Saudi Journal of Biological Sciences 26 (2019) 1661–1667

Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: www.sciencedirect.com

Fitness parameters of *Plutella xylostella* (L.) (Lepidoptera; Plutellidae) at four constant temperatures by using age-stage, two-sex life tables

Shafqat Saeed [a,*], Waqar Jaleel [b], Muhammad Nadir Naqqash [c], Qamar Saeed [d], Syed Muhammad Zaka [d], Zahid Mahmood Sarwar [d], Muhammad Ishtiaq [a], Mirza Abdul Qayyum [a], Muhammad Umair Sial [e], Qurat-Ul-Aine [d], Muazzama Batool [d], Khalid Ali Khan [f,g], Hamed A. Ghramh [f,g,h], Muhammad Hafeez [i], Mohammad Javed Ansari [j,k], Girish Kumar Sharma [k]

[a] *Department of Entomology, Muhammad Nawaz Sharif University of Agriculture, Multan 60000, Pakistan*
[b] *College of Agriculture, South China Agricultural University, Guangzhou 510642, Guangdong Province, China*
[c] *Department of Plant Production and Technologies, Faculty of Agricultural Sciences and Technology, Niğde University, Turkey*
[d] *Department of Entomology, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan 60800, Pakistan*
[e] *Institute of Plant Protection, Chinese Academy of Agricultural Sciences, Beijing 100081, China*
[f] *Biology Department, Faculty of Science, King Khalid University, P.O. Box 9004, Abha 61413, Saudi Arabia*
[g] *Unit of Bee Research and Honey Production, Faculty of Science, King Khalid University, P.O. Box 9004, Abha 61413, Saudi Arabia*
[h] *Research Center for Advanced Materials Science (RCAMS), King Khalid University, P.O. Box 9004, Abha 61413, Saudi Arabia*
[i] *Hubei Insect Resources Utilization and Sustainable Pest Management Key Laboratory, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei 430070, China*
[j] *Bee Research Chair, Plant Protection Department, College of Food and Agriculture Sciences, King Saud University, PO Box 2460, Riyadh 11451, Saudi Arabia*
[k] *Department of Botany, Hindu College Moradabad, 244001, India*

ARTICLE INFO

Article history:
Received 30 July 2018
Revised 7 August 2018
Accepted 25 August 2018
Available online 27 August 2018

Keywords:
Age-stage
Plutella xylostella
Lepidoptera
Temperature
Life table

ABSTRACT

Different temperature zones have significant impact on the population dynamics of *Plutella xylostella*. Effective management of *P. xylostella* requires the knowledge of temperature tolerance by different life stages. In the current study, fitness parameters of diamondback moth were reported by using age-stage, two-sex life table traits at four constant temperatures (15, 20, 25 and 30 °C). The life cycle of *P. xylostella* was significantly longer at 15 °C. The 20 °C level of temperature was found optimal for fecundity, gross reproductive rate (51.74 offspring) and net reproductive rate (44.35 offspring per individual). The adult pre-oviposition period was statistically at par at all four level of temperatures. However, the survival was maximum at 20 °C as compared to other three temperature ranges. Based on the current study, it was concluded that temperature has a great role in population build-up of *P. xylostella* and effective management tactics should be applied to prevent significant damage to cabbage and other cruciferous crops when the temperature in the field is near 20 °C.

1. Introduction

Diamondback moth, *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) is a one of the major pest of vegetables across the world (Garrad et al., 2016; Jaleel et al., 2017; Shakeel et al., 2017; Steinbach et al., 2017). This pest has been reported to cause up to 90% yield losses under high population levels with 4–5 billion US dollars spent for its management globally (Zalucki et al., 2012). This is due to high fecundity, short generation time, wide host range, insecticide resistance and ability to survive under wide range of temperatures (Furlong et al., 2013; Gu et al., 2010; Shelton and Nault, 2004). The relationship between temperature and insects is well studied. Being poikilothermic organisms, the growth, fecundity, survival and other biological factors of insects are highly influenced by external temperature conditions (Denlinger and Hallman, 1998). Each species has its own thermal window at which it can survive and reproduce in a particular area

* Corresponding author at: Department of Entomology, Muhammad Nawaz Sharif University of Agriculture, Multan 60000, Pakistan.
E-mail address: shafqat.saeed@mnsuam.edu.pk (S. Saeed).
Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

https://doi.org/10.1016/j.sjbs.2018.08.026
1319-562X/

(Jarošík et al., 2002). Hence such relationships are very important in planning the integrated management of diamondback moth (Ahn et al., 2012; Kim and Lee, 2010; Notter-Hausmann and Dorn, 2010).

