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BIOLOGY AND LIFETABLE OF DIAMOND BACK MOTH *PLUTELLA XYLOSTELLA* (L) ON CRUCIFEROUS CROPS

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ABSTRACT

***Plutella xylostella* L., commonly known as diamondback moth (DBM), is an important pest of cruciferous crops worldwide. In this study, biology and life table parameters of *P. xylostella*, reared on cauliflower (*Brassica oleracea* L. var *botrytis*), cabbage (*B. oleracea* L. var *capitata*) and radish (*Raphanus sativus* L.), were measured to evaluate the suitability of these plants. The developmental period, survivorship and fecundity of *P. xylostella* were statistically same on all three test plants, however longevity of female was significantly higher on cabbage compared to cauliflower and radish. The mortality of larvae was significantly higher during early developmental stages, i.e. first and second larval instars, when reared on cauliflower and cabbage leaves but it was evenly distributed throughout the developmental stages when reared on radish. Moreover, the intrinsic rate of increase (rm) was highest on cauliflower (0.35) as compared with cabbage (0.29) and radish (0.33), rendering it the most suitable host plant for *P. xylostella*. Present study may be helpful in calculating population dynamics and predicting time of action threshold for the application of insecticides and other control measures for the management of this pest.**

Key words: *Plutella xylostella*, biological parameters, cruciferous vegetables, diamondback moth, host suitability, larval period, life table, population dynamics, survivorship.

The diamondback moth (DBM), *Plutella xylostella*, is globally distributed pest, which was reported from India in 1914 (Fletcher, 1914), but now widely distributed in 128 countries (Shelton, 2004). This has been reported to cause 52% yield loss on cabbage in India (Krishnamoorthy, 2004). Globally, this pest has been reported to cause more than 90% of production loss of crucifer crops (Talekar and Shelton, 1993; Furlong et al., 2013; Paudel et al., 2022). The cost for its management was estimated US $1.0 billion annually in 1993 (Talekar and Shelton, 1993) and US $5.0 billion in 2012 (Zalucki et al., 2012). The genetic elasticity of *P. xylostella* has enabled it to develop resistance against wide range of insecticides (Sakeel et al., 2017; Uesugi, 2021; Banazeer et al., 2022; Shehzad et al., 2023). This insect has been also reported to develop resistance against biopesticide, *Bacillus thuringiensis* (Ferre and Van Rie, 2002; Sarfraz, 2004). Thus, the management of this pest has become nightmare for farmers (Shelton et al., 1993; Regupathy, 1996; Sarfraz et al., 2006; Furlong et al., 2013; Philips et al., 2014; Li et al., 2016; Jamtsho et al., 2021; Shehzad et al., 2023).

Life table studies are important conceptual and analytical tools for understanding the population dynamics of insect species (Harcourt, 1969; Rossini et al., 2024). Variation in quality of host-plants affects the growth and development of insects which, in turn, determine their life-history parameters. Even different cultivars and geographical areas of host plants have been observed to affect various life table parameters of *P. xylostella* (Ebrahimi et al., 2009; Hasanshahi et al., 2014; Nazrussalam and Ansari, 2018; Fathipour et al., 2019; Hussain et al., 2019; Jafary-Jahed et al., 2019; Kaur et al., 2021). Thus it is important to know the most vulnerable stage of this pest for its successful management. The biology and life table parameters of *P. xylostella* on various cruciferous crops have been studied in China (Niu et al., 2013), Pakistan (Syed and Abro, 2003; Ramzan et al., 2021) and Iran (Golizadeh et al., 2009; Jafary-Jahed et al., 2019). However, there is hardly any report about comparative account of various biological and life table parameters of *P. xylostella*, on widely cultivated commercial cultivars of cauliflower, cabbage and radish in India. Present study was undertaken to evaluate and compare suitability of these host plants for *P. xylostella*, and find its most vulnerable stage, for developing cost-effective control strategies.

