chart (Chi, 2014). Age specific fecundity (m_x), age-specific survival rate (l_x) and population parameters were calculated according to Huang and Chi (2012). The intrinsic rate of increase (r_m) value was calculated as

$$r_m = \log_e \frac{R_0}{T_c}$$

The l_x , m_x and R_0 values are calculated using

$$l_x = \sum_{j=1}^k S_{xj}$$

$$m_x = \sum_{j=1}^k S_{xj} f_{xj} / \sum_{j=1}^k S_{xj}$$

$$R_0 = \sum_{x=\alpha}^{\beta} l_x m_x$$

The Gross Reproductive Rate (GRR) was calculated by the formula: $GRR = \sum m_x$. Mean separations of oviposition period and adult longevity were done by Duncan's Multiple Range Test (DMRT) using IBM SPSS v. 22 statistical program. Similar procedures were used for other parameters (r_m , λ , R_0 , T , GRR and t).

The mean values of life table parameters were subjected to Bootstrap analysis ($n=1,00,000$) and the standard errors were estimated.

Results and Discussion

Life table is an important analytical tool to understand the growth, development and reproduction of insects under varying conditions. To get accurate estimates of fitness parameters, bootstrap technique was utilized with $n=1,00,000$ and the means were used for calculating the standard errors (Huang and Chi, 2012). Insects can survive under a wide range of temperatures. The effect of temperature on the growth and development of various insects has been studied (Golizadeh et al., 2009; Manikandan et al., 2013; Chen et al., 2017; Soh et al., 2018).

P. xylostella completed its development at temperatures between 31 and 34°C. All the third instar larval stages died at 35°C whereas at 36°C, the eggs of *P. xylostella* did not hatch. The egg development time was significantly shorter at 35°C than other temperatures ($P < 0.001$). The duration of first, second, third and fourth instar larvae were significantly longer at the minimum temperature treatment of 31°C (1.99, 1.91, 2.07 and 2.03 days)

Fig 1. Influence of four different temperatures on the age – stage – specific survival rate (S_{xj}) of *Plutella xylostella*; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

Table 1 : Influence of different temperatures on the biological traits of *Plutella xylostella* in cauliflower

Parameters (Days) (n=100)	Temperature (°C)					F	P
	31	32	33	34	35		
Egg	2.73 ± 0.05 ^b	2.61 ± 0.05 ^b	2.60 ± 0.04 ^b	2.63 ± 0.05 ^b	2.56 ± 0.05 ^a	11.26	< 0.001
I instar	1.99 ± 0.01 ^c	1.97 ± 0.02 ^c	1.93 ± 0.03 ^c	1.86 ± 0.04 ^b	1.89 ± 0.04 ^a	3.208	< 0.001
II instar	1.91 ± 0.07 ^a	1.71 ± 0.07 ^d	1.50 ± 0.06 ^c	1.27 ± 0.05 ^b	1.35 ± 0.10 ^a	4.807	< 0.001
III instar	2.07 ± 0.06 ^d	1.91 ± 0.05 ^d	1.42 ± 0.06 ^c	1.13 ± 0.04 ^b	1.14 ± 0.14 ^a	3.829	< 0.001
IV instar	2.03 ± 0.05 ^d	2.04 ± 0.05 ^d	1.82 ± 0.05 ^c	1.44 ± 0.06 ^b	1.00 ± 0.01 ^a	4.251	< 0.001
Pupa	3.16 ± 0.05 ^d	3.12 ± 0.05 ^d	2.94 ± 0.06 ^c	2.67 ± 0.07 ^b	0.00 ± 0.00 ^a	4.603	< 0.001
Pre-adult	13.91 ± 0.14 ^d	13.39 ± 0.18 ^c	12.23 ± 0.13 ^b	10.93 ± 0.11 ^a	-	198.76	< 0.001

Means in the same row followed by same letter are not significantly different ($P > 0.05$) using bootstrap test.

Fig. 2. Influence of different temperatures on age-stage-specific life expectancy (e_{xj}) of *Plutella xylostella*; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

and the duration steadily reduced at higher temperature of 35°C (1.89, 1.35, 1.14 and 1.00 days). The pupal duration lasted for about 3.16 ± 0.05 days at 31°C whereas it significantly reduced to 2.67 days at 34°C ($P < 0.001$) (Table 1) (Fig. 1 and 2).

Similarly, in cabbage and cauliflower the survival rate of *P. xylostella* was reduced at 35°C (Golizadeh *et al.*, 2009).

Shirai (2000) found that 20–25°C was the favorable condition for the reproduction of *P. xylostella*, while in our study the fecundity can be observed up to 34°C. Also, Liu *et al.* (2002) concluded that *P. xylostella* developed successfully from egg to adult stage at temperatures ranging from 8–32°C and there was only partial development at temperatures ranging from 34–40°C.

Fig. 3. Age-stage reproductive value (v_x) of *Plutella xylostella*; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

Table 2: Oviposition period of *Plutella xylostella* in cauliflower at different temperatures

Parameters	Temperature				F	P
(Days) (n=100)	31°C	32°C	33°C	34°C		
Male longevity	10.62 ± 0.14 ^d	9.14 ± 0.15 ^c	8.11 ± 0.10 ^b	3.87 ± 0.11 ^a	1649.30	< 0.001
Female longevity	11.61 ± 0.08 ^d	10.54 ± 0.13 ^c	8.35 ± 0.10 ^b	4.60 ± 0.09 ^a	447.70	< 0.001
APOP	1.73 ± 0.11 ^c	1.93 ± 0.12 ^{bc}	1.53 ± 1.33 ^b	0.87 ± 0.09 ^a	0.953	0.05
TPOP	15.6 ± 0.42 ^d	14.87 ± 0.39 ^c	13.66 ± 0.25 ^b	11.2 ± 0.22 ^a	6.085	< 0.001
Oviposition	8.6 ± 0.21 ^d	7.47 ± 0.16 ^c	5.66 ± 0.15 ^b	2.66 ± 0.15 ^a	1.084	0.399
Fecundity (total eggs/ female)	150.86 ± 19.32 ^c	142.80 ± 3.62 ^{bc}	117.07 ± 5.27 ^{ab}	100.33 ± 8.27 ^a	1.205	0.307

Means in the same row followed by same letter are not significantly different ($P > 0.05$) using bootstrap test.