Although numerous studies have been conducted in several countries to study the biology of *P. xylostella* under different temperature (Golizadeh et al., 2009; Liu et al., 2002; Shirai, 2000) but such studies are lacking in Pakistan. Moreover, populations of pest in different ecological regions vary for thermal requirements (Chen et al., 2015; Gomi et al., 2003). Such variations demand to study the biology/fitness of that specific pest for its better management.

In the current study, life traits of diamondback moth were studied on four different temperatures by using the two-sex life table traits along with age-stage on Chinese cabbage (*Brassica rapa* var. Pekinensis). The population of *P. xylostella* belong to arid climatic conditions of Multan, Pakistan. We aimed to find out how arid population of *P. xylostella* performs at different temperatures. The purpose was to find relationship between the *P. xylostella* and temperature and use that information for future management of this destrctive pest in Pakistan.

2. Materials and methods

2.1. Population of P. xylostella

For growing of plants, seeds of Chinese cabbage or bok choy were sown in beds (having area = 5 m^2) and plastic boxes ($6 \times 10 \times 20$ cm) at the research farm of Bahauddin Zakariya University, Multan, Pakistan. The cabbage leaves from these plants were used for laboratory studies. The larval and pupal stages of diamondback moth were collected from cabbage fields located near Central Cotton Research Institute (CCRI), Multan, Pakistan. Briefly, the collected larvae were reared on leaves of cabbage plants in glass petri dishes untill pupae. The pupae were transferred to glass jars for adult emergence. The adults moths were provided with 10% honey solution as diet until egg laying and death. They were reared in same manner untill enough numbers were obtained for experiments (Jaleel et al., 2017). In addition, they were reared on each temperature (15, 20, 25 and 30 °C) for two generations in the incubators for acclimatization (Model VELP # 90E Japan) before using for experiments.

2.2. Life table traits of P. xylostella

For this purpose, 150 leaves (5.5 cm × 1.2 cm) of cabbage were cut and placed individually in Petri dishes at 15, 20, 25, and 30 °C temperatures in incubators. A total of 150 eggs were collected from leaves at each temperature with the help of camel hair brush. They were placed in petri dishes on a piece of cabbage leaf placed at the bottom of petri dish. Each egg denoted as a replication. Fresh cabbage leaves were given after every 2 days during the experimental period. Life cycle of diamondback moth was recorded daily at each temperature.

To study the reproduction potential of diamondback moth, both male and female moths were kept together in a glass jar (14 cm × 20 cm). Thirty replications were made at each temperature. The 10% honey solution was prepared and given to adults. The cabbage leaves were placed in the glass jars for egg laying. Daily, leaves of cabbage were replaced and the numbers of eggs were counted (Jaleel et al., 2017).

Following parameters were recorded at each temperature: Adult pre-oviposition period (APOP = the time period between the female adult emergence to its first egg laying), total pre-oviposition period (TPOP = the time interval between birth to the start of egg laying), oviposition period, and daily fecundity by using the methodology of Colinet et al. (2015). Each stage of diamondback moth was weighed sensitive analytical electric balance (Model#SE-391).

2.3. Statistical analysis of experiments

Two-sex life table program, TWO-SEX-MS Chart in computer was used to analyze different biological parameters (egg, larva, pupa, adult pre-oviposition period, total pre-oviposition period, fecundity) by following the methodology of Chi (1988, 2015). In the age-stage, two-sex life table, the l_x, m_x, and R_0 values are calculated as

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

$$m_x = \sum_{j=1}^{k} S_{xj} f_{xj} / \sum_{j=1}^{k} S_{xj} \tag{2}$$

$$R\circ = \sum_{x=0}^{\infty} l_x m_x \tag{3}$$

where k is a number of stages, s_{xj} is the survival rate of diamondback moth where x = age in days and j = stage), f_{xj} is the age-stage-specific fecundity, l_x is age-specific survival rate, m_x is age-specific fecundity, e_{xj} age-stage life expectancy, v_{xj} age-stage reproductive value, R_0 is net reproductive rate, k is finite rate of increase, and T is the mean generation).

In this study, the iterative bisection method from the Euler–Lotka formula was used to estimate r (r is intrinsic rate of increase) is using the with age indexed from 0 (Goodman, 1982) as shown in Eq. (2).