MATERIALS AND METHODS

The seeds of cauliflower (*Brassica oleracea* L. var. *botrytis*; var. Poosi spl), cabbage (*B. oleracea* L. var. *capitata*; var. Golden acre) and radish (*Raphanus sativus* L.; var. Pusa chetki), were obtained from the National Seeds Corporation, Indian Agriculture Research Institute, New Delhi. Plants were grown from these seeds in the field plots of Zoology Department, University of Delhi, under pesticide free condition, following standard agronomic practices. Leaves from approximately 4-5 weeks old plants at 5-7 leaves stage were used from field plots for the experiments and maintaining culture. *P. xylostella* culture was started with the larvae collected from the cauliflower fields, located on the outskirts of Delhi, and maintained in the laboratory as described by Vats et al., 2019. Insects were reared for 3-4 generations under laboratory conditions for the purpose of acclimatization before using them for bioassay. The culture was replenished at frequent intervals from fresh batch of larvae collected from fields, so as to maintain the vigour of culture. For studying various biological attributes, the freshly laid eggs of *P. xylostella* were taken from culture, sterilized and kept in plastic boxes. After hatching, 10 neonate larvae were transferred with the aid of a fine hair brush on the tender leaves of different test plants, placed in round plastic jars (9 cm diameter x 2 cm height). The bottoms of these jars were lined with moist tissue paper to maintain moisture inside. The larvae were transferred daily into clean plastic jars, provisioned with freshly excised leaves. Observations for survival, mortality and moulting into next instar were recorded daily at a fixed time of the day. Larvae were arranged sex-wise during last instar and kept in separate boxes (7 x 7 cm) for pupation and adult eclosion. The emerging males and females were released in Perspex oviposition cage (20 x 20 x 20 cm) for egg laying. Number of eggs laid by female was recorded daily till all the females stopped laying eggs or died. The experiment was replicated 5 times from different batches of insects, and each replicate consisted responses of 10 larvae.

Stage-specific life table was constructed, following the methods described by Morris and Miller (1954), to calculate mortality and survival rate at each developmental stage. For calculating the adult survival and reproductive parameters, age of the adults from the time of emergence was taken into account. The age-specific lifetable was constructed based on the method described by Atwal and Bains (1974), and Syed and Abro (2003). Sex-ratios for different host plants were calculated according to the formula, F/F+M, where F = number of females and M = number of males. Depending upon the sex-ratio, the numbers of eggs laid by individual female were used to get the number of female birth (mx). The values of pivotal age in days (x), survival of female at age x (lx) and age schedule for female birth at age x (mx), were calculated from the data on life table with respect to each host plant. The number of individuals survived and mean number of female offspring produced at each age interval were recorded. The following life table parameters were calculated from the data: net reproductive rate (R_o) = $\sum$lx.mx, mean generation time (T_c) = $\sum$x.lx.mx /R_o, intrinsic rate of increase (rm) = LogeRo/To and the finite rate of population increase (λ) = e^{rm}. The various biological and life table parameters were subjected to one way Analysis of Variance (ANOVA) followed by Tukey's post-hoc test. All statistical analyses were performed using the computer software programme, Sigma Stat 2.0. The linear relationship between intrinsic rate of increase (rm) and generation time (T_c) was established by computing R^2 (square of Pearson correlation coefficient) using MS- Excel software program.

RESULTS AND DISCUSSION

There are various reports about influence of host plants on the biological parameters of lepidopteran insect pests (Syed and Abro, 2003; Razmjou et al., 2014; Huaripata and Sanchez, 2019; Kaur et al., 2021; Ramzan et al., 2021; Ahmed et al., 2022; Gopalakrishnan and Kalia, 2022; Mason, 2022; Keerthi and Suroshe, 2024). These findings have been cross-checked in present study on cabbage, cauliflower and radish which indicated significant effects of host plants on the survival, development, longevity and life table parameters of *P. xylostella*. In present study, growth and development of *P. xylostella* varied on different test plants, i.e. cauliflower, cabbage and radish (Table 1). The durations of larval period were 7.8 days on cauliflower, 7.7 days on radish and 8.5 days on cabbage, the difference being not statistically significant ($p > 0.05$). Our observation on larval period is consistent with earlier reports on cabbage (Ahmad et al., 2011; Rasool et al., 2021), cauliflower (Gowri and Manimegalai, 2017; Jafary-Jahed et al., 2019) and radish (Yang et al., 2021). However, significant differences were observed in the pupal duration for the larvae reared on these test plants. Pupal duration on cauliflower (3.6 days) was significantly lower, as compared to cabbage (4.9 days) and radish (4.9 days) ($p < 0.001$). Our findings are in conformity with earlier reports about cauliflower being the best host plant for *P. xylostella* (Dube and Chand, 1977; Syed and Abro, 2003; Golizadeh et al., 2009). The total number of larvae that successfully developed and survived to emerge as normal adults were statistically equal on all the three host plants.