Adult pre-oviposition period (APOP) did not vary significantly between the temperatures 31°C and 34°C ($P = 0.514$) and total pre-oviposition period (TPOP) ranged from 15.6 ± 0.42 days to 11.2 ± 0.22 days when the temperature increase from 31°C to 34°C, respectively ($P < 0.001$). The oviposition days of *P. xylostella* were inversely proportional with the increasing temperatures. At 31°C, the females oviposited for 8.6 days whereas it was decreased to 2.66 days at 34°C. Similarly, the

fecundity reduced from 150.866 eggs per female at 31°C to 100.33 eggs per female at 34°C (Fig. 3).

The longevity of female is negatively correlated with the increasing temperatures. At 31°C, the longevity of female was 11.61 days and it significantly abridged to 4.60 days when the temperature was raised to 34°C. The maximum longevity of male was observed at 31°C (10.62 days) and minimum was at 34°C

Fig 4: Influence of different temperatures on the survival rate (l_x) and fecundity (m_x) of *Plutella xylostella*.

Table 3: Influence of different temperatures on the life table parameters of *Plutella xylostella*

Parameters	Temperature				F	P
	31°C	32°C	33°C	34°C		
r_m	0.22 ± 0.001^a	0.23 ± 0.002^a	0.24 ± 0.002^b	0.28 ± 0.007^c	188.00	< 0.001
λ	1.25 ± 0.008^b	1.27 ± 0.171^b	1.28 ± 0.003^b	0.32 ± 0.007^a	4014.61	< 0.001
R_0	74.98 ± 0.737^c	80.17 ± 1.355^d	60.90 ± 0.507^b	42.07 ± 1.007^a	343.78	< 0.001
T	19.13 ± 0.038^c	18.59 ± 0.377^c	14.68 ± 0.122^b	13.25 ± 0.324^a	94.23	< 0.001
GRR	83.76 ± 0.179^c	94.02 ± 1.663^d	74.58 ± 1.474^b	62.67 ± 1.501^a	82.74	< 0.001
t	3.07 ± 0.010^d	2.94 ± 0.016^c	2.77 ± 0.015^b	2.45 ± 0.038^a	104.38	< 0.001

r_m : The intrinsic rate of increase (per day); λ : The finite rate of increase (per day); R_0 : The net reproductive rate (offspring/individual); T: The mean generation time (days); t: Population doubling time; GRR: Gross reproductive rate (offspring); Means in the same row followed by the same letter are not significantly different ($P > 0.05$) using bootstrap test.

(3.87 days) (Table 2). There was an inverse relationship between temperature and age – specific survival rate (l_x) and fecundity (m_x) (Fig.4). Likewise, Garrad *et al.* (2016) found that *P. xylostella*

reared at 30°C have shorter life span than insects reared at any other temperature, suggesting decreased fitness; however, they did produce a large number of eggs in the few days they were alive.

The fitness parameters of *P. xylostella* were notably affected by the increasing temperatures of 31°C to 34°C. The intrinsic rate of increase (r_m) had increased significantly from 0.22 to 0.28 when temperature increased from 31°C to 34°C ($P < 0.001$). Ngowi *et al.* (2017) showed that r_m value increased from 0.001 at 10°C to 0.20 at 30°C. It had been reported that the pre-adult and adult development rate varied at different temperatures (Folguera *et al.*, 2010). The development time from an egg to adult, as well as the fecundity of insect pests attributed to the variations in r_m value (Badenes-Perez *et al.*, 2005).

The net reproductive rate (R_0) was maximum with 80.14 individuals per female per lifetime at 32°C followed by 74.98 individuals per female per lifetime at 31°C and lowest R_0 value of 42.07 individuals per female per lifetime was observed at 34°C. The longest mean generation time was 19.13 days at 31°C compared to the shortest of 13.25 days at 34°C. The highest GRR value (94.02 numbers of offsprings per day) was found at 32°C; while lowest (62.67 numbers of offsprings per day) at 34°C (Table 3).

Jafary-Jahed *et al.* (2019) found that the net reproductive rate (R_0) of *P. xylostella* was 65.46 offsprings per individual when larvae were reared on cauliflower at 30°C, which nearly corroborated with the present finding where the net reproductive rate (R_0) was 74.98 individuals per female per lifetime at 31°C. The GRR is a measure of rapid increase of population that depends on the number of eggs laid, eggs hatched and adult eclosion, and all these parameters are exaggerated by temperature (Khaliq *et al.*, 2007). In our study, the GRR decreased to 62.67 numbers of offsprings per day when the temperature increased to 34°C. The population increases only when net reproductive rate will be greater than 1 and $r > 0$ (Chen *et al.*, 2017, Southwood and Henderson, 2009). The findings of this study also confirmed the aforesaid theory. The information obtained from the present study can be used for developing forecasting models and formulating optimal integrated pest management strategies in the future era of global climate change.

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Add-on Information

Authors' contribution: K. Haripriya: Conduct of experiment, data recording and writing of manuscript; J. S. Kennedy: Conceptualization and supervision of research plan; V. Geethalakshmi: Review and finalization of paper, Supervision; D. Rajabaskar: Review and finalization of paper, Supervision.

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