The e_{xj} is defined as the length of duration or time that an individual or insect of x and j is predictable to living, calculated by the methodology of Chi and Su (2006) as

$$e_{xj} = \sum_{i=x}^{\infty} \sum_{y=j}^{k} s'_{iy} \tag{4}$$

where s'_{iy} is define as the probability that individuals of x and j will survive to age i and stage y and, is found by assumings$'_{iy}$ = 1 (Tuan et al., 2014).

The v_{xj} was estimated by following the methodology of Abbas et al. (2014) and was calculated as

$$v_{xj} = \frac{e^{-r(x+1)}}{S_{xj}} \sum_{i=x}^{\infty} e^{-r(x+1)} \sum_{y=j}^{k} s'_{iy} f_{iy} \tag{5}$$

Finally, the standard errors and variances of fruit preference (number of visits and oviposition punctures) and means of different parameters were compared LSD and bootstrap technique respectively by following the methodology of Efron and Tibshirani (1994).

3. Results

3.1. Life table parameters

The egg development time of *P. xylostella* was longer at 15 °C in comparison to other three temperatures ($P < 0.001$). The 1st, 2nd, 3rd, and 4th instar of *P. xylostella* were longer at 15 °C than those at other three temperatures ($P < 0.001$). Males and females of diamondback moth lived longer at 15 °C with significant difference to other three temperatures ($P < 0.001$). Statistically, adult pre-

oviposition period of *P. xylostella* was not significantly different at all four temperatures.

Differences were also observed in the total pre-reproductive period (TPRP), oviposiiton period and fecundity. TPRP was significantly longer at 15 °C, while significantly shorter at 30 °C ($P < 0.001$). Similarly, shortest oviposition period was observed at 15 °C while there was no significant difference regarding oviposition period among all the rest of temperatures. Mean fecundity values fecundity per female (288.09 eggs) was recorded at 20 °C temperature ($P < 0.05$) (Table 1).

Second, third, fourth larval instars and pupae of *P. xylostella* were significantly different in term of weight at each temperature (Fig. 1). Overall pupal body weight was higher than fourth, third, and second instar. Each instar was significantly gained highest weight at 15 °C among other temperatures.

3.2. Life table parameters

The *r* was significantly higher at 25 and 30 °C and significantly less at 15 °C ($P < 0.05$) (Table 2). The *GRR* and R_0 were significantly higher at 20 °C ($P < 0.05$) while decreased at 15 °C (Table 2). The *T* significantly decreased from 34.55 ± 0.67 to 16.67 ± 0.51 days when temperature was 15 °C to 30 °C ($P < 0.05$).

The detailed age-stage-specific survival rate (S_{xj}) of *P. xylostella* at different temperatures (15, 20, 25 and 30 °C) have shown in Fig. 2. There was significant difference in survival rates of eggs at different temperature with higher rate at 20 °C temperature and lowest at other temperature (15, 25 and 30 °C).

Fig. 3 showed the age-specific survival rate (l_x), age-specific fecundity of whole population (m_x) and their product viz. age-specific maternity ($l_x m_x$) at different temperatures. There was inverse relationship recoded between age specific-survival rate and the temperature however age-specific fecundity was directly proportional to temperatures 15 and 20 °C only. Age-specific maternity also depicted a similar trend to age-specific fecundity.

Age-stage-specific life expectancy (e_{xj}) of *P. xylostella* at each stage as affected by temperature is shown in Fig. 4 and was inversely proportional to temperature viz. it decreased from 40.6 to 21.67 days while moving from 15 to 30 °C (Fig. 4).

Age-stage reproductive value (v_{xj}) which is the scale of population forecasting and is shown in Fig. 5. The curves of reproductive value at each temperature significantly increased after adult emergence from pupae up to 3–6 days depending upon the temperature. It was significantly higher at 20 °C as compared to the remaining tested temperatures.