The quality of host plant species and their cultivars have been reported to affect oviposition of herbivorous insects (Awmack and Leather, 2002). Our study on the ovipositional responses revealed that egg laying by *P. xylostella* females starts from the first day of emergence, which continues till 15thday, the highest being on the second day (Fig. 1). The females lay more than 50% of her eggs in first three days of emergence. The post-ovipositional period (when ≤ 2 eggs per female were laid) lasts for 2-3 days for the females reared during larval stages on cauliflower and radish, whereas those reared on cabbage were significantly longer and extended for 7-8 days. The number of eggs laid by the females,

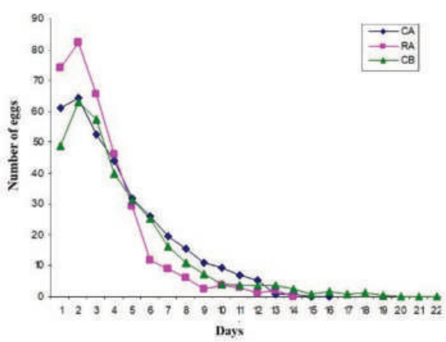

Fig. 1. Ovipositional response of *P. xylostella* in relation to their age. CA, cauliflower; RA, radish; CB, cabbage

developed from larvae fed on cauliflower, cabbage and radish leaves were 338.2, 314.8 and 337.1 respectively, the difference being not statistically significant. This indicates equal suitability of all the three cruciferous plants for oviposition of *P. xyostella*. However, Niu et al. (2013) recorded significant differences between fecundity of diamondback moth females reared on cauliflower and radish leaves. We observed significantly higher longevity of females reared on cabbage as compared to those reared on cauliflower and radish (Table 1). The longevity and fecundity of females are considered a 'trade-off' relationship. The increase in fecundity of females has been observed to shorten their longevity (Bell and Koufopanou, 1986; Begum et al., 1996; Thyloor et al., 2016)). Similar significant correlation between adult longevity and fecundity was also observed when *P. xylostella* larvae were reared on radish and pea leaves (Yang et al., 2021). Females from larvae reared on cabbage lived longer than those fed on cauliflower and radish. However, higher longevity of females, developed from larvae fed on cabbage, did not manifest into decrease in oviposition. It appears that these females maintain extra nutrient reservoir to utilize for fecundity, as reported in case of *Spodoptera litura* (Yu et al., 2014).

Shorter developmental time and higher ovipositional potential of an insect on a plant are indicators of its high host suitability (Van Lenteren and Noldus, 1990). Earlier studies on the comparative performance of *P. xylostella* found that radish was not a good host for *P. xylostella* (Dube and Chand, 1977; Singh and Singh, 1982; Saeed et al., 2010). However, present study indicates radish to be equally good host as cauliflower and cabbage, having similar developmental time, survivorship and oviposition. This difference may have been caused due to differences in the cultivars of plant species.

The stage-specific life table constructed in the present study reveals that maximum mortality occurred

Table 1. Biological parameters of *P. xylostella* on three host plants (detached leaf bioassay)

Host plants	Larval duration (days)	Rate of larval pupation (%)	Pupal duration (days)	Rate of survival to adults (%)	Fecundity/ female	Female longevity (days)
Cauliflower	7.83± 0.37^{a}	80± 10.00^{a}	3.61± 0.28^{a}	78± 8.37^{a}	338.17± 26.79^{a}	13.13± 2.67^{a}
Radish	7.66± 1.31^{a}	82± 13.04^{a}	4.96± 0.12^{b}	76± 11.4^{a}	337.11± 9.35^{a}	12.44± 3.63^{a}
Cabbage	8.53± 1.02^{a}	76± 11.40^{a}	4.87± 0.15^{b}	72± 8.37^{a}	314.82± 15.66^{a}	17.61± 4.16^{b}

Values are mean ± SD; Means followed by different lower case letter in a coloumn are significantly different ($p < 0.001$) (one way ANOVA and the means separated by Tukey's test) during early developmental stages, i.e. first (L1) and second (L2) larval stages, both on cauliflower (16.6%) and cabbage (24.8%). This indicates the vulnerability of this insect during early stages. Thus, control measures applied during early larval stages will be more effective. Mortality was quite low during later developmental stages, i.e. L3, L4 and pupal stage, which accounts 7.26% on cauliflower and 5.26% on cabbage. However, mortality on radish was evenly distributed during the larval and pupal stages (Table 2).

A classical age-specific life table gives a clear understanding of the age dynamics of adult population under controlled laboratory conditions (Carey, 2001). The intrinsic rate of increase (rm) is an important parameter in life table. This parameter appropriately summarizes the physiological state of insect in relation to its capacity to increase in number, and thus considered suitable index to evaluate the ability of an insect to colonize on host plants in fields (Southwood and Henderson, 2000). The age-specific life table parameters of *P. xylostella* on different host plants are shown in Table 3. The net reproductive rate of female birth (R_o) was highest on cauliflower (201.1) followed by cabbage (169.2) and radish (162.2), the difference being not significant. The mean generation time (T_c) was significantly higher on cabbage (17.7 days) as compared to cauliflower (15.2 days) and radish (15.3 days) ($p < 0.001$) (Table 3). However, mean generation time on cauliflower and radish was statistically equal ($p > 0.05$). The intrinsic rate of population increase (rm) was significantly lower on cabbage (0.29) as compared to cauliflower (0.35) and radish (0.33) (p <