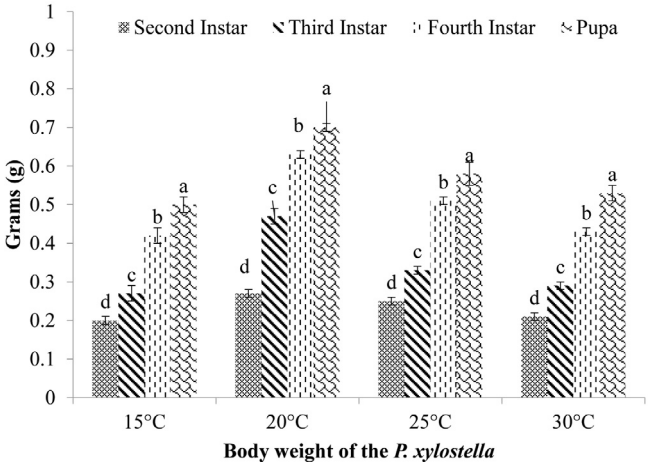

Fig. 1. The body weight of the *Plutella xylostella* at four different constant temperatures; Different letters above each bar indicate significant differences between instar treatments using one-way ANOVA, LSD test, and at $P < 0.05$.

There was inverse relationship between the *T* and temperature. Intrinsic rate of increase was inversely proportional to the highest finite rate of increase as compared to the *T*. The *r* was significantly higher at 25 °C followed by 30 °C while it was significantly lower at 15 °C (Table 2).

4. Discussion

Life table, an important research tool used for ecology studies, enables to study important biological components of organisms like growth rate, survival rate and reproductive potential of an organism under different conditions. Growth rate is highly dependent on first reproductive age and the age approaching the peak of reproductive value (Lewontin and Felsenstein, 1965). Due to drawbacks of Jackknife method (Huang and Chi, 2012, 2013), bootstrap technique was used with $n = 100{,}000$ to get precise estimate of population parameters. Means of all resampling ($n = 100{,}000$) were used to estimate the standard errors. A normal frequency distribution can be generated by bootstrap which in turn proves effective for analysis of variance and comparison of means (Akköprü et al., 2015).

Insect pests are ectothermic in nature, and their biology, behaviour, and fitness are greatly affected by abiotic factors (Cui et al.,

Table 1
Influence of four different temperature on the biological traits of the diamondback moth.

	Temperature			
Parameters	15 °C	20 °C	25 °C	30 °C
Egg duration (d)	4.36 ± 0.23 a	3.38 ± 0.14 b	2.34 ± 0.15 c	1.83 ± 0.14 d
1st instar (d)	5.20 ± 0.06 a	3.17 ± 0.09 b	2.32 ± 0.08 c	1.14 ± 0.02 d
2nd instar (d)	4.28 ± 0.08 a	2.76 ± 0.06 b	2.10 ± 0.08 c	1.44 ± 0.10 d
3rd instar (d)	3.76 ± 0.06 a	1.87 ± 0.08 b	1.64 ± 0.10 bc	1.12 ± 0.02 c
4th instar (d)	3.55 ± .07 a	2.43 ± 0.04 b	1.76 ± 0.03 c	1.22 ± 0.05 d
Pupal duration (d)	7.26 ± 0.14 a	6.24 ± 0.06 b	3.86 ± 0.06 c	3.11 ± 0.07 d
Male adult longevity (d)	19.15 ± 0.28 a	15.31 ± 0.18 b	13.89 ± 0.18 c	11.55 ± 0.29 d
Female adult longevity (d)	17.54 ± 0.16 a	12.76 ± 0.26 b	11.29 ± 0.12 c	10.15 ± 0.16 d
DT from egg to male adult (d)	47.00 ± 0.63 a	35.64 ± 0.50 b	27.27 ± 0.18 c	24.23 ± 0.64 d
DT from egg to female adult (d)	45.91 ± 0.69 a	33.67 ± 0.66 b	25.83 ± 0.56 c	23.42 ± 0.61 d
APOP/APRP (d)	1.00 ± 0.33 a	0.50 ± 0.26 a	1.00 ± 0.33 a	1.00 ± 0.00 a
TPOP/TPRP (d)	30.00 ± 0.67 a	21.05 ± 0.50 b	15. 65 ± 0.98 c	12.67 ± 0.76 c
Oviposition (d)	9.91 ± 0.25 b	10.75 ± 0.63 a	9.67 ± 0.22 a	8.58 ± 0.19 a
Fecundity (total eggs/female)	101.93 ± 4.58 d	288.09 ± 4.65 a	261.93 ± 2.68 b	194.53 ± 3.09 c

APOP: Adult pre-oviposition period of female adult, APRP: Adult pre-reproduction period of female adult. TPOP: Total pre-oviposition period of female counted from birth, TPRP: Total pre-reproduction period of female counted from birth. Means in the same row followed by the same letter are not significantly different (P > 0.05) using bootstrap test.

Table 2
Influence of four different temperatures on the life table parameters of *Plutella xylostella*.

Parameters	Temperature			
	15 °C	20 °C	25 °C	30 °C
r	0.11 ± 0.01 c	0.17 ± 0.01 b	0.22 ± 0.02 a	0.25 ± 0.02 a
ƛ	1.12 ± 0.01 c	1.19 ± 1.17 b	1.25 ± 0.02 a	1.29 ± 0.02 a
GRR	76.52 ± 17.43 c	103.48 ± 22.46 a	95.34 ± 20.41 b	87.91 ± 18.78 c
R_0	61.10 ± 14.92 c	88.70 ± 20.03 a	79.10 ± 17.75 b	70.66 ± 16.05 ab
T	34.55 ± 0.67 a	26.13 ± 0.55 b	19.21 ± 0.58 c	16.67 ± 0.51 d

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

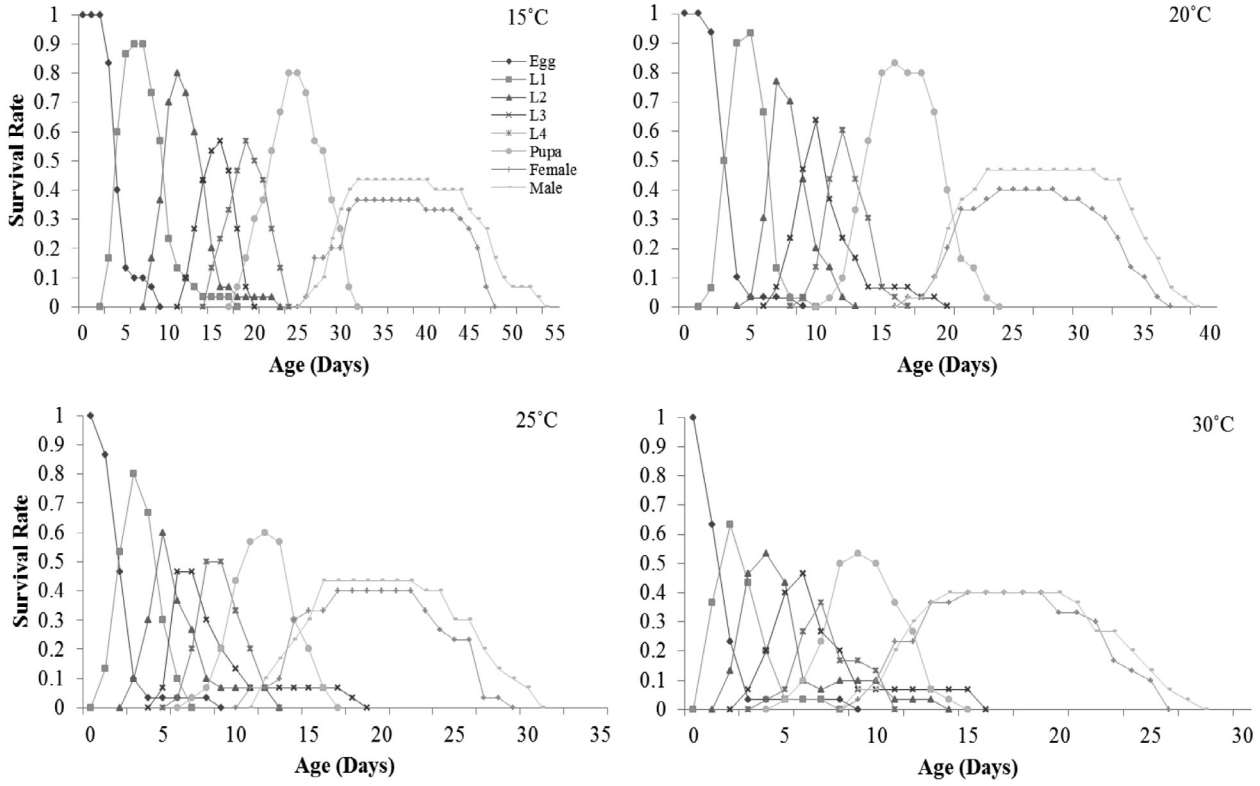

Fig. 2. Influence of four different temperatures on the age-stage-specific survival rate (Sxj) of the *Plutella xylostella*; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

2008; Jaleel et al., 2018). There are various studies showing the effect of temperature on survival and development of different insects (Garrad et al., 2016; Golizadeh et al., 2009; Powell and Bentz, 2009) but none have studied the two-sex life table traits with age stage survival and age specific fecundity of *P. xylostella*. Marchioro and Foerster (2011) reported that *P. xylostella* can tolerate wider ranges of temperatures however, temperature more than 30 °C negatively affect its survival.