Table 2. Stage specific life table of *P. xylostella* on three host plants

Stage of the Insect (x)	Host Plant	No. living at the beginning (n_x)	Survivorship (l_x)	No. dying during x (d_x)	Factors responsible for d_x (d_xf)	d_x as % of n_x ($100q_x$)	Survival rate within x (S_x)
Eggs	Cauliflower	50	1	0	-	0	1
	Cabbage	50	1	0	-	0	1
	Radish	50	1	0	-	0	1
Larva I	Cauliflower	50	1	6	Inability to come out from the leaf	12	0.88
	Cabbage	50	1	2	Inability to come out from the leaf	4	0.96
	Radish	50	1	1	Inability to come out from the leaf	2	0.98
Larva II	Cauliflower	44	0.88	2	Unknown	4.55	0.95
	Cabbage	48	0.96	10	Unknown	20.8	0.79
	Radish	49	0.98	4	Unknown	8.1	0.92
Larva III	Cauliflower	42	0.84	2	Unknown	4.76	0.95
	Cabbage	38	0.76	0	-	-	1
	Radish	45	0.90	1	Unknown	2.2	0.98
Larva IV	Cauliflower	40	0.80	1	Unknown	2.5	0.98
	Cabbage	38	0.76	0	-	-	1
	Radish	44	0.88	4	Unknown	9.1	0.91
Pupa	Cauliflower	39	0.78	0	-	-	1
	Cabbage	38	0.76	2	Unknown	5.26	0.95
	Radish	40	0.80	2	Pupa Shrunk and dried up	5.0	0.95
Adult	Cauliflower	39	0.78	-	-	-	-
	Cabbage	36	0.72	-	-	-	-
	Radish	38	0.76	-	-	-	-

Table 3. Life table parameters of *P. xylostella* on three host plants

Host plants	R_o	T_c	Rm	$\lambda = e^{rm}$
Cauliflower	201.13± 36.93[a]	15.22± 0.47[a]	0.348± 0.006[a]	1.415± 0.009[a]
Radish	162.19± 33.33[a]	15.32± 0.79[a]	0.332± 0.025[a]	1.394± 0.034[a]
Cabbage	169.20± 35.71[a]	17.70± 0.94[b]	0.289± 0.021[b]	1.336± 0.028[b]

Values are mean ± SD; Means followed by different lower case letter in a column are significantly different; (p < 0.001) according to one way ANOVA and the means were separated by Tukey's test.

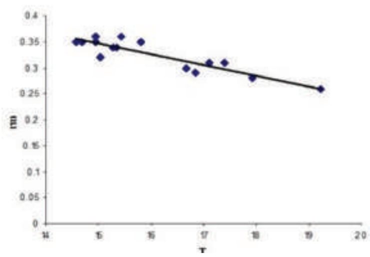

Fig. 2. Intrinsic rate of increase (rm) vs mean generation time (Tc) of *P. xylostella* (R^2= 0.906, p <0.001)

0.001). Similarly, the finite rate of increase (e^{rm}) was significantly lower for cabbage (1.34) as compared to cauliflower (1.42) and radish (1.39) (p < 0.001). Multiple linear regression analysis between mean generation time (T_c) (independent variable) and the intrinsic rate of population increase (rm) (dependent variable) yielded R^2 = 0.906 (p < 0.001) (Fig. 2). Thus, a higher T_c value decreases rm value, indicating a negative effect of T_c on rm. Present study clearly indicates that cauliflower is the most suitable host plant for *P. xylostella* as its intrinsic rate of increase (rm), resulting from faster development (shorter generation time, T_c), higher survivorship and higher oviposition, was highest on this plant. Thus, population growth of *P. xylostella* will be much faster on this crop and will require frequent monitoring for application of effective control measures. Similar finding of high intrinsic rate of increase (rm) of *P. xylostella* on cauliflower was also reported by Saeed et al. (2010). It was also observed that the rm value of *P. xylostella* reared on radish was significantly higher as compared to cabbage. The present study provides a comprehensive account of biological and life table parameters of *P. xylostella* on three brassicaceae crop plants, which will help to understand the performance of this pest in Indian scenario. This information would be useful in developing effective control strategies to keep this pest in check.

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AUTHOR CONTRIBUTION STATEMENT

S S contributed to conceptualization and methodology; SS, J S, and P Sh conducted experiments. Analysis of the experimental data was done by S M, A D and S S. S S, A D and P Si wrote the original manuscript. S M reviewed and edited the manuscript. All authors have contributed at different stages of bioassays and approved for the submission of this manuscript for publication.

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CONFLICT OF INTEREST

No conflict of interest.

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