It has been reported that the pre-adult and adult development rate varies at different temperatures (Folguera et al., 2010). The present study concluded that *P. xylostella* had short life cycle at 30 °C as compared to other temperatures (15, 20, and 25 °C), while the fecundity was highest at 20 °C (Table 1). This may be due to more feeding at 20 °C. The feeding capability of test insects was found dependent on the temperature. Shirai (2000) described that 20–25 °C temperature is more suitable for the fecundity of *P. xylostella*, while in our study at 20 °C fecundity and hatching percentage were found maximum indicating that 20 °C is a suitable temperature (Table 1).

Zheng et al. (2008) also reported that the feeding capability of *P. xylostella* was found dependent on the temperature. The present study showed that larval weight was highest at 20 °C (Table 1). This could be due to the fact that the weight of larvae is also affected by consumption, and growth rate (Gilbert et al., 2004). Lower body weight at higher temperatures attributed to rapid developmental time (Colinet et al., 2015; Keil et al., 2015) while in our study rapid development of *P. xylostella* was completed at 30 °C also gain less weight (Table 1).

The *GRR* is the indication of rapid increase of population that depends on the number of eggs laid, eggs hatched, and adult eclosion, and all these parameters are affected by temperature (Khaliq et al., 2007). In two other studies, Colinet et al. (2015) and Keil et al. (2015) found positive relationship between intrinsic rate (*r*) increase and temperature up to certain extent due to a higher

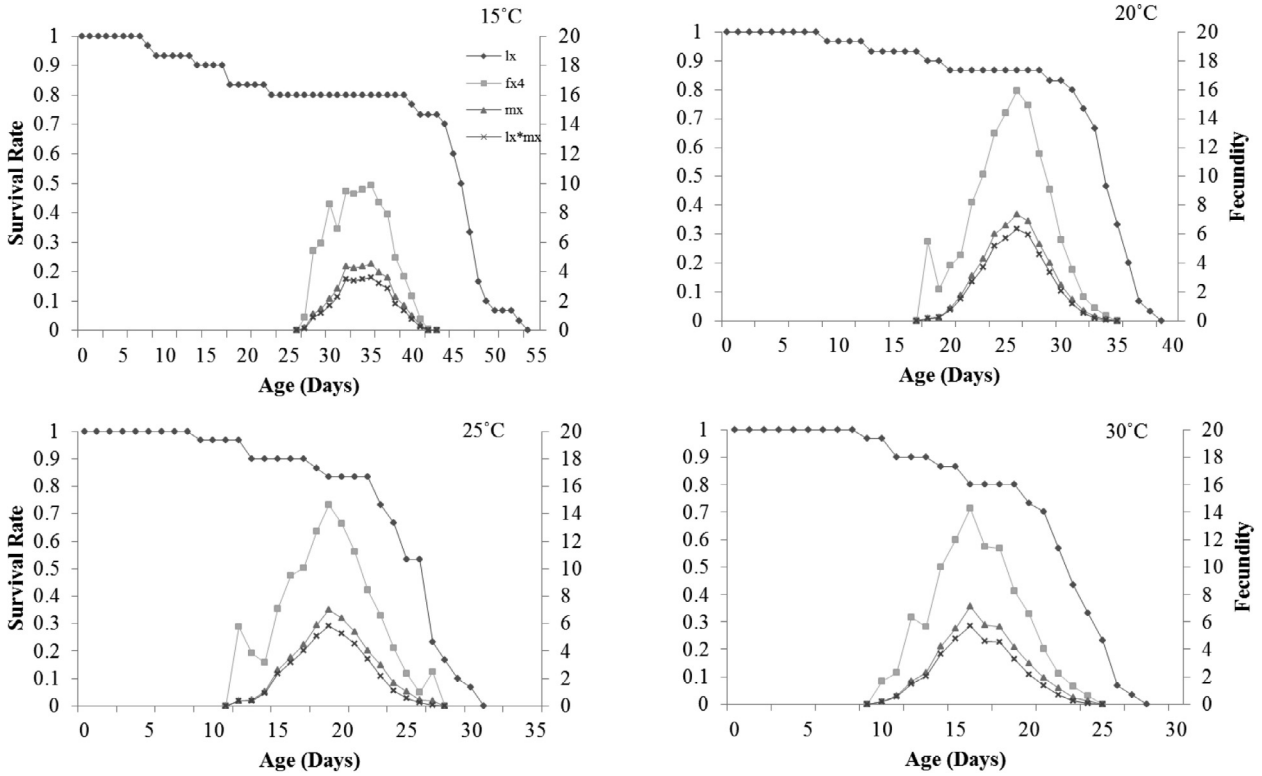

Fig. 3. Influence of four different temperatures on the Age-specific survival rate (l_x), female age-specific fecundity (f_{x4}), age-specific fecundity (m_x), and age-specific maternity (l_x·m_x) of the *Plutella xylostella*; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

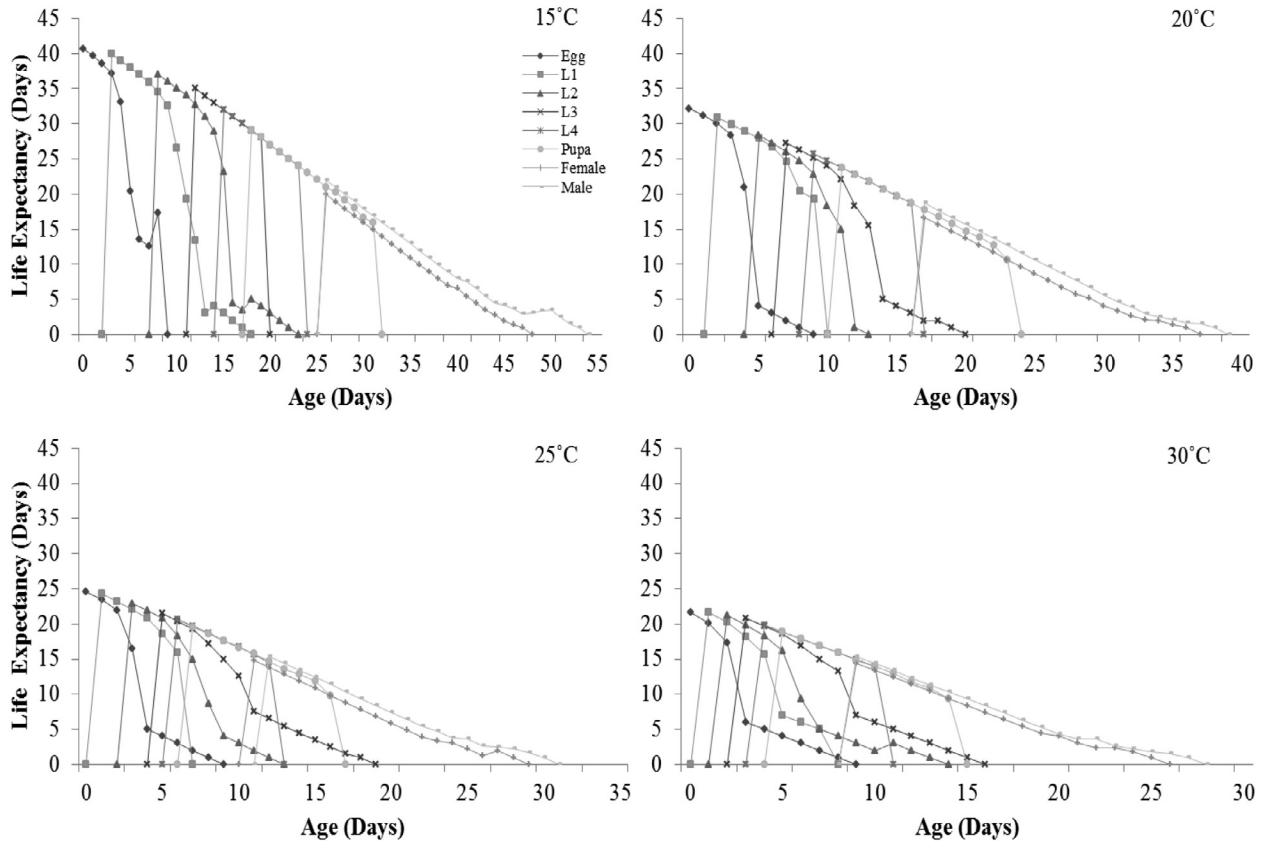

Fig. 4. Influence of four different temperatures on the age-stage-specific life expectancy (e_{xj}) of the *Plutella xylostella*; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

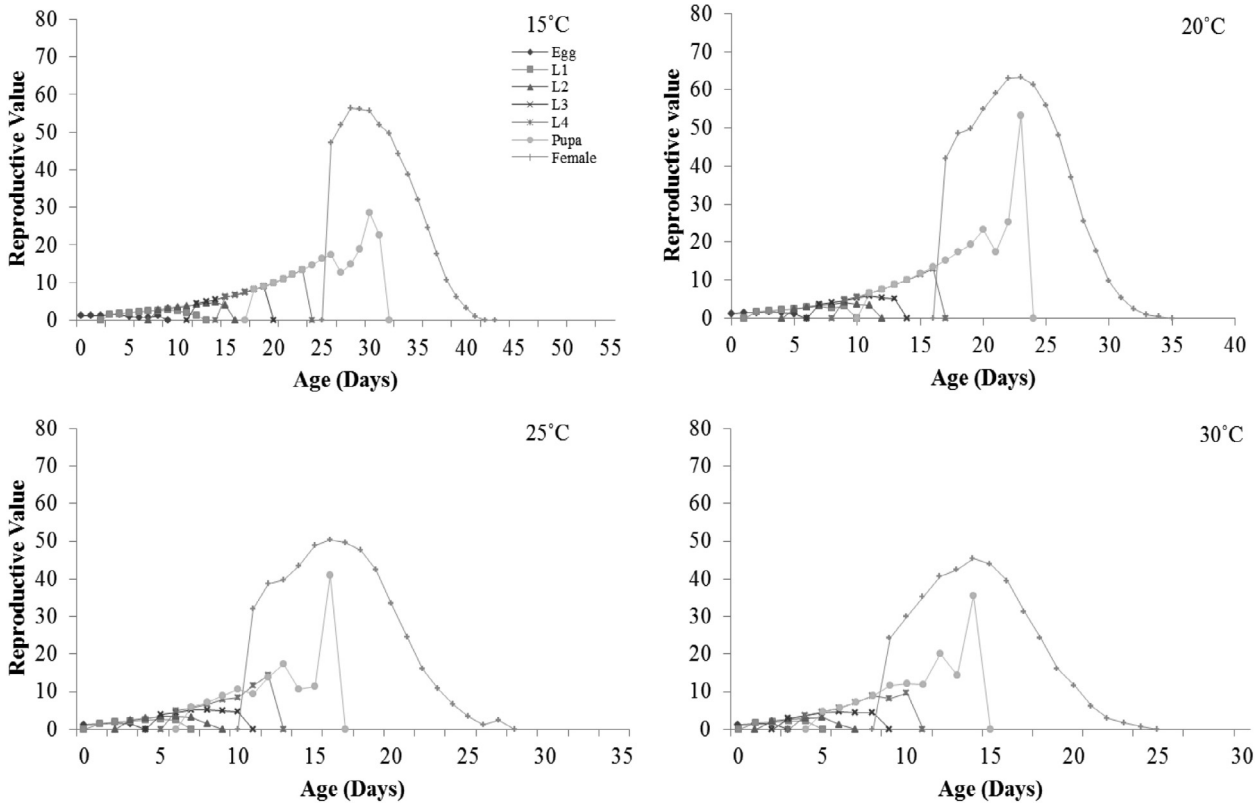

Fig. 5. Age-stage reproductive value (v_{xj}) of the *Plutella xylostella* as affected by temperature; L1 = 1st Instar, L2 = 2nd Instar, L3 = 3rd Instar, L4 = 4th Instar.

growth rate. In the present study, the *GRR* was highest at 20 °C and r increased from 15 to 30 °C (Table 2). Such extraordinarily high growth rates must be due to the rapid development and high fecundity of *P. xylostella*. The population increases only when net reproductive rate will be greater than 1 and $r > 0$ (Chen et al., 2017; Southwood and Henderson, 2009). Our results were also according to this above-mentioned theory.

5. Conclusion

Based on the current study, it is concluded that *P. xylostella* has potential to grow and reproduce on all four temperatures 15, 20, 25 and 30 °C but the most favourable temperature for *P. xylostella* is 20 °C. The results can be used to forecast pest population under field conditions. So, it is recommended that farmers should plan insecticide application when the field temperature is near 20 °C.

Acknowledgement

This research was done under financial project Pakistan Science Foundation (Project No. PSF/NSLP/P-BZU [130]).